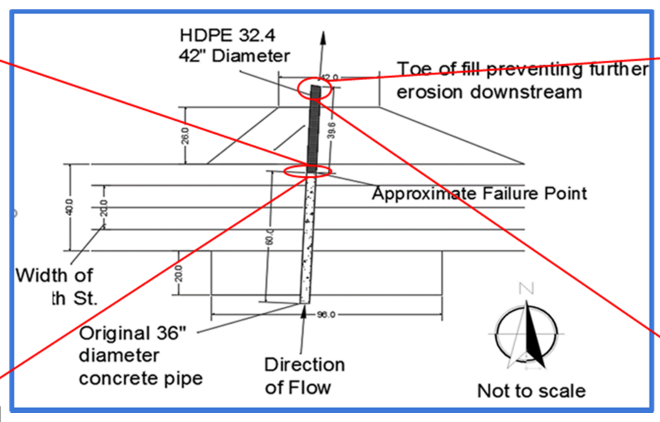
Replacement Design of a Culvert to Allow Fish Passage

Project Details: Local county requested assistance in designing replacement for failed culvert, making it fish passable. Original culvert built 50 years ago consisted of 10' sections of 36" diameter precast concrete. Downstream end of culvert failed in 2015 compromising integrity of road. County replaced the failed portion with 42" HDPE pipe.

Original Concrete Culvert



Plan View of Culvert

HDPE Replacement

Student team tasks:

- Research project challenges, applicable codes, regulations and permits
- Recommend replacement option
- Widen and redesign road to meet current code
- Perform cost estimate
- Develop construction sequence

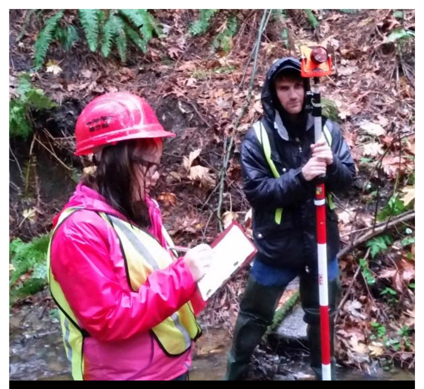
Multidisciplinary Features of Project

- Environmental and Water Resources Engineering
  - Hydraulic modeling, culvert sizing
- Transportation Engineering
  - Roadway design
- Geotechnical Engineering
  - Trench wall, culvert bedding design
- Aquatic Biology
  - Fish behavior and migration patterns
- Computer Aided Drafting
  - Preparation of engineering drawings
- Construction Planning
  - Construction sequencing
- Cost Estimation and Permitting

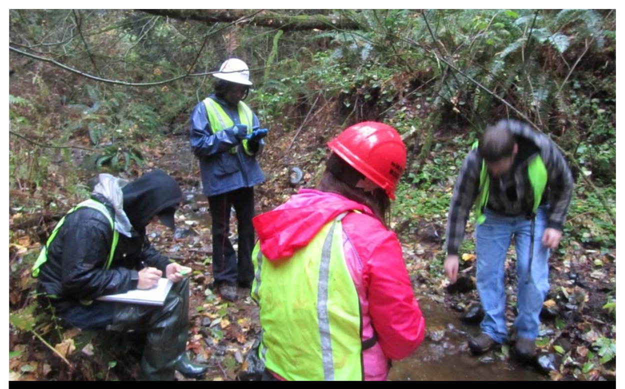
Project Scope and Analysis

Field Reconnaissance and Background Research

- Team studied applicable codes, guidelines and permits
- Carried out land survey to develop cross sections and longitudinal profiles of stream
- Performed pebble count to simulate culvert bedding



Surveying the creek



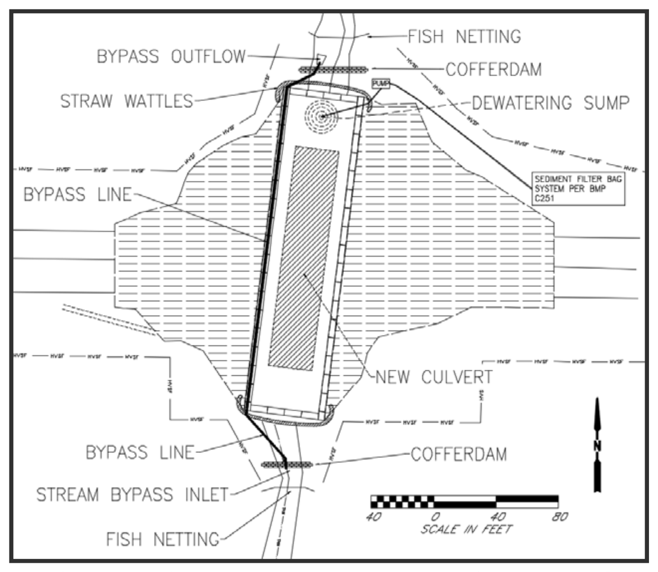
Performing pebble count

Engineering Analysis and Design

- Performed hydraulic analysis to size culvert
- Evaluated 2 culvert options (corrugated metal pipe (CMP) and Concrete Box Culvert) and decided on latter
- Designed
  - culvert bed enabling fish migration
  - trench wall to retain soil
  - backfill and final grading
  - geogrid for embankment
  - roadway above culvert to meet demand and improve safety
- Prepared engineering plan set
- Performed cost estimates
- Completed preliminary permits

Engineering Design Drawings and Construction Sequencing

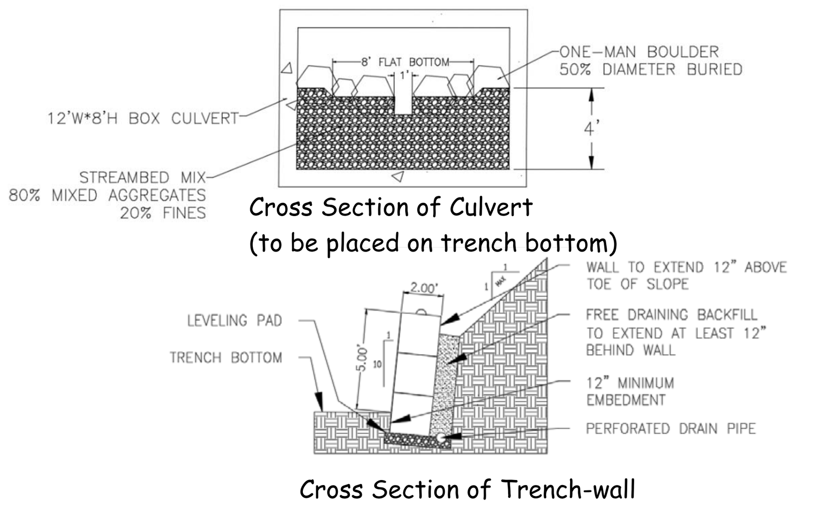
Excavation and Stream Diversion



Plan view showing stream diversion, placement of new culvert and grading of surrounding

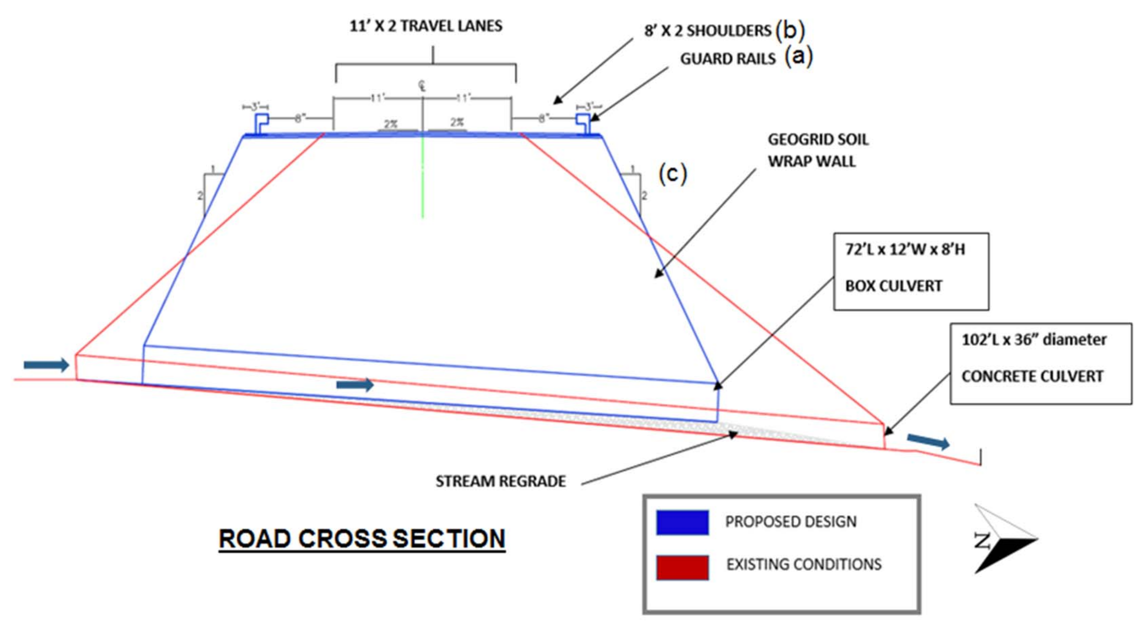
Highlights: Installation of stream bypass during construction will consist of fish netting (to protect fish), coffer dam (to provide a dry area to work), and a dewatering sump (to provide dry bed)

Trench Wall Construction and Culvert Placement and Backfilling



Highlights: Trench wall provides worker safety during 36ft deep excavation; culvert bottom simulates natural stream bed for smooth fish passage; culvert can handle low and high flows

Final Recommendations and Design Package

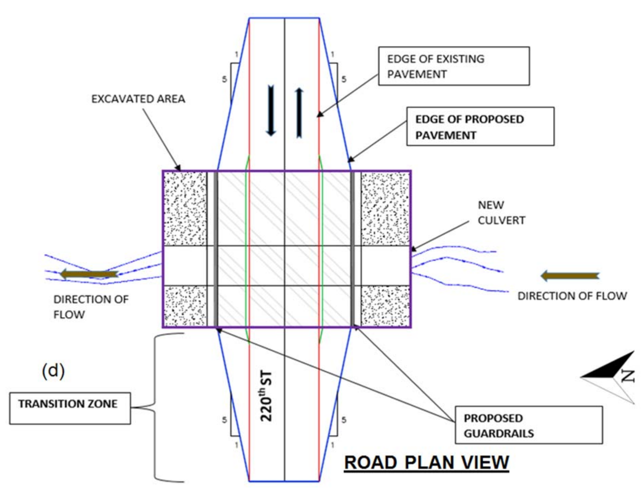


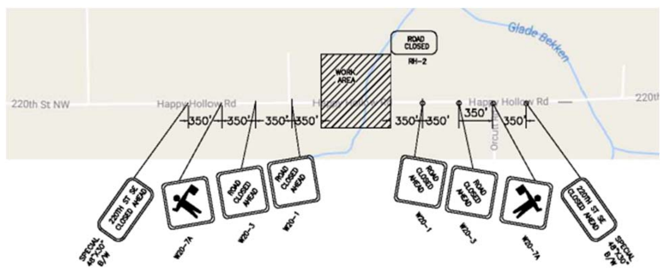
Highlights: Team prepared engineering plan set showing existing site conditions, detour map and signage, plans for temporary erosion and sediment control, stream diversion and dewatering, excavation, culvert placement, final site grading, embankment stabilization with geogrids, roadway improvement and revegetation

Completed the Preliminary drafts of the two relevant permits

Estimated Cost of Project = $834,300

Roadway Improvement





Excerpt of Detour Map and Signage

Highlights: Road redesigned to meet current codes; guard rails added, lanes and shoulder widths increased. Developed detour routes and signage for public safety

Protection of Public Health, Safety and Welfare

- Project area is undergoing rapid development; roadway expansion will improve transportation safety and bring the road up to county codes
- During culvert replacement, team designed signage and traffic detour to ensure driver and pedestrian safety
- Team considered environmental health and safety issues (soil erosion, water pollution and fish migration) in construction planning

Collaboration with Professional Engineers, Land Surveyor and Other Allied Professionals

Students

- Two faculty members - one a PE, the other PE, PLS - supervised
- A PE and an aquatic biologist from County mentored
- Drafter from local company assisted with Civil 3D drawings
- Native American Biologist educated on fish migration
- County engineers, managers, construction personnel and licensed engineers from University's advisory board provided feedback on oral presentations

Knowledge and Skills Gained

Technical

- Gained skills using state Fish and Wildlife regulations on water crossing structures, Federal Emergency Management (FEMA) regulations, National Pollutant Discharge and Elimination (NPDES) permits, State Department of Transportation (DOT) manuals, County Codes, Drafting Standards, and Drainage Codes
- Familiarity with software: Hydraulic Modeling Software (HEC-RAS), Computer Aided Drafting (Civil 3D)
- Cost Estimation using bid tabs provided by County

Communication

- Oral presentations to class, to professional engineers from Department Advisory Board, to County, and at local professional society meetings
- Developed technical writing skills through proposal, final report, and professional emails
- Worked with a wide range of professionals

Professional

- Developed project management and leadership skills
- Prepared agenda and ran meetings, followed up on action items, managed schedules and budgets, worked as a team

Replacement Design of a Culvert to Allow Fish Passage

Abstract

A local county requested our university's assistance to design a culvert that had failed underneath a county road – the culvert was also considered a fish barrier. The original culvert was designed and built over 50 years ago prior to regulations governing fish passage. Furthermore, because of the rapid growth in the region, the road above the culvert was not meeting local codes. The county requested the team to develop two culvert options that were fish passable, evaluate them and recommend a preferred option. Following that the team had to finalize the preferred option with the roadway above the culvert widened to meet current codes, develop a construction sequence for replacement of the culvert, estimate the cost of the project, identify relevant permits and complete preliminary drafts of these permits.

The project encompassed **multiple disciplines** - environmental and water resources engineering for stream flow simulation and culvert sizing; geotechnical engineering for trench wall design and for selection culvert base material such that it matches the stream bed, making it fish friendly; transportation engineering for roadway design; aquatic biology to understand fish behavior and migration patterns; drafting to develop professional quality engineering drawings; knowledge of applicable permits, cost estimation and construction methods.

The students **collaborated with individuals from multiple disciplines**. A faculty member with a dual Professional Engineering and Land Surveying (PE, PLS) license served as the advisor to the team. A PE taught the senior capstone course. A PE and an aquatic biologist from the county provided technical guidance to the team. A biologist from a local Native American tribe advised the team on fish migration issues. The team presented their project to engineers, managers, and construction managers from the county and received valuable feedback. In addition, the team presented their work to department's advisory board members who are all PEs. One of these PEs provided feedback on the final drafts of the project proposal and the report. A drafter from a local engineering company assisted the team to develop professional quality engineering drawings.

Public health, safety and welfare played a vital role in several aspects of the project. The team widened the roadway to bring it up to county codes and to improve traffic safety. The team designed the signage and a traffic detour route for use during culvert replacement to ensure driver and pedestrian safety. When developing the construction sequence the team considered several health and safety issues relating to soil erosion, water pollution and fish migration.

Through this project experience, the students **gained a wide range of knowledge and skills**. They learned to use local, state and federal design guidelines and specifications; developed oral and written communication skills and other professional skills such as leadership, time and budget management, and working as a team.

REPLACEMENT DESIGN OF A CULVERT
TO ALLOW FISH PASSAGE

I. Project Description

Introduction

A local county approached our engineering program requesting assistance with the design of a culvert that had failed underneath a county road – the culvert was also considered a fish barrier. The original culvert was designed and built over 50 years ago when there were no regulations governing fish passage and was comprised of multiple 10 ft long sections of 36" diameter precast concrete. In 2015, the downstream segment of the culvert failed compromising the integrity of the road. The county responded by installing a temporary 42 in diameter 40 ft long High Density Polyethylene (HDPE) pipe for the failed portion of the culvert. The county desired a permanent, fish-passable replacement.

Figure 1 shows the plan view of the roadway, the original precast concrete portion of the culvert and the HDPE replacement. The existing roadway width is 24 ft with guard rails on the upstream side of the road. The temporary HDPE retrofit protects the integrity of the road but is undersized to handle large storm events and does not meet current fish passage regulations. In addition, the project area has gone through rapid development and hence the roadway does not meet current county standards. The team sought to correct these deficiencies in its design and also had to consider overhead power lines and underground telephone lines.

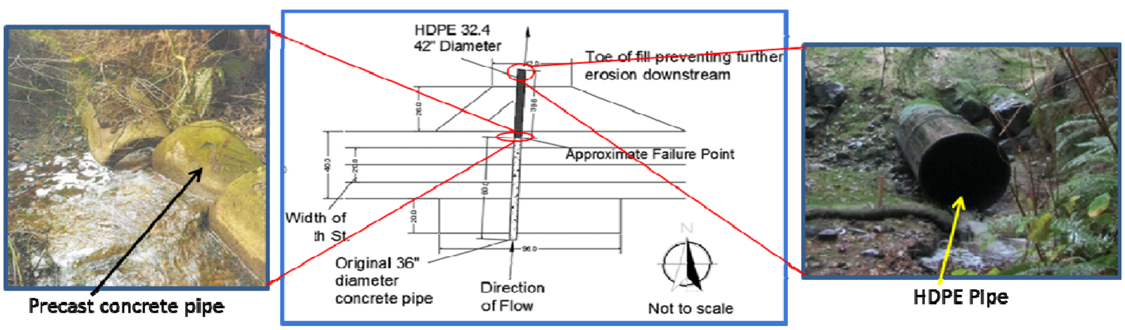


Figure 1. Plan view of Roadway and Culvert (center), Failed Precast Concrete Culvert (left) and View from Downstream of HDPE Retrofit (right)

Project Deliverables Requested by County

The county requested the senior design team to complete the following tasks:

- Background research on the challenges facing the project, applicable design codes, regulations and permits
- Hydraulic analysis of the creek at culvert location for the 100 year flood elevation
- Evaluation of two options of fish passable culvert structure types
- Recommended preferred alternative with details of type and size
- Preliminary cost analysis of preferred alternative
- Proposed alignment and profile of road and culvert
- Right of way needs, proposed utility relocation and construction sequencing

Characteristics of the Project Site and Applicable Permits

The project site has a drainage area of 0.67 sq. miles with 33 in. of annual average rainfall. The creek is home to various types of fish, amphibians and macro-invertebrates and has a wetland nearby. There is a high water table within the site - thus any design option selected should include a dewatering system that channels water into detention ponds at both upstream and downstream ends of the culvert. The team also found that there were two state specific permits that were applicable for this project.

Overall Project Approach

The project was multi-disciplinary in nature intertwining land surveying, hydraulics, geotechnical engineering, fish biology, and road way design. The students also needed skills in construction planning and cost estimation, providing a well-rounded experience.

a) Culvert and Roadway Design

The team researched the local, state and federal design guidelines for fish passable water crossing. From the research findings the team adopted a stream simulation hydraulic design which is based on the premise that if the inside of a culvert can simulate the adjacent natural channel's stream velocity and streambed material, the fish can pass through the culvert with no more challenge than in the natural stream. This model simulates field conditions well when the average bank-full width (BFW) is less than 15 ft, and the total length of the culvert is less than 120 ft. The model also takes into account flood flow conveyance and transport of wood and sediment transport rate that mimic the natural stream.

The team performed a topographic survey under the supervision of a faculty member who is a licensed land surveyor to study the existing conditions of the site. The topographic survey spanned a length of 100 ft upstream and 100 ft downstream of the culvert at 20 ft intervals along the stream. An extended stream profile survey revealed that the average BFW of the creek was 8 ft; the entire stream had a natural slope of 6% while the existing grade within close vicinity of the culvert was 4% upstream and 12% downstream. This change in grade was ascribed to the fact that the original culvert was undersized resulting in a change in the geomorphology at the downstream end of the culvert.

The team studied the county design and engineering standards for the roadway design and determined that the lane and shoulder widths should be 11 ft and 8 ft, respectively. With

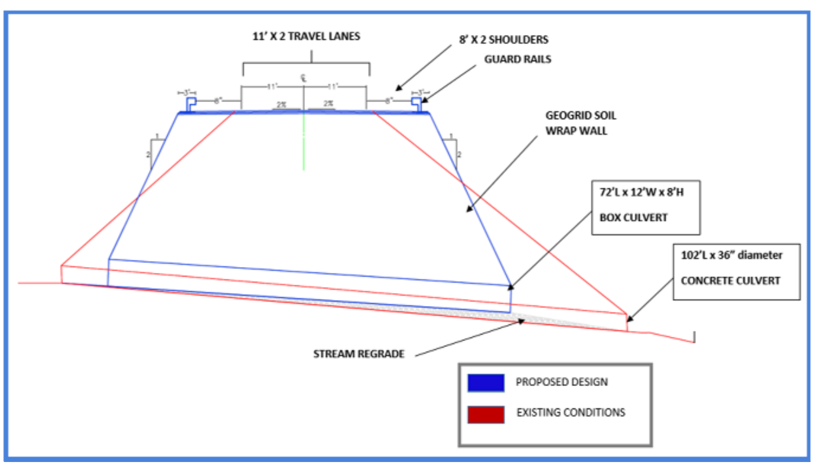


Figure 2. Cross Section of Existing and Proposed Culvert

shoulders and guard rails, and 2V:1H embankments on either side of the roadway, the total length of culvert was determined to be 72 feet, as shown in Figure 2, thus meeting the stream simulation model requirements.

The team investigated two culvert options: a corrugated metal pipe (CMP) and a precast concrete box culvert. After discussions with the county the team selected a concrete box culvert as the preferred alternative due to its longer life span despite its higher cost of installation. Based on the bankfull width, the internal and external widths of the culvert were determined to be 12 ft and 14 ft, respectively.

The county geotechnical engineers provided the team with a geotechnical report prepared for the project site which summarized the geologic setting and the subsurface conditions. The team used this information and their knowledge of geotechnical engineering and hydraulics to mimic the natural streambed within the culvert. They collected representative samples of the bed material at several locations in the vicinity of the culvert and determined the particle size distributions of the natural stream. These samples were also used to determine the Manning's roughness coefficient of the natural stream bed to use in the hydraulic model. Design guidelines provided equations that related the design of bed material particle size gradations within the culvert to the stability of the stream bed which is a function of slope of the natural stream and the bed material found in the natural stream. From the above analysis, the team recommended a concrete box culvert filled to 50% of the opening height with cobbles ranging from 10" to 4" with 20% fine material to achieve a non-porous stream bed where small size gravel will not be washed out.

According to fish and wildlife guidelines, fish require a minimum water depth of 1ft to migrate. The team created a stepped low-flow channel inside the culvert to achieve this. As shown in Figure 3a, there are two channel widths inside the culvert: in the low flow conditions the width and depth will be 1 ft. During a 100-year flood event, the flow depths will be 0.5 ft on the sides of the channel and 1.5 ft in the thalweg (line connecting lowest points) of the channel.

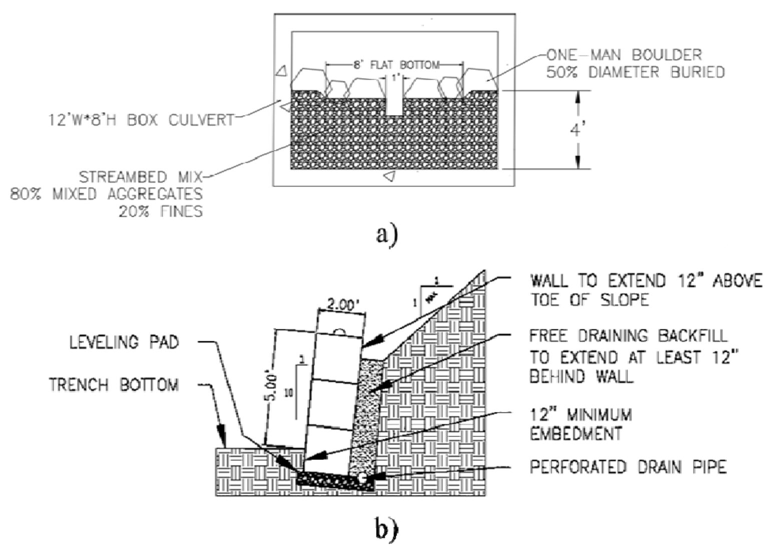


Figure 3. Cross Section of Proposed a) Culvert, b) Trench Wall (Culvert will sit on Trench bottom)

The team had to check if the proposed culvert can safely handle large flow events. If not, water may back up upstream of the culvert and result in alteration of the geomorphology of the stream. In order to check this, the team created a HEC-RAS model of the proposed culvert and tested it with 100-year flows. Model results showed that the proposed culvert was able to handle large flow events in a safe and satisfactory manner.

The team used the county roadway design guidelines to determine the required lane and shoulder widths and the guard rail layout for the roadway.

b) Construction Planning

After completing the design work, the team developed an installation sequence for the culvert. First the ground will be excavated up to a depth of 36 ft and the existing culvert removed. When the excavation is completed, the bottom trench will be 28 ft wide to accommodate the 14 ft wide box culvert, a 4 ft work space on either side, and another 3 ft space on either side for the installation of a short trench wall and drainage system as shown in Figure 3b. Excavation of side slopes beyond the trench wall shall not be steeper than 3H:2V per code as indicated in Figure 4. The temporary trench wall will consist of lock blocks; the drainage system behind the wall will prevent water buildup (Figure 3b).

A bypass system will be used to divert the stream during construction as presented in Figure 4. The bypass system will comprise of a pipe placed parallel to the trench wall with gravity flow, two cofferdams at either ends of the culvert and a fish netting barrier beyond the cofferdam. Because the water table is high in the area, a dewatering sump will be installed to pump any excess water.

Prior to placing the new box culvert, the base will be prepared by compacting the subbase and creating a final grade of 6% slope as required in the design. Following grading, culvert sections will be placed from the downstream end and connected flush through spigot and bell connections. Butyl sealants will be applied at the connections to prevent leakage.

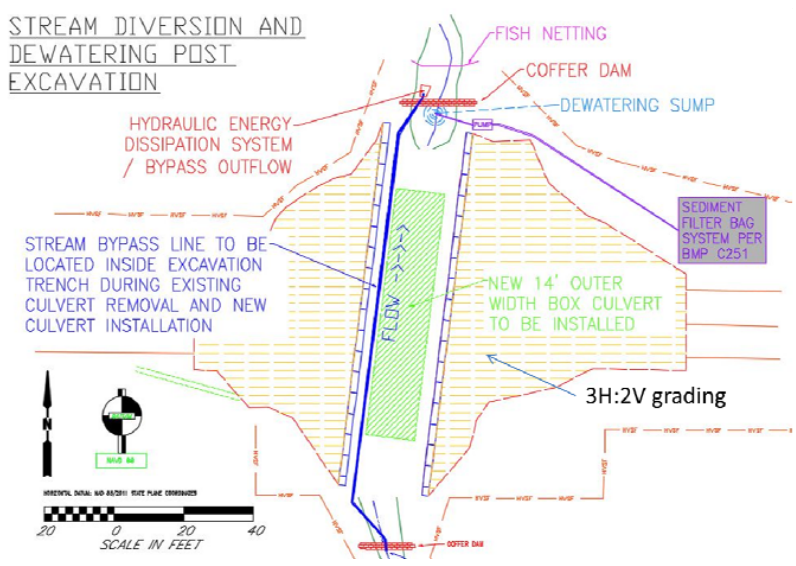


Figure 4. Stream Diversion Plan during Construction (Plan View)

After the installation of the culvert, the trench will be backfilled with controlled density fill (CDF) and native soil and compacted to meet specifications. On the upstream and downstream ends of the culvert geogrid soil wrap walls will be installed as presented in Figure 2. This will be followed by revegetation to prevent any erosion of the embankments. The embedded culvert will be filled with streambed material to simulate the natural stream bed as described earlier.

Public safety was vital during construction phase because the excavation was going to be 36 ft deep and the width of the road was going to be narrow during construction. To ensure safe and efficient traffic flow the team developed a detour plan to redirect traffic around the project site during construction.

Furthermore the team found that the project could not be contained within the County property. The county was made aware that a permanent slope easement to utilize a private property on the north side of the road right-of-way would be required.

c) Cost Estimate
Finally the team prepared a cost estimate for the project based on multiple contractor bids for the county on similar projects. This estimate includes excavation, bedding, fill, soil wrap wall, roadway restoration, guard rail, erosion control, landscaping and traffic control. With the 40% contingency the total estimated cost was found to be $835,000. Table 1 shows a summary of the total cost.

Table 1. Summary of Cost Estimate

Item	Cost
Site Preparation (mobilization, clearing and grubbing, removal of existing structure and any obstructions)	$119,400
Grading	$44,088
Drainage materials (stream bed sediments, cobbles, boulders)	$7,695
Culvert (material and transportation)	$168,584
Surface preparation (crushed rock for base and top courses	$5,1156
Erosion Control and Roadside Planting (high visibility fence, seeding, mulching)	$1,941
Temporary Traffic Control	$35,750
Miscellaneous (temporary stream bypass, geogrid, cofferdam, retaining wall)	$15,722
Subtotal	$539,795
Total (with tax and 40% contingency)	**$834,300**

d) Relevant Permits
The students identified two relevant state specific hydraulic permits for the project. The students assisted the county by completing preliminary drafts of the permit applications.

II. Collaboration of Faculty, Students and Licensed Professional Engineers

At our institution all engineering students work on a real world project during their senior year under the mentorship of a sponsoring agency or company. A diverse group of four students worked on this project and were mentored by a liaison engineer from the county and two faculty members from the university, all licensed professional engineers. One of the faculty members is also a licensed land surveyor.

Our department has an active advisory board consisting of local civil engineering licensed practitioners. It meets twice a year to provide feedback on curriculum, future growth, internship/job opportunities for students and other industry-academic issues. The team presented the project to the board members twice. The first presentation early in the year covered their understanding of the project scope and how they plan to accomplish the work. The second presentation at the end of the year covered the work accomplished, conclusions and recommendations. In addition, an advisory board member reviewed the final drafts of the proposal and report. The team addressed the reviewer's comments before finalizing the documents.

III. Protection of Health, Safety and/or Welfare of the Public

The project area has experienced rapid development in recent years. Bringing the road up to current code would alleviate traffic congestion, which is a public welfare issue. The team planned signage and traffic detours because of the 36 ft deep excavation which could affect driver and passenger safety. The students considered soil erosion and water pollution issues when considering stream diversion options during construction.

IV. Multidiscipline and/or Allied Profession Participation

This project required knowledge of various sub-disciplines within civil engineering: <u>environmental and water resources engineering</u> for stream flow simulation and sizing the culvert, <u>geotechnical engineering</u> for simulating the culvert base to match the stream bed and for trench wall design, and <u>transportation engineering</u> for roadway design. Furthermore, an <u>aquatic biologist</u> from the county and a <u>biologist</u> from a Native American tribe advised the team on issues related to fish migration. The university hired a <u>drafter</u> from a consulting company to serve as a resource to the team in preparing professional quality Civil 3D engineering drawing. When the team presented their work to the county, <u>engineers, managers, and construction managers</u> attended the presentations, asked questions and provided valuable feedback to the team.

V. Knowledge and Skills Gained

The capstone experience is unique in that it helps students develop a variety of important skills needed for practicing engineers.

<u>Technical</u> - The project gave the students an opportunity to apply what they have learned from their course work in environmental, water, transportation, geotechnical, structural engineering in a single project. Along the process, they acquired the skill to use the following tools:

- <u>Design Manuals, Specifications and Guidelines</u>: State Fish and Wildlife regulations on water crossing structures, Federal Emergency Management Agency (FEMA) regulations, National Pollutant Discharge and Elimination System (NPDES), state Department of Transportation manuals
- <u>County Codes</u>: county engineering design and development standards, county Computer Aided Design and Development (CADD) standards
- <u>Computer Aided Drafting</u> Civil 3D
- <u>Design Software</u>: hydraulic modeling (HEC-RAS), state specific hydraulic model
- <u>Familiarity with Permits</u>: Two state specific hydraulic permits for water crossing

Additionally the students learned constructability issues by developing the installation plan for the culvert.

Communication – During the year students developed both writing and speaking skills. The students submitted a written proposal to the county at the end of fall quarter, outlining their understanding of the project, scope of work, plan of implementation, work breakdown structure and schedule. At the end of spring quarter, they submitted a final report describing the work done, engineering drawings, calculations and other deliverables requested by the county.

The students were required to make oral presentations to their peers twice a quarter. Every student was required to make at least one presentation each quarter. In addition, students presented their proposed work to the county at the end of fall quarter and their final design recommendations at the end of spring quarter. The academic year concluded with a conference style event, where the team presented its work to the entire university community, sponsors of all the various senior capstone projects, prospective sponsors, friends, family and alumni.

Professional Skills – Students developed project management, leadership and client interaction skills through practice. The student team met weekly with the faculty advisor. Because the sponsor was about 35 miles away from the university, the team had weekly conference calls with the sponsor. The team also met in person with the sponsor every month or as needed. Throughout the year, students took turns serving as the project manager. The project manager was responsible for preparing the meeting agenda, leading meetings, assigning tasks and tracking overall progress.

VI. SUMMARY

A team of four civil engineering seniors provided engineering services to a county to replace a failed culvert to make it fish passable. They also redesigned the roadway above the culvert so that it meets current county codes. The team was guided by a professional engineer and an aquatic biologist from the county. From the university, the students worked under the supervision of two faculty members, both licensed professional engineers, and one also a licensed land surveyor. The students designed the culvert and the roadway, developed a construction sequence for the installation of the culvert, estimated the cost of construction and completed preliminary drafts of the applicable permits. The students applied the technical skills learned in a wide range of civil engineering courses to a real world problem. The project also helped the team to learn construction sequencing, cost estimation and permitting. Moreover, the students were exposed to various design manuals, design software and also developed project management, leadership and communication skills, and client relations.