Development of a Culvert Evaluation Program

Connecting habitats and safeguarding communities

Project Summary

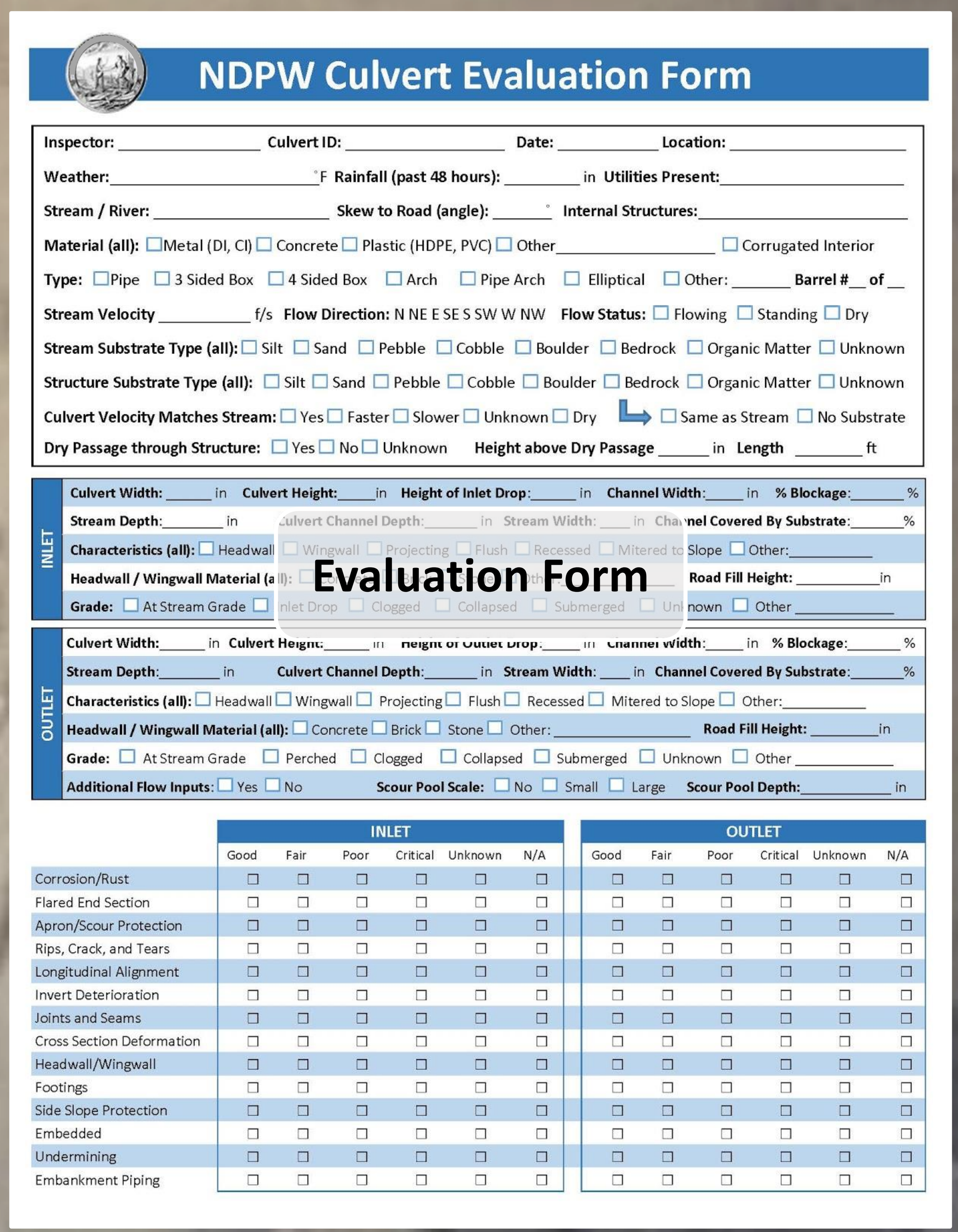
Culverts are an important part of existing infrastructure that allow for stream and organism passage underneath roads. City N currently has no systematic method of evaluating their culverts or selecting culverts for replacement. The team was tasked with developing a **culvert evaluation program** for City N that encompassed both structural and ecological concerns as well as provided a priority ranking system for culvert replacement. The evaluation package includes an **evaluation form**, **scoring system and database**, and an accompanying **user guidance manual**.

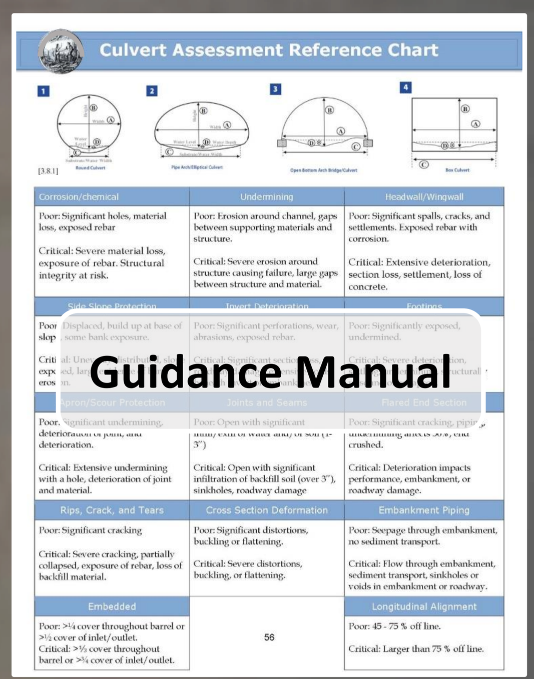
The student team developed and verified the evaluation package through multiple field visits, including a case study analyzing a culvert within City N before and after replacement. The project was managed and lead by a team of three students who were responsible for all project management responsibilities, including project timeline, pace, and scope development. A team of reviewers provided input throughout the project to ensure that the evaluation program included different perspectives and disciplines. The team presented the evaluation program to City N as a complete and user-friendly package. The culvert evaluation program will be implemented beginning this summer on culverts in City N.

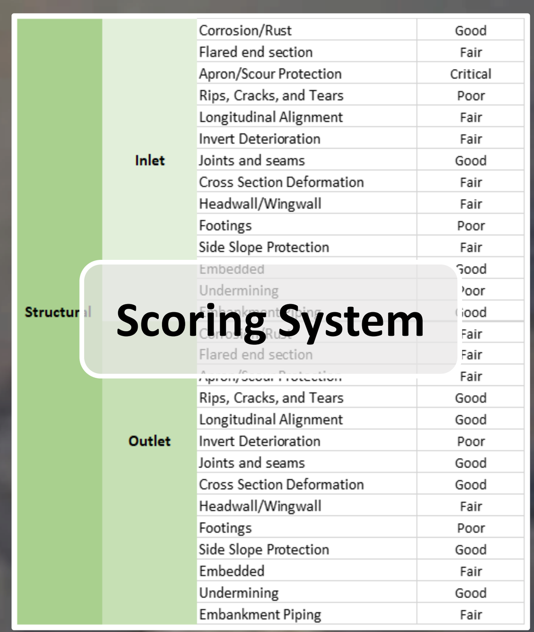
Multidisciplinary and Professional Collaboration

A diverse team of **16 reviewers (9 with PE licenses)** provided feedback on the development of the evaluation program and its implementation into industry and municipalities. The students collaborated directly and regularly with the director of City N's Department of Public Works. Additional reviewers included Institution A faculty, students, alumni, and other professionals locally and around the country. The PE reviewers have their licenses in **Structural, Environmental, Water Resources, and Transportation Engineering,** and other reviewers specialized in Hydraulics and Hydrology, Landscape and Environmental Studies, Ecology, Biology, and Geographic Information Systems. By interacting with the reviewers, the students learned how to balance multiple disciplines, how partnerships manifest between industry and government, and how to conduct themselves in a professional manner.

Due to the diverse team of reviewers and the project goal of including both structural and ecological concerns, the evaluation program represents a wide variety of backgrounds, and allows for culverts to be prioritized and ranked in a comprehensive manner.







"As for the form's application outside of [City N], I think it could be very applicable." [PE Reviewer]

Culvert replacement promotes habitat reconnection

Stranded critters rescued during construction

"Overall, I think [the form] looks professional and covers a lot of good information." [PE Reviewer]

"This [guidance manual] would save me a lot of time because I could give it to an entry-level engineer and be confident that they could go out and do successful inspections." [PE Reviewer]

Inspecting a culvert that periodically floods a resident's land

Inspecting a deteriorating culvert

Public Heath, Safety, Welfare

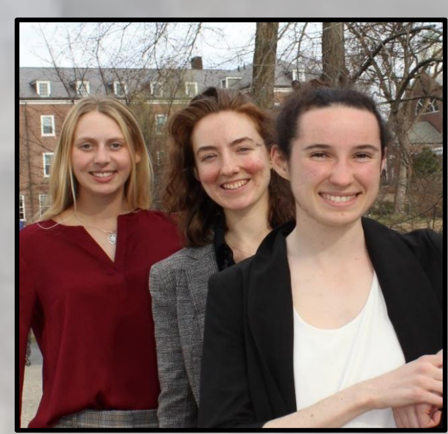
Culverts can present large public welfare concerns when they are not properly built or maintained. Structural failure can lead to road destruction that can last months, which poses a threat to the movement and dispatch of emergency vehicles. Ecological issues can drastically impact the movement and survival of endangered and native species as well as water flow.

This culvert evaluation package allows for the ranking and prioritization of the culverts from a **combined structural and ecological approach**. City N cannot replace all of its poor condition culverts at once due to limited funding; this system allows them **to identify which culverts are in highest priority** and properly address the issues and allocate resources surrounding each individual culvert. This evaluation program **will help avoid culvert failure** and **further harm to ecological health**, which are both vital to public health, safety, and welfare.

The program also addresses public safety in the inspection of these culverts. The guidance manual includes instructions detailing a parking plan, how to properly prepare for an inspection to limit the amount of field time, and how to safely navigate a public road to inspect the culvert with regard to safety and OSHA guidelines.

Knowledge and Skills Gained

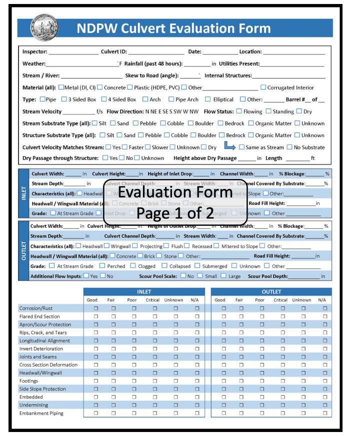
- Safety Regulations
- Professional Skills (communication, networking)
- Ethical Responsibility
- Project Management
- Data Collection and Analysis
- Construction Practices
- Field Work Protocols
- Teamwork
- Environmental Standards
- User-Centered Design
- Software Tools (GIS, HydroCAD, HY-8)
- Balancing Multiple Disciplines



Development of a Culvert Evaluation Program

Culverts are a vital part of existing infrastructure that allow for stream and organism passage underneath roads. City N currently has no systematic method of evaluating their culverts or selecting culverts for replacement; information collection and replacement prioritization is challenging. The scope of this project was to **develop a culvert evaluation program** that would (1) address the lack of integration of ecological and structural concerns within existing culvert evaluations and (2) provide an objective method for prioritizing culverts for replacement. The evaluation program includes an evaluation form, a scoring system and database, and an accompanying user guidance manual.

The project was managed and led by **a team of three women engineering students** who were responsible for all project management responsibilities, including project timeline, pace, and scope development. Over the course of two semesters, the student team worked closely with their PE liaison from City N's Department of Public Works, and met weekly with a faculty liaison from Institution A and multiple times a week independently. By coordinating and scheduling all communication themselves, the student team learned the importance of both flexibility and accountability. The team developed a two-sided culvert evaluation form, an accompanying guidance manual, a condensed reference sheet for field work, ecological priority area shapefiles in GIS, and a culvert scoring system and database.



The students developed and refined the form through multiple field visits and input from four employees from City N's DPW (2 PEs), five faculty from Institutions A and B in both Engineering and Environmental Science, and seven PEs who work at civil engineering and water resource firms both locally and nationally. This **team of mentors and reviewers** involved throughout the project provided a range of perspectives and disciplines, supporting the team in creating a comprehensive product and in gaining a deeper understanding about the work of **multidisciplinary professional engineers**. The students verified that their evaluation program met all the project requirements: fast and easy deployment, integration of ecological and structural considerations, differentiation between culverts, and inter-rater reliability. The students also completed a verification case study of a culvert in City N directly before and after replacement, demonstrating that the scoring system provides sufficient distinction for City N's DPW to prioritize culverts for both structural and ecological health.

The team presented the culvert evaluation program to City N as a complete and user-friendly package; implementation will begin summer 2019 in City N. Although the culvert evaluation program was developed for City N, it is **applicable to municipalities around the country,** as confirmed by the feedback from the seven PEs outside of City N. A fundamental lesson the students learned during this project was the **immense importance of culverts to public health and safety** and to **ecological health and habitat connectivity**.

All three students involved in this project plan to take the Fundamentals of Engineering (FE) exam by the beginning of Summer 2019, and all three will also be completing an ABET-accredited engineering degree. Two of the students have already accepted jobs working under licensed female engineers, and all three plan to continue to pursue licensure and careers in engineering.

Development of a Culvert Evaluation Program

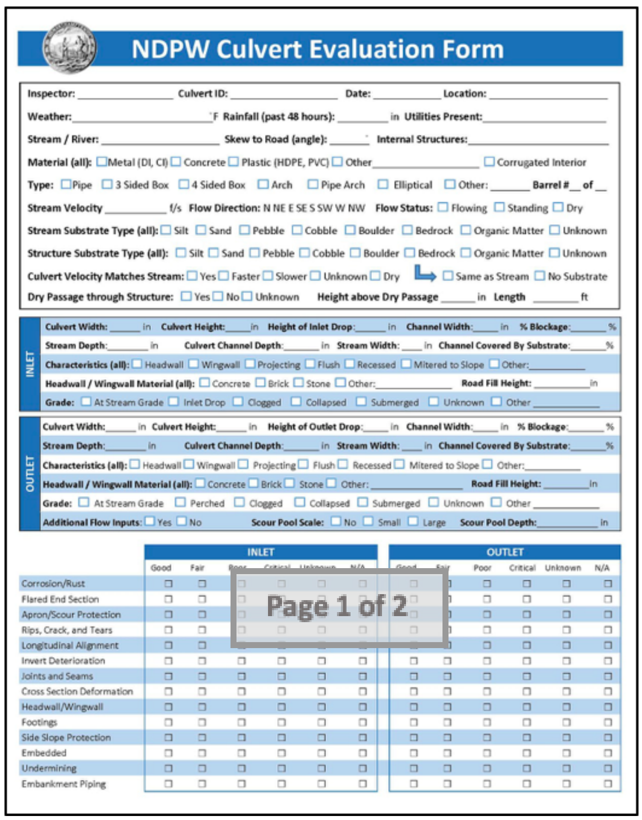
I. Project Description

Culverts - structures that allow streams to cross under roadways - are a vital part of the infrastructure of a city and the ecological environment in which they are placed. As structures whose failure can induce a public safety emergency, culverts require periodic inspection for structural safety. Culverts have a direct influence in the number of species of aquatic and terrestrial organisms which can travel up or down streams. As such, they are increasingly being evaluated for their impact on the surrounding ecosystem in addition to established protocols to evaluate their structural state. City N's Department of Public Works currently lacks a method and database with which to determine and store culvert condition, does not have a standardized inspection program, and lacks a system to prioritize culvert rehabilitation. This student-led capstone design project was created to address these needs at the City N's DPW.

The scope of the project included design and testing of all parts of a culvert evaluation program. After extensive background research and communication with stakeholders, the student team at Institution A identified three necessary components of the program:

- a two-sided evaluation form completed using desktop analysis and fieldwork
- a user guidance manual with one-page reference chart
- a ranking system that additionally functions as a storage database

The evaluation form includes both an in-field physical examination and a desktop analysis completed based on a Geographic Information System (GIS) map depicting high ecological priority zones. The map was created from a GIS analysis overlaying culvert locations with ecologically sensitive areas in City N.



NDPW Culvert Evaluation Form

Inspector: ____ Culvert ID: ____ Date: ____ Location: ____
Weather: ____ °F Rainfall (past 48 hours): ____ in Utilities Present: ____
Stream / River: ____ Skew to Road (angle): ____ ° Internal Structures: ____
Material (all): ☐ Metal (DI, CI) ☐ Concrete ☐ Plastic (HDPE, PVC) ☐ Other ____ ☐ Corrugated Interior
Type: ☐ Pipe ☐ 3 Sided Box ☐ 4 Sided Box ☐ Arch ☐ Pipe Arch ☐ Elliptical ☐ Other: ____ Barrel # __ of __
Stream Velocity ____ f/s Flow Direction: N NE E SE S SW W NW Flow Status: ☐ Flowing ☐ Standing ☐ Dry
Stream Substrate Type (all): ☐ Silt ☐ Sand ☐ Pebble ☐ Cobble ☐ Boulder ☐ Bedrock ☐ Organic Matter ☐ Unknown
Structure Substrate Type (all): ☐ Silt ☐ Sand ☐ Pebble ☐ Cobble ☐ Boulder ☐ Bedrock ☐ Organic Matter ☐ Unknown
Culvert Velocity Matches Stream: ☐ Yes ☐ Faster ☐ Slower ☐ Unknown ☐ Dry ☐ Same as Stream ☐ No Substrate
Dry Passage through Structure: ☐ Yes ☐ No ☐ Unknown Height above Dry Passage ____ in Length ____ ft

INLET
Culvert Width: ____ in Culvert Height: ____ in Height of Inlet Drop: ____ in Channel Width: ____ in % Blockage: ____ %
Stream Depth: ____ in Culvert Channel Depth: ____ in Stream Width: ____ in Channel Covered By Substrate: ____ %
Characteristics (all): ☐ Headwall ☐ Wingwall ☐ Projecting ☐ Flush ☐ Recessed ☐ Mitered to Slope ☐ Other: ____
Headwall / Wingwall Material (all): ☐ Concrete ☐ Brick ☐ Stone ☐ Other: ____ Road Fill Height: ____ in
Grade: ☐ At Stream Grade ☐ Inlet Drop ☐ Clogged ☐ Collapsed ☐ Submerged ☐ Unknown ☐ Other ____

OUTLET
Culvert Width: ____ in Culvert Height: ____ in Height of Outlet Drop: ____ in Channel Width: ____ in % Blockage: ____ %
Stream Depth: ____ in Culvert Channel Depth: ____ in Stream Width: ____ in Channel Covered By Substrate: ____ %
Characteristics (all): ☐ Headwall ☐ Wingwall ☐ Projecting ☐ Flush ☐ Recessed ☐ Mitered to Slope ☐ Other: ____
Headwall / Wingwall Material (all): ☐ Concrete ☐ Brick ☐ Stone ☐ Other: ____ Road Fill Height: ____ in
Grade: ☐ At Stream Grade ☐ Perched ☐ Clogged ☐ Collapsed ☐ Submerged ☐ Unknown ☐ Other ____
Additional Flow Inputs: ☐ Yes ☐ No Scour Pool Scale: ☐ No ☐ Small ☐ Large Scour Pool Depth: ____ in

	INLET						OUTLET					
	Good	Fair	Poor	Critical	Unknown	N/A	Good	Fair	Poor	Critical	Unknown	N/A
Corrosion/Rust	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Flared End Section	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Apron/Scour Protection	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Rips, Crack, and Tears	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Longitudinal Alignment	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Invert Deterioration	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Joints and Seams	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cross Section Deformation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Headwall/Wingwall	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Footings	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Side Slope Protection	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Embedded	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Undermining	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Embankment Piping	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

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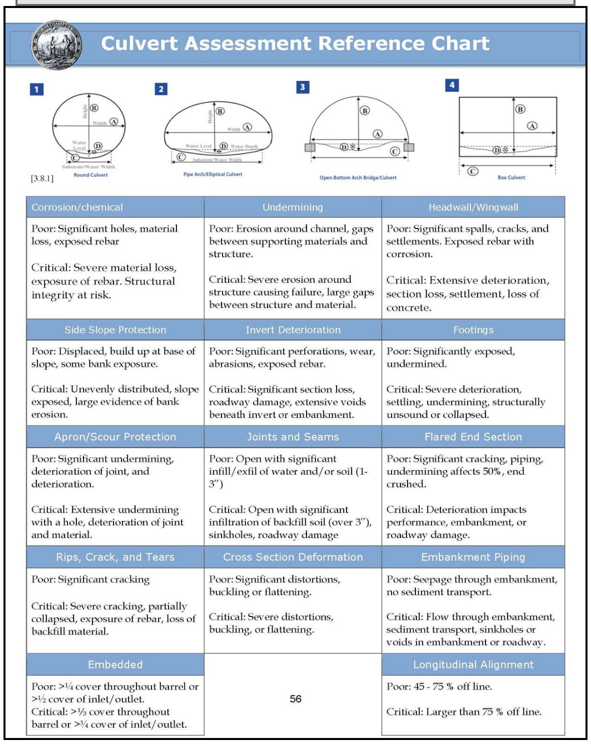
The student team conducted a thorough literature review of current evaluation protocols from both structurally and ecologically focused organizations and government agencies to identify the areas of greatest need for culvert evaluation. The team completed multiple field visits in varying weather conditions to help inform how evaluation forms function for field-employees and to give context to the culvert characteristics that would be incorporated into the final evaluation program. Collaboration with DPW employees, interdisciplinary professionals outside of Institution A, fellow capstone design students, and alumni from Institution A working as P.E.s around the United States led to a refined culvert evaluation program that is widely applicable, in City N and beyond.

Reference chart from guidance manual



Culvert Assessment Reference Chart

Corrosion/chemical	**Undermining**	**Headwall/Wingwall**
Poor: Significant holes, material loss, exposed rebar Critical: Severe material loss, exposure of rebar. Structural integrity at risk.	Poor: Erosion around channel, gaps between supporting materials and structure. Critical: Severe erosion around structure causing failure, large gaps between structure and material.	Poor: Significant spalls, cracks, and settlements. Exposed rebar with corrosion. Critical: Extensive deterioration, section loss, settlement, loss of concrete.
Side Slope Protection	**Invert Deterioration**	**Footings**
Poor: Displaced, build up at base of slope, some bank exposure. Critical: Unevenly distributed, slope exposed, large evidence of bank erosion.	Poor: Significant perforations, wear, abrasions, exposed rebar. Critical: Significant section loss, roadway damage, extensive voids beneath invert or embankment.	Poor: Significantly exposed, undermined. Critical: Severe deterioration, settling, undermining, structurally unsound or collapsed.
Apron/Scour Protection	**Joints and Seams**	**Flared End Section**
Poor: Significant undermining, deterioration of joint, and deterioration. Critical: Extensive undermining with a hole, deterioration of joint and material.	Poor: Open with significant infill/exfil of water and/or soil (1-3″) Critical: Open with significant infiltration of backfill soil (over 3″), sinkholes, roadway damage	Poor: Significant cracking, piping, undermining affects 50%, end crushed. Critical: Deterioration impacts performance, embankment, or roadway damage.
Rips, Crack, and Tears	**Cross Section Deformation**	**Embankment Piping**
Poor: Significant cracking Critical: Severe cracking, partially collapsed, exposure of rebar, loss of backfill material.	Poor: Significant distortions, buckling or flattening. Critical: Severe distortions, buckling, or flattening.	Poor: Seepage through embankment, no sediment transport. Critical: Flow through embankment, sediment transport, sinkholes or voids in embankment or roadway.
Embedded		**Longitudinal Alignment**
Poor: >¼ cover throughout barrel or >½ cover of inlet/outlet. Critical: >⅓ cover throughout barrel or >¾ cover of inlet/outlet.	56	Poor: 45 - 75 % off line. Critical: Larger than 75 % off line.

As a case-study in verification of the program, the student team completed a full evaluation of a poor-condition culvert in City N directly before and after it was replaced with an ecologically designed three-sided box culvert, enhanced by a visit to Site A during construction. The team experienced first-hand how culvert construction is managed, and gained technical understanding of construction practices. The team saw both problems and solutions arise throughout the installation, allowing them to understand such issues in practical and theoretical contexts. The student team finished the project with a deep understanding of the resounding, most often invisible, impact of culverts on both human residents and the environment. By comparing the evaluation scores both before and after replacement, the team also demonstrated the utility and effectiveness of their culvert evaluation program.

At the culmination of this project, the evaluation program was presented to the DPW as a complete and user-friendly package that addressed neglected culvert needs in City N. The program will be implemented starting Summer 2019 by the City N's DPW.

II. Collaboration of Faculty, Students, and Licensed Professional Engineers

This project involved a student team of three engineering seniors, coached by an engineering faculty member. The team collaborated closely with a professional engineer at City N's Department of Public Works (DPW), who served as both liaison and mentor. The team submitted weekly progress reports and had regular meetings with both the coach and the liaison. The team worked closely with each other, meeting several times each week for the duration of the eight month project. They were in charge of coordinating the project throughout the duration, scheduling meetings, organizing work sessions, holding design reviews, and identifying and reaching out to collaborators for feedback and advice. Through this management process, the team learned the importance of self-accountability and scheduling. They also collaborated with four fellow senior engineering students who served as shadows to the project, testing the evaluation form and participating in design reviews. The team also received feedback on the evaluation materials from four other faculty members at Institution A, two within the engineering department and two from Landscape and Environmental Studies, plus six PEs working in civil engineering and water resources firms regionally and nationally.

Field inspecting a poor condition culvert in City N

The team gained valuable input on their design work from multiple professional engineers and, in turn, used the input to improve the clarity and quality of every part of the evaluation program: the form, the guidance manual, and the scoring system. Many PE comments reinforced the importance of the components of the evaluation program that the team had already developed. The team's initial scope of work was to develop a culvert evaluation program specifically for City N, but the team gained insight about adapting the evaluation program and form through their interaction with PEs around the county; the form could easily be applicable for use in other municipalities and states.

The team learned many lessons through collaboration that they would not have learned in a classroom setting. They experienced professional networking directly and through observation. They learned about how industry and government partner on projects through the case study of a culvert replacement. Since City N's engineers do not have time to undertake the design work needed for culvert replacement, they bid out the project to local consulting firms. The team also learned about how government engineering organizations and the public interact, in particular about how city governments communicate with the public and those affected by public works projects, as well as the influence the public has over these processes. In the case study of culvert replacement, the city had to push back the timeline for the replacement process due to public pressure, because the traffic detour required by the project was substantial. The team learned about the construction process through a visit to the culvert replacement site, gaining a more thorough understanding of the coordination it takes to complete a project in a residential area.

This project connected directly to many issues and ideas that professional engineers grapple with every day. At the center of the project was the process of balancing the need for both structural safety and ecological health while minimizing cost. The team learned about which culverts get funded for replacement, which do not, and how this process happens. This knowledge came directly from the collaboration with professional engineers.

III. Benefit to Public Health, Safety, and Welfare of the Public

Culvert condition has great impacts on the health, safety, and welfare of the public. The main goal of this project is to bring culverts with certain structural or ecological issues to the forefront of the DPW's attention so they can be properly targeted and prioritized in respect to other culverts in the city that may not have pressing needs. The primary benefit of a culvert priority ranking system to the greater public is that it can help prevent larger problems from occurring. From a structural view, if a culvert were to washout or fail, the roads over these culverts can be out for months at a time. From a public safety standpoint, a collapsed road can prevent the proper movement and dispatch of emergency vehicles, which can have great impacts on a community. Along with these issues, a failed culvert puts a large financial burden on the city at hand to rush through a design process and replacement. With culvert replacements costing hundreds of thousands of dollars, finding out which culverts are close to failure and replacing them before they do fail is in the best interest of the DPW and the public.

Poor condition culvert in City N before replacement

On the other hand, ecological issues can also present unique challenges. Culverts that limit aquatic and terrestrial organism passage can bring about the death of native and endangered species, which in turn can impact the ecological, and public health of the surrounding area. For example, there is a culvert in City N that does not allow for proper terrestrial organism passage from downstream to an upstream pond and breeding ground. Due to the physical barrier, the terrestrial animals, such as turtles, have to cross the road in order to reach their destination. When they attempt to cross the road, they are killed by passing cars. A citizen in City N routinely brings posters of the dead turtles to City N City Council meetings to try to bring awareness to this issue.

After developing the evaluation package and researching other packages in use around the country, the team clearly recognized that the impacts of poorly designed culverts extend far beyond water overtopping roads. The greater structural and ecological implications that culverts can have are often hidden from the public until it is too late. By developing a culvert priority ranking system that brings the problematic structures to the forefront of the DPW, the city can tackle issues in a timely manner and address previously invisible problems before they devastate infrastructure and residents' lives.

Along with the prioritization scoring, the team also addressed public safety in the inspection of these culverts. For example, the guidance manual includes instructions detailing how to inspect culverts with regards to OSHA and other safety guidelines. The instructions include a detailed parking plan, how to properly prepare for an inspection to limit the amount of field time, and how to safely navigate a public road to inspect the culvert.

While this project was initially intended specifically for City N's DPW, there are many themes that ring true to communities nationally. Most importantly, the project's key value is that it takes two traditionally separated culvert concerns - structural and ecological - and considers both on the same scale. Traditionally, city DPWs care primarily about a culvert's structural condition, and environmental advocacy groups focus on the ecological angle. This new integrated framework enables DPWs to more actively and systematically include ecological perspectives as well as properly allocate resources for culvert replacement, which will allow for a more sustainable future for the culverts and city infrastructure. There are tens of millions of culverts across the United States. If more DPWs could implement clearer culvert ranking systems that encourage interdisciplinary thinking like City N, the impact on the health, safety, and wellbeing of the nation would be immense.

IV. Multidiscipline and Allied Profession Participation

This project is inherently interdisciplinary due to the nature of combining structural and ecological considerations in the evaluation protocol. There were multiple branches of civil engineering incorporated in the evaluation package, including structural, transportation, environmental, and water resources. The student team ensured that these engineering disciplines were included by assembling a diverse team of collaborators and reviewers that encompassed these concerns. The nine PE collaborators/reviewers represented all the engineering disciplines mentioned above. Disciplines outside of engineering were also integral to understanding the greater role culverts play in ecosystems and in infrastructure. As such, the team also collaborated with professionals with specialties in Geographic Information Systems, Landscape and Environmental Science, and Ecology/Biology (including a representative from the U.S. Fish & Wildlife Service).

After reviewers submitted their comments on the evaluation package at various stages throughout the development process, the team incorporated the feedback into the final product. This process allowed the team to better grasp how integral culverts are to many different disciplines, and how to best evaluate them to reflect this interdisciplinary impact. Based on reviewer comments, the team added characteristics for evaluation that they had not learned through their research or in a classroom. For example, the team added an estimate of stream velocity to the form rather than simply noting if the velocity is the same or different upstream and downstream after receiving feedback from a hydrologist that collecting this data could be valuable for determining fish passage. The professional collaboration utilized in this project created a more thorough and interdisciplinary evaluation, which will serve City N's DPW and the public well in future dissemination and implementation of this work.

It is also worth noting that within this team of students, faculty, and professionals, women were especially well represented. The student team itself was three women; the primary faculty member and City N liaison were both also women, as were 5 of the PE reviewers. The mentoring and role modeling enabled by this project nurtured future women professional engineers, enriching diversity in the primarily male-dominated engineering profession.

V. Knowledge and Skills Gained

Ethics

The process of prioritizing culverts for replacement is rooted deeply in ethical considerations. Which area will be prioritized when two culverts are both in need of replacement and the city only has funding for one? The student team weighted the structural considerations over the ecological considerations when creating the scoring system after learning about how the DPW wanted to prioritize replacement to emphasize public health and safety over ecological health of the area.

Safety

The student team had to think deeply about the safety aspects of culvert evaluation and replacement. The team emphasized safety in procedure and supply prescriptions in the guidance manual. After consultation with their liaison, the team also recommended the collection of the length of the culvert be estimated through desktop analysis rather than in the field, due to traffic concerns. There is a section on the form outlining access issues that may pose a hazard to evaluators, such as steep slopes. The student team also thought deeply about how road closures affect access to emergency services and the role of a well maintained road system in the safety of the public. The team learned how to utilize existing standards and regulations, such as the State A Stream Crossing Standards are guidelines with best management practices for ecological health but have no regulations attached to them. Integrating ecological impacts into this culvert evaluation was one of the team's most significant decisions while designing the evaluation program. Uplifting environmental health in an official and documented capacity supports a movement to encourage municipalities to reach beyond historically basic regulations - a movement already garnering support from other governmental organizations.

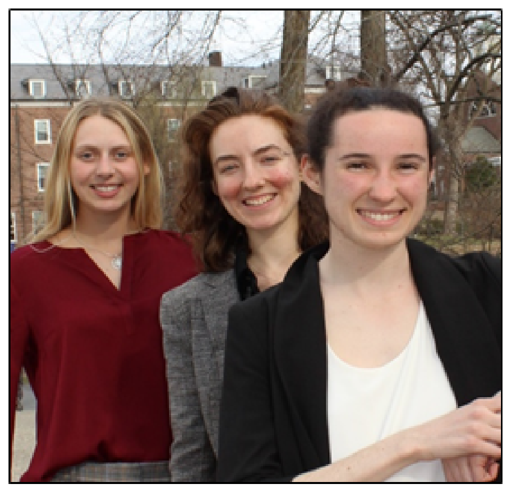
User-centered Design

The student team was able to complete a full design process during the creation of the form. The team identified stakeholder needs and translated them into design requirements. The team focused their design on ease of use for the evaluator while creating the form. The content and the overall design were consistently edited based on creating greater clarity for users. Decisions such as using Microsoft Office software for the form and database design were also based on ease of use for City N's DPW.

Software Tools

The student team gained experience using different software packages that support culvert evaluation and replacement, including GIS, HydroCAD, and HY-8. The team initially focused on self-direction to learn this software, but then recognized when they needed help and asked for it. The team used professional engineers expertise to guide and understand the proper use of the software.

Professional Communication



The student team gained substantial experience with written, visual, quantitative and oral communication, skills that are constantly applied and essential in the professional world. The team created three comprehensive revisions of the report as the project developed, building technical writing experience. The team produced a GIS map of the ecological priority areas in City N. iterating their map with feedback on the clarity of the information from their faculty coach and DPW liaison. They learned how best to present information visually through creating poster presentations and slideshow presentations to accompany oral presentations. The team also had to consider how best to translate culvert condition into a quantitative measurement. The team learned that focusing on not only creating a good design but also communicating that design effectively are essential for the success of a project.

Data Collection and Analysis

The team gained experience in collecting and storing data. They learned the importance of striking a balance between making a form comprehensive while also making it easy enough to use so that the process is efficient and the evaluator does not skip any fields. This learning was supported through conversations with the student team's liaison in the DPW and also through conversation with the regional expert in culvert evaluation whom the team contacted. The team also considered how to store data so it can be properly utilized and archived. In developing their database, the team emphasized ease of data entry and automated scoring to reduce potential human errors. The team also consulted with their faculty coach and DPW liaison about the best way to input, display, and store the data. They learned how using known software such as MS Excel can improve the accessibility of the data rather than using more complicated software such as Matlab.

Project Management
Each student had the experience of managing the project for at least one quarter of the year. In this rotating project management role, the team learned how to set agendas, create Gantt charts, run meetings, delegate tasks, monitor project pace and development, manage a project timeline, and communicate with team members and liaisons to maximize project efficiency and quality.

Construction Practices
In the process of the project, the team shadowed the construction of a replacement culvert. They utilized their connections with an engineering consulting firm to learn more about the construction process, including stream management, excavation, power management, the process of precasting and shipping culvert sections, and the management of human resources and quality control on the site.

Teamwork
The team also gained knowledge about how to best work together to complete tasks efficiently. They learned how to recognize different skills in the team and use those skills to move the project forward effectively. For example, they leveraged one team member's knowledge of GIS software to move the priority area analysis forward, as well as using that process for the rest of the team to gain familiarity. Two of the team members found creating the first draft of technical writing documents easier, so the third team member was often in charge of the editing process.

Balancing Multiple Disciplines
Another skill gained through this project was how to balance different disciplines. A main motivation for the project was an objective evaluation of culverts to prevent disagreement within the DPW about which culverts to replace first, as people in the environmental division often pushed for different culvert replacement than the highway division. The team found drastically different approaches to culvert design and consideration during the design process. For example, the attitude toward the use of rip rap from an environmental science faculty member was rather hostile, but it is seen as a very viable option by the DPW liaison.


Culvert replacement protects native creatures and enables habitat connection

Network Building
The team also learned how to utilize the network of the professional engineers and faculty to grow their professional network. They then used this network to improve their evaluation package. For example, their faculty coach connected them with the Institution A alumni for feedback on the form, and their DPW liaison connected them with an engineer from a local agency. The team learned how to ask for time resources from others in a professional setting and are better poised to leverage their extended network in the future as they begin their own professional engineering careers.