Design Project Report

Creek Crossing,

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Note: All electronic files including, HEC-RAS numerical modelling and spreadsheet calculations, are available upon request.

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ABSTRACT

An existing crossing is located on a creek which is a tributary to a larger regional river. This crossing serves as a secondary access point to several important pieces of infrastructure and is used in emergencies.

The current infrastructure consists of an unpaved road over circular culverts made of corrugated steel pipe. Every year during the spring months the creek basin tends to flood, damaging the crossing and road, which subsequently require significant maintenance. The current crossing design does not provide sufficient conveyance during these floods, resulting in significant on-going costs to the client organization. It has been determined that the current crossing needs to be repaired or re-designed.

In order to provide a design which will resist damage due to flooding, meet provincial codes and enable continued operational access to the area, a numerical model of the creek system was built. The critical flood states which incur most of the damage to the crossing may be caused by backwater from the larger river rather than runoff events from the creek's watershed. Through modelling, the high water level and critical state for this design were determined.

This design was provided to the client in order to enable remediation or replacement of the infrastructure at the crossing site and ensure continued operations in the areas accessed via this crossing.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. PROJECT OVERVIEW

1.1. Introduction

The purpose of this document is to provide a detailed design report of the requirements as requested by the client. This report includes design considerations and criteria used for the selection and detailing of design components. Additional environmental assessments would be required by the client organization in order to move forward with construction.

1.2. Project Background

This project proposes a design to replace the existing crossing at the design site specified by the client to accommodate frequent flooding in the area. The crossing is considered critical for operations within the area.

The creek drains into the main regional river system. Due to the proximity of the crossing to this junction the river may pose further flood risks due to backwater conditions. Furthermore, the design considers sensitive aquatic species in the area.

Four options were considered for the replacement design:

Option 1: Construct a new causeway crossing, incorporating culverts;

Option 2: Construct a new crossing using concrete box-culverts;

Option 3: Construct a bridge at the crossing site; and,

Option 4: Maintain the status quo.

After a review of these options, option 1 was selected due to:

1. Flow capacity
2. Ease of installation
3. Longevity

Tables 1 and 2 describe the criterion used for project selection.

Table 1: Creek Crossing Options Analysis.

	Causeway & Culvert	Box Culvert w/ RC Abutments	Bridge	Remediate existing crossing
Materials	2	1	2	3
Cost	3	2	1	2
Environmental Impact	2	2	2	1
Complexity	2	1	1	2
Construction Time	2	1	1	3
Flood Protection	2	2	2	1
TOTAL SCORE:	**13**	9	9	12
RANK:	**1**	3	3	2

Table 2: Creek Crossing Options Analysis Descriptions.

Proposed Metrics:	0	1	2	3	Comments
Materials	100% externally sourced	70% or more externally sourced	40 - 70% externally sourced	Only unavailable materials externally sourced	Estimated % of total project not readily available on site or which cannot be fabricated using on site materials
Cost	Cost exceeds on-going maintenance costs in current state	Cost is approximately equal to on-going maintenance in current state	Cost reduced 20-49% less than on-going maintenance in current state	Cost reduced by 50% or more compared to on-going maintenance	Cost of construction and maintenance over the design period
Environmental Impact	Creates flooding of local basin, redirects river or prevents wildlife passage	Challenging conditions to some species, prolongs flooding or other significant changes	Allows passage of fish and wildlife, minimal changes in local environment	No predicted significant effects on local environment	
Complexity	Highly complex, most components require precise fabrication	Many components require high precision design and external fabrication	Some components require precision design, Engineering supervision may be required during installation	Can be fabricated and installed by existing personnel	
Construction Time	30 or more days	21 - 30 Days	14 - 21 days	Less than 14 days	During low water conditions, weather permitting
Flood protection	Erosion & flood induced failure likely during significant runoff events	Remains usable following a flood event but requires significant maintenance.	Minimal erosion, minor reparations may be required following a flood	Resist erosion & flood induced failures, can be built higher than HWL	

The 4th year class of RMCC Civil Engineering proposes a design for a new crossing for this creek. This project, as stipulated by the client, will allow MLC 30 vehicles to cross the creek's flood plain and will resist damage due to hydraulic activity in the area.

1.3. Revised Client's Problem Statement

A design project to support operations in the operating area was given to the RMCC civil engineering department. A supervisor was designated as the representative for the client. The current crossing is incapable of allowing the passage of sufficient flood flow, consequently it becomes unserviceable too frequently. The installation of a new crossing design has been selected as the most viable solution. The new design must:

- Accommodate an MLC 30 vehicle;
- Allow conveyance of a 5-year flood stage; and,
- Minimize damage from a 10-year flood stage.

A complete statement of requirements is included in Appendix 1.

1.4. Environmental Assessment Screening

As part of any Department of National Defence (DND) project, and environmental assessment (EA) is required; as the design team is comprised of DND students, this was considered a requirement. The environmental assessment screening form, provided to the project team, was completed with the information available. The results of the EA screening form were that the project may be able to be constructed, however information available is insufficient to draw any conclusions. It is strongly recommended that a complete EA be conducted by the local personnel. The EA screening form is included in Appendix 2.

2. WATERSHED CONDITIONS

2.1. Introduction

This section describes the creek watershed and flow conditions occurring within the flood plain. Using information from the Ontario provincial government a description of the watershed and estimation of flow conditions were established. The conditions of the watershed and its flood stages are considered critical design factors for this project. The characteristics used to describe the watershed were obtained from OFAT III.

2.2. Creek Watershed

The creek watershed is a forested area of land in south eastern Ontario. The watershed consists of a drainage area of 124.62 km^2, or 12462 hectares. The main channel of the creek is 62.7km long with a mean slope of 0.32% and experiences an annual precipitation of 888mm. Land cover in the area is overwhelmingly undeveloped forest, described by Table 3.

Table 3. Watershed Land Cover (OFAT III, 2016.)

Area (km^2)	Percentage	Cover Type
45.52	36.5	Coniferous treed land
36.01	28.9	Mixed treed land
21.11	16.9	Sparse treed land
1.81	1.4	Deciduous treed land
0.42	0.3	Community & infrastructure

The slope of the floodplain was also calculated using survey point data provided by the client organization. The floodplain in which the crossing will be constructed has a local mean slope of 0.1% and is approximately 250 meters across at the location of the crossing. A watershed map, land cover map and elevation model showing surveyed cross sections are included in Appendix 3.

2.3. Flow Conditions

Flood stage flows were determined for the 5 and 10-year stages in order to determine design requirements for the crossing. A rational method was used to estimate flows using an IDF curve from Environment Canada and a runoff coefficient was estimated using United States Geological Survey (USGS) guidelines. These flow estimates were then compared to results from OFAT III to support the accuracy of the flow values obtained. OFAT III provides flow estimates using several models; the Moin Shaw Multiple Regression and Moin Shaw 85 Index Flood with Expected Probability Adjustment were used for this comparison.

The most conservative (largest) flood flows were selected for use as design parameters. From the Moin Shaw Multiple Regression, a 5-year flood flow of 30.7 m^3/s and 10-year flood flow of 38.2 m^3/s were used for selection of design parameters. Appendix 4 details flood flow analysis.

2.4. Backwater Conditions

The crossing to be designed is in close proximity to the creek's junction with the main river. Spaced approximately 200 m away, the flood conditions at the crossing may be significantly impacted by backwater conditions from the River. The backwater conditions for the river were estimated using geomorphological information from the Rosgen Stream Classification Technique. The bankfull discharge of a river typically represents a 1.5-2 year return period, with little difference between a 2 and 5-year flood level. A flood stage water surface was used to represent the backwater conditions, with a surface elevation of 156.2 m.

2.5. Independent Flow Modelling

Independent flow modelling, using HEC-HMS, was attempted for this design project. Snow melt is believed to be responsible for the largest flows in the watershed and would therefore govern design estimates. Due to a lack of data from the nearest weather reporting stations, modelling of this type was not possible. In order to support and confirm these design considerations, it is recommended that in-situ measurements are made during high flows and that improvement of the reporting of snow pack conditions be examined.

3. CULVERT DESIGN

3.1. Introduction

Section 3 of this report outlines the culvert design process used for the proposed design. The Ministry of Transportation of Ontario (MTO) Gravity Pipe Design Guidelines were followed for the complete design process of the culverts selected. These were supplemented by the use of Ontario Provincial Standard Drawings (OPSDs), design guides from the Corrugate Steel Pipe Institute (CSPI) and Province of Québec design guides. Table 4, at the end of this section, summarizes characteristics of selected CSP culverts.

3.2. Culvert Requirements

The culverts to be used for this project were selected to meet the client's design requirements. Culverts used must provide a total flow capacity of 30.71 m^3/s or greater flow, match the natural slope of the waterway and exceed both the cross design service life (DSL) of 10 years and MTO requirement for estimate mean service life (EMSL) of 25 years. The MTO EMSL requirement will govern selection of a culvert. The required flow capacity and pipe diameters (to avoid debris blockage) restrict the design to the use of corrugate steel pipe (CSP) or structural plate corrugated steel pipe (SPCSP). Polymer laminated pipes were not considered for this project due to cost. Appendix 5 details the complete design process, including formulae and calculations, for the culvert design.

3.3. Estimate Mean Service Life

The EMSL of the normally galvanized CSP was determined using the California Method. Chart B5 in the MTO Gravity Pipe Design Guidelines provides the most conservative estimate of service life using the California Method. The selected CSP arch-pipe has an EMSL of 89 years. As the EMSL significantly exceeds the DSL requirements, no life cycle cost analysis for the restoration or replacement of the culvert is required.

MTO guidelines provide resistivity ranges for surface water and soil for design purposes. PH ranges for EMSL calculations were determined using Environment Canada charts. Resistivity was calculated using the extremes of the soil ranges (30,000 – 50,000 ohm-cm) and the surface water (5000 ohm-cm), as well as PH intervals of 0.1 for the range of 4.4-7. It has been shown PH as high as 9.5 has minimal effect on the service life of galvanized CSP, however ranges above 7 were not included as they are believed to be unlikely.

Abrasion concerns are not significant, as culvert flows do not approach or exceed 5 m/s. Additionally, the modest slope of the culvert should serve to minimize abrasion. The primary source of abrasion will be debris in the main channel, however the embedment of the culvert base will improve abrasion protection for the base of the culvert.

3.4. Hydraulic Evaluation

MTO specifies the estimation of pipe flow capacity using Manning's equation. Manning's number is provided by the MTO design guidelines and other parameters are obtained from standard design tables. As arch-pipes are formed by bending an equivalent diameter circular pipe to the appropriate shape, the hydraulic radius was determined using the perimeter of the equivalent diameter pipe. To meet the required flow capacity for a 5-year storm, 2 3890 mm (span) by 2690 mm (rise) arch pipes were selected, providing an estimated flow capacity of 32.3 m^3/s. In order to remain in normal CSP ranges, this section requires a thickness of 4.2mm and 125 x 25 mm corrugation profile. Structural plate CSP is undesirable due to significant cost increases associated with a change to this type of component.

Advantages contributing to the selection of the arch-pipe are:

- Greater flow capacity at the full-flow state compared to circular pipes;
- Better debris passage; and,
- Smaller surface exposed to corrosive and abrasive forces during normal or low flows.

3.5. Structural Evaluation

The structural evaluation of the culvert was conducted with several methods. MTO requires simply that a depth of cover, required to provide the structural strength of the CSP conduit, be selected from OPSD 805.020. Additionally, the design team conducted the CSPI structural calculations and it was determined that the conduits have sufficient strength to support the load from the MLC design vehicle considered for this project. The minimum height of fill was determined to be 679mm of granular A compacted to 95% standard proctor density. The crossing design provides 730mm of cover. Structural requirements also specify the edge-to-edge spacing of the conduits, which was determined to be 1.4m. The stress from factored thrust loading on the conduits was determined to be 48.27. The conduits were determined to have an ultimate strength of 176.27 MPa.

Longitudinal seam strength was also considered in the structural evaluation. The total factored thrust load was determined to be 218.23 kN/m. Using a seam joint consistent of 10 mm rivets with a single row, 68 x 13 mm layout, seam strength was determined to be 260.4 kN/m. A double riveted seam would significantly increase the strength of the seam but would be cost ineffective.

3.6. End Treatment

End treatments usually improve hydraulic performance of CSP conduits. CSPI recommends step bevels for all sizes of pipe sections. To provide resistance to hydraulic forces, particularly during periods of rapid change in hydraulic activity within the conduit, a concrete collar is recommended. The collar provides resistance to hydraulic uplift forces, horizontal movement, piping and buckling at the end of the conduit section. For the arch pipe selected, a 0.4 m x 0.6 m concrete collar is recommended with a stepped bevel cut. The cost of cutting the sections, form work and pouring concrete for the collar has been estimated at approximately \$1000 per m^3. The end treatment should be anchored to the fill material using anchor hooks.

Due to time constraints, the project design team was unable to fully design this feature.

3.7. Hydraulic Considerations

Hydraulic forces can cause considerable damage to the culvert group structure, leading to failure. Uplifting forces at the inlet of the culvert, during high flows, result from a variety of hydraulic factors and may be counteracted with structural anchorage at the end of the conduit.

For the collared bevel recommended for this design, hook anchors should be embedded in the slope protection to provide this anchorage and protect against bending.

Hydraulic piping is the other major hydraulic concern for this design. Piping describes the erosion of fill, typically fine material, from the fill along the conduit and typically may occur during high flows, where the conduit group is submerged and hydrostatic pressure is increased. The concrete collar previously mentioned will help resist this effect. Additionally, a 300 mm clay cap will be placed along the fill slope at the ends of the culvert group to prevent water from infiltrating and eroding backfill.

A 2.0 mm thick HDPE geomembrane is recommended to prevent vertical infiltration, from rainfall and seepage, in order to avoid piping and the development of voids along the conduits. These membranes will be anchored to the retaining walls (discussed later in this report) on either side of the conduit group. The lower membrane will have a total area of 431.2 m^2 (15.4 x 28 m). The lower membrane will be 183.4 m^2 (15.4 x 11.9 m). These membranes are expected to cost \$10/m^2. Due to time constraints in the design of this project, price estimates were not obtained and detailed design of the anchoring of the membranes was not possible.

3.8. Culvert Stationing

The culvert group will be stationed on the natural channel's path in order to minimize impact on the area and help prevent changes to the channels path. Note that the stations described herein are based upon the survey data provided by the client, which has been modeled so that the zero point along each survey cross section is located on the north bank. As the channel stations were estimated within the numerical model, they should be confirmed on site before construction begins. The centerline of the conduits will be located at 183.9 m and 189.2 m respectively.

3.9. Retaining Walls

As part of the design, the culvert group is confined by two retaining walls running longitudinally parallel to the conduits. Military vehicles typically impose much higher dynamic loads than those from more common civilian vehicles. As a result, this dynamic loading may displace fill around the culverts, eventually leading to a structural failure within the culvert group as a result of voids developed by this loading. As no design standard was found for the spacing between the culvert edge and the retaining wall, it was assumed that the structural requirements for fill around the culvert should be the same as those applied to groups of multiple culverts. The retaining walls will therefore be placed at a 1.4m edge to edge spacing from the culverts. Note that the retaining wall design is described in section 7.

3.10. Summary of Culvert Design

Two arch-pipe CSP conduits were selected for this design. The pipes will be placed to match the natural channel slope at the crossing site of 1%. Table 4 summarizes the culvert group design. Figures 6-1 and 6-2 in Appendix 6 show the culvert cross-section and layout diagram.

Table 4. Summary of Culvert Group Design Characteristics.

Span (mm)	3890	Rise (mm)	2690
# of conduits	2	End area (m^2)	8.29
Flow per conduit (m^3/s)	16.16	Total flow capacity (m^3/s)	32.32
Conduit length (m)	28	Steel thickness (mm)	4.2
Equivalent diameter (m)	3.3	Corrugation profile (mm)	125 x 25
Cover (mm)	730	Embedment (mm)	270
Spacing (mm)	1400	EMSL (years)	89
Slope	1 %	Ultimate strength (MPa)	176.27

4. CROSSING DESIGN

4.1. Introduction

The design of the floodplain crossing is described in this section. The crossing was designed to provide the minimum structural requirements of the conduit group, meet MTO guidelines and ensure when design flows are exceeded that damage to the conduit group is minimized. The crossing will act as a causeway in most cases, and allow weir flow to occur on the north side when design flows for the conduit group are exceeded. Details of the crossing design and conduit group are shown in Appendix 6.

4.2. Design Vehicle

The design vehicle for this project is a standard military load class (MLC) 30 wheeled vehicle. This vehicle was specified by the client, and is lighter than the CL-625-ONT design vehicle used in other cases. The structural strength of the conduit group is significantly higher than the stress the design vehicle loads impose upon it, so much heavier vehicles should be able to cross without damaging the conduit group, dependent upon axle configuration and loading. However, heavier vehicles were not examined in the analysis and design of this crossing and the operator should perform such analyses before crossing with heavier vehicles. Figure 1 shows the specifications for the MLC 30W design vehicle.

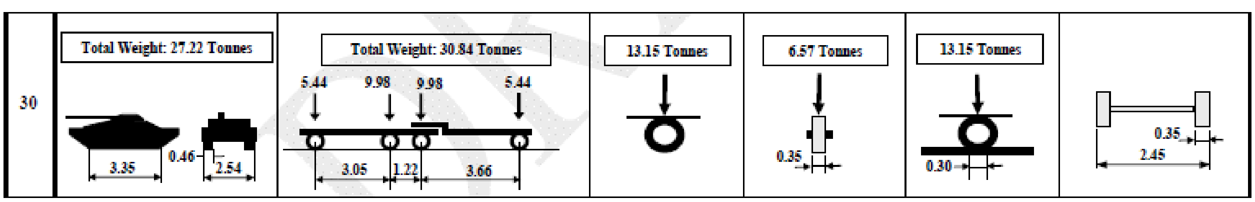

Figure 1. MLC 30W Design Vehicle. (Canadian Military Bridge Manual, Draft Appendix B)

4.3. Crossing Elevation

The crossing elevation was selected to provide sufficient free board for the road surface, structural cover for the conduit group and to allow wash over from a 10-year storm to be directed away from the conduit group. From the south bank of the flood plain, which includes the culvert group, the crossing elevation is 158.3 m for a distance of 81 m. A 3% slope over 67 meters transitions the crossing to an elevation of 156.75 m. This section continues for 114 m where it meets the north bank. The crossing will intersect the in-situ road at both banks. Refer to Appendix 6 for crossing and culvert group drawings, and Appendix 8 for hydraulic modelling of the crossing.

4.4. Road Surface

Vehicles will travel on a road surface running the 250 m length of the crossing. The road surface will be a granular course, composed of granular A material compacted to 95% standard proctor density and adhering to *Ontario Provincial Standard Specification, Material Specification For Aggregates – Base, Subbase, Select Subgrade, and Backfill Material* (OPSS.MUNI 1010).

The road will be 4 m wide in order to safely accommodate the design vehicle and provide clearance in the event of wider loads. Additionally, this road width will permit troops to walk alongside vehicles for inspection, maintenance and training purposes. The road will not have shoulders. Road geometry is based on OPSD 206.010. A crown at the center of the roadway will provide a 2% slope to the edges of the road. The sides of the road and crossing will have a slope of 3H:1V. This slope results in a base width of 26.8 m at the south bank and conduit group and a width of 14.8m at the north bank. Figure 6-3 in Appendix 6 shows the cross-section of the crossing.

4.5. Fill Material

This design assumes granular A material, compacted to 95% standard proctor density and adhering to OPSS.MUNI 1010 will be used for the entire fill of the crossing. As a cost saving measure, the existing crossing and fill have been assumed as granular B, based on the available information at the time of design, and have been included in the design parameters. The granular A specification is **mandatory** for the conduit group fill. The 730 mm cover in the conduit section will continue the length of the full crossing as the road structure and will be granular A. Quality assurance specifications for the fill material require sampling every 5000 tonnes to ensure material quality and consistency.

4.6. Erosion Control

Erosion control measures are an important safeguard to ensure the stability and effectiveness of the crossing. Rip-rap and reinforced concrete abutments were considered for this application. As a result of the length of the span, the abutment option was less economical. Additionally, the complexity of installing form work, arranging reinforcing bars and pouring the concrete would not only increase the construction time, but require labour not readily available from local personnel. Consequently, rip-rap was chosen as the desired erosion control method.

4.7. Riprap Design

Riprap is used on the sides of embankments in order to minimize the amount of erosion done to the embankment surface. The riprap layer was designed in accordance with the Riprap Design and Construction Guide from the Public Safety Section of the Water Management Branch. The selected design standard also meets the requirements of OPSD 801.010. In addition to the considerations for the rip-rap layer, toe protection and the design of a filter layer were required. (These are described later in this section.)

Riprap normally has a density between 2400kg/m^3 and 2800kg/m^3. Many factors play a role in the thickness and slope required for the riprap. A slope of two horizontals to one vertical is the steepest a riprap cover should be. The steepness of the slope is reduced further if there is ice or debris that is typically present. A slope of three horizontals to one vertical was selected due to the frequent presence of debris in the creek flow.

The required thickness and nominal stone size was determined using a table from the Riprap Design and Construction Guide and some other considerations:

The thickness cannot be less than 350mm or more than 1.5 times the nominal stone size.

The required thickness was calculated to be 600mm thick with a nominal stone size of 400mm. Riprap must also be machine placed if nominal rock dimension is greater than 350mm.

The following table was used to determine the nominal stone size. A velocity of 3.5m/s was used.

Stone Sizes For Scour And Erosion Protection – Low Volume Roads							
Velocity (m/s)	< 2.0	< 2.6	< 3.0	< 3.5	< 4.0	< 4.7	< 5.2
Nominal Stone Size[1] (mm)	100	200	300	400	500	800	1000
Notes 1) Maximum stone size to be 1.5 times the nominal stone size. 80% of stones (by mass) must have a diameter of at least 60% of nominal stone size.							

Figure 2. Nominal Stone Size for Low Volume Roads (Water Management Branch, Canada, 2000).

4.8. Toe Protection

A rock-filled toe trench will be used to prevent toe scour. Toe scour is erosion that occurs at the base of the embankment. It is important that the base of the embankment does not get eroded otherwise the embankment or culvert group may fail, dependent upon the location and nature of the erosion.

4.9. Filter Design

The filter lay was designed in accordance with the Riprap Design and Construction Guide from the Public Safety Section of the Water Management Branch. Water that passes through the riprap has the potential to wash away fine particles of soil over time. The filter layer is used to prevent fine particles from being washed away by erosion. The Ministry of Environment, Lands, and Parks recommends that crushed rock or gravel be used. Appendix 7 describes the filter layer design.

4.10. Cut and Fill

Cut and fill for this design was determined to be 5600 m^3 of granular A material. This assumes the existing crossing and fill material will be used wherever possible to reduce cost materials. Rip rap material requires a fill volume of approximately 1300 m^3 and he filter material requires a fill volume of 430 m^3. Additionally, the clap cap layer, which is restricted only to the culvert group, requires a fill volume of 40m^3.

5. HYDRAULIC MODELLING

5.1. Introduction

The crossing was modelled using the United States Army Corps of Engineers Hydrologic Engineering Center (HEC) River Analysis System (RAS). HEC-RAS models the floodplain from surveyed cross sections (provided to the design team by MCE) and the crossing using input design data. This software is routinely used throughout North America for this type of application. For this project, modelling in HEC-RAS was used to help guide and confirm design decisions. Appendix 7 summarizes the HEC-RAS results for this design and includes visual representations of the crossing for the 5 and 10-year flood stages.

5.2. Crossing Elevations

The 5 and 10-year flood flows were modelled in HEC-RAS to determine initial estimates of crossing height and ensure that when the flood stage becomes excessive weir action would occur in the region of the crossing intentionally designed for this use. Iteration was then used to refine the elevations.

5.3. Conduit Conveyance

Using HEC-RAS, the capacity of the conduit group when in full flow was also confirmed. The model shows the conduit group having a capacity slightly higher than expected, with 32.6 m^3/s in full flow at the 10-year flood stage. The model also allowed determination of the controlling flow state. In both cases (5 and 10-year floods) the conduit group is in a state of outlet control when including the effects of backwater conditions.

5.4. 5-year Flood Flow

The 5-year flood flow for this watershed is 30.7 m^3/s. During this flow, the crossing is subject to minimal submersion and there is a change of 0.19 m in elevation of the water surface in the culverts. The results for the modelling of the 5-year flood are show in figure 2. Further information is shown in Appendix 8.

Q Culv Group (m3/s)	30.70	Culv Full Len (m)	
# Barrels	2	Culv Vel US (m/s)	3.51
Q Barrel (m3/s)	15.35	Culv Vel DS (m/s)	3.27
E.G. US. (m)	157.47	Culv Inv El Up (m)	154.90
W.S. US. (m)	157.36	Culv Inv El Dn (m)	154.62
E.G. DS (m)	156.29	Culv Frctn Ls (m)	0.27
W.S. DS (m)	156.09	Culv Exit Loss (m)	0.35
Delta EG (m)	1.18	Culv Entr Loss (m)	0.56
Delta WS (m)	1.27	Q Weir (m3/s)	
E.G. IC (m)	156.96	Weir Sta Lft (m)	
E.G. OC (m)	157.47	Weir Sta Rgt (m)	
Culvert Control	Outlet	Weir Submerg	
Culv WS Inlet (m)	156.28	Weir Max Depth (m)	
Culv WS Outlet (m)	156.09	Weir Avg Depth (m)	
Culv Nml Depth (m)	1.37	Weir Flow Area (m2)	
Culv Crt Depth (m)	1.38	Min El Weir Flow (m)	157.57

Errors, Warnings and Notes	
Note:	During supercritical analysis, the culvert direct step method went to normal depth. The program then assumed normal depth at the outlet.
Note:	During the supercritical calculations a hydraulic jump occurred inside of the culvert.

Figure 3. 5-year flood modelling results.

5.5. 10-year Flood Flow

The 10-year flood flow for this watershed is 38.2 m^3/s. The conduit group is fully submerged during this flood stage and weir action occurs on the north side of the crossing along the section with the lower elevation. This action is intended. Figure 3 shows the detailed results of this model, and visual representations are included in the appendix.

Q Culv Group (m3/s)	32.64	Culv Full Len (m)	
# Barrels	2	Culv Vel US (m/s)	3.58
Q Barrel (m3/s)	16.32	Culv Vel DS (m/s)	3.60
E.G. US. (m)	157.57	Culv Inv El Up (m)	154.90
W.S. US. (m)	157.57	Culv Inv El Dn (m)	154.62
E.G. DS (m)	156.35	Culv Frctn Ls (m)	0.28
W.S. DS (m)	156.01	Culv Exit Loss (m)	0.36
Delta EG (m)	1.23	Culv Entr Loss (m)	0.59
Delta WS (m)	1.57	Q Weir (m3/s)	111.71
E.G. IC (m)	157.05	Weir Sta Lft (m)	16.87
E.G. OC (m)	157.57	Weir Sta Rgt (m)	150.05
Culvert Control	Outlet	Weir Submerg	0.00
Culv WS Inlet (m)	156.33	Weir Max Depth (m)	0.82
Culv WS Outlet (m)	156.04	Weir Avg Depth (m)	0.70
Culv Nml Depth (m)	1.42	Weir Flow Area (m2)	92.66
Culv Crt Depth (m)	1.43	Min El Weir Flow (m)	157.57

Errors, Warnings and Notes	
Warning:	During the culvert outlet control computations, the program could not balance the culvert/weir flow. The reported outlet energy grade answer may not be valid.
Note:	During supercritical analysis, the culvert direct step method went to normal depth. The program then assumed normal depth at the outlet.
Note:	The flow in the culvert is entirely supercritical.

Figure 4. 10-year flood flow modelling results.

5.6. Errors and Limitations

The factors of error for this model and the design are difficult to estimate as data from a variety sources, and within the numerical models used by HEC-RAS, compound each other. The ability to predict expected flows based on historical observations is increasingly erroneous as a result of climate change and the increased frequency of extreme weather events in recent years.

Additionally, HEC-RAS assumes linearized cross-sections for the modelled river systems and calculates only 1-dimensional flow. The resolution level of survey data available to the design team at the time of the project was limited, resulting in a probable increase in error in the numerical modelling of the design. While 1-dimensional flow analysis can approximate the system being modeled for practical purposes, this results in a limitation in the accuracy of the model. As a result of the uncertainty of these errors and their compounding effects, the total accuracy of the design and numerical model has not been determined.

6. ENVIRONMENTAL CONSIDERATIONS

6.1. Introduction

Environmental considerations were required during the design of the creek crossing. As it is located in a flood plain, there is potential for significant impacts on local fauna, the watercourse and sensitive species in the area. This section details these considerations

6.2. Species Present

There are two species present in the main river which may use the creek as a spawning site. Consequently, they are considered sensitive aquatic species for the potential impacts of this project. The species of concern are the Brook Trout and Northern Pike.

It is important to note that a proper assessment is recommended to determine the presence (or lack thereof) of these species. At the time of this design project, no confirmation of their presence or use of the creek as a spawning bed was available.

6.3. Swimming Velocity for Sensitive Aquatic Species

The Brook Trout and Northern Pike both have different swimming velocities. The Brook Trout is the weaker swimmer of the two species, since the Northern Pike is a predatory fish, it is able to swim at higher velocities for limited periods of time. Belford and Gould (1989) reported that brook trout could swim distance of 30 metres against bottom water velocities up to 80.0 cm/s. No information of swimming endurance of northern pike could be located; however, maximum swimming capacity appears to be at least 174 cm/s. Figure 5 shows the burst velocities of the Northern Pike.

Speed (cm/s)	Length (cm)	Temp. (°C)	Reference
174.0	20.7	15.0	Webb (1978a)
529.0	35.8	15.0	Harper & Blake (1990)
415.0	35.8	15.0	Harper & Blake (1990)
429.0	35.8	15.0	Harper & Blake (1990)
280.0	39.6	8.0	Frith & Blake (1995)

Figure 5. Burst velocities of the Northern Pike (Oceans and Habitat Management Branch, Canada, 2008).

6.4. Spawning Seasons

The spawning seasons of the two fish species vary region by region. For the Southern Region of Ontario, the spawning seasons of the Brook Trout and Northern Pike are October 1st to May 31st, and March 15th to May 31st respectively. Construction time is limited to the period of time between June 1st and September 30th, in order to avoid interference with these spawning seasons.

6.5. Fish Wait Time

Fish will wait up to three days if conveyance is not possible. When flows at peak flood stages are too high to allow for fish passage, fish will wait up to three days for the flow to slow to a rate at which they can pass. Therefore, the flow should not be greater than the maximum allowable flow rate for fish passage for a period of time exceeding three days.

6.6. Department of Fisheries and Oceans Development Proposal Review

The development proposal review and decision-making process is a process that is used to decide if the project requires authorization. Below are the factors taken into consideration.

- Are there potential impacts to fish or fish habitat that are part of or support a commercial, recreational and Aboriginal fishery?
- Will impacts be avoided or mitigated?
- Will impacts result in *serious harm to fish?*

The Department interprets *serious harm to fish* as:

- the **death of fish**;
- a **permanent alteration** to fish habitat of a spatial scale, duration or intensity that limits or diminishes the ability of fish to use such habitats as spawning grounds, or as nursery, rearing, or food supply areas, or as a migration corridor, or any other area in order to carry out one or more of their life processes;
- the **destruction of fish habitat** of a spatial scale, duration, or intensity that fish can no longer rely upon such habitats for use as spawning grounds, or as nursery, rearing, or food supply areas, or as a migration corridor, or any other area in order to carry out one or more of their life processes.

The creek is not used by any fisheries, nor for recreational fishing. The impacts to the fish are avoided by planning construction outside of their spawning season. No fish should be seriously injured during the construction of the culvert or during its extended use.

6.7. Channel Alteration

The introduction of this crossing design has the potential to alter the natural course of the stream. Alterations to the natural course of the stream may result in changes to its depth and velocity and may subsequently impact the local ecosystem as a result. In order to minimize the probability of altering the channel's course, the conduits have been placed directly on the main channel of the creek. On site confirmation at the time of construction is required.

6.8. Standing Pools and Blockages

As the crossing is located in the flood plain of the creek, standing pools are not uncommon as water levels recede. During the flood stage, the presence of the crossing may result in the development of standing pools on the upstream side; these pools already develop as a result of the existing crossing. The new crossing should not significantly impact the presence of standing pools.

Blockages of the conduits may, however, cause problems. In addition to the creation, or extension of the life of standing pools in the flood plain, they may result in damage to the crossing. There are two primary sources of blockages the design team has considered:

- Debris; and,
- Beaver activity.

Debris build up was a problem with the previous crossing design. Due to the nature of the floodplain and area where the crossing is located, using boulders or other physical blocking mechanisms upstream of the inlet was considered impractical and uneconomical. The use of the arch-pipe shape for the conduits should significantly reduce debris caught by the inlet and minimize this concern, though the site should be inspected from time to time to ensure no blockage issues arise.

Beaver activity is known to occur in the area. If a beaver dam is built at the inlet of the conduits, water levels may rise sufficiently to cause the north portion of the crossing to experience wash over during events much smaller than the 10-year design intention, resulting in damage and increased maintenance. Beaver dams should be avoided by inspection of the site, and when required, removal of any apparent damming.

7. GEOTECHNICAL CONSIDERATIONS

7.1. Introduction

In order to ensure stability and safety of the crossing design, several geotechnical considerations needed to be examined. Ensuring that the crossing, retaining walls and in-situ soil will not experience any of several modes of failure was a significant factor in this design. This section details those considerations and the determined factors of safety. Sample calculations are shown in Appendix 8.

7.2. Estimation of In-Situ Soil Strata

Accurate information on the in-situ soil strata at the project site was not available to the design team and procuring boreholes was not possible. Consequently, the team estimated the strata at the site for design purposes. The strata were estimated using a project proposal for a temporary modular bridge at a nearby site. Using the borehole logs from that report and the elevation at the project site, as well as information provided by the client, the design strata shown in Table 5 was determined.

Table 5. Estimated soil strata at project site.

Sandy Silt	1 m
Sandy Gravel	3 m
Impermeable bedrock	

7.3. Retaining Wall Design

The retaining walls confining the culvert group were designed to resist movement from forces within the culvert group and from the crossing fill outside it. The dimensions of the retaining wall are detailed in table 6 and the design is shown in figure 6.

Dimensions		
Height of wall	2.8	m
Width of wall	0.5	m
Length of heel	0.8	m
Height of heel	0.25	m
Length of toe	0.4	m
Height of toe	0.25	m
Soil height above wall	1	m

Table 6. Dimensions of retaining wall design.

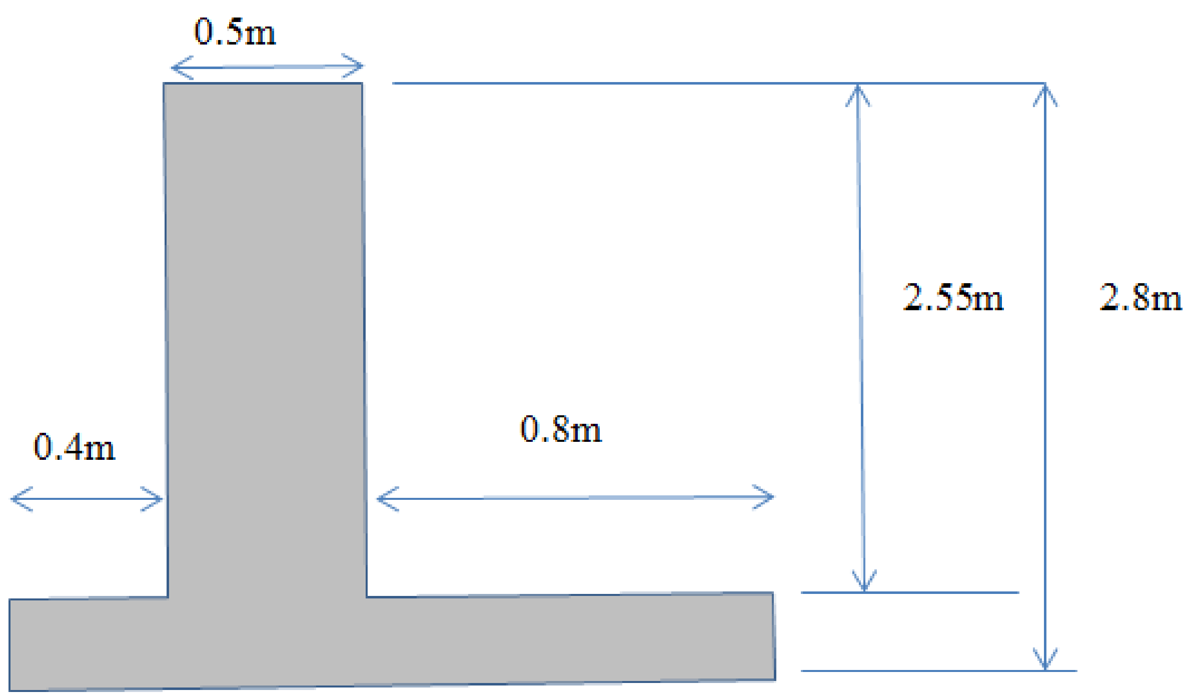

Figure 6. Retaining wall design.

Reinforcement for the retaining wall was not designed or detailed due to time constraints.

7.4. Modes of Failure Considered

Modes of failure for the project had to be considered for both the crossing itself and the retaining walls within the conduit group. Bearing capacity, slope stability and hydrostatic uplift were examined for the crossing. For the retaining walls, bearing capacity, sliding and overturning were examined.

7.5. Geotechnical Data Used

Soil geotechnical data such as unit weights, friction angles, etc., were obtained from a geotechnical borehole log report from a nearby area in Ontario. The accuracy of these numbers were confirmed from soil density databases online.

7.6. Factors of Safety for Crossing

Equations for the factor of safety of the embankment against Bearing capacity and Hydrostatic uplift were taken from the Recommended Design Guideline for EPS Embankments by the National Cooperative Highway Research Program (NCHRP). Although for Geo-foam embankments, the equations are the same since they are based upon material weights and geometries of the embankment. Since the minimum recommended design Factor of Safety for embankments is 2.5, the chosen design was aimed towards having a Factor of Safety of 3.0.

The factor of safety for bearing capacity was found to be significantly greater than 3 and the loading of the embankment was found out to be approximately 42 kPa. The allowable loading was in excess of a 100 kPa.

The Factor of safety for slope stability was calculated using charts developed by Dr. Bathurst and Mr. Sina Javankhoshdel. Since Granular soils have minimal cohesion, a value of zero was assumed. The angle of the slope for 3:1 (H:V) slope, β was calculated to be 18.43°. With a friction angle of 35 degrees for the granular A type soil, a Factor of safety was determined to be 1.84, which was higher than the minimum required 1.5.

For a conservative estimation of the factor of safety against hydrostatic uplift, the height of the water was taken to be at the very edge of the road, which surpasses the 10-year design life of the embankment. In addition, the concrete collars were not considered. The concrete collars add further mass to the embankment, thereby increasing the factor of safety. The FoS against floatation or hydrostatic uplift was found to be 1.35 which is higher than the minimum required factor of safety of 1.2 (NCHRP, 2004). Figure 6 illustrates hydrostatic uplift forces.

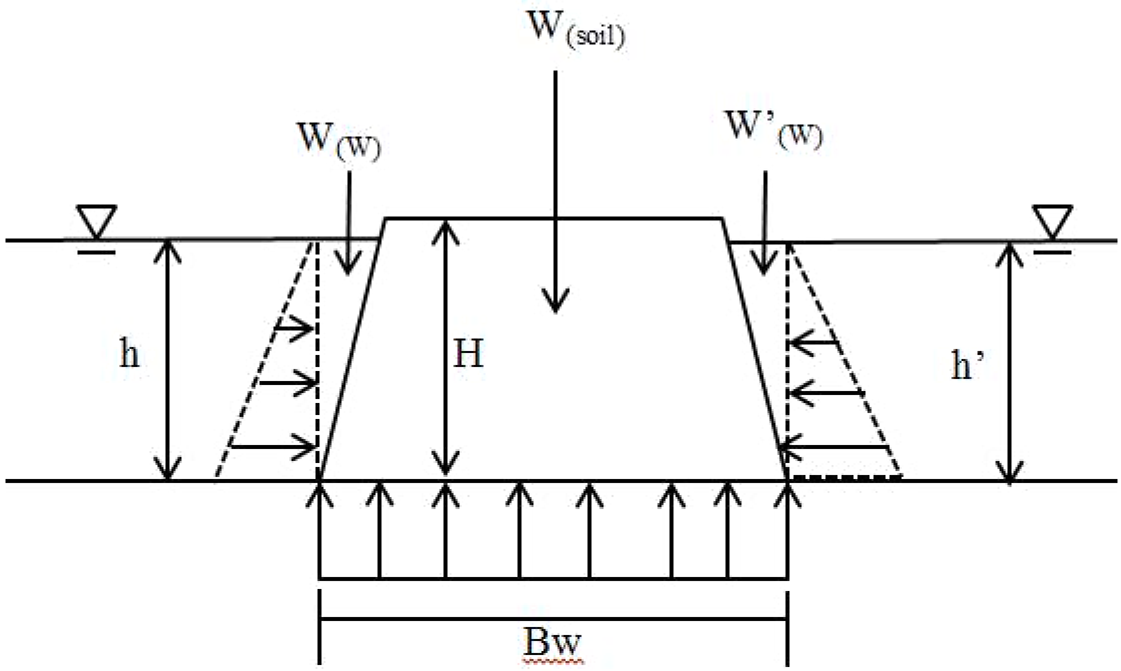

Figure 7. Diagram of hydrostatic uplift forces.

7.7. Factors of Safety for Retaining Walls

Bearing capacity failure, sliding failure and overturning were examined for the retaining walls. The factor of safety requirement against sliding is typically 1.5 and is determined by the driving forces. In this case, the driving forces are the forces that translate the retaining wall on either side of the culvert to the outer extremities. The resisting forces were determined to be 354 kN while the driving forces were determined to be 230 kN, providing a factor of safety against sliding of 1.55. The factor of safety of overturning uses moments resulting from driving forces. The minimum factor of safety against overturning is 2.0 and the factor of safety of the design was determined to be 2.1. Bearing capacity factor of safety in a cohesive soil environment is required to be greater than 2.5 and was determined to be 4.5 for the retaining walls.

7.8. Summary of Evaluated Factors of Safety

The factors of safety determined for the crossing and the retaining walls are shown in tables 6 and 7.

Factor of Safety requirement	Minimum by guideline	Embankment design FoS
Bearing Capacity	2.5	>>3
Sliding (Slope Stability)	1.5	1.84
Hydrostatic uplift	1.2	1.35

Table 7. Summary of factors of safety for crossing design.

FoS Condition	Minimum FoS	Design FoS
Bearing Capacity	2.5	4.5
Overturning	2.0	2.1
Sliding	1.5	1.55

Table 8. Summary of factors of safety for retaining wall design.

8. COST ESTIMATE

8.1. Introduction

Cost estimates were conducted for both the existing crossing and this design. Cost estimates were then compared to determine the feasibility of this project. A detail cost estimate is provided in Appendix 9.

8.2. Existing Crossing

The cost of the existing crossing, over the 10-year design period, was evaluated for comparison to the construction cost of this design. It is important to note that the cost of the existing crossing may be significantly higher than the estimates provided herein, as little information was available on the real costs. The costs used were estimated by the design team assuming the dimensions, fill material, required equipment and costs of labour. (Dimension estimates were provided by the client.) The final estimate for the cost of the existing crossing is a present value of $800,000.

8.3. New Crossing Design

The new crossing design cost was estimated using RSMeans 2012. Appropriate contingencies and location factors were included in the analysis. The cost of labour is likely higher than the estimate costs, as it was not made clear to the design team the cost of, or quantity of labour which would be performed by existing personnel, nor the type and volume of fill material available on the base itself. The new crossing design is estimated to cost $790,000.

It should be noted that this cost estimate assumes the fill for the existing crossing will be used wherever possible. This results in significant cost savings. The majority of materials will be transported from a local contractor, located an estimated 32 km from the project site. The cost estimates provided include transportation costs and utilize estimate quotes from ES Hubbell for the cost of culverts, provided on 17 Nov 2015.

8.4. Cost Savings

Cost savings for this design is therefore determined to be approximately $10,000 over the 10-year design return period. The actual savings are likely much higher, as intermittent maintenance costs will be lower with this design and it is probable that the cost estimate of the existing design is significantly undervalued. Furthermore, the probability of the design event occurring during the 10-year design period is only 65%. This event should only require partial repair of the road surface on the north side of the crossing. If the 10-year flood event does not occur for a longer period of time, cost savings are only increased with this design.

If the client wishes to further reduce costs, removal of the geomembranes around the culvert group may be considered, as the water levels a the 10-year flood stage should be similar on each side of the crossing, resulting in minimal seepage. Removal of the retaining wall confinement is not recommended due to the increased potential for failure of the crossing.

8.5. Recommendations

Based on the analysis of the existing crossing and the new design described herein, the design team believes this project to be a viable improvement to the creek crossing. However, a detailed cost analysis of the existing crossing and investigation of the other items noted within this report should be conducted before a final recommendation can be made.

9. CONSTRUCTION PROCESS

9.1. Introduction

The considerations required during construction the crossing is described briefly in this section. As a result of the significant number of considerations required and time constraints imposed upon the design team, a complete construction plan is not provided.

9.2. Coffer Dams

Coffer dams must be established for construction purposes, in order to “work in the dry”. Hydraulic activity can significantly complicate any construction activities. A coffer dam is a barrier established around the construction site to block water flow. A pump is then used to move the water around the dammed area to the next section of the natural channel.

A coffer dam should be established around the construction site. The feasibility of a single dam versus two, working inwards, has not been evaluated and should be considered. The significant span of the crossing may result in a single coffer dam being both impractical and uneconomical.

The pumps used for the coffer dam should be able to accommodate the flows of the creek. Mean annual flow is approximately 1.2 m^3/s. The pumps provided should be able to displace this flow plus a reasonable volume of run off. Pumps should not be located more than 20 meters from the main channel.

9.3. Fill Lifts & Compaction

As described previously in this report, the design criteria for this crossing calls for compaction to 95% standard proctor density. The fill should be placed and compacted in lifts of 200mm until the appropriate grade is achieved.

Following excavation of the site to be occupied by the culvert and retaining wall group, a layer of 0.5m granular a, compacted to 95% standard proctor density must be placed. This layer should be shaped to the form of the base of the arch-pipes to be placed. Fill around the base of the arch-pipes, in particular the corners, should be placed by shovel and compacted by hand. Care must be taken to prevent voids and soft spots from occurring around the haunches of the pipes as they may allow for the development of a structural failure. Lifts around the conduits should again be 200mm, however it is also important to ensure that the difference in fill on either side of the arch-pipe does not exceed a single lift in height. No vehicle should be permitted to pass over or near the conduit group until the crossing has been built up to its specified height and adequately compacted.

9.4. Placement of Conduits

The placement of the conduits should occur before placement of fill, but not until the reinforced concrete for the retaining walls has adequately hardened. While the CSP arch-pipe is fairly robust and designed to be resistant to rough handling, care should be taken during unloading and placement to ensure no damage occurs and the placement is correct.

Once placed, the formwork for the end treatments should be constructed and the concrete poured. These should also be allowed to harden adequately before the placement of the fill material.

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APPENDIX No. 1: Statement of Requirements

Client

Redacted at the client's request.

Introduction

This statement of requirements is proposed as the guidelines for a potential project to design a replacement for the creek crossing. The proposed design for the crossing should reduce damage and washout caused by annual flooding or significant runoff events at the creek crossing.

Project Background

The creek crossing is a causeway type crossing in southeastern Ontario. It has been subjected to significant damage on a near annual basis as a result of flooding and large runoff events, placing a high demand on maintenance resources and requiring frequent remediation.

No official design records exist for the creek crossing and there are no detailed records of past failures or remediation performed at this site. The site allows alternate access to several live weapon ranges and has on occasion been used as an egress route for vehicles and troops. While it sees relatively low traffic load, vehicles using the site have been identified up to Military Load Class (MLC) 30 and include Light Armored Vehicles (LAVs), Buffalos, various heavy equipment and HWW tractor trailers.

The site is located in a relatively undisturbed area of wilderness in southerneastern Ontario. The surrounding area is mostly comprised of forest with a few roads use for operational purposes. Materials used in the construction and maintenance of the site have typically been available locally and were likely extracted from locations in the area.

Objectives & Constraints

Objectives

The primary objective of this project is to design a replacement crossing for this location to allow land vehicles to pass the creek. Specific objectives are as follows:

a. Use modelling to determine the high water level and minimum conveyance requirement at the creek.
b. Design the conveyance channel:
   i) To provide sufficient conveyance to eliminate flood damage.
   ii) To minimize impact on the environment, such as local wildlife and sensitive species.
c. Design the crossing:
   i) To resist erosion and minimize maintenance requirements.
   ii) To accommodate a single traffic lane, year round.

Constraints

a. Design the conveyance channel:
   i) To provide a minimum conveyance determined from modelling.
   ii) To permit passage of local aquatic species.
   iii) Without significant diversion of natural stream flow.
b. Design the crossing:
   i) Utilizing local and provincial codes as guidelines.
   ii) To exceed the high water level modelled by at least 1m.
   iii) To use local materials whenever possible.
   iv) To accommodate an MLC 30 design vehicle.

Design Criteria

The crossing should meet requirements for a MLC 30 vehicle load. Standard practice in the area is to cross one vehicle at a time; therefore, the crossing should accommodate 1 lane of traffic. Provincial and local codes are to be used as guidelines wherever possible in the design process.

Constraints

The client has identified that the continued access to live ranges through the gate, accessed by the creek crossing, is an operational imperative. The crossing must not be relocated. The project must minimize impact on the local ecosystem and allow passage for local fish which may use the creek as a spawning area, specifically the Brook Trout. The design should place the road surface on the crossing above the high water level of the flood plane. The design should be as cost effective as possible and require minimal maintenance.

Deliverables

The deliverable for this project will be a formal engineering report. It will consider the hydrological characteristics of the area, impacts on sensitive species, and environmental effects. The report will include design specifications for a replacement crossing, along with the accompanying drawings of bridges and roads. Hydrological modelling will also be included, along with minimal conveyance requirements and expected return periods for the design. Throughout the design process, the team will also provide two design presentations, a project poster presentation and each presentation will be accompanied by an interim report detailing the progress of the project.

APPENDIX No. 2: Environmental Assessment Screening

DND EA REPORT

PART I PROJECT IDENTIFICATION

Note: This part must be submitted to the Base/Wing Environmental Officer for registration on the Canadian Environmental Assessment Registry within 14 days of the commencement of the environmental assessment.

Project Title: CREEK CROSSING

Description of the project: *At the crossing annual snowmelt, backwater flow from the main river and flow from the creek causes stress on existing infrastructure, damaging the crossing as the culverts placed are not sufficient to accommodate flow.*

The aim of project is to redesign the crossing to accommodate the flow at the crossing. Arch pipe culverts were used with addition of rip-rap slopes and measures such as fish baffles to let fish passage.

Project schedule: *May 2016 - October 2016*

Project Location: *REDACTED*

Originating Directorate, Base, or Unit: N/A

EA Start Date: January 2016

Type of Project:

a) Physical work Yes [X] No [ ]
b) Physical Activity Yes [X] (Part VII: 43, 45, 46, Part VIII: 48.1) No [ ]

EA "Trigger":

a) Proponent Yes [X] No [ ]
b) Funding Yes [ ] No [X]
c) Land Yes [ ] No [X]
d) Permit Yes [X] No [ ]

OPI's EA/project File reference #: **CEA Registry # :** (provided through NDHQ/DGE after registration)
Other Responsible Federal authorities: Fisheries Act (Ministry of Fisheries and Oceans)

Federal Environmental Assessment Coordinator:
Contacts: **FEAC Point of Contact:** The principle initial point of contact between DND and the public on environmental concerns relating to the EA, the EA report and follow-up. **Project OPI/principle point of contact:** The person who is responsible for ensuring that the environmental assessment is conducted for the project. a) Phil Lamarche, Dr, and Professor b) Sawyer Building, RMCC Kingston c) Phillipe.lamarche@rmc.ca
Public Notification: Due to the time constraint of the project there were no requests for public input on the project, excluding 3 design review boards consisting of civilian engineers and professors with expertise on the subject.

PART II ASSESSMENT OF EFFECTS AND CONCLUSIONS

Note: This part must be submitted to the Base/Wing Environmental Officer for registration on the Canadian Environmental Assessment Registry.

Assessment of environmental effects

The detailed assessment of environmental effects and supporting documentation is at Annex A (with additional annexes or enclosures as necessary)

Executive Summary

After a detailed EA conducted by local personnel, sufficient data must be available to know if the project is carry on. An inspection of proposed design is recommended every two years for erosion control. Inspection of site is also recommended to assess flow pattern and impact of infrastructure on fish species due to flow rates.

EA Determination

On the basis of this EA Report, it has been determined that the impact of this project on the environment is as follows (indicate with an X):

- The project is likely to cause significant adverse environmental effects. The project **cannot** proceed without a detailed environmental assessment and data collection by the client [X]

Follow-up

Is a follow up or monitoring program required? Yes [x] No [ ]

After a detailed EA conducted by the client, sufficient data must be available to know if the project is carry on. An inspection of proposed design is recommended every two years for erosion control. Inspection of site is also recommended to assess flow pattern and impact of infrastructure on fish species due to flow rates.

PART III RECOMMENDATIONS AND SIGN-OFF

EA Report prepared by:

NCdt Aithal – Group 3 with OCdt Savage, OCdt Conrad (07/04/2016)

Signature block, signature, and date

EA Report reviewed by (with recommendation by NDHQ, Formation or Base/Wing Environmental Specialist Staff if applicable)

Signature block, signature, and date

EA Report accepted and approved by

The undersigned accepts the determination and recommendations of this environmental screening report.

Signature block, signature, and date of the DND/CF decision-making authority for the project

ANNEX A ASSESSMENT OF ENVIRONMENTAL EFFECTS

Project Description and Scope

a. **General Description of the project**: New culverts are proposed to be added at the crossing in addition to increasing the slope of the embankment from a 1:1 (H:V) to a 3:1(H:V) embankment. The proposed design is meant for a 10-year design period.

b. **Project components, scope, and timeframe**: Major considerations in design are the impact of placement of culverts on stream flow, size of culverts on flow rates, which in turn impact the spawning period of the fish species native to creek area. The proposed construction time frame from May to October 2016 is deliberately chosen to avoid the spawning period of the fish species.

Description of the existing environment

a. **Sources of information, including site visits**: Site visits were never done due to time constraints, budget. The client has requested to remediate the problem. Existing flow data was given from client. Environmental details on fish species effected were found on online databases

b. **General description:** The area of the flood basin was considered was above 12000 ha, feeding water to the main river. Backflow was a consideration during the assessment of flow rates. A Moin-Shaw regression was used to estimate the flow rates in the existing infrastructure and matched with an approximation using the rational method. Peak flow rates due to snow melt and run-off affect fish species and erosion control in the area with existing infrastructure, leading to a destruction of the existing embankment every year.

c. **Valued Ecosystem Components:** Existing flora surrounding the embankment area will need to be modified during the construction process due to excavation, utilising compaction equipment as well as establishing of a coffer-dam to minimize flooding of construction area. Disruption of flow during the construction process will have an impact on the fish species as well as vegetation in the area.

Consultation

a. **Consultation within DND**:

b. **Consultation with the Public:**

c. **Consultation with other Dept.'s, agencies or jurisdictions:** Throughout the process of the design professors from the Department of Civil Engineering at the Royal Military College of Canada were consulted for guidance. The proposed embankment design was evaluated in three design review boards.

Environmental Effects

Environmental effects are detailed in the matrix below. Major environmental impacts are

- Fill material pile
- Excavation of existing culverts
- Compaction of soil (noise, dust)

- Clearing of area for cofferdam
- Change in stream flow during construction

ENVIRONMENTAL EFFECTS MATRIX

PROJECT COMPONENT Enter each component e.g. phases of construction, aspects of operation.	VALUED ECOSYSTEM COMPONENTS Add to/delete from matrix below as necessary) Show potential effects with an "X"																		
	PHYSICAL							BIOLOGICAL						SOCIAL						
	Atmosphere	Surface Water	Ground Water	Soils	Terrain	Ambient Noise		Terrestrial Animals	Terrestrial Habitat	Aquatic Animals	Aquatic Habitat	Vegetation		Heritage/Historical	Recreation/Aesthetic	People/Health	Economy	Services	Land Use	
Survey	-	-	-	-	-	-		-	-	-	-	-		-	-	-	-	-	-	
Removal of existing culverts at 8H	X	X	-	-	-	X		-	-	X	X	-		-	-	-	-	-	-	
Installation of Arch pipe on site	-	-	-	-	-	X		-	-	X	X	X		-	X	-	-	-	-	
Hauling in Gran-A fill material/Rip-wrap	-	-	-	X	-	X		-	-	-	X	-		-	-	-	X	X	-	
Expansion of fill material	X	-	-	X	X	X		-	-	-	X	X		-	X	-	-	-	X	
Compaction of fill material	X	-	-	X	X	X		-	-	-	-	-		-	-	-	X	-	-	
Addition of Rip-wrap	-		-	X	X	X		-	-	-	-	X		-	-	-	X	X	-	

Follow-up program

Follow-up program required for the project Yes [x] No [ ]

If yes, provide details of the program.

Conclusions

The area of the flood basin was considered was above 12000 ha, feeding water to the main river. Peak flow rates due to snow melt and run-off affect fish species and erosion control in the area with existing infrastructure, leading to a destruction of the existing embankment every year.

New culverts are proposed to be added at the crossing in addition to increasing the slope of the embankment from a 1:1 (H:V) to a 3:1(H:V) embankment. The proposed design is meant for a 10-year design period.

After a detailed EA conducted by the client, sufficient data must be available to know if the project is carry on. An inspection of proposed design is recommended every two years for erosion control. Inspection of site is also recommended to assess flow pattern and impact of infrastructure on fish species due to flow rates.

APPENDIX No. 3: Watershed Details

Appendix redacted for CSPI Student Paper contest submission at request of the client.

APPENDIX No. 4: Flood Flow Assessments

Figure 4-1. IDF curve redacted for CSPI Student Paper contest submission at request of client..

$$t = \frac{G(1.1 - c)L^{0.5}}{(100S)^{\frac{1}{3}}}$$

Equation 4-1. FAA Rational Equation, where:

c: Runoff coefficient

S: Watercourse slope

L: Longest flow length

t: Time of concentration

G: FAA constant, G=1.8

Time of concentration:		
G	1.8	m/s2
c	0.1	
L	62273	m
S	0.0032	m/m
t =	**656.71**	**min**

Table 4-1. Time of concentration.

$$Q = 0.00278CIA$$

Equation 4-2. Rational method, where:

A: Area, in hectares

I: Intensity, mm/hr

C: Runoff coefficient

Area: 12467.8 hectares

C range: 0.1-0.3

C used: 0.2

Flood stage (years)	IDF Flow (m^3/s)	Moin-Shaw Multiple Regression (m^3/s)	Moin & Shaw 85 Index Flood with Expected Probability Adjustment (m^3/s)	IDF Intensity (mm/h)
2	31.2	20.1	22.1	4.5
5	34.7	**30.7**	27.3	5
10	41.6	**38.2**	31.7	6
20	47.1	46.1	36.9	6.8
50	55.5	54.4	43.9	8
100	62.4	62.3	49.4	9

Table 4-2. Flood flows for creek watershed.

APPENDIX No. 5: Culvert Design

Culvert Design Steps & Calculations

As described by MTO Gravity Pipe Design Guidelines (May, 2007)

Step 1 - Project Description

Use at least 1 culvert on main channel.

Main channel must have at least 1 pipe which allows fish passage by limiting velocity to:

0.8 m/s (Brook trout passing a 30m length governing.)

Crossing design service life (DSL): 10 years, from MTO Highway Drainage Manual

Culvert DSL: 25 years (Table C5.0, MTO Gravity Pipe Design Guidelines)

Required total flow at 5-year flood stage: 30.71 m3/s (From OFAT 3)

Pipe locations on crossing: Stationing to be determined in numerical model.

Pipes to be placed at base of crossing (ground elevation of selected station).

Slope to approximately match stream slope.

For this design, replacement of pipes is not considered an option. Therefore, EMSL must exceed DSL requirements for the culvert.

Step 2 - Selection/Elimination of Pipe Types

Required diameters eliminate non-reinforced concrete, HDPVC and other options.

For this project, we are considering normally galvanized CSP and reinforced concrete box culverts.

RC Box Culvert analysis will be conducted separately.

The limitation to normally galvanized CSP is in adherence to the clients request to use materials available on site as much as possible, as the client has indicated CSP is available on site through existing stores and contracts.

MTO design guidelines indicate that polymer laminated pipe can be assumed to add 50 years to the EMSL of a normally galvanized pipe.

Step 3 - Estimate Durability

MTO Designates use of Figure B5 - Galvanized Corrugated Steel Pipe Estimated Material Service Life - California Method

PH Ranges of rainfall from Table D1	4.4-4.6			
PH Influences of soils from Table D2	Low Ph in our region; unlikely to resist surface water acidification from rainfall.			
Resistivities from Table 3.1:				
	Surface water (ohm-cm):	R	>	5000
	Sand (ohm-cm):	50000	>	R
		R	>	30000

Big Eddy report notes that surface water PH is neutral to mildly acidic.

Therefore, we will calculate EMSL for PH from 4.4-7, for pipes 2, 2.8 and 3.5mm thick at the 3 resistivities listed here.

We will then take an average of the EMSL for each pipe case to estimate our service life.

In this manner, we should be able to reasonably determine EMSL based on the various factors which can impact time to perforation of the pipe.

The following formula is given to more accurately calculate values for Figure B5:

$$Years = 13.79[Log_{10}R - Log_{10}(2160 - 2490Log_{10}PH0]$$

Years should be multiplied by the respective factor for the pipe thickness being evaluated.

Years EMSL			Based on R =			
Thickness (mm)	Factor	Ph	5000	30000	50000	EMSL (years)
2	1.6	4.4	21.01572362	38.184853	43.079724	**42.1**
		4.5	21.44256515	38.611694	43.506565	
		4.6	21.87926374	39.048393	43.943264	
		4.7	22.32674444	39.495874	44.390744	
		4.8	22.78602632	39.955156	44.850026	
		4.9	23.25823836	40.427368	45.322238	
		5	23.74463857	40.913768	45.808639	
		5.1	24.24663705	41.415766	46.310637	
		5.2	24.76582427	41.934953	46.829824	
		5.3	25.30400587	42.473135	47.368006	
		5.4	25.86324607	43.032375	47.927246	
		5.5	26.4459223	43.615051	48.509922	
		5.6	27.05479476	44.223924	49.118795	
		5.7	27.69309627	44.862225	49.757096	
		5.8	28.3646497	45.533779	50.42865	
		5.9	29.07402422	46.243153	51.138024	
		6	29.82674641	46.995876	51.890746	
		6.1	30.62959172	47.798721	52.693592	
		6.2	31.49099543	48.660125	53.554995	
		6.3	32.42164779	49.590777	54.485648	
		6.4	33.43538194	50.604511	55.499382	
		6.5	34.55054657	51.719676	56.614547	
		6.6	35.79222039	52.96135	57.85622	
		6.7	37.19597582	54.365105	59.259976	
		6.8	38.81470689	55.983836	60.878707	
		6.9	40.73210899	57.901238	62.796109	
		7	43.09251358	60.261643	65.156514	

2.8	2.2	4.4	28.89661998	52.504173	59.23462	**57.9**
		4.5	29.48352708	53.09108	59.821527	
		4.6	30.08398765	53.69154	60.421988	
		4.7	30.69927361	54.306826	61.037274	
		4.8	31.33078619	54.938339	61.668786	
		4.9	31.98007775	55.58763	62.318078	
		5	32.64887804	56.256431	62.986878	
		5.1	33.33912594	56.946679	63.677126	
		5.2	34.05300837	57.660561	64.391008	
		5.3	34.79300807	58.400561	65.131008	
		5.4	35.56196335	59.169516	65.899963	
		5.5	36.36314316	59.970696	66.701143	
		5.6	37.2003428	60.807895	67.538343	
		5.7	38.07800737	61.68556	68.416007	
		5.8	39.00139334	62.608946	69.339393	
		5.9	39.9767833	63.584336	70.314783	
		6	41.01177632	64.619329	71.349776	
		6.1	42.11568862	65.723241	72.453689	
		6.2	43.30011871	66.907671	73.638119	
		6.3	44.57976571	68.187318	74.917766	
		6.4	45.97365017	69.581203	76.31165	
		6.5	47.50700153	71.114554	77.845002	
		6.6	49.21430304	72.821856	79.552303	
		6.7	51.14446676	74.752019	81.482467	
		6.8	53.37022197	76.977775	83.708222	
		6.9	56.00664986	79.614202	86.34465	
		7	59.25220618	82.859759	89.590206	

3.5	2.8	4.4	36.77751634	66.823492	75.389516	**73.7**
		4.5	37.52448901	67.570465	76.136489	
		4.6	38.28871155	68.334688	76.900712	
		4.7	39.07180277	69.117779	77.683803	
		4.8	39.87554606	69.921522	78.487546	
		4.9	40.70191714	70.747893	79.313917	
		5	41.5531175	71.599094	80.165117	
		5.1	42.43161484	72.477591	81.043615	
		5.2	43.34019247	73.386169	81.952192	
		5.3	44.28201027	74.327986	82.89401	
		5.4	45.26068063	75.306657	83.872681	
		5.5	46.28036403	76.32634	84.892364	
		5.6	47.34589084	77.391867	85.957891	
		5.7	48.46291847	78.508895	87.074918	
		5.8	49.63813698	79.684113	88.250137	
		5.9	50.87954238	80.925518	89.491542	
		6	52.19680623	82.242782	90.808806	
		6.1	53.60178551	83.647762	92.213786	
		6.2	55.109242	85.155218	93.721242	
		6.3	56.73788364	86.78386	95.349884	
		6.4	58.5119184	88.557894	97.123918	
		6.5	60.46345649	90.509433	99.075456	
		6.6	62.63638569	92.682362	101.24839	
		6.7	65.09295769	95.138934	103.70496	
		6.8	67.92573706	97.971713	106.53774	
		6.9	71.28119073	101.32717	109.89319	
		7	75.41189877	105.45787	114.0239	

4.2	3.4	4.4	44.6584127	81.142812	91.544413	**89.4**
		4.5	45.56545094	82.04985	92.451451	
		4.6	46.49343545	82.977835	93.379435	
		4.7	47.44433194	83.928731	94.330332	
		4.8	48.42030593	84.904705	95.306306	
		4.9	49.42375652	85.908156	96.309757	
		5	50.45735696	86.941756	97.343357	
		5.1	51.52410373	88.008503	98.410104	
		5.2	52.62737657	89.111776	99.513377	
		5.3	53.77101247	90.255412	100.65701	
		5.4	54.95939791	91.443797	101.8454	
		5.5	56.19758489	92.681984	103.08358	
		5.6	57.49143887	93.975838	104.37744	
		5.7	58.84782957	95.332229	105.73383	
		5.8	60.27488062	96.75928	107.16088	
		5.9	61.78230146	98.266701	108.6683	
		6	63.38183613	99.866236	110.26784	
		6.1	65.08788241	101.57228	111.97388	
		6.2	66.91836528	103.40276	113.80437	
		6.3	68.89600156	105.3804	115.782	
		6.4	71.05018663	107.53459	117.93619	
		6.5	73.41991145	109.90431	120.30591	
		6.6	76.05846833	112.54287	122.94447	
		6.7	79.04144862	115.52585	125.92745	
		6.8	82.48125214	118.96565	129.36725	
		6.9	86.5557316	123.04013	133.44173	
		7	91.57159136	128.05599	138.45759	

Table 5-1. Estimated Mean Service Life (EMSL) based on steel thickness.

STEP 4 - List pipes which meet criteria thus far.

All cases significantly exceed the design life requirement.
Therefore, all pipes proposed in the price list at the start of this document are suitable alternatives.
Diameters required for flow and structural requirements will govern pipe thickness.

STEP 5 - Hydraulic evaluation of pipe alternatives

MTO designates the use of Manning's Equation for the analysis of pipe flow:

$$Q = \frac{AR^{\frac{2}{3}}S^{\frac{1}{2}}}{n}$$

Q	Flow in m3/s
n	Manning's number
A	Inside area of pipe (m2)
R	Hydraulic radius
S	Slope of pipe (m/m)

Assume full flow state for each pipe case.
We will use several different slopes, since velocities may differ in each pipe at full flow state.

Mannings number, n, obtained from MTO Gravity Pipe Design Guidelines Table C2.0

Maximum Pipe Flows			s (m/m):		0.0032		
Equiv D(m)	P(m)	A(m2)	R	n	Q (m3/s)	V (m/s)	V (cm/s)
1.6	5.03	1.93	0.384	0.025	2.31	1.20	119.53
1.8	5.65	2.44	0.431	0.025	3.15	1.29	129.21
2	6.28	2.97	0.473	0.025	4.08	1.37	137.30
2.2	6.91	3.44	0.498	0.025	4.89	1.42	142.11
2.4	7.54	4.27	0.566	0.025	6.61	1.55	154.89
2.7	8.48	5.39	0.635	0.025	9.01	1.67	167.24
3	9.42	6.6	0.700	0.025	11.78	1.78	178.44
3.3	10.37	8.29	0.800	0.025	16.16	1.95	194.94
3.6	11.31	9.76	0.863	0.025	20.02	2.05	205.10

Flow calculated using equivalent diameter and the actual area is approximately representative of flow capacity of the arch-pipes. Actual flow for the arch-pipe will likely exceed calculated flow in this table.

Use 2 arch-pipes of (Span x Rise) 3890x2690mm, equivalent diameter 3.3m.

Estimated flow:	32.32	m3/s
Req'd flow:	30.71	m3/s

Therefore, these pipe-arches provide sufficient flow for the 5-year design.

STEP 6 - Structural Evaluation

Using CSPI Handbook of Steel Drainage & Highway Construction, determine structural requirements for the arch-pipe selected.

Given 2xPipe-arch, 3890mm span x 2690mm rise

Minimum spacing between culverts:	1400mm	pg210
MLC 30 Live Load		
Soil Group	1	90-95% Standard Proctor Density
Unit weight of soil, gamma:	22	kN/m3

Secant modulus, Es:	12	Mpa

Required:
Determine minimum cover
Check wall thickness is sufficient for MLC 30 live load

Geometric Properties:

B (N.A.)	915	mm	
Rt	1975	mm	
Rc	815	mm	
Rb	6015	mm	
A	8.29	m2	
Dh	3890	mm	
Dv	3550	mm	Note: Equal to 2(Rise-B)

1. Minimum Cover (Hmin)

Largest of:

0.6 m	=	600	mm	
(Dh/6)(Dh/Dv)^(1/2)	=	679	mm	**Governs**
0.4(Dh/Dv)^2	=	480	mm	

Hmin =	679	mm
H =	730	mm

Therefore, cover provided is sufficient for structural requirements.

2. Dead Load Thrust (Td)

$$T_D = 0.5(1.0 - 0.1C_S)A_f W$$

Dh/Dv =	1.10	
H/Dh =	0.188	
Af =	1.48	Fig 6.13 p232

$$C_S = \frac{1000E_S D_V}{EA}$$

$$W = \gamma[(HD_H) + Area\ between\ springline\ \&\ Crown]$$

Note: Approximating area between springline & crown as no formula to determine this has been found.

A =	8.29	m2
B =	0.915	m2
Span =	3.89	m2

Area between springline & crown = A - (B x Span) = 4.73065 m2

Gamma:	22	kN/m3
W =	166.55	kN/m

Cs = 0.0942

E	200000	MPA	
Es	24	MPA	Secant modulus of stiffness, Tb 6.6 p 209
Plate area:	4.521	mm2/mm	Tb 6.2 p206

Td = 122.1

3. Live Load Thrust (TL)

$$T_L = 0.5(lesser\ of\ D_H\ and\ l_t)\sigma_L m_f$$

Note: Only calculate 1 lane case, as design is a single lane crossing.

mf = 1

$$\sigma_L = \frac{Axle\ Load}{l_t w}$$

Axle load: position the maximum number of design vehicle axles over a single span

Axle load = 195.8 kN

lt = distance between outermost axles plus 2H

lt = 2.68 m

Smaller than Dh (3.89m)

w = width from outermost tires plus H

w = 3.18 m

sigmaL = 22.97 kPa

TL = 30.79 kN/m

4. Earthquake Thrust - Not Applicable

5. Total Factored Thrust (TF)

$$T_f = \alpha_D T_D + \alpha_L T_L (1 + DLA)$$

alphaD 1.25

alphaL 1.7

$$DLA = 0.40(1 - 0.5D_c) \geq 0.10$$

Dc = H = 0.73 m

DLA = 0.254

TF = 218.23 kN/m

6. Compressive Stress at ULS (sigmaU)

$$\sigma_u = \frac{T_f}{Area}$$ where Area is the plate Area

sigmaU =	48.27	MPA

7. Wall Strength in Compression (fb)

Definition of upper zone:

i) $$\theta_o = 1.6 + 0.2log\left[\frac{EI}{E_m R^3}\right]$$ radians, where:

$$E_m = E_s\left[1 - \left[\frac{R_t}{R_t + 1000(H + H')}\right]^2\right]$$

Es	24	Mpa	
R = Rt	1975	mm	
H	0.73	m	
H'	887.5	m	
I	394.84	mm4/mm	Tb 6.2 p206
Em =	24.00	Mpa	
Sigma-o =	0.326	radians	

ii) $$\lambda = 1.22\left[1.0 + 1.6\left[\frac{EI}{E_m R_t^3}\right]^{0.25}\right]$$

Lamda =	1.366		

iii) $$K = \lambda \left[\frac{EI}{E_m R_c^3} \right]$$

K =	5.835E-07		

iv) $$\rho = \left[1000 \frac{(H + H')}{R_t} \right]^{0.5} \leq 1.0$$

rho =	21.207		
Therefore, use:			
rho =	1		

v) $$R_e = \frac{r}{K} \left[\frac{6E\rho}{F_y} \right]^{0.5}$$

Fy	230	Mpa	
r	9.345	mm, Tb 6.2 p206	
Re =	3658	mm	

vi) Two conduits, therefore:

$$F_m = \left(0.85 + \frac{0.3S}{D_h} \right) \leq 1.0$$

S =	1.4	m	
Fm =	0.958	<	1

vii) R < Re

$$f_b = \phi_t F_m \left[F_y - \frac{(F_y K R)^2}{12 E r^2 \rho} \right]$$

Phit	0.8	Tb 6.14 p228
fb =	176.27	Mpa
SigmaU	48.27	

Since SigmaU is less than fb, 4.2mm plate thickness satisfies compressive stress criteria in the upper zone (where R=815m).

vii) Check Lower Zone Arcs for Wall Strength in Compression

Lambda	1.22	
Em = Es	24	Mpa
Rho	1	
R1 (top)	1975	mm
R2 (corner)	815	mm
R3 (bottom)	6015	mm

	R1	R2	R3
K	5.835E-07	7.42E-06	1.845E-08
Re (mm)	3658	288	115721
Fb (Mpa)	176.27	176.27	176.27

4.2mm plate satisfies compressive stress criteria for all radii within the lower zone of the culvert.

8. Strength Requirements During Construction

Should not be required, as vehicle loads should not be applied to arch-pipes during construction and retaining wall reinforcement should provide sufficient confinement to ensure full structural strength of corrugated pipe is achieved.

9. Factored Longitudinal Seam Strength, Sf

$$S_f = \phi_j S_S \geq T_f$$

Phij	0.7		
Ss	372	kN/m	Tb 6.4a p207
Sf	260.4	kN/m	
Tf	218.23	kN/m	

Seam strength is sufficient using single 10mm rivets with a 68x13mm seam.

10. Radius of Curvature

$$\frac{R_t}{R_c} \leq 5.0$$

Rt	1975	
Rc	815	
Rt/Rc	2.423	< 5.0, OK

APPENDIX No. 6: Crossing & Culvert Group Drawings

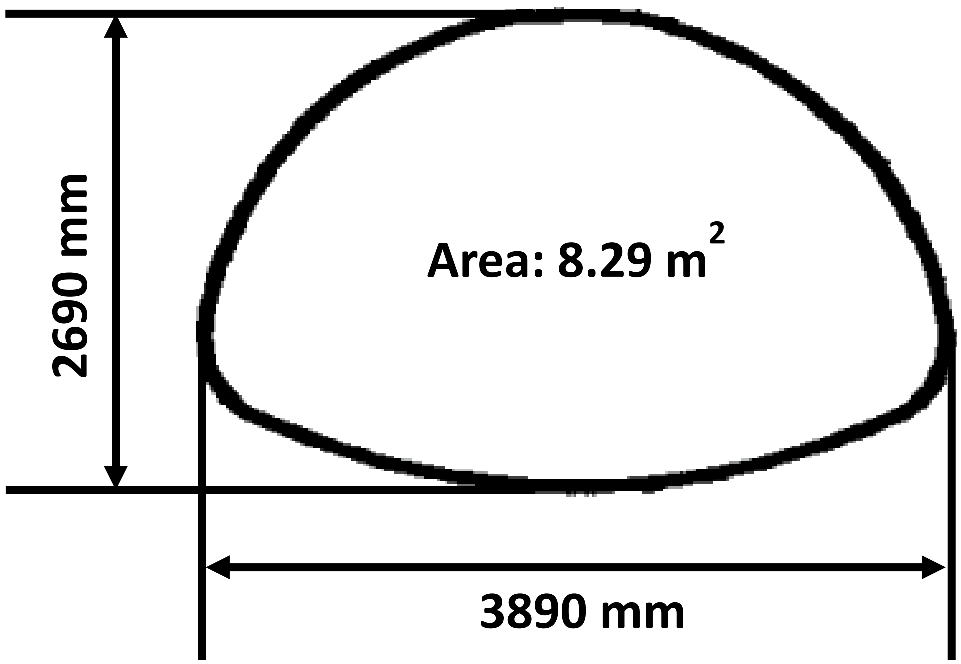

Figure 6-1. Arch-pipe Cross Section Diagram.

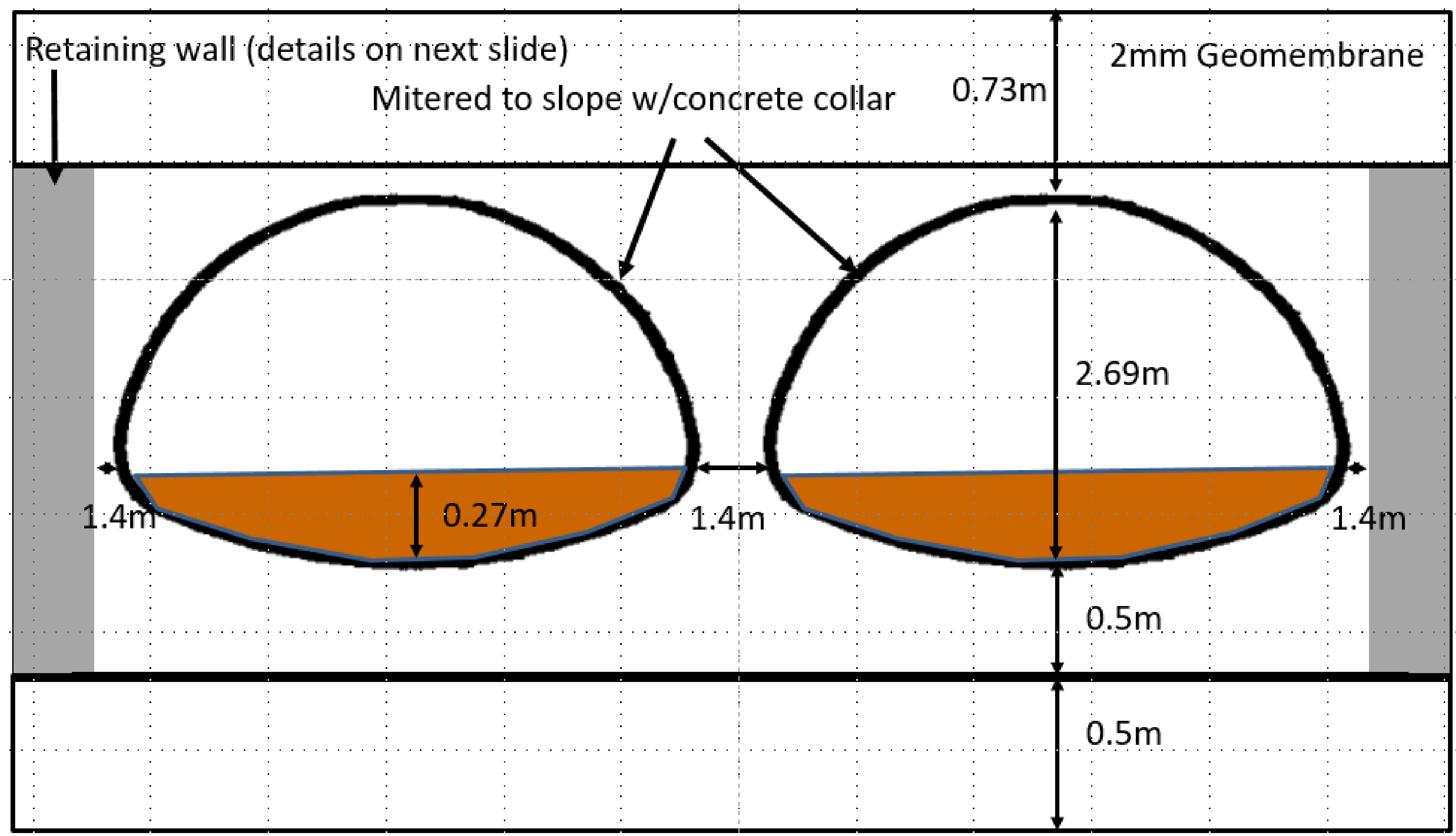

Figure 6-2. Culvert Group Layout Diagram. (Not to scale.)

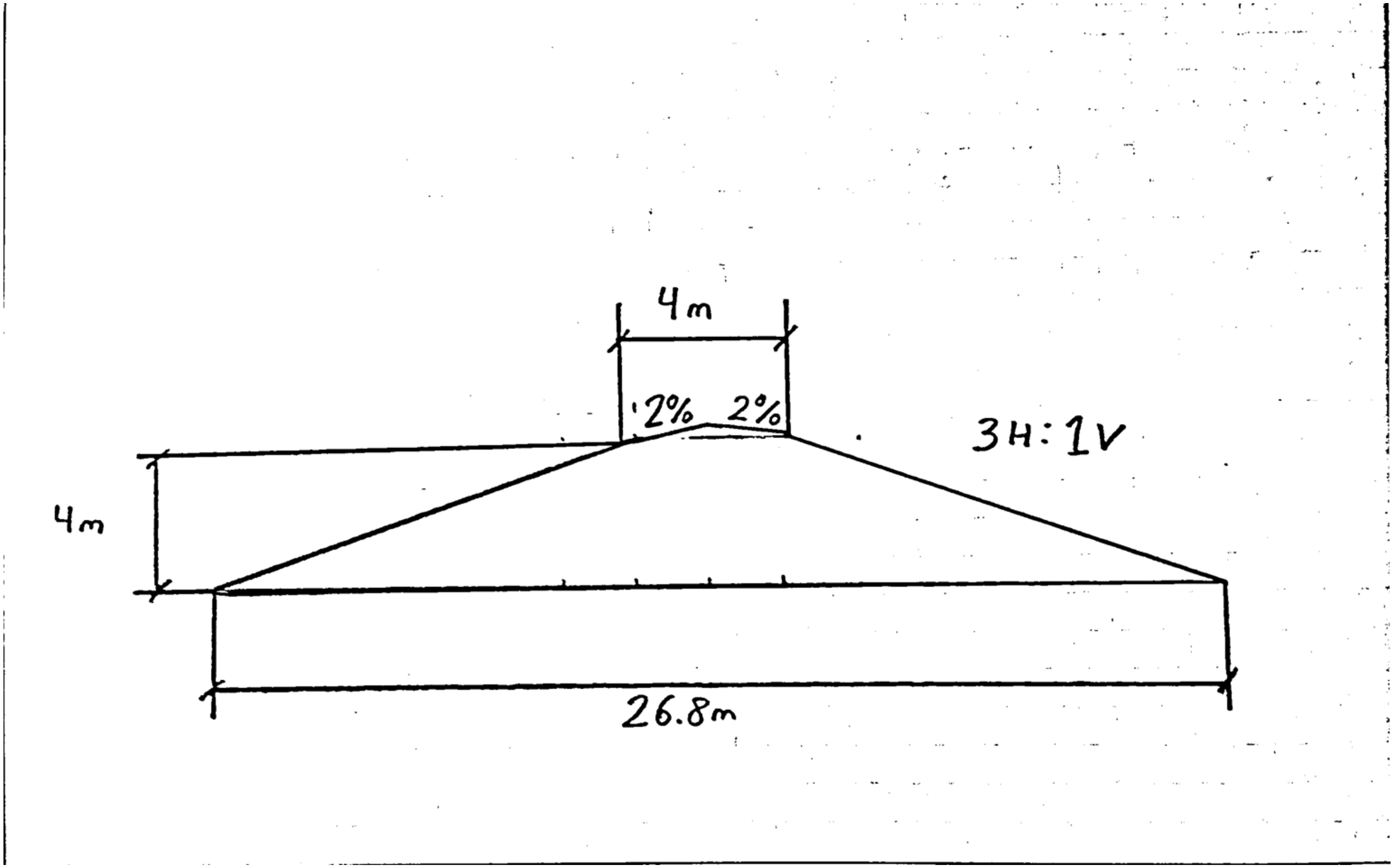

Figure 6-3. Crossing and Road Diagram. (To scale.)

APPENDIX No. 7: Filter Design

Filter Layer

Sieve # or inches	Size (mm)	Retained Percent %	Cumulative percent	Pass Percentage %
5	125	1	1	99.0
4	100	3	4	96.0
3.00	75	4	8	92.0
2.12	53	2	10	90.0
1.75	45	6	16	84.0
1.25	31.5	3	19	81.0
1	25	5	24	76.0
0.75	19	3	27	73.0
0.53	13.2	4	31	69.0
0.44	11.2	5	36	64.0
0.3125	8	4	40	60.0
0.25	6.3	6	46	54.0
No. 4	4.75	2	48	52.0
No. 6	3.35	9	57	43.0
No. 8	2.36	5	62	38.0
No. 12	1.68	9	71	29.0
No. 16	1.18	2	73	27.0
No. 20	0.85	3	76	24.0
No. 30	0.6	5	81	19.0
No. 40	0.425	2	83	17.0
No. 50	0.3	2	85	15.0
No. 60	0.25	3	88	12.0
No. 80	0.18	4	92	8.0
No. 100	0.15	2	94	6.0
No. 140	0.106	3	97	3.0
No. 200	0.075	0	97	3.0
No. 270	0.053	3	100	0.0

Table 7-1. Sieve analysis for filter design.

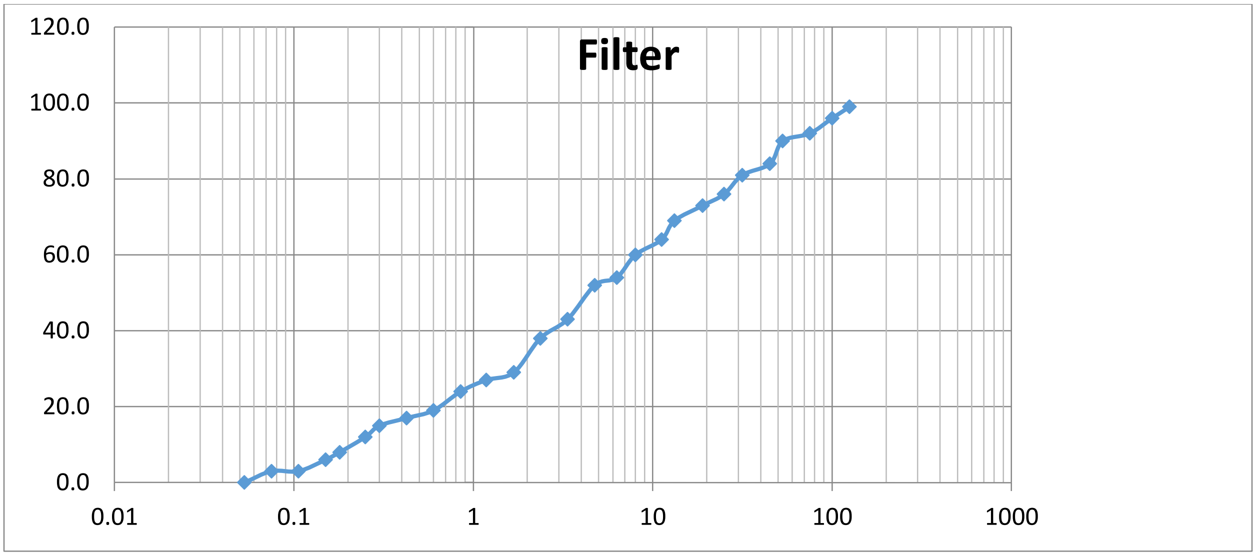

Figure 7-1. Filter layer sieve analysis graph.

Sieve #	Coarse Fraction Size (mm)	Retaine d Percent %	Cumulativ e percent	Pass Percentag e %
5	125	1.03	1.03	98.97
4	100	3.09	4.12	95.88
3.00	75	4.12	8.25	91.75
2.12	53	2.06	10.31	89.69
1.75	45	6.19	16.49	83.51
1.25	31.5	3.09	19.59	80.41
1	25	5.15	24.74	75.26
0.75	19	3.09	27.84	72.16
0.53	13.2	4.12	31.96	68.04
0.44	11.2	5.15	37.11	62.89
0.3125	8	4.12	41.24	58.76
0.25	6.3	6.19	47.42	52.58
No. 4	4.75	2.06	49.48	50.52
No. 6	3.35	9.28	58.76	41.24
No. 8	2.36	5.15	63.92	36.08
No. 12	1.68	9.28	73.20	26.80
No. 16	1.18	2.06	75.26	24.74
No. 20	0.85	3.09	78.35	21.65
No. 30	0.6	5.15	83.51	16.49
No. 40	0.425	2.06	85.57	14.43
No. 50	0.3	2.06	87.63	12.37
No. 60	0.25	3.09	90.72	9.28
No. 80	0.18	4.12	94.85	5.15
No. 100	0.15	2.06	96.91	3.09
No. 140	0.106	3.09	100.00	0.00

Table 7-2. Coarse fraction sieve analysis of filter layer design.

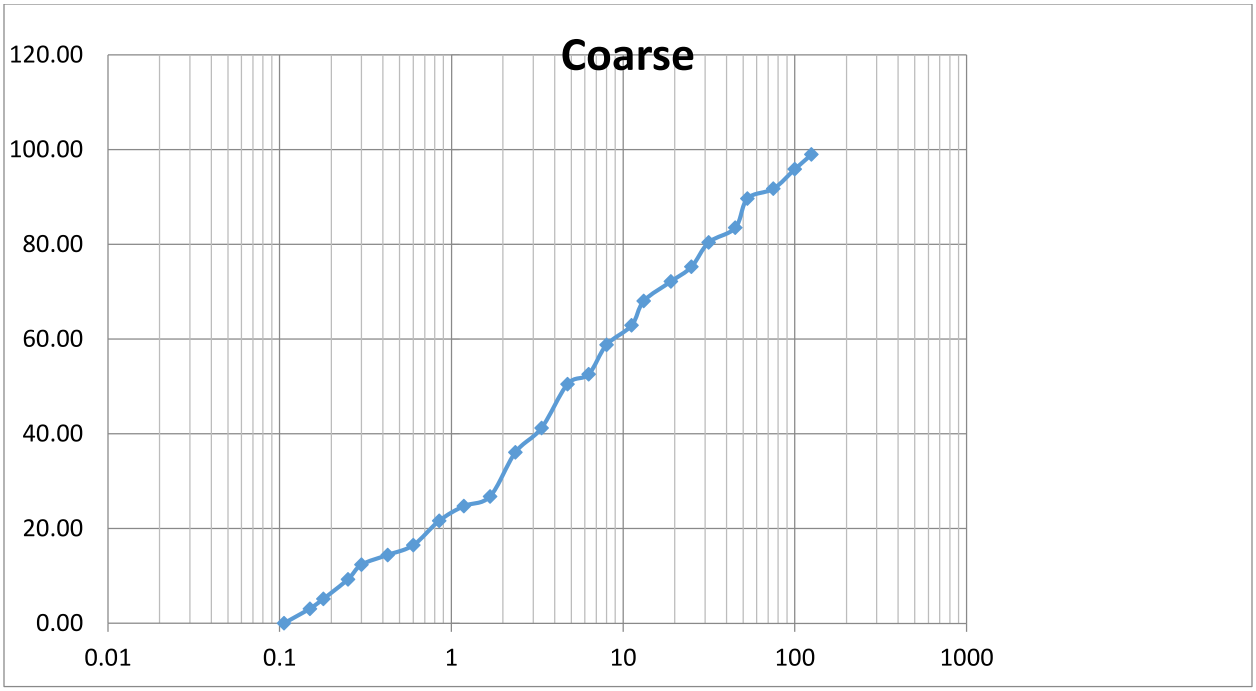

Figure 7-2. Coarse fraction sieve analysis of filter layer design graph.

Fine Fraction

Sieve #	Size (mm)	Retained Percent %	Cumulative percent	Pass Percentage %
200	0.075	0	0	100
270	0.053	100	100	0

Table 7-3. Fine fraction sieve analysis of filter layer design.

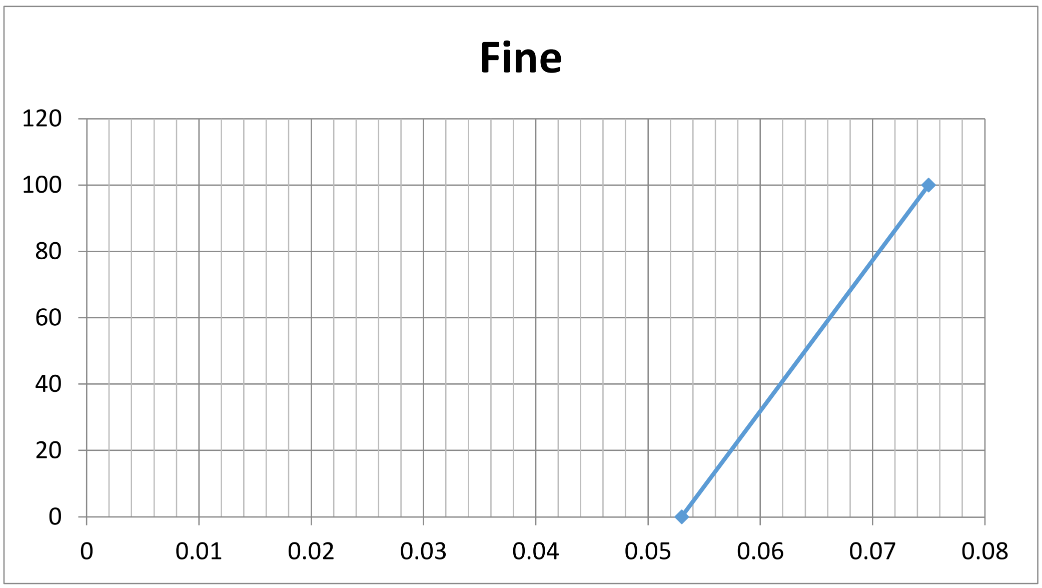

Figure 7-3. Fine fraction sieve analysis of filter layer design.

Calculations

Filter Layer Calculations

There are three formulas that govern the design of the filter layer.

$$\frac{D_{15c}}{D_{85f}} < 5$$

$$\frac{D_{15c}}{D_{15f}} > 5$$

$$\frac{D_{15c}}{D_{15f}} < 40$$

c refers to coarse layer

f refers to fine layer

15 and 85 refer to 15% and 85% sieve passing sizes

From these graphs the following values were obtained;

$D_{15c} = 0.3mm$
$D_{15f} = 0.056mm$
$D_{85f} = 0.072mm$

$\frac{D_{15c}}{D_{85f}} < 5$ value obtained 4.17

$\frac{D_{15c}}{D_{15f}} > 5$ value obtained 5.36

$\frac{D_{15c}}{D_{15f}} < 40$ value obtained 5.36

The thickness of the filter layer must be between 150-380mm.

250mm was chosen

Toe Scour Calculations

The volume needed per metre of bank is calculated using;

$V_T = 3.35T \times D_s$

Where T = required thickness of riprap on embankment

D_s = Diameter of nominal stone size

APPENDIX No. 8: Hydraulic Modelling Results

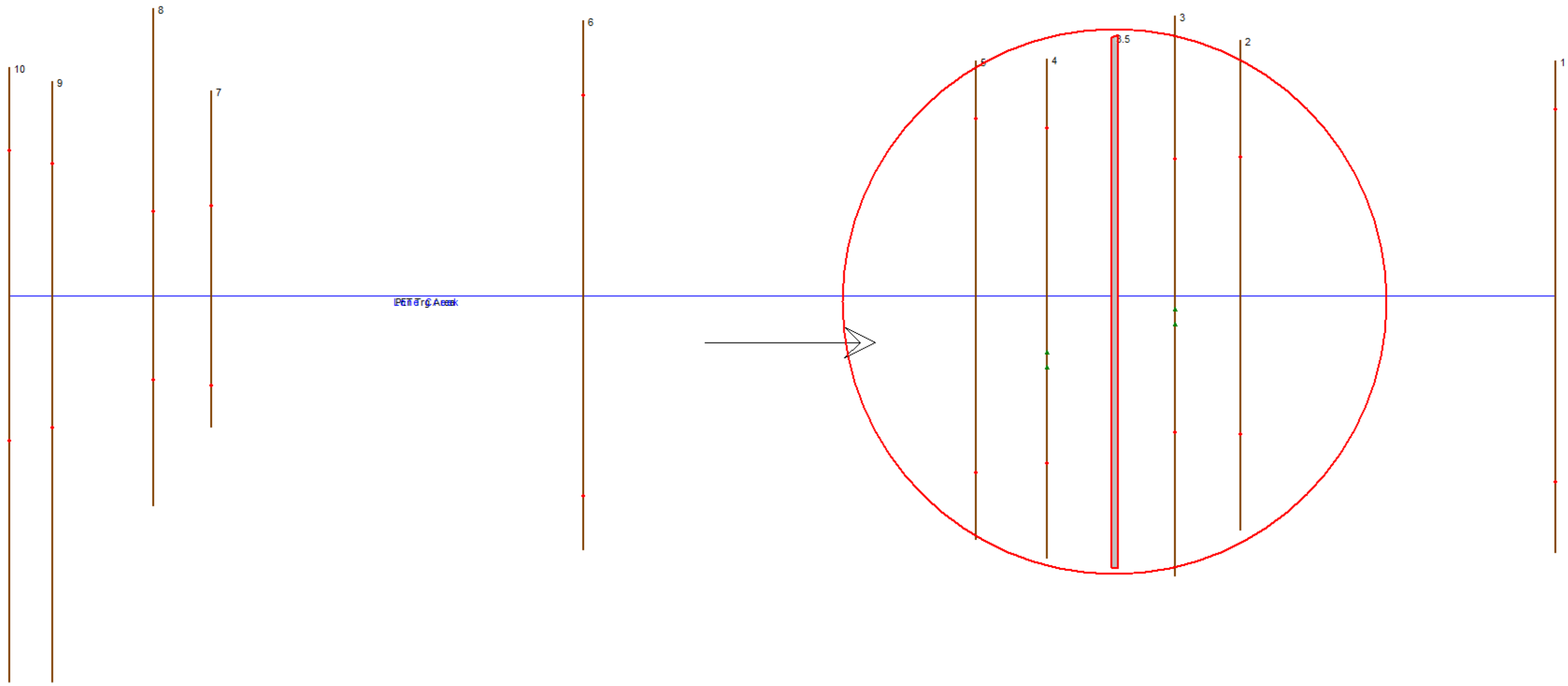

Figure 7-1. Creek river reach model cross section overview.

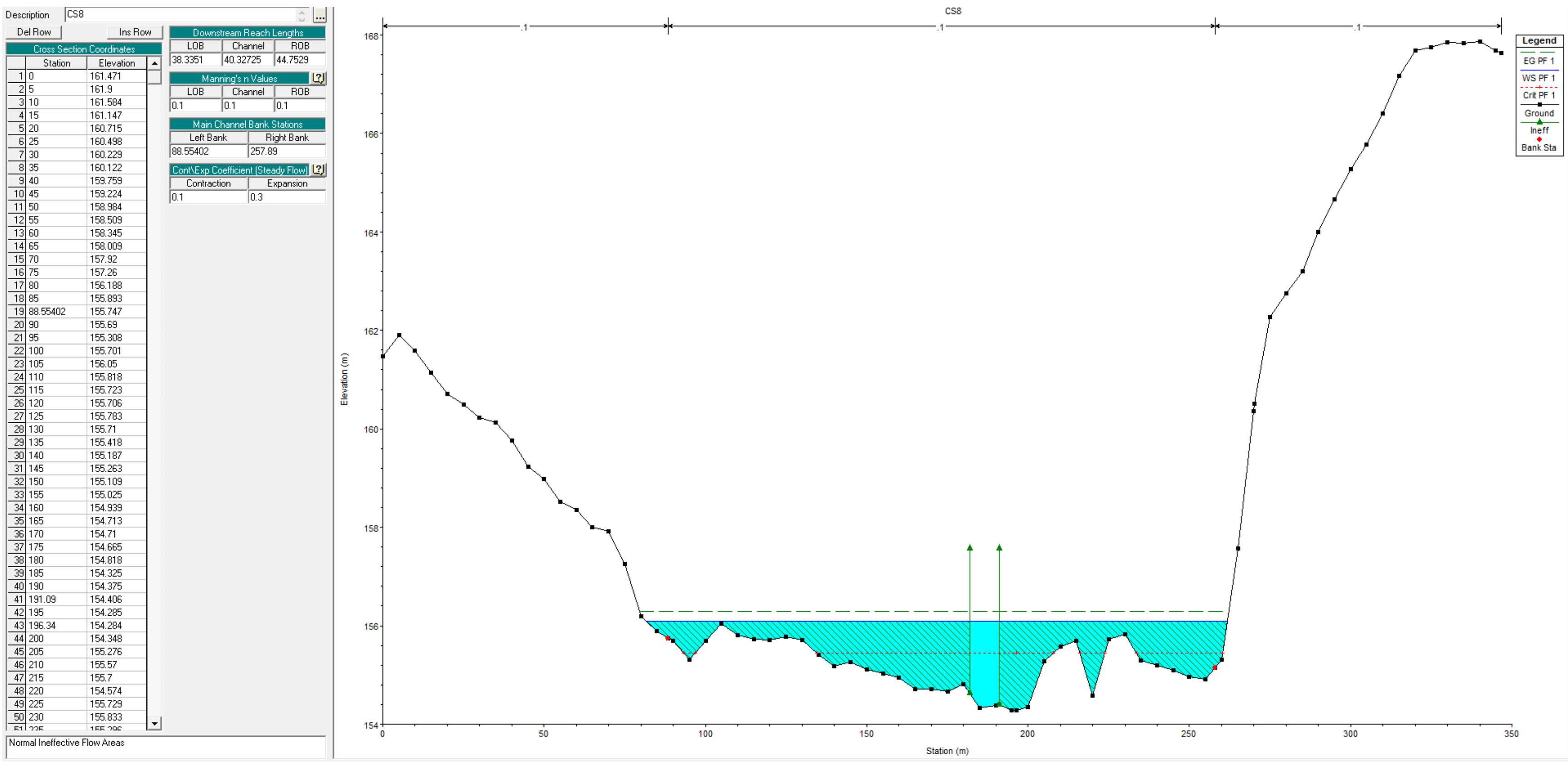

Figure 7-2. Example of cross section entry (cross section 3, immediately downstream of crossing, shown).

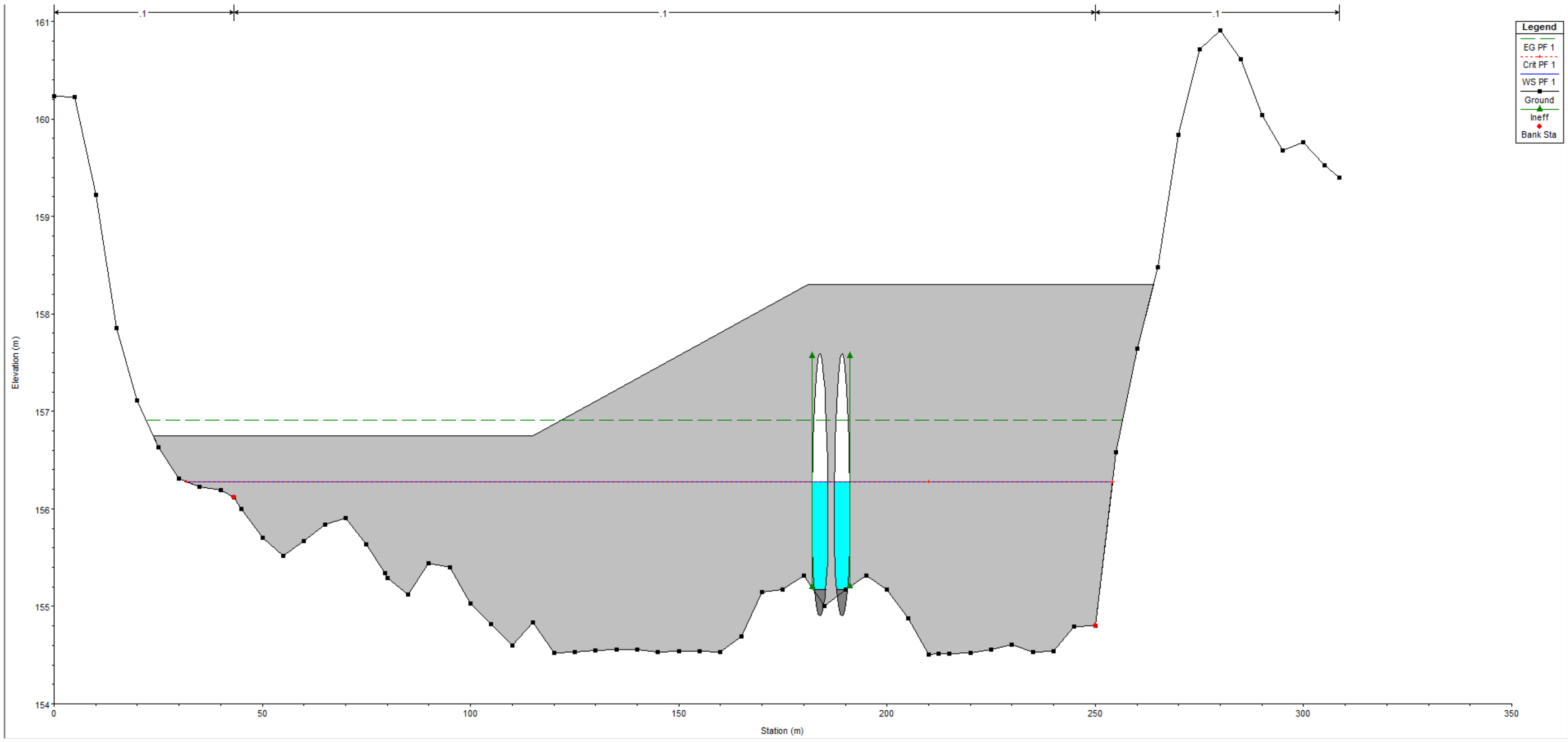

Figure 7-3. Crossing upstream side at 5-year flood stage.

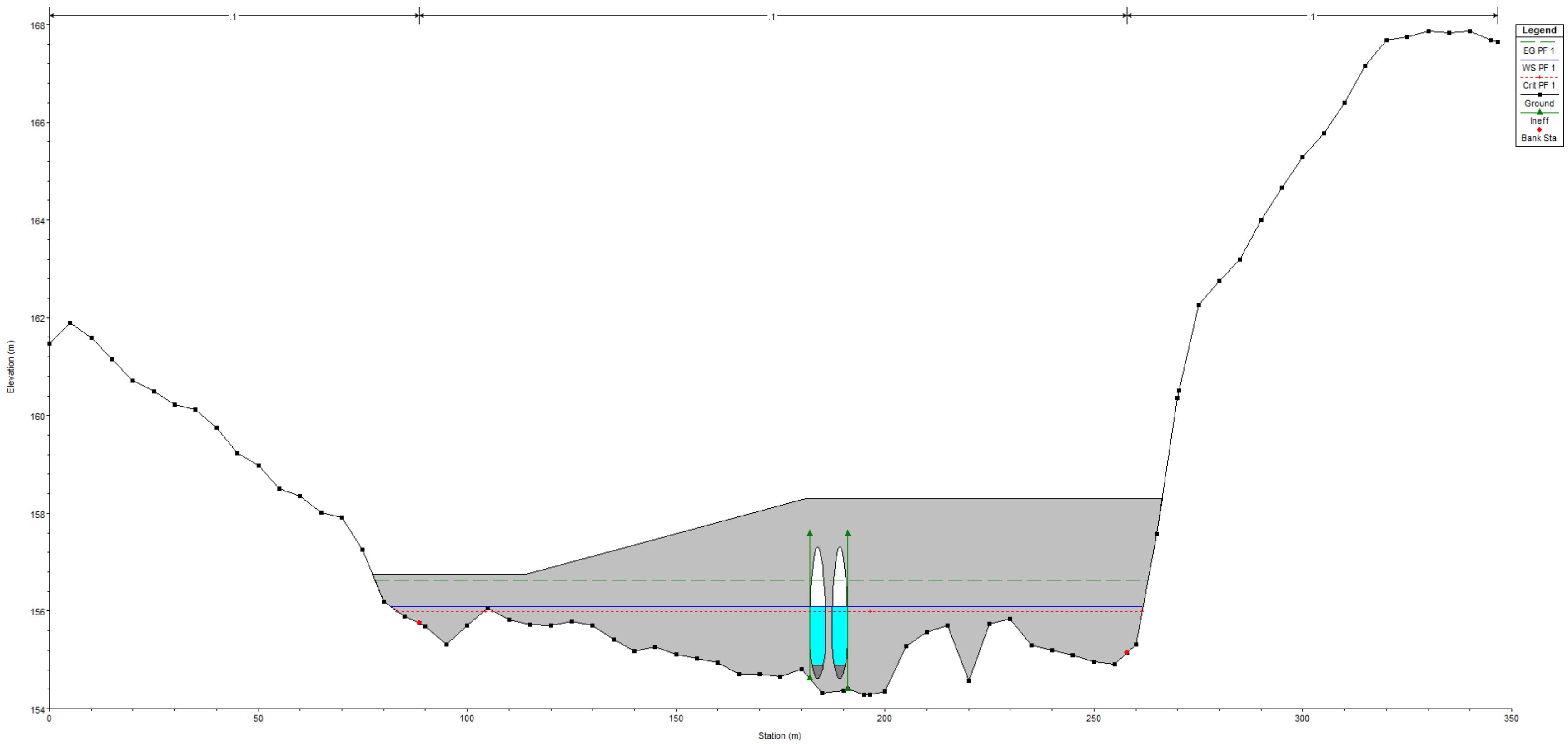

Figure 7-4. Crossing, downstream side at 5-year flood stage.

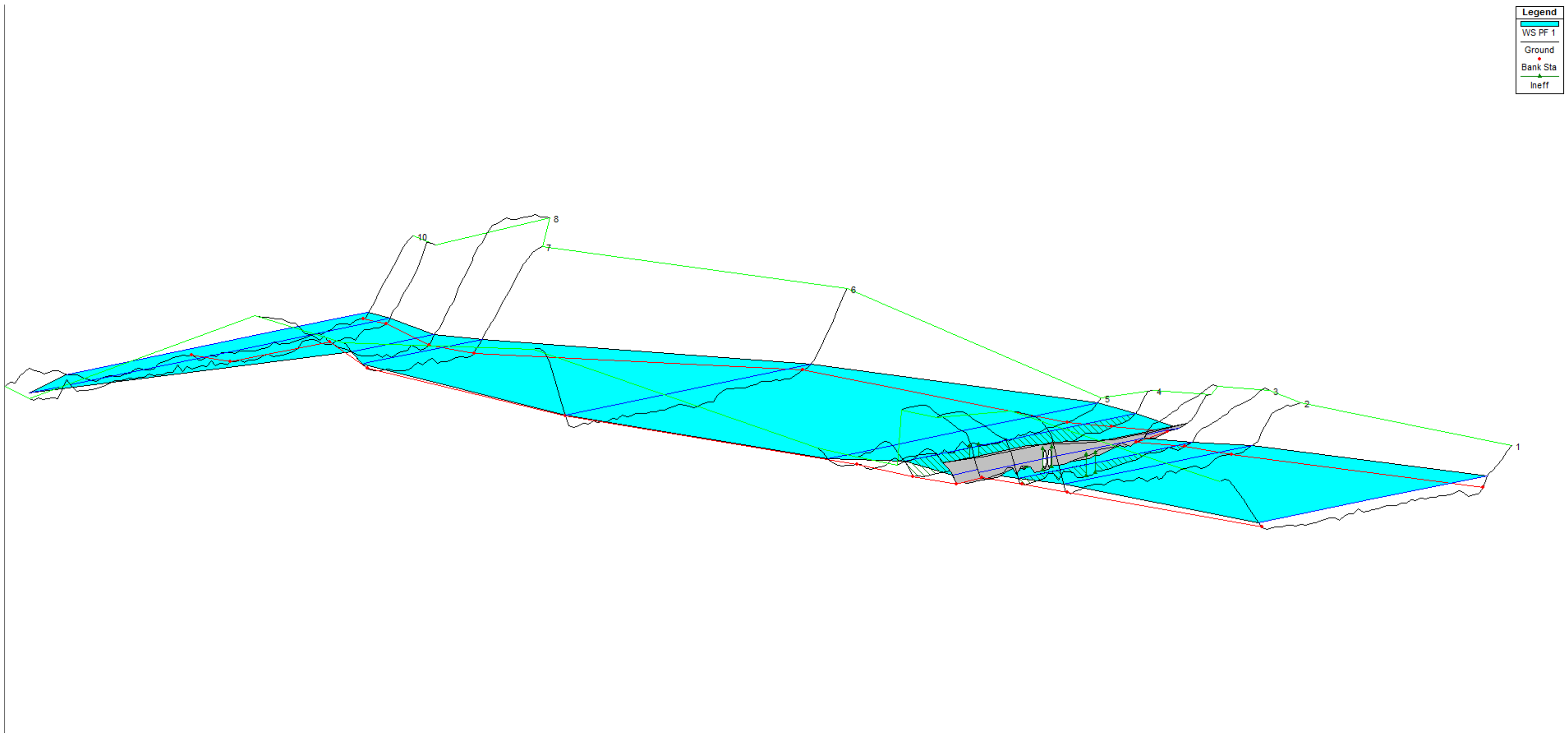

Figure 7-5. 3-dimensional representation of 5-year flood stage.

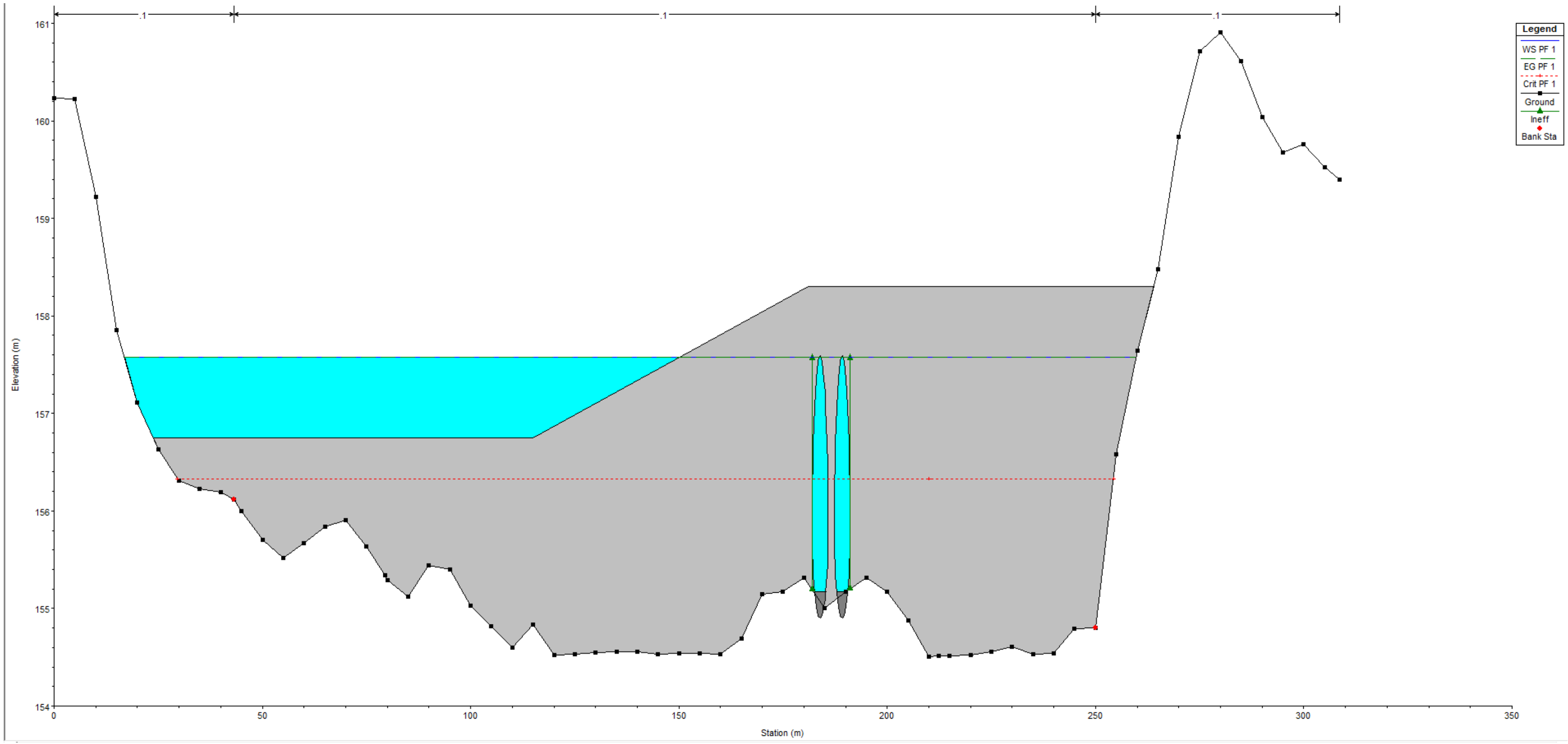

Figure 7-6. Crossing, upstream side at 10-year flood stage.

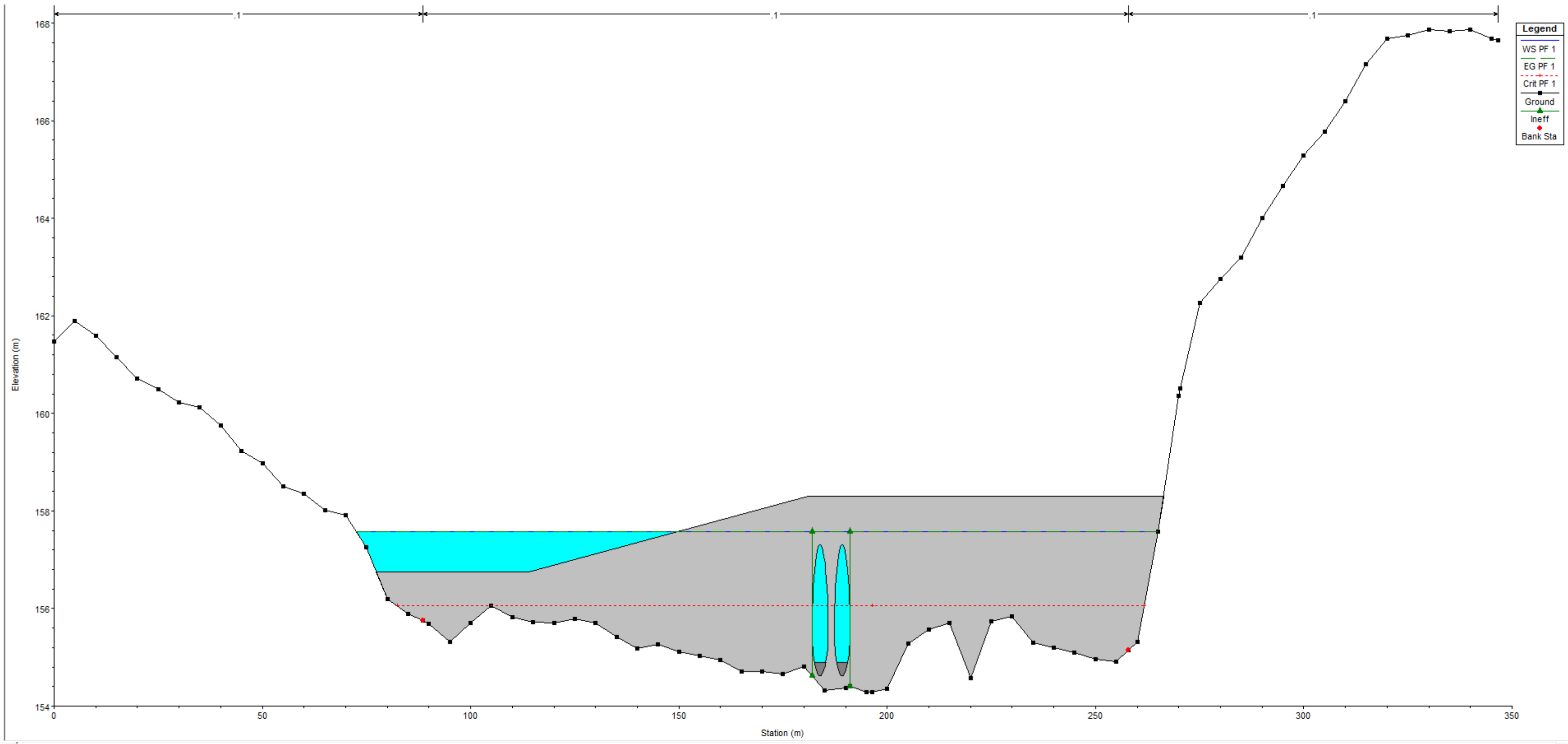

Figure 7-7. Crossing, downstream side at 10-year flood stage.

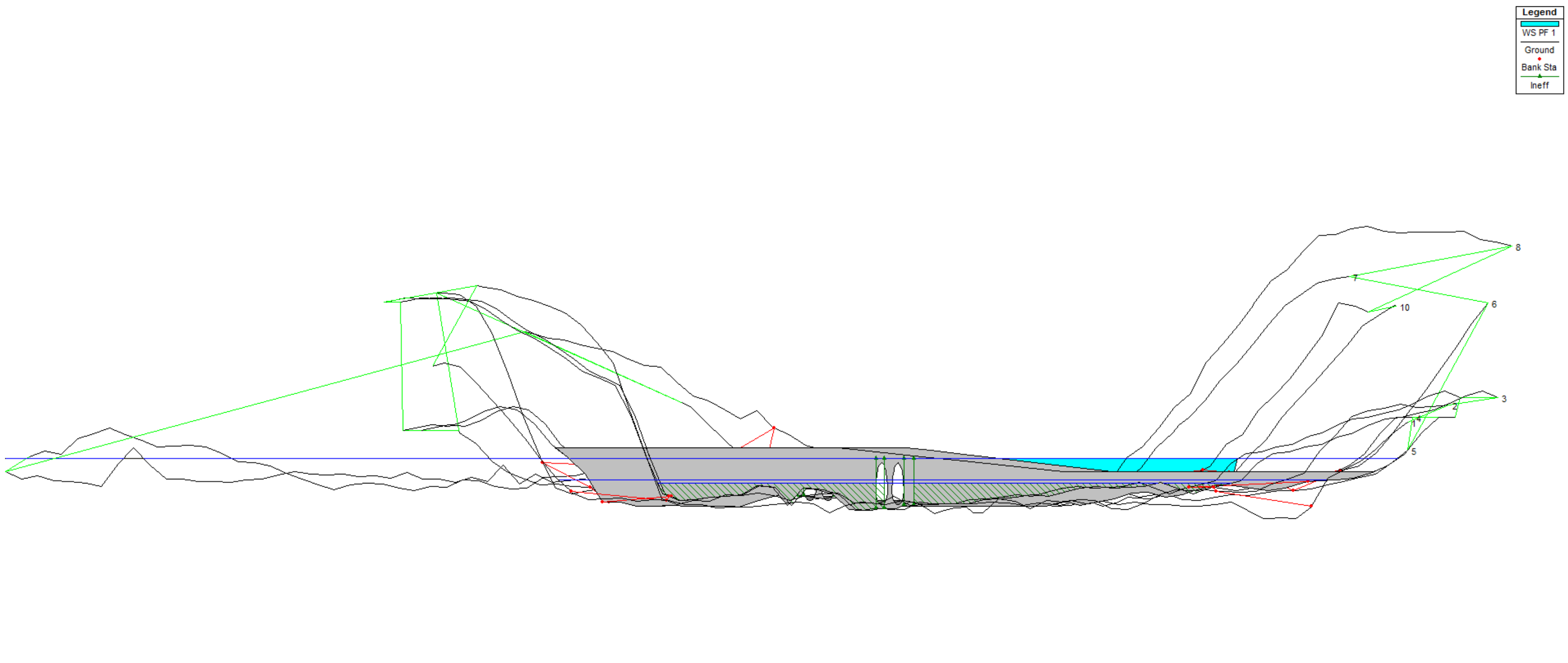

Figure 7-8. 3-dimensional representation of wash over at 10-year flood stage.

APPENDIX No. 9: Cost Estimates

Line Number	Description	Qty	Unit	Material	Labor	Equipment	Total
01 45 23.50 5550	Technician for inspection, per day, earthwork	2	Ea.		$640.00		$640.00
Quality Control	**Subtotal**						**$640.00**
01 54 16.50 0100	All-terrain forklift, 45' lift, 35' reach, 9000 lb. capacity	3.00	Week	$309.00	$5,400.00	$7,200.00	$309.00
01 54 36.50 0020	Dozer, loader, backhoe, excav., grader, paver, roller, 70 to 150 H.P.	1.00	Ea.		$70.50	$126.00	$196.50
01 54 36.50 0100	Above 150 HP	2	Ea.		$188.00	$566.00	$754.00
01 54 39.70 0010	Small Tools		% Total		0.50%		
Construction Aids	**Subtotal**						**$1,259.50**
01 71 23.13 1400	Crew for roadway layout, 4 person crew	5	Day		$7,500.00	$392.50	$7,892.50
01 71 23.19 0010	**Surveyor Stakes**						
01 71 23.19 0100	2" x 2" x 18" long	2	C	$148.00			$148.00
01 71 23.19 0150	2" x 2" x 24" long	2	C	$260.00			$ 260.00
Examination and Preparation	**Subtotal**						**$8,300.50**
02 32 13.10 0020	Borings, initial field stake out and determination of elevations	1	Day		$705.00	$78.50	$783.50
02 32 13.10 0100	Drawings showing boring details	1	Total		$310.00		$310.00
02 32 13.10 0200	Report and recommendations from P.E.	1	Total		$720.00		$720.00
02 32 13.10 0300	Mobilization and demobilization	1	Total		$209.00	$246.00	$455.00
Geotechnical Investigations	**Subtotal**						**$2,268.50**
31 23 16 Excavation (maybe)							
31 23 23.17 0011	General Fill by dozer, no compaction	1100	L.C.Y		$561.00	$1,364.00	$1,925.00
Crew B-10B	1 Equip. Oper., .5 Laborer, 1 Dozer, 200 H.P.	1	Day		$1,755.80		
31 23 23.20 4272	20 C.Y. truck 20 mi. wait/Ld./Uld., 35MPH ave, cycle 40 miles	1100	L.C.Y		$3,102.00	$7,260.00	$10,362.00
Crew B-34D	1 Truck Driver (heavy), 1 Truck tractor, 6x4, 380 H.P., 1 Dump Trailer, 20 C.Y.	1	Day		$942.40		
31 23 23.23 5050	Riding, vibrating roller, 6'' lifts, 2 passes	1100	E.C.Y		$143.00	$143.00	$286.00

Crew B-10Y	1 Equip. Oper. (med.), .5 Laborer, 1 Dozer. 105 H.P.	2	Day				$2,055.20
Gran A Fill	Gran A Fill	1100	B.C.Y	$23,650.00			$23,650.00
Excavation and Fill	**Subtotal**						**$14,628.20**

Table 9-1. Biennial cost breakdown of replacement of existing crossing.

		Material	Labor	Equipment	Total	
Estimate Subtotal		$ 24,367.00	$ 22,246.71	$ 17,376.00	$ 63,989.71	
	Gen. Requirements	$ 3,655.05	$ 3,337.01	$ 2,606.40	$ 9,598.46	**Gen. Requirements**
0%	**Sales Tax**	0.00	0.00	0.00	0.00	**Sales Tax**
	Subtotal	$ 28,022.05	$ 25,583.71	$ 19,982.40	$ 73,588.16	**Subtotal**
10%	**GC O & P**	$ 2,802.21	$ 2,558.37	$ 1,998.24	$ 7,358.82	**GC O & P**
	Subtotal	$ 30,824.26	$ 28,142.08	$ 21,980.64	$ 80,946.98	**Subtotal**
5%	**Contingency**	$ 1,541.21	$ 1,407.10	$ 1,099.03	$ 4,047.35	**Contingency**
	Subtotal	$ 32,365.47	$ 29,549.19	$ 23,079.67	$ 84,994.33	**Subtotal**
1%	**Bond**	$ 323.65	$ 295.49	$ 230.80	$ 849.94	**Bond**
	Subtotal	$ 32,689.12	$ 29,844.68	$ 23,310.47	$ 85,844.27	**Subtotal**
	Location Adjustment	1.23	0.91	1.00	1.07	**Location Adjustment**
	Grand Total	$ 40,174.93	$ 27,069.12	$ 23,310.47	**$ 90,554.52**	**Grand Total**

Table 9-2. Biennial cost total of replacement of existing crossing.

Line Number	Description	Qty	Unit	Material	Labor	Equipment	Total
01 45 23.50 5550	Technician for inspection, per day, earthwork	2	Ea.		$640.00		$640.00
Quality Control	**Subtotal**						**$640.00**
01 54 16.50 0100	All-terrain forklift, 45' lift, 35' reach, 9000 lb. capacity	3	Week	$309.00	$5,400.00	$7,200.00	$12,909.00
01 54 36.50 0020	Dozer, loader, backhoe, excav., grader, paver, roller, 70 to 150 H.P.	1	Ea.		$70.50	$126.00	$196.50
01 54 36.50 0100	Above 150 HP	3	Ea.		$282.00	$849.00	$1,131.00
01 54 39.70 0010	Small Tools		% Total		0.50%		
Construction Aids	**Subtotal**						**$14,236.50**
01 71 23.13 1400	Crew for roadway layout, 4 person crew	5	Day		$7,500.00	$392.50	$7,892.50
01 71 23.19 0010	**Surveyor Stakes**						
01 71 23.19 0100	2" x 2" x 18" long	2	C	$148.00			$148.00
01 71 23.19 0150	2" x 2" x 24" long	2	C	$260.00			$260.00
Examination and Preparation	**Subtotal**						**$8,300.50**
02 32 13.10 0020	Borings, initial field stake out and determination of elevations	1	Day		$705.00	$78.50	$783.50
02 32 13.10 0100	Drawings showing boring details	1	Total		$310.00		$310.00
02 32 13.10 0200	Report and recommendations from P.E.	1	Total		$720.00		$720.00
02 32 13.10 0300	Mobilization and demobilization	1	Total		$209.00	$246.00	$455.00
Geotechnical Investigations	**Subtotal**						**$2,268.50**

31 23 16 Excavation (maybe)							
31 23 23.17 0011	General Fill by dozer, no compaction	7200	L.C.Y		$3,672.00	$8,928.00	$12,600.00
Crew B-10B	1 Equip. Oper., .5 Laborer, 1 Dozer, 200 H.P.	7	Day		$12,290.60		$12,290.60
31 23 23.20 4272	20 C.Y. truck 20 mi. wait/Ld./Uld., 35MPH ave, cycle 40 miles	7200	L.C.Y		$20,304.00	$47,520.00	$67,824.00
Crew B-34D	1 Truck Driver (heavy), 1 Truck tractor, 6x4, 380 H.P., 1 Dump Trailer, 20 C.Y.	1	Day		$942.40		$942.40
31 23 23.23 5050	Riding, vibrating roller, 6'' lifts, 2 passes	7200	E.C.Y		$936.00	$936.00	$1,872.00
Crew B-10Y	1 Equip. Oper. (med.), .5 Laborer, 1 Dozer. 105 H.P.	2	Day		$2,055.20		$2,055.20
Gran A Fill	Gran A Fill	7200	B.C.Y	$154,800.00			$154,800.00
Excavation and Fill	**Subtotal**						**$252,384.20**
31 37 13.10 0200	Riprap and Rock Lining, Machine Placed for slope protection, 18" thickness min.	2000	S.Y	$39,500.00	$80,000.00	$26,300.00	$145,800.00
Crew B-13	1 Labor Foreman (outside), 4 Laborers, 1 Equip. Oper. (crane), 1 Equip. Oper. Oiler 1 Hyd. Crane, 25 Ton	2	Day		$5,659.20		$5,659.20
Riprap	**Subtotal**						**$151,459.20**
Crew B-13	1 Labor Foreman (outside), 4 Laborers, 1 Equip. Oper. (crane), 1 Equip. Oper. Oiler 1 Hyd. Crane, 25 Ton	2	Day				$
Archpipes	Custom Archpipes			$56,052.86			$56,052.86
Culverts	**Subtotal**						**$ 56,052.86**
31 32 19.16 1500	Geotextile fabric, Heavy Duty, 600 lb. tensile strength	2000	S.Y	$3,700.00	$440.00		$4,140.00
Crew 2 Clab	Common Laborer	12	Hour		$421.20		$421.20
Soil Stabilization	**Subtotal**						**$4,561.20**

35 31 16.19 0210	Steel sheeting, with 4' x 4' x 8" concrete deadmen, @ 10' O.C. 12' high, shore driven	90	L.F	$ 9,090.00	$9,450.00	$11,520.00	$30,060.00
	Pump					$13,400.00	$13,400.00
Cofferdam	**Subtotal**						**$43,460.00**
03 31 05.35 0300	Concrete Ready Mix, 4000 psi	60	C.Y	$6,183.60			$6,183.60
	Common Laborer	24	Hour		$842.40		$842.40
Retaining Wall	**Subtotal**						**$7,026.00**

Table 9-3. Cost estimate breakdown of proposed design.

		Material	Labor	Equipment	Total	
Estimate Subtotal		$270,043.46	$152,849.51	$117,496.00	$540,388.96	
	Gen. Requirements	$40,506.52	$22,927.43	$17,624.40	$81,058.35	**Gen. Requirements**
0%	**Sales Tax**	0.00	0.00	0.00	0.00	**Sales Tax**
	Subtotal	$310,549.98	$175,776.93	$135,120.40	$621,447.31	**Subtotal**
10%	**GC O & P**	$31,055.00	$17,577.69	$13,512.04	$62,144.73	**GC O & P**
	Subtotal	$341,604.98	$193,354.62	$148,632.44	$683,592.04	**Subtotal**
5%	**Contingency**	$17,080.25	$9,667.73	$7,431.62	$34,179.60	**Contingency**
	Subtotal	$358,685.23	$203,022.36	$156,064.06	$717,771.65	**Subtotal**
1%	**Bond**	$3,586.85	$2,030.22	$1,560.64	$7,177.72	**Bond**
	Subtotal	$362,272.08	$205,052.58	$157,624.70	$724,949.36	**Subtotal**
	Location Adjustment	1.23	0.91	1.00	1.07	**Location Adjustment**
	Grand Total	$445,232.39	$185,982.69	$157,624.70	**$788,839.78**	**Grand Total**

Table 9-4. Cost estimate total of proposed design.