2020 TAMC Culvert Condition Assessment Final Report

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ABSTRACT

This project follows the 2018 Transportation Asset Management Council (TAMC) local agency culvert pilot with continued inventory and condition inspection training, evaluation of collected culvert data from combined sources, a comparison between condition evaluation systems, and a follow-up survey of the agencies that participated in the pilot. Culvert data from combined sources was reviewed to determine if duplicate data existed and a procedure was identified for detection of duplicate data. The two predominate condition evaluation methods were evaluated; the TAMC Pilot system used by local agencies and the system used by the Michigan Department of Transportation. These were compared for the purpose of establishing the appropriateness of displaying local and state culvert condition data side by side in a dashboard. The American Association of State Highway and Transportation Officials released a new method at the end of the project schedule which was incorporated into the comparison alongside the current methods for the purpose of understanding the impact of adopting the new evaluation system. Interviews were conducted with non-transportation agencies who work with culvert data and a survey was conducted of the pilot participants to learn how both parties use the data that came out of the pilot. Understanding how the data is used will help provide guidance to the TAMC bridge committee as they work on developing culvert data collection policy.

DISCLAIMER

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LIST OF ACRONYMS

AOP	Aquatic Organism Passage
CMP	Corrugated Metal Pipe
CRC	County Road Commission
CSS	Center for Shared Solutions
CTT	Center for Technology & Training
DEQ	Department of Environmental Quality
DNR	Department of Natural Resources
DTMB	Department of Technology, Management, and Budget
FAQ	Frequently Asked Questions
FHWA	Federal Highway Administration
GIS	Geographical Information System
GPS	Global Positioning System
GUID	Globally Unique Identification
LDC	Laptop Data Collector
MiBridge	Michigan Web-based Structure Management System
MDOT	Michigan Department of Transportation
MPO	Metropolitan Planning Organizations
NBI	National Bridge Inventory
NCHRP	National Cooperative Highway Research Program
PA	Public Act
TAMC	Transportation Asset Management Council
TAMS	Transportation Asset Management System

EXECUTIVE SUMMARY

In 2018, the Transportation Asset Management Council (TAMC) Bridge Committee was tasked with managing a work plan for a pilot project for the collection of data and the evaluation of culverts owned by local transportation agencies within Michigan. The Center for Technology & Training (CTT) at Michigan Technological University (Michigan Tech) worked with the TAMC Bridge Committee to accomplish their goals for the pilot program and has continued to offer culvert inventory and condition evaluation training since. In 2020, the CTT submitted a work plan to the TAMC consisting of the following tasks:

Task 1: Conduct Culvert Condition Assessment Training

CTT staff provided two, two-hour data webinars on culvert data collection using Roadsoft and three, three-hour webinars on culvert condition evaluation. Both webinars were as-developed during the 2018 pilot.

Task 2: Evaluate Culvert Data from Combined Sources

The CTT evaluated culvert data collected and stored from a variety of sources throughout the state. Data from the Michigan Department of Natural Resources (MDNR), the Michigan Department of Transportation (MDOT), and the TAMC was reviewed and analyzed to determine if it could be easily combined to create a statewide culvert inventory. The most immediate concerns with combining data from different sources is identifying duplicate assets. Another concern included rectifying the different data fields used by each agency. The CTT used data from the Michigan Open GIS portal to gather existing culvert data from both the DNR and MDOT Transportation Asset Management System. They also used TAMC local agency culvert pilot data from the Center for Shared Solutions.

After reviewing sample data from the three sources, the CTT developed generalized process flows for both the DNR and MDOT data sets to assist in identifying duplicate culverts. Processing of the 2230 records in the DNR stream crossing data produced the following results when analyzed with MDOT culvert and bridge data:

- 130 stream crossings were in MDOT's sphere of influence
  - 23 were rejected as ambiguous
  - 18 were identified as matches (Present in both data sets)
  - 50 were identified as possible previously unidentified MDOT culverts

Processing of the 2230 records in the DNR stream crossing data produced the following results when analyzed with local agency culverts and bridge data:

- 642 stream crossings were within the sphere of influence of local roads
  - 37 were rejected as ambiguous
  - 65 were identified as matches (present in both data sets)

- 331 were identified as possible previously unidentified local road culverts

As part of this task, the CTT also conducted interviews with four non-transportation related agencies that were identified as having an interest in culvert data, as well as one county road commission that was interested in using data that had been collected by non-transportation agencies. These agencies included Huron Pines, the Conservation Resource Alliance, the Southeast Michigan Council of Governments, the Michigan State Hydrography Improvement Pilot, and the Wexford County Road Commission.

In general, these interviews indicated some interest in sharing culvert data. While it was expected that each agency would have specific data needs that they would want to collect according to their specifications, it was thought that some data, like general inventory and location data, would be of common interest to all agencies. The general consensus was that the data each agency already has is of adequate quality to meet their needs, but data from other sources could be helpful if it was readily available. There was some interest in condition data that might help identify areas of potential partnership for replacement of culverts to the benefit of both the local agency and the environmental quality of the stream. There was also some interest in data for areas of expanded interest, either geographically or informationally, where the agency would otherwise be starting from scratch to collect data.

Task 3: Culvert Condition Assessment System Translation

There are currently two culvert condition assessment systems used in Michigan. Most local agencies use the 1986 Federal Highway Administration (FHWA) Culvert Inspection System found in Roadsoft which was updated in 2018 as part of the TAMC Culvert Pilot. The TAMC Pilot system added additional deterioration descriptions for specific culvert material types not included in the 1986 FHWA Culvert Inspection System. MDOT has its own condition assessment system which consists of two methods; one for culverts less than 10-ft, and another for larger culverts. The Transportation Asset Management System (TAMS) method is used for culverts less than 10-ft and the National Bridge Inventory System (NBIS) is used for culverts 10 to 20-ft.

The TAMC and MDOT systems currently in use evaluate specific elements within a culvert system to determine the overall culvert condition. They appear to meet the needs of the respective users, and each group has a significant investment in historical data. Generally speaking, these systems have the same function, assess similar defects, and have a similar scale direction; however, the systems are not identical and therefor pose a potential discrepancy when data is displayed side-by-side or combined. The goal of Task 3 was to create a system for translating MDOT and TAMC culvert data for the purpose of creating dashboards that would allow comparison between these two condition data sets while maintaining the integrity of each agency’s detailed element level collection criteria.

The American Association of State Highway and Transportation Officials (AASHTO) published an updated replacement for the 1986 FHWA culvert guide in August of 2020. The new publication, *Culvert & Storm Drain System Inspection Guide*, provides guidance on inspection of materials commonly found in culvert systems. This system was added to the comparisons of Task 3 for the purpose of understanding the impact that using the AASHTO method would have on the existing data collection efforts.

While individual elements may rate differently between the two existing systems, particularly between fair and poor, it is expected that in general, the TAMC Pilot and MDOT TAMS data sets could be displayed side-by-side when reduced to a Good/Fair/Poor/Severe generalization of the overall controlling condition. In general, the AASHTO method could be expected to produce lower ratings, but this is dependent on the specific deterioration found during the inspection. For example, in the evaluation of concrete for structural deterioration, the TAMC method would allow some exposed rebar in the fair category, but AASHTO doesn't allow any exposed rebar until reaching the poor category. This difference would only be seen if exposed rebar were the contributing factor. If only minor cracking and spalling were observed the two systems would produce the same rating; fair.

The AASHTO method considers more elements than either the existing TAMC or MDOT methods; however, it covers approximately the same elements if one were to combine those two systems. While more culvert elements are considered for an evaluation, it is not clear if this would translate to more time spent in the field conducting an analysis as the AASHTO method considers four condition states for each element instead of the ten condition state descriptions provided for each element within the TAMC method. Therefore, while more elements are considered, it may take less time to determine the appropriate rating for each one.

Additional Tasks

A survey was added to the project work plan as a follow-up to the 2018 pilot. Respondents were asked what data, a year after participating in the pilot, did they continue to find useful. All data was deemed to have value by the participants, although the value placed on the collected data elements varied. Respondents were asked how they used the data they collected from the 2018 pilot. One common response was that the data was used for preparing estimates for road repair, prioritizing maintenance schedules, and developing asset management plans.

Next Steps

Policy:

- A policy document needs to be created to establish TAMC involvement, the inspection frequency, range of applicability, condition evaluation system, database and information sharing procedures, and a QA/QC program.
- Statement of TAMC interest/involvement
    - Maintain estimate of state-wide culvert inventory and value
    - Report trends in size, material, number of culverts
    - Report condition of culverts (could be subset, i.e. culverts above a certain span)
    - Sampling vs census to maintain this information
        - Concerned with risk/cost of big culverts and total numbers (guiding principle)
    - Support infrastructure owners (guiding principle)
        - Training
        - Technical assistance on data collection
- Evaluation system
    - If standardization in culvert inspection procedures within the state is desired, interested parties should be brought to the table.
    - TAMC will need to decide on adoption of a condition evaluation system
        - The AASHTO *Culvert & Storm Drain System Inspection Guide* became available on August 13, 2020. If this method is approved, it could be accepted either in full or part and any state-specific modifications that may be necessary could be added.
- Transition plan if a new evaluation system is approved:
    - A change of this magnitude will require a transition plan to be effective.
        - Implementation schedule including training in new method, period of acceptance for multiple evaluation methods, date for acceptance of only selected method.
        - During period of mixed method acceptance, a supplemental inspection checklist would be helpful to allow for estimating evaluations between methods. For example, 'exposed rebar' is specifically identified in two of the three methods considered in this report and is attributed to different evaluation categories. A supplemental checklist could help identify if 'exposed rebar' was the distress associated with the original rating.
        - Determine a data handling process for period of transition.
        - Longevity of existing culvert data
            - How long should existing data be considered valid?
            - To what extent does existing data need to be converted or is it enough to know rating and method used to get rating? A study could be performed

to evaluate if a culvert system translation is needed between the multiple systems.

- Field Verification
    - If data is to be compiled and used comparatively for culvert systems across the state a QA/QC system needs to be created to ensure an adequate training program is established to help assure that each inspector would assign the same rating to a culvert within an established tolerance.

Training:

- Training should be updated to include the rating system as adopted by TAMC (option to do refresher training that highlights only the changes in the updated system).
- QA/QC program should feed back into training to help improve program.

Revised Data Collection Pilot:

- A pilot program could be initiated in an effort to 'test' the TAMC policy document while it is in a draft state and raise any issues or highlight changes that may be beneficial.

Data:

- A culvert database should be finalized and if not publically available made accessible to those who own culverts so they can retrieve their data (local or centralized storage). Protocols should be established to define who has access to this data and how data is managed.
- The sharing of culvert data is of interest to various agencies within the state. These agencies should be invited to a summit for the purpose of establishing a data standard to facilitate the sharing of data. Each agency could continue to collect data independently and for their purposes; however, a data standard would ensure the collected data is uniform across participating agencies.
- TAMC should develop a data schema to summarize culvert data from the pilot and MDOT TAMS. This would include common denominator fields for materials, shapes, and physical measurements that would make combining data from multiple sources easier and consistent.
- Using the process identified in this report identify previously un-inventoried MDOT and local agency culverts to better complete those data sets.

BACKGROUND

2018 Pilot Study:

The TAMC Bridge Committee was tasked with managing a work plan for the collection of data and the evaluation of culverts located within Michigan. Culverts, for the purposes of the pilot, were defined as linear drainage conduits underneath a public roadway that were not considered "bridges" by the Federal Highway Administration (FHWA). FHWA's definition of brides includes any structure with a combined span over twenty feet. Culverts are differentiated from storm sewers in that they are straight-line conduits that are open at each end, and do not include intermediate drainage structures (manholes, catch basins, etc.). Only culverts found within PA 51 Certified Roads were considered in the collection.

The goal of this pilot was to ensure the TAMC had a strategy that could be used across the state to further streamline and standardize the collection of culvert data and to develop best practices for the asset management of culverts in the state. Obtaining local culvert inventory and condition evaluation data in a representative group of local agencies helped determine the level of effort and cost to advance a similar effort statewide.

2020 TAMC Culvert Initiative Overview:

With the pilot complete, the next steps for the TAMC Bridge Committee involved processing the data and lessons learned from the pilot to create a policy for the assessment and evaluation of culverts into the future. This report details CTT's work in four areas to assist in TAMC's culvert initiative.

The CTT was tasked with continuing to provide webinar-based training for local agency inventory and condition evaluation procedures, evaluating data handling procedures for combining data from several sources, and determining if a translation procedure would be needed to relate TAMC Pilot data to MDOT TAMS data.

Training was an important component as many local agencies indicated a strong desire to continue to collect culvert data for their own purposes beyond the pilot. The training helped provide and maintain consistency in that data and allowed new agencies to get involved in asset management of their culverts.

Culvert data is collected by numerous agencies and organizations around the state. Interest in creating a centralized, shared access database was expressed during the pilot. The 2020 work plan sought to identify and interview organizations who may be interested in sharing or using culvert data. Combining data sets requires having rules for how this data is combined and which data takes priority. A first step in establishing a data handling procedure was to identify a process for identifying duplicate culverts: those that were inventoried in multiple sources of data.

Culvert condition evaluation was conducted in the pilot, and an overall condition rating was established based on evaluation of individual elements. Condition data exists for both state and locally owned culverts. The ratings were determined using two unique rating systems. In order to display this data publically there needs to be a clear translation between the two data sets; either displaying data to the least common denominator, or noting key differences. This task looked at evaluating the two systems and provided recommendations on how data could be displayed for informational purposes.

Lastly, a survey of participants in the 2018 Culvert Pilot was conducted. The purpose of this survey was to learn what data collected during the pilot has been found useful for the local agencies and what they might do different in the future. This information will be used to help establish culvert inspection and condition evaluation policy for the asset management of culverts.

The AASHTO published an updated replacement for the 1986 FHWA culvert guide in August of 2020. The new publication, *Culvert & Storm Drain System Inspection Guide*, provides guidance on inspection of materials commonly found in culvert systems. This system was added to the comparisons of existing evaluation methods for the purpose of understanding the impact that using the AASHTO method would have on the existing data collection efforts.

2020 WORK PLAN TASKS AND RESULTS

Task 1 - Culvert data collection and condition assessment training

This task included presentation of five webinar sessions of approximately two to three-hours each. The training modules provided detailed information on the three primary aspects of collecting culvert inventory and condition data: equipment, data collection, and data validation.

Culvert Data Collection using Roadsoft Webinar

This two-hour webinar provided a visual walkthrough of Roadsoft's Culvert module, focusing on data collection and data handling. Topics for the training included: recommended equipment for culvert data collection; completing data collection with Roadsoft using visual walk-throughs of the software to explain the processes needed to collect each piece of information, and the overall process of data management and quality control.

Culvert Condition Evaluation Webinar

This three-hour webinar provided information to participants on the technical points of assessing culvert condition using the TAMC Pilot condition evaluation system, which was a modification to the FHWA Culvert Inspection System to include additional material types. The training presented example culverts and allowed participants to rate them using the condition assessment system. The training included at least one example of every major culvert material type along with a variety of culvert conditions. Instructors provided guidance on the correct use of the TAMC Pilot condition evaluation system and discussed each example with reference to the culvert rating table provided as a handout.

Task 1 - Results

Culvert Data Collection using Roadsoft

- March 31st (48 registered attendees)
- September 17th (24 registered attendees)

Culvert Condition Evaluation

- April 7th (59 registered attendees)
- April 9th (18 registered attendees)
- September 24th (9 registered attendees)

Full details of these training events, including demographics of attendees, will be provided in CTT's year-end training report to TAMC.

Task 2 - Evaluate culvert data from combined sources

Regional culvert data is collected and stored locally from a variety of sources throughout the state. Data is known to exist from the MDNR, MDOT, and TAMC. The purpose of this task was to determine if there is a desire by the various parties collecting data to share this data for their combined interests, and if so, if there are any concerns with combining this data. For example, the existence of duplicate culverts – those existing in more than one dataset.

It is clear that culvert data provides important information for road owning agencies trying to manage their assets; however, the value of this data goes far beyond the asset owner, providing benefit to groups involved with stream conservation and habitat improvement activities which all rely on culvert data to determine the suitability of culverts to allow aquatic organism passage (AOP). Accurate culvert data is also valuable to groups involved in macro scale hydraulic and risk modeling. Each of these uses needs basic culvert inventory and location data, along with other more specific information which differs by use.

The MDNR facilitated the collection of culvert data from the perspective of gathering information on aquatic habitat in 2013. MDOT gathered culvert data as part of a pilot study in 2016 and 2017. In 2018 TAMC developed a pilot program for the inventory and condition evaluation of local agency culverts. Each of these studies produced data for very specific purposes: some of this data is potentially of use to other agencies and some may not be. This task reviewed existing data from the three main sources; MDNR, MDOT, and TAMC, and looked at how this data could be combined to create a statewide culvert inventory.

The largest immediate concern with combining these data sets is the issue of the same (duplicate) culvert appearing in two or more of the datasets since the DNR dataset is not limited by jurisdictional boundaries. Duplicate culverts can be hard to identify simply on spatial information alone, since the error involved in geographical location data may be as much as 30 feet. Additionally, different standards in precision can also make identifying duplicates difficult.

Duplicate culverts may represent one of three real life scenarios which may or may not be relevant:

1) A single culvert located two times respectively in each system where measurement error makes them appear as separate assets. In this case the duplicate should be removed.
2) A single culvert that has been replaced and exists in one or more systems before and after replacement. In this case the older (removed culvert) data should be removed or marked as deprecated.
3) A multiple barrel culvert where each barrel is located separately. This case may need intervention or a case by case review to determine the appropriate action.

In most cases culvert data from transportation agencies can easily be attributed to the jurisdictional owner of the road or trail system where the culvert is present. It is uncommon for road owners to collect data on parts of the road network that they do not own, with the possible exception of roads on jurisdictional boundaries or intersections where jurisdictions meet, which further adds to the differentiation between these two data sets. The Michigan framework basemap provides an accurate map to easily distinguish local roads and their associated culverts, state owned roads, and the culverts managed by MDOT.

The MDNR owns a number of culverts and bridges that relate to state owned recreational facilities, such as trails, state parks, and state owned public land. In many cases these trail systems run parallel to state or local roads, which may make differentiation of their ownership difficult using purely location data. The DNR also has an interest in culverts that are owned by other entities as a source of stream crossing information for analysis of barriers to AOP and for regional hydraulic modeling activity. Culverts in particular are a concern as they can be significant barrier to AOP due to features such as high flow rates or perched outfalls. Michigan DNR routinely collects stream crossing data on culverts and bridges owned by state or local transportation agencies as part of a stream survey collection activity which may contain data from all infrastructure owners along a particular stream.

The DNR stream crossing data can be a useful source of data because it may include assets that have not been inventoried by road owning agencies. Similarly, the DNR may find value in using transportation agency data on culvert locations to augment the work they are doing; however, combining the data sets provides some challenges. Figure 1 illustrates some of these challenges. The culvert which has been highlighted by the yellow circle is spatially shown located half way between the recreational trail and the state owned road, so it is unclear if the stream survey data shown as a red dot is representative of the same culvert shown as a blue line from MDOT's data set, or if there are actually two discrete culverts there, one for the MDOT road and one for the trail. Similarly, in Figure 1 the culvert highlighted in the purple circle may be located on the recreational trail or it may be located on a local agency owned road. Identifying culverts unique to one data set as well as identifying assets that are duplicated is complicated by the location accuracy of the data sets, which varies between sub-meter accuracy, and recreation grade GPS (within 30') for different data sets.

Figure 1: DNR Trail located adjacent to MDOT owned highway and crossing local roads. MDOT culverts shown in blue, DNR Stream crossings (culverts) shown in in red.

This task will attempt to identify duplicate culverts in each of the datasets based on a comparison of other fields in the inventory, collection date, location data, and any other information present. It is expected that this task will help take the first steps at establishing a protocol for sharing culvert data amongst multiple agencies while maintaining individual agency needs, each agency's standards for data collection, and the ability of an agency to update and manage their data with respect to shared data.

Task 2 – Results

Evaluation of culvert data

Objective

This task details a process that will allow state and local road agencies the ability to use data sets from the Michigan DNR stream crossing surveys to identify new culverts which may not be in their inventory. This task will provide a process for combining multi-jurisdictional data sources like MDNR's stream crossing data with data sets maintained by MDOT and local agencies without producing duplicate records for culverts which have been inventoried in multiple data set.

Data Sources Used in Analysis

All data used for the analysis in this task were collected from the Michigan Open GIS portal with the exception of the local agency culvert pilot data, which was received directly from the Center for Shared Solutions (CSS). Data sets from the Michigan Open GIS portal were chosen because they represent an outward facing, reproducible product that is already being distributed. Figure 2 illustrates an example of the range of culvert and bridge data available for this analysis in Houghton County.

Figure 2: Example bridge and culvert data. Local culverts shown as orange circles, transportation bridges shown as light blue diamonds, DNR owned culverts and bridges shown as green diamonds, DNR stream crossing surveys shown as red circles, MDOT culverts shown as dark blue lines.

MDOT Culvert Data

MDOT has been aggressively collecting network-wide culvert data for the last several years, and is embarking on an active asset management process to manage ancillary structures such as culverts. Currently, culvert data from MDOT is stored in two separate databases, dependent on the span of the structure. Culverts that are less than ten feet in span (width) are stored in the TAMS, while culverts ten feet and over in span are stored in the MiBridge system, which is the system that stores the federally defined bridge data for all public roads in Michigan. This business process manages culverts relative to the risk and cost to the public by grouping large culverts with bridges. The current culvert data set that is publically available on the State of Michigan Open GIS portal contains data on 47,699 MDOT culverts under ten feet in span. MDOT culvert data includes culverts located in the vicinity of an MDOT road and do not necessarily have to cross under the road. The State of Michigan Open GIS portal Bridge File contains 4,501 MDOT-owned bridges and 6,672 local bridges. The MiBridge data set contains approximately 1,103 MDOT-owned culverts that are 10’ spans or larger. This data set was not used in the analysis; however, it could easily be integrated into the process by joining it with

MDOT's TAMS culvert data set. It is assumed that location data from these files were collected using at least sub meter accurate survey equipment.

Local Agency Culvert Data

Local agency practice for collecting culvert data varies greatly across the state. Some local agencies collect condition and inventory data on a routine cycle while others have not started the process. The largest unified collection effort occurred in 2018 when TAMC completed a local agency culvert collection pilot which collected information on 49,664 local agency owned culverts which are located on local agency owned roads. The primary tool for collecting local agency culvert data is Roadsoft, which provides a unified data schema and process for collection. The data set used for this task was received from CSS and included 43,202 local agency culverts that were collected using Roadsoft during the pilot. It was assumed that all local agency culvert data was located using recreational grade GPS data with an accuracy of +/-30 feet.

DNR Culvert and Stream Crossing Data

The DNR-managed culvert database available on the State of Michigan Open GIS portal contains information on 1201 culverts and bridges managed by the DNR which are primarily located on recreation trails and state park facilities. For the purposes of this task it was assumed that the culverts and bridges in this database were correctly identified as owned by the DNR, and as such were not considered in the evaluation for comparison against the MDOT or Local Agency culvert data sets.

The Michigan DNR maintains a database of stream crossing surveys which have been compiled on culverts and bridges. These stream crossings can be completed by DNR staff, hired consultants, and conservation groups, like Huron Pines Association or Trout Unlimited. Stream crossing surveys are usually collected on a watershed basis so they are likely to collect data on culverts from multiple owners. Stream crossing data can be a valuable source of data for detecting new culverts which may not be in an infrastructure owner's database; however, they also pose a problem since they do not fit into a discrete sphere of influence. The stream crossing data available on Michigan's Open GIS Portal contains stream crossing data representing 2,230 bridges and culverts.

Methods

During the development of the data handling process, DNR stream crossing data sets were compared to the MDOT culvert and bridge data and the Local Agency culvert and bridge data separately. Separating these analysis processes allows the stream crossing data to be matched up with both the MDOT and Local data sets without interference between sets, which removes bias in the matching process.

During the development of the process, the project team used the following guiding principles to make decisions on processing data.

a) Each asset owner (MDOT, DNR, Local Agency) has a sphere of influence where their data will have primacy over other users. This ensures that the owner's data will in all cases remain intact as they have presented it in cases where joining sets is the intent. The sphere of influence varies with the expected width of the road right of way and the total assumed error in location measurement between data sets.

b) Data which occurs at areas where spheres of influence overlap, such as parallel right of ways or intersecting roads and trails, will be tested to eliminate duplicates and identify new assets that the road owning agency may have missed. Testing includes finding agreement on critical inventory fields including: length, shape, material, height, and width.

c) Critical inventory fields may be interpreted differently between data sets, so exact matches are not likely and a reasonable buffer or conversion must be provided around the recorded inventory fields to determine a match. For example, some stream crossing data might appear with inventory data such as width or height which were measured literally vs providing the nominal pipe size that culverts are usually classed in. i.e. recorded at 31.4" pipe rather than 30" pipe.

d) Culvert shape and material data needs to be reduced down to the lowest common denominator removing some of the specificity before matches can be determined. For example, "reinforced concrete pipe" and "precast concrete pipe" would be reduced down to "concrete", and "3 sided box", "rectangle" and "box" would be reduced to "rectangle".

e) The goal of the process should be to identify a limited number of locations that can be field verified if data is not present or if a match is not clear, while separating data that is clearly discrete within a set.

A generalized process flow was developed that can be used for analysis of DNR stream crossing data with MDOT and local agency data, with only slight modifications to the two process. Figure 3 illustrates the process for analyzing DNR Stream crossing data with MDOT culvert data. Both the local agency and MDOT process flow charts, along with GIS process notes, are included in the Appendix.

Process flow for intake of DNR stream crossing data and rectification with MDOT culvert data

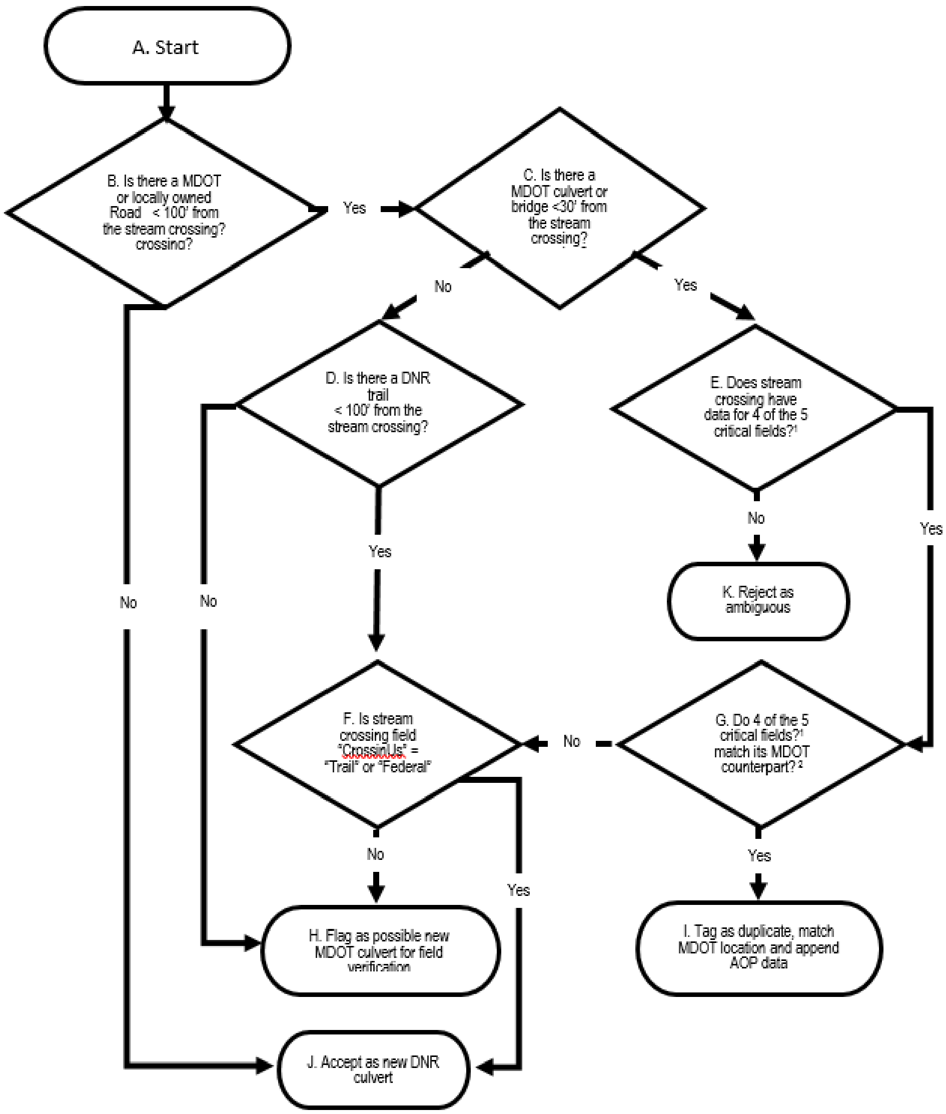

Figure 3: Process flow chart for matching DNR stream crossing data with MDOT culvert data

[1]Critical stream crossing fields are: "StructureLength" "StructureWidth" "StructureHeight" "StructureShape" "StructueMaterial"

[2]Matching is defined as within the following tolerances: StructureLength is within 25% of MDOT length, StructureWidth is within 15% if MDOT width or span, StructureHeight is within 15% of MDOT height or rise, StrucutreSshape matches MDOT shape after being transformed, StructureMaterial matches MDOT material after being transformed

Process Narrative:

The first step in the process (Step B) is to separate stream crossings that are outside of MDOT's sphere of influence, which in this case was set at 100 feet from either side of the MDOT centerline as shown on the framework base map. Stream crossings under 100 feet from an MDOT road are considered for further analysis in Step C to determine if there is a known MDOT bridge or culvert within 30 feet of their location. Thirty feet was chosen to represent the possible inaccuracy of using recreational grade GPS for determining the location of stream crossing data.

Stream crossings that are found to be within 30 feet of an existing MDOT culvert or bridge are evaluated to determine if they are matches with known MDOT culverts or bridges by comparing the critical inventory fields of shape, material, length, height and width in Step E, J, K and I. Stream Crossings that do not have sufficient data in critical fields are marked as ambiguous in Step K, since there is not sufficient data to determine if a match exists. These locations will need to be field verified to determine their ownership and inventory information.

Stream crossings that are in MDOT's sphere of influence but are not within 30 feet of a known bridge or culvert are checked to see if they are located near the crossing point of a DNR trail in Step D. Stream crossings that are not within 100 feet of a DNR trail are considered for possible new MDOT culvert locations which need to be field checked before being included in MDOT's database (Step H). Stream crossings that are not near a trail are evaluated to determine if they have information describing the crossing type. In many cases the crossing type filed is blank; however, when it is listed as "trail" or "federal" the incidence of it being a MDOT owned crossing is low, so the crossing will be processed to Step J where it is added back into the DNR's culvert set.

The process for local agency culvert data is identical to the MDOT process with the exception that the sphere of influence threshold for Step C is increased to 100 feet to account for the presumed lower location accuracy.

Processing of the 2230 records in the DNR stream crossing data produced the following results when analyzed with MDOT culvert and bridge data:

- 130 stream crossings were in MDOT's sphere of influence (Step C Input)
    - 23 were rejected as ambiguous (step K)
    - 18 were identified as matches (Present in both data sets)
    - 50 were identified as possible previously unidentified MDOT culverts

The 23 stream crossings that were marked as ambiguous because they lack critical inventory data are still worth field verification.

The 50 stream crossing that were identified by the process as potential new culverts produced several false positives that can quickly be identified and dismissed by visual inspection of the

GIS data. Most of the false positives are located at bridges and are a result of how bridge data is collected using one data point, which is usually located at the abutment. Longer bridges will create false positives since the stream crossing point in many cases will be located at the center of the creek, which may be over 30 feet from the bridge abutment. These false positives are easy to identify and are relatively few in number, so it does not warrant a change in the collection protocol. Figure 4 and Figure 5 illustrate these types of false positives. Figure 6, Figure 7, and Figure 8 illustrate examples of potential new MDOT culverts.

Figure 4: False positive new MDOT culvert shown by red star icon. MDOT bridge shown as blue diamond, MDOT culverts shown as dark blue lines

Figure 5: False positive new MDOT culvert shown by red star icon. MDOT bridge shown as blue diamond, MDOT culverts shown as dark blue lines.

Figure 6: Potential new MDOT culvert shown as red star. Known MDOT culverts shown as dark blue lines, other stream crossing surveys shown as red circles.

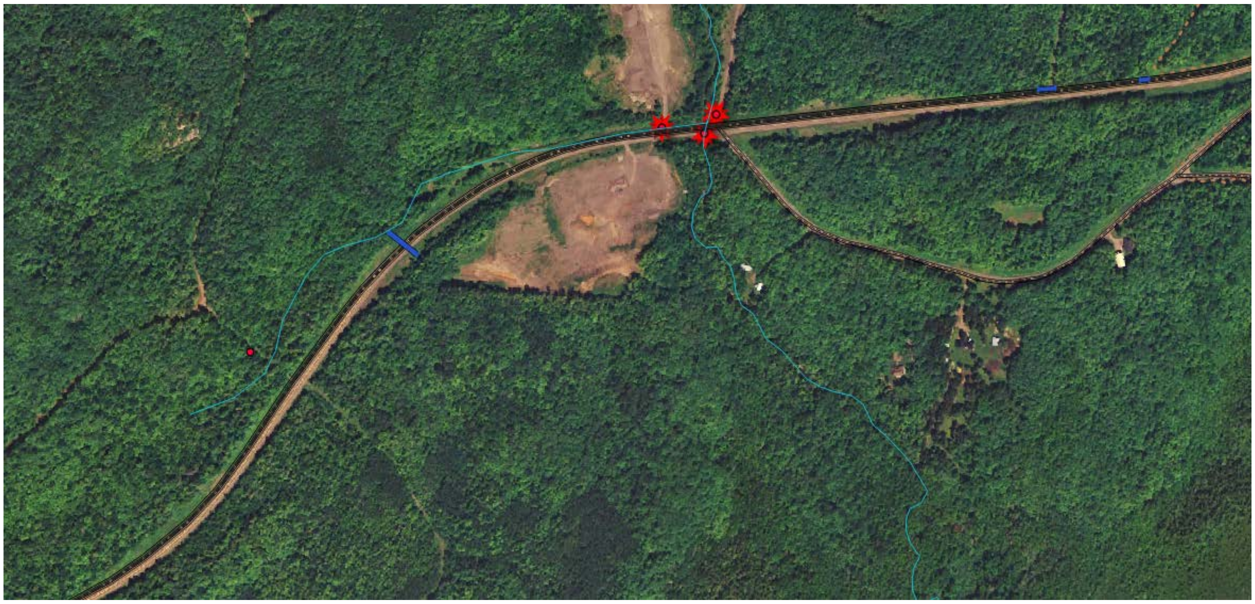

Figure 7: Potential new MDOT culverts shown as red stars. Known MDOT culverts shown as dark blue lines, other stream crossing surveys shown as red circles.

Figure 8: Potential new MDOT culverts shown as red stars. Existing MDOT culverts shown as dark blue lines, DNR bridges and culverts shown as green diamonds and other stream crossing surveys shown as red circles.

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Processing of the 2230 records in the DNR stream crossing data produced the following results when analyzed with local agency culverts and bridge data:

- 642 stream crossings were within the sphere of influence of local roads (Step C Input)
    - o 37 were rejected as ambiguous (step K)
    - o 65 were identified as matches (present in both data sets)
    - o 331 were identified as possible previously unidentified local road culverts

Figure 9 illustrates examples of potential new local agency culverts identified by the process.

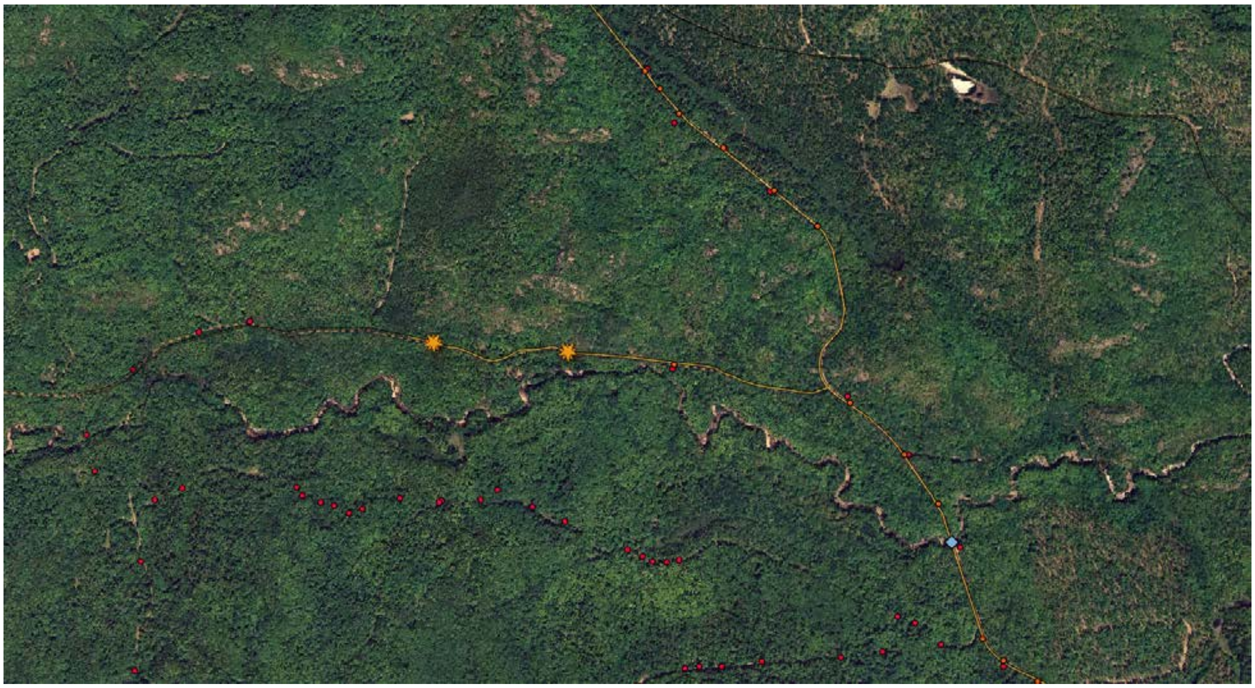

Figure 9: Potential new local agency culverts shown as orange stars, other stream crossings shown as red circles, known local agency culverts shown as orange circles, transportation bridges shown as blue diamonds

Case Study Interviews

The CTT conducted interviews with agencies identified as having an interest in culvert data outside of the transportation area to determine potential case studies whereby the TAMC Local Agency Pilot data may be of benefit. One local transportation agency was added to the interviews as they had very little self-generated culvert data and desired to reach out to non-transportation agencies who had data in their jurisdiction with the hope of using that data as a start for their collection efforts.

Specific details for each agency interview are presented below. In general, the interview process indicated some interest in sharing culvert data. While it was expected that each agency would have specific data needs that they would want to collect, according to their specifications, it was thought that some data, like general inventory and location data, would be of common interest to all agencies. The general consensus was that the data each agency already has is of adequate quality to meet their needs, but data from other sources could be helpful for forming partnerships to replace culverts (condition data) or for an agency to expand areas of data coverage (geographically or depth of detail) where an agency would otherwise be starting from scratch. These are just a couple examples brought forth as agencies discussed how they may benefit from shared data. The data sharing discussion evolved over the course of this project from limited interest by culvert data holders to an increased interest as they found more potential benefits from working with other agency data. The reflections presented in this section are statements in time and could change as agencies discuss strategies for working together and forming partnerships to meet mutual interests.

Huron Pines – Gaylord and Alpena

Huron Pines is an organization with a mission to conserve and enhance Northern Michigan's natural resources to ensure healthy water, protected habitat, and vibrant communities. Through strategic partnerships at the federal, state, and local level, Huron Pines influences strategy and vision for the future conservation in Michigan while also executing on-the-ground projects with immediate impacts on environmental quality.

Their main objective is to replace or rehabilitate culverts and dams for the benefit of fish passage. Typically, they are involved with six to ten culverts per year. They generally work with local agencies to achieve this, where Huron Pines works to secure funding for material and then engages a local agency to help provide equipment and labor for the duel benefit of having new culvert that improves on fish passage.

Huron Pines feels they have the data that is most important to them, which includes severity ranking based on stream condition, location, material, and size. Good/Fair/Poor/Severe condition data may be helpful for them to prioritize projects that may be mutually beneficial to their interests and those of the local agencies they work with.

Conservation Resource Alliance – Traverse City

The Conservation Resource Alliance (CRA) is a private, not for profit corporation committed to "sensible stewardship of the land." Their main objective is optimizing stream flow and fish habitat with focus on achieving their goals across an entire watershed while being able to take advantage of opportunities to optimize stream crossings being replaced for other reasons.

They work with local agencies on culvert replacements by securing project funding and then partnering with local agencies to provide equipment and labor. Their interest in culvert data would be to the extent that they could keep an eye on opportunities to improve or replace culverts that would align with their objectives. Culvert cost data would be helpful as they would like to focus on a cost data-driven approach to culvert replacement – cost of prevention vs cost of emergency response and the value of enhanced habitat.

SEMCOG

The Southeast Michigan Council of Governments (SEMCOG) is working on a project to take a wide approach to infrastructure asset management that includes environmental, flooding, and transportation needs. Their goal is to provide flood consideration input into projects considered for funding. The data SEMCOG is interested in includes location, material, and size as they have found this data to be somewhat lacking. Culvert data related to flood risk, including condition, would be highly valued.

Michigan State Hydrography Improvement Pilot

Michigan State University's work on the Hydrography Improvement Pilot is to develop models, scripts, and procedures for realigning hydrology features and flow lines to create a realignment of the National hydrography dataset (NHD) in the state of Michigan. The NHD represents the water drainage network of the United States with features such as rivers, streams, canals, lakes, ponds, coastlines, dams, and stream gages. Their Hydrography Improvement Pilot V2 features the Kalamazoo watershed.

Culverts are an important part of getting these flow lines correct. One of the most important culvert attributes for creating flow lines is location data. The culvert points are collected, then models are created that turn culvert points into channels through barriers. Other useful attributes include skew, length, and diameter of the culverts.

Data was collected from TAMC, MDOT, and counties for the pilot. Several problems arose while processing this data. Those included eliminating duplicates of culverts from different entities, and inaccurate GPS data. Those issues were solved by using spatial selection and a manual review of the culverts. A proposed way to solve the inaccurate GPS data in the future would be to create a standard for GPS collecting units.

Wexford County Road Commission

Wexford County Road Commission would like to create a culvert asset management plan and inventory. Their desire is to be more proactive with budgeting and planning for culvert maintenance activities. They also feel the increased knowledge of their culvert assets would allow for more efficient partnering with resource agencies for mutual benefit. They are currently working with the US Forest Service, DNR, Trout Unlimited, and CTT to gather existing data and import it into Roadsoft. They have found some of the data they received to be helpful – GPS coordinates, length, and diameter; however, other data would be useful but is generally not present from these sources. Examples of other useful data would include condition ratings and pictures of the inlet & outlet.

They would be interested in participating in partner agency training and assist with data collection while on site for other purposes to the extent that the additional time spent would be no more than 5-10 additional minutes per culvert.

They noted some difficulty in gaining access to data from other agencies and expressed concern with importing this data. They also noted the need to have a process to ensure that data considered by the county to be accurate was not potentially overwritten by incoming data from other sources.

Michigan DNR Online Reporting Tool and Knowledge Base

The CTT worked with the Michigan DNR to register for access to their Great Lakes Stream Crossing Inventory data hub at https://great-lakes-stream-crossing-inventory-michigan.hub.arcgis.com/ Site users are encouraged to become involved through training and volunteer opportunities, as well as to contribute data. There is a sign-up for access to the Stream Crossing Collector.

Interactive maps provide crossing locations and information such as the number of crossings, estimated annual erosion tonnage, aquatic passability, stream crossing condition, crossing type, and additional information.

Task 3 - Culvert condition assessment system translation

Two culvert condition assessment systems are currently in use in Michigan; the TAMC Pilot and the MDOT systems. Both systems evaluate specific elements within a culvert system to determine the overall culvert condition. They appear to meet the need of the respective users and each group has a significant investment in historical data. Recently, a third assessment system was added, an update to the 1986 FHWA method (basis of TAMC Pilot system) published by AASHTO in August of 2020. Generally speaking, all three systems have the same function and assess similar defects; however, the systems are not identical and therefor pose a potential problem when data is displayed side-by-side or combined. The goal of Task 3 was to create a system for translating MDOT and TAMC culvert data for the purpose of creating dashboards that would allow comparison between these two condition data sets while maintaining the integrity of each agency's detailed element level collection criteria. These existing systems were also compared to the new AASHTO system for the purpose of understanding what would be gained or potentially lost by adopting the new AASHTO system.

TAMC

The FHWA Culvert Inspection System had been incorporated into Roadsoft and has been used by local agencies. The TAMC Pilot system added additional deterioration descriptions for specific culvert types not included in the 1986 FHWA Culvert Inspection System. The TAMC Pilot system is organized around the culvert material type. Each material type is broken down into relevant elements for which condition should be evaluated. A description is provided for each element to describe its condition for each of the condition states. This system allows a numerical ranking from 10 to 1 with 10 being a culvert in excellent condition. This represents a shift from the numeric values used by FHWA (9 to 0) for consistency with other rating systems used within Roadsoft. The numerical values are divided into the general condition categories of Good (10-8), Fair (7-6), Poor (5-4), and Serious (3-1). A detailed description for each condition state is provided for each numeric rating value specifically intended to address common forms of distress seen in each of the culvert types included in the inspection system; corrugated metal pipe (CMP), concrete pipe, plastic pipe, masonry, slab & abutment, and timber. The TAMC pilot used a lowest-rating method within Roadsoft to determine the overall culvert condition from individual inspection element ratings.

MDOT TAMS

MDOT has its own condition assessment system which consists of two methods; one for culverts less than 10-ft and another for larger culverts. The TAMS method is used for culverts less than 10-ft. The TAMS system looks at elements associated with a culvert system, including elements that are in the vicinity of the culvert barrel, such as the roadway over the culvert and the embankment. Culvert barrel element descriptions are generally not material dependent though some element descriptions are differentiated between metal and concrete. This system assigns a numeric rating from 9 to 1 with 9 considered good. The numeric values are summarized as Good (9-8), Fair (7-6), Poor (5-4), and Critical (3-1). A general description of distress associated with the four general categories; good, fair, poor, and critical is provided for each element under consideration. General descriptions for some elements (invert deterioration and corrosion) contain separate descriptions for distress of metal and concrete. The MDOT TAMS Asset Collection & Condition Assessment Guide for 1’-<10’ Span Culverts (revised June 2018) states that the overall condition rating is based on the lowest rating for the critical attributes (elements).

MDOT NBIS

For larger structures (10-ft to 20-ft), MDOT uses the NBIS method and ratings are entered into the MiBridge database according to the FHWA Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation’s Bridges. This document identifies a rating system for culverts under Item 62. This rating system provides a basic description for a 0 to 9 rating system and cites the FHWA Culvert Inspection Manual (July 1986) for a more detailed discussion. Because this is the same source used to develop the TAMC Pilot method, it is assumed that the larger structures rated by MDOT would naturally compare to the TAMC Pilot ratings and only the TAMS approach used by the smaller culverts will require translation.

AASHTO

The new AASHTO system considers similar elements as seen in the TAMC and MDOT TAMS systems and adds some additional elements. The AASHTO system is organized differently than the two current systems; containing components of both. AASHTO considers elements in the vicinity of the culvert, including the roadway above and the embankment as found in the MDOT TAMS system. It also provides condition descriptions specific to characteristics of material type. The one fundamental difference between AASHTO and the two current systems is AASHTO specifically does not summarize a culvert's condition to a single rating. The condition rating for each element is reported to allow specific maintenance decisions to be made as part of the asset management process. The rating system is based on 4 points which translate to Good/Fair/Poor/Severe but unlike the current systems a value of 1 is associated with the good condition and 4 with severe.

System Comparison

Figure 10 shows a sample of the rating values, general conditions, and detailed descriptions associated with section deformation for a CMP culvert with a round cross section. Note: the TAMC Pilot system provides a different set of descriptions specific to eight different cross-sectional shapes of CMP and one set of descriptions for plastic pipes. The MDOT TAMS system describes section deformation for all pipes with one set of descriptions, but those descriptions are not broken down into individual numeric rating values. The descriptions are instead broken down into the general conditions of good, fair, poor, and critical. This breakdown essentially creates a general condition rating system allowing the inspector to indicate better or worse ratings within each bin through their numeric selection. The AASHTO method provides descriptions based on the four general condition levels; good/fair/poor/severe.

Modified FHWA (TAMC)	Excellent	Very Good	Good	Satisfactory	Fair	Poor	Serious	Critical	Imminent Failure	Imminent Failure
	10	9	8	7	6	5	4	3	2	1
Section Deformation (CMP - Round)	New Condition	Good, smooth curvature in barrel. Horizontal diameter (span) dimension within 10% of original design.	Generally good, top half of pipe smooth but minor flattening of bottom. Horizontal diameter (span) dimension within 10% of original design.	Fair, top half has smooth curvature but bottom half has flattened significantly. Horizontal diameter (span) dimension within 10% of original design.	Generally fair, significant distortion at isolated locations in top half and extreme flattening of the invert. Horizontal diameter (span) dimension 10% to 15% greater than original design.	Marginal significant distortion throughout length of pipe, lower third may be kinked. Horizontal diameter (span) dimension 10% to 15% greater than original design.	Poor with extreme deflection at isolated locations, flattening of the crown, crown radius 20 to 30 feet. Horizontal diameter (span) dimension in excess of 15% greater than original design.	Critical, extreme distortion and deflection throughout pipe, flattening of the crown, crown radius over 30 feet. Horizontal diameter (span) dimension more than 20% greater than original design.	Partially collapsed with crown in reverse curvature	Structure collapsed
MDOT		Good		Fair		Poor		Critical		
		9	8	7	6	5	4	3	2	1
Section Deformation		None		Slight, perceptible deformation or local buckling		Deformation with longitudinal cracking or crushing in crown, invert, or spring lines		Excessive deformation resulting in extensive infiltration of soil with roadway/embankment damage.		
AASHTO	Good			Fair		Poor		Severe		
	1			2		3		4		
Shape (Closed Shape) (CMP)	Smooth curvature in barrel, deformation less than 5% of inside diameter			Top half smooth. Minor bulges or flattening of bottom. Deformation 5%-10% of original inside diameter.		Significant distortions or flattening. Lower third may be kinked. Deformation greater than 10% -15% of original inside diameter. Visible out-of-roundness		Extreme distortion throughout pipe, local areas of reverse curvature and kinds. Deformation greater than 15% of original inside diameter. Significant out-of-roundness		

Figure 10: Example rating values, general conditions, and detailed descriptions for CMP as used in the TAMC Culvert Pilot, the MDOT TAMS, and AASHTO rating methods

A detailed breakdown between each of the rating systems is discussed in the results section of this report. While both current rating systems produce numeric values representative of the overall culvert condition, the broad descriptions applied to general conditions within the MDOT TAMS system do not allow for a direct comparison between the two rating systems at a detailed numeric scale level. At the general condition level, all of the associated condition descriptions between the two systems can be compared for general agreement. However, since there is no difference in the description between numeric ratings within a general condition category in the MDOT TAMS system, there is not sufficient information to compare at the numeric level. References are made within this report to numeric values within both systems.

These are made for the purpose of discussion and not in suggestion of a direct translation between the two systems.

Results:

Reported Controlling Rating Value:

Each of the rating systems discussed in this report vary in the elements considered for condition evaluation. These can be broken up into two broad categories; the vicinity of culvert, and the culvert barrel. The TAMC Pilot, given specific direction from legislature and a tight deadline, focused the condition evaluation effort on the culvert barrel. The culvert barrel was investigated in greater detail, while the vicinity evaluation considered only scour and blockage, which are both immediately adjacent to the culvert. The MDOT TAMS method considered more items in the vicinity of the culvert and looked at elements associated with the culvert barrel with less specific detail than the TAMC Pilot. The new AASHTO method approximates a combination of the two approaches. There is balance between evaluation of elements in the vicinity of a culvert and the barrel itself. Each element has a detailed description associated with it, similar to the descriptions provided in the TAMC Pilot. However, like the MDOT TAMS method, these descriptions are associated with general conditions so there are only four category descriptions to consider when rating an element as opposed to 10 descriptions for the TAMC Pilot method.

One more significant difference between the three methods is that AASHTO establishes a condition rating for each system component, while the other two provide one overall condition rating associated with the culvert system. The AASHTO method consists of system components and each of these contains characteristics that are evaluated. The condition rating associated with a component is the worst rating of the characteristics considered. This adds a level of reporting not present in the other two methods which rate for each element. Sample evaluation forms provided by AASHTO indicate that while notes would exist for each of the characteristics considered, only the overall rating for each component would be recorded. This is essentially no different than the other systems where only the overall condition for the culvert would be reported and element level information would be available in the associated notes. This is significant, however, in that it would make translation of a rating from one system to another exceedingly difficult. A good example of this issue may be found with scour. The TAMC Pilot method identified scour as its own element and a value for scour would be available in the inspection notes even if scour did not control the final rating. Scour is not considered in the MDOT TAMS system in the overall rating so any information on scour would have to be found in the inspection notes. AASHTO includes some aspect of scour in three of their system components; Channel Alignment and Protection, End Treatments and Appurtenant Structures, and Concrete Footings and Invert Slabs. A rating specific to scour would again have to be pulled from notes as it wouldn't be clear otherwise if the rating for any of these components was based on scour or another characteristic.

A summary and comparison of the elements and system components/characteristics involved in the condition rating of each system is shown in Table 1. Green text indicates elements from the TAMC Pilot method that have similarities in the other systems. Blue text indicates elements from MDOT TAMS that are not present in the TAMC Pilot method but are present in AASHTO.

Table 1: Summary and comparison of elements involved condition rating between TAMC Pilot and MDOT TAMS

AASHTO	TAMC	MDOT TAMS
Vicinity of Culvert		
Approach Roadway Condition State Definitions	**General Elements**	**General Elements**
Pavement	Blockage	Road Over
Guardrail	Scour	End Section (non-critical)
Shoulders		Apron (non-critical)
Embankment Condition State Definitions		Scour (non-critical)
Slope Stability and Embankment Erosion		Riprap (non-critical)
Channel Alignment and Protection Condition State Definitions		Sediment
Channel Alignment		Invert Location (non-critical)
Bank Erosion and Scour		Embankment
Protection		Footing Exposed? (non-critical)
Waterway Adequacy (Non-AOP)		
End Treatments and Appurtenant Structures Condition State Definitions		
Cracking (concrete)		
Surface Damage, Spalling, Delamination (concrete)		
Deformation and Damage (metal)		
Corrosion (metal)		
Scour and Stability		
Settlement/Rotation		
Concrete Footings and Invert Slabs Condition State Definitions		
Differential Settlement and Movement		
Scour and Stability		
Cracking		
Surface Damage		
Spalling, Delamination, and Patches		
Barrel Alignment Condition State Definitions		
Barrel Alignment		
Culvert Barrel		
Plastic Barrel Condition State Definitions	**Plastic Pipe**	**General Elements**
Shape	Structural Deterioration	Invert Deterioration (metal)
Surface Damage	Invert Deterioration	Invert Deterioration (concrete)
Local Buckling, Splits, and Cracking	Section Deformation	Section Deformation
Concrete Barrel Condition State Definitions	**Concrete Pipe**	Corrosion (metal)
Cracking	Structural Deterioration/Closed Bottom Invert Deterioration	Corrosion (concrete)
Slabbing, Spalling, Delamination, Patches	Open Bottom Invert Deterioration	
Deterioration		
Corrugated Metal Barrel Condition State Definitions	**CMP**	
Surface Damage	Structural Deterioration (corrosion)	
Corrosion	Closed Bottom Invert Deterioration	
Abrasion	Open Bottom Invert Deterioration	
Shape (Closed Shape)	Section Deformation	
Shape (Open Shape)		
Masonry Barrel Condition State Definitions	**Masonry**	
Masonry Units and Movement	Structural Deterioration	
Mortar	Invert Deterioration	
Efflorescence		
Timber Barrels Condition State Definitions	**Timber**	
Connections and Missing Members	Structural Deterioration	
Decay	Invert Deterioration	
Checks and Shakes		
Structural Cracks		
Delamination		
Abrasion/Impact Damage		
Distortion		
	Slab & Abutment	
	Structural Deterioration	
	Invert Deterioration	
	Concrete Abutment	
	Masonry Abutment	
Shared Barrel Elements (Joints - Plastic, Concrete, Metal & Seams - Metal)		
Joint Condition State Definitions	**Joints & Seams**	**General Elements**
Joint Separation, Offset, and Rotation	Joints/Seams	Joints
Joint Cracking (concrete)	Pipe Joints or Seams (CMP)	
Infiltration and Exfiltration	Multi-plate Joints or Seams (CMP)	
Seams of Corrugated Metal Plate Condition State Definitions		
Infiltration/Exfiltration		
Seam Alignment		
Seam Bolts/Fasteners		
Seam Bolt Holes		
Outcome		
Individual rating for each component (controlling characteristic rating)	Overall controlling rating value	Overall controlling rating value

Review of Table 1 shows many similarities between the three systems. System components/characteristics and elements that generally correspond to each other are compared in the next section.

Rating Components/Characteristics or Elements:

Each rating system consists of components/characteristics or elements within the culvert system that are rated based on a description of what distress could reasonably be expected to be found associated with that element. The approach and level of detail applied to each of the three systems differ. The TAMC Pilot organized the condition evaluation guidance first by culvert type, then by detailed condition descriptions associated with typical distress at each element under consideration for that culvert type. The MDOT TAMS system looked at elements and descriptions more universally where most elements are applicable to all culvert types with some specific elements having been broken down into descriptions based on metal or concrete material type. The AASHTO method contains detailed condition descriptions for each culvert type but for the four general condition categories. These differences result in the need for an element by element comparison of distress descriptions in order to determine how closely related the systems are.

Blockage:

Modified FHWA (TAMC)	Excellent	Very Good	Good	Satisfactory	Fair	Poor	Serious	Critical	Imminent Failure	Imminent Failure
	10	9	8	7	6	5	4	3	2	1
Blockage	No blockage. Designed condition.	Minor amounts of sediment build-up with no appreciable loss of opening.	**Culvert waterway blockage is less than 5% of the cross sectional area of the opening. Bank and channel have minor amounts of drift.**	Culvert waterway blockage is less than 10% of the cross sectional area of the opening. Sediment buildup causing flow through 1 of 2 pipes. Silt and Gravel buildup restricts half of the channel. Tree or bush growing in the channel. Fence placed at inlet or outlet. Rock dams in culvert.	**Culvert waterway blockage is less than 30% of the cross sectional area of the opening. Tree or bush growing in channel. Fence placed at inlet or outlet. Rock dams in culvert.**	**Culvert waterway blockage is less than 40% of the cross sectional area of the opening. Occasional overtopping of roadway. Large deposits of debris are in the waterway.**	**Culvert waterway blockage is less than 80% of the cross sectional area of the opening. Overtopping of roadway with significant traffic delays.**	Culvert waterway blockage is 80% or greater of the cross sectional area of the opening. Frequent overtopping of roadway with significant traffic delays.	Culvert waterway completely blocked and causing water to pool. Road closed because of channel failure.	Total failure of pipe.
MDOT		Good		Fair		Poor		Critical		
		9	8	7	6	5	4	3	2	1
Sediment		Same condition as initial placement		**Additional material has moved into culvert but does not exceed 20% of rise.**		**Sediment exceeds 20% but is less than 50% of rise**		Sediment significantly impacting the capacity of culvert.		
AASHTO	Good			Fair		Poor		Severe		
	1			2		3		4		
Waterway Adequacy (Non-AOP)	Waterway is open and free flowing with no obstructions			Minor sedimentation or debris accumulation. Depth of blockage less than 10% of pipe diameter. No indication of scour. Evidence of ponding.		Partial blockage of channel due to trees, shrubs, sedimentation or debris. Depth of blockage between 10% and 30% of pipe diameter. Ponding deeper than 10% of diameter.		Culvert blocked or severely restricted due to mass drift accumulation. Depth of blockage greater than 30% of pipe diameter. Frequent flooding, high water marks indicating roadway overtopped in high flows.		

Figure 11: Blockage rating comparison between the TAMC Culvert Pilot, the MDOT TAMS, and AASHTO rating methods

When considering blockage or sediment in the pipe, the TAMC Pilot system is likely to have higher G/F/P/S ratings than the MDOT TAMS rating system. For each general condition category, the allowable percent of culvert blocked is lower using the MDOT TAMS system. Culverts rated as 9 or 8 (good) with the TAMC Pilot would be considered 7 (fair) using the MDOT TAMS system. Likewise, 6 and 4 (fair and poor) using the TAMC Pilot system would be considered 5 and 3 (poor and severe) respectively in the MDOT TAMS system. Some good ratings in the TAMC Pilot system would translate to fair in the MDOT TAMS system.

Comparing both of these systems with the AASHTO method, one could expect to find lower ratings using the AASHTO system. This is due mostly to the description of the amount of blockage by percentage of culvert opening. The TAMC Pilot system allowed a greater percent of blockage in each category than what was allowed by MDOT TAMS which in turn allowed a greater percentage than AASHTO. Fair and Poor in both the TAMC Pilot and MDOT TAMS would be entered as Poor and Severe using AASHTO

In general, the details described in the description for each category are similar in content and extent between all three systems. Slightly less details are provided with the MDOT TAMS method.

Scour:

Modified FHWA (TAMC)	Excellent	Very Good	Good	Satisfactory	Fair	Poor	Serious	Critical	Imminent Failure	Imminent Failure
	10	9	8	7	6	5	4	3	2	1
Scour	No evidence of scour at either inlet or outlet of culvert.	Minor scour holes developing at inlet or outlet. Scour protection placed.	Minor scour holes developing at inlet or outlet. Top of footings is exposed. Probing indicates soft material in scour hole.	Minor scour holes, 1 foot or less deep, developing at inlet or outlet. Footings along the side are exposed less than 6 inches. Damage to scour counter measures. Probing indicates soft material in scour hole.	Minor scour holes, 2 feet or less deep, developing at inlet or outlet. Footings along the side are exposed less than 12 inches. Damage to scour counter measures. Probing indicates soft material in scour hole.	Significant scour holes, 3 feet or less deep, developing at inlet or outlet. Does not appear to be undermining cutoff walls or headwalls. Bottom of footing is exposed. Major stream erosion behind headwall that threatens to undermine culvert.	**Major scour holes, 3 feet or deeper, at inlet or outlet undermining cutoff walls or headwalls. Footing is undermined.**	Streambed degradation causing severe settlement.	Culvert closed because of channel failure.	Total failure of culvert because of channel failure.
MDOT*		Good		Fair		Poor		Critical		
		9	8	7	6	5	4	3	2	1
*Scour** **MDOT does not include scour in overall rating*		*Stream width consistent with culvert inlet/outlet.*		*Stream has minor widening at culvert inlet/outlet.*		*Stream significantly wider at culvert inlet/outlet. Minor local erosion of streambanks.*		*Stream significantly wider at culvert inlet/outlet. Stream banks showing significant erosion.*		
AASHTO	Good			Fair		Poor		Severe		
	1			2		3		4		
Scour & Stability	No exposure of previously buried sections of footing. No rotation from installed condition.			Scour exposing any surface of previously buried structure or footing. No undermining. No rotation from installed condition.		Scour exposing vertical base of previously buried structure or footing. No undermining or rotation of footing.		Scour with significant undermining of footing. Severe rotation leading to structure distress (kinking of metal culvert; cracking of concrete culvert; cracking of mortar; displacement of masonry units).		

Figure 12: Scour rating comparison between the TAMC Pilot, the MDOT TAMS, and AASHTO rating methods

Scour descriptions for each of the general rating categories are similar between the TAMC Pilot and AASHTO systems. One difference is in a rating of 4 in the TAMC Pilot system where undermining of the footing would be OK it is not in AASHTO and would be considered Severe. The MDOT TAMS system provides information on scour assessment but does not consider the scour rating when determining the overall rating for the culvert. The provided descriptions are also focused on evaluation of the stream more so than the effect of scour on the culvert. For these reasons the MDOT TAMS system was not compared with the other two for scour but has been shown for informative purposes.

Plastic:

Plastic pipes are not specifically identified in the MDOT TAMS system. Therefore, the discussion below is limited to a comparison between the TAMC Pilot and AASHTO methods. The TAMC Pilot system considered three aspects of plastic pipe deterioration in the condition evaluation; structural deterioration, invert deterioration, and section deformation. Each distress type is compared individually below.

Modified FHWA (TAMC)	Excellent	Very Good	Good	Satisfactory	Fair	Poor	Serious	Critical	Imminent Failure	Imminent Failure
	10	9	8	7	6	5	4	3	2	1
Structural Deterioration (Plastic Pipe)	New condition.	Isolated rip or tear less than or equal to 6 inches caused by floating debris or construction. Minor discoloration at isolated locations.	**Split less than or equal to 6 inches but not open more than 1/4 inch at two or three locations. Damage due to cuts, gouges, or distortion at end sections from construction or maintenance.**	Split less than 6 inches with width not to exceed 1/2 inch at two or three locations. Damage due to cuts, gouges, burnt edges, or distortion at end sections from construction or maintenance.	Split less than 6 inches with width exceeding 1/2 inch at two or three locations. Damage due to cuts, gouges, or distortion to end sections from construction or maintenance.	**Split less than 6 inches with width exceeding 1/2 inch at several locations. Splits causing loss of backfill material.**	**Split less than 6 inches with width exceeding 1 inch at several locations. Splits causing loss of backfill material.**	Split larger than 6 inches with width exceeding 1 inch at several locations. Splits causing loss of backfill material.	Pipe partially collapsed or collapse is imminent.	Total failure of pipe.
AASHTO	Good			Fair		Poor		Severe		
	1			2		3		4		
Local Buckling, ,Splits, and Cracking	Smooth interior wall. No splits in welded seams or cracking in wall.			Initiation of local buckling indicated by rippling in wall. Wall cracking or splits, less than a quarter of circumference. No infiltration. No longitudinal cracking.		Advanced and widespread local wall buckling indicated by extensive interior surface rippling. Wall cracking or splits up to half of circumference. Minor water infiltration but no soil infiltration. Longitudinal cracking less than or equal to 12 in. in length.		Kinks through full wall thickness. Pipe wall buckles inward locally. Wall cracking or splits greater than half of pipe circumference. Longitudinal cracking more than 12 in. in length. Cracks with indication of soil infiltration.		

Figure 13: Plastic pipe structural deterioration condition rating comparison between the TAMC Pilot and AASHTO rating methods

Structural deterioration of plastic pipe is similarly described in both the TAMC Pilot and AASHTO systems. The TAMC Pilot system allows some limited splitting in the good category where AASHTO does not. Descriptions in the poor category are similar. However, infiltration of soil is allowed in the TAMC Pilot poor category whereas that is not seen until severe in AASHTO. Where these issues occur the TAMC Pilot method will produce a higher rating than AASHTO.

Modified FHWA (TAMC)	Excellent	Very Good	Good	Satisfactory	Fair	Poor	Serious	Critical	Imminent Failure	Imminent Failure
	10	9	8	7	6	5	4	3	2	1
Invert Deterioration (Plastic Pipe)	New condition.	Minor discoloration at isolated locations.	**Perforations caused by abrasion located within 5 feet of outlet and not located under roadway.**	Perforations caused by abrasion located within 5 feet of inlet and outlet and not located under roadway.	Substantial perforations caused by abrasion located within 5 feet of inlet and outlet and not located under roadway.	Perforations caused by abrasion located throughout pipe.	Section loss caused by abrasion located throughout pipe.	Section loss caused by abrasion located throughout pipe with at least at least 2 foot in length by 1/2 foot in width invert section eroded away.	Pipe partially collapsed or collapse is imminent.	Total failure of pipe.
AASHTO	Good			Fair		Poor		Severe		
	1			2		3		4		
Surface Damage	No indication of wear, abrasion, impact damage, or UV degradation.			Minor wear and/or abrasion, less than 10% of wall thickness. Minor staining or UV degradation. Blistering over less than 25% of pipe inner surface (FRP).		Wear and/or abrasion that equals or exceeds 10% of wall thickness. UV degradation (pipe ends) causing discoloration. Blistering over equal to or greater than 25% of pipe inner surface (FRP).		Wear, abrasion that exceeds 25% of wall thickness. UV degradation (pipe ends) resulting in cracked or broken pipe wall.		

Figure 14: Plastic pipe invert deterioration condition rating comparison between the TAMC Pilot and AASHTO rating methods

Specific locations within the pipe are focused on with the TAMC Pilot method more so than in AASHTO. Invert Deterioration is not specifically addressed in AASHTO but the general issue associated with that area is surface damage due to abrasion. The surface damage description in AASHTO was therefore used in the comparison with the TAMC Pilot. The two systems compare closely in descriptions for invert deterioration/surface damage. One difference is that perforation is allowed in a rating 8 (good) in the TAMC Pilot method and is not indicated in AASHTO. A key point however in the TAMC Pilot method is that this is only allowable for the last five feet of a pipe and not under the roadway. This location restriction is not found in AASHTO. It would be reasonable to assume similar results from these two methods when evaluating a culvert for the conditions present under the roadway.

Modified FHWA (TAMC)	Excellent	Very Good	Good	Satisfactory	Fair	Poor	Serious	Critical	Imminent Failure	Imminent Failure
	10	9	8	7	6	5	4	3	2	1
Section Deformation (Plastic Pipe)	Smooth wall. Span dimension up to 2% greater than design.	Smooth wall. Span dimension up to 5% greater than design.	**Relatively smooth wall. Span dimension up to 7.5% greater than design.**	**Minor dimpling appearing at an isolated small area: Less than 1/16th of circumference area and 1 foot in length. Dimpling less than 1/4 inch deep. Span dimension up to 10% greater than design.**	**Minor dimpling appearing over 1/16 to 1/8 of circumference area and 2 feet in length. Dimples between 1/4 and 1/2 inch deep. Pipe deflection less than 12.5% from original shape.**	**Wall Crushing or hinging occurring with lengths less than 3 feet. Pipe deflection less than 15% from original shape.**	**Wall Crushing or hinging occurring with lengths greater than 3 feet. Moderate degree of dimpling appearing. Dimples more than ½ inch deep. Wall tearing or cracking in the buckled region. Pipe deflection less than 20% from original shape.**	Wall Crushing or hinging occurring over the majority of the length of pipe under the roadway. Moderate degree of dimpling appearing. Dimples more than ½ inch deep. Wall tearing or cracking in the buckled region. Pipe deflection greater than 20% from original shape. Severe dimpling accompanied with wall splits.	Pipe partially collapsed or collapse is imminent.	Total failure of pipe.
AASHTO	Good			Fair		Poor		Severe		
	1			2		3		4		
Shape	Barrel maintains round shape with no local wall flattening. Vertical deformation less than 5% of original inside diameter.			Minor wall flattening. Vertical deformation 5%-7.5% of original inside diameter.		Significant wall flattening or increased wall curvature. Vertical deformation greater than 7.5%-10% of original inside diameter. Visual out-of-roundness.		Extreme wall flattening with reversal of curvature (global buckling), and/or kinks. Vertical deformation greater than 10% of original inside diameter. Significant visual out-of-roundness.		

Figure 15: Plastic pipe sectional deformation condition rating comparison between the TAMC Pilot and AASHTO rating methods

The TAMC Pilot method will consistently produce higher ratings than AASHTO when considering the shape of the pipe. Evaluation is controlled by the percentage of span to original value. This allowance is less in AASHTO resulting in a one to two step difference in condition rating. For example, what was rated as good using the TAMC Pilot approach would be a fair or poor in AASHTO, depending on the percent difference in span.

Structural Deterioration/Closed Bottom Invert Deterioration (Concrete):

Modified FHWA (TAMC)	Excellent	Very Good	Good	Satisfactory	Fair	Poor	Serious	Critical	Imminent Failure	Imminent Failure
	10	9	8	7	6	5	4	3	2	1
Structural Deterioration/ Closed Bottom Invert Deterioration (Concrete Pipe)	New Condition. Superficial and isolated damage from construction.	Hairline cracking without rust staining or delamination(s). Surface in good condition.	**Hairline cracking: Less than 1/16th inch wide parallel to traffic without rust staining. Light scaling: Less than 1/8th inch deep with less than 10% of exposed area. Delaminated or Spalled area: Less than 1% of surface area. Note: cast-in-place box culverts may have a single large crack less than 3/16th inch on each surface parallel traffic direction.**	**Hairline and map cracking: Cracks less than 1/8th inch parallel to traffic with minor efflorescence or minor amounts of leakage. Scaling: Less than 1/4th inch deep or 20% of exposed area. Spalled areas with exposed reinforcing: Less than 5%. Total delaminated and spalled areas less than 5% of surface area.**	**Map cracking with hairline cracks less than 1/8th inch parallel to traffic or less than 1/16th inch transverse to traffic with efflorescence, or rust stains, or leakage or all. Scaling 3/16th inch deep on less than 30% of surface area. Spalled areas with exposed reinforcing on less than 10% of surface area. Total delaminated and spalled areas less than 15% of surface area.**	**Transverse cracks open greater than 1/8th inch with efflorescence and rust staining. Spalling at numerous locations. Extensive surface scaling on invert greater than 1/2 inch. Extensive cracking with cracks open more than 1/8th inch with efflorescence. Spalling has caused exposure of heavily corroded reinforcing steel on bottom or top of slab. Extensive surface scaling on invert greater than 3/4th inch or approximately 50% of culvert invert.**	**Extensive cracking with spalling, delamination, and slight differential movement. Scaling has exposed all surfaces of the reinforcing steel in bottom and top slab or invert with approximately 50% loss of wall thickness at invert. Concrete very soft.**	Full depth holes. Extensive cracking greater than 1/2 inch. Spalled areas with exposed reinforcing greater than 25%. Over 50% of the surface area is delaminated, spalled, or punky. Reinforcing steel bars have extensive section loss and bar perimeter is completely exposed.	Culvert partially collapsed or collapse is imminent.	The culvert is collapsed.
MDOT		Good		Fair		Poor		Critical		
		9	8	7	6	5	4	3	2	1
Invert Deterioration (Concrete)		Little or no abrasion with aggregate exposed		Moderate abrasion and scaling with minor aggregate loss. No exposure of reinforcement		Heavy abrasion and scaling with exposed reinforcement		Holes or section loss with voids beneath and roadway/embankment damage.		
Corrosion (Concrete)		Little to no efflorescence		Minor cracking and spalling		Exposed reinforcement		Significant section loss of steel reinforcement that causes pipe deformation, holes, and embankment/roadway damage.		
AASHTO	Good			Fair		Poor		Severe		
	1			2		3		4		
Cracking	No measurable crack width greater than hairline (maximum 0.01 in.).			Longitudinal cracks 0.01 in. to 0.05 in. wide (thickness of dime) with spacing of 3.0 ft. or more. Some circumferential cracks wit no infiltration. Efflorescence but no rust staining emanating from cracks.		Longitudinal cracks between 0.05 in. and 0.1 in. wide, no exposed rebar with spacing 1.0-3.0 ft. Water infiltration through circumferential cracks. Efflorescence and/or rust staining emanating from cracks. No cracks with vertical offset. No increase in cracking from previous inspection.		Longitudinal cracks greater than 0.1 in. wide, exposed rebar, significant water infiltration and/or soil migration. Cracks with vertical offset. Large areas of rust staining emanating from cracks.		
Slabbing, Spalling, Delamination, Patches	No spalling or slabbing, as indicated by wall visual appearance. No delamination. Patched areas that are sound.			Localized spalls less than 1/2 in. depth and less than 6 in. diameter. No exposed rebar. No slabbing. Small delamination indicated by hollow sounds at patches but patch remains stable.		Spalling and/or delamination from 1/2 in to 3/4 in. in depth and larger than 6 in. diameter. No exposed rebar. Some rust staining from spalled areas, structure stable No slabbing. Patched areas that are delaminated or deteriorating.		Widespread spalling greater than 3/4 in. in depth or delamination with exposed rebar, structure unstable. Slabbing of concrete.		
Deterioration	No scaling, abrasion, or other surface damage			Light or moderate scaling (less than 0.25 in. exposed aggregate). Abrasion less than 0.25 in. deep over less than 20% of pipe surface. Localized superficial (less than 0.25 in.) impact damage. No rebar exposed. Multiple plugged weep holes.		Moderate to severe scaling (aggregate clearly exposed). Abrasion between 0.25 in. and 0.5 in. deep over more than 30% of pipe surface. Impact damage with exposed rebar.		Extensive surface damage and aggregate pop-out. Includes exposed and/or corroded rebar. Complete invert deterioration and loss of pipe wall section.		

Figure 16: Invert deterioration of concrete pipe rating comparison between the TAMC Culvert , the MDOT TAMS, and AASHTO rating methods

The TAMC Pilot approach focuses on distress at specific locations within a culvert. Because of this, the description for invert deterioration may contain associations with several of the elements evaluated in the other systems - invert deterioration and corrosion of concrete in MDOT TAMS, and cracking, slabbing, spalling, delamination, patches, and deterioration in AASHTO.

The TAMC Pilot ratings have greater detail in specific condition measurements than the MDOT TAMS ratings. For lack of specific descriptions, the MDOT TAMS ratings could expect to fall within the same G/F/P/S categories as the TAMC Pilot approach, with the exception of the Fair category. Culverts rated as Fair using the TAMC Pilot approach would likely rate as Poor using MDOT TAMS rating system if the culvert had exposed rebar. The AASHTO system is more specific and in comparison would likely result in culverts being placed into lower condition categories depending on the distress exhibited. Exposure of rebar would drop the rating from a TAMC Pilot fair to an AASHTO poor.

Structural Deterioration/Invert Deterioration (CMP):

Modified FHWA (TAMC)	Excellent	Very Good	Good	Satisfactory	Fair	Poor	Serious	Critical	Imminent Failure	Imminent Failure
	10	9	8	7	6	5	4	3	2	1
Structural Deterioration (Corrosion) (CMP)	New condition. Galvanizing intact. No corrosion.	Discoloration of surface. Galvanizing partially gone. No layers of rust.	Discoloration of surface. Galvanizing gone along invert but no layers of rust. Minor section loss at ends of pipe not located beneath roadway.	Galvanizing gone with layers of rust. Moderate section loss at ends of pipe not located beneath roadway. Moderate section loss: Less than 6 in²/ft².	**Heavy rust and scale throughout. Heavy section loss with perforations not located under the roadway. Heavy section loss: Up to 15 in²/ft².**	Extensive heavy rust and scaling throughout. Perforations throughout with an area less than 30 in²/ft². Overall thin metal, which allows for an easy puncture with chipping hammer.	Extensive heavy rust and scaling throughout. Perforations throughout with an area less than 36 in²/ft².	Perforations throughout with an area greater than 36 in²/ft² .	Pipe partially collapsed.	Total failure of pipe.
Closed Bottom Invert Deterioration (CMP)	New condition; galvanizing intact; no corrosion.	Discoloration of surface. Galvanizing partially gone along invert. No layers of rust.	Discoloration of surface. Galvanizing gone along invert but no layers of rust. Minor section loss at ends of pipe not located beneath roadway.	Galvanizing gone along invert with layers of rust. Moderate section loss at ends of pipe not located beneath roadway. Moderate section loss: Less than 4% of invert area.	**Heavy rust and scale throughout. Heavy section loss with perforations in invert not located under the roadway. Heavy section loss: Up to 10% of invert area.**	Extensive heavy rust and scaling throughout. Perforations throughout invert with an area less than 20% of invert area. Overall thin metal, which allows for an easy puncture with chipping hammer.	Extensive heavy rust and scaling throughout. Perforations throughout invert with an area less than 25% of invert area.	Perforations throughout invert with an area greater than 25% of invert area.	Pipe partially collapsed.	Total failure of pipe.
MDOT		Good		Fair		Poor		Critical		
		9	8	7	6	5	4	3	2	1
Corrosion (Metal)		Little or no surface rust or coating loss		Minor surface rust and limited pitting		Perforations visible or easily made, connection hardware failing		Significant section loss resulting in extensive infiltration of soil with roadway/embankment damage.		
Invert Deterioration (Metal)		Little or no surface rust or coating loss		General corrosion, scaling, or pitting but significant remaining metal section.		Perforations visible or easily made by hammer test strike		Significant section loss in invert beyond perforations resulting in voids beneath invert and/or roadway/embankment damage.		
AASHTO	Good			Fair		Poor		Severe		
	1			2		3		4		
Surface Damage	No dents or other localized damage.			Small dents or impact damage to pipe wall or end section with no wall breaches.		Large dents or impact damage to pipe wall or end section with localized wall breaches, no more than one corrugation over circumferential length of 6 in.		Dents or damage that warrant engineering evaluation. Through-wall holes greater than one corrugation over a length more than 6 in., allowing unimpeded soil infiltration		
Corrosion	Isolated areas of freckled rust.			Freckled rust, corrosion of pipe wall material. No loss of section, no through-wall penetration from corrosion.		Corrosion of pipe material and widespread section loss less than 10% of wall thickness. Localized deep pitting. Several holes less than or equal to 1 in. diameter. Penetration possible with hammer pick strike.		Widespread through-wall penetration Invert missing in localized sections. Holes greater tan 1 in. diameter or many smaller holes grouped closely.		
Abrasion	No damage due to abrasion.			Small or local abrasion of wall or coating with no breaches in the coating exposing structural wall or signs of corrosion.		Widespread abrasion of protective coating with breaches exposing the pipe wall material and allowing through-wall penetration during inspection probing with a pick.		Abrasion has worn large holes through the metal pipe greater than one corrugation in length for more than 6 in. around the circumference.		

Figure 17: Structural deterioration of CMP rating comparison between the TAMC Culvert Pilot, the MDOT TAMS, and AASHTO rating methods

TAMC Pilot ratings have greater detail in specific condition considerations for CMP culverts than the MDOT TAMS or AASHTO ratings. Generally, ratings could expect to fall within the same G/F/P/S categories for all three systems. One potential difference is in a rating of 6 using the TAMC Pilot system where perforations are allowed in areas not under the roadway. Perforations in the AASHTO system would lead to a poor rating, however no location distinction is made. Depending on an inspector's discretion these may or may not rate the same between the TAMC Pilot and AASHTO systems.

Section Deformation:

Modified FHWA (TAMC)	Excellent	Very Good	Good	Satisfactory	Fair	Poor	Serious	Critical	Imminent Failure	Imminent Failure
	10	9	8	7	6	5	4	3	2	1
Section Deformation (CMP - Round)	New Condition	**Good, smooth curvature in barrel. Horizontal diameter (span) dimension within 10% of original design.**	**Generally good, top half of pipe smooth but minor flattening of bottom. Horizontal diameter (span) dimension within 10% of original design.**	Fair, top half has smooth curvature but bottom half has flattened significantly. Horizontal diameter (span) dimension within 10% of original design.	**Generally fair, significant distortion at isolated locations in top half and extreme flattening of the invert. Horizontal diameter (span) dimension 10% to 15% greater than original design.**	Marginal significant distortion throughout length of pipe, lower third may be kinked. Horizontal diameter (span) dimension 10% to 15% greater than original design.	Poor with extreme deflection at isolated locations, flattening of the crown, crown radius 20 to 30 feet. Horizontal diameter (span) dimension in excess of 15% greater than original design.	Critical, extreme distortion and deflection throughout pipe, flattening of the crown, crown radius over 30 feet. Horizontal diameter (span) dimension more than 20% greater than original design.	Partially collapsed with crown in reverse curvature	Structure collapsed
MDOT		Good		Fair		Poor		Critical		
		9	8	7	6	5	4	3	2	1
Section Deformation		None		Slight, perceptible deformation or local buckling		Deformation with longitudinal cracking or crushing in crown, invert, or spring lines		Excessive deformation resulting in extensive infiltration of soil with roadway/embankment damage.		
AASHTO	Good			Fair		Poor		Severe		
	1			2		3		4		
Shape (Closed Shape) (CMP)	Smooth curvature in barrel, deformation less than 5% of inside diameter			Top half smooth. Minor bulges or flattening of bottom. Deformation 5%-10% of original inside diameter.		Significant distortions or flattening. Lower third may be kinked. Deformation greater than 10% -15% of original inside diameter. Visible out-of-roundness		Extreme distortion throughout pipe, local areas of reverse curvature and kinds. Deformation greater than 15% of original inside diameter. Significant out-of-roundness		

Figure 18: Section deformation comparison between the TAMC Culvert Pilot, the MDOT TAMS, and AASHTO rating methods

Section deformation in the TAMC Pilot system contains detailed descriptions for CMP and plastic pipe with CMP further broken down into eight different cross-sectional shapes. Detailed descriptions for round pipe was used for a comparison with the generalized MDOT TAMS description of section deformation. Overall, the general G/F/P/S descriptions appear to be aligned between the two systems with the exception of the TAMC Pilot system ratings of 9 and 8. These rating values allow some cross sectional deformation, though to a small degree. For lack of an apparent allowance in the MDOT TAMS system for slight discrepancies, culverts with those ratings would likely be rated in the fair category (7 or 6) in the MDOT TAMS system.

The TAMC Pilot ratings have a similar level of detail as the AASHTO method. There are notable differences in the allowable percent difference from original shape where by the TAMC Pilot method would allow slightly greater distortions in shape for the Good and Fair categories.

Masonry:

Modified FHWA (TAMC)	Excellent	Very Good	Good	Satisfactory	Fair	Poor	Serious	Critical	Imminent Failure	Imminent Failure
	10	9	8	7	6	5	4	3	2	1
Structural Deterioration	New Condition.	No cracking. No missing or dislocated masonry. Surface in great condition.	Surface deterioration at isolated locations.	Minor cracking in masonry units.	Minor cracking. Slight dislocation of masonry units. Large areas of surface scaling. Split or cracked stones.	Extensive cracking. Significant dislocation of masonry units. Large areas of surface scaling. Split or cracked stones.	Severe cracking with spalling. Delamination(s). Slight differential movement. Individual lower masonry units of structure missing or crushed.	Cracking very severe with significant spalling, delamination, and differential movement. Individual masonry units in lower part of structure missing or crushed. Individual masonry units in top of culvert missing or crushed.	Structure partially collapsed or collapse is imminent.	Total failure of structure.

AASHTO	Good	Fair	Poor	Severe
	1	2	3	4
Masonry Units and Movement	No cracking, split, or missing masonry units. No displaced masonry units. No surface deterioration. No measurable cross sectional distortion.	Cracking of isolated individual units. Surface weathering or spalling. No movement of masonry unites.	Split or cracked masonry units. Large areas of moderate spalling, scaling, or weathering. Pronounced movement or dislocation of masonry units but does not warrant engineering evaluation.	Widespread cracking, splitting, or crushing of masonry units or missing units. Large areas of heavy spalling, scaling, or weathering. Holes through structure wall. Significant movement of individual units. Visible movement or distortion of cross sectional shape, structure appears unstable.
Mortar	Mortar is intact with no deterioration.	Localized cracked or missing mortar. Widespread areas of shallow mortar deterioration, possible minor water infiltration (no active flow) or exfiltration through joints.	Extensive missing mortar. Extensive mortar deterioration, small flow but no soil/fines, infiltration or exfiltration through joints. Vegetation sprouting from between units.	Missing mortar with backfill infiltration, possible voids in roadway.
Efflorescence	Localized areas of efflorescence less than 2 in^2.	Widespread areas of efflorescence without rust staining.	Heavy buildup of efflorescence with rust staining.	Cannot cause severe rating.

Figure 19: Masonry structural deterioration rating comparison between the TAMC Culvert Pilot and AASHTO rating methods

Both TAMC and AASHTO methods could be expected to produce the same G/F/P/S rating given the individual element level descriptions. MDOT TAMS does not have specific descriptions for the evaluation of masonry culverts.

Timber:

Modified FHWA (TAMC)	Excellent	Very Good	Good	Satisfactory	Fair	Poor	Serious	Critical	Imminent Failure	Imminent Failure
	10	9	8	7	6	5	4	3	2	1
Structural Deterioration	New condition.	No evidence decay or abrasion/wear. Connections are in place and functioning as intended.	Little to no evidence of decay. Minor abrasion/wearing. Connections are in place and functioning as intended. No issues with structural members. Checks/cracks penetrate <5% of the member thickness. Member does not have splits or shakes.	Some evidence of decay, moderate abrasion/wearing, negligible section loss in structural members. Affects less than 10% of member section. Loose fasteners but the connection is in place and functioning as intended. Checks/Cracks penetrate 5-50% of the member thickness and not in tension zone.	Some evidence of decay, moderate abrasion/wearing, negligible section loss in structural members. Affects less than 10% of member section. Loose fasteners or pack rust without distortion is present but the connection is in place and functioning as intended. Checks/Cracks penetrate 5-50% of the member thickness and not in tension zone. Member has splits/shakes with length less than member depth.	Decay and section loss affects 10% or more of the member but does not warrant structural review. Loose fasteners or pack rust without distortion is present but the connection is in place and functioning as intended. Checks/cracks penetrate >50% of member thickness or >5% in tension zone. Member has splits/shakes with length greater than member depth.	Decay and section loss affects 10% or more of the member but does not warrant structural review. Missing bolts, rivets, broken welds, fasteners, or pack rust with distortion but does not warrant structural review. Checks/cracks penetrate >50% of member thickness or >5% in tension zone. Member has splits/shakes with length greater than member depth and have not been arrested.	The condition warrants a structural review to determine the effect on strength, or serviceability of the element OR a structural review has been completed and the defects impact strength or serviceability.	Structure partially collapsed or collapse is imminent.	Total failure of structure.

AASHTO	Good	Fair	Poor	Severe
	1	2	3	4
Connections and Missing Members	No loose bolts, broken welds, missing rivets, or missing fasteners. No surface rust.	Loose bolts or fasteners; freckled rust (no pitting or section loss), rust staining on face of members, but connection is functioning as designed.	Missing bolts, rivets or fasteners, broken welds, surface rusting with some pitting, pack rust without distortion, but connection is functioning as designed.	Connection integrity is in question. Missing bolts, rivets, or fasteners, broken welds causing movement in connected elements. Heavy rusting with section loss, and/or pack rust causing deterioration. Imminent collapse.
Decay	No sunken faces, staining, or discoloration of member surfaces. No signs of fruiting bodies.	Decay allowing probe penetration less than or equal to 10% of the member cross section. Localized hollow sounds.	Decay allowing probe penetration greater than 10% to up to 20% of the member cross section, but is away from connections and tension zone of bending member.	Probe penetrates more than 20% of member cross section or more than 10% near connections or in a tension zone of bending member. Fruiting bodies.
Checks & Shakes	Checks or shakes penetrating less than 5% of member thickness.	Checks or shakes penetrating 5% to 50% of member cross section, but away from connections and tension zones of bending members.	Checks or shakes penetrating more than 50% of member cross section or up to 10% near connections or in a tension zone of bending member.	Checks or shakes penetrating more than 10% near connections or in a tension zone of bending member.
Structural Cracks	No structural cracking.	Structural cracking that has been arrested.	Structural cracking exists, but projects less than 5% into the member cross section.	Structural cracking exists with differential movement across crack.
Delamination	No separation between laminations.	Delamination length less than the total member depth and away from connections, or has been arrested.	Delamination length equal to or greater than the total member depth, but only present away from connections.	Delamination near connections; imminent collapse of member or structure.
Abrasion/Impact Damage	No section loss due to abrasion.	Section loss of less that 10% of the member cross section.	Section loss of 10% to 20% of the member cross section.	Section loss of more than 20% of the member cross section.
Distortion	No change in structure cross section. No warping, crushing, or sagging of individual members.	Warping or sagging of single or few members not requiring mitigation or has been previously mitigated.	Warping, sagging causing distortion of cross sectional shape. Crushing of member(s).	Significant distortion of cross sectional shape or widespread warping, crushing, or sagging.

Figure 20: Timber structural deterioration rating comparison between the TAMC Culvert Pilot and AASHTO rating methods

Both TAMC and AASHTO methods could be expected to produce similar G/F/P/S rating given the individual element level descriptions for timber. MDOT TAMS does not contain specific guidance on the rating of timber culverts.

Joints or Seams:

Modified FHWA (TAMC)	Excellent	Very Good	Good	Satisfactory	Fair	Poor	Serious	Critical	Imminent Failure	Imminent Failure
	10	9	8	7	6	5	4	3	2	1
Joints/Seams	Straight line between sections.	No settlement or misalignment. Tight with no defects apparent.	**Minor misalignment at joints. Minor settlement. Distress to pipe material adjacent to joint.**	Misalignment of joints but no infiltration. Settlement. Dislocated end section. Extensive areas of shallow deterioration. Minor cracking.	Joint open and allowing backfill to infiltrate. Significant cracking, spalling, or buckling of pipe material. Joint offset less than 3 inches. End sections dislocated and about to drop off from main portion of the structure. Infiltration staining apparent.	Differential movement and separation of joints. Significant infiltration or exfiltration at joints. Joint offset less than 4 inches. Voids seen in fill through offset joints. End sections dropped off at inlet.	Significant openings. Dislocated joints at several locations exposing fill material with joint offsets greater than 4 inches. Infiltration or exfiltration causing misalignment of pipe and settlement or depressions in roadway. Large voids seen in fill through offset joints.	Culvert not functioning due to alignment problems throughout. Large voids seen in fill through offset joints.	Pipe partially collapsed or collapse is imminent.	Total failure of pipe.
Multi-plate Joints or Seams	Minor amounts of efflorescence or staining	Light surface rust on bolts due to loss of galvanizing. Efflorescence staining.	**Metal has cracking on each side of a bolt hole: Less than 3 in a seam section. Minor seam openings that are less than ⅛ inch. Potential for backfill infiltration. More than 2 missing bolts in a row. Rust scale around bolts.**	Evidence of backfill infiltration through seams.	**Moderate cracking at bolt holes along a seam in one section. Backfill being lost through seam causing slight deflection. Less than 6 missing bolts in a row or 20% along the total seam.**	Major cracking of seam near crown. Infiltration of backfill causing major deflection. Partial cocked and cusped seams. 10% section loss to bolt heads along seams.	Longitudinal cocked and cusped seams. Metal has 3 inch crack on each side of the bolt hole run for the entire length of the culvert. Missing or tipping bolts.	Seam cracked from bolt to bolt. Significant amounts of backfill infiltration.	Pipe partially collapsed or collapse is imminent.	Total failure of pipe.
MDOT		Good		Fair		Poor		Critical		
		9	8	7	6	5	4	3	2	1
Joints		No gaps		Open with minor infill/exfill of water and/or soil		Open or displaced with significant infill/exfill of soil and water. Voids visible		Open or displaced with significant infiltration of soil with accompanying roadway damage		
AASHTO	Good			Fair		Poor		Severe		
	1			2		3		4		
Joint Separation, Offset, and Rotation	Joints are tightly installed with proper alignment and functioning well			Joint separation, offset, or rotation with no indication of distress. Gasket not exposed.		Joint separation, offset, or rotation in one or more joints, with exposed or missing gasket materials		Joint separation, offset, or rotation with exposed backfill material. Multiple location of exposed or missing gaskets.		
Joint Cracking (concrete)	No joint cracking.			Longitudinal crack of 0.01 in. to 0.05 in. wide (thickness of dime) emanating from joint. No spalling, or small spalls along edge of spigot end that do not expose reinforcement or joint sealant.		Between 0.05 and 0.1 in. wide longitudinal cracks emanating from joint. Moderate spalls along edge of spigot end, possible exposed reinforcing or joint sealant.		Greater than 0.1 in. longitudinal cracks emanating from joint. Large spalls along edge of spigot end with associated structural cracking.		
Infiltration & Exfiltration (Joints)	Joints are performing as intended with respect to infiltration and exfiltration.			Not applicable. Joint must meet performance requirement specified in design or will rate as poor.		Joint distress identified by coarse-grained soil infiltration through soil-tight joints. Fines infiltration through silt-tight joints. Any water infiltration/exfiltration through leak-resistant or watertight joint.		Joint distress directly causes distress to barrel/end section, roadway/shoulder, or embankment.		
Infiltration & Exfiltration (Seams)	No signs of infiltration or exfiltration			Minor water infiltration through leak-resistant seams but no soil infiltration		Significant water infiltration and evidence of fine soils infiltrating through seams.		Coarse soil infiltration through seam openings. Possible hollow sounds behind structure wall near seams indicating loss of backfill support. Evidence of piping due to exfiltration.		
Seam Alignment	No visible misalignment			Slight cocked seams without cusp effect, but does not affect cross section shape.		Cocked seams such that it affects cross section shape. Cusped effect with local wall bending.		Cocked seams severely affecting cross section shape. Cusp effect with seam cracking. Seam capacity loss imminent.		
Seam Bolts/Fasteners	No loose or missing bolts/fasteners.			Less than 5% loose or missing bolts in any seam.		5% to 15% loose or missing bolts in any seam.		Greater than 15% loose or missing bolts in any seam.		
Seam Bolt Holes	No yielding or deformation of bolt holes. No wall prying due to bolt tipping.			Minor yielding of steel and/or cracking/splitting less than 1 in. long local to bolt holes. Minor corrosion developing around bolt holes or on bolts.		Yielding of steel and/or cracking/splitting 1 in. up to 3 in. long local to bolt holes. Corrosion with section loss around bolt holes or on bolts.		Significant yielding of steel at bolt holes. Cracking/splitting greater than 3 in. or more local to bolt holes. Corrosion with section loss around bolt holes or on bolts.		

Figure 21: Joints & Seams rating comparison between the TAMC Culvert Pilot, the MDOT TAMS, and the AASHTO rating methods

The TAMC Pilot ratings have greater detail in specific condition measurements than the MDOT TAMS ratings. For lack of specific descriptions, the MDOT TAMS ratings could expect to fall within the same G/F/P/S categories as the TAMC Pilot method. The AASHTO condition descriptions provide more details and would result in some joints rating lower using the AASHTO system if cracking were present around bolts.

Summary:

The two culvert rating systems currently in use within the state of Michigan, TAMC Pilot and MDOT TAMS, differ in their organizational approach and the level of detail provided in the element level descriptions of distress. The newly published AASHTO Culvert & Storm Drain System Inspection Guide contains a level of element inspection generally comparable to a combination of the data collected by each of the current systems.

The TAMC Pilot method contains distress descriptions based on elements of deterioration common to specific culvert type/shape/material. The MDOT TAMS system is more generalized, leaving culvert type/shape considerations to an inspector's interpretation. For example, plastic pipes are specifically described in the TAMC Pilot system, but an inspector following the MDOT TAMS system would have to conduct their evaluation based on the guidance available for either metal or concrete culverts. The AASHTO method contains detailed characteristic descriptions for each culvert system component.

The level of detail provided in the element/characteristic descriptions of distress has resulted in the need to make comparisons between the systems at the level of general conditions; good, fair, poor, and serious. In many cases the description provided in either the TAMC Pilot system or AASHTO could reasonably fall within the general description of the MDOT TAMS system. Where discrepancies occurred it was generally in areas where specific measurements were cited. For example, fixed percentages used to describe culvert blockage/sediment, or an allowance for a diminutive amount of deterioration, or an acceptable range versus an absolute statement on the presence of distress.

For the purposes of comparison between the systems, an absolute adherence to the descriptions provided for deterioration was assumed. In reality, an inspector may stray from this, either through experience and personal bias, or as a result of clarification provided through training. Without field verification and a comparative study on how inspectors apply the guidance from each system, it is impossible to know to what extent an inspector would allow a diminutive amount of deterioration or if they would apply a "representative of the whole" approach to their rating.

A general comparison between the systems was made using only the descriptions provided for each of the above elements and assuming any amount of distress (when no acceptable range was provided) triggered placement within a respective general category. Under these conditions, it would be reasonable to say that the systems are generally aligned; however, in some situations, the TAMC Pilot system may rate the culvert in a better general condition category than the other two. The difference is generally limited to one condition level but could potentially be up to two levels, for example if exposed rebar is present.

Relationships were established for each of the comparable elements/characteristics in which a distress described in a TAMC Pilot rating category would fall into another category in one of the other systems. A direct translation between systems could not be established, as several indicators of distress may be provided in each description and just because one distress indicator crosses between the general condition categories does not mean it would always be present or take priority over the other descriptions.

CONCLUSIONS & GENERAL RECOMENDATIONS

This section provides key points from this study and provides a framework to assist the TAMC with the development and implementation of a strategy that can be used across the state to further streamline and standardize the collection of culvert data assets owned by local agencies throughout Michigan.

Inspection Frequency

Inspection frequency should be established to ensure an agency's data is up-to-date. The follow-up survey (see Appendix) was used to gauge participant's thoughts on this subject based on their experience with changes in a culvert's condition over time. The AASHTO *Culvert & Storm Drain System Inspection Guide* provides additional guidance.

Too frequent of an inspection interval results in little to no change between data sets and an inefficient work plan. Too much time between intervals and significant changes could have occurred resulting in missed opportunities for maintenance and potential risk of failure. The survey looked at three variables that may affect the inspection frequency; culvert size, material, and condition. A culvert's size affects the relative risk associated with failure, each material type has a different deterioration profile which would affect the period between inspections, and as a culvert reaches poorer condition states the need to inspect more frequently may increase as well. The AASHTO guide recommends the same considerations and adds culvert age, roadway average daily traffic (ADT), and special functions (such as aquatic organism passage) which may have additional guidelines on inspection frequency.

Size: The survey indicated, in general, that responders would be comfortable with an inspection frequency of more than six years for culverts 24 inches and smaller and four years for culverts greater than 48 inches. The responses varied for culvert sizes between these two diameters with no clear prevailing opinion on preferred inspection frequency. This would provide between eight and twelve inspections over a typical fifty-year culvert service life. Culverts over 48 inches in poor or lower condition should be inspected yearly according to one survey response.

The AASHTO guide provided an example frequency for routine inspections that indicated inspecting all culverts during roadway maintenance activities and at least every ten years for culverts between 4 to 10-ft and five years for culverts greater than or equal to 10-ft.

Material: Most survey participants identified a four-year inspection frequency for most of the material types with a potential to inspect concrete culverts at an interval greater than six years and plastic culverts at a six-year interval. AASHTO indicates a more frequent (than otherwise required) inspection cycle may be needed where corrosion is of particular concern.

Condition Rating: The survey responses regarding inspection frequency were fairly clear in identifying a four-six-year frequency on culverts rated good but then lowering the frequency to four years when the culvert is rated at fair, two years at poor, and every year at severe. AASHTO does not provide any 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.

The 2018 pilot study conducted a literature review to see what other agencies around the country use for inspection frequency. This varied widely by agency, ranging from annual inspections up to a six-year interval. Size and condition were two factors affecting recommended frequencies.

A data analysis program could be established to monitor changes in condition state over time in an effort to create a more efficient inspection frequency schematic. Rating too often would result in little to no change between inspections, too long and maintenance opportunities will be lost and risk of failure will increase.

Condition Evaluation

The TAMC Pilot condition evaluation method was considered a detailed system and there was feedback from pilot participants to allow a simplified Good/Fair/Poor/Serious rating method for a subset of culverts that wouldn't require detailed data. The follow-up survey revealed a mixed reaction to offering a simplified rating system. Approximately 50% of respondents preferred a detailed system and 50% preferred a simplified system. The AASHTO rating method may meet both of these desires by providing a Good/Fair/Poor/Severe system with detailed characteristic distress descriptions and several culvert system components to provide sufficient details.

In a related question, responders were asked to identify a culvert size threshold where they would be most comfortable switching from a simplified system to a detailed one. The majority, approximately 31% of the respondents, said 36 inches although 75% of the respondents indicated a size equal to or less than 48 inches.

The AASHTO guide does not provide a different set of criteria for how to rate a culvert based on size but does recommend one of three means of entry based on size – person-entry internal (recommended for less than or equal to 4-feet, non-entry internal (less than 4-feet in diameter and less than 60-feet long), and remote-entry internal for smaller or longer culverts.

Database

The 2018 TAMC Pilot discussed the creation of a centralized database for the storage of culvert inventory and condition evaluation on a statewide basis. The vision for this was to have shared access so that data from a variety of sources beyond transportation agencies could be combined to create a single database with the purpose of avoiding duplicative effort and allowing agencies to focus on collecting only that data relevant to their needs which isn't already in the database. The follow-up survey indicated that only 22% of respondents said it would be beneficial to import stream crossing survey data into a transportation agency database. Interviews with non-transportation agencies with a potential interest in culvert data revealed similar findings; indicating that they had the data they needed and could request data exports if the need presented itself. As a result, non-transportation agencies didn't place a great value on creating a single centralized data source but did indicate an interest in sharing data. This is not to say a centralized transportation database would not have value for TAMC. A centralized database would allow agencies to see what others have collected without having to request exports from multiple data sources.

Culvert Matching

The processes shown in Task 2 illustrated methods for utilizing the DNR stream crossing database as a detection method for previously unidentified MDOT and local agency culverts to better complete those data sets. The process can be run using standard GIS tools in a reasonable amount of time. These process can also be used to form a general rule set for software that the CSS has procured (One Spatial) to automate the combination of data sets from numerous sources.

QA/QC & Field Verification

A QA/QC program should be defined if data is made available for public interpretation. The pilot provided a means for local agencies to get involved with inventory and condition assessment of their culverts. A training program was created in an effort to help establish consistency amongst raters; however, there were no QA/QC programs in place to test if two raters would consistently rate the same culvert. The ability to provide a relative ranking to a single agency's culverts can be achieved by having a single inspector and this will meet their asset management needs. However, if data between agencies is to be combined or compared for a larger purpose, an appropriate program should exist to ensure the data is consistent between collecting organizations. Feedback between the QA/QC program and training helps ensure, over time, that consistency is narrowed and maintained.

A QA/QC program is a good way to ensure consistent ratings within a rating system. However, if different systems are compared or data is combined or shown together, field verification would help identify the relationship between the systems. Task 3 showed general agreement between the three systems when compared at a general condition level and assuming absolute adherence to the rating descriptions. Each rating category contains descriptions of multiple kinds of distress associated with that rating. The specific types of distress vary between the systems. Therefore, a translation process could be created, but only if the controlling distress were identified. This would require additional data to be collected and would essentially be a data-based re-rating into another evaluation system. Another option would be to conduct field verification of condition ratings. This would help identify, statistically, the difference between the systems. This could allow dashboard-level translation between the data sets but would not allow a person to translate a rating between systems for an individual culvert.

Reporting & Dashboards

A note should be added to dashboards and any other publically available condition rating data that states the two condition ratings systems used within the state are similar in their outcomes when considering the general condition (good, fair, poor, serious) but not identical, some differences in condition rating outcome can be expected, and the current data has not undergone a QA/QC procedure.

Any direct comparison between TAMC Pilot and MDOT TAMS data should also remove any data that is not consistent between the two data sets. For example, the overall controlling condition rating using the TAMC Pilot system does not include ratings based on the condition of the road over the culvert or of the embankment. Likewise, the overall rating from the MDOT TAMS dataset does not include any ratings due to scour. These three condition elements are in one but not both datasets and if they controlled in one system that data should be removed from the comparative dataset.

Inspection frequency must also be considered when making data publically available. There is currently no policy in place that would require condition evaluation or set the inspection frequency. If this information is to be voluntarily submitted at a frequency determined by individual culvert owners, it would be difficult to maintain a condition dashboard unless displayed data is limited to submittals over a relative period of time.

NEXT STEPS

Policy:

- A policy document needs to be created to establish TAMC involvement, the inspection frequency, range of applicability, condition evaluation system, database and information sharing procedures, and a QA/QC program.
- Statement of TAMC interest/involvement
    - Maintain estimate of state-wide culvert inventory and value
    - Report trends in size, material, number of culverts
    - Report condition of culverts (could be subset, i.e. culverts above a certain span)
    - Sampling vs census to maintain this information
        - Concerned with risk/cost of big culverts and total numbers (guiding principle)
    - Support infrastructure owners (guiding principle)
        - Training
        - Technical assistance on data collection
- Evaluation system
    - If standardization in culvert inspection procedures within the state is desired, interested parties should be brought to the table.
    - TAMC will need to decide on adoption of a condition evaluation system
        - The AASHTO *Culvert & Storm Drain System Inspection Guide* became available on August 13, 2020. If this method is approved, it could be accepted either in full or part and any state-specific modifications that may be necessary could be added.
- Transition plan if a new evaluation system is approved:
    - A change of this magnitude will require a transition plan to be effective.
        - Implementation schedule including training in new method, period of acceptance for multiple evaluation methods, date for acceptance of only selected method.
        - During period of mixed method acceptance, a supplemental inspection checklist would be helpful to allow for estimating evaluations between methods. For example, 'exposed rebar' is specifically identified in two of the three methods considered in this report and is attributed to different evaluation categories. A supplemental checklist could help identify if 'exposed rebar' was the distress associated with the original rating.
        - Determine a data handling process for period of transition
        - Longevity of existing culvert data
            - How long should existing data be considered valid?
            - To what extent does existing data need to be converted or is it enough to know rating and method used to get rating? A study could be performed

to evaluate if a culvert system translation is needed between the multiple systems.

- Field Verification
    - If data is to be compiled and used comparatively for culvert systems across the state a QA/QC system needs to be created to ensure an adequate training program is established to help assure that each inspector would assign the same rating to a culvert within an established tolerance.

Training:

- Training should be updated to include the rating system as adopted by TAMC (option to do refresher training that highlights only the changes in the updated system).
- QA/QC program should feed back into training to help improve the program

Revised Data Collection Pilot:

- A pilot program could be initiated in an effort to 'test' the TAMC policy document while it is in a draft state and raise any issues or highlight changes that may be beneficial.

Data:

- A culvert database should be finalized and if not publically available made accessible to those who own culverts so they can retrieve their data (local or centralized storage). Protocol should be established to define who has access to this data and how data is managed.
- The sharing of culvert data is of interest to various agencies within the state. These agencies should be invited to a summit for the purpose of establishing a data standard to facilitate the sharing of data. Each agency could continue to collect data independently and for their purposes; however, a data standard would ensure the collected data is uniform across participating agencies.
- TAMC should develop a data schema to summarize culvert data from the pilot and MDOT TAMS. This would include common denominator fields for materials, shapes, and physical measurements that would make combining data from multiple sources easier and consistent.
- Using the process identified in this report, identify previously un-inventoried MDOT and local agency culverts to better complete those data sets.

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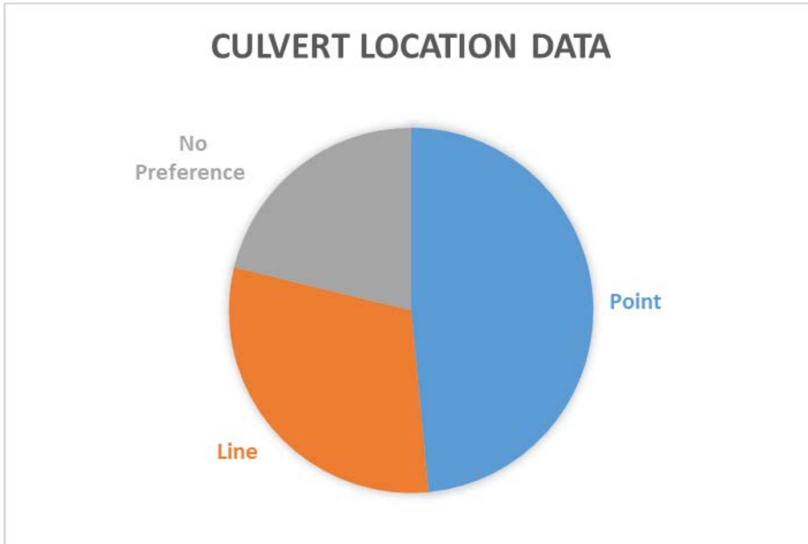
APPENDIX

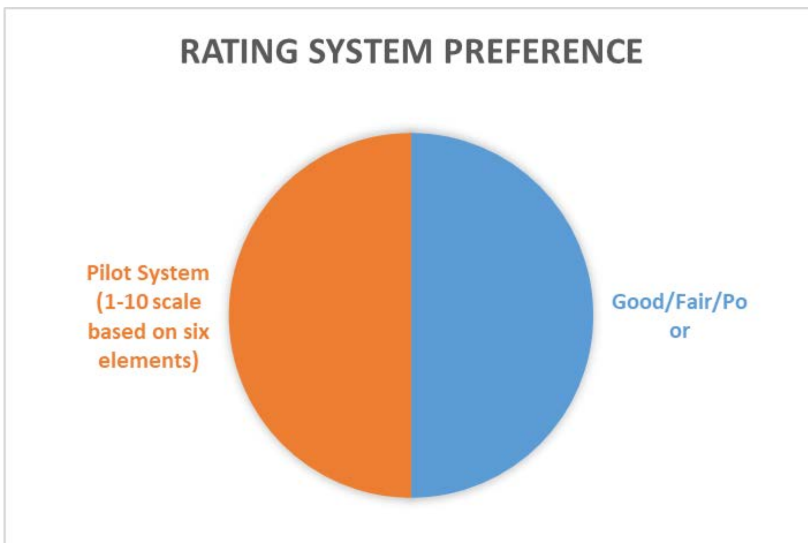
Follow-up Survey

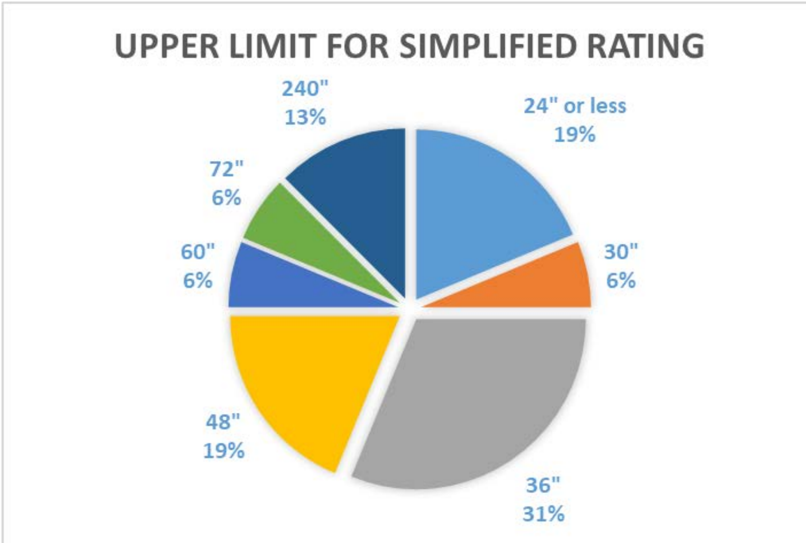
Added to project work plan as a follow-up to the 2018 pilot because CTT had contact list and resources to conduct survey and results would be beneficial to TAMC Bridge Committee for their effort in creating a culvert inspection and condition evaluation policy document.

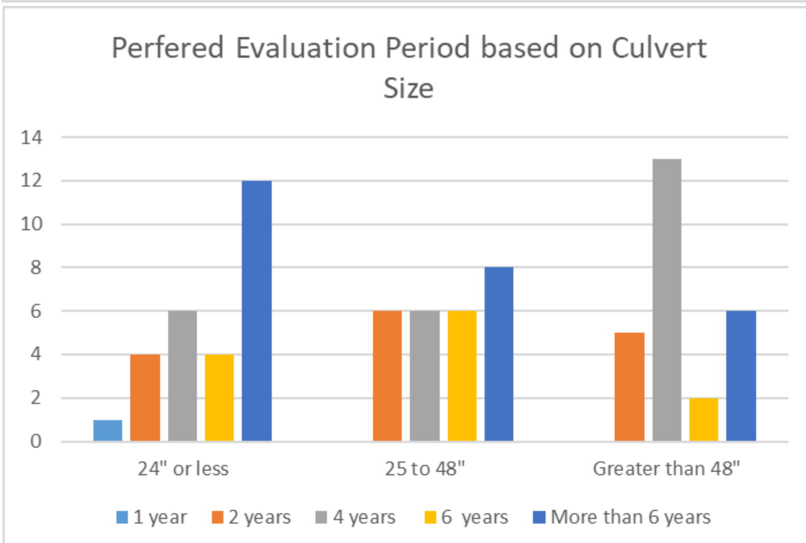
- **Percent of respondents who found pilot data useful one-year after pilot:**
  - Inventory ID (65%)
  - GPS coordinates (85%)
  - Material type (100%)
  - Asset collection date (77%)
  - Shape (100%)
  - Skew angle (74%)
  - Length (100%)
  - Span (width) (100%)
  - Rise (height or diameter) (97%)
  - Depth of cover (90%)
  - Roadway surface type (81%)
  - Culvert Condition (97%)
  - Photographs (optional) (78%)
  - *Additional comments:*
    - *Additional notes specific to culvert or location*
    - *Depth of cover doesn't matter until it is about 5 ft (trench protection) and 10 ft and deeper (larger excavator)*

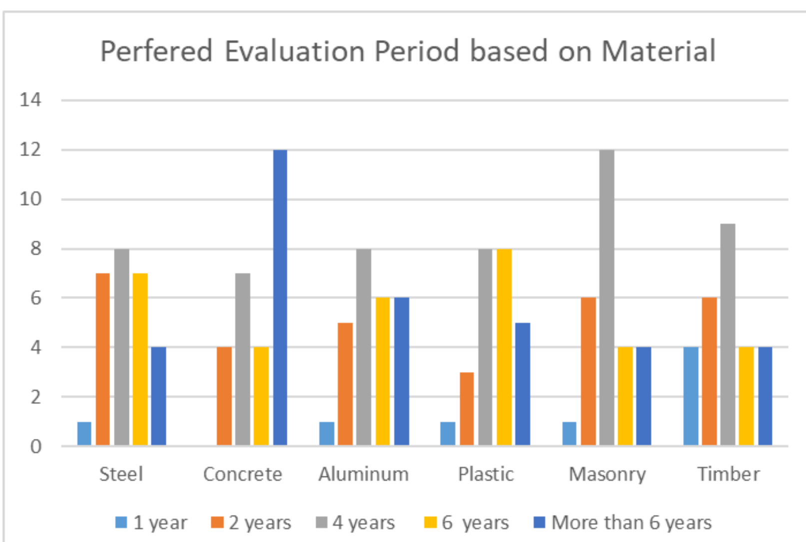
- **Percent of respondents who found pilot condition evaluation data useful:**
  - Invert deterioration (79%)
  - Structural deterioration (93%)
  - Section deformation (79%)
  - Joint/seam condition (90%)
  - Channel blockage (90%)
  - Scour (86%)
  - *Additional comments:*
    - *These are only useful when it is bad. Still think that a single rating for the pipe and a single rating for the channel & stream would be fine. We are not doing different fixes for all the individual ratings, but basically replace it or not.*

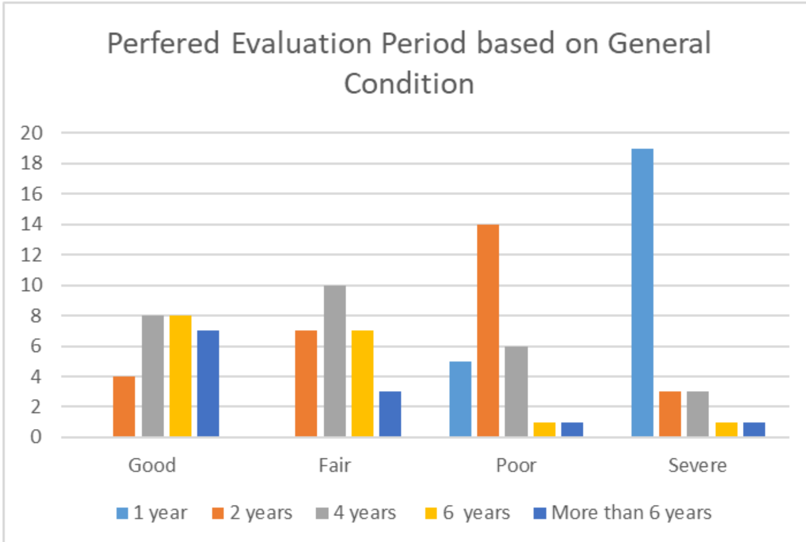

CULVERT LOCATION DATA
No Preference
Point
Line


RATING SYSTEM PREFERENCE
Pilot System (1-10 scale based on six elements)
Good/Fair/Po or


UPPER LIMIT FOR SIMPLIFIED RATING
240"
13%
24" or less
19%
72"
6%
60"
6%
30"
6%
48"
19%
36"
31%


Perfered Evaluation Period based on Culvert Size
14
12
10
8
6
4
2
0
24" or less
25 to 48"
Greater than 48"
1 year
2 years
4 years
6 years
More than 6 years


Perfered Evaluation Period based on Material
14
12
10
8
6
4
2
0
Steel
Concrete
Aluminum
Plastic
Masonry
Timber
1 year
2 years
4 years
6 years
More than 6 years



- **How have you used the culvert data that you collected in the 2018 pilot?**
    - Helps when preparing estimates for road repair for identifying before field measuring and for rough estimates of cost
    - Look up culvert info from the desk to at least get a good idea of what is there
    - Culvert Asset Management program for the county and township
    - The City did not have data on all the culverts prior to this pilot program. Since then, all culvert data has been uploaded to GIS for employee use.
    - Marked the locations so the crew can locate them
    - We provided the township where the pilot was completed data to help with planning of sanitary sewer projects.
    - Inventory data and updating database as additional culverts are found and culverts are replaced.
    - We used the information to prioritize our maintenance schedule.
    - Helps us with estimates on road projects knowing how many culverts are on a segment of road before going into the field to verify.
    - Plan maintenance projects
    - Incorporated it into Cityworks
    - We have used the condition data for our 5-year replacement plan.
    - The data has been helpful when we rebuild a roadway corridor to really think carefully about examining the culverts carefully to see if they require attention.
    - Used to prioritize replacements, scope resurfacing projects to see if culvert replacements are needed
    - Determining culvert replacements and culvert lining on future projects
    - To find the location of culverts to replace prior to road construction/maintenance.

- Haven't. Shared the "bad ones" with maintenance foremen, but we don't have the time or money to be proactive. Just fix replace when it fails.

- **67% of respondents have continued collection after the pilot**
    - Not on a routine cycle. Catching culverts that were missed in initial survey and updating when repairs or replacements are made.
    - New culverts have continually been added
    - Collecting locations and rating culverts as they are replaced, and as discovered because some were missed during the pilot. Also, rating culverts at known problem areas, and as time allows.
    - Any time our foreman or working foreman come across a new culvert, it gets added by engineering. Every road project we scope and evaluate all culverts in that stretch to make sure that none need to be replaced prior to HMA work occurring. All culverts that get replaced during the year are updated in Roadsoft that following winter/spring, to make sure the data is accurate. We have a close working relationship with the drain commissioner, and have shared the culvert layer data with them in ArcGIS. This has been way easier to view and use then in Roadsoft.
    - When possible we are collecting the same data that was collected with the pilot program.
    - We filtered out our current database and have been inspecting local road culverts, 4' span and larger. All the primary road culverts have been inspected and our database has been updated.
    - Same as in the pilot, currently finishing the initial collection of all culverts with in the county
    - We have continued on project by project basis. When we work on a project culverts are reviewed and rated.
    - We will still try to evaluate a culvert with the full number of condition categories.
    - Every time we replace a culvert we update that info in RoadSoft.
    - We have set a 5-year inspection cycle. We have approximately 3200 culverts and ideally would like to inspection 650 per year. In 2019 we fell short of that goal inspecting around 300. So far this year we are at around 800 inspections. The inspectors are verifying the data input from 2018 as well as updating the condition rating. They are also finding a few culverts that were missed during the culvert pilot.
    - First, we have completed a draft of our asset management document and often discuss "scope" in terms of the number of culverts we think we own and the overall condition. This data has been helpful in budgetary discussions and formulating plans to manage our risk. The data has slightly shifted the discussion

from "oh this can wait a few more years, to "we better do this now, because there will be other culvert problems waiting, and we must pace ourselves".
  - Continue to use the method developed for the pilot project
  - Length, width, height, diameter, material type, depth of cover, rating, entrance structure, exit structure, number of culverts, span, rise, waterway sometimes, as well as the memo on the rating.
  - Length, depth, material, shape, size, and the pipe condition

- **22% said it would be beneficial to import stream crossing survey data**
- **78% said they have no concerns sharing their basic culvert data in an open, statewide database**
  - Everything we share with the state seems to be used against us eventually. But we would do it.
  - Yes and no. Any data is subjective, but now you have the fact that in memo fields any data can be entered and then anyone state wide can see it. We had one culvert point that said in the memo best Chinese food in the county. To proof thousands of points would be extremely cumbersome, in addition to the numerous duplicate points that were in the system prior to the TAMC.
  - Data could be incorrect or missing pieces.
  - Culverts can be in terrible condition visually but with the right amount of cover and supporting soil around it, can last a long time. Sharing data will likely lead to mandated inspections instead of voluntary. Resources are slim so inspections are completed when time permits.
  - Could be a liability if a failure occurs prior to repair
  - The only concern is that the user needs to field verify all data.
  - But must qualify my answer; as long as the state and federal agencies "work with us" cooperatively.

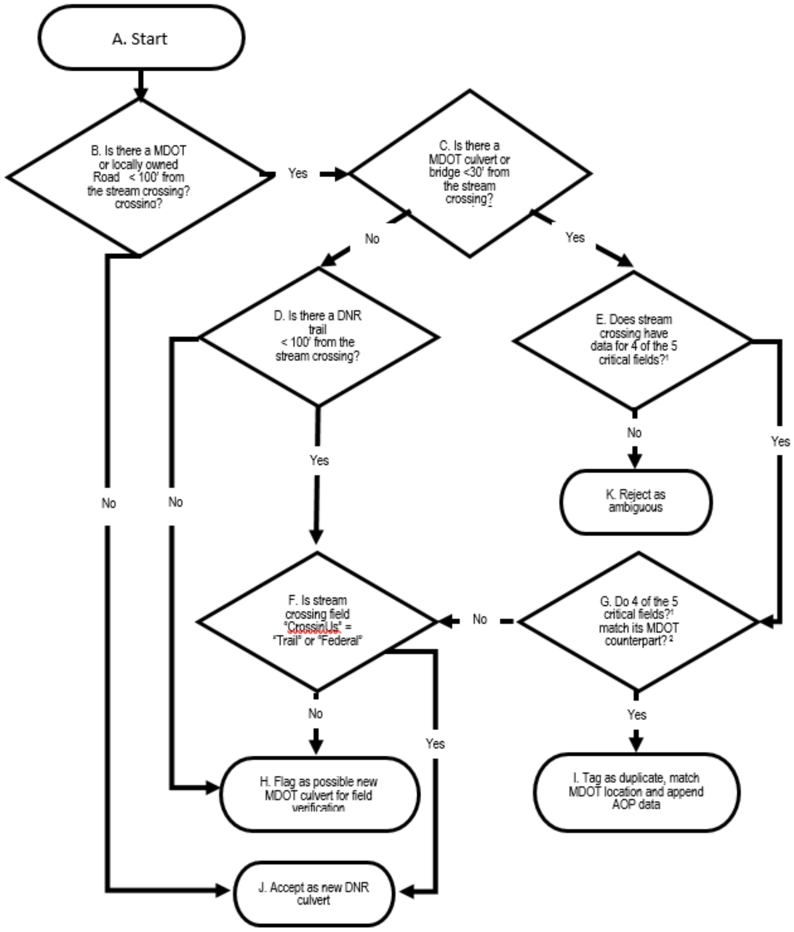
- **What Resources, if any, do you need to actively collect data on your culverts?**
  - Time (7 responses)
  - People/funding (9 responses)
  - The City has all resources needed such as survey/GPS equipment, measuring tape, camera, etc.
  - Technology that would allow the data collection to be more efficient.
  - I would like a handheld GPS data collector device. The windows tablet is too awkward for field use. Its just as well to use a laptop as the ergonomics of the tablet are not suitable for this activity, when doing solo work.
  - GIS support
  - Roadsoft, Laptop & GPS
  - We have the equipment needed.

  - The use of our smarter "summer kids" who where science-based degree seekers, was a good resource in 2018 and I would not hesitate to do that again. With Covid 19, we had a period where we wanted our construction assistants "out of the office" before construction season started. We gave them a tablet and told them "To hit the road" with culvert inspections. This has been successful to date.
  - Challenging to do when vegetation gets too high in summer.
  - Tape measure, 125' tape, something with a gps is extremely helpful, and a poker to test the bottom of the tubes to get a better idea on what on what to rate the culvert condition itself.
  - It would be nice to know which ones are close to failure so maintenance crews can fix before failure.

- **Other feedback for TAMC related to culvert inventory and data collection:**
  - Too much data was collected, which isn't needed. Decisions are based on follow up site visit, not based on some inventory years before.
  - Work orders. Need a field originated work order process with customizable drop down choices for typical repairs associated with culverts.
  - I am glad we are having this state-wide discussion on asset management. It is just the right thing to do fiscally.
  - Rating on the condition of the culvert is more important then waterway, channel rating. it should almost be the only rating in all honesty.
  - For small culverts, just 1 rating for the culvert in a good fair poor is more than enough. If you want to rate the channel, not opposed, but nothing will happen until the culvert is replaced

Data Process Flowcharts

Process flow for intake of DNR stream crossing data and rectification with MDOT culvert data



[1]Critical stream crossing fields are: "StructureLength" "StructureWidth" "StructureHeight" "StructureShape" "StructueMaterial"

[2]Matching is defined as within the following tolerances: StructureLength is within 25% of MDOT length, StructureWidth is within 15% if MDOT width or span, StructureHeight is within 15% of MDOT height or rise, StrucutreSshape matches MDOT shape after being transformed, StructureMaterial matches MDOT material after being transformed

Step 1: Do Nearest Neighbor Join (NN Join)with DNR Stream Crossing GIS file and MDOT Roads (framework) as Target

Step 2: In joined layer from Step 1, select stream crossing based on join distance from MDOT roads, and save into two layers with join fields removed with the exception of join distance

- Select join distance >100 (30.4 M) = Flow Chart Item J
- Select join distance <100 (30.4M) = Flow Chart Item C

Step 3: Do NN Join with Flow Chart Item C and MDOT Culverts as target

Step 4: Do NN Join with result of Step 3 and MDOT Bridges as target

Step 5: Select stream crossings from Step 4 based on join distance from MDOT culver and MDOT bridge and save into two layers with join fields, keep all join fields

- Select culvert or bridge distance >100 (30.4 M) = Flow Chart Item D
- Select culvert and bridge distance <100 (30.4 M) = Flow Chart Item E

Step 6; Select stream crossings from Flow Chart Item E based on the presence of data in the critical stream crossing fields are: "StructureLength" "StructureShape" "StructueMaterial" and "StructureWidth" or "StructureHeight" and the related fields in the MDOT database

- Select does not have data in all 4 fields = Flow Chart Item K
- Select does have data in all 4 fields = Flow Chart Item G

Step 7: Do NN Join with Flow Chart Item D and DNR trail layer. May need to add a step to do NN Join with output of this step and USFS roads within national forest boundaries.

Step 8: Select stream crossings from Step 7 based on join distance from DNR trail layer and save into two layers with join fields removed with the exception of join distance

- Select join distance >100 (30.4 M) = Flow Chart Item H
- Select join distance <100 (30.4M) = Flow Chart Item F

Step 9: Create CSV from Flow Chart Item G stream crossings and check to see if 4 of 5 critical fields match, which is defined as within the following tolerances: StructureL is within 25% of MDOT length, StructureW is within 15% of MDOT width, StructureH is within 15% of MDOT height, StrucutreS matches MDOT shape (after transformed) StructureM matched MDOT material.

- If >= 4 fields are in tolerances = Flow Chart Item J
- If < 4 field are in tolerances = Flow Chart Item H

Step 10: Join records from Step 8 and Step 9 to create a single set representing Flow Chart Item F

Step 11: Select stream crossings from Step 10 based on "CrossingUse" field and save into two layers with all join fields

- Select CrossingUse = Trail or Federal = Flow Chart Item J
- Select CrossingUse not = Trail or Federal = Flow Chart Item H

Step 12: Join components of Flow Chart Item H into unified layer and Join components of Flow Chart Item J in unified layer

Results from test run:

Start

Flow Chart Item A and B

MDOT Culverts = 47,699 records

DNR Stream Crossings = 2,230 records

Flow Chart Item C

130 Stream Crossings

Flow Chart Item D

79 Stream Crossings

Flow Chart Item E

51

Flow Chart Item F

44 + 10 = 54

Flow Chart Item G

28

Flow Chart Item H

35 +15 = 50

Flow Chart Item I

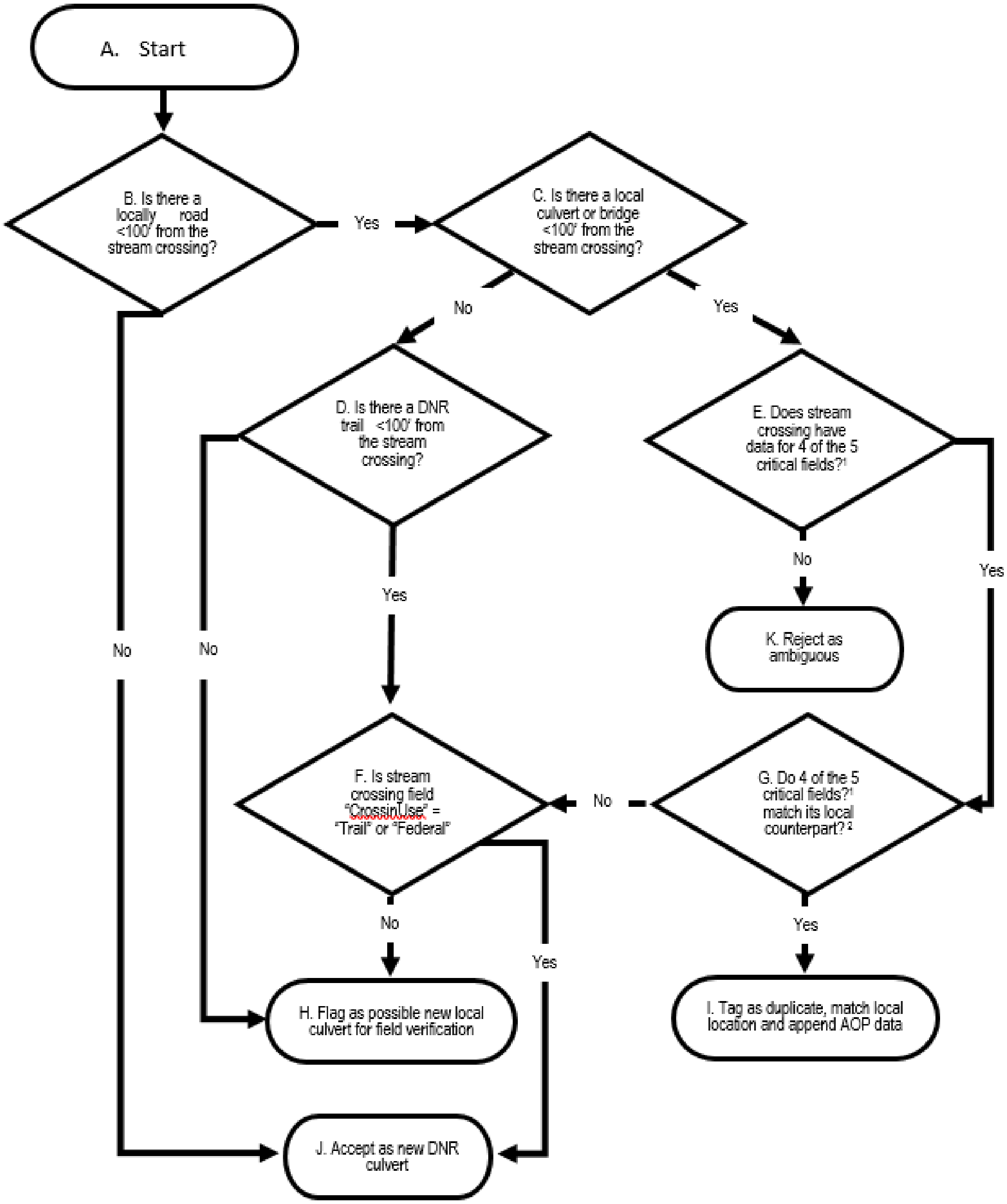
18

Flow Chart Item J

2100 + 39 = 2139

Flow Chart Item K 23

Process flow for intake of DNR stream crossing data and rectification with Local Agency culvert data



[1]Critical stream crossing fields are: "StructureLength" "StructureWidth" "StructureHeight" "StructureShape" "StructueMaterial"

[2]Matching is defined as within the following tolerances: StructureLength is within 25% of local length, StructureWidth is within 15% if local width or span, StructureHeight is within 15% of local height or rise, StrucutreSshape matches local shape after being transformed, StructureMaterial matches local material after being transformed.

Step 1: Do Nearest Neighbor Join (NN Join) with DNR Stream Crossing GIS file and Local Roads (framework) as Target

Step 2: In joined layer from Step 1, select stream crossing based on join distance from local roads, and save into two layers with join fields removed with the exception of join distance

- Select join distance >100 (30.4 M) = Flow Chart Item J
- Select join distance <100 (30.4M) = Flow Chart Item C

Step 3: Do NN Join with Flow Chart Item C and Local Agency Culverts as target

Step 4: Do NN Join with result of Step 3 and Local Agency Bridges as target

Step 5: Select stream crossings from Step 4 based on join distance from Local Agency culver and MDOT bridge and save into two layers with join fields, keep all join fields

- Select culver or bridge distance >100 (30.4 M) = Flow Chart Item D
- Select culver and bridge distance <100 (30.4 M) = Flow Chart Item E

Step 6: Select stream crossings from Flow Chart Item E based on the presence of data in the critical stream crossing fields are: “StructureLength” “StructureShape” “StructueMaterial” and “StructureWidth” or “StructureHeight” and the related fields in the local database

- Select does not have data in all 4 fields = Flow Chart Item K
- Select does have data in all 4 fields = Flow Chart Item G

Step 7: Do NN Join with Flow Chart Item D and DNR trail layer. May need to add a step to do NN Join with output of this step and USFS roads within national forest boundaries.

Step 8: Select stream crossings from Step 7 based on join distance from DNR trail layer and save into two layers with join fields removed with the exception of join distance

- Select join distance >100 (30.4 M) = Flow Chart Item H
- Select join distance <100 (30.4M) = Flow Chart Item F

Step 9: Create CSV from Flow Chart Item G stream crossings and check to see if 4 of 5 critical fields match, which is defined as within the following tolerances: StructureLength is within 25% of Local length, StructureWidth is within 15% of Local width (unit conversions needed), StructureHeight is within 15% of Local height (unit conversions sometime needed), StrucutreShape matches Local shape (after transformed) StructureMaterial matched Local material. Note: Materials and shapes will need to be transformed to the lowest common denominator, for example: “precast concrete pipe”, “Reinforced concrete pipe” would be transformed to “concrete”; for pipe shape “Box”, “Square open bottom” and “Rectangle” would be transformed to “Rectangle”

- If >= 4 fields are in tolerances = Flow Chart Item I
- If < 4 field are in tolerances = Flow Chart Item F

Step 10: Join records from Step 8 and Step 9 to create a single set representing Flow Chart Item F

Step 11: Select stream crossings from Step 10 based on “CrossingUse” field and save into two layers with all join fields

- Select CrossingUse = Trail or Federal = Flow Chart Item J
- Select CrossingUse not = Trail or Federal = Flow Chart Item H

Step 12: Join components of Flow Chart Item H into unified layer, then join components of Flow Chart Item J in unified layer

Results from test run:

Start (Flow Chart Item A and B)
    Local Culverts = 43202 records
    DNR Stream Crossings = 2230 records
Flow Chart Item C
    642 DNR Stream Crossings
Flow Chart Item D
    398 DNR Stream Crossings
Flow Chart Item E
    244 DNR Stream Crossings
Flow Chart Item F
    372 (230+142) DNR Stream Crossings
Flow Chart Item G
    207 DNR Stream Crossings
Flow Chart Item H
    331 (141+168+22) DNR Stream Crossings
Flow Chart Item I
    65 DNR Stream Crossings
Flow Chart Item J
    1797 (1588+208+1) DNR Stream Crossings
Flow Chart Item K
    37 DNR Stream Crossings