CCI

Government of Northwest Territories

Dempster Highway – Culvert Replacement Project

Design Memo – KM 40.2

DOCUMENT No. 2567-CCI-Design Memo

CCI PROJECT No. 2567

Prepared:	**Adam Hebert**
Revision:	**A**
Date:	**2022/05/05**
Hydrotechnical Review:	**Nic Boelhouwer**
Approved:	**Jami Taschuk**

Edmonton Area Office
17816 – 118 Ave NW
Edmonton, AB T5S 2W5
P: 780.784.1990

Calgary Area Office
2600, 520 – 5th Ave. SW
Calgary, AB T2P 3R7
P: 403.932.0560

Vancouver Area Office
1000, 700 West Pender Street
Vancouver, BC V6C 1G8
P: 604.500.0909

Houston Area Office
20445 State Hwy 249 Suite 250
Houston, TX 77070
P: 832.210.1030

Revision Log

Revision	Issue Status	Prepared by	Reviewed by	Approved by	Date Approved
A	IFR	Nic Boelhouwer Adam Herbert	Adam Hebert	Jami Taschuk	2022/05/05

Prepared by:

Nicolas Boelhouwer, P.Geo.
Engineering Geologist

Approved by:

Jami Taschuk P.Eng.
Project Manager

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The Government of the Northwest Territories has retained CCI Inc. (CCI) (GNWT) to analyze and design the replacement and decommissioning of three (3) existing culverts located along the Dempster Highway No.8 in the Northwest Territories. Culvert locations, as well as basic details regarding the existing culverts, are shown below in Table 1:

Table 1: Existing Culvert Details

Location (HWY Chainage)	Coordinates		Length (m)	Diameter (m)	Cover
KM 266.1	68º 20' 9.0."	133º 39 20.5."	43.2	2.5	5.5
KM 147.0	67º 29' 1.7"	133º 46' 0.7"	61.6	1.8	11.3
KM 40.2	**67º 13' 5.9"**	**135º 30' 15.9"**	**44.2**	**2.0**	**8.6**

This report addresses the proposed culvert installation and rehabilitation of the existing culvert located at KM 40.2 only.

2 KILOMETRE POINT 40.2 CULVERT

2.1.1 Location Summary

Kilometre Point 40.2 of the Dempster Highway (KM40.2) is located along HWY 8 approximately 40 km southwest of Fort McPherson, NWT. The existing culvert at this location has a nominal diameter of 2.0 m and an installed length of 44.2 meters. The depth of cover (DOC) from the top of the pipe to the road centreline is 8.6 m. The culvert has north south alignment, with upstream situated on the north side of the culvert. Drainage flow ultimately feeds into the Mackenzie River via several tributaries. After a structural and hydraulic assessment by GNWT, the culvert at this location has been selected for replacement and decommissioning.

The survey at this location was performed by White Bear Geometrics Ltd. and can be found in Appendix A. The imagery of the site location can be seen below:

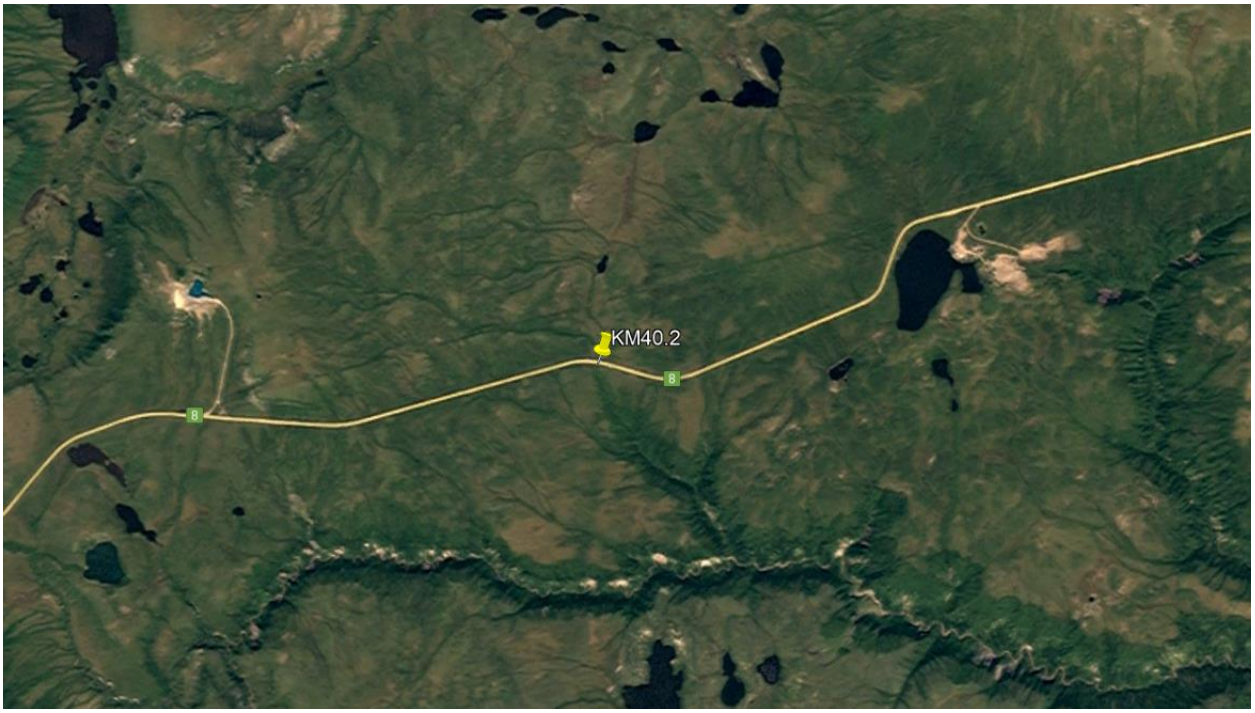


Figure 1: KM40.2 Crossing Location

2.1.2 Geotechnical Information

Tetra Tech Canada Inc. was retained by GNWT, Department of Infrastructure to complete a geotechnical investigation to conduct a geotechnical site investigation at the culvert crossing at KM 40.2 on the Dempster Highway (HWY 8). As part of the project, two (2) boreholes, labelled as BH-04 and BH-05, were drilled near the KM40.2 culvert location. A summary of the information garnered from drilling and sampling of these boreholes is listed below in Table 2:

Table 2: KM40.2 Boreholes

Borehole	Depth (m)	Location UTM (NAD 83 UTM Z8)	Description	Primary Geotechnical Concerns
BH-04	24 m	N: 7455798 E: 478210	5 m Sand (Fill) 19 m Clay	High plastic clay, permafrost and ice rich zones
BH-05	20.7m	N: 7455821 E: 478191	5.5 m Silt (Fill) 17.3 m Clay	High plastic clay, permafrost and ice rich zones

The road embankment will require a trenchless installation technique for the culvert replacement. This will be discussed further in the Design Considerations section of this report.

Tetra Tech's Borehole Logs as part of Project No.: ENG.YARC03234-01 "*Geotechnical Investigation of Existing Culverts"* completed by Tetra Tech can be found in Appendix B of this report

3 ENGINEERING

3.1 HYDROTECHNICAL DESIGN

3.1.1 Hydrology

3.1.1.1 Flood Design Discharge

As outlined in the Project Design Basis, the new culvert "shall be able to accommodate a 100-year return period flow." As well, "climate change shall be accounted for while calculating flow rates."

The Flood Design Discharge for the KM40.2 watercourse was estimated in Tetra Tech's *"Hydrotechnical Assessment of Culvert Streams"* File No.: 704-TRN.WTRM03108-01. The analysis was reviewed by CCI and the values for flood discharge at the culvert location were determined to be reasonable.

A flood design discharge of 5.5 m^3/s was selected. This allows for a 30% increase to the Q100 to accommodate climate change impacts.

3.1.1.2 Safe Fish Design Discharge

To determine the Safe Fish Passage Design Discharge, the 3Q10 design discharge was specified as part of the Project Design Basis.
The Fish Passage Design Discharge for the KM40.2 watercourse was estimated in Tetra Tech's *"Hydrotechnical Assessment of Culvert Streams"* File No.: 704-TRN.WTRM03108-01. The analysis was reviewed by CCI and the values for fish passage design discharge at the culvert location were determined to be reasonable.

A fish passage design discharge of 1.40 m^3/s was selected.

3.1.1.3 Low Flow Design Discharge

Low flow conditions were considered as part of the design. During the summer/fall season (determined to be July 15 to October 31), the flow is typically very low. Tetra Tech measured the discharge at the crossing location and documented the results within their report *"Hydrotechnical Assessment of Culvert Streams"* File No.: 704-TRN.WTRM03108-01. On September 11, 2018, the measured discharge was 0.0004 m^3/s. This value was used as the Average Daily Discharge for the summer/fall season at the KM40.2 watercourse.

Between November and April water discharge is negligible due to frozen conditions.

3.1.1.4 Construction Design Discharge

The construction of the new 3.0m culvert is expected to commence in the fall and be completed in the winter. As part of the design, the water flows expected during the construction timeframe will be managed as part of the isolation procedure to ensure safe fish passage and minimize any potential siltation caused by construction activities.

To determine a construction design discharge for the KM40.2.0 watercourse, Environment Canada Gauge Station - 10LC017 Havipak Creek Near Inuvik was used. It was noted that daily discharges have recently increased significantly which is understood to be attributed to climate change. The Highest Annual Daily Discharge from July 15 to October 31 has increased significantly from 0.2 m^3/s (1995 to 2004) to 1.49 m^3/s (2008 to 2017). Upon reviewing the flow data, a deterministic rather than probabilistic approach was used to arrive at a Construction Design Discharge of 0.5 m^3/s.

3.1.2 Culvert Hydraulics

The culvert hydraulics are modelled using the US Department of Transportation Federal Highway Administration HY-8 Culvert Hydraulic Analysis Program.

From the hydrology analysis described above, the following design discharges were selected for the hydraulic analysis.

- Flood Discharge = 5.5 m^3/s
- Safe Fish Passage Design Discharge (3Q10) = 1.4 m^3/s
- Low Flow Design Discharge = 0.0004 m^3/s
- Construction Design Discharge = 0.5 m^3/s (July 15 to November 1)

Upon completion of the hydraulic analysis, a technical risk, a cost assessment, and a construction logistical analysis was completed the results were provided to the Government of the Northwest Territories. It was determined that a single 3.0 m diameter smooth steel bored culvert which will be embedded 0.6 m with substrate holders to promote safe fish passage was the preferred option.

Table 4 summarizes the output of the hydraulic analysis.

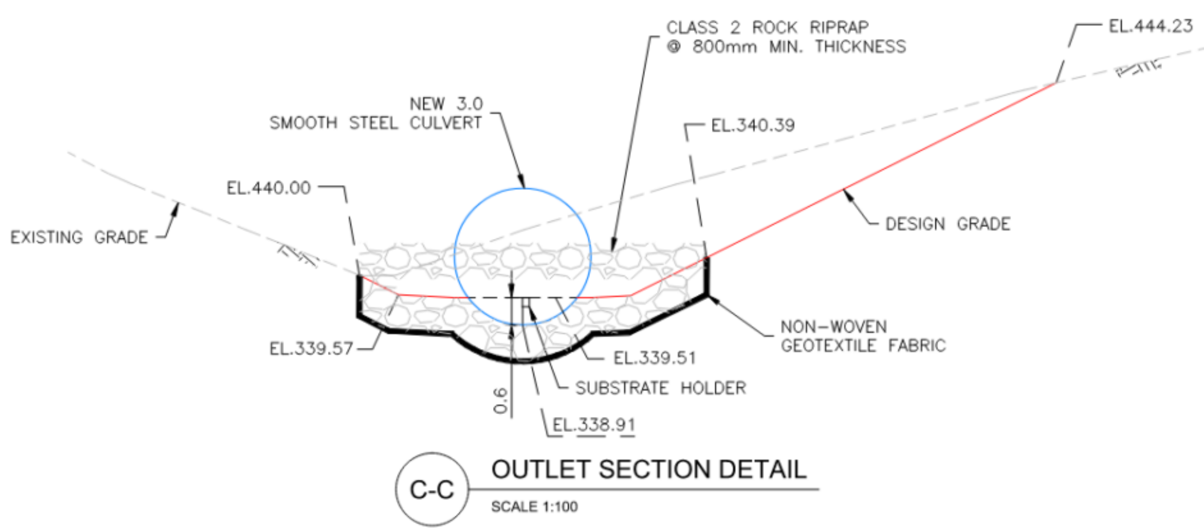


Figure 2 Culvert Geometry (Outlet)

Table 3 Hydraulic Analysis Output

Design Discharge	Culvert Outer Diameter (m)	Culvert Length (m)	Headwater Elevation from Invert (m)	Outlet Depth from Invert (m)	Outlet Velocity (m/s)
Flood Condition ($Q=5.5\ m^3/s$)	3.0	49.0	1.98	1.36	2.63
Safe Fish Passage ($Q = 1.4\ m^3/s$)	3.0	49.0	1.18	1.02	1.27
Low Flow Condition ($Q = 0.04\ m^3/s$)	3.0	49.0	0.81	0.6	0.13

The following sub-sections describe the various design variables, assumptions and considerations used in the design of the culvert.

3.1.2.1 Culvert Diameter

3.0 m smooth steel bored culvert (embedded 0.6 m for safe fish passage).

Given the approximately 8.6 m depth of cover between the proposed 3.0 m culvert and the highway surface, it is believed that the best construction method will be a trenchless bored smooth steel culvert. A bored installation will negate the need for a large conventional excavation and associated traffic disruptions. A review of trenchless vendors was conducted, and it was determined that the largest commercially available trenchless bore diameter would be 3.0 m. Accordingly, the culvert size has been selected based on a maximum 3.0 m diameter.

Based on field survey data (Q2, 2021), it was determined that the existing culvert had deformed to such an extent that it would not be practical to place a culvert liner within the existing culvert of any size that would significantly enhance flow capacity.

3.1.2.2 Culvert Slope

The slope of the 3.0 m culvert will be 1%.

The existing 2 m corrugated culvert has a slope of 1.6%. Since the installation of the culvert in 1973, it appears that the culvert slope has adequately provided sediment transportation as evidenced by only minor bed aggradation and degradation immediately upstream and downstream of the culvert. Accordingly, the design of the new bored 3.0 m culvert will occur at a slope of 1%.

3.1.2.3 Culvert Length

The length 3.0 m culvert is 49.0 m.

3.1.2.4 Safe Fish Passage Design Measures

To accommodate fish passage for a range of flow conditions, various design measures have been included in the design including:

1) Embedment of the 3.0 m culvert.
2) Substrate holders in the 3.0 m culvert.
3) Resting area immediately upstream of the culvert.

Initially, as part of the pre-engineering design phase, a safe fish passage design approach using more natural stream characteristics such as embedding the 3.0 m culvert to a depth of 20% and using large rock and natural bed material to provide resting areas within the culvert. This design approach has been implemented by Alberta Transportation in certain instances.

To determine the potential level of acceptance that DFO may have for this approach, a series of informal meetings and preliminary design information was shared with DFO staff.

DFO staff reiterated that their design criteria for reviewing culverts for safe fish passage is by comparing the average velocity in the culvert as determined from the 3Q10 discharge and comparing these average velocities with fish swimming performance curves.

DFO staff were aware of the present limitations to fish swimming performance curves given the limited data available. The use of fish swimming curves can provide significantly conservative calculations leading to large or multiple culverts. DFO staff were very helpful and open to considering alternate design methodologies to address safe fish passage and stated that if that was the proposed methodology, a formal Request for Review would be required as part of the submission.

During the detailed design phase, it was determined that the best engineered solution to accommodate all potential fish species was the use of substrate holders. For the KM40.2 watercourse crossing, the 3Q10 discharge of 1.4 m3/s was used as the Safe Fish Passage Design Discharge (FPDD). From the hydraulic modelling, the outlet velocity of the 3.0 m culvert (embedded 20%) is 1.27 m/s (3Q10 velocity).

A fish study was completed by Kavik-Stantec (Ref. *Dempster Highway km 40.2 Fish and Fish Habitat Assessment*) for the watercourse crossing at KM40.2 that concluded that although no fish were found as part of the study, there was fish habitat and that the various fish species identified in Table 4 Fish Swimming Performance data for potential fish species at KM 40.2, may be present within the watercourse.

The DFO Fish Calculator was used to determine the swimming performance of the potential species identified in the KM40.2 Fish Study. The DFO Fish Calculator uses a collection of fish swimming performance fatigue (swim speed versus endurance time) and distance (swim distance versus water velocity) curves. The results are presented in the following table.

Table 4 Fish Swimming Performance data for potential fish species at KM 40.22

Table 4 Fish Swimming Performance data for potential fish species at KM 40.2

Table 4 Fish Swimming Performance data for potential fish species at KM 40.2 (continued)

Common Name	Scientific Name	Spawning Timing	Average Length (cm)	DFO Equivalency Name	Fish Swimming Performance Velocity Probability (able to meet design velocity) - Based on 49 m Culvert	Burst Velocity Probability - Based on 2 m swimming distance
Arctic grayling	*Thymallus arcticus*	May-Jun	30-40	Salmon and Walleye Group	Length = 350mm 50% - 1.1 m/s 87.5% - 0.64 m/s	Length = 350mm 50% - 2.8 m/s 87.5% - 1.9 m/s
Arctic lamprey	*Lampetra camtschatica*	Apr-Jul	20-30	Eel Group	Length = 250mm 50% - 0.21 m/s 87.5% - 0.13 m/s	Length = 250mm 50% - 1.6 m/s 87.5% - 1.2 m/s
Broad whitefish	*Coregonus nasus*	Oct-Nov	41-50	Salmon and Walleye Group	Length = 450mm 50% - 1.3 m/s 87.5% - 0.79 m/s	Length = 450mm 50% - 3.3 m/s 87.5% - 2.2 m/s
Brook stickleback	*Culaea inconstans*	May-Jul	5	Salmon and Walleye Group	Length = 50mm 50% - 0.21 m/s 87.5% - 0.13 m/s	Length = 50mm 50% - 0.61 m/s 87.5% - 0.37 m/s
Burbot	*Lota lota*	Feb-Mar	30-40	Eel Group	Length = 380mm 50% - 0.33 m/s 87.5% - 0.2 m/s	Length = 380mm 50% - 1.7 m/s 87.5% - 1.2 m/s
Cisco	*Coregonus artedi*	Sep-Dec	20-30	Salmon and Walleye Group	Length = 250mm 50% - 0.81 m/s 87.5% - 0.48 m/s	Length = 250mm 50% - 2.2 m/s 87.5% - 1.4 m/s
Dolly varden	*Salvelinus malma*	Sep-Nov	38-61	Salmon and Walleye Group	Length = 500mm 50% - 1.4 m/s 87.5% - 0.86 m/s	Length = 500mm 50% - 3.5 m/s 87.5% - 2.4 m/s
Finescale dace	*Phoxinus neogaeus*	Jun-Jul	7	Salmon and Walleye Group	Length = 70mm 50% - 0.28 m/s 87.5% - 0.17 m/s	Length = 70mm 50% - 0.81 m/s 87.5% - 0.48 m/s
Flathead chub	*Platygobio gracilis*	Jul-Aug	20-30	Salmon and Walleye Group	Length = 250mm 50% - 0.61 m/s 87.5% - 0.36 m/s	Length = 250mm 50% - 1.8 m/s 87.5% - 1.1 m/s
Lake chub	*Couesius plumbeus*	Apr-Aug	5-9	Salmon and Walleye Group	Length = 70mm 50% - 0.28 m/s 87.5% - 0.17 m/s	Length = 70mm 50% - 1.1 m/s 87.5% - 0.66 m/s
Lake trout	*Salvelinus namaycush*	Sep-Oct	45-65	Salmon and Walleye Group	Length = 508mm 50% - 1.5 m/s 87.5% - 0.87 m/s	Length = 508mm 50% - 3.5 m/s 87.5% - 2.4 m/s
Lake whitefish	*Coregonus clupeaformis*	Sep-Nov	40-55	Salmon and Walleye Group	Length = 475mm 50% - 1.1 m/s 87.5% - 0.68 m/s	Length = 475mm 50% - 2.9 m/s 87.5% - 2.0 m/s

Common Name	Scientific Name	Spawning Timing	Average Length (cm)	DFO Equivalency Name	Fish Swimming Performance Velocity Probability (able to meet design velocity) - Based on 49 m Culvert	Burst Velocity Probability - Based on 2 m swimming distance
Least cisco	*Coregonus sardinella*	Jul-Oct	10-20	Salmon and Walleye Group	Length =150mm 50% - 0.53 m/s 87.5% - 0.31 m/s	Length = 150mm 50% - 1.5 m/s 87.5% - 0.92 m/s
Longnose dace	*Rhinichthys cataractae*	May-Aug	5-9	Salmon and Walleye Group	Length =70 mm 50% - 0.28 m/s 87.5% - 0.17 m/s	Length =70mm 50% - 0.81 m/s 87.5% - 0.48 m/s
Longnose sucker	*Catostomus catostomus*	May-Jul	30-50	Salmon and Walleye Group	Length =350mm 50% - 1.1 m/s 87.5% - 0.64 m/s	Length =350mm 50% - 2.8 m/s 87.5% - 1.9 m/s
Ninespine stickleback	*Pungitius pungitius*	May-Jul	51	Salmon and Walleye Group	Length = 510mm 50% - 1.5 m/s 87.5% - 0.87 m/s	Length = 510mm 50% - 3.5 m/s 87.5% - 2.4 m/s
Northern pike	*Esox lucius*	Immediately after ice out	40-50	Northern Pike (Derived)	Length = 450mm 50% - 0.6 m/s 87.5% - 0.41 m/s	Length = 450mm 50% - 2.2 m/s 87.5% - 1.7 m/s
Northern redbelly dace	*Phoxinus eos*	Jul-Aug	4-5	Salmon and Walleye Group	Length = 45mm 50% - 0.19 m/s 87.5% - 0.12 m/s	Length = 450mm 50% - 2.2 m/s 87.5% - 1.7 m/s
Pond smelt	*Hypomesus olidus*	June-July	10-20	Salmon and Walleye Group	Length = 150mm 50% - 0.53 m/s 87.5% - 0.31 m/s	Length = 150mm 50% - 1.5 m/s 87.5% - 0.92 m/s
Rainbow smelt	*Osmerus mordax*	Mar-May	10-25	Salmon and Walleye Group	Length = 175mm 50% - 0.6 m/s 87.5% - 0.36 m/s	Length = 175mm 50% - 1.7 m/s 87.5% - 1.0 m/s
Round whitefish	*Prosopium cylindraceum*	Oct-Dec	20-30	Salmon and Walleye Group	Length = 250mm 50% - 0.81 m/s 87.5% - 0.48 m/s	Length = 250mm 50% - 2.2 m/s 87.5% - 1.4 m/s
Slimy sculpin	*Cottus cognatus*	May-Jun	61	Salmon and Walleye Group	Length = 610mm 50% - 1.7 m/s 87.5% - 1.0 m/s	Length = 610mm 50% - 3.9 m/s 87.5% - 2.7 m/s
Spoonhead sculpin	*Cottus ricei*	Aug-Sep	81	Salmon and Walleye Group	Length = 810mm 50% - 2.2 m/s 87.5% - 1.3 m/s	Length = 810mm 50% - 4.7 m/s 87.5% - 3.2 m/s
Spottail shiner	*Notropis hudsonius*	Jun-Jul[9]	6-8	Salmon and Walleye Group	Length = 70mm 50% - 0.28 m/s 87.5% - 0.17 m/s	Length = 70mm 50% - 0.81 m/s 87.5% - 0.48 m/s
Trout-perch	*Percopsis omiscomaycus*	May-Aug	7.5-10	Salmon and Walleye Group	Length = 90mm 50% - 0.34 m/s 87.5% - 0.21 m/s	Length = 90mm 50% - 1.0 m/s 87.5% - 0.6 m/s
Walleye	*Sander vitreus*	Apr-May	40-60	Salmon and Walleye Group	Length = 500mm 50% - 1.4 m/s 87.5% - 0.86 m/s	Length = 500mm 50% - 3.5 m/s 87.5% - 2.4 m/s

Alberta Transportation Methodology

Several studies have been conducted that demonstrate that actual velocities in a culvert vary significantly from the "average velocity" which is the criteria used by DFO to assess culvert sizing. As indicated in Figure 3 Culvert Cross Section Velocity, velocities are significantly lower at the interface of the water with the substrate and culvert walls providing areas of low velocities promoting fish passage. Recent studies (Alberta Transportation May 2020) have concluded:

- "20% of the flow area will have point velocities less than 70% of the mean velocity
- the average of all point velocities in the region will be less than 50% of the section-averaged mean velocity.
- This suggests that application of fish swimming performance curves using the mean velocity from culvert hydraulics models can substantially underestimate the potential for fish passage."

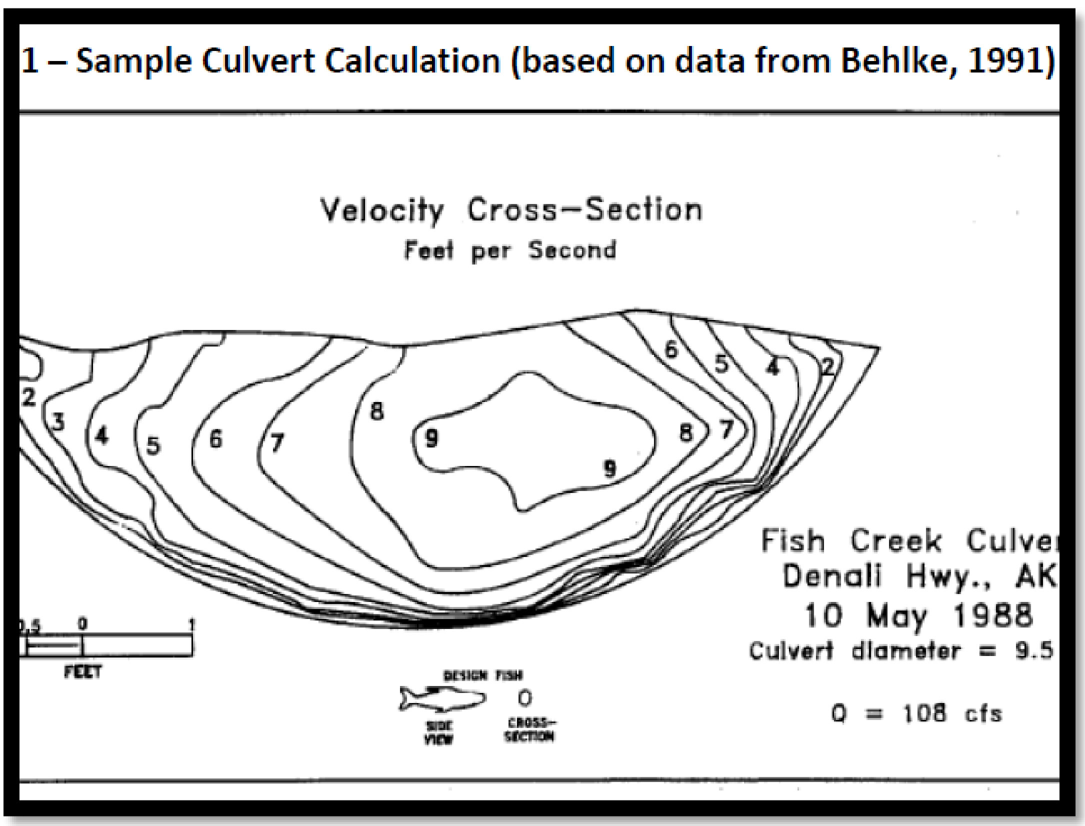


Figure 3 Culvert Cross Section Velocity

Substrate holders and pipe embedment

Substrate holders (or baffles) are intended to create allowable velocities during fish passage flows, while not exceeding fish turbulence thresholds. Substrate holders divide the culvert into a series of cells and bays, creating resting areas between the substrate holders, and points of higher velocity at the substrate holders. Fish are assumed to use their prolonged swimming speed along lower velocity areas and in between the substrate holders, use their burst speed to navigate around the substrate holders.

Some of the most comprehensive substrate holder research available comes from number of studies completed at the University of Alberta under the direction of Dr. Rajaratnam. Much of this research was funded and supported by the DFO.

Based on this research, Dr Rajaratnam, was consulted and recommended a weir substrate holder identified in Figure 2 Culvert Geometry (Outlet). The weir substrate holder will be embedded within the 3.0 m culvert to a depth of 0.6 m. The length between substrate holders will be 1.8 m. Natural bed material will fill between the substrate holders. In times of larger discharges (and velocities) the substrate holders will create turbulent flow and allow for fish resting areas between the substrate holders.

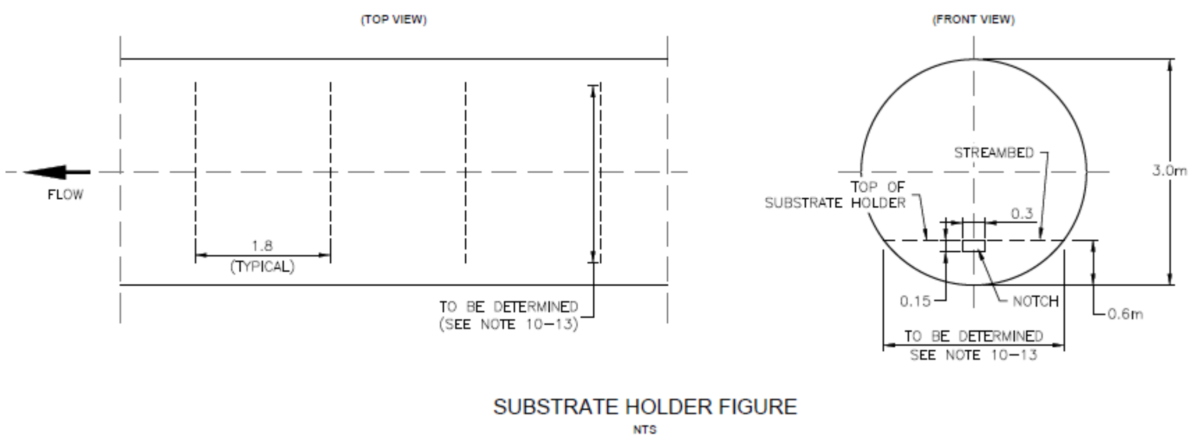


Figure 4: Substrate Holder Detail

A notch measuring 300 mm wide and 200 mm deep will be placed in the centre of the substrate holder. The notch will provide the necessary flow depth to allow fish passage during low flow conditions. In addition, the low flow channel has been extended into the outlet apron/dissipation pool to ensure a defined watercourse pathway.

Resting areas immediately upstream and downstream of the culvert – The large rock rip rip rap immediately upstream and downstream of the culvert will create areas with lower velocities for fish resting areas.

At the Culvert Inlet, two or three large Class 2 riprap rocks will be placed in the inlet apron to provide a resting area. The large Class 2 rocks will be field placed so that the top of the rocks extend to the surface for the Fish Passage Design Discharge. The rocks will be placed to minimize any potential impact to the flow characteristics of the inlet and culvert.

3.1.2.5 Inlet and outlet design

Inlet Design

To accommodate the high velocities and to streamline the flow of water into the culverts, an apron comprised of Class 1 Rock Rip underlain by a non-woven geotextile will be used as shown in Figure 5 Inlet Plan View.

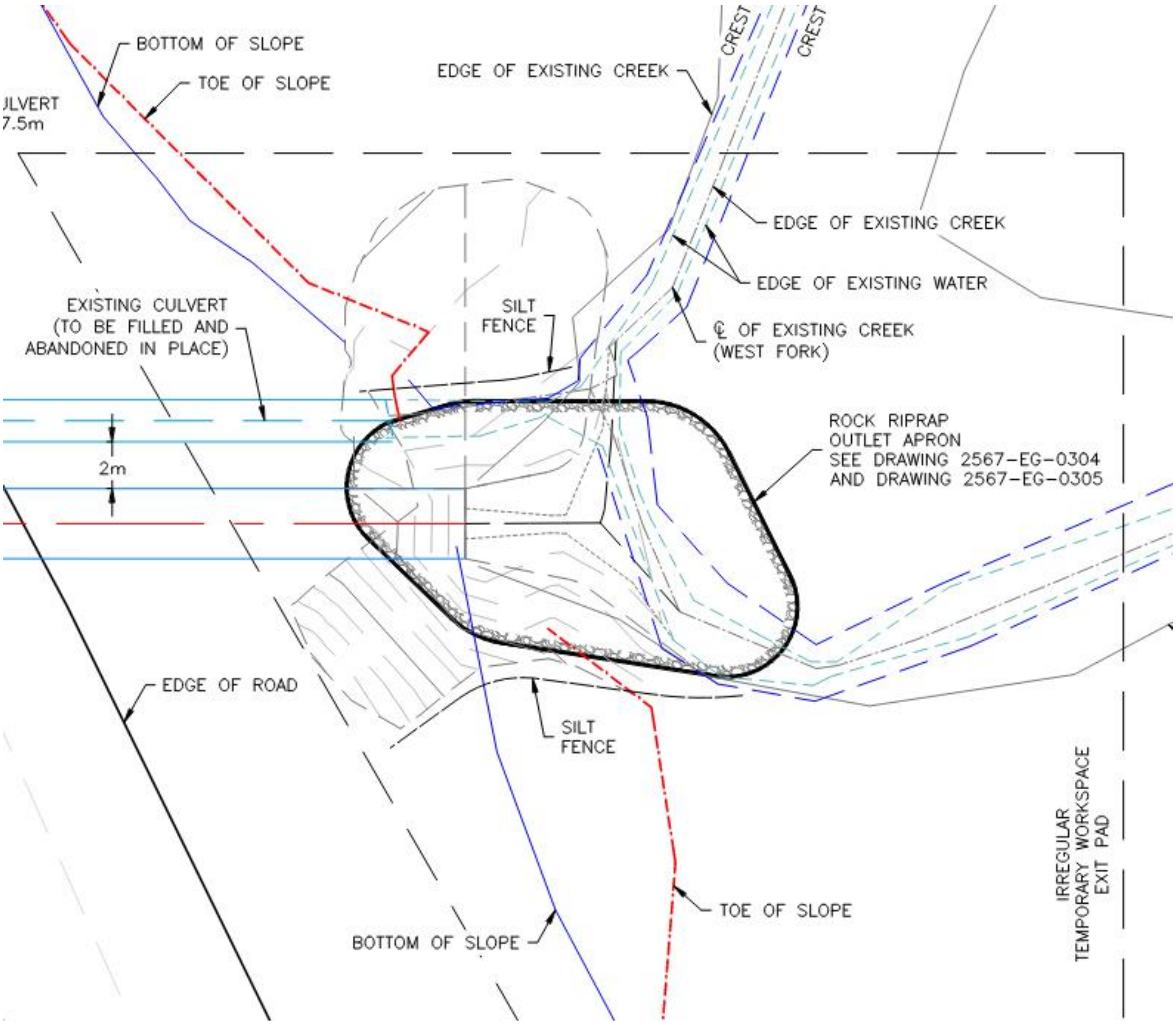


Figure 5 Inlet Plan View

From the hydraulic modelling, the culvert is inlet controlled with the headwater being just below the top of the culverts for the flood discharge. To accommodate potential ice and debris impacting the culvert hydraulics, the rock rip rap will be extended to the top of the culvert.

Compaction specifications for the new culverts have been included on the design drawings. Environmental remediation measures will be installed as part of the construction to minimize siltation and degradation of the area immediately surrounding the culvert inlet and outlet.

Outlet Design

As indicated in Figure 6 Outlet Plan View the main channel originally flows into a pool from the culvert outlet. This pool is the result of a beaver dam just downstream from the outlet. As part of the culvert outlet design, this beaver dam will be removed to streamline flow conditions and promote fish passage.

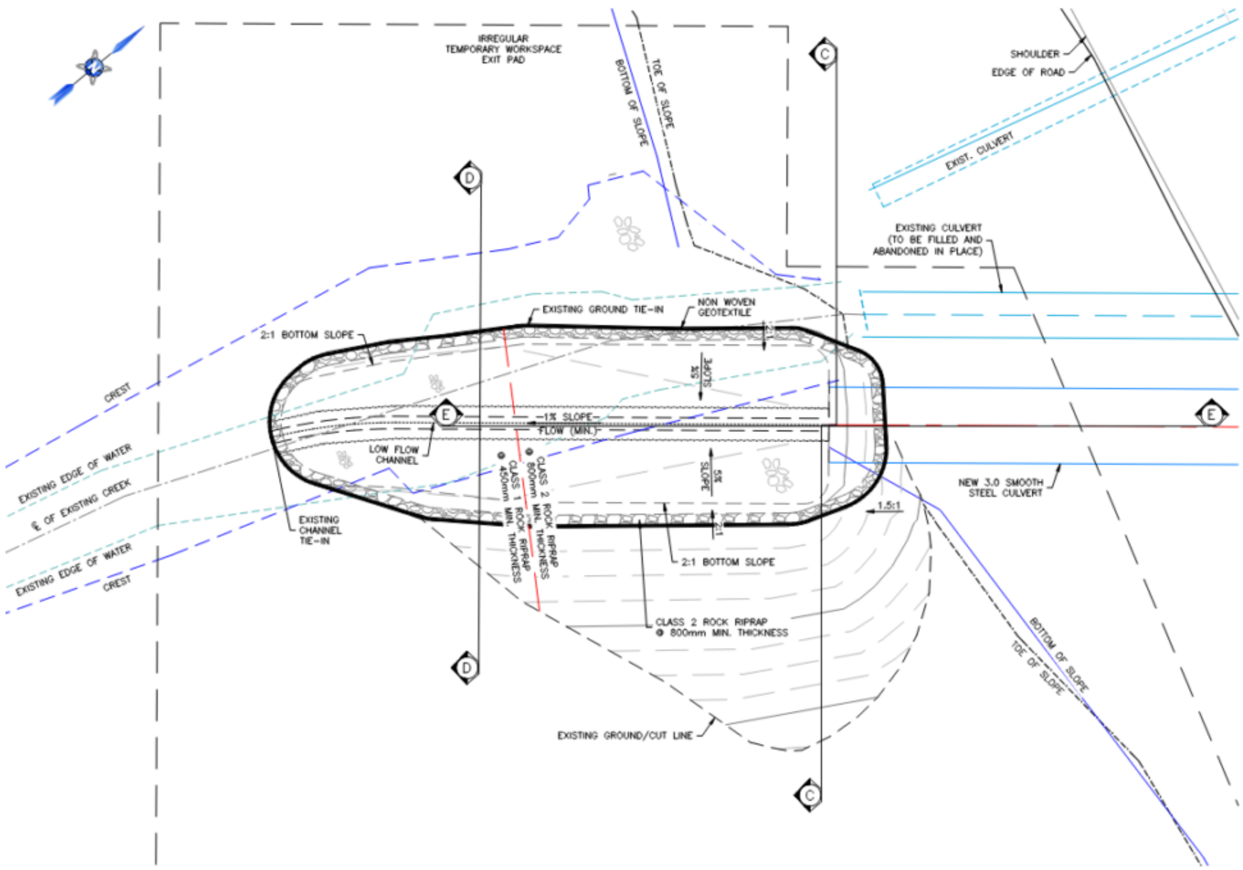


Figure 6 Outlet Plan View

The new 3.0 m culvert will be bored approximately 4.5 m center-to centre away from the existing 2.0 m culvert in an area that presently comprised of a large side slope. The 3.0 m culvert will be bored from the inlet to the outlet. As part of installation of the boring machine setup, the sidehill we be graded to a similar elevation and geometry as the outlet basin apron.

To dissipate the waterflow energy for large flood events and corresponding high velocities, a basin with Class 1 Rock Rip Rap underlain with a non-woven geotextile liner will be created. The Rock Rip Rap will encompass the basin walls at a slope of 2H:1V to the height of the 100-year flood event water level.

To accommodate fish passage in low flow conditions, the basin will be sloped to a low flow channel as indicated in Figure 7.

3.2 PIPE CONSIDERATIONS

3.2.1 Culvert Specifications

Table 5: Estimated Pipe Specifications

Diameter (m)	Grade (MPa)	Length (m)	Wall Thickness (mm)	Depth Under Highway(m)	Operating Pressure
3.0	290 (X42)	65.4..	25.4	10.6	Atmospheric

3.2.2 New Culvert Installation Stress Analysis

Table 6: Alignment Summary

Section #	From M.D. (m)	To M.D. (m)	Length (m)	Tangent Angle (°)	Curve Radius (m)	Notes
1	0	10	10	0	∞	Non-Lubricated
2	10	42	32	0	∞	Lubricated

Table 7: Friction Summary

Dynamic Case			
Section	Lubrication Friction Force Flb (kN)	Front Force Ff (kN)	Friction Between Pipe and Tunnel Wall (kN)
1	4.7	2216.4	160.1
2	21.6	2216.4	733.3
Static Case			
Section	Lubrication Friction Force Flb (kN)	Front Force Ff (kN)	Friction Between Pipe and Tunnel Wall (kN)
1	9.4	2216.4	320.2
2	43.2	2216.4	1466.7

Table 8: Jacking Force Summary

<table>
<tr><th colspan="5">Without Safety Factor</th><th rowspan="2">Equipment Specification Check</th></tr>
<tr><th>Section</th><th>Dynamic (kN)</th><th>Dynamic (lbf)</th><th>Static (kN)</th><th>Static (lbf)</th></tr>
<tr><td>1</td><td>2381</td><td>535148</td><td>2546</td><td>572191</td><td rowspan="3">Overall Maximum Expected Thrust Force (Tonne) = 517</td></tr>
<tr><td>2</td><td>3136</td><td>704805</td><td>4056</td><td>911505</td></tr>
<tr><td colspan="5"></td></tr>
</table>

					Recommended Min. Jacking Capabilities =
With Safety Factor					
	Dynamic SF= 1.5		Static SF = 1.25		700 Tons
Section	Dynamic (kN)	Dynamic (lbf)	Static (kN)	Static (lbf)	
1	3572	539711	2207	496063	
2	4704	1057208	5070	1139381	

4 ENVIRONMENT AND REGULATORY

The detailed design and construction planning for the installation of the 3 m culvert and the decommissioning of the 2 m culvert considered potential environmental effects and regulatory requirements at the federal level through Fisheries and Oceans Canada, and the territorial level.

Over the past year there has been ongoing discussion amongst and between CCI, the GNWT and Fisheries and Oceans Canada (DFO) with regard to meeting the environmental requirements for a crossing pursuant to federal legislation, regulations and policy. CCI was retained by the GNWT to provide support for submitting additional information to complete a DFO Request for Review application for the project.

In support of the detailed design and construction planning, desktop assessments were completed to describe the fish community and fish habitat within the vicinity of the proposed project. An initial field assessment was undertaken to update available desktop information and to characterize fish habitat at the proposed project site. This work was carried out for CCI by Kavik-Stantec Inc. (Kavik) and is documented in their *Dempster Highway Km 40.2 Fish and Fish Habitat Assessment* report (Kavik 2021).

These assessments formed the baseline for the environmental setting and fish and fish habitat for consideration and inclusion in the detailed design. Additional information was considered through the design process and site-specific characteristics of the project site were considered through the development of construction planning. This effort has culminated in the development of the Watercourse Crossing Environmental Protection Plan (WCEPP) (CCI 2022). The WCEPP provides the regulatory framework, baseline environmental and fish and fish habitat assessment information, the construction sequencing and the environmental mitigation to avoid and/or minimize potential environmental effects through the construction process. Supplemental drawings were developed to spatially present the construction sequencing from construction commencement through reclamation; please refer to drawing 2567-EG-0307-B.

5 CONSTRUCTION

5.1 NEW CULVERT INSTALLTION – OVERVIEW OF TRENCHLESS METHODOLOGY

Construction using a Tunnel Boring Machine (TBM), or an equivalent Excavator Boring Shield Machine (EBS) is a trenchless installation technique to install pipe(s) beneath the ground surface under road, existing utilities, rail and watercourses.

The launch and reception of the TBM is typically done from/to a shaft or pit constructed down lower than the alignment, this additional depth depends on the contractor's equipment requirements.

Jacking or casing pipe for TBM style of installation can consist of reinforced concrete pipe (RCP), Steel where each joint must be welded to form a watertight seal, HOBAS reinforced fibreglass resin structure and Permalok steel with press fit joints. Vitrified clay jacking pipe can also be utilized but is not typically preferred within the industry for these diameters, lengths, and formations.

Jacking pipe is then placed behind the TBM in segments and is advanced along the proposed alignment, the press is moved back to allow for the next section of jacking pipe to be lowered on to the rails. As the machine is advanced the contractor will pump lubrication fluid through the pre-installed ports in the jacking pipe, this helps manage jacking forces and supports the soils around the tunnel wall.

The tooling at the face excavates the material and cuttings transported along a conveyor belt back to where the muck bucket and haul unit (figure 4) are situated. Once full, the haul unit is electrically driven along a pre-installed rail system to the launch pit / shaft. A piece of lifting equipment then removes the muck bucket form the pit and unloads to the cuttings on surface before the bucket is lowered back onto the rail system and shuttled back to the conveyor belt.

Once the machine punched out into the receiving pit / shaft is can be removed using an appropriately rated equipment, leaving the casing / carrier pipe in situ. The lubrication and grout ports are then used to pump a flowable grout in the annular space to restrain the casing / carrier pipe within the formation. Any ports added into the casing pipe for pumping of grout or lubrication can be welded closed to prevent migration of ground water into the pipe.

5.1.1 Tunnel Boring Machine

5.1.1.1 Diameters and Sizing

The TBM comes in a range of sizes between 1219.1mm (48") to 4267mm (168"), customs sizes are available from the manufacture upon request. The overcut for these machines typically is 0.75" radially.

Figure 7. Tunnel Boring Machine

5.1.1.2 Excavator Boring Shield (EBS) Face Support & Excavation

The native material at the face that is being excavated can be supported using the hydraulically operated sand shields, these sand shields prevent excessive material from sluffing in causing over excavation. This style of TBM works best in sand, medium to stiff clay, dry or dewatered soil and weather rock in regions without groundwater present. The excavator backhoe claw has a full range of motion connected to the EX-50 boom and can reach beyond the face of the bore to remove or breakup material before they are carried by the conveyor system.

Figure 8. Tunnel Boring Machine Showing Shields and Excavator "Claw"

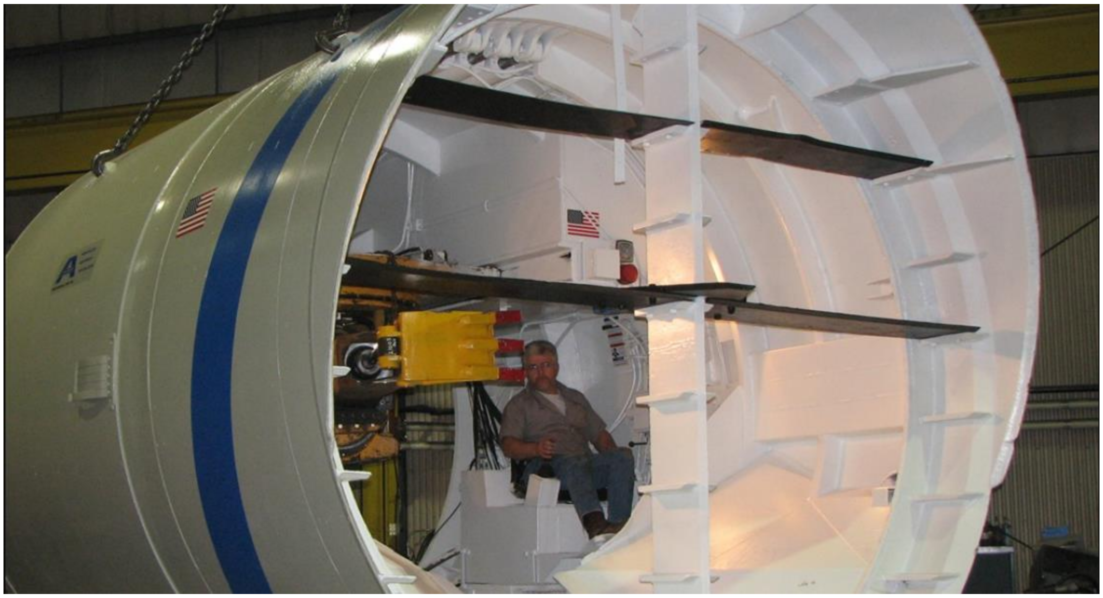


Figure 9. Tunnel Boring Machine Showing Internal View

5.1.1.3 TBM – Face Support and Excavation

5.1.2 The Press or Keyhole Jacking Frame

The equipment that provides the jacking forces through the extension of hydraulic cylinders, once fully extended they retract to allow the next section of pipe to be lowered into place. The keyhole jacking frame is typically used for pipe installation diameters above 96" and have the jacking capacity of between 400 to 1200 tonnes for force.

The jacking fame is welded to a surveyed and leveled rig mat, fine tuning can me managed with the threaded puck feet.

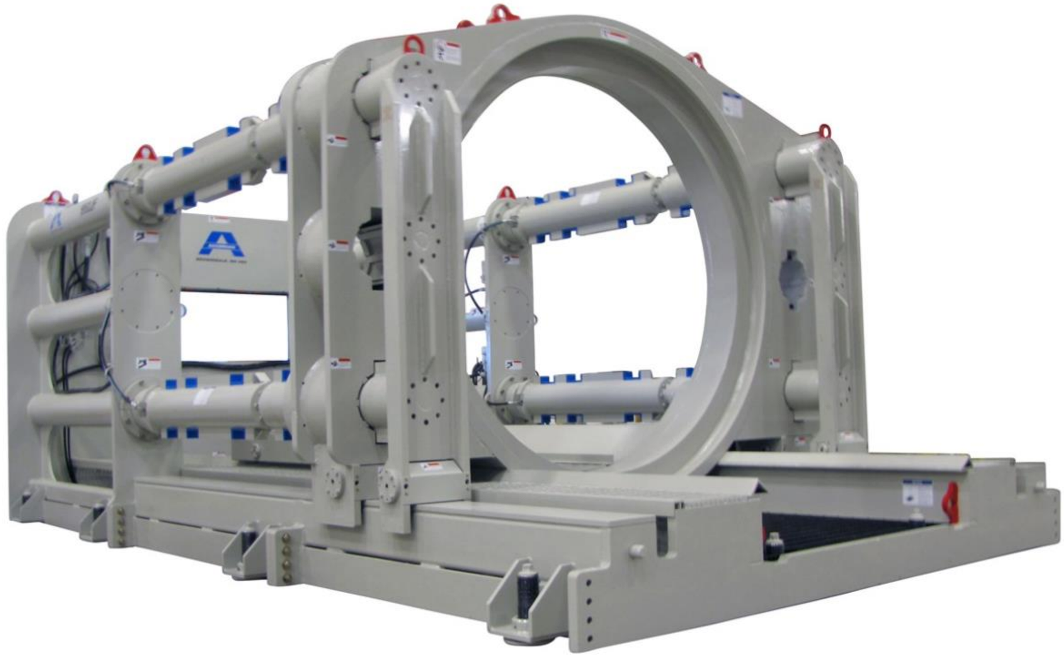


Figure 10. Keyhole Jacking Frame

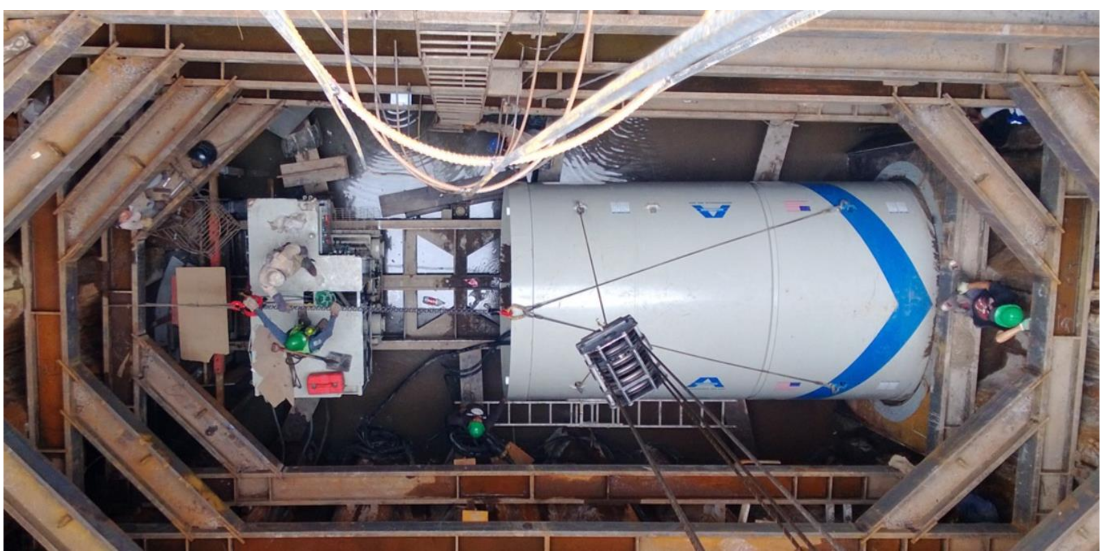


Figure 11. 5200 Press Unit Setup on Rails

5.1.3 Guidance Control

The EBS is steered by the operator situated close to the face of the machine, the operator is referencing a laser that is shot along the alignment from the launch pit to a target at the face. The laser is housed in a protective box which has its own standalone footings, this is surveyed in and confirmed with a laser level. A stringline will be surveyed in and run across the top of the launch pit this is a manual check the laser alignment before and periodic throughout the drive.

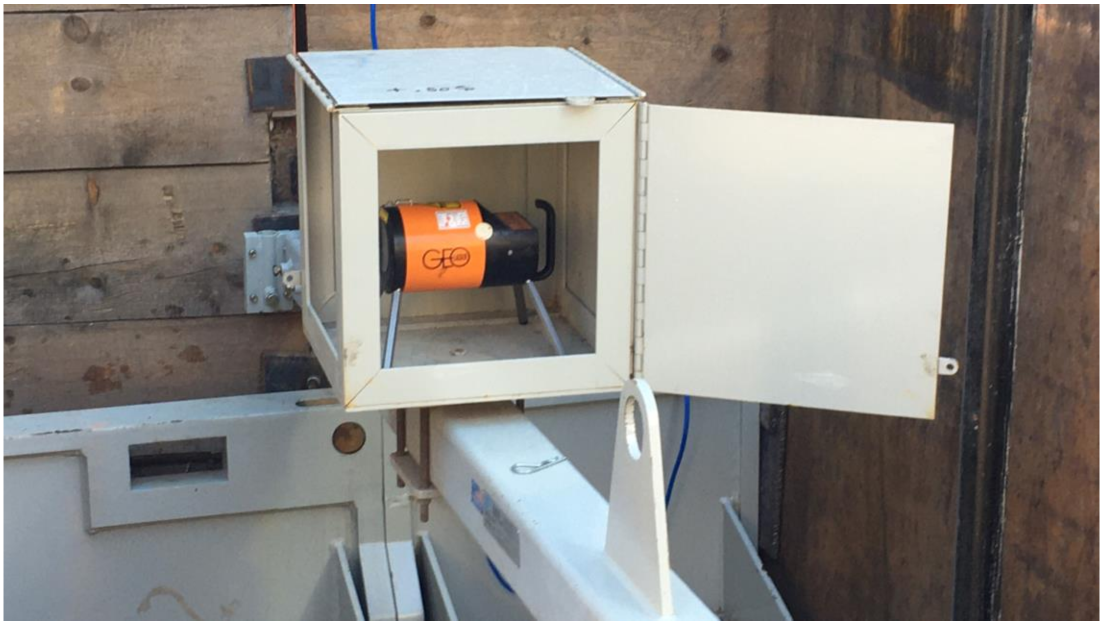


Figure 12. Geo Laser KL-91L

5.1.4 Haul Unit & Muck Bucket

Cuttings are transported from the face to the muck bucket using a conveyor belt suspended from the roof of the EBS. Once the muck bucket is full the haul unit is electrically operated and travels along the installed rail system to bring the cuttings into the launch pit. A crane of piece of lifting equipment the lifts the muck bucket to surface where is it emptied out. The empty muck bucket is then lowered back down onto the haul unit and returns to the EBS so tunnelling can resume.

Figure 13. Muck Bucket and 1548 Haul Unit

CCI has prepared drawings to show each phase of construction.

- Phase I, II and III(Drawing 2567-EG-0206)
  - Phase I Dam Removal
  - Phase II Culvert Installation Site Preparation
- Phase IV, V & Notes (Drawing 2567-EG-107)
  - Phase III New Culvert Installation
  - Phase IV Grouting
  - Phase V Final Reclamation

6 NEW CULVERT INSTALLATION EXECUTION

6.1 DAM REMOVAL – PHASE I

Prior to culvert installation, the beaver dam on the outlet sideof the culvert must be removed to facilitate apron construction as well as reclamation efforts.

The dam shall be removed implementing the procedure and mitigation presented in Department of Fisheries and Oceans Canada (DFO) interim code of practice: Beaver Dam Removal

Detailed steps for beaver dam removal can be found in CCI IFP drawing 2567-EG-0207.

6.2 SITE PREPARATION – PHASE II

Access to tunneling area on both downstream and upstream sides of the culvert installation will be constructed as per the construction drawing package.

- Culvert Installation (Drawing 2567-EG-0201)
- Culvert Installation Notes (Drawing 2567-EG-0202)

With reference to the site layout requirements and detailed drawings, the area will be graded level and flat to allow for equipment to be spotted safely into place before the contractor mobilizes the equipment to site.

Construction is targeted to be completed during the fall months for an anticipated reduced flow in the watercourse which will save time, cost, environmental and safety associated to this water control.

The contractor should utilize the existing culvert to isolate the water flow during the new installation.

A traffic management plan should be developed to allow the contractor to safely mobilize their equipment to prepare the site prior to the trenchless installation. The highway must remain open during all phases of construction.

6.2.1 Mobilization

The contractor will mobilize all necessary from their yard to the provided laydown yard close to the construction site. Equipment will be cleaned and inspected before being transported to site.

6.3 INSTALLATION – PHASE III

The installation will be completed using machine able to excavate along the alignment within the specification that will be outlined within the Issues for Construction (IFC) engineering drawing.

The contractor will provide a jacking unit that provides sufficient jacking force to successfully install the steel pipe. The jacking frame will be secured via an engineered anchoring plan that is able withstand the forces that the jacking unit will apply (including a safety factor) during the installation.

6.4 GROUTING – PHASE IV

The annular space between the tunnel wall and the new culvert pipe will need to be grouted to mitigate short term settlement and ensure the culvert is restrained in place for its lifecycle.

Before the grouting contractor is mobilized to site, the ends of the overcut will be sealed off with a quick set grout using formwork, this will then be capped with clay to provide additional support. The contractor will then use the pre-installed grout ports to pump a flowable grout mixture from the inside of the tunnel into the overcut, the contractor will follow their preapproved execution plan which will outline sequencing and pressures.

Grout samples should be collected so they can be tested after the full cure cycle has been completed to verify the strength.

6.4.1 Demobilization

The contractor will clean the site and remove all equipment back to the laydown yard before demobilizing full to their company base.

6.5 FINAL RECLAMATION – PHASE V

Site reclamation will commence once the trenchless installations and grouting activities are complete.

Final grade and contouring shall be completed as per the design drawing to ensure the inlet area channels water directly into the culverts. Clean riprap is placed to mitigate scour, stabilize the bank and promote aquatic habitat.

The outlet area design incorporates a large armoured pool, downstream of the culverts that provides scour mitigation and an opportunity for fish to rest prior to swimming upstream through the culverts.

Willow staking on the watercourse banks will be placed to stabilize the disturbed areas and provide shade cover for aquatic species. Silt fencing will be installed to avoid the potential soil movement and runoff into the water. The disturbed areas will be seeded to promote vegetation regrowth and root-mat.

7 SUMMARY

A new culvert is required to provide increased flow potential at KM 40.2 and is planned to be completed by trenchless methodologies to reduce the construction disturbance to the highway traffic and community. Construction will commence late summer with civil works, pad preparation and stream isolation. The installation of the new 3m culvert will be completed by a tunneling machine, advancing from launch to receiving point with welded segments of smooth steel pipe. The steel culvert will be grouted in place.

The existing culvert will be decommissioned and grouted in place.

Inlet and outlet pools will be sized and armoured to dissipate flow energy, reclaim the past flooded area and provide an improved aquatic habitat.

8 REFERENCE DOCUMENTS

1. This report is based on the following design drawings.

Type	Drawing Number
Culvert Installation	2567-EG-0201
Construction Notes	2567-EG-0202
Inlet Details	2567-EG-0203
Outlet	2567-EG-0204
Hydrotechnical Notes and Liner	2567-EG-0205
Phase I & II	2567-EG-0206
Phase III & Notes	2567-EG-0207
Phase Profiles	2567-EG-0208

2. White Bear Geomatics Ltd: "*Survey of Creek Crossing at 67 29'01"N, 133 46'01"W, Near Tsiigehchic, NT.*

3. Geotechnical Report: Tetra Tech Project No.: ENG.YARC03234-01 "*Geotechnical Investigation of Existing Culverts" Boreholes BH-08 and BH-09*

4. Tetra Tech Consulting Ltd. Hydrotechnical Assessment: *"Hydrotechnical Assessment of Culvert Streams"* Document No.: 704-TRN.WTRM03108-01

APPENDIX A – LOCATION SURVEY

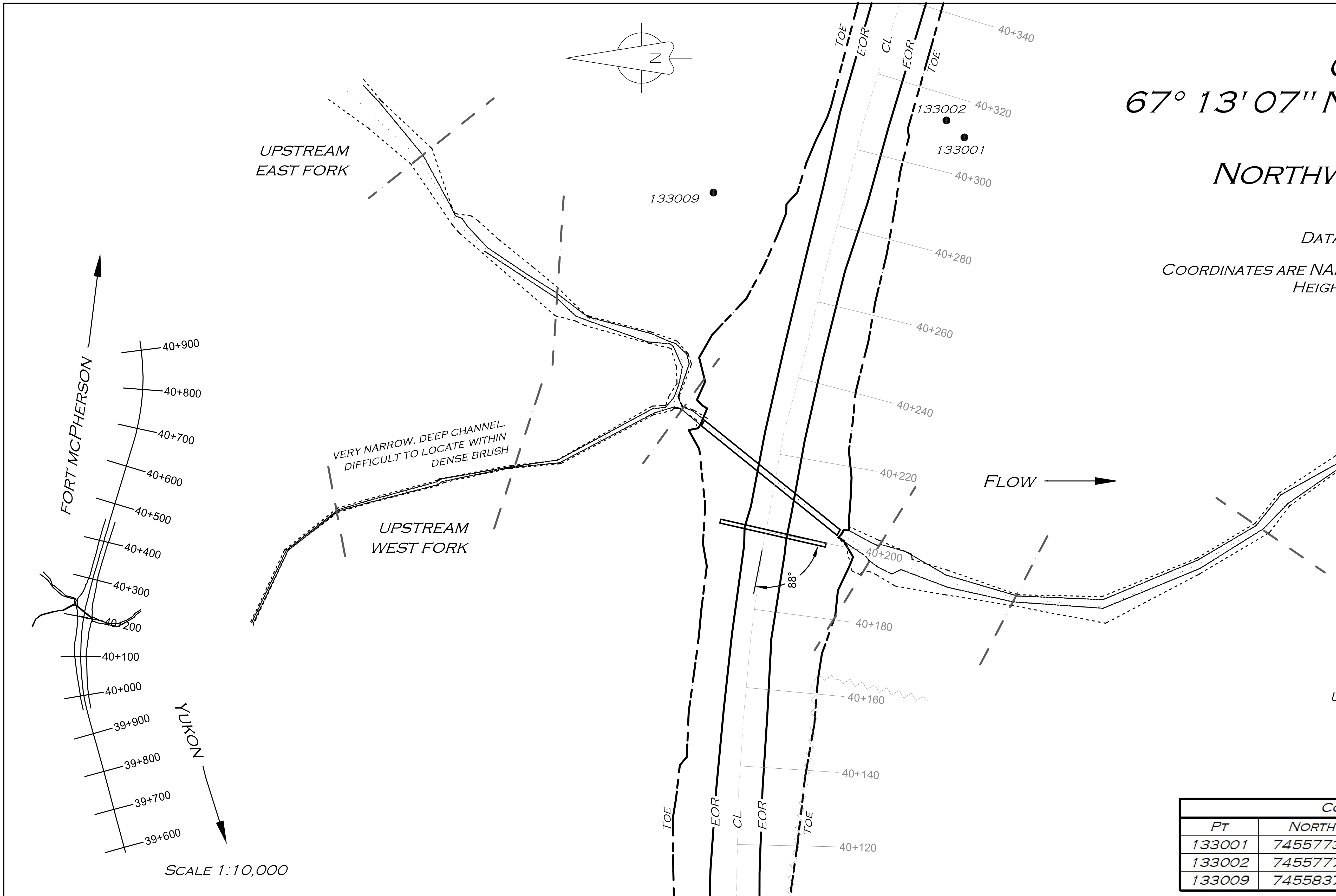
Survey of Crossing No. 33
67° 13' 07" N, 135°30'15" W
KM 40.2, HWY 8
Northwest Territories

Data Collected on August 21 2018

Coordinates are NAD83 CSRS (2010.0), UTM zone 8
Heights are Orthometric - CGG 2013

Local scale factor: 0.999551
Units are Metres

Notes:



Control Monument ●
Feature
CL Creek
CL Road
Edge of Road
Edge of Water
Top of Bank
Toe
Culvert
Treeline
Cross-Section Line
Shoulder

Culvert Diameter: 2m height upstream. 1.8m height downstream
Culvert Length: 44.3
Culvert Angle to Road: 88°
Typ. Road Width: 10.5
Typ. Shoulder Width: N/A

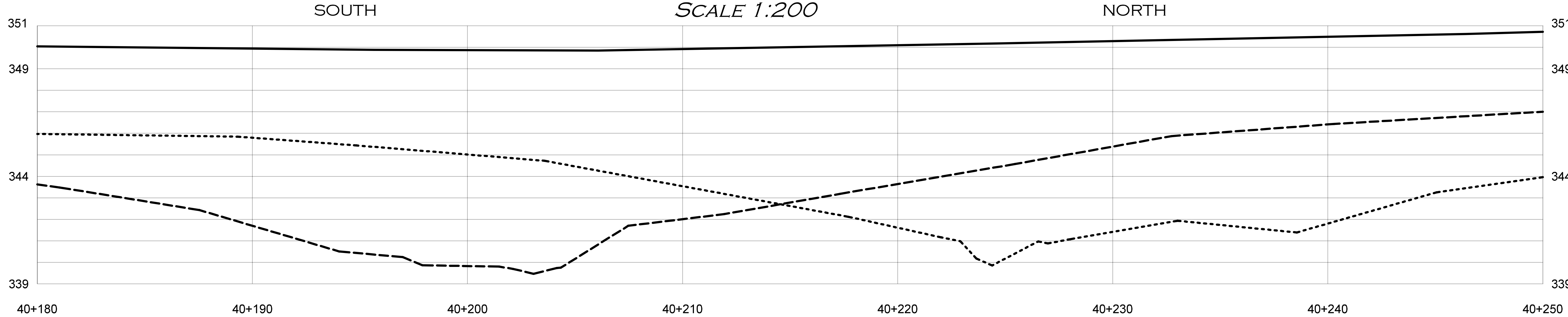
Control Stations			
Pt	Northing	Easting	Elevation
133001	7455773.407	478295.498	350.889
133002	7455777.970	478299.808	351.386
133009	7455837.265	478281.428	346.667

White Bear Geomatics Ltd.
www.whitebeargeo.com
867-688-4442 (office)
403-580-9398 (cell)

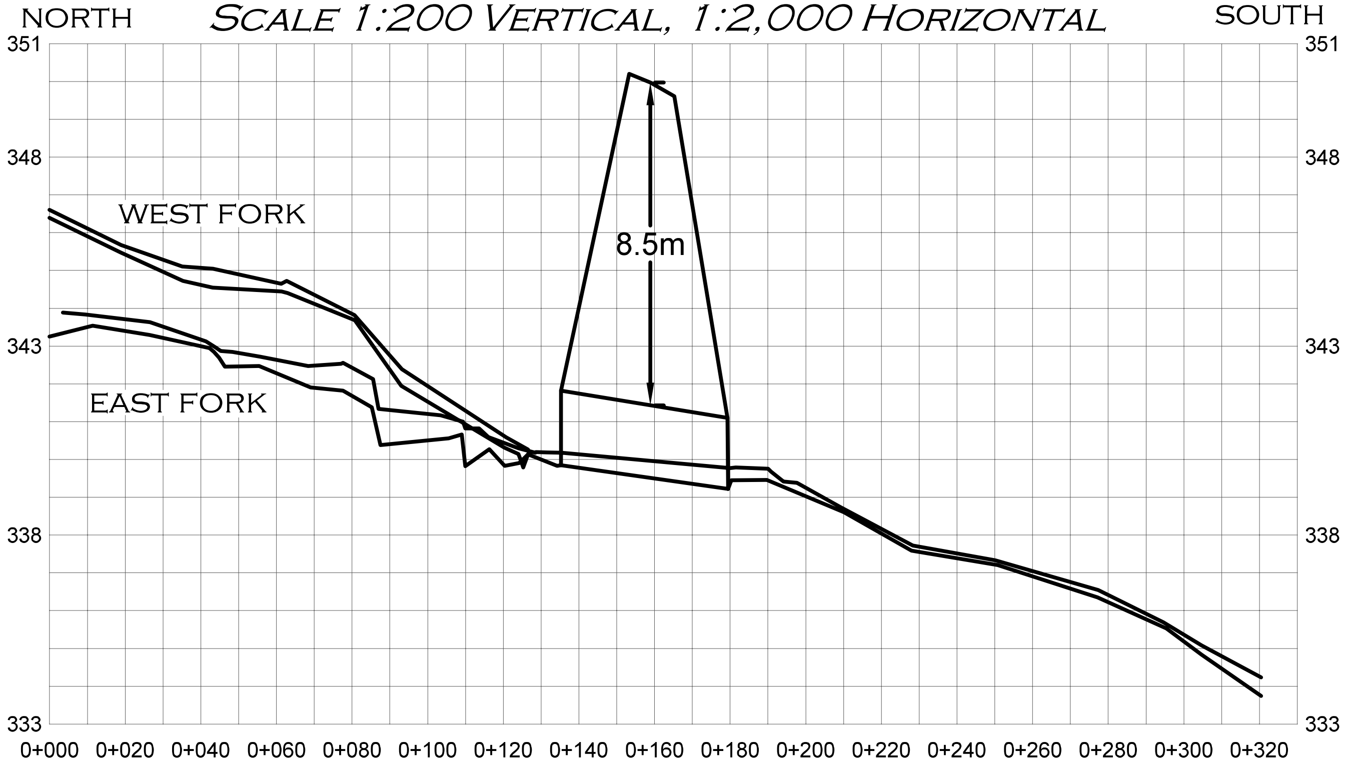
Scale: 1:1,000

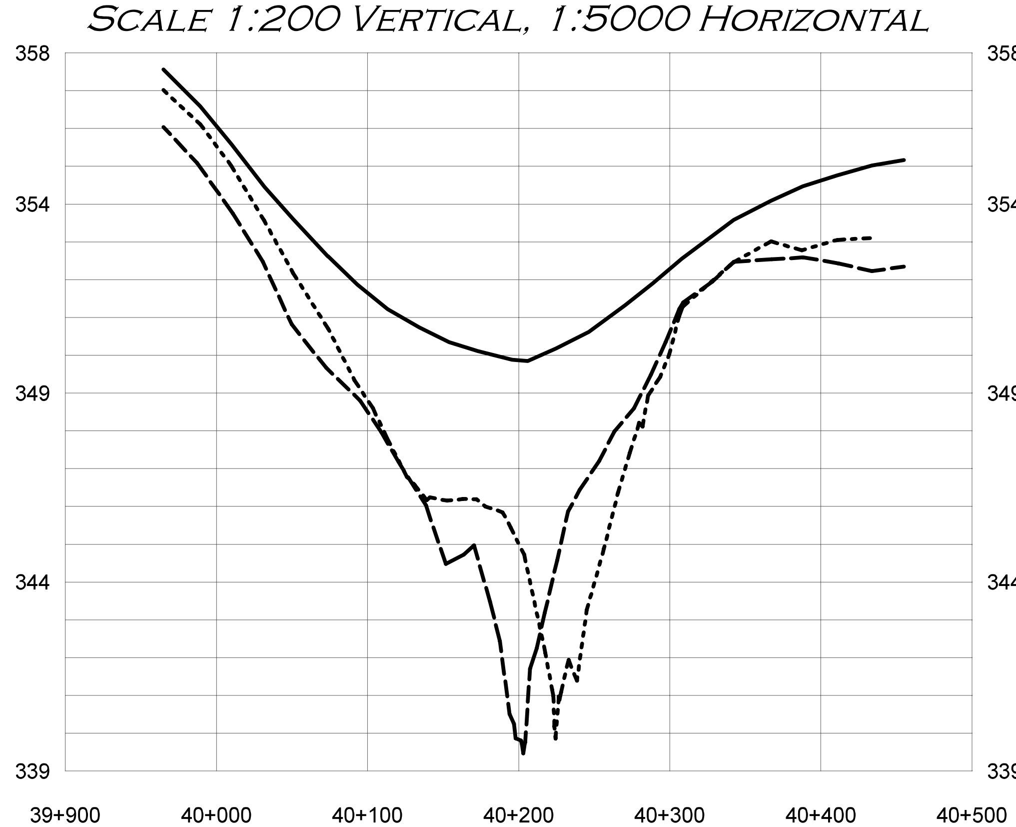
Rev: 0
File: 18-216 33.dwg
Date: October 25 2018

Survey of Crossing No. 33
67° 13' 07" N, 135°30'15" W
KM 40.2, HWY 8 NWT



NORTH TOE
SOUTH TOE

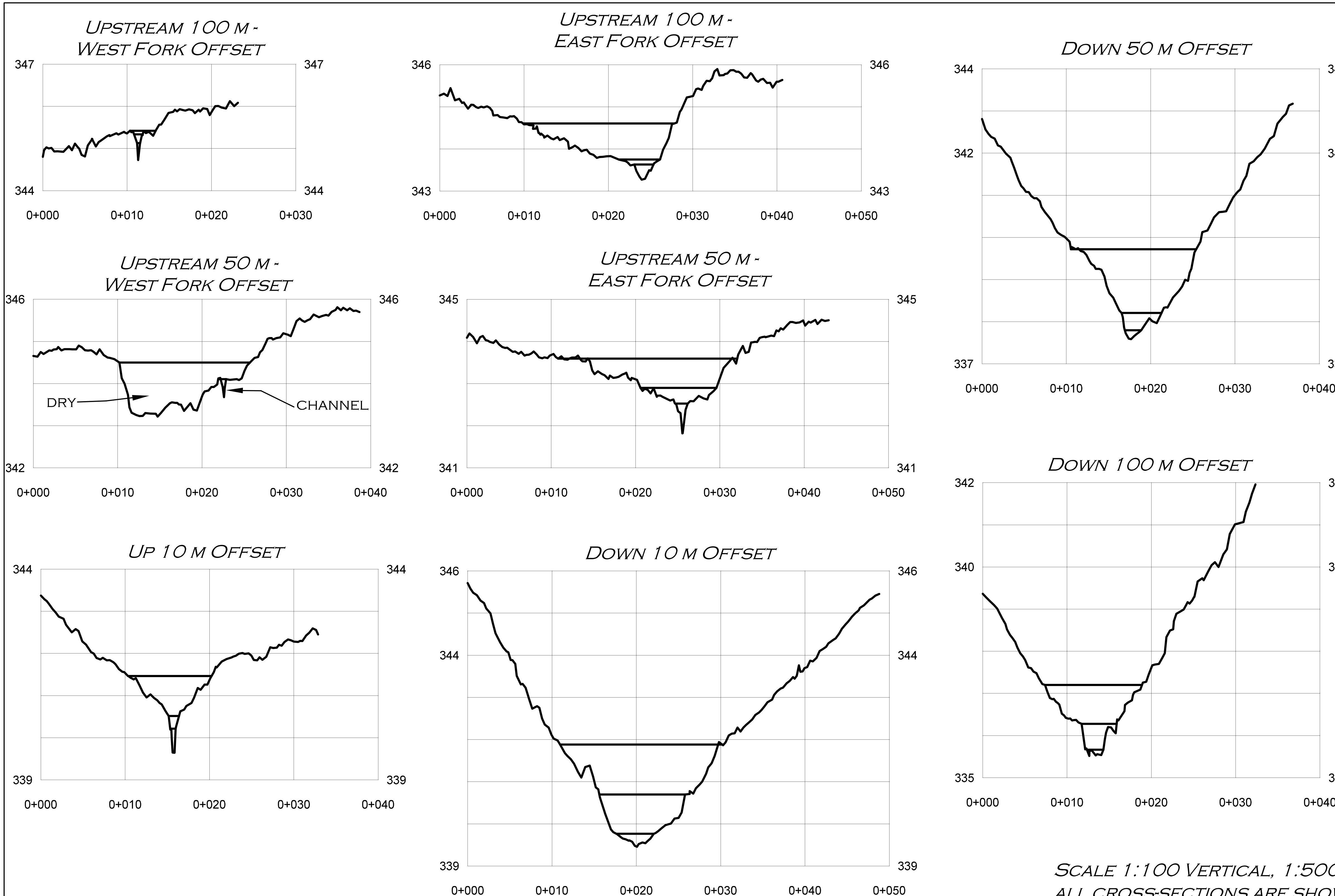




WHITE BEAR GEOMATICS LTD.
WWW.WHITEBEARGEO.COM
867-688-4442 (OFFICE)
403-580-9398 (CELL)

SCALE: AS SHOWN
REV: 0
FILE: 18-216 33.DWG
DATE: OCTOBER 25 2018

Survey of Crossing No. 33 67° 13' 07" N, 135°30'15" W KM 40.2, HWY 8 NWT



Stream Cross-Sections

Scale 1:100 Vertical, 1:500 Horizontal unless shown otherwise
All cross-sections are shown looking downstream (left bank on the left)

White Bear Geomatics Ltd.
www.whitebeargeo.com
867-688-4442 (office)
403-580-9398 (cell)

Cross Section Details

Dim	Description	Up 100 West	Up 50 West	Up 100 East	Up 50 East	Up 10	Down 10	Down 50	Down 100
A	Flood Prone Width	3.04	15.5	17.95	21.24	9.88	19.39	14.86	11.49
B	Bankfill Width	0.94	0.95	4.90	9.02	1.24	10.17	4.75	4.16
C	Water Surface	0.35	0.57	2.27	1.47	0.64	4.43	1.94	1.96
H1	Bankfill Depth	0.61	0.43	0.48	1.08	0.87	0.81	0.75	0.75
H2	Flood Prone Depth	0.7	0.82	1.33	1.77	1.82	2.42	2.13	1.67

Scale: As Shown

Rev: 0
File: 18-216 33.dwg
Date: October 25 2018

APPENDIX B – GEOTECHNICAL REPORT

TETRA TECH

Geotechnical Evaluation of Culvert Crossing NWT Highway 8, km 40.1

PRESENTED TO

Government of the Northwest Territories, Department of Infrastructure

MARCH 27, 2019
ISSUED FOR USE
FILE: ENG.YARC03234-01

Tetra Tech Canada Inc.
Box 2244, 201, 4916 - 49 Street
Yellowknife, NT X1A 2P7 CANADA
Tel 867.920.2287 Fax 867.873.3324

This page intentionally left blank.

TABLE OF CONTENTS

LIST OF TABLES IN TEXT

APPENDIX SECTIONS

FIGURES

PHOTOGRAPHS

APPENDICES

LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of the Government of Northwest Territories, Department of Infrastructure and their agents. Tetra Tech Canada Inc. (Tetra Tech) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than the Government of Northwest Territories, Department of Infrastructure, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this document is subject to the Limitations on the Use of this Document attached in the Appendix or Contractual Terms and Conditions executed by both parties.

1.0 INTRODUCTION

1.1 General

Tetra Tech Canada Inc. (Tetra Tech) was requested by the Government of Northwest Territories, Department of Infrastructure (INF) to conduct a geotechnical site investigation at the culvert crossing at km 40.1 on Highway 8, also known as the Dempster Highway.

Tetra Tech was retained by the Government of Northwest Territories, Department of Infrastructure (INF), under Contract: SC-INF01-1982, signed on September 24, 2018.

This report presents Tetra Tech's findings from the site investigation and recommendations based on those findings for the km 40.1, Highway 8 crossing site.

1.2 Project Details

The INF issued a Request for Proposals (RFP), Event ID0000002553, on July 31, 2018, asking for a subsurface investigation at four sites along Highway 8, to aid them in their design of replacement drainage structures at these locations.

The second of these sites on Highway 8 is at a culvert location at km 40.1 that is understood will be reconstructed. Two culverts exist at this site. The culvert controlling water flow at the time of the investigation is 43 m long and 1.83 m in diameter structural plate corrugated steel pipe. The other culvert was approximately 35 m long and 1.21 m in diameter was present at approximately 3 m higher within the embankment than the aforementioned culvert.

Tetra Tech understands that the issues being experienced at the km 40.1 culvert location are severe rusting, wide cracks and deformation of the culvert structure.

A geotechnical investigation, including drilling, sampling and laboratory testing on samples retrieved from locations identified by INF, was carried out by Tetra Tech. Two boreholes were drilled to a depth of 24 m each. The results of the site investigation will be used to provide an assessment of the conditions and soils encountered.

1.3 Scope of Work

The scope of work was outlined in the original Request for Proposal and was understood to comprise the following, as outlined in Tetra Tech's proposal of August 16, 2018:

- Two boreholes were to be advanced to a depth of 24 m below the road surface, or 3 m into bedrock, whichever is shallower. If bedrock is encountered 3 m of core will be collected. Standard penetration testing will be performed every 1.5 metres during soil logging using the Unified Soil Classification System. Samples will be collected every 1.5 m and when there is a change in the soil stratigraphy. The temperature of all samples will be measured using a hand-held infrared thermometer. Pocket penetration or field vane shear tests will be completed, where applicable. If bedrock is encountered, 3 m of core will be collected for confirmation of bedrock and testing.
- Install six single bead thermistor cables in each of two selected boreholes. The cables will be installed using PVC casing that has been trenched into the road to the shoulder so that the strings are not damaged or destroyed. The cables will be read at the end of the drilling program on days 1, 2, and 20 days after the cables have been installed or at a time agreed to by the INF site representative.

- Laboratory testing completed in accordance with AASHTO standard methods will be conducted on selected samples retained from the field work. For each borehole one water content test on samples taken every 1.5 m. Other testing included, per borehole: two Atterberg limits, two sieve analyses, one hydrometer, two salinity testing, and soluble sulphate content. Soluble sulphate samples will be sent to ALS Laboratories for analysis. Additional testing may be completed upon retained samples after discussion with the INF representative.
- Prepare and submit geotechnical evaluation reports for each culvert location that provide geotechnical assessments of the conditions and soils encountered, a professional opinion on the root cause of culvert failure and distress and provide foundation recommendations for either a new bridge or a culvert(s).

2.0 METHODOLOGY

Borehole locations were established on site by Doug Yokoyama, P.Eng., of Tetra Tech.

Between September 30 and October 1 of 2018, Mr. Yokoyama observed the drilling of two boreholes by a track mounted Multipower Prospector P1 drill rig operated by Midnight Sun Drilling Ltd. (Midnight Sun), of Whitehorse, YT. Subsurface conditions were logged in the field and samples were taken at regular intervals for laboratory testing. Borehole logs, describing the subsurface conditions, are presented in Appendix B. Selected photos that were taken during the site investigation are presented at the back of this report.

Traffic control was provided by two trained flag persons working in tandem. Tailgate safety meetings were held on each day before commencing work, and field work was completed without incident.

Seven thermistor cables each were installed in BH-04 and six thermistor cables were installed in BH-05. The boreholes were backfilled with drill cuttings and loose embankment material. The blade at the front of the drill rig was used to create a trench approximately 50-100 mm deep from the borehole to the side embankment to protect the thermistor cables from traffic and equipment.

Samples were returned to Tetra Tech's Yellowknife laboratory for the purpose of soil classification and determination of engineering properties. Tests performed included determination of natural moisture content, grain size analysis (sieve and hydrometer) and Atterberg limits. Select samples were shipped to Tetra Tech's Calgary and Edmonton laboratories for soluble sulphate and porewater salinity testing, respectively. Laboratory results are presented in Appendix C.

3.0 SITE CONDITIONS

3.1 Location

The location under investigation is located at km 40.1 of Highway 8, approximately 40 km southwest of Fort McPherson, NT. Two culverts were present at the site in a stacked configuration with one being approximately 3 m higher than the other.

BH-04 was drilled to the southeast of the culvert in the eastbound lane, approximately 7 m from the culvert centreline and around 2 m from the edge of the highway. BH-05 was drilled to the southwest of the culvert in the westbound lane, approximately 7 m from the culvert centerline and around 2 m from the edge of the road.

3.2 Climate

The nearest weather station consistently maintained by Environment Canada is Inuvik, located approximately 165 km northeast of the culvert location. Environment Canada has maintained records at this weather station going back to 1958 (Environment Canada 2018). The mean annual air temperature for the period of record is -8.5°C.

The annual air temperature has been gradually increasing. The temperature warming trend was analyzed using linear interpolation of the average annual temperature data between 1958 and 2017. The average rate of increase has been about 0.07°C per year over the last 30 years, with the biggest increase occurring in the winter months of November to February. Over the past 30 years, the mean annual air temperature has averaged -7.3°C.

Over the period of record, the freezing index has decreased by about 21 C°-days/year, while the thawing index has increased by about 5 C°-days/year, with most of that change occurring since 1970. Over the past 30 years, (1989 to 2018), the freezing index was about 3965 C°-days and the thawing index about 1336 C°-days. The freezing index has decreased by about 26 C°-days/year, and the thawing index has increased by about 2 C°-days/year over the past 30 years. Therefore, both winters and summers are still becoming warmer, and the changes are even more noticeable in winter than they were before.

According to the Environment Canada climate normals for 1981 to 2010, annual precipitation at Inuvik is about 241 mm, of which 159 mm is snowfall, and 115 mm is rain. Analysis of precipitation data does not indicate a clear trend. It is noted that the variability in annual precipitation is increasing, with some of the highest and lowest values ever recorded in Inuvik occurring in the past 15 years.

3.3 Geology

Based on a surficial geology map of the Fort McPherson – Bell River area (Duk-Rodkin and Hugues, 1992), glacial deposits of the Late Wisconsinan are mapped in the area of Highway 8 km 40.1. These deposits comprise unsorted silt, sand and clay with some coarser clasts (till) deposited by glacial ice and occurring as hummocky moraine with 10 to 20 m of relief, up to 20 m thick.

The surficial deposits are underlain by horizontal Lower Cretaceous concretionary marine shale, siltstone and lesser sandstone of the Arctic Red Formation (Norris, 1981). An unconformity separates the Cretaceous rocks from underlying Devonian to Cambrian succession of sedimentary rocks, which in turn are underlain by Proterozoic sedimentary rocks (Jones et al., 2007).

3.4 Surface Conditions

3.4.1 General

The road surface was a compacted silty sand fill with some gravel to a nominal size of 20 mm. The gravel portion appeared to be rounded to subrounded. The side embankments were at slopes of approximately 1V:1.5H and had cobbles up to a nominal size of 150 mm. The road surface was approximately 6 m higher than the creek. The embankment was observed to be eroding at various locations along the southern bank, with the greatest amount of erosion leading from the culvert at higher elevation to the highway surface. The northern bank was snow covered and therefore, it was impossible to tell if that side of the embankment had eroded.

The culvert site is located within a small gully. The immediate area surrounding the culvert site appeared to rise slightly to the north and drop slightly to the south. The natural ground was snow covered at the time of the investigation. Coniferous trees upwards of 4 m in height and 0.1 m in diameter were sparsely spread out in the surrounding area. Vegetation under the snow was assumed to be small shrubs and grass.

One creek was noted at this site, which flowed through the bottom culvert. No water flow was observed through the culvert at higher elevation.

3.4.2 Culvert Conditions

There are two culverts at this site with the larger diameter culvert situated within the creek and the smaller one located roughly halfway up the highway embankment. The lower culvert is considerably rusted and experiencing deformation according to email correspondence with INF on February 14, 2019. The upper culvert was dry during the time of the site investigation. Tetra Tech assumes the culvert at higher elevation was possibly installed to allow water to flow through the highway embankment during flood conditions although it is not known if it has ever been underwater.

Photo 2 shows the upper culvert protruding out of the highway embankment 3 m above the water course below.

Photo 3 shows both culverts. The lower culvert contained flowing water at the time of the site investigation and displays signs of deformation on the downstream portal.

Photo 4 shows significant erosion as seen from the edge of the highway shoulder. This erosion appears to be from roadway surface runoff.

Photo 5 shows both culverts on the north or upstream side of the highway. There does not appear to be evidence of extensive flooding that would result in water passing through the upper culvert. Therefore, it may be possible that the upper culvert has never actually been used.

Photo 6 shows a closeup view of the lower 1.8 m diameter culvert on the north (upstream) side of the highway embankment. It appears rusted but not deformed.

3.5 Subsurface Conditions

Silty Sand (Highway Embankment Fill)

A layer of silty sand with some gravel was encountered starting from the ground surface in all boreholes. The gravel was rounded to subrounded with a nominal size of 100 mm and varied in colour. The sand and silt were brown. The layer was 5.0 m thick in BH-04 and 5.5 m thick in BH-05. Moisture contents ranged from 5.5 to 12.6%.

Photos 1 to 4 show the highway embankment from the surface.

Organics

A thin organic layer was encountered in BH-05 directly below the embankment layer. A strong odour was observed. Rootlets, peat and grass were among the organic content noted.

Clay

Silty clay with trace sand was encountered directly below the embankment layer in BH-04 and below the organic layer in BH-05. Trace gravel was present in BH-04 from 5.0 m to 9.5 m in depth. The clay was generally medium to high plastic with a plasticity index ranging from 18 to 32 and averaging 27. Moisture contents ranged from 17.1 to 54.5%.

Soluble sulphate results taken from 5.5 m to 7.5 m deep between the boreholes indicated water soluble contents from 0.00 to 0.02%. The potential degree of sulphate attack on concrete placed within the silty clay layer may therefore be considered to be low.

Various ice strata were noted within the clay layer, beginning at 8.7 m deep in BH-04. Ice crystals were observed from ODEX cuttings in BH-05 starting at 9.0 m deep. Photos 11 to 18 show ice at different depths within the clay soil as recovered via SPT split spoons.

Bedrock

Bedrock was not encountered in any of the boreholes drilled.

3.6 Groundwater

Groundwater was not observed in either borehole. However, it is expected that groundwater is present within the active layer due to the close proximity to water. Due to the nature of the ODEX drilling and casing used, groundwater was not easily identified. The groundwater table likely coincides with the surface water elevation near the invert of the lower culvert.

In areas of permafrost, groundwater is typically found in the active layer near the frozen/unfrozen interface and may flow through the site during periods of high rainfall precipitation and in the summer after the seasonal frost melts.

3.7 Permafrost

The subject site is located in the zone of continuous permafrost, near the boundary between continuous and discontinuous permafrost (Heginbottom et al. 1995). Within the zone of continuous permafrost, 90 to 100% of the area is expected to be underlain by permafrost, with the exception of developed/disturbed areas and areas located adjacent to bodies of perennially unfrozen water.

Permafrost was observed within the clay layer during the site investigation at depths noted in Section 3.5 Surface Conditions. The active layer is estimated to range between 5.0 m to 5.5 m deep. Excluding the active layer, the average ground temperature was -1.2°C based off of early winter temperature readings.

Ground temperatures measured at the subject site are presented below in Table 3-7.

Table 3-7: Ground Temperature Measurements

Borehole Number (Date Installed)	Depth (m)	Ground Temperature Measured (°C)			
		October 1, 2018	October 3, 2018	December 18, 2018	December 20, 2018
BH-04 (September 30, 2018)	3.0	2.0	1.7	-0.2	-
	5.0	-0.0	-0.2	-0.3	-
	7.5	-0.4	-0.8	-0.8	-
	10.0	-0.7	-1.0	-1.0	-
	14.0	-0.9	-1.2	-1.5	-
	17.0	-1.2	-1.3	-1.5	-
	22.5	-1.4	-1.6	-1.7	-
BH-05 (October 1, 2018)	4.0	-	0.4	-	-0.2
	6.0	-	-0.1	-	-0.7
	9.0	-	-0.4	-	-0.9
	12.0	-	-0.2	-	-1.0
	15.0	-	-0.8	-	-1.1
	18.0	-	-0.9	-	-1.3

3.8 Soil Porewater Salinity

Porewater salinity was conducted on four samples at depths ranging from 5.5 m to 18.0 m below grade. Salinity is measured in parts per thousand (ppt), and values recorded from laboratory testing ranged from 0 ppt to 2 ppt, and averaged 1 ppt.

4.0 RECOMMENDATIONS

4.1 General

From a geotechnical perspective, the culverts appear to be in an operable condition. If they are to be replaced, then one or two new larger (properly sized) culverts at the creek elevation are recommended. Although permafrost exists at this location, the existing culverts do not appear to have been significantly affected, and the future performance of replacement culverts is expected to be similar.

It is recommended that the replacement culverts be installed as late in the season as possible, to minimize the effects of excavation and backfill on the permafrost surface. After construction, a transition to winter temperatures and seasonal freezing as quickly as possible is desirable.

No review of the stream and existing culvert hydrological conditions was undertaken by Tetra Tech. This should be completed by a qualified consultant as part of the stream crossing replacement analysis and design.

4.2 Climate Change Considerations

The impacts of potential climate change should be considered in the design of the stream crossing replacement structure. A procedure for screening the vulnerability of a development to climate change is outlined by the Canadian Standards Association (CSA, 2010).

The sensitivity of the site to climate change is governed by the characteristics of the permafrost at the site. Presently, the permafrost temperature is conservatively estimated at -1.2°C based on early winter readings.

CSA (2010) gives guidance on the potential implications of climate change on ground temperature. Under a “high” green-house gas emission scenario, warming of about 1.1°C can be expected over the next 30 years in the Western Arctic region of the Mackenzie Delta. Warming of the ground is conservatively assumed to take place in step with air temperature. This warming is in addition to the potential effect on ground temperatures resulting from disturbance from construction and operations. Based on the approximated temperatures, this warming can be expected to bring the ground to the threshold of thawing, which, in fact, may already be occurring, given that the permafrost is already so warm. However, because of excess ice in the soils, the rate of warming and the impact of warming air temperature on ground temperature is difficult to quantitatively assess, particularly as the ground temperature becomes closer to 0°C. The latent heat consumed in thawing ice results in a lag in ground temperature. Nonetheless, it can be assumed that the mean annual ground temperature at depth will certainly be at or near 0°C after 30 years. The sensitivity of the site to potential climate change is therefore considered to be “medium.”

A consequence of a warming climate would be an increase in permafrost creep in ice-rich soils, thereby reducing the bearing resistance of the soils, and potentially also a thickening of the active layer during the service life. The active layer is already considered to be quite thick as a result of the large highway fill embankment present overtop of the culvert at this stream crossing. Therefore, the active layer may not actually change much over time as it is considered to be somewhat limited to the native soil fill embankment interface at this time. However, an increase in seasonal movements across the site and settlement due to creeping or thawing of permafrost due to an increase in active layer thickness could result in differential movements of the highway embankment. These consequences would ordinarily be considered to be relatively “minor” (CSA Table 7.1), due to the general flexible nature of soil. Ongoing highway maintenance should be expected.

Level “C” warrants a qualitative analysis. Sufficient performance data should be available for the particular structure to provide a reasonable level of confidence in the judgment that arises from the comparison. A systematic performance monitoring program is recommended to identify if corrective action is required at some future time. Instrumentation has been installed to provide for ongoing monitoring of the permafrost conditions over time and to allow for a comparison with other highways infrastructure.

4.3 Culvert Design Recommendations

The usual practice for installing a culvert is to sub excavate frozen material from beneath the culvert. This is not recommended in a permafrost location based on our experience.

The present highway embankment has been established for many years. However, new construction may alter the embankment adversely.

To limit the potential for perched ends to the culvert, it is recommended that the ends of the culvert be seated nominally below existing grade. A depth of 200 mm is recommended. This is not considered sub excavation, which is excavation and then backfilling with replacement fill. The depth of seating is well within the active layer, so it is not expected to result in significant disturbance to the thermal regime in the vicinity of the culvert.

Because settlement under the centre of the embankment and culvert is inevitably larger than settlement at the ends of the culvert, it is recommended that the culvert be installed with a camber. The recommended camber is on half the magnitude of the cross-fall from the upstream to the downstream end of the culvert, to a maximum of 1.5% of the culvert length. The camber should be formed with granular material compacted to 100% SPD. The structural fill should be placed and compacted in lifts not exceeding 150 mm in compacted thickness. The backfill should be compacted to at least 98% SPD adjacent to and above the culvert.

Several key factors to successful culvert installations include:

- Use of quality well-graded granular backfill materials with low fines content and low to optimum moisture content;
- Adequate compaction of backfill materials meeting compaction requirements. Achievable in unfrozen conditions, not possible in winter frozen conditions;
- Proper compaction in areas where the interface radial pressures between the soil and culvert wall are high;
- Suitable foundation soils for culvert installation;
- Limited sub excavation if necessary to remove only near surface ice rich materials;
- Install all closed-bottom culverts with camber;
- The culvert must be adequately sized for the hydrology. Hydrology in flowing streams must consider winter icing that could render the structure useless during spring freshet; and
- Maintain sufficient cover over the culvert to protect the culvert from structure damage and operations and maintenance issues related to over grading.

Once the replacement culvert(s) have been installed, the former culverts installed may be removed and the embankment reconstructed in that area.

4.4 Construction Excavations

The Government of the Northwest Territories Safety Act and Regulations and standard good practices should be followed for all trenches/excavations. Excavations deeper than 1.5 m should have sloped sidewalls. A slope of 1H:2V is the steepest recommended slope for temporary excavations in the soils encountered at the site. Localized instability (seeping/sloughing/flowing soil) in trench/excavation walls may occur. In these cases, side slopes would need to be made flatter, under the direction of a qualified geotechnical engineer.

Seepage may be encountered in excavations during construction. If seepage does occur, a system of ditches leading to sumps equipped with pumps should be used to dewater excavations. General guidelines with respect to excavations are presented in Appendix D.

5.0 DESIGN AND CONSTRUCTION GUIDELINES

Recommended general design and construction guidelines are provided in Appendix D, under the following headings:

- Construction Excavations (1 page)
- Backfill Materials and Construction Guide (3 pages)

These guidelines are generic and intended to present standards of good practice. They have been developed largely from Tetra Tech's southern practices. We have attempted to address specific local requirements in the main text of this report. These guidelines are supplemental to the main text of this report. In the event of any discrepancy between the main text of this report and Appendix D, the main text should govern. The design and construction guidelines are not intended to represent detailed specifications for the works, although they may prove useful in the preparation of such specifications.

6.0 REVIEW OF DESIGN AND CONSTRUCTION

Tetra Tech should be given the opportunity to review details of the design and specifications related to the geotechnical aspects of this project prior to construction.

All recommendations presented in this report are based on the assumption that an adequate level of monitoring will be provided during construction and that all construction activities will be carried out by suitable qualified contractors, experienced in earthworks and foundation construction in the North. Adequate levels of monitoring are considered to be:

- For earthworks, particle size analysis on "non-frost-susceptible" or "frost-stable" fill.
- Observations of the site conditions prior to placing fill.
- Full-time monitoring and associated density testing during fill placement.

All such quality assurance monitoring should be carried out by qualified persons, on behalf of the owner, independent of the contractor. If the contractor also carries out testing for quality control, all parties should be made aware of this. One of the purposes of providing an adequate level of monitoring is to check that the recommendations provided in the report are pertinent to soil conditions encountered at the site, or to other areas should the foundations be relocated. Tetra Tech will provide these services upon request.

7.0 CLOSURE

We trust this report meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech Canada Inc.

Prepared by:
Doug Yokoyama, P.Eng.
Geotechnical Engineer, Arctic Group
Direct Line: 867.920.2287 x9201108
Doug.Yokoyama@tetratech.com

Prepared by:
Tim Schaap, P.Eng.
Geotechnical Engineer, Arctic Group
Direct Line: 867.688.1748
Tim.Schaap@tetratech.com

REGISTERED PROFESSIONAL ENGINEER
J. Richard Trimble
Mar 27/19
LICENSEE
N.W.T.

PERMIT TO PRACTICE
TETRA TECH CANADA INC.
Signature
Date March 27/19
PERMIT NUMBER: P 018
NT/NU Association of Professional Engineers and Geoscientists

Reviewed by:
J. Richard Trimble, P.Eng., FEC
Principal Consultant, Arctic Group
Direct Line: 867.668.9216
Richard.Trimble@tetratech.com

/kla

REFERENCES

Burn, C.R, and Kokelj, S.V., 2009. The environment and permafrost of the Mackenzie Delta area. Permafrost and Periglacial Processes, 20: 83-105

Canadian Standards Association (CSA), 2010. Technical Guide Infrastructure in Permafrost, a Guideline for Climate Change Adaptation. CSA Reference Number: Plus 4011-10.

Heginbotton, J.A., Dubreuil, M.A., and Harker, P.T., 1995. Canada – Permafrost. In National Atlas of Canada, Natural Resources of Canada, Ottawa, 1995. Map Number: MCR 4177, Scale 1:7,500,000.

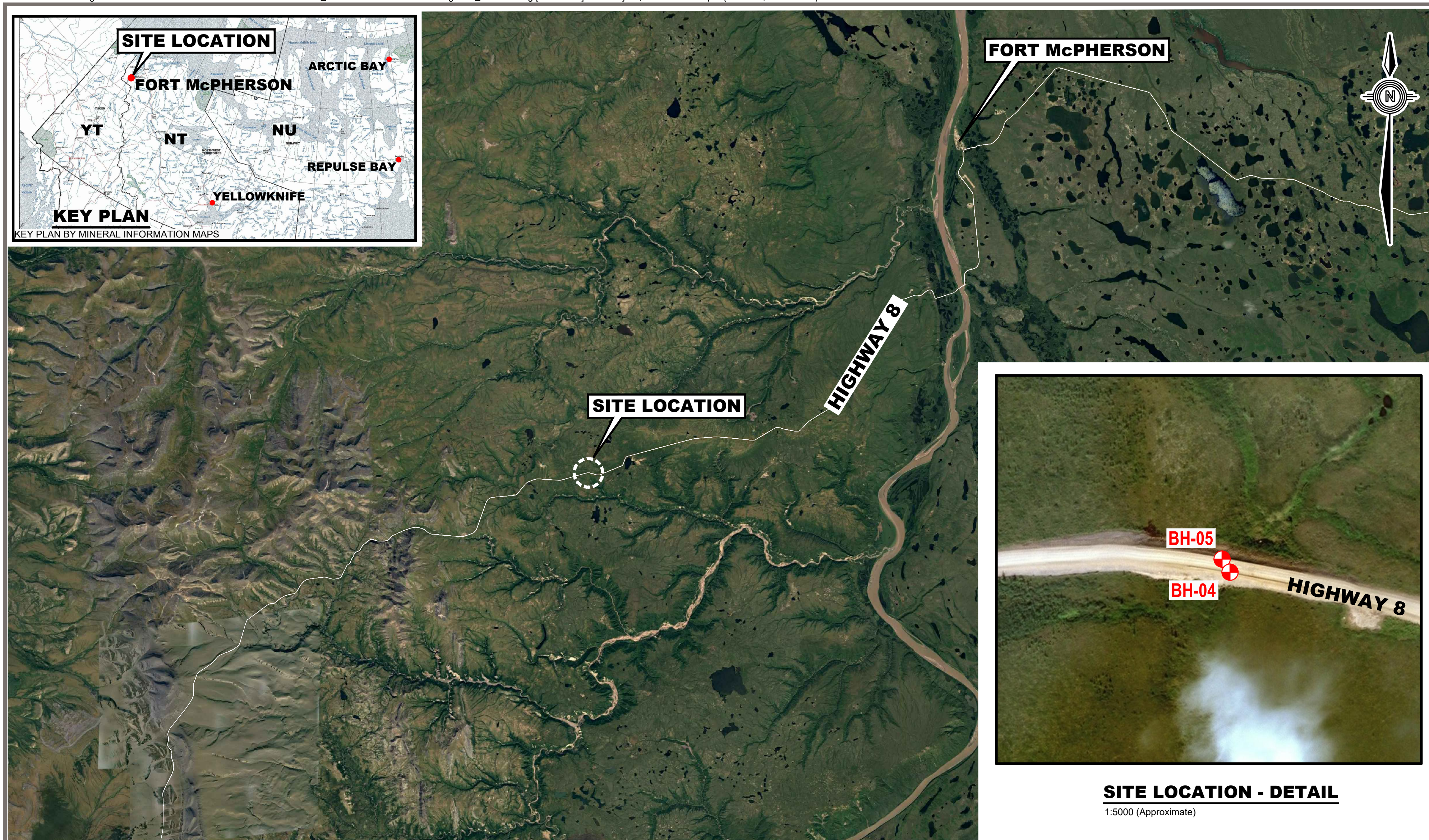
Duk-Rodkin, A. and Hughes, O.L. 1992. Surficial geology, Fort McPherson-Bell River, Yukon-Northwest Territories. Geological Survey of Canada Map 1745A, scale 1:250,000.

Jones, A.L. & Pyle, L.J. (compilers), 2007. Roadside Geology of the Dempster Highway, Northwest Territories & Yukon, A geological roadmap for Canada's most northwestern road; Northwest Territories Geoscience Office and Yukon Geological Survey, NWT Open Report 2007-009 & YGS Open File 2007-11, 1 folded map.

Norris, D.K., 1981. Geology: Fort McPherson, District of Mackenzie. Geological Survey of Canada, Map 1520A (Scale 1:250 000).

FIGURES

Q:\Edmonton\Drafting\PROJECTS\704-ENG.YARC\ENG.YARC03234-01\03_Acad\ENG.YARC03234-01 Figure 1_km 40.1.dwg [FIGURE 1] February 21, 2019 - 3:41:26 pm (BY: DAS, DEBASHIS)



NOTE:

BASE IMAGE IS TAKEN FROM GOOGLE EARTH
IMAGERY YEAR: 2015

0 — 20

Scale: 1: 400 (kilometres)
(Approximate)

LEGEND:

- BOREHOLE LOCATION

CLIENT

Northwest Territories

TETRA TECH

GEOTECHNICAL INVESTIGATION AT
HIGHWAY 8 CULVERT SITES, NT

HIGHWAY 8, KM 40.1
SITE PLAN SHOWING BOREHOLE LOCATIONS

PROJECT NO.	DWN	CKD	REV
ENG.YARC03234-01	DBD	DY	0

OFFICE	DATE
EDM	February 2019

Figure 1

PHOTOGRAPHS

Photo 1	Overall site, facing west.
Photo 2	South side of embankment, facing east.
Photo 3	South side of embankment, facing north.
Photo 4	Erosion above top culvert on south side of embankment.
Photo 5	Both culverts on the north side of the highway embankment; view looking south
Photo 6	Closeup of the lower 1.8 m diameter culvert on the north side of the highway embankment.
Photo 7	Creating trench for thermistor cables for BH-04, facing west.
Photo 8	Clearing thermistor cable trench for BH-04.
Photo 9	Upper (dry) culvert on the north (upstream) side of the highway embankment.
Photo 10	SPT sample collection for BH-04, facing west.
Photo 11	BH-04 9.9-10.5 m SPT sample.
Photo 12	BH-04 11.4-12.0 m SPT sample.
Photo 13	BH-04 14.4-15.0 m SPT sample.
Photo 14	BH-04 14.4-15.0 m SPT sample 2.
Photo 15	BH-04 9.9-10.5 m SPT sample 2.
Photo 16	BH-04 11.4-12.0 m SPT sample 2.
Photo 17	BH-04 9.9-10.5 m SPT sample 3.
Photo 18	BH-04 11.4-12.0 m SPT sample 3.
Photo 19	Drill setup for BH-05, facing north.
Photo 20	Highway backfilled from thermistor cable trenching for BH-05, facing north.
Photo 21	Thermistor cable trench for BH-05.

Photo 1: Overall site, facing west.

Photo 2: South side of embankment, facing east.

Photo 3: South side of embankment, facing north.

Photo 4: Erosion above top culvert on south side of embankment.

Photo 5: Both culverts on the north side of the highway embankment; view looking south. The larger lower 1.8 m culvert is centred in the photo. The upper 1.2 m culvert is circled.

Photo 6: Closeup of the lower 1.8 m diameter culvert on the north side of the highway embankment.

Photo 7: Creating trench for thermistor cables for BH-04, facing west.

Photo 8: Clearing thermistor cable trench for BH-04.

Photo 9: Upper (dry) culvert on the north (upstream) side of the highway embankment.

Photo 10: SPT sample collection for BH-04, facing west.

Photo 11: BH-04 9.9-10.5 m SPT sample.

Photo 12: BH-04 11.4-12.0 m SPT sample.

Photo 13: BH-04 14.4-15.0 m SPT sample.

Photo 14: BH-04 14.4-15.0 m SPT sample 2.

Photo 15: BH-04 9.9-10.5 m SPT sample 2.

Photo 16: BH-04 11.4-12.0 m SPT sample 2.

Photo 17: BH-04 9.9-10.5 m SPT sample 3.

Photo 18: BH-04 11.4-12.0 m SPT sample 3.

Photo 19: Drill setup for BH-05, facing north.

Photo 20: Highway backfilled from thermistor cable trenching for BH-05, facing north.

Photo 21: Thermistor cable trench for BH-05.

APPENDIX A

TETRA TECH'S LIMITATIONS ON THE USE OF THIS DOCUMENT

LIMITATIONS ON USE OF THIS DOCUMENT

GEOTECHNICAL

1.1 USE OF DOCUMENT AND OWNERSHIP

This document pertains to a specific site, a specific development, and a specific scope of work. The document may include plans, drawings, profiles and other supporting documents that collectively constitute the document (the "Professional Document").

The Professional Document is intended for the sole use of TETRA TECH's Client (the "Client") as specifically identified in the TETRA TECH Services Agreement or other Contractual Agreement entered into with the Client (either of which is termed the "Contract" herein). TETRA TECH does not accept any responsibility for the accuracy of any of the data, analyses, recommendations or other contents of the Professional Document when it is used or relied upon by any party other than the Client, unless authorized in writing by TETRA TECH.

Any unauthorized use of the Professional Document is at the sole risk of the user. TETRA TECH accepts no responsibility whatsoever for any loss or damage where such loss or damage is alleged to be or, is in fact, caused by the unauthorized use of the Professional Document.

Where TETRA TECH has expressly authorized the use of the Professional Document by a third party (an "Authorized Party"), consideration for such authorization is the Authorized Party's acceptance of these Limitations on Use of this Document as well as any limitations on liability contained in the Contract with the Client (all of which is collectively termed the "Limitations on Liability"). The Authorized Party should carefully review both these Limitations on Use of this Document and the Contract prior to making any use of the Professional Document. Any use made of the Professional Document by an Authorized Party constitutes the Authorized Party's express acceptance of, and agreement to, the Limitations on Liability.

The Professional Document and any other form or type of data or documents generated by TETRA TECH during the performance of the work are TETRA TECH's professional work product and shall remain the copyright property of TETRA TECH.

The Professional Document is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of TETRA TECH. Additional copies of the Document, if required, may be obtained upon request.

1.2 ALTERNATIVE DOCUMENT FORMAT

Where TETRA TECH submits electronic file and/or hard copy versions of the Professional Document or any drawings or other project-related documents and deliverables (collectively termed TETRA TECH's "Instruments of Professional Service"), only the signed and/or sealed versions shall be considered final. The original signed and/or sealed electronic file and/or hard copy version archived by TETRA TECH shall be deemed to be the original. TETRA TECH will archive a protected digital copy of the original signed and/or sealed version for a period of 10 years.

Both electronic file and/or hard copy versions of TETRA TECH's Instruments of Professional Service shall not, under any circumstances, be altered by any party except TETRA TECH. TETRA TECH's Instruments of Professional Service will be used only and exactly as submitted by TETRA TECH.

Electronic files submitted by TETRA TECH have been prepared and submitted using specific software and hardware systems. TETRA TECH makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.

1.3 STANDARD OF CARE

Services performed by TETRA TECH for the Professional Document have been conducted in accordance with the Contract, in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Professional judgment has been applied in developing the conclusions and/or recommendations provided in this Professional Document. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of the Professional Document.

If any error or omission is detected by the Client or an Authorized Party, the error or omission must be immediately brought to the attention of TETRA TECH.

1.4 DISCLOSURE OF INFORMATION BY CLIENT

The Client acknowledges that it has fully cooperated with TETRA TECH with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for TETRA TECH to properly provide the services contracted for in the Contract, TETRA TECH has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

1.5 INFORMATION PROVIDED TO TETRA TECH BY OTHERS

During the performance of the work and the preparation of this Professional Document, TETRA TECH may have relied on information provided by third parties other than the Client.

While TETRA TECH endeavours to verify the accuracy of such information, TETRA TECH accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage.

1.6 GENERAL LIMITATIONS OF DOCUMENT

This Professional Document is based solely on the conditions presented and the data available to TETRA TECH at the time the data were collected in the field or gathered from available databases.

The Client, and any Authorized Party, acknowledges that the Professional Document is based on limited data and that the conclusions, opinions, and recommendations contained in the Professional Document are the result of the application of professional judgment to such limited data.

The Professional Document is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present, or variation in assumed conditions which might form the basis of design or recommendations as outlined in this document, at or on the development proposed as of the date of the Professional Document requires a supplementary exploration, investigation, and assessment.

TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.7 ENVIRONMENTAL AND REGULATORY ISSUES

Unless stipulated in the report, TETRA TECH has not been retained to explore, address or consider and has not explored, addressed or considered any environmental or regulatory issues associated with development on the subject site.

1.8 NATURE AND EXACTNESS OF SOIL AND ROCK DESCRIPTIONS

Classification and identification of soils and rocks are based upon commonly accepted systems, methods and standards employed in professional geotechnical practice. This report contains descriptions of the systems and methods used. Where deviations from the system or method prevail, they are specifically mentioned.

Classification and identification of geological units are judgmental in nature as to both type and condition. TETRA TECH does not warrant conditions represented herein as exact, but infers accuracy only to the extent that is common in practice.

Where subsurface conditions encountered during development are different from those described in this report, qualified geotechnical personnel should revisit the site and review recommendations in light of the actual conditions encountered.

1.9 LOGS OF TESTHOLES

The testhole logs are a compilation of conditions and classification of soils and rocks as obtained from field observations and laboratory testing of selected samples. Soil and rock zones have been interpreted. Change from one geological zone to the other, indicated on the logs as a distinct line, can be, in fact, transitional. The extent of transition is interpretive. Any circumstance which requires precise definition of soil or rock zone transition elevations may require further investigation and review.

1.10 STRATIGRAPHIC AND GEOLOGICAL INFORMATION

The stratigraphic and geological information indicated on drawings contained in this report are inferred from logs of test holes and/or soil/rock exposures. Stratigraphy is known only at the locations of the test hole or exposure. Actual geology and stratigraphy between test holes and/or exposures may vary from that shown on these drawings. Natural variations in geological conditions are inherent and are a function of the historical environment. TETRA TECH does not represent the conditions illustrated as exact but recognizes that variations will exist. Where knowledge of more precise locations of geological units is necessary, additional exploration and review may be necessary.

1.11 PROTECTION OF EXPOSED GROUND

Excavation and construction operations expose geological materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration. Unless otherwise specifically indicated in this report, the walls and floors of excavations must be protected from the elements, particularly moisture, desiccation, frost action and construction traffic.

1.12 SUPPORT OF ADJACENT GROUND AND STRUCTURES

Unless otherwise specifically advised, support of ground and structures adjacent to the anticipated construction and preservation of adjacent ground and structures from the adverse impact of construction activity is required.

1.13 INFLUENCE OF CONSTRUCTION ACTIVITY

Construction activity can impact structural performance of adjacent buildings and other installations. The influence of all anticipated construction activities should be considered by the contractor, owner, architect and prime engineer in consultation with a geotechnical engineer when the final design and construction techniques, and construction sequence are known.

1.14 OBSERVATIONS DURING CONSTRUCTION

Because of the nature of geological deposits, the judgmental nature of geotechnical engineering, and the potential of adverse circumstances arising from construction activity, observations during site preparation, excavation and construction should be carried out by a geotechnical engineer. These observations may then serve as the basis for confirmation and/or alteration of geotechnical recommendations or design guidelines presented herein.

1.15 DRAINAGE SYSTEMS

Unless otherwise specified, it is a condition of this report that effective temporary and permanent drainage systems are required and that they must be considered in relation to project purpose and function. Where temporary or permanent drainage systems are installed within or around a structure, these systems must protect the structure from loss of ground due to mechanisms such as internal erosion and must be designed so as to assure continued satisfactory performance of the drains. Specific design details regarding the geotechnical aspects of such systems (e.g. bedding material, surrounding soil, soil cover, geotextile type) should be reviewed by the geotechnical engineer to confirm the performance of the system is consistent with the conditions used in the geotechnical design.

1.16 DESIGN PARAMETERS

Bearing capacities for Limit States or Allowable Stress Design, strength/stiffness properties and similar geotechnical design parameters quoted in this report relate to a specific soil or rock type and condition. Construction activity and environmental circumstances can materially change the condition of soil or rock. The elevation at which a soil or rock type occurs is variable. It is a requirement of this report that structural elements be founded in and/or upon geological materials of the type and in the condition used in this report. Sufficient observations should be made by qualified geotechnical personnel during construction to assure that the soil and/or rock conditions considered in this report in fact exist at the site.

1.17 SAMPLES

TETRA TECH will retain all soil and rock samples for 30 days after this report is issued. Further storage or transfer of samples can be made at the Client's expense upon written request, otherwise samples will be discarded.

1.18 APPLICABLE CODES, STANDARDS, GUIDELINES & BEST PRACTICE

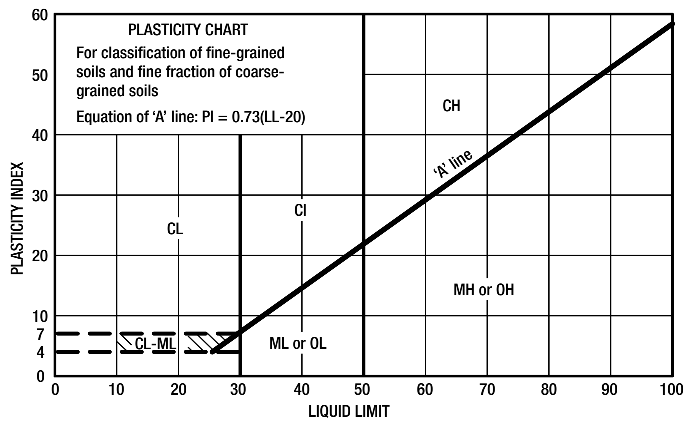
This document has been prepared based on the applicable codes, standards, guidelines or best practice as identified in the report. Some mandated codes, standards and guidelines (such as ASTM, AASHTO Bridge Design/Construction Codes, Canadian Highway Bridge Design Code, National/Provincial Building Codes) are routinely updated and corrections made. TETRA TECH cannot predict nor be held liable for any such future changes, amendments, errors or omissions in these documents that may have a bearing on the assessment, design or analyses included in this report.

APPENDIX B

BOREHOLE LOGS

MODIFIED UNIFIED SOIL CLASSIFICATION

MAJOR DIVISION			GROUP SYMBOL	TYPICAL DESCRIPTION	LABORATORY CLASSIFICATION CRITERIA		
COARSE - GRAINED SOILS More than 50% retained on No. 75 µm sieve*	GRAVELS 50% or more of coarse fraction retained on No. 4 sieve	CLEAN GRAVELS	GW	Well-graded gravels and gravel-sand mixtures, little or no fines	Classification on basis of percentage of fines: Less than 5% pass 75 µm sieve: GW, GP, SW, SP; More than 12% pass 75 µm sieve: GM, GC, SM, SC; 5% to 12% pass 75 µm sieve: Borderline classification requiring use of dual symbols	$C_u = D_{60} / D_{10}$ Greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
			GP	Poorly-graded gravels and gravel-sand mixtures, little or no fines		Not meeting both criteria for GW	
		GRAVELS WITH FINES	GM	Silty gravels, gravel-sand-silt mixtures		Atterberg limits plot below 'A' line or plasticity index less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols
			GC	Clayey gravels, gravel-sand-clay mixtures		Atterberg limits plot above 'A' line and plasticity index greater than 7	
	SANDS More than 50% of coarse fraction passes No. 4 sieve	CLEAN SANDS	SW	Well-graded sands and gravelly sands, little or no fines		$C_u = D_{60} / D_{10}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
			SP	Poorly-graded sands and gravelly sands, little or no fines		Not meeting both criteria for SW	
		SANDS WITH FINES	SM	Silty sands, sand-silt mixtures		Atterberg limits plot above 'A' line and plasticity index less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols
			SC	Clayey sands, sand-clay mixtures		Atterberg limits plot above 'A' line and plasticity index greater than 7	
FINE-GRAINED SOILS (by behavior) 50% or more passes 75 µm sieve*	SILTS	Liquid limit <50	ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands of slight plasticity			
		Liquid limit >50	MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts			
	CLAYS Above "A" line on plasticity chart negligible organic content	Liquid limit <30	CL	Inorganic clays of low plasticity, gravelly clays, sandy clays, silty clays, lean clays			
		Liquid limit 30-50	CI	Inorganic clay of medium plasticity, silty clays			
		Liquid limit >50	CH	Inorganic clay of high plasticity, fat clays			
	ORGANIC SILTS AND CLAYS	Liquid limit <50	OL	Organic silts and organic silty clays of low plasticity			
		Liquid limit >50	OH	Organic clays of medium to high plasticity			
HIGHLY ORGANIC SOILS			PT	Peat, muck and other highly organic soils			

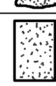


* Based on the material passing the 75 mm sieve

† ASTM Designation D 2487, for identification procedure see D 2488 USC as modified by PFRA

GROUND ICE DESCRIPTION

ICE NOT VISIBLE

GROUP SYMBOL	SYMBOL	SUBGROUP DESCRIPTION	
N	Nf	Poorly-bonded or friable	
	Nbn	No excess ice, well-bonded	
	Nbe	Excess ice, well-bonded	

VISIBLE ICE LESS THAN 50% BY VOLUME

GROUP SYMBOL	SYMBOL	SUBGROUP DESCRIPTION	
V	Vx	Individual ice crystals or inclusions	
	Vc	Ice coatings on particles	
	Vr	Random or irregularly oriented ice formations	
	Vs	Stratified or distinctly oriented ice formations	

VISIBLE ICE GREATER THAN 50% BY VOLUME

ICE	ICE + Soil Type	Ice with soil inclusions	
	ICE	Ice without soil inclusions (greater than 25 mm thick)	

NOTES:

1. Dual symbols are used to indicate borderline or mixed ice classifications.
2. Visual estimates of ice contents indicated on borehole logs ± 5%
3. This system of ground ice description has been modified from NRC Technical Memo 79, Guide to the Field Description of Permafrost for Engineering Purposes.

LEGEND: Soil ☐ Ice ■

TERMS USED ON BOREHOLE LOGS

TERMS DESCRIBING CONSISTENCY OR CONDITION

COARSE GRAINED SOILS (major portion retained on 0.075mm sieve): Includes (1) clean gravels and sands, and (2) silty or clayey gravels and sands. Condition is rated according to relative density, as inferred from laboratory or in situ tests.

DESCRIPTIVE TERM	RELATIVE DENSITY	N (blows per 0.3m)
Very Loose	0 TO 20%	0 to 4
Loose	20 TO 40%	4 to 10
Compact	40 TO 75%	10 to 30
Dense	75 TO 90%	30 to 50
Very Dense	90 TO 100%	greater than 50

The number of blows, N, on a 51mm O.D. split spoon sampler of a 63.5kg weight falling 0.76m, required to drive the sampler a distance of 0.3m from 0.15m to 0.45m.

FINE GRAINED SOILS (major portion passing 0.075mm sieve): Includes (1) inorganic and organic silts and clays, (2) gravelly, sandy, or silty clays, and (3) clayey silts. Consistency is rated according to shearing strength, as estimated from laboratory or in situ tests.

DESCRIPTIVE TERM	UNCONFINED COMPRESSIVE STRENGTH (KPA)
Very Soft	Less than 25
Soft	25 to 50
Firm	50 to 100
Stiff	100 to 200
Very Stiff	200 to 400
Hard	Greater than 400

NOTE: Slickensided and fissured clays may have lower unconfined compressive strengths than shown above, because of planes of weakness or cracks in the soil.

GENERAL DESCRIPTIVE TERMS

Slickensided - having inclined planes of weakness that are slick and glossy in appearance.
Fissured - containing shrinkage cracks, frequently filled with fine sand or silt; usually more or less vertical.
Laminated - composed of thin layers of varying colour and texture.
Interbedded - composed of alternate layers of different soil types.
Calcareous - containing appreciable quantities of calcium carbonate.;
Well graded - having wide range in grain sizes and substantial amounts of intermediate particle sizes.
Poorly graded - predominantly of one grain size, or having a range of sizes with some intermediate size missing.

BOREHOLE KEYSHEET

Water Level Measurement

- Measured in standpipe, piezometer or well
- Inferred

Sample Types

- A-Casing
- Core
- Disturbed, Bag, Grab
- HQ Core
- Jar
- Jar and Bag
- NQ Core
- No Recovery
- Split Spoon/SPT
- Tube
- CRREL Core

Backfill Materials

- Asphalt
- Bentonite
- Cement/ Grout
- Drill Cuttings
- Grout
- Gravel
- Sand
- Slough
- Topsoil Backfill

Lithology - Graphical Legend[1]

- Asphalt
- Bedrock
- Cobbles/Boulders
- Clay
- Coal
- Concrete
- Fill
- Gravel
- Limestone
- Mudstone
- Organics
- Peat
- Sand
- Sandstone
- Shale
- Silt
- Siltstone
- Till
- Topsoil

1. The graphical legend is an approximation and for visual representation only. Soil strata may comprise a combination of the basic symbols shown above. Particle sizes are not drawn to scale

TETRA TECH

Borehole No: **BH-04**

Project: Geotechnical Investigation of Existing Culverts	Project No: ENG.YARC03234-01
Location: NWT Highway 8, km 40.1	
NWT Highway 8, Northwest Territories	UTM: 478210 E; 7455798 N; Z 8

Method: ODEX

Depth (m)	Soil Description	Ground Ice Description	Temperature (°C)	SPT (N)	Moisture Content (%)
0	SAND (EMBANKMENT) - silty, gravelly, trace cobbles, dry to damp, brown, subrounded cobbles to 100 mm diameter	Unfrozen			
1.3					7.7
2.9			-0.2	11	5.5
4.1	- suspected boulder for 500 mm				7.3
5.0	CLAY - silty, trace sand, trace gravel, stiff, medium to high plastic, dark grey		-0.4		
5.2		Permafrost			
5.6	- (Gravel - 40%; Sand - 31%; Silt & Clay - 29%)			75	10.6
7.1	- (Soluble sulphate content = 0.00%)				12.6
7.5			-0.7		
8.7		Small ice veins, Vr trace		79 /225mm	17.1
9.5	ICE - clay - silty, trace sand, high plastic, dark grey	50% by volume			
10.0			-1	31	39.4
10.5	CLAY - silty, trace sand, high plastic, dark grey	Ice strata, Vs, 20% by volume			
11.7				41	27.6
13.5					23.1
14.0			-1.5		
14.6	- (Gravel - 9%; Sand - 45%; Silt - 47%; Clay - 39%)			54	26.1

Contractor: Midnight Sun Drilling	Completion Depth: 24 m
Drilling Rig Type: Track mounted Multipower Prospector P1	Start Date: 2018 September 30
Logged By: DY	Completion Date: 2018 September 30
Reviewed By: RG	Page 1 of 2

Borehole No: **BH-04**

Project: Geotechnical Investigation of Existing Culverts	Project No: ENG.YARC03234-01
Location: NWT Highway 8, km 40.1	
NWT Highway 8, Northwest Territories	UTM: 478210 E; 7455798 N; Z 8

Depth (m)	Method	Soil Description	Ground Ice Description	Sample Type	Temperature (°C)	SPT (N)	Moisture Content (%)	Thermistors	Depth (ft)
15–24	ODEX		Permafrost						50–78
16.5				Sample			29.5		
17					-1.5			Thermistor	
18				Sample			54.5 (Salinity △)		
19.5				Sample			34.7		
21				Sample			19.6		
22.5				Sample	-1.7		22.2	Thermistor	
24		- (Gravel - 0%; Sand - 1%; Silt & Clay - 99%)		Sample			18.9		

Chart axes: Salinity (ppt) 5, 10, 15, 20; SPT (N) 20, 40, 60, 80; Plastic Limit – Moisture Content – Liquid Limit 20, 40, 60, 80

END OF BOREHOLE (24.00 metres)
Single bead thermistors installed to 3.00, 5.00, 7.50, 10.00, 14.00, 17.00 and 22.50 metres
Temperature readings taken on December 18, 2018

Contractor: Midnight Sun Drilling	Completion Depth: 24 m
Drilling Rig Type: Track mounted Multipower Prospector P1	Start Date: 2018 September 30
Logged By: DY	Completion Date: 2018 September 30
Reviewed By: RG	Page 2 of 2

Borehole No: **BH-05**

Project: Geotechnical Investigation of Existing Culverts	Project No: ENG.YARC03234-01
Location: NWT Highway 8, km 40.1	
NWT Highway 8, Northwest Territories	UTM: 478191 E; 7455821 N; Z 8

Northwest Territories

Depth (m)	Method	Soil Description	Ground Ice Description	Sample Type	Temperature (°C)	Moisture Content (%)	Thermistors	Depth (ft)
0	ODEX	SILT (EMBANKMENT) - sandy, some gravel, trace cobbles, damp, brown sand and silt, multicoloured gravel, rounded to subrounded gravel to 100 mm diameter	Unfrozen					0
1				sample		9.7		4
2.5				sample		7.4		8
4		- (Gravel - 20%; Sand - 45%; Silt & Clay - 35%)		sample	-0.2	9.1	■	13
5			Permafrost					16
5.5		ORGANICS - rootlets, peat, grass, strong organic odour - (Soluble sulphate content = 0.02%)	Ice crystals, Vx trace	sample		38.4 (salinity △)		18
6		CLAY - silty, trace sand, high plastic, dark grey			-0.7		■	20
7				sample		23.5		24
8.5				sample		23		28
9					-0.9		■	30
10		- (Gravel - 1%; Sand - 49%; Silt & Clay - 51%)		sample		25 (Plastic/Liquid limit shown)		34
11.5				sample		25.9		38
12					-1		■	40
13				sample		23		44
14.5				sample		19.7 (salinity △)		48
15							■	

Chart scales: △ Salinity (ppt) △ 5 10 15 20; Plastic Limit, Moisture Content, Liquid Limit 20 40 60 80

TETRA TECH

Contractor: Midnight Sun Drilling	Completion Depth: 22.8 m
Drilling Rig Type: Track mounted Multipower Prospector P1	Start Date: 2018 October 1
Logged By: DY	Completion Date: 2018 October 1
Reviewed By: RG	Page 1 of 2

Borehole No: **BH-05**

Project: Geotechnical Investigation of Existing Culverts	Project No: ENG.YARC03234-01
Location: NWT Highway 8, km 40.1	
NWT Highway 8, Northwest Territories	UTM: 478191 E; 7455821 N; Z 8

Depth (m)	Method	Soil Description	Ground Ice Description	Sample Type	Temperature (°C)	Moisture Content (%)	Plastic Limit / Moisture Content / Liquid Limit (20 40 60 80); △ Salinity (ppt) △ (5 10 15 20)	Thermistors	Depth (ft)
15	ODEX		Permafrost		-1.1				50
16						24.9			52, 54
17						23			56, 58
18					-1.3				60
19		- (Gravel - 0%; Sand - 1%; Silt - 54%; Clay - 45%)				19.6			62, 64
20									66
21						23.8			68, 70
22						23.7			72, 74
23		END OF BOREHOLE (22.80 metres) Single bead thermistors installed to 4.00, 6.00, 9.00, 12.00, 15.00 and 18.00 metres Temperature readings taken on December 20, 2018							76
24									78, 80
25									82
26									84, 86
27									88, 90
28									92
29									94, 96
30									98

Contractor: Midnight Sun Drilling	Completion Depth: 22.8 m
Drilling Rig Type: Track mounted Multipower Prospector P1	Start Date: 2018 October 1
Logged By: DY	Completion Date: 2018 October 1
Reviewed By: RG	Page 2 of 2

APPENDIX C

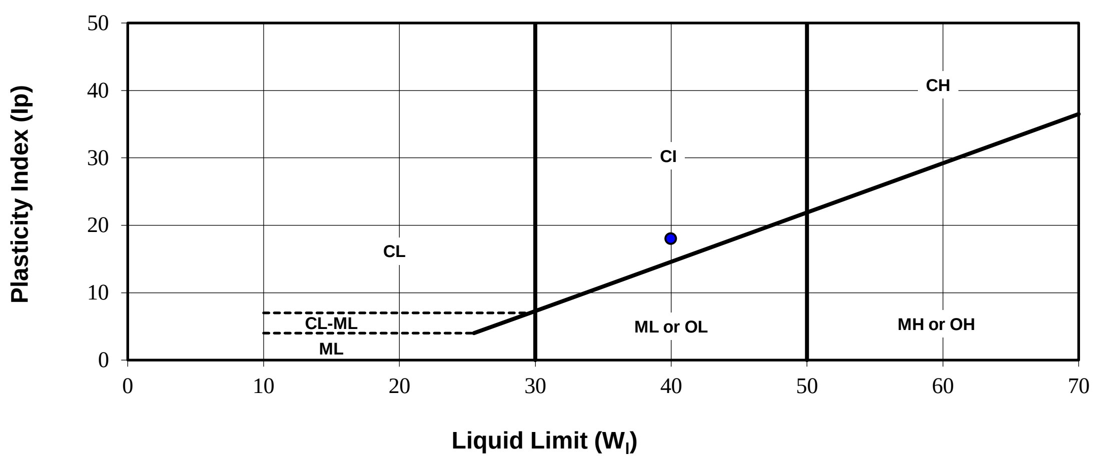
LABORATORY REPORTS

ATTERBERG LIMITS TEST REPORT

ASTM D4318

Project:	Geotechnical Investigation, Highway 8 Culverts	Sample Number:	6868-048
Project No:	ENG.YARC03234-01	Borehole Number:	BH-04
Site:	NWT Hwy 8, km 14.3	Depth:	5.4 - 6.0 m
Client:	GNWT - INF	Sampled By:	DY
		Tested By:	SS
Attention:	Baoquan An	Date Sampled:	September 30, 2018
		Date Tested:	November 13, 2018

Sample Description: GRAVEL, sandy, silty/clayey, brown with reddish orange streaks



Liquid Limit ($W_{1)}$:	40	Natural Moisture (%)	10.6
Plastic Limit :	22	Soil Plasticity:	Medium
Plasticity Index (Ip) :	**18**	Mod.USCS Symbol:	CI

Remarks: Atterberg performed on fine portion of sample. Overall classification is GM.

Reviewed By: ________________ AScT

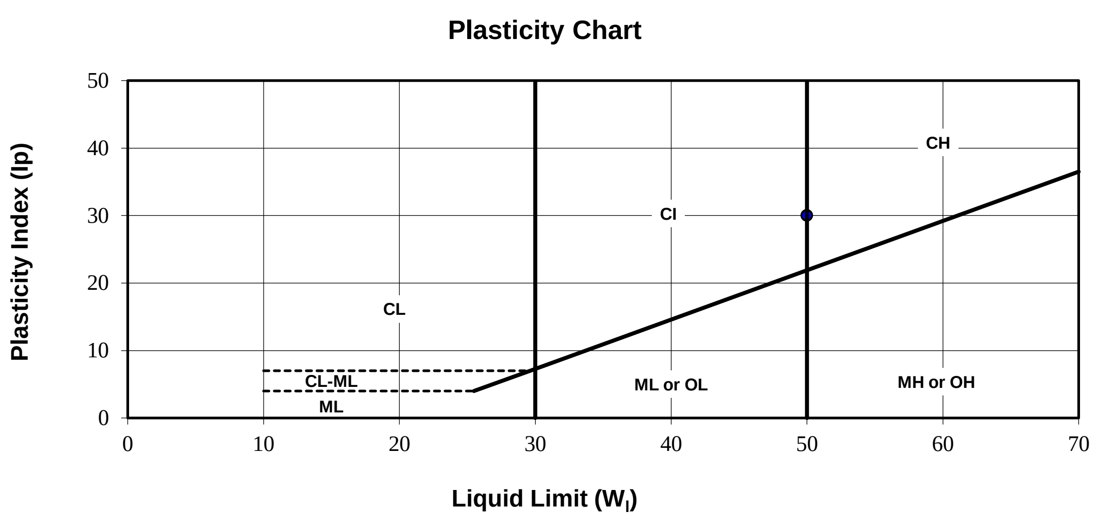
TETRA TECH

ATTERBERG LIMITS TEST REPORT

ASTM D4318

Project:	Geotechnical Investigation, Highway 8 Culverts	Sample Number:	6868-054
		Borehole Number:	BH-04
Project No:	ENG.YARC03234-01	Depth:	14.4 - 14.5 m
Site:	NWT Hwy 8, km 40.1	Sampled By:	DY Tested By: SS
Client:	GNWT - INF	Date Sampled:	September 30, 2018
Attention:	Baoquan An	Date Tested:	November 13, 2018

Sample Description: CLAY, silty, trace gravel, trace sand, medium grey



Liquid Limit ($W_{1)}$:	50	Natural Moisture (%)	26.1
Plastic Limit :	20	Soil Plasticity:	Medium to High
Plasticity Index (Ip) :	**30**	Mod.USCS Symbol:	CI-CH

Remarks:

Reviewed By: ______________ AScT

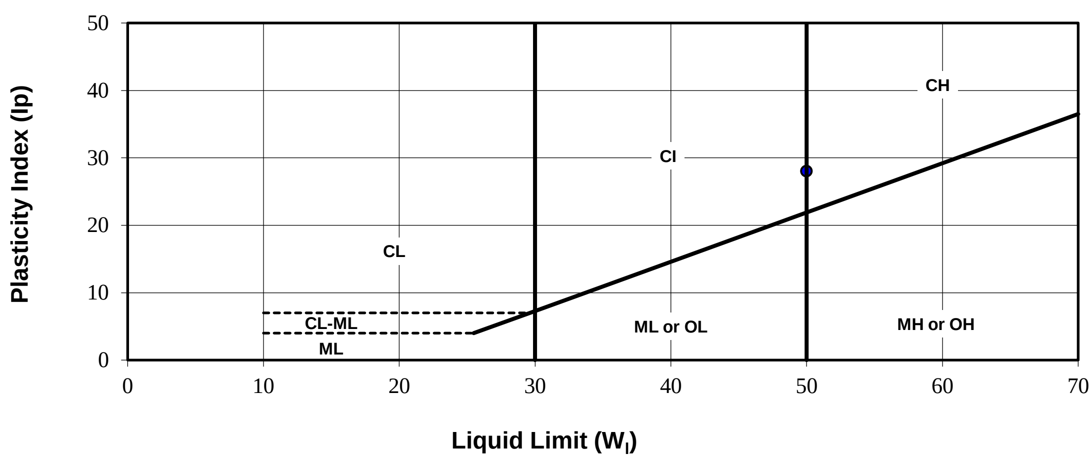
TETRA TECH

ATTERBERG LIMITS TEST REPORT

ASTM D4318

Project:	Geotechnical Investigation, Highway 8 Culverts	Sample Number:	6868-067
Project No:	ENG.YARC03234-01	Borehole Number:	BH-05
Site:	NWT Hwy 8, km 40.1	Depth:	10.0 - 10.5 m
Client:	GNWT - INF	Sampled By:	DY Tested By: SS
Attention:	Baoquan An	Date Sampled:	October 1, 2018
		Date Tested:	November 13, 2018

Sample Description: CLAY/SILT and SAND, grey



Liquid Limit (W_1) :	50	Natural Moisture (%)	25.0
Plastic Limit :	22	Soil Plasticity:	Medium to High
Plasticity Index (Ip) :	**28**	Mod.USCS Symbol:	CI-CH

Remarks:

Reviewed By: AScT

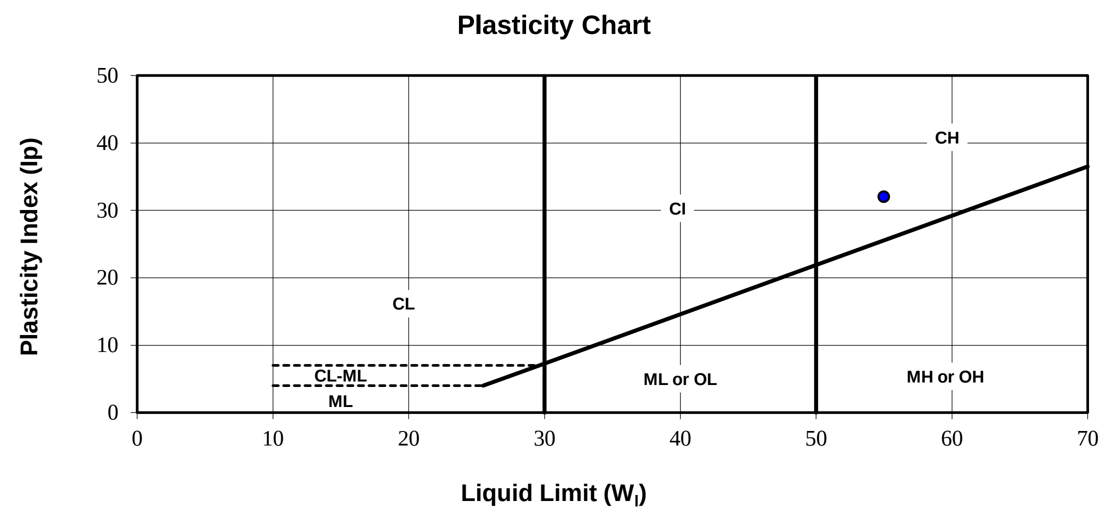
TETRA TECH

ATTERBERG LIMITS TEST REPORT

ASTM D4318

Project:	Geotechnical Investigation, Highway 8 Culverts	Sample Number:	6868-073
		Borehole Number:	BH-05
Project No:	ENG.YARC03234-01	Depth:	19.0 - 19.5 m
Site:	NWT Hwy 8, km 40.1	Sampled By:	DY Tested By: SS
Client:	GNWT - INF	Date Sampled:	October 1, 2018
Attention:	Baoquan An	Date Tested:	November 13, 2018

Sample Description: CLAY, silty, trace sand, organic, grey



Liquid Limit ($W_{1)}$:	55	Natural Moisture (%)	19.6
Plastic Limit :	23	Soil Plasticity:	High
Plasticity Index (Ip) :	**32**	Mod.USCS Symbol:	CH

Remarks:

Reviewed By: AScT

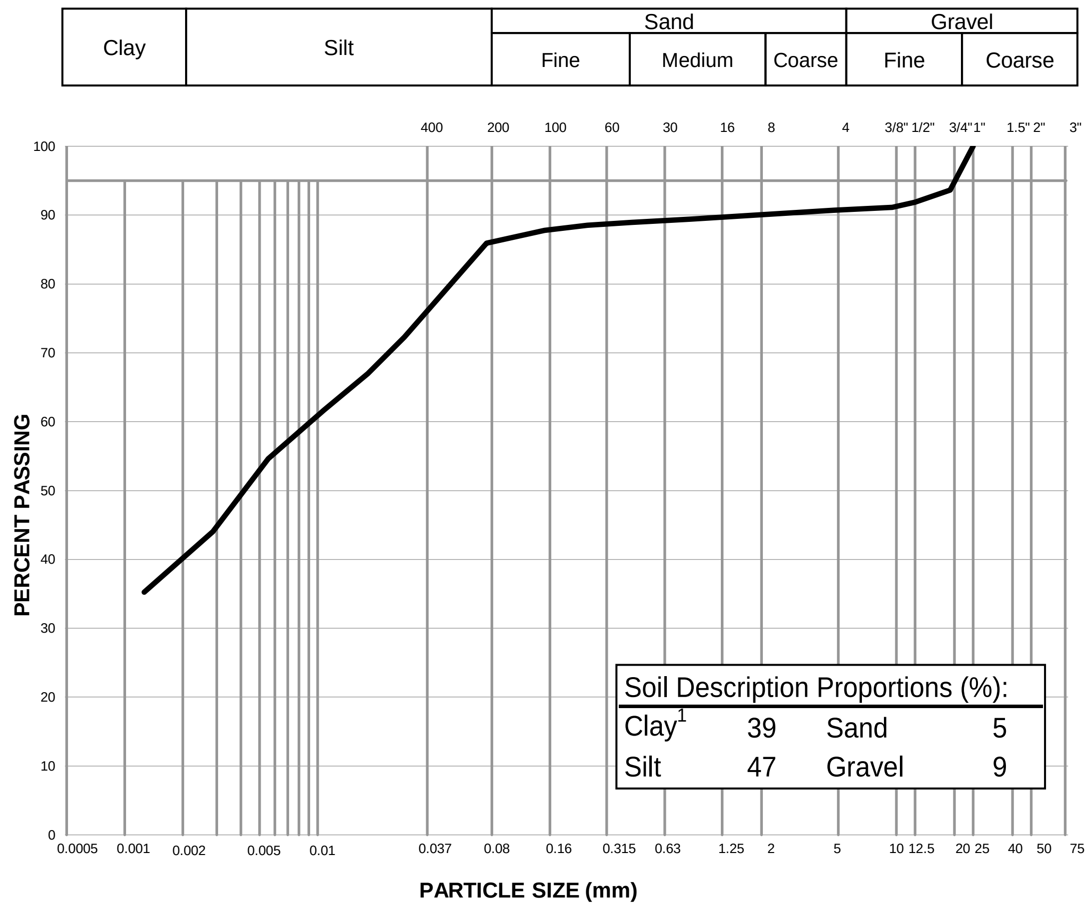
TETRA TECH

PARTICLE SIZE ANALYSIS REPORT

ASTM D7928

Project:	Geotechnical Investigation at Hwy 8	Sample No.:	6868-054
Project No.:	ENG.YARC03234-01	Material Type:	Native
Site:	NWT Hwy 8, km 40.1	Borehole No.:	BH-04
Client:	GNWT - INF	Sample Depth:	14.4 - 15.0 m
Client Rep.:	Baoquan An	Sampling Method:	SPT
Date Tested:	November 5, 2018 By: WM	Date sampled:	September 30, 2018
Soil Description[2]:	CLAY, silty, trace gravel, trace sand	Sampled By:	DY
		USC Classification:	CH Cu: #N/A
Moisture Content:	26.1%		Cc: #N/A

Particle Size (mm)	Percent Passing
75	
50	
37.5	
25	100
19	94
12.5	92
9.5	91
4.75	91
2	90
0.85	89
0.425	89
0.25	89
0.15	88
0.075	85.9
0.0281	72.2
0.0182	67.0
0.0108	61.7
0.0077	58.2
0.0055	54.6
0.0029	44.1
0.0013	35.2



Soil Description Proportions (%):			
Clay[1]	39	Sand	5
Silt	47	Gravel	9

Notes: [1] The upper clay size of 2 um, per the Canadian Foundation Engineering Manual

[2] The description is visually based & subject to Tetra Tech description protocols

Specification:

Remarks:

Reviewed By: ________________ AScT

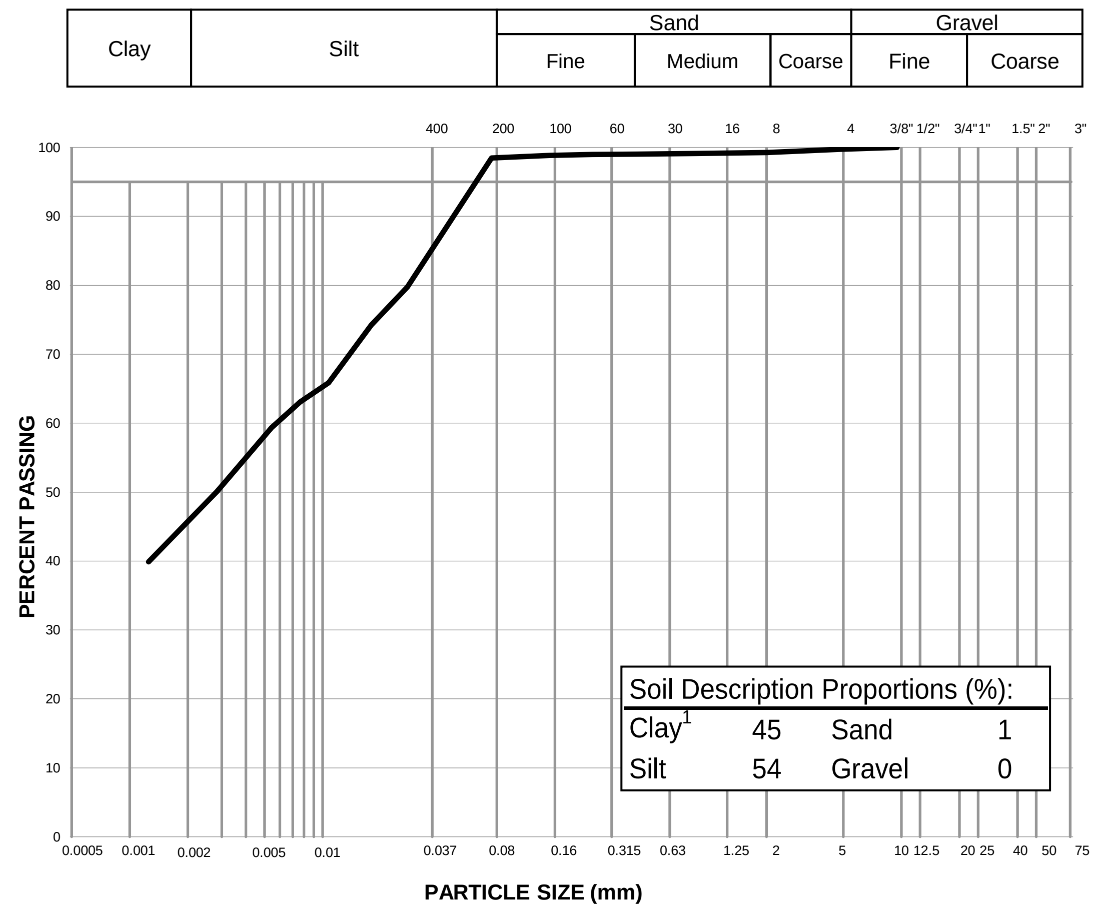
TETRA TECH

PARTICLE SIZE ANALYSIS REPORT

ASTM D7928

Project:	Geotechnical Investigation at Hwy 8	Sample No.:	6868-073
Project No.:	ENG.YARC03234-01	Material Type:	Native
Site:	NWT Hwy 8, km 40.1	Borehole No.:	BH-05
Client:	GNWT - INF	Sample Depth:	19.0 - 19.5 m
Client Rep.:	Baoquan An	Sampling Method:	SPT
Date Tested:	November 5, 2018 By: WM	Date sampled:	October 1, 2018
Soil Description[2]:	CLAY, silty, trace sand	Sampled By:	DY
		USC Classification:	CH Cu: #N/A
Moisture Content:	19.6%		Cc: #N/A

Particle Size (mm)	Percent Passing
75	
50	
37.5	
25	
19	
12.5	
9.5	100
4.75	100
2	99
0.85	99
0.425	99
0.25	99
0.15	99
0.075	98.5
0.0275	79.8
0.0179	74.2
0.0107	65.9
0.0077	63.1
0.0054	59.4
0.0028	50.1
0.0013	39.9



Soil Description Proportions (%):			
Clay[1]	45	Sand	1
Silt	54	Gravel	0

Notes: [1] The upper clay size of 2 um, per the Canadian Foundation Engineering Manual

[2] The description is visually based & subject to Tetra Tech description protocols

Specification:

Remarks:

Reviewed By: ______________________ AScT

TETRA TECH

MOISTURE CONTENT TEST RESULTS

ASTM D2216

Project:	Geotechnical Investigation, Hwy 8 Culvert Sites	Sample No.:	6868
Project No.:	ENG.YARC03234-01	Date Tested:	October 25, 2018
Client:	Government of the Northwest Territories - INF	Tested By:	SS
Address:	NWT Hwy 8, km 40.1	Page:	1 of 2

B.H. Number	Depth (m)	Moisture Content (%)	Visual Description of Soil
BH-04	1.0 - 1.5	7.7	SAND, gravelly, some silt, trace clay, brown.
BH-04	2.7 - 3.0	5.5	GRAVEL, sandy, some silt, trace clay, brown.
BH-04	4.0 - 4.5	7.3	SAND and GRAVEL, some silt, trace clay, light brown.
BH-04	5.4 - 6.0	10.6	GRAVEL, sandy, silty/clayey, brown with reddish orange streaks.
BH-04	7.0 - 7.5	12.6	SAND, some gravel-gravelly, silty, trace clay, brown.
BH-04	8.4 - 9.0	17.1	CLAY, silty, sandy, trace gravel, medium greyish brown.
BH-04	9.9 - 10.5	39.4	CLAY, some silt, trace sand, trace gravel, organic, medium grey.
BH-04	11.4 - 12.0	27.6	CLAY, some silt, trace sand, trace gravel, organic, medium grey.
BH-04	13.4 - 13.5	23.1	CLAY, some silt, trace sand, organic, medium grey.
BH-04	14.4 - 15.0	26.1	CLAY, silty, trace gravel, trace sand, medium grey.
BH-04	16.4 - 16.5	29.5	CLAY, some silt, some sand, trace gravel, medium grey.
BH-04	17.9 - 18.0	54.5	CLAY, some silt, some sand, medium grey.
BH-04	19.4 - 19.5	34.7	CLAY, some silt, some sand, organic, medium grey.
BH-04	20.9 - 21.0	19.6	CLAY, some silt, some sand, organic, medium grey.
BH-04	22.4 - 22.5	22.2	CLAY, some silt, some sand, organic, medium grey.
BH-04	23.9 - 24.0	18.9	SILT/CLAY, trace sand, organic, medium grey.

Reviewed By: ______________ AScT

TETRA TECH

MOISTURE CONTENT TEST RESULTS

ASTM D2216

Project:	Geotechnical Investigation, Hwy 8 Culvert Sites	Sample No.:	6868
Project No.:	ENG.YARC03234-01	Date Tested:	October 26, 2018
Client:	Government of the Northwest Territories - INF	Tested By:	TO
Address:	NWT Hwy 8, km 40.1	Page:	2 of 2

B.H. Number	Depth (m)	Moisture Content (%)	Visual Description of Soil
BH-05	1.0 - 1.5	9.7	SAND, some gravel, some silt, trace clay, brown.
BH-05	2.5 - 3.0	7.4	SAND, gravelly, some silt, brown.
BH-05	4.0 - 4.5	9.1	SAND and SILT/CLAY, some gravel, brown.
BH-05	5.5 - 6.0	38.4	CLAY, silty, trace gravel, organic, brown.
BH-05	7.0 - 7.5	23.5	CLAY, silty, trace gravel, organic, brown.
BH-05	8.5 - 9.0	23.0	CLAY, silty, some sand, organic, greyish brown.
BH-05	10.0 - 10.5	25.0	CLAY/SILT and SAND, trace gravel, grey.
BH-05	11.5 - 12.0	25.9	CLAY, some silt, trace sand, organic, grey.
BH-05	13.0 - 13.5	23.0	CLAY, trace silt, trace sand, organic, grey.
BH-05	14.5 - 15.0	19.7	CLAY, silty, sandy, organic, grey.
BH-05	16.0 - 16.5	24.9	CLAY, trace silt, trace sand, organic, grey.
BH-05	17.5 - 18.0	23.0	CLAY, trace silt, trace sand, organic, grey.
BH-05	19.0 - 19.5	19.6	CLAY, silty, trace sand, organic, grey.
BH-05	20.5 - 21.0	23.8	CLAY, some sand, trace silt, organic, grey.
BH-05	22.0 - 22.5	23.7	CLAY, some sand, trace silt, organic, grey.

Reviewed By: ______________ AScT

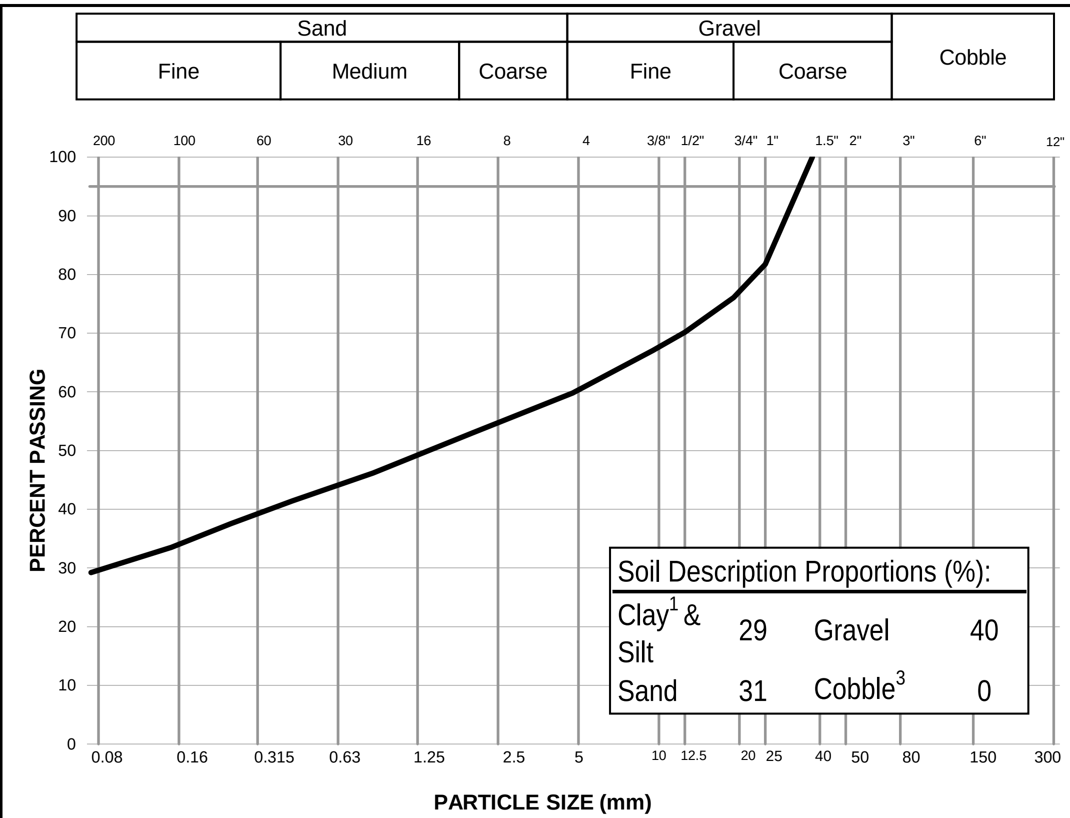
TETRA TECH

PARTICLE SIZE ANALYSIS REPORT

ASTM D422, C136 & C117

Project:	Geotechnical Investigation at Hwy 8	Sample No.:	6868-048
Project No.:	ENG.YARC03234-01	Material Type:	Native
Site:	NWT Hwy 8, km 40.1	Sample Loc.:	BH-04
Client:	GNWT - INF	Sample Depth:	5.4 - 6.0 m
Client Rep.:	Baoquan An	Sampling Method:	SPT
Date Tested:	October 25, 2018 By: SS/TO	Date sampled:	September 30, 2018
Soil Description[2]:	GRAVEL, sandy, silty/clayey	Sampled By:	DY
		USC Classification:	GM Cu: #N/A
Moisture Content:	10.6%		Cc: #N/A

Particle Size (mm)	Percent Passing
300	
200	
150	
100	
75	
50	
37.5	100
25	82
19	76
12.5	70
9.5	67
4.75	60
2	53
0.85	46
0.425	41
0.25	38
0.15	34
0.075	29.2



Notes: [1] The upper clay size of 2 um, per the Canadian Foundation Engineering Manual
[2] The description is visually based & subject to Tt WM4400 description protocols
[3] If cobbles are present, sampling procedure may not meet ASTM C702 & D75

Specification: ______________________

Remarks: ______________________

Reviewed By: ______________________ AScT

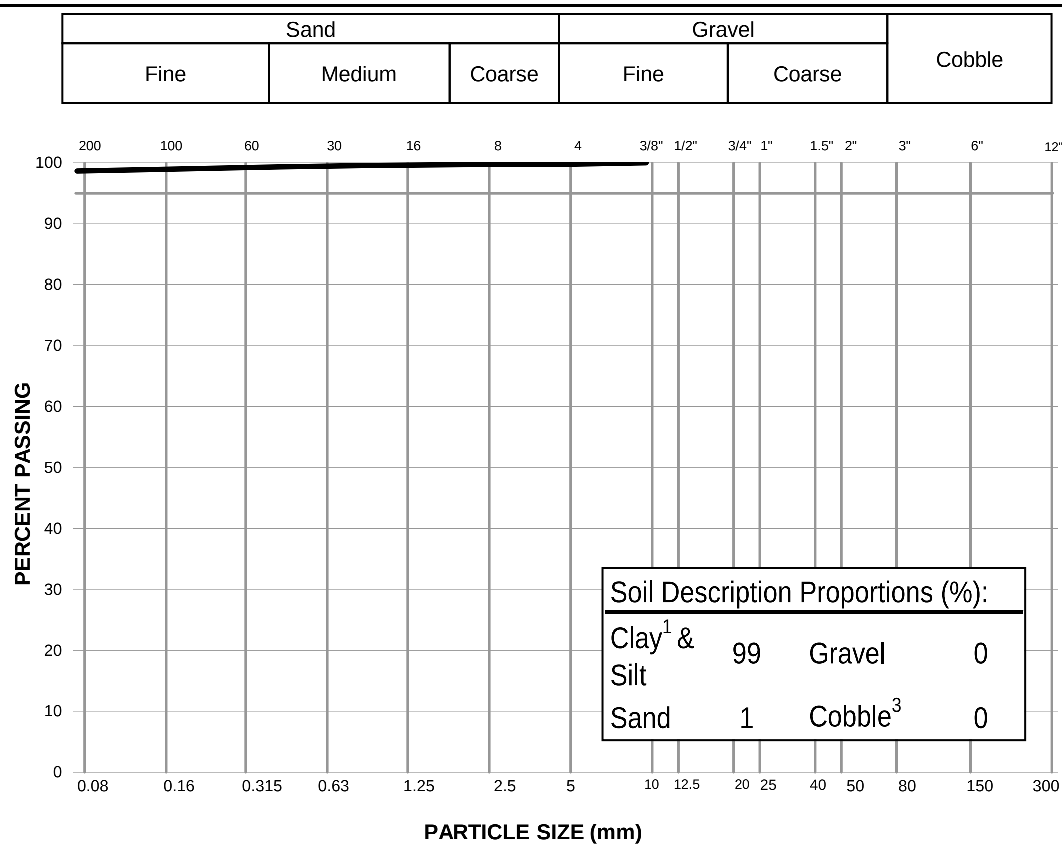
TETRA TECH

PARTICLE SIZE ANALYSIS REPORT

ASTM D422, C136 & C117

Project:	Geotechnical Investigation at Hwy 8	Sample No.:	6868-060
Project No.:	ENG.YARC03234-01	Material Type:	Native
Site:	NWT Hwy 8, km 40.1	Borehole No.:	BH-04
Client:	GNWT - INF	Sample Depth:	23.9 - 24.0 m
Client Rep.:	Baoquan An	Sampling Method:	Grab
Date Tested:	October 25, 2018 By: SS/TO	Date sampled:	September 30, 2018
Soil Description[2]:	CLAY, silty, trace sand	Sampled By:	DY
		USC Classification:	CL Cu: #N/A
Moisture Content:	18.9%		Cc: #N/A

Particle Size (mm)	Percent Passing
300	
200	
150	
100	
75	
50	
37.5	
25	
19	
12.5	
9.5	100
4.75	100
2	100
0.85	100
0.425	99
0.25	99
0.15	99
0.075	98.7



Soil Description Proportions (%):			
Clay[1] & Silt	99	Gravel	0
Sand	1	Cobble[3]	0

Notes: [1] The upper clay size of 2 um, per the Canadian Foundation Engineering Manual
[2] The description is visually based & subject to Tt WM4400 description protocols
[3] If cobbles are present, sampling procedure may not meet ASTM C702 & D75

Specification:

Remarks:

Reviewed By: [signature] P.Eng.

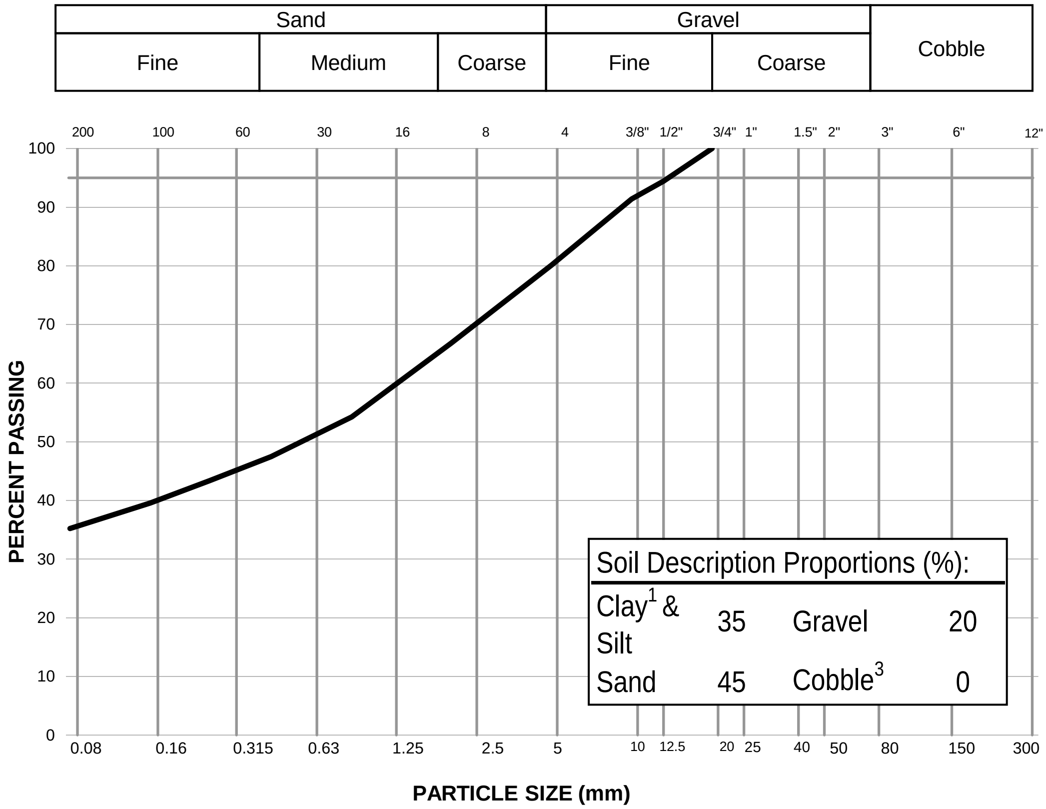
TETRA TECH

PARTICLE SIZE ANALYSIS REPORT

ASTM D422, C136 & C117

Project:	Geotechnical Investigation at Hwy 8	Sample No.:	6868-063
Project No.:	ENG.YARC03234-01	Material Type:	Embankment
Site:	NWT Hwy 8, km 40.1	Borehole No.:	BH-05
Client:	GNWT - INF	Sample Depth:	4.0 - 4.5 m
Client Rep.:	Baoquan An	Sampling Method:	Grab
Date Tested:	October 26, 2018 By: TO	Date sampled:	October 1, 2018
Soil Description[2]:	SAND and SILT/CLAY, some gravel	Sampled By:	DY
		USC Classification:	SM Cu: #N/A
Moisture Content:	9.1%		Cc: #N/A

Particle Size (mm)	Percent Passing
300	
200	
150	
100	
75	
50	
37.5	
25	
19	100
12.5	94
9.5	91
4.75	80
2	67
0.85	54
0.425	47
0.25	43
0.15	40
0.075	35.2



Soil Description Proportions (%):			
Clay[1] & Silt	35	Gravel	20
Sand	45	Cobble[3]	0

Notes: [1] The upper clay size of 2 um, per the Canadian Foundation Engineering Manual
[2] The description is visually based & subject to Tt WM4400 description protocols
[3] If cobbles are present, sampling procedure may not meet ASTM C702 & D75

Specification:

Remarks:

Reviewed By: AScT

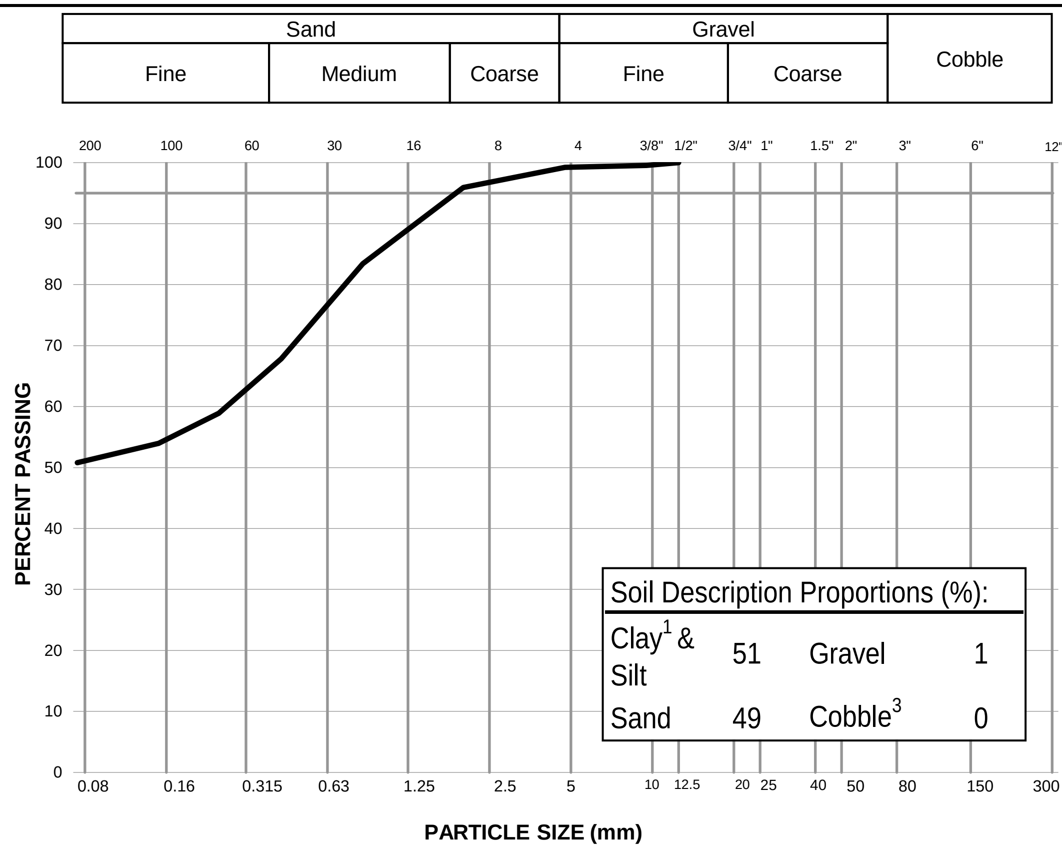
TETRA TECH

PARTICLE SIZE ANALYSIS REPORT

ASTM D422, C136 & C117

Project:	Geotechnical Investigation at Hwy 8	Sample No.:	6868-067
Project No.:	ENG.YARC03234-01	Material Type:	Native
Site:	NWT Hwy 8, km 40.1	Borehole No.:	BH-05
Client:	GNWT - INF	Sample Depth:	10.0 - 10.5 m
Client Rep.:	Baoquan An	Sampling Method:	Grab
Date Tested:	October 26, 2018 By: TO	Date sampled:	October 1, 2018
Soil Description[2]:	CLAY, silty, sandy, trace gravel	Sampled By:	DY
		USC Classification:	CH Cu: #N/A
Moisture Content:	25.0%		Cc: #N/A

Particle Size (mm)	Percent Passing
300	
200	
150	
100	
75	
50	
37.5	
25	
19	
12.5	100
9.5	100
4.75	99
2	96
0.85	83
0.425	68
0.25	59
0.15	54
0.075	50.8



Notes: [1] The upper clay size of 2 um, per the Canadian Foundation Engineering Manual
[2] The description is visually based & subject to Tt WM4400 description protocols
[3] If cobbles are present, sampling procedure may not meet ASTM C702 & D75

Specification: ______________________

Remarks: ______________________

Reviewed By: [signature] P.Eng.

TETRA TECH

Determination of the Soluble Salt Content of Soils by Refractometer

ASTM D4542

Project:	Geotechnical Investigation for Hwy 8 Culverts	**Sample No.:**	See below
Project No:	ENG.YARC03234-01	**Date Sampled:**	Sept 30-Oct 1
Client:	Government of Northwest Territories, INF	**Sampled By:**	DY
Location:	NWT Hwy 8, km 40.1	**Date Tested:**	October 30, 2018
Attention:	Baoquan An	**Tested By:**	LL
Email:	baoquan_an@gov.nt.ca	**Office:**	Edmonton

Sample No.	Location	Depth (m)	Soil Type	Salinity (ppt)
Sample 51	BH-04	9.9-10.5	CLAY, silty, trace sand, grey	0.0
Sample 56	BH-04	17.9-18.0	CLAY, silty, trace sand, grey	0.3
Sample 64	BH-05	5.5-6.0	CLAY, silty, trace sand, gravel, brown	0.6
Sample 70	BH-05	14.5-15.0	CLAY, silty, trace sand, brown	1.9

Remarks:

Reviewed By: ____________________ P.Eng.

TETRA TECH

SOLUBLE SULPHATE ION CONTENT OF SOIL

(CSA Designation A23.2-2B & A23.2-3B)

Project:	Geotechnical Investigation at HWY 8 Culvert Sites, Fort MacPherson, NT	Date Tested:	October 31, 2018
Project No.:	704-ENG.YARC03234-01	Tested By:	JB
Client:	Government of Northwest Territories	Sample Source:	see below
Location:	NWT Hwy 8, km 40.1	Laboratory:	Calgary

Sample Number	49	64				
Borehole Number	BH-04	BH-05				
Depth (m)	7.0-7.5	5.5-6.0				
Sulphate Content %	0.00	0.02				
Degree of Exposure (Class)	Negligible	Negligible				

Class of exposure	Degree of exposure	Water-soluble sulphate (SO_4)† in soil sample, %	Sulphate (SO_4) in groundwater samples, mg/L‡	Water soluble sulphate (SO_4) in recycled aggregate sample, %	Cementing materials to be used§
S-1	Very severe	> 2.0	> 10 000	> 2.0	HS or HSb
S-2	Severe	0.20–2.0	1500–10 000	0.60–2.0	HS or HSb
S-3	Moderate	0.10–0.20	150–1500	0.20–0.60	MS, MSb, LH, HS, or HSb

**For sea water exposure, see Clause 4.1.1.5.*
†In accordance with CSA A23.2-3B.
‡In accordance with CSA A23.2-2B.
§Cementing material combinations with equivalent performance may be used (see Clauses 4.2.1.2, 4.2.1.3, and 4.2.1.4). Type HS cement shall not be used in reinforced concrete exposed to both chlorides and sulphates. Refer to Clause 4.1.1.6.3.

Limitations:

i) The degree of exposure class included herein are valid only if drainage and weeping systems meet the requirements of the site conditions.

ii) The degree exposure class should be re-verified if backfill soils for foundation walls originate from an unknown source.

Remarks:

Reviewed By: ____________________ P.Geol.

TETRA TECH

APPENDIX D

DESIGN AND CONSTRUCTION GUIDELINES

CONSTRUCTION EXCAVATIONS

Construction should be in accordance with good practice and comply with the requirements of the responsible regulatory agencies.

All excavations greater than 1.5 m deep should be sloped or shored for worker protection.

Shallow excavations up to about 3 m depth may use temporary sideslopes of 1H:1V. A flatter slope of 2H:1V should be used if groundwater is encountered. Localized sloughing can be expected from these slopes.

Deep excavations or trenches may require temporary support if space limitations or economic considerations preclude the use of sloped excavations.

For excavations greater than 3 m depth, temporary support should be designed by a qualified geotechnical engineer. The design and proposed installation and construction procedures should be submitted to Tetra Tech for review.

The construction of a temporary support system should be monitored. Detailed records should be taken of installation methods, materials, in situ conditions and the movement of the system. If anchors are used, they should be load tested. Tetra Tech can provide further information on monitoring and testing procedures if required.

Attention should be paid to structures or buried service lines close to the excavation. For structures, a general guideline is that if a line projected down, at 45 degrees from the horizontal from the base of foundations of adjacent structures intersects the extent of the proposed excavation, these structures may require underpinning or special shoring techniques to avoid damaging earth movements. The need for any underpinning or special shoring techniques and the scope of monitoring required can be determined when details of the service ducts and vaults, foundation configuration of existing buildings and final design excavation levels are known.

No surface surcharges should be placed closer to the edge of the excavation than a distance equal to the depth of the excavation, unless the excavation support system has been designed to accommodate such surcharge.

BACKFILL MATERIALS AND COMPACTION (GENERAL)

1.0 DEFINITIONS

"Landscape fill" is typically used in areas such as berms and grassed areas where settlement of the fill and noticeable surface subsidence can be tolerated. "Landscape fill" may comprise soils without regard to engineering quality.

"General engineered fill" is typically used in areas where a moderate potential for subgrade movement is tolerable, such as asphalt (i.e., flexible) pavement areas. "General engineered fill" should comprise clean, granular or clay soils.

"Select engineered fill" is typically used below slabs-on-grade or where high volumetric stability is desired, such as within the footprint of a building. "Select engineered fill" should comprise clean, well-graded granular soils or inorganic low to medium plastic clay soils.

"Structural engineered fill" is used for supporting structural loads in conjunction with shallow foundations. "Structural engineered fill" should comprise clean, well-graded granular soils.

"Lean-mix concrete" is typically used to protect a subgrade from weather effects including excessive drying or wetting. "Lean-mix concrete" can also be used to provide a stable working platform over weak subgrades. "Lean-mix concrete" should be low strength concrete having a minimum 28-day compressive strength of 3.5 MPa.

Standard Proctor Density (SPD) as used herein means Standard Proctor Maximum Dry Density (ASTM Test Method D698). Optimum moisture content is defined in ASTM Test Method D698.

2.0 GENERAL BACKFILL AND COMPACTION RECOMMENDATIONS

Exterior backfill adjacent to abutment walls, basement walls, grade beams, pile caps and above footings, and below highway, street, or parking lot pavement sections should comprise "general engineered fill" materials as defined above.

Exterior backfill adjacent to footings, foundation walls, grade beams and pile caps and within 600 mm of final grade should comprise inorganic, cohesive "general engineered fill". Such backfill should provide a relatively impervious surficial zone to reduce seepage into the subsoil against the structure.

Backfill should not be placed against a foundation structure until the structure has sufficient strength to withstand the earth pressures resulting from placement and compaction. During compaction, careful observation of the foundation wall for deflection should be carried out continuously. Where deflections are apparent, the compactive effort should be reduced accordingly.

In order to reduce potential compaction induced stresses, only hand-held compaction equipment should be used in the compaction of fill within 1 m of retaining walls or basement walls. If compacted fill is to be placed on both sides of the wall, they should be filled together so that the level on either side is within 0.5 m of each other.

All lumps of materials should be broken down during placement. Backfill materials should not be placed in a frozen state, or placed on a frozen subgrade.

Where the maximum-sized particles in any backfill material exceed 50% of the minimum dimension of the cross-section to be backfilled (e.g., lift thickness), such particles should be removed and placed at other more suitable locations on site or screened off prior to delivery to site.

Excavation and construction operations expose materials to climatic elements (freeze/thaw, wet/dry) and/or mechanical disturbance which can cause severe deterioration of performance. Unless otherwise specifically indicated in this report, the walls and floors of excavations, and stockpiles, must be protected from the elements, particularly moisture, desiccation, frost, and construction activities. Should desiccation occur, bonding should be provided between backfill lifts. For fine-grained materials the previous lift should be scarified to the base of the desiccated layer, moisture-conditioned, and recompacted and bonded thoroughly to the succeeding lift. For granular materials, the surface of the previous lift should be scarified to about a 75 mm depth followed by proper moisture-conditioning and recompaction.

3.0 COMPACTION AND MOISTURE CONDITIONING

"Landscape fill" material should be placed in compacted lifts not exceeding 300 mm and compacted to a density of not less than 90% of SPD unless a higher percentage is specified by the jurisdiction.

"General engineered fill" and "select engineered fill" materials should be placed in layers of 150 mm compacted thickness and should be compacted to not less than 98% of SPD. Note that the contract may specify higher compaction levels within 300 mm of the design elevation. Cohesive materials placed as "general engineered fill" or "select engineered fill" should be compacted at 0 to 2% above the optimum moisture content. Note that there are some silty soils which can become quite unstable when compacted above optimum moisture content. Granular materials placed as "general engineered fill" or "select engineered fill" should be compacted at slightly below (0 to 2%) the optimum moisture content.

"Structural engineered fill" material should be placed in compacted lifts not exceeding 150 mm in thickness and compacted to not less than 100% of SPD at slightly below (0 to 2%) the optimum moisture content.

4.0 "GENERAL ENGINEERED FILL"

Low to medium plastic clay is considered acceptable for use as "general engineered fill," assuming this material is inorganic and free of deleterious materials.

Materials meeting the specifications for "select engineered fill" or "structural engineered fill" as described below would also be acceptable for use as "general engineered fill."

5.0 "SELECT ENGINEERED FILL"

Low to medium plastic clay with the following range of plasticity properties is generally considered suitable for use as "select engineered fill":

Liquid Limit	= 20 to 40%
Plastic Limit	= 10 to 20%
Plasticity Index	= 10 to 30%

Test results should be considered on a case-by-case basis.

"Pit-run gravel" and "fill sand" are generally considered acceptable for use as "select engineered fill." See exact project or jurisdiction for specifications.

The "pit-run gravel" should be free of any form of coating and any gravel or sand containing clay, loam or other deleterious materials should be rejected. No material oversize of the specified maximum sieve size should be tolerated. This material would typically have a fines content of less than 10%.

The materials above are also suitable for use as "general engineered fill."

6.0 "STRUCTURAL ENGINEERED FILL"

Crushed gravel used as "structural engineered fill" should be hard, clean, well graded, crushed aggregate, free of organics, coal, clay lumps, coatings of clay, silt, and other deleterious materials. The aggregates should conform to the requirement when tested in accordance with ASTM C136 and C117. See exact project or jurisdiction for specifications. This material would typically have a fines content of less than 10%.

In addition to the above, further specification criteria identified below should be met:

"Structural Engineered Fill" – Additional Material Properties

Material Type	Percentage of Material Retained on 5 mm Sieve having Two or More Fractured Faces	Plasticity Index (<400 μm)	L.A. Abrasion Loss (percent Mass)
Various sized Crushed Gravels	See exact project or jurisdiction for specifications	See exact project or jurisdiction for specifications	See exact project or jurisdiction for specifications

Materials that meet the grading limits and material property criteria are also suitable for use as "select engineered fill."

7.0 DRAINAGE MATERIALS

"Coarse gravel" for drainage or weeping tile bedding should be free draining. Free-draining gravel or crushed rock generally containing no more than 5% fine-grained soil (particles passing No. 200 sieve) based on the fraction passing the 3/4-inch sieve or material with sand equivalent of at least 30.

"Coarse sand" for drainage should conform to the following grading limits:

"Coarse Sand" Drainage Material – Percent Passing by Weight

Sieve Size	Coarse Sand*
10 mm	100
5 mm	95 – 100
2.5 mm	80 – 100
1.25 mm	50 – 90
630 μm	25 – 65
315 μm	10 – 35
160 μm	2 – 10
80 μm	0 – 3

* From CSA A23.1-09, Table 10, "Grading Limits for Fine Aggregate", Class FA1

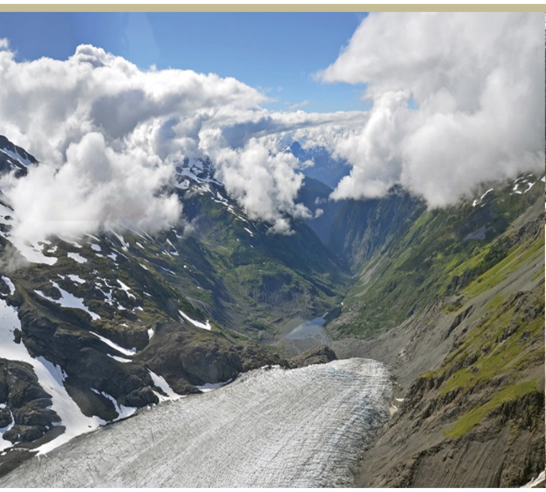
Note that the "coarse sand" above is also suitable for use as pipe bedding material. See exact project or jurisdiction for specifications.

8.0 BEDDING MATERIALS

The "Coarse Sand "gradation presented above in Section 7.0 is suitable for use as pipe bedding and as backfill within the pipe embedment zone, however see exact project or jurisdiction for specifications.

APPENDIX C – HYDROTECHNICAL ASSESSMENT

Hydrotechnical Assessment of Culvert Streams



PRESENTED TO

Government of the Northwest Territories

APRIL 10, 2019
ISSUED FOR USE
FILE: 704-TRN.WTRM03108-01

Tetra Tech Canada Inc.
Suite 1000 – 10th Floor, 885 Dunsmuir Street
Vancouver, BC V6C 1N5 CANADA
Tel 604.685.0275 Fax 604.684.6241

This page intentionally left blank.

EXECUTIVE SUMMARY

Tetra Tech was retained by the Government of the Northwest Territories (GNWT) to undertake a Hydrotechnical Assessment of 31 culvert crossings along the Mackenzie Highway, the Ingraham Trail, the Liard Highway and the Dempster Highway.

The assessment was conduced through the staged approach outlined below:

- Collect and review existing information;
- Complete a late-summer field investigation to assess current culvert conditions and measure stream baseflow;
- Complete a hydrologic assessment based on topographic information, historical regional hydrometric data, streamflow measurements, channel survey information, and observed characteristics at each crossing;
- Develop hydraulic models for the crossing locations;
- Calibrate these models to available information;
- Conduct a sensitivity analysis for parameters that have a significant influence on results; and
- Identify crossings which require upgrades or replacement and develop preliminary recommendations.

The adequacy of the existing culverts to convey the 100-year peak flow was assessed on the basis of modelled freeboard and clearance. The culverts were flagged as needing capacity upgrades if the freeboard (before road overtopping) was less than 1.0 m or if the culvert inlet was submerged by more than 0.5 m during passage of the 100-year design flow. These thresholds are considered reasonable but are subject to reconsideration and do not consider possible mitigating circumstances such as peak flow attenuation by floodplain storage upstream of the crossings.

Preliminary recommendations for replacement structures were initiated using nomograph-based sizing of circular culvert with projecting inlets to achieve headwater targets for each of three design scenarios: (1) 100-year design flood, (2) Scenario 1 plus 25% embeddedness of culvert for fish passage or environmental enhancement; and (3) Scenario 2 plus 100-year design flows increased by 25% to represent a climate change condition. Preliminary recommendations for the crossing type, selecting from circular culvert, box (or arch) culvert and bridge alternatives, were then made using the initial sizing results for the third and most conservative design scenario.

Additional considerations should be addressed when refining the preliminary recommendations. These considerations may include, but are not limited to, consultation with maintenance personnel to identify what past designs approaches have provided the best performance to date, and areas of concern or where improvements are sought. Site-specific fish presence and geotechnical considerations (permafrost, bedrock depth) will influence the designs and the reasonableness of preliminary recommendations made without this information. Expected capital and maintenance costs and life span will be important factors in the final selection of crossing types and designs.

The objective of the current analysis is to provide sufficient hydrotechnical assessments and preliminary sizing recommendations to guide the future design and decision process.

TABLE OF CONTENTS

LIST OF TABLES IN TEXT

LIST OF FIGURES IN TEXT

APPENDICES

LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of the Government of the Northwest Territories and their agents. Tetra Tech Canada Inc. (Tetra Tech) does not accept any responsibility for the accuracy of any of the data, the analysis, or the recommendations contained or referenced in the report when the report is used or relied upon by any Party other than the Government of the Northwest Territories, or for any Project other than the proposed development at the subject site. Any such unauthorized use of this report is at the sole risk of the user. Use of this document is subject to the Limitations on the Use of this Document attached in the Appendix or Contractual Terms and Conditions executed by both parties.

INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) was retained by the Government of the Northwest Territories (GNWT) to undertake a Hydrotechnical Assessment of 31 culvert crossings along the Mackenzie Highway (Hwy), the Ingraham Trail, the Liard Hwy, and the Dempster Hwy. The scope of the assignment was as described in GNWT Request for Tender (RFT) Event ID 0000002540 dated July 26, 2018. A companion contract for Culvert Stream Surveys at 39 sites was issued separately, to White Bear Geomatics Ltd, with scope as described in the GNWT RFT 0000002540.

The hydraulic modelling for the hydrotechnical assessment presented herein relies on the topographic and cross section surveys made under the separate survey assessment. Although these are companion studies, the RFTs for the respective contracts did not use a common numbering sequence. Survey results were produced and delivered with crossing numbers that do not match those in the Hydrological Assessment RFT. For example, the culvert crossing of the Rengleng River at Dempster Highway (No. 8) KM 177.8 is identified as Crossing #35 in the Survey RFT (and survey deliverable) but as Crossing #27 in the Hydrotechnical RFT. This report accommodates both numbering sequences, for example the Rengleng River is identified as Crossing 35/27.

There were instances of minor discrepancies between the survey results and RFT information on culvert size(s) or site location defined by road KM and/or geographic coordinates. This report presents the survey results.

Hydrotechnical design procedures for bridges, large culverts (greater than 3 m span), and channel control works, where applicable, were done to be consistent with the TAC Guide to Bridge Hydraulics and CAN/CSA S6-14 Canadian Highway Bridge Design Code (CHBDC). Hydrotechnical and fish passage guidelines published by various British Columbia and Alberta government agencies were also considered where applicable.

1.0 SCOPE OF WORK

A hydrotechnical assessment was undertaken for each of the 31 crossings specified in the Hydrotechnical Assessment RFT. This assessment included analysis of both hydrologic and hydraulic information to evaluate the ability of existing culverts to convey the 100-year design flows. Recommended culvert sizes were developed where existing culverts were deemed to be insufficient.

The assessment was conduced through the staged approach outlined below:

- Collect and review existing information;
- Complete a late-summer field investigation to assess current culvert conditions and measure stream baseflow;
- Complete a hydrologic assessment based on topographic information, historical regional hydrometric data, streamflow measurements, channel survey information, and observed characteristics at each crossing;
- Develop hydraulic models for the crossing locations;
- Calibrate these models to available information;
- Conduct a sensitivity analysis for parameters that have a significant influence on results;
- Identify crossings which require upgrades or replacement and develop preliminary crossing structure recommendations; and

The following sections elaborate on each of the tasks completed as part of this study.

2.0 BACKGROUND INFORMATION

The current assignment was expected to include a review of GNWT culvert maintenance and inspection records giving information on site-specific operational issues including but not limited to ice conditions. Maintenance and inspection records were however not available at the time of this study and therefore not reviewed. Prior hydrotechnical studies were similarly not available.

Historical streamflow information from Water Survey Canada (WSC) stations in the vicinity of the study area(s) was used at length for the hydrologic analysis. The stations used in the analysis are described in Section 3.1.

Spatial information in the form of 1:50,000 National Topographic Service (NTS) digital base maps were acquired from the Government of Canada and used in the delineation of the drainage areas to the crossings. Orthographic imagery was acquired from Google Earth and helped develop a macro scale understanding of the local geography and environment for the hydrologic analysis and to assist in the delineation of the contributing watersheds.

3.0 SITE VISIT

A field investigation was conducted from September 10 to September 17, 2018 by two Tetra Tech staff members with the following objectives:

- Gather site-specific crossing information;
- Inspect proximate bridges, culverts, and other hydraulic controls;
- Assess drainage characteristics relevant to estimation of the parameters reflecting the channel and bank roughness and conveyance capacity;
- Take flow measurements; and
- Assess potential debris and identify high water marks.

Our site investigation covered all 31 RFT-specified culvert crossings along the Mackenzie Highway (No.1), the Ingraham Trail (No. 4), the Liard Highway (No. 7) and the Dempster Highway No. 8). All culverts were accessible from the respective highways.

Section 4.1 presents a master list of sites including location of the existing culverts, followed by a summary of observations for each site.

Section 4.2 presents a summary of flow measurements.

Section 4.3 presents surveyor provided-information including estimated channel widths and depths representing bankfull and extreme flood conditions.

Site photographs are presented in Appendix A.

Surveyor site plans for each crossing are presented in Appendix B.

Surveyor-reported estimates of flood prone and bankfull widths and depths are presented in Appendix C.

3.1 Site Inspection

A total of 31 culvert sites have been identified by the GNWT for hydraulic assessment spanning across four highways; Mackenzie Highway (No. 1), Ingraham Trail (No. 4), Liard Highway (No. 7) and Dempster Highway (No. 8). The Ingraham Trail crossing is the furthest east crossing found near Yellowknife. The Mackenzie and Liard Highway crossings are concentrated in the southwest region of the territory while the Dempster Highway crossings are found in the territory's northwest corner in the Inuvik Region.

Information obtained from the late summer field investigation included site descriptions, channel measurements, field observations and photographs for the sites. Table 1 below provides a summary of the crossing locations and existing culverts.

Table 1: Crossing Information

Crossing Number(s)	Kilometre Number	Length (m)	Diameter (m) or Span x Height (m)	Year Constructed	Latitude	Longitude
Mackenzie Highway (No.1) Culverts						
1/1	20.2	38 + 34	1.6 + 1.0	1983	60°07'11" N	116°44'25" W
2/2	287.9	21	1.1 x 1.85	1970	61°08'27" N	119°12'31" W
3/3	348.5	18	1.5	1971	61°12'26" N	120°15'20" W
4/4	456.1	40.2	1.5	1987	61°44'20" N	121°12'49" W
7/5	517.1	41.3	Surveyed width varies 4.7 to 5.3; RFT says 5.73 dia.	1977	62°01'31" N	122°01'44" W
8/6	522.8	68 (2)	3.8 (2)	1977	62°02'12" N	122°08'13" W
10/7	531.2	83.2	3.1 x 3.7	1977	62°04'20" N	122°16'35" W
14/8	677.5	54.6	2.3 x 2.6	1979	63°09'11" N	123°16'52" W
15/9	678.5	39	2.3	1979	63°09'28" N	123°17'55" W
Ingraham Trail (No. 4) Culvert						
16/10	2.1	30.5	3.0	1991	62°29'12" N	114°21'52" W
Liard Highway (No. 7) Culverts						
17/11	3.0	52.4	1.55	1982	60°01'12" N	122°58'14" W
18/na[1]	48.3	58.4	1.3 x 1.7	1982	60°18'49" N	123°18'25" W
19/13	55.3	27.2	1.5 x 1.65	1977	60°22'40" N	123°19'17" W
20/14	66.2	48.4	1.4 x 1.7	1983	60°28'13" N	123°22'29" W
21/15	69.5	28.6	Surveyed width 3.44; RFT says 3.0 dia.	1982	60°29'29" N	123°25'05" W
22/16	83.2	29.1	1.45 x 1.65	1982	60°36'40" N	123°28'33" W
23/17	100.1	45.6	1.55	1981	60°43'36" N	123°19'29" W
25/18	152.8	30.1	3.0	1980	61°06'39" N	122°50'24" W

[1] Survey RFT crossing #18 (Liard Hwy KM 48.3) is located between Hydrotechnical RFT crossings #11 and #13 but did not align with Hydrotechnical RFT crossing #12 (Liard Hwy 14.3). Hence the location designator 18/na.

Crossing Number(s)	Kilometre Number	Length (m)	Diameter (m) or Span x Height (m)	Year Constructed	Latitude	Longitude
26/19	170.4	58.4	4.8	1980	61°13'18" N	122°37'09" W
27/20	187.2	28	1.6	1979	61°17'22" N	122°20'52" W
Dempster Highway (No. 8) Culverts						
29/21	9.6	27	1.8	1973	67°06'58" N	136°04'58" W
30/22	12.0	36.3	2.8	1973	67°07'52" N	136°02'44" W
31/23	14.4	26 (2)	4.26 (2)	1973	67°08'29" N	135°59'37" W
32/24	14.5	26	3.8 x 4.1	1973	67°08'33" N	135°59'32" W
33/25	40.2	44.3	Surveyed height varies 1.8 to 2.0; RFT says 1.83 dia.	1973	67°13'07" N	135°30'15" W
34/26	85.1	40	3.95	1973	67°25'26" N	134°52'14" W
35/27	177.8	53 (5)	4.7 (5)	1995	67°45'14" N	133°51'37" W
36/28	192.4	34.4	3.8	1975	67°51'30" N	133°40'01" W
37/29	195.4	55.5 (2)	2.4 (2)	1975	67°52'49" N	133°37'37" W
38/30	239.8	29	1.5	1973	68°13'47" N	133°19'11"W
39/31	244.1	35 (2)	4.0 + 1.7	1973	68°15'42" N	133°15'53" W

3.1.1 KM 20.2 Mackenzie Highway No. 1 (Crossing 1/1)

Located at KM No. 20.2 of Mackenzie Highway (Hwy No. 1) and adjacent to the Hay River, Crossing 1/1 features double barrel construction with 1.6 m and 1.0 m diameter CSP pipes with 38 m and 34 m lengths respectively and mitered ends. The culverts are at a 73˚ angle to the road (compared to 90˚ for a perpendicular crossing). Site conditions are shown in Appendix A Photos 1 to 4.

Existing bank stabilization at culvert ends consist of finished concrete with a 0.4 m drop from top of concrete to streambed on the outlet side. The left side 1.0 m diameter culvert (looking downstream to inlet) is blocked with vegetation and branches likely from animal activity. The culvert is rusted around its full diameter and both the CSP material and concrete showed surface cracking.

Beavers are active in the crossing vicinity, and a beaver was observed nearby during the site visit. There is a large active beaver dam located about 10 m upstream from the culvert inlet and the surveyor site plan identifies two log jams not holding water (possibly remnant beaver dams) located between 60 to 90 m downstream of the culvert outlet.

The channel bed is comprised of small grasses and well-rounded uniform rocks while the banks consist of dense foliage and bushes. Channel bankfull width downstream of the beaver pond is in the range of 3 to 9 m, with depths in the range of 1.0 to 1.6 m. The channel width in the ponded area upstream of the beaver dam is in the range of 12 to 40 m, with depths 1.5 to 3 m.

3.1.2 KM 287.9 Mackenzie Highway No. 1 (Crossing 2/2)

Located at KM No. 287.9 of Hwy 1, Crossing 2/2 features a single elliptical CSP culvert approximately 1.85 m high x 1.1 m wide and 21 m in length with projecting ends. The culvert is at a 71˚ angle to the road and is in generally good condition except for a large dent at the top of culvert outlet. The outlet invert is perched about 0.8 m higher than the stream bed immediately downstream. Site conditions are shown in Appendix A Photos 5 to 8.

The watercourse at this crossing is in a wide and shallow valley with gentle vegetated slopes that do not show evidence of instabilities. The watercourse is poorly defined and is generally characterized as ponded water occupied by shrubs and grass.

The channel bed is comprised of mosses and branches in spots overlying mud and rocks. The banks consist of dense vegetation. Channel bankfull width is in the range of 2 to 3 m, with depths of 0.2 to 0.5 m.

3.1.3 KM 349 Mackenzie Highway No. 1 (Crossing 3/3)

Located at KM No. 348.5 of Hwy 1, Crossing 3/3 features a single 18 m long 1.5 m dia. CSP culvert with projecting ends. The culvert is at an 81˚ angle to the road and is in generally good condition other than minor rusting within the pipe. Site conditions are shown in Appendix A Photos 9 to 12.

Limited riprap is present, and a high-water mark exists at 0.43 m. There are boulders in the stream bed 0.25 to 0.4 m in diameter overlying mud. The banks consist of dense grass vegetation. Surveyor notes indicate burned conifer forest on both sides of the crossing. The upstream channel has dense brush re-growth within the channel bed and the downstream channel bed has areas filled with deadfall. The channel bankfull width is in the range of 3 to 9 m, with depths typically 0.4 to 2 m.

3.1.4 KM 456.1 Mackenzie Highway No. 1 (Crossing 4/4)

Located at KM No. 456.1 of Hwy 1 and flowing towards the nearby Mackenzie River, Crossing 4/4 is a 40.2 m long 1.5 m dia. CSP culvert with projecting ends. The culvert is at an 88˚ angle to the road, near perpendicular, and has an inlet segment that is steeply sloped at about 30% grade before connecting to a more normal slope for the main barrel for the rest of the crossing. The culvert is rusted and has some surface cracking. Site conditions are shown in Appendix A Photos 13 to 16.

Riprap is not present at the inlet or outlet. A highwater mark of 0.11 m is visible at the outlet prior to a substantial drop of 1.3 m from the invert of the perched culvert outlet to the adjacent channel bottom.

The channel bed is comprised of silts and clays at the upstream end, larger rocks (0.5 m -1.0 m) at the downstream end and aquatic grasses throughout the bed. Streambanks consisted of dense foliage and bushes. The channel slope changes from a flat grade on the upstream side of the road to a very steep grade downstream; this is the likely reason for the constructed steep drop at the culvert inlet. The downstream channel has a bankfull width less than 5 m and depth of about 1 m. The upstream channel bankfull width is greater than 15 m.

3.1.5 KM 517 Mackenzie Highway No. 1 (Crossing 7/5)

Located at KM No. 517.1 of Hwy 1 flowing towards the nearby Mackenzie River, Crossing 7/5 is a 41 m long, large diameter CSP culvert with mitered ends. The surveyor-reported culvert widths are 4.7 m and 5.3 m at the upstream and downstream ends respectively. Due to incomplete measurements, subsequent modeling was done using the RFT-reported culvert diameter of 5.73 m. The culvert is perpendicular to the road and is in generally good condition. Site conditions are shown in Appendix A Photos 17 to 20.

Riprap is not present at the inlet or outlet ends. A highwater mark could not be defined and the outlet condition is smooth flow. A beaver dam is present approximately 50 m downstream. The channel bed appears to be relatively smooth although deeper water limited the extend of observation. Streambanks consisted of dense foliage and trees.

The channel bankfull width with the backwater pool of the beaver dam (including a survey section 10 m upstream of the culvert) varies from about 15 to 20 m, with depths up to 3.5 m on the downstream side. Upstream and downstream of the backwater pool, the bankfull width is typically about 6 to 8 m with a depth of 0.8 to 1.6 m.

3.1.6 KM 523 Mackenzie Highway No. 1 (Crossing 8/6)

Located at KM No. 522.8 of Hwy 1 flowing towards the nearby Mackenzie River, Crossing 8/6 is comprised of two 68 m long, 3.8 m diameter CSP culverts with mitered ends. The culverts are at a 97° angle to the road and are in fair condition. The left-hand culvert looking downstream has sustained substantial inward deflection of the mitered inlet, reducing capacity; rusting is present on both culverts. A large pile of weathered logs on the upstream side of the crossing suggests that prior removal of debris blockage has occurred as a maintenance activity. Site conditions are shown in Appendix A Photos 21 to 24.

The channel bed is comprised of pebble size material in the immediate vicinity of the culverts within the highway right of way, but much larger cobble size material is prevalent downstream Streambanks beyond the right of way are heavily vegetated.

The channel bankfull width beyond the cleared right of way is between 10 m and 11 m, with a corresponding depth of about 1.0 m. The bankfull width at the culvert outlet is about 20 m.

3.1.7 KM 531.2 Mackenzie Highway No. 1 (Crossing 10/7)

Located at KM No. 531.2 of Hwy 1 flowing towards the nearby Mackenzie River, Crossing 10/7 is an 83 m long, oblong 3.7 m high by 3.1 m wide CSP culvert with mitered ends. The culvert is at a 134° (or 46°) angle to the road and is in generally good condition with minor rusting present on connection bolts. Site conditions are shown in Appendix A Photos 25 to 28.

Previously placed riprap at the inlet and outlet ends is scattered and provides little bank protection. Visible highwater marks vary between 0.5 m and 1.0 m in height. Flows at the time of observations were very low and velocity measurements were not possible as flow at outlet was almost stagnant. Streambanks consisted of high trees and bushes.

Because of extremely dense brush, deadfall and willows, survey information for this site is limited to a single cross section 10 m upstream of the culvert and a profile which ends at the culvert outlet. Based on site photographs, the surveyed upstream channel section is believed to be representative of the downstream channel as well.

3.1.8 KM 677.5 Mackenzie Highway No. 1 (Crossing 14/8)

Located at KM No. 677.5 of Hwy 1, Crossing 14/8 is comprised of a single 55 m long, 2.3 m x 2.6 m CSP culvert with mitered ends. The culvert is at a 104° angle to the road and is in generally good condition other than minor surface cracking and loose bolts. Site conditions are shown in Appendix A Photos 29 to 32.

Previously placed riprap has been washed away into stream channel and provides no bank protection. An outlet end drop of 0.23 m is present and a highwater mark of 0.1 m is visible. The channel bed is comprised of mud overlain by fallen logs and rocks less than 2 cm in dia. and larger rocks on the upstream end (~ 0.3 m). Streambanks consisted of dense foliage with fallen trees and branches logs.

The bankfull width varies from 3 to 7 metres, with depths from 0.75 to 1.1 m.

3.1.9 KM 678.5 Mackenzie Highway No. 1 (Crossing 15/9)

Located at KM No. 678.5 of Hwy 1, Crossing 15/9 is comprised of a single 39 m long, 2.3 m diameter CSP culvert with mitered ends. The culvert is at a 127° angle to the road and is in generally good condition. Site conditions are shown in Appendix A Photos 33 to 36.

Minor amounts of small riprap (10 - 30 cm) are present. No high-water mark was observed, and the outlet condition is smooth and unbroken flow. There is minor surface cracking and small holes were found. The channel bed is comprised of sand and dense low standing grassy vegetation. Streambanks at immediate outlet ends are comprised of low-lying vegetation; further upstream vegetation densifies, and coniferous trees are present.

The surveyor described downstream conditions as having no defined channel, with water running slowly on saturated mud/silt. The upstream channel was not accessible due to deadfall in the creek bed. Bankfull widths varied from 6 to 16 m, and depths from 0.3 to 0.9 m.

3.1.10 KM 2.1 Ingraham Trail No. 4 (Crossing16/10)

The only crossing assessed on Ingraham Trail (Hwy No. 4) is Crossing 16/10 located at KM No. 2.1 just north of Yellowknife. It is comprised of a single 31 m long, 3.05 m diameter CSP culvert with mitered ends. The culvert is at 96° angle to the road, receiving inflow from a highway ditch flowing perpendicular to the road; water therefore makes a 90° turn at the culvert inlet. There is a 1.2 m diameter culvert about 20 m north (upstream along the road ditch), and a beaver dam in the road ditch about 80 m further upstream. Site conditions are shown in Appendix A Photos 37 to 40.

Riprap is present at the culvert inlet end only, where there are two distinct high-water marks visible in the culvert at 0.8 m and 1.2 m. An outlet drop of 0.15 m was present at the downstream end. Culvert condition is generally good. Minor rust is present on interior of pipe and bolts. Upstream culvert is dented on one side. The channel bed is comprised of mostly rocks 5 to 30 cm in size. Streambanks are covered by high brush vegetation.

The bankfull width varies from 4 to 10 m, with depths from about 0.6 to 0.8 m.

3.1.11 KM 3.0 Liard Hwy No. 7 (Crossing 17/11)

Located at KM No. 3.0 of Liard Highway (Hwy No. 7), Crossing 17/11 is comprised of a single 53 m long, 1.55 m diameter CSP culvert with projecting ends. The culvert is at a 77° angle to the road and is in generally good condition except for minor denting at the inlet and being half-full of silt at the outlet. Site conditions are shown in Appendix A Photos 41 to 44.

No riprap is present and no distinct highwater marks are visible. There was no flow though the culvert at the time of site visit and it appeared a significant duration of time had passed since it was last flowing. The channel bed is comprised of mostly soil and grassy vegetation. Streambanks are generally comprised of high brush vegetation.

Due to dense vegetation and lack of a defined channel, cross sections were surveyed only at the culvert inlet and outlet. The estimated bankfull depth is about 0.1 to 0.2 m.

3.1.12 KM 48.3 Liard Hwy No. 7 (Crossing 18/na)

Located at KM No. 48.3 of Hwy No. 7, Crossing 18/na is comprised of a single 54 m long, 1.3 m wide by 1.7 m high CSP culvert with projecting ends and some concrete slope protection. Location information specified in the RFTs for the respective survey and hydrotechnical study components did not coincide for this highway segment, so the analysis was made at Survey RFT Site 18 rather than Hydrotechnical RFT Site 12 for which no survey information was available. The culvert is at a 71˚ angle to the road and is in fair condition with a dented outlet and broken concrete end protection. Erosion control silt fence is installed on the road embankments above both ends of the culvert. Site conditions are shown in Appendix A Photos 45 to 48.

The surveyor reported extremely dense willows and trees both upstream and downstream of the culvert, and channel sections were surveyed only at the culvert inlet and outlet. The bankfull width is about 4 m, and depth about 0.6 to 0.8 m,

3.1.13 KM 55.3 Liard Hwy No. 7 (Crossing 19/13)

Located at KM No. 55.3 of Hwy No. 7, Crossing 19/13 is comprised of a single 27.2 m long, 1.5 m wide by 1.65 m high CSP culvert with projecting ends. The culvert is at a125˚ angle to the road and is in generally adequate condition with dents and rusting on the visible top portions of pipe. Site conditions are shown in Appendix A Photos 49 to 52.

Riprap rocks approx. 0.3-0.8 m in size were observed to have fallen into the stream. High water marks visible at 0.6 m on the downstream side and 0.7 m on the upstream side. Flows at the time of site visit were stagnant. The channel was poorly defined, with a mud bed with grass vegetation. Dense low-lying brush dominates the stream banks. The surveyor’s plan drawing shows earth dams (probably from beaver activity), not captured by the survey sections, both upstream and downstream of the culvert.

The estimate bankfull depth is 0.5 to 0.9 m with widths up to 15 m as a result of channel blockages.

3.1.14 KM 66.2 Liard Hwy No. 7 (Crossing 20/14)

Located at KM No. 66.2 of Hwy No. 7, Crossing 20/14 is comprised of a single 48 m long, 1.4 m wide by 1.7 m high CMP culvert with projecting ends. The culvert is at an 87˚ angle to the road and is in generally adequate condition generally with its non-circular shape possibly being due of deflection since its original construction. Large rocks approx. 0.4-0.5 m in size are present at the outlet and inlet ends and gave reasonable bank protection. A high-water mark is visible at 1.13 m. Flows at the time of site visit were partially stagnant flowing at < 0.11 m/s at all depths. Site conditions are shown in Appendix A Photos 53 to 56.

The downstream channel consists of dense willows, deadfall and brush, which limited the downstream survey to a single cross section below the outlet, where the reported bankfull width and depth were 2.5 m and 0.6 m respectively. Upstream bankfull widths ranged from 5 to 20 m, with depths typically about 0.7 m.

3.1.15 KM 69.5 Liard Hwy No. 7 (Crossing 21/15)

Located at KM No. 69.5 of Hwy No. 7, Crossing 21/15 is comprised of a single 24 m long, 3.4 m wide CSP culvert with mitered ends. The surveyor reported the culvert width but not height, possible due to its being half-full of water during the survey. Due to incomplete measurements, subsequent modeling was done using the RFT-reported culvert diameter of 3.0 m. The culvert is at a 78˚ angle to the road and is in generally good condition, with rust marks at prior high-water levels. Site conditions are shown in Appendix A Photos 57 to 60.

No riprap is visible at the inlet or outlet ends of this culvert. Two distinct high-water marks are visible at 2.5 m and 2.8 m from the culvert invert. Flows at the time of site visit were stagnant at the inlet and outlet. Dense low-lying brush, grasses and deciduous trees encroach on the channel. The surveyor notes show two log jams across the channel upstream of the culvert, not captured by the cross-section locations. Starting about 15 m downstream of the outlet the channel is bounded by a broad low-lying area consisting of swamp with grass and some willows.

Downstream of the low-lying swampy area, the bankfull width is typically between 2.5 to 5 m, with depths of 0.6 to 1.1 m.

3.1.16 KM 83.2 Liard Hwy No. 7 (Crossing 22/16)

Located at KM No. 83.3 of Hwy No. 7, Crossing 22/16 is comprised of a single 29 m long, 1.45 m wide by 1.65 m high CSP culvert with projecting ends. The culvert is at an 84˚ angle to the road and is in adequate condition with some concentrated areas of rusting. Site conditions are shown in Appendix A Photos 61 to 64.

Riprap is present on the upstream end with rocks sized 0.5 - 1.0 m. Two distinct high-water marks are visible at 0.3 m and 0.4 m up from culvert invert. The streambed contains large rocks 0.7 to 1.0 m in size and very dense mid-rise brush and deciduous trees encroach on the channel.

Due to dense vegetation, survey cross sections are limited to two upstream and one downstream of the culvert. Bankfull width is typically 3 to 6 m and depth about 0.7 to 0.9 m.

3.1.17 KM 100.1 Liard Hwy No. 7 (Crossing 23/17)

Located at KM No. 100.1of Hwy No. 7, Crossing 23/17 is comprised of a single 46 m long, 1.55 m diameter CSP culvert with projecting ends. The culvert is at a 112˚ angle to the road and is in poor condition with concentrated areas of rusting. A crack in the bottom half of the barrel is causing water to flow under the culvert rather than through it and a severe sag is present. Retrofit support structures have been installed which include vertical steel bracing near the inlet and an internal steel band near the outlet. Site conditions are shown in Appendix A Photos 65 to 68.

Riprap is present on the upstream end with rocks approximately 0.3 m in size and on the downstream end fallen riprap 0.3 - 0.4 m in size exists. Two distinct high-water marks are visible at 0.25 m at the downstream end and 0.4 m at the upstream end. Flows at the time of site visit were small with 0.23 m of water depth flowing very slowly and stagnated in areas. The streambed is composed of mud, dirt, and conglomerate rocks. Low lying grasses and rocks are present at the culvert inlet and outlet. Dense brush and deciduous trees dominate the streambanks further down the channel.

Due to dense vegetation, cross sections were surveyed only at the culvert ends. Bankfull width and depth upstream of the culvert are 10 m and 1 m respectively; downstream width and depth are 5 m and 0.55 m respectively

3.1.18 KM 152.8 Liard Hwy No. 7 (Crossing 25/18)

Located at KM No. 152.8 of Hwy No. 7, Crossing 25/18 is comprised of a single 30 m long, 3.0 m wide CSP culvert with mitered ends. Surveyor did not report culvert height, possibly due to the culvert being embedded with large rock on the culvert bottom. The culvert is at an 86˚ angle to the road and is in generally good condition with some rusting up to highwater mark. Site conditions are shown in Appendix A Photos 69 to 72.

Three distinct high-water marks of varying colours are visible at 0.4, 0.5 and 0.6 m. Water was flowing at time of site visit however depth and quantity was minimal. The streambed is primarily rocky with fallen logs and stumps.

Low lying grasses are present at the culvert inlet and outlet. Denser brush and deciduous trees dominate embankments further down channel.

The channel bankfull width is generally in the range of 3 to 5 m, with depths in the range of 0.5 to 0.9 m.

3.1.19 KM 170.4 Liard Hwy No. 7 (Crossing 26/19)

Located at KM No. 170.4 of Hwy No. 7, Crossing 26/19 is comprised of a single 58.4 m long, 4.8 m dia. CSP culvert with mitered ends. Dimensions are as reported in the project RFTs and were not independently confirmed during the surveys. The culvert is at a 128˚ angle to the road and is in generally good condition. Site conditions are shown in Appendix A Photos 73 to 76.

Minor riprap is present on the upstream and downstream end embankments with rocks approximately 0.3 - 0.5 m in size. Two distinct high-water marks of varying colours are visible at 1.25 m and 1.7 m. Fast flowing water was present across a 2.2 m wide channel. The streambed has larger boulders 0.2 to 1.5 m in size and tall trees and bushes are on the banks.

Surveyor-reported bankfull width ranges from 5 to 13 m; bankfull depth ranges from 0.9 to 1.6 m.

3.1.20 KM 187.2 Liard Hwy No. 7 (Crossing 27/20)

Located at KM No. 187.2 of Hwy No. 7, Crossing 27/20 is comprised of a single 28 m long, 1.6 m diameter CSP culvert with projecting ends. The culvert is at a 79˚ angle to the road and is in generally adequate condition with vertical steel supports within the culvert barrel. Site conditions are shown in Appendix A Photos 77 to 80.

Riprap is not visible, and soil surrounds the culvert. A distinct high-water mark is visible at 0.1 m. Very low flows were present at the time of site visit. The streambed includes heavy amounts of grass vegetation. Mid-rise bushes and vegetation have formed on the banks surrounding the culvert and stream.

Survey cross sections were constrained by dense willows; sections were limited to a single upstream section and downstream sections at 10 m and 30 m below the outlet. Bankfull widths and depths were not reported, presumably due to the willows and overgrown conditions.

3.1.21 KM 9.6 Dempster Hwy No. 8 (Crossing 29/21)

Located at KM No. 9.6 of the Dempster Highway (Hwy No. 8), Crossing 29/21 is comprised of a single 27 m long, 1.8 m diameter CSP culvert with projecting ends. The culvert is at a 124˚ angle to the road and is in generally good condition with some rusting on culvert and bolts. Site conditions are shown in Appendix A Photos 81 to 84.

Riprap approx. 1 m in sizing exists on the inlet and outlet embankments. A distinct high-water mark is visible at 1.1 m above the culvert invert. The stream was flowing consistently at time of site visit. The streambed is composed of rocks of varying sizes with some short length grasses. Low-rise bushes and grasses cover the creek banks.

The surveyor notes that the stream is shallow and contained within a shoulder area with shrubs and grasses. Bankfull widths vary from 1.9 to 11 m; corresponding depths vary from 0.2 to 0.7 m.

3.1.22 KM 12.0 Dempster Hwy No. 8 (Crossing 30/22)

Located at KM No. 12.0 of Highway No. 8, Crossing 30/22 is comprised of a single 36 m long, 2.8 m wide CSP culvert with projecting ends. The culvert is at a 143˚ angle to the road and is in generally good condition with some minor holes on top and side of the barrel. Site conditions are shown in Appendix A Photos 85 to 88.

Large riprap is present at the inlet and outlet embankments and splash zones. A distinct high-water mark is visible at 1.3 m above culvert invert. The stream was flowing consistently at time of site visit. The streambed is composed of rocks of varying sizes up to 0.75 m. Sparse low-rise bushes and grasses cover the creek banks. The survey plans described the channel downstream from the culvert as a wet grassy creek bottom wih narrow channel.

Bankfull widths are generally from 10 to 13 m, except for a narrow 3 m width reported below the outlet. Bankfull depths range from 0.4 to 1.1 m.

3.1.23 KM 14.4 Dempster Hwy No. 8 (Crossing 31/23)

Located at KM No. 14.4 of Highway No. 8, Crossing 31/23 of James Creek West is comprised of two 26 m long, 4.26 m diameter CSP culverts with mitered ends. The culverts are at an 81˚ angle to the road and are in generally good condition. Under normal flow conditions, the majority of the flow passes through the south culvert. Site conditions are shown in Appendix A Photos 89 to 94.

Surveyed channel sections reflecting the full channel to and from both culverts have bankfull widths ranging from 12 to 70 m, and corresponding depths from 0.5 to 1.7 m.

South Culvert

Riprap approximately 0.5 m in size exists on the inlet and outlet embankments. A distinct high-water mark is visible at 0.7 m above culvert invert. A downstream vertical drop of approx. 0.2 m is present. The stream was flowing steadily across a channel width of approximately 2 m. The streambed is composed of rocks of varying sizes. Sparse low-rise bushes and grasses cover the creek banks.

North Culvert

Riprap approximately 0.5 m in size exists on the inlet and outlet embankments. A distinct high-water mark is visible at 0.8 m above culvert invert and a drop of 0.3 m was present at the outlet end. Stream flows for the east culvert were minimal and the bulk of flow passed through the south culvert. The streambed is composed of rocks of varying sizes and sparse low-rise bushes and grasses cover the creek banks.

3.1.24 KM 14.5 Dempster Hwy No. 8 (Crossing 32/24)

Located at KM No. 14.5 of Highway No. 8, Crossing 32/24 of James Creek East is a 26 m long, 4.1 m high by 3.8 m wide CSP culvert with mitered ends. The culvert is at a 78˚ angle to the road and is in generally good condition. Site conditions are shown in Appendix A Photos 95 to 98.

Minor riprap 0.5 m in size is present but does not completely cover embankments where much of the soil remains exposed. A high-water mark is visible at 0.8 m up from culvert invert. Flows in this culvert during site inspection were stagnant. The streambed is composed of rocks and gravels of varying sizes. Low-rise bushes and grasses cover the creek banks and continue for distance of creek within view.

Bankfull width varies from 4.5 to 8 m, with corresponding depths from about 0.3 to 0.8 m.

3.1.25 KM 40.2 Dempster Hwy No. 8 (Crossing 33/25)

Located at KM No. 40.2 of Highway No. 8, Crossing 33/25 is a 44 m long CSP culvert with varying heights from 1.8 to 2.0 m and projecting ends. The culvert geometry is distorted, most noticeably at the downstream end Due to incomplete measurements, subsequent modeling was done using the RFT-reported culvert diameter of 1.83 m. The culvert is at a 63˚ angle to the road and is in only fair condition due to distortion at outlet. At this crossing there is an additional smaller culvert in excellent condition situated significantly higher (at least 2 m) than the main culvert. The purpose of the secondary culvert is presumably to provide emergency relief in the event of a blockage of the main culvert or its collapse. Site conditions are shown in Appendix A Photos 99 to 102.

Minor riprap 0.5 to 1.0 m in size is present but does not completely cover embankments and large areas of soil remain exposed. A high-water mark of 1.8 m was visible. Flows in this culvert were near stagnant with all velocity measurements below 0.25 m/s during site visit. The streambed is composed of rocks of varying sizes along with mud and sediment. Low-rise bushes and grasses cover the creek banks.

Bankfull width dowstream from the crossing varies from about 4 to 10 m, with corresponding widths typically about 0.8 m. Upstream widths are reported for two separate forks, one of which is desribed by the surveyor as a very narrow deep channel that is difficult to locate within dense brush.

3.1.26 KM 85.1 Dempster Hwy No. 8 (Crossing 34/26)

Located at KM No. 85.1 of Highway No. 8, Crossing 34/26 is a 40 m long, 3.95 m high CSP culvert with projecting ends. The culvert is at a 62˚ angle to the road and is in generally good condition with some minor rust spots. At the time of survey, the culvert was approximately half full with standing water. Site conditions are shown in Appendix A Photos 103 to 106.

Riprap is not present at the inlet or outlet ends and the embankments are composed of exposed soil. No distinct high-water marks were visible. Flows in this culvert appear to be completely stagnant; this crossing appears to serve as an equalization culvert that connects a terminal lake immediately west of the culvert to the north end of a long remnant meandering channel from the east, for which flow direction could not be determined from available data. The remnant meandering channel appears to function as a lake with possible outflow from both its south and north ends, should water levels rise sufficiently for outflow to occur.

3.1.27 KM 177.8 Dempster Hwy No. 8 (Crossing 35/27)

Located at KM No. 177.8 of Highway No. 8, Crossing 35/27 of the Rengleng River has a total of five 4.7 to 5.0 m diameter CSP culverts each approximately 53 m long, with mitered ends. The culvert alignment is perpendicular to the road, but the alignment has culvert inlets that are also at right angles to the flow. The river position approaching the road is confined by a high valley wall and is directed to the north by the road embankment where it encounters the five culverts one by one, starting from the south. Most flows will be conveyed by the first two or three southernmost culverts while the last and most northern culvert will receive flow last. The culvert barrels and outlets are aligned to match the downstream channel. Site conditions are shown in Appendix A Photos 107 to 110.

Site inspection observations for the last (5th and northernmost) culvert with least hazardous access are that there was standing stagnant water to a depth of about 2.35 m and a high-water mark visible at 2.5 m above the invert. The culvert is in generally good condition. The surveyor reported still water at both the 4th and 5th culverts.

The streambed is composed of rocks of varying sizes up to 0.75 m. Sparse low-rise bushes and grasses cover the creek banks.

The bankfull channel width typically varies from about 20 to 27 m, with corresponding depths from 1.3 to 3.4 m.

3.1.28 KM 192.4 Dempster Hwy No. 8 (Crossing 36/28)

Located at KM No. 192.4 of Highway No. 8, Crossing 36/28 at Lynx Creek m is a 34 m long, 3.8 m diameter CSP culvert with projecting ends. The culvert is at a 91° angle to the road and is in generally good condition. The inlet is at nearly a right angle to the approach flow of the upstream channel. Site conditions are shown in Appendix A Photos111 to 114.

Riprap is not present at the inlet or outlet ends and the embankments leading into the culvert are formed from exposed soil. Two distinct high-water marks were visible, a grey line at 0.95 m and red line at 1.25 m from culvert invert. Flow was steady in this culvert with a stream width of 2 m at outlet. The streambed is composed of rocks of varying sizes which cause eddies and rapids. Dense mid-rise bush covers the creek banks

The channel bankfull width typically ranges from about 2 to 7 m, with corresponding depths 0.6 to 1.4 m. At the culvert outlet the bankfull width is significantly wider at 14 m and deeper at 3 m.

3.1.29 KM 195.4 Dempster Hwy No. 8 (Crossing 37/29)

Located at KM No. 195.4 of Highway No. 8, Crossing 37/29 is composed of two 55 m long, 2.4 m diameter CSP culverts with projecting ends. The culverts are at a 148° angle to the road and are in generally good condition. Site conditions are shown in Appendix A Photos 115 to 118.

Riprap is not present at the inlet or outlet ends and the embankments leading into the culvert is formed from exposed soil. A distinct high-water mark is visible at 1.5 m up from culvert invert. Flow was steady with a stream width of 1.4 m at outlet. The streambed is composed of silt and mud and mid-rise bushes and grasses cover the creek banks. The surveyor noted a beaver dam about 10 m upstream from the north culvert and also dense willows throughout.

The bankfull width is about 3 to 4 m at the culvert ends, and about 12 to 15 m at cross sections 50 m upstream and dowstream. The bankfull depth ranges from about 0.5 m to 1.2 m.

3.1.30 KM 239.8 Dempster Hwy No. 8 (Crossing 38/30)

Located at KM No. 239.8 of Highway No. 8, Crossing 38/30 is a 29 m long, 1.5 m diameter CSP with a mitered inlet and projecting outlet. The culvert is at a 107° angle to the road and is in adequate condition with retrofitted vertical supports throughout the length of the pipe. It is sagging in the middle with water pooling in the middle of the culvert. Site conditions are shown in Appendix A Photos119 to 122.

Riprap is not present at the inlet or outlet ends and the embankments leading into the culvert is formed from exposed soil. A high-water mark is visible at 0.45 m from culvert invert. A downstream vertical drop of approx. 1 m is present at the outlet. Flow was steady in this culvert with a velocity at 60% depth measured as 2.2 m/s to 2.5 m/s. The visible portion of streambed is composed of grasses, silt and mud and low to high-rise brush and grasses cover the creek banks growing denser and higher with distance from inlet and outlet.

Due to very dense brush and thick overhanging vegetation beyond the road right of way, survey cross sections were only taken 10 m from the culvert ends. Bankfull width is 1.7 m upstream and 5.9 m downstream; corresponding depths are 0.8 m and 0.6 m.

3.1.31 KM 244.1 Dempster Hwy No. 8 (Crossing 39/31)

Located at KM No. 244.1 of Highway No. 8, Crossing 39/31 is has two parallel 35 m long CSP culverts with diameters of 4.0 m (south) and 1.7 m (north) respectively, with projecting ends. The culverts are at a 60° angle to the road and are in generally good condition with the larger culvert appearing to be the newest of the two. Site conditions are shown in Appendix A Photos 123 to 126.

Riprap is present and sized 0.5 to 1.0 m. At the larger south culvert, a high-water mark is visible at 0.65 m above the culvert invert. Flow was steady at the time of site visit with a surface speed of 1.3 m/s at the inlet. The visible portion of streambed is composed of gravels mixed with silt and mud. Mid-rise brush and grasses are present along streambanks.

The bankfull width varies from about 10 to 16 m, with corresponding depths of 0.7 to 1.7 m.

3.2 Flow Measurements

Flow measurements were attempted at all crossings. In many cases, accurate velocity and flow measurements were not possible due to lack of water depth, stagnant flow or obstacles such as rocks and boulders. A total of 14 crossings provided sufficient velocity readings to obtain a flow measurement. A summary of the flow measurements is provided in Table 2 below.

Table 2: Crossings with Flow Measurements

Crossing Number	Hwy & Kilometre Number	Measured Discharge (l/s)	Date of Measurement
1/1	No. 1 - 20.2	38	September 12th, 2018
3/3	No. 1 - 348.5	0.4	September 16th, 2018
4/4	No. 1 - 456.2	6.5	September 13th, 2018
6/8	No. 1 - 522.8	27.5	September 14th, 2018
9/15	No. 1 - 678.6	5.4	September 14th, 2018
10/16	No. 4 - 2.1	55.2	September 17th, 2018
18/25	No. 7 - 152.5	6.2	September 16th, 2018
19/26	No. 7 - 170.5	201	September 16th, 2018
20/27	No. 7 - 187.2	0.2	September 16th, 2018
21/29	No. 8 - 9.2	56	September 11th, 2018
23/31	No. 8 - 14.3	450	September 11th, 2018
25/33	No. 8 - 40.2	0.4	September 11th, 2018
28/36	No. 8 - 192.5	423	September 10th, 2018
29/37	No. 8 - 195.3	440	September 10th, 2018

Flow measurements were taken approximately 15 days after the channel topographic surveys by White Bear Geomatics. It was assumed, for purposes of data review, that the measured flows were at water levels similar to those reported by the survey.

The RFT anticipated that the measured flows would be used to calibrate the hydraulic models, but this was not achievable for most of the crossings due to: (1) practical challenges of model calibration to very low flows combined with sparse cross section data and (2) low flow characteristics that are not applicable to the higher flows of interest. Channel roughness increases at shallower depths as the bed material grain size or bedform size becomes large relative to the water depth. Also, gravel bars or shallow pool/riffle features that function as hydraulic controls at low flow will drown out at higher flows.

The estimated 2-year flows were used to calibrate the hydraulic models to surveyed geometry (widths and depths) representing bankfull conditions. As discussed later, multiple approaches were considered to estimate the 2-year discharges on streams that did not have a WSC stream gauge.

3.3 Surveyor Site Plans and Channel Sections

Surveyor site plans with plan views of each crossing are presented in Appendix B. The surveyor drawings also include sheets with channel section and profiles not reproduced herein but which are available from the surveyor's deliverables to the GNWT. All surveyor drawings were accompanied by AutoCAD files with exportable channel geometry (cross sections) which were used to develop the HEC-RAS hydraulic models.

As part of the surveyor's stream topographic surveys, estimates were made of bankfull and flood-prone conditions at each surveyed section, in accordance with the Survey RFT sketch shown on Figure 1. Widths and depths were estimated to represent: (A) extreme high-water conditions; (B) normal high-water representing a bankfull level at the transition from mineral bed/bank to vegetated shoreline; and (C) the water level at the time of survey.

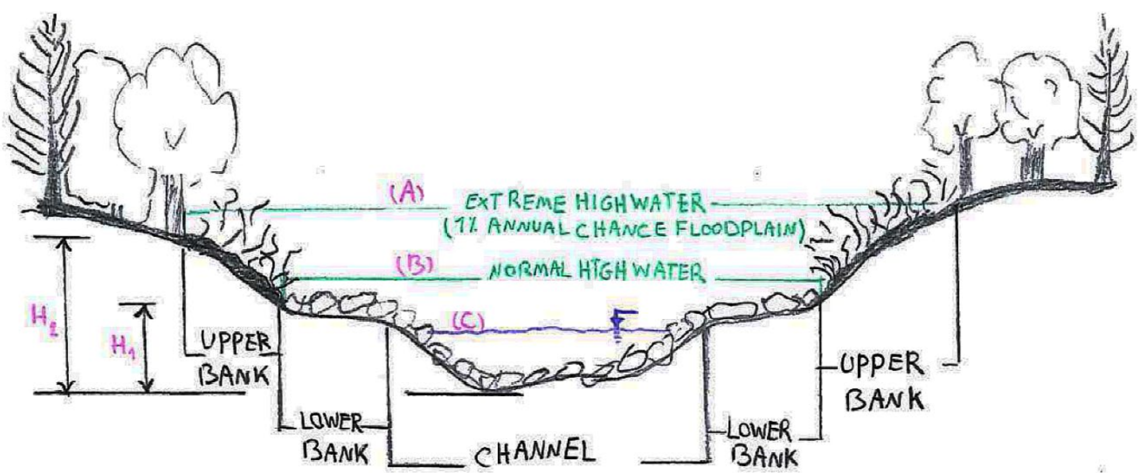


Figure 1: Definition Sketch for Survey Estimates of Bankfull and High-Water Conditions

Surveyor estimates of extreme high-water level were supposed to be based on start of upper bank woody vegetation (trees) which may not exist in many of the survey sections, especially for channels in flat terrain. Surveyor estimates of extreme high water are therefore very subjective and unlikely to provide a reliable estimate of 100-year flow conditions but can provide a check on model estimates.

Appendix C summarizes the surveyor-reported flood prone and bankfull widths and depths for all surveyed sections. Sections were surveyed, when possible, at distances of 10 m, 50 m and 100 m upstream and downstream of the culvert ends. Sections were not surveyed in areas of thick brush that prevented access.

4.0 HYDROLOGIC ANALYSIS

A hydrologic assessment was conducted to estimate 2-year and 100-year peak flows for use in hydraulic model calibration and culvert capacity assessments, and 3-day 10-year delay flows typically used for fish passage assessments. The “delay” term reflects the concept of a period in which fish are unable to swim upstream through the culvert, resulting in a delay in their seasonal migration.

A variety of hydrologic methods were employed for each of the 31 crossings as discussed in the sections below, with method selection being dependent on watershed size, terrain type, observed channel characteristics, and availability of proximal watercourses gauged by WSC.

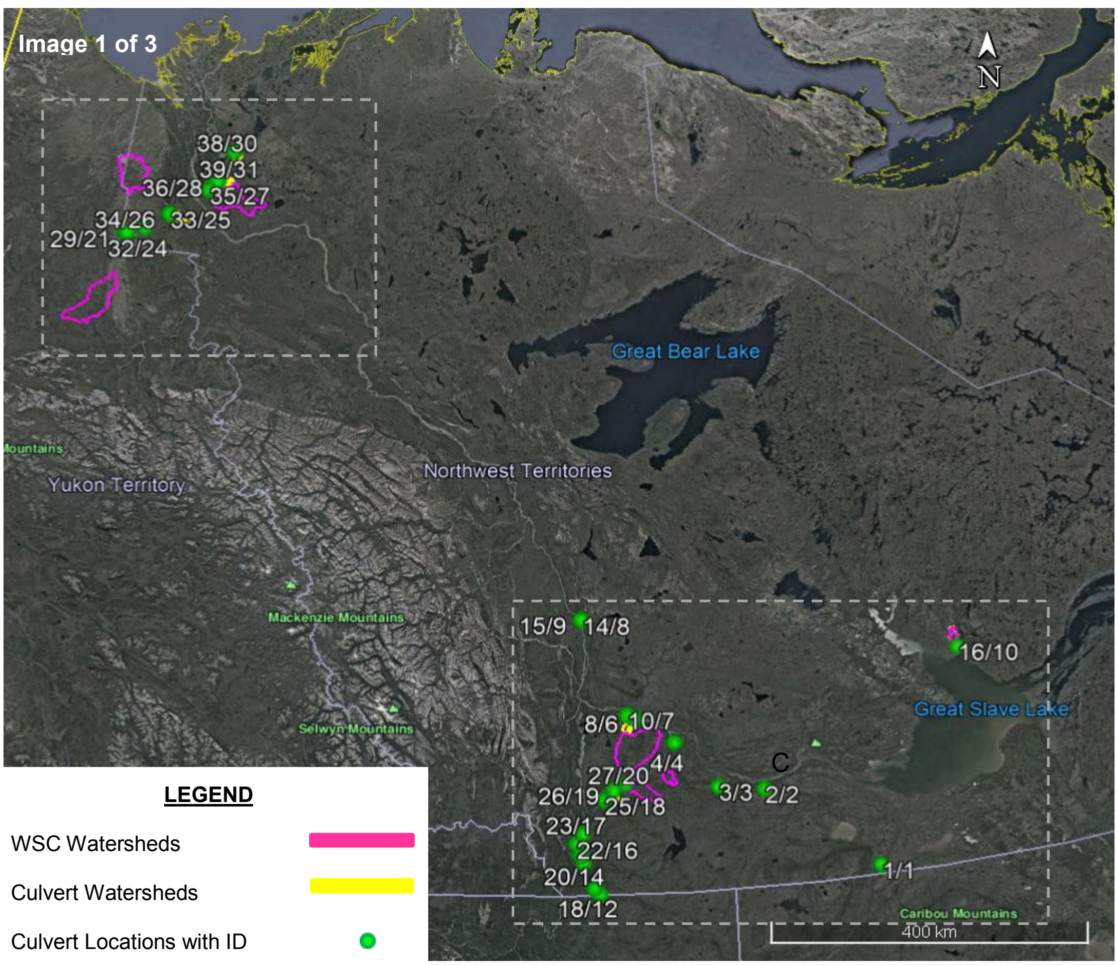
4.1 Watershed Delineation

Watershed areas were determined for relevant WSC stream gauges in the project region, and for each of the culvert crossing sites. WSC stream gauges were determined to be relevant on the basis of having a minimum of nine years of peak flow records, excluding gauges on major rivers (Mackenzie, Liard) with basins too large to be meaningfully representative of the hydrologic process characteristics of the smaller basins of interest.

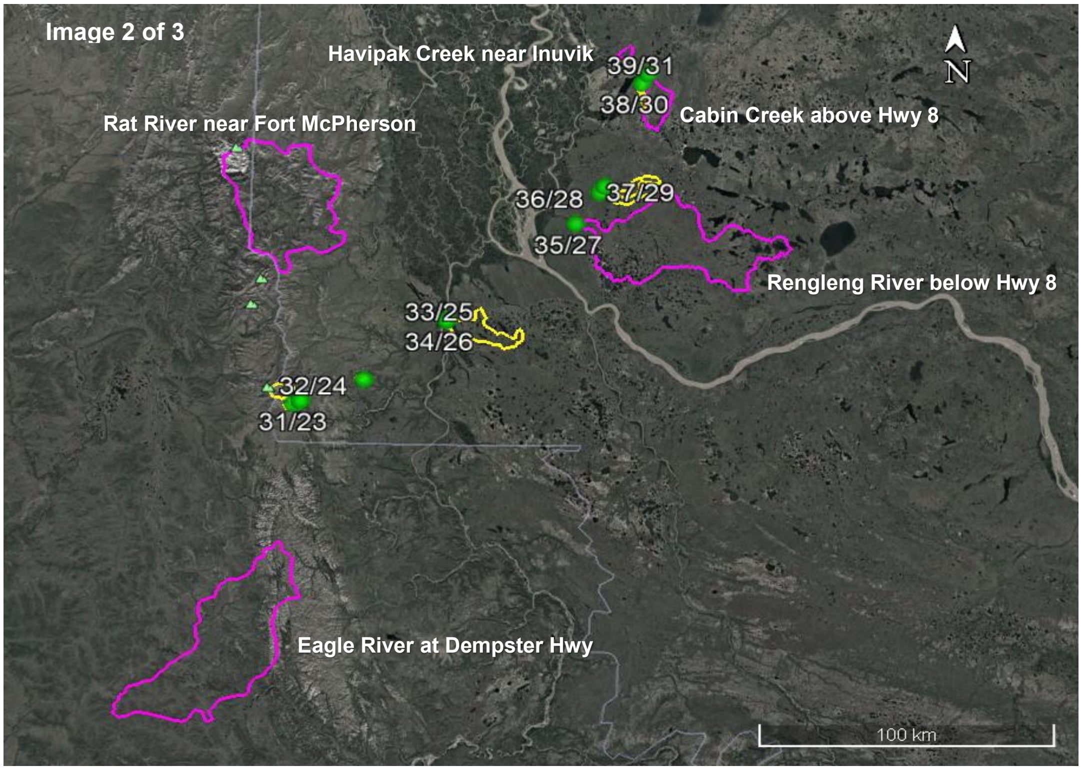
Delineation of watersheds in the Northwest Territories can be challenging, particularly in areas with little relief and small lakes without obvious outlets. Watershed areas for each of the 31 culvert crossings were initially delineated by performing a GIS analysis of the digital elevation models developed with the 1:50,000 scale National Topographic Survey data. Delineation algorithms in ArcMap 10.2.3 produced watersheds with a broad resolution. These watersheds were then further refined manually based on visual inspection of the NTS topographic maps and Google Earth satellite imagery which best illustrates small ephemeral stream paths as corridors outlined by strongly contrasting vegetation cover.

Figure 2 (overview plus north and south enlargements) show the culvert crossing locations together with outlines of the basins to the WSC stream gauges considered in detail. These figures also show the basins draining to the culvert crossings. Expanded views of the watershed areas are presented in Appendix D.

WSC station information, culvert crossing watershed areas and design flows are presented in Section 4.3.



TETRA TECH



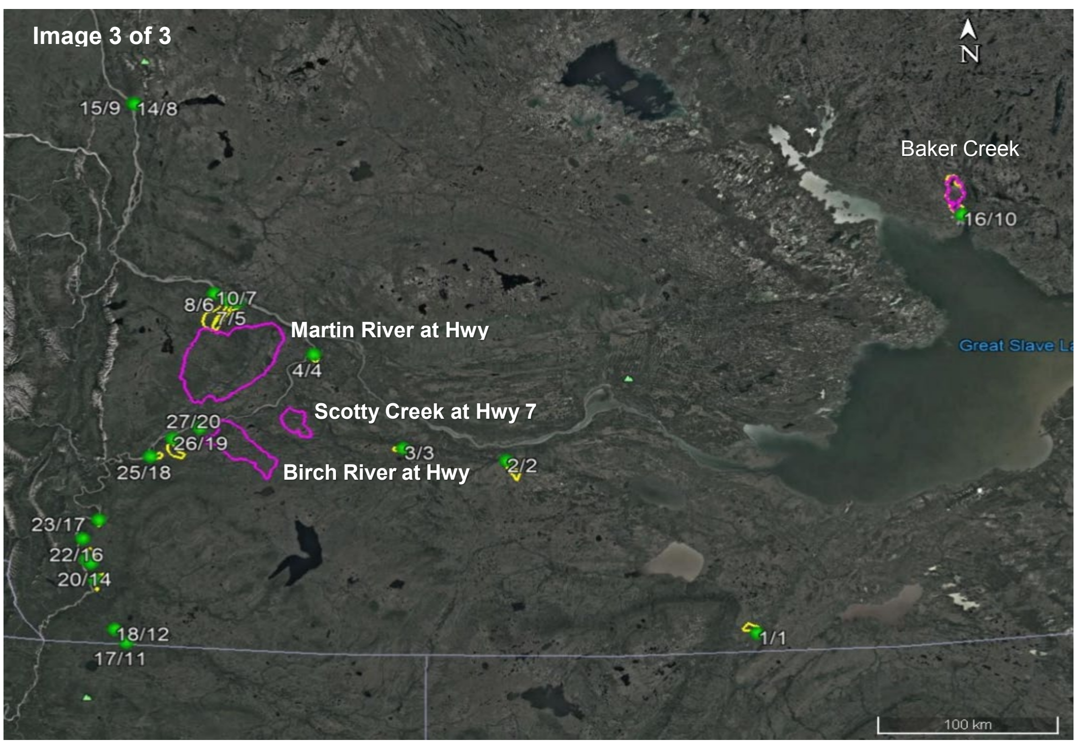


Figure 2: Study Area Location Plans (a) Overview, (b) Northern Crossings and (c) Southern Crossings

4.2 Hydrologic Methods

Due to the wide spatial distribution of the culvert crossings throughout the territory and range of watershed sizes, a custom hydrological analysis was completed for each individual crossing.

A number of different approaches were utilized in the analysis, with one or more approaches being used on each watercourse depending on circumstantial suitability. The various approaches utilized for determining Q2, 3Q10, and Q100 are summarized in Table 3 below. The calculation of Q2 for each watercourse, though not a requirement of the RFT, was frequently used as a basis for model calibration to channel bankfull conditions and as a base value to scale/estimate the 3Q10 and the Q100 values.

The methods used are consistent with those provided in the Transportation Association of Canada (TAC) Guide to Bridge Hydraulics, 2004, including (1) statistical frequency analysis of regional streamflow data and (2) empirical methods including the Rational Method, flood peak/drainage area correlations, and channel hydraulics. The frequency analyses methodology and results are summarized in Section 4.3 below with companion frequency curves presented in Appendix E. Empirical methods are described on a site-specific basis in Section 4.4.

Frequency analysis results were supplemented with an empirical relationship to correlate peak flows to basin areas. A TAC table of approximate drainage area coefficients for transferring extreme flood data lists exponents of 0.8 for drainage areas from 10 to 100 km^2 and 0.65 for drainage areas from 100 to 1000 km^2. According to TAC, these approximate exponents are based roughly on a Creager-type plot for severe floods in Canada. For the present study, a single exponent of 0.785 was adopted based on its development for province-wide use across the full range of hydrographic zones that occur across British Columbia and its consistency with the TAC guidance. However, this was not the sole method for determining flows.

A second empirical method to determine peak flows was to estimate the channel hydraulic capacity at the ordinary high-water level or bankfull stage. This level is associated with the transition from a mineral bed/bank condition to vegetated banks and is a physical condition generally associated with a mean annual or 2-year return period peak flow. The bankfull or 2-year flow for each site was estimated using a hydraulic model developed from the surveyed channel sections. Prominent rust lines within culverts were sometimes used as an alternate or supplementary indicator of the ordinary high water level. The 2-year flow was then scaled up to yield a 100-year flow using Q100/Q2 factors computed from the frequency analysis results for local streamflow stations.

As per the TAC, the use of two or more methods for peak flow estimation provides a check on the reasonableness of the independent estimates. Efforts to achieve convergence, when needed, typically included re-assessment and refinement of initial basin delineations and the stream-specific hydraulic models.

For very small basins, especially those lacking a defined mineral channel, the Rational Method was used for flow estimation. The rainfall Intensity Duration Frequency (IDF) curves used for these analyses are presented in Appendix E.

Table 3: Summary of Hydrological Methods used to Estimate the Q2, 3Q10, and Q100

Event	Estimation Methods
Q2	▪ Statistical analysis of hydrometric data collected by WSC on the watercourse. ▪ Transposition of Q2 flows estimated for WSC hydrometric data collected on nearby similar watercourse(s) through use of an area-based scaling equation. ▪ Rational method calculations, based on estimated basin time of concentration and Environment Canada published rainfall Intensity Duration Frequency data, used only for very small and well-drained watersheds ▪ 1D HEC-RAS hydraulic modelling of the watercourse for "bankfull" or "ordinary high water mark" conditions considered as typically equivalent to a 1:2-year return period event. ▪ 1D HEC-RAS hydraulic modelling of culvert flow to prominent water/rust lines within the culvert barrel, possibly an alternative indicator of an ordinary high water (2-year) event.
3Q10 and Q100	▪ Statistical analysis from data collected by WSC data on the watercourse. ▪ Transposition of 3Q10 and Q100 flows estimated for WSC hydrometric data collected on nearby similar watercourse(s). ▪ Via a factor applied to the watercourse's Q2 flow estimate. Where the selected factor is representative of other WSC stations with similar physiographic traits.

Transposition of flow quantiles from gauged basins to ungauged sites was done when basins were judged to have reasonably similar characteristics in terms of gradient (low-land versus well-drained), lake coverage, and vegetation characteristics. Statistically-determined peak flows for steam gauge locations were transposed using the following equation developed for the British Columbia Streamflow Inventory (Coulson and Obedkoff, 1998):

$$Q_2 = Q_1 \times \left(\frac{A_2}{A_1}\right)^k$$

Where:

- Q_1 and Q_2 denote peak flows of two watersheds;
- A_1 and A_2 denote corresponding watershed areas (km^2); and
- k exponent on the ratio of basin areas is a peaking factor, recognizing heightened unitized runoff within smaller catchments. The British Columbia Streamflow Inventory specifies a constant value of 0.785 for the whole province; this was determined by plotting peak flow against drainage area for each of 41 unique hydrologic zones. This same factor was used for the present GNWT study considering its derivation to represent a broad variety of geographic and hydrologic conditions within a neighbouring province.

Estimation of the 3Q10 values for ungauged basins was completed by using a regional transposition approach when basins were judged to be reasonably similar. When regional transposition was judged to be unreliable, the 3Q10 flow was instead computed by scaling the Q2 estimates. Scaling factors ranging from 1.0 to 1.7 were used. These factors are based on calculated ratios of 3Q10 to Q2 for individual WSC hydrometric stations.

An additional approach for flow estimation, attempted in the early stages of the analysis, was to estimate the 2-year flow as a multiplier (e.g., 30 times) on the base flow measured during the site visit. Multipliers considered historical ratios between September mean flows and statistical 2-year peak flows for WSC gauge sites. This method was judged to have low reliability and was used only infrequently as a reasonableness check on other methods.

Frequency analyses to determine flow quantiles from Water Survey of Canada data were done using HYFRAN software with built-in common statistical distributions including but not limited to Extreme Value, Lognormal, and

Log Pearson III. The selected distribution for each gauge was selected from a visual assessment of goodness of fit, with the Log Pearson III commonly used.

2-year and 100-year peak flow quantiles were derived from frequency analyses of data sets consisting of the highest peak flow for each year of the station period of record.

The 3Q10 flow (the 1 in 10-year 3-day delay discharge) methodology is used to identify fish passage flows based on an assumption that certain fish species will only tolerate a delay of three days before giving up on their migration and reabsorbing their eggs. Statistically, the flow was evaluated by identifying the fourth highest consecutive mean daily discharge for each year of record, and then conducting a frequency analysis on the resulting series to determine the 10-year quantile.

3Q10 flows have been computed as required by the RFT, but determination of actual fish presence, suitability of the 3Q10 methodology and the need for culvert designs to accommodate fish passage are all beyond the scope of the present assignment.

4.3 WSC Regional Station Hydrology Results

Our hydrologic analysis methodology relied upon existing flow data sets from WSC stream gauging stations representing the study area regions and applied that information to ungauged watercourses (i.e., the crossings).

An evaluation of all available Water Survey of Canada gauges in the area was conducted to assess suitability for inclusion in our analysis. Station suitability encompasses multiple factors including:

- Share similarities in watershed size to subject watersheds;
- Share similar physiographic properties to subject watersheds;
- Are reasonably close in proximity to subject watersheds; and
- Have sufficient period-of-record, preferably greater than 10 years, to allow for meaningful statistical return period analysis;

We identified ten WSC hydrometric stations which had a sufficient period of record and were geographically similar to the watersheds of interest. Figure 2 shows the location of the WSC stations and their catchment areas. Expanded views of these catchments are included in Appendix D. Table 4 summarizes the station characteristics, listed from north to south.

Table 4: WSC Station Summary

Station ID	Station Name	Watershed Area (km²)	Years of Peak Daily Flow Data	Number of Years of Peak Instantaneous Flows
10LC017	Havipak Creek near Inuvik	15.2	19	9
10LC009	Cabin Creek above Hwy No. 8	150	12	7
10LC003	Rengleng River below Hwy. No. 8	1300	40	21
10MC007	Rat River near Fort McPherson	1260	9	7
09FB002	Eagle River at Dempster Highway Bridge	1720	20	18
07SB013 / 07SB009	Baker Creek at Outlet of Lower Martin Lake / Baker Creek near Yellowknife	121 / 126	34 / 14	30 / 10
10GC003	Martin River at Hwy No. 1	2050	42	37
10ED003	Birch River at Hwy. No. 7	542	42	34
10ED009	Scotty Creek at Hwy No. 7	202	22	18
07OB006	Lutose Creek Near Steen River	292	27	28

A flood frequency analysis was conducted using peak instantaneous flows for each of the stations. In years where a station had a maximum daily flow reported, but no maximum instantaneous flow, a maximum instantaneous flow was synthesized by multiplying the maximum daily flow by the average ratio of maximum instantaneous to maximum daily values in years where both values were available.

A flood frequency analysis of the peak instantaneous flows was completed at each station by fitting to probability distributions. A similar analysis was completed on 3-day exceedance flows to estimate a 3Q10 for each WSC station. Table 5 presents the results of this frequency analysis, including ratio of 3Q10 to Q2 which was utilized in the estimation of 3Q10 from Q2 for several of the culvert crossings. Appendix E presents the frequency curve plots, showing the position of the statistical curves in relation to the underlying recorded data.

Table 5: WSC 3Q10 and Flood Frequency Results (m³/s)

Station ID	Watershed Area (km²)	3Q10	Q2	Q5	Q10	Q20	Q50	Q100	Q200	3Q10/ Q2 Ratio	Q100/Q2 Ratio
10LC017	15.2	2.1	1.9	2.9	3.6	4.2	5.0	5.6	6.2	1.11	2.95
10LC009	150	15.7	33.6	54.3	68.0	81.2	98.2	111	124	0.95	3.30
10LC003	1300	95.6	50.4	91.4	120	149	184	210	235	1.90	4.17
10MC007*	1260	-	156	166	-	-	-	-	-		-
09FB002	1720	217	225	335	408	477	568	635	703	0.96	2.82
07SB013 / 07SB009	121 / 126	4.2	1.3	3.1	4.4	5.6	7.1	8.1	9.1	3.23	6.23
10GC003	2050	192	86.9	181	267	369	531	679	850	2.21	7.81

Station ID	Watershed Area (km^2)	3Q10	Q2	Q5	Q10	Q20	Q50	Q100	Q200	3Q10/ Q2 Ratio	Q100/Q2 Ratio
10ED003	542	57.4	31.5	70.0	106	148	217	279	352	1.82	8.86
10ED009	202	10.9	7.3	11.4	14.1	16.7	20.1	22.6	25.1	1.49	3.10
07OB006	292	10.7	6.0	10.3	13.3	16.1	19.8	22.4	24.9	1.78	3.73

* Q10 thru Q200 were not calculated due to less than 10 years of maximum daily flow record.

4.4 Crossing Site Hydrology Results

Site hydrology was completed for each of the 31 watercourses included within the scope of this project. Watershed areas and methods utilized to develop the 3Q10 and 100-year flow estimates are described below. Results are also tabulated in Table 6.

Crossing 1/1		
Watershed Area:	31.9 km^2	
3Q10:	1.88 m^3/s	
Q100:	3.94 m^3/s	
Methodology:	3Q10 and Q100 for this culvert crossing were both estimated based on hydrometric data collected on *Lutose Creek near Steen River.* 3Q10 and Q100 values for Lutose Creek were scaled to Crossing 1/1's watershed area based on the following scaling: $$Q_{C1/1} = Q_{Lutose} \times \left(\frac{WSA_{C1/1}}{WSA_{Lutose}}\right)^{0.785}$$	

Crossing 2/2		
Watershed Area:	43 km^2	
3Q10:	1.88 m^3/s	
Q100:	3.94 m^3/s	
Methodology:	3Q10 and Q100 for this culvert crossing were both estimated based on hydrometric data collected on *Lutose Creek near Steen River.* 3Q10 and Q100 values for Lutose Creek were scaled to Crossing 2/2's watershed area based on the following scaling: $$Q_{C2/2} = Q_{Lutose} \times \left(\frac{WSA_{C2/2}}{WSA_{Lutose}}\right)^{0.785}$$ A visual inspection of Google Earth aerial photography reveals a flow split occurs at a pond outlet upstream of Crossing 2/2 where a portion of flow from this catchment is directed towards 2 x 800 mm culverts located 800 m to the east (as per survey results). Clarity on flow division at this split is poor; however, based on vegetation indicating the presence of water, we conservatively estimate 45% of the flow will be directed towards Crossing 2/2. Therefore, an additional factor of 0.45 was applied to account for this split.	

Crossing 3/3	
Watershed Area:	17.7 km^2
3Q10:	1.87 m^3/s
Q100:	3.85 m^3/s
Methodology:	3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The Q2 for this crossing was estimated to be 1.1 m^3/s, which was the flow necessary to achieve bankfull flow in a 1D model of the watercourse. The factors relating Q2 to 3Q10 and Q2 to Q100 were selected as 1.7 and 3.5 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Mackenzie Highway area.

Crossing 4/4	
Watershed Area:	9.2 km^2
3Q10:	1.7 m^3/s
Q100:	3.5 m^3/s
Methodology:	3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The Q2 for this crossing was estimated to be 1.0 m^3/s, which was the flow necessary to fill the channel to the toe of the steep eroded banks ~10 metres downstream of the culvert in the HEC-RAS model. The factors relating Q2 to 3Q10 and Q2 to Q100 were selected as 1.7 and 3.5 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Fort Simpson area.

Crossing 7/5	
Watershed Area:	56 km^2
3Q10:	11.4 m^3/s
Q100:	40.2 m^3/s
Methodology:	3Q10 and Q100 for this culvert crossing were both estimated based on hydrometric data collected on *Martin River at Hwy No.1*. 3Q10 and Q100 values for Martin River were scaled to Crossing 7/5's watershed area based on the following scaling: $$Q_{C7/5} = Q_{Martin} \times \left(\frac{WSA_{C7/5}}{WSA_{Martin}}\right)^{0.785}$$

Crossing 8/6	
Watershed Area:	97.5 km^2
3Q10:	17.6 m^3/s
Q100:	62.2 m^3/s
Methodology:	3Q10 and Q100 for this culvert crossing were both estimated based on hydrometric data collected on *Martin River at Hwy No.1*. 3Q10 and Q100 values for Martin River were scaled to Crossing 8/6's watershed area based on the following scaling: $$Q_{C8/6} = Q_{Martin} \times \left(\frac{WSA_{C8/6}}{WSA_{Martin}}\right)^{0.785}$$

Crossing 10/7		
Watershed Area:	7.34 km^2	
3Q10:	2.31 m^3/s	
Q100:	8.16 m^3/s	
Methodology:	3Q10 and Q100 for this culvert crossing were both estimated based on hydrometric data collected on *Martin River at Hwy No.1*. 3Q10 and Q100 values for Martin River were scaled to Crossing 10/7's watershed area based on the following scaling: $$Q_{C10/7} = Q_{Martin} \times \left(\frac{WSA_{C10/7}}{WSA_{Martin}}\right)^{0.785}$$	

Crossing 14/8		
Watershed Area:	0.68 km^2	
3Q10:	0.49 m^3/s	
Q100:	0.87 m^3/s	
Methodology:	Rational method was relied upon to estimate Q2 and Q100 of this small watercourse. A time-of-concentration of 45 minutes a runoff coefficient of 0.15 were used. Rainfall intensities for a 2-year and 100-year return event were taken from the Environment Canada published IDF curve for Fort Simpson Airport. 3Q10 was calculated by applying a factor of 1.7 to the Q2. 1.7 is based on statistical analysis of WSC gauged watercourses in the Fort Simpson area.	

Crossing 15/9		
Watershed Area:	2.44 km^2	
3Q10:	0.48 m^3/s	
Q100:	0.85 m^3/s	
Methodology:	A single lake takes up a considerable portion of this entire watershed area. Due to the attenuating effect of this lake, peak flows at the culvert crossing will be heavily dependent on the runoff from the catchment area not captured by the lake. This portion of the catchment outside of lake influence was delineated to be only 0.83 km^2. Rational method was relied upon to estimate Q2 and Q100 of this subcatchment. A time-of-concentration of 45 minutes a runoff coefficient of 0.10 were used. Rainfall intensities for a 2-year and 100-year return event were taken from the Environment Canada published IDF curve for Fort Simpson Airport. 3Q10 was calculated by applying a factor of 1.7 to the Q2. 1.7 is based on statistical analysis of WSC gauged watercourses in the Fort Simpson area. The Q2, 3Q10, and Q100 were then scaled up by an additional 20% to account for concurrent lake outflow during this hypothetical 100-year storm event.	

Crossing 16/10		
Watershed Area:	128 km^2	
3Q10:	4.35 m^3/s	
Q100:	8.38 m^3/s	

Methodology:	Crossing 16/10 is located on the Baker Creek. WSC operated two hydrometric stations on Baker Creek near the highway crossing between 1968 and 2016. 3Q10 and Q100 estimates for this culvert crossing were both calculated directly from the dataset of flow values from the hydrometric station and scaled upwards by 3% to account for a slight increase in watershed area at the highway crossing.3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing.

Crossing 17/11		
Watershed Area:	0.98 km^2	
3Q10:	0.90 m^3/s	
Q100:	1.62 m^3/s	
Methodology:	Rational method was relied upon to estimate Q2 and Q100 of this small watercourse. A time-of-concentration of 30 minutes a runoff coefficient of 0.15 were used. Rainfall intensities for a 2-year and 100-year return event were taken from the Environment Canada published IDF curve for Fort Simpson Airport. 3Q10 was calculated by applying a factor of 1.7 to the Q2. 1.7 is based on statistical analysis of WSC gauged watercourses in the Fort Simpson area.	

Crossing 18/12		
Watershed Area:	1.56 km^2	
3Q10:	1.14 m^3/s	
Q100:	2.02 m^3/s	
Methodology:	Rational method was relied upon to estimate Q2 and Q100 of this small watercourse. A time-of-concentration of 45 minutes a runoff coefficient of 0.15 were used. Rainfall intensities for a 2-year and 100-year return event were taken from the Environment Canada published IDF curve for Fort Simpson Airport. 3Q10 was calculated by applying a factor of 1.7 to the Q2. 1.7 is based on statistical analysis of WSC gauged watercourses in the Fort Simpson area.	

Crossing 19/13		
Watershed Area:	9.8 km^2	
3Q10:	1.87 m^3/s	
Q100:	3.85 m^3/s	
Methodology:	3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The Q2 for this crossing was estimated to be 1.1 m^3/s, which was the flow necessary to achieve bankfull flow in a 1D model of the watercourse. The factors relating Q2 to 3Q10 and Q2 to Q100 were selected as 1.7 and 3.5 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Fort Simpson area.	

Crossing 20/14	
Watershed Area:	5.3 km^2
3Q10:	1.36 m^3/s

Q100:	2.8 m^3/s
Methodology:	3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The Q2 for this crossing was estimated to be 0.8 m^3/s, which was the flow necessary to replicate the prominent rust line in a 1D model of the watercourse. The factors relating Q2 to 3Q10 and Q2 to Q100 were selected as 1.7 and 3.5 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Fort Simpson area.

Crossing 21/15	
Watershed Area:	32.6 km^2
3Q10:	5.89 m^3/s
Q100:	12.2 m^3/s
Methodology:	3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The Q2 for this crossing was estimated to be 3.47 m^3/s, which calculated through scaling Q2 values for the WSC on Birch River to Crossing 21/15 watershed area based on the following equation: $$Q_{C21/15} = Q_{Birch} \times \left(\frac{WSA_{C21/15}}{WSA_{Birch}}\right)^{0.785}$$ The factors relating Q2 to 3Q10 and Q2 to Q100 were selected as 1.7 and 3.5 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Fort Simpson area.

Crossing 22/16	
Watershed Area:	2.4 km^2
3Q10:	1.2 m^3/s
Q100:	2.5 m^3/s
Methodology:	3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The Q2 for this crossing was estimated to be 0.7 m^3/s, which was the flow necessary to replicate the prominent rust line in a 1D model of the watercourse. The factors relating Q2 to 3Q10 and Q2 to Q100 were selected as 1.7 and 3.5 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Fort Simpson area.

Crossing 23/17	
Watershed Area:	5.1 km^2
3Q10:	1.4 m^3/s
Q100:	2.8 m^3/s
Methodology:	3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The Q2 for this crossing was estimated to be 0.81 m^3/s, which calculated through scaling Q2 values for the WSC on Birch River to Crossing 23/17 watershed area based on the following equation: $$Q_{C23/17} = Q_{Birch} \times \left(\frac{WSA_{C23/17}}{WSA_{Birch}}\right)^{0.785}$$ The factors relating Q2 to 3Q10 and Q2 to Q100 were selected as 1.7 and 3.5 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Fort Simpson area.

Crossing 25/18	
Watershed Area:	16.6 km^2
3Q10:	3.5 m^3/s
Q100:	7.2 m^3/s
Methodology:	3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The Q2 for this crossing was estimated to be 2.04 m^3/s, which calculated through scaling Q2 values for the WSC on Birch River to Crossing 25/18 watershed area based on the following equation: $$Q_{C25/18} = Q_{Birch} \times \left(\frac{WSA_{C25/18}}{WSA_{Birch}}\right)^{0.785}$$ The factors relating Q2 to 3Q10 and Q2 to Q100 were selected as 1.7 and 3.5 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Fort Simpson area.

Crossing 26/19	
Watershed Area:	48.3 km^2
3Q10:	8.0 m^3/s
Q100:	16.5 m^3/s
Methodology:	3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The Q2 for this crossing was estimated to be 4.72 m^3/s, which calculated through scaling Q2 values for the WSC on Birch River to Crossing 26/19 watershed area based on the following equation: $$Q_{C26/19} = Q_{Birch} \times \left(\frac{WSA_{C26/19}}{WSA_{Birch}}\right)^{0.785}$$ The factors relating Q2 to 3Q10 and Q2 to Q100 were selected as 1.7 and 3.5 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Fort Simpson area.

Crossing 27/20	
Watershed Area:	2.45 km^2
3Q10:	0.68 m^3/s
Q100:	1.40 m^3/s
Methodology:	3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The Q2 for this crossing was estimated to be 0.4 m^3/s. The factors relating Q2 to 3Q10 and Q2 to Q100 were selected as 1.7 and 3.5 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Fort Simpson area.

Crossing 29/21	
Watershed Area:	1.73 km^2
3Q10:	2.60 m^3/s
Q100:	7.80 m^3/s
Methodology:	3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The Q2 for this crossing was estimated to be 2.60 m^3/s, which was the flow necessary to achieve bankfull flow in a 1D model of the watercourse. The factors relating Q2 to 3Q10 and Q2 to Q100

	were selected as 1.0 and 3.0 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Fort Resolution area, particularly *Eagle River at Dempster Highway*.

Crossing 30/22	
Watershed Area:	1.30 km^2
3Q10:	0.80 m^3/s
Q100:	2.4 m^3/s
Methodology:	3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The Q2 for this crossing was estimated to be 0.80 m^3/s, which was the flow necessary to achieve bankfull flow in a 1D model of the watercourse. The factors relating Q2 to 3Q10 and Q2 to Q100 were selected as 1.0 and 3.0 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Fort Resolution area, particularly *Eagle River at Dempster Highway*.

Crossing 31/23	
Watershed Area:	42.2 km^2
3Q10:	9.45 m^3/s
Q100:	27.6 m^3/s
Methodology:	3Q10 and Q100 for this culvert crossing were both estimated based on hydrometric data collected on *Eagle River at Dempster Highway*. 3Q10 and Q100 values for Eagle River were scaled to Crossing 31/23's watershed area based on the following scaling: $$Q_{C23} = Q_{Eagle} \times \left(\frac{WSA_{C31/23}}{WSA_{Eagle}}\right)^{0.785}$$ An additional factor of 0.8 was then applied to account for the estimated distribution of flows between Crossing 23 and Crossing 24, which are both located 100 m apart on the same watercourse. Based on visual inspection of the two braids of the watercourse and 1D hydraulic modelling of the channel geometries we estimate 80% of the flow will be directed towards Crossing 31/23.

Crossing 32/24	
Watershed Area:	42.2 km^2
3Q10:	2.36 m^3/s
Q100:	6.91 m^3/s
Methodology:	3Q10 and Q100 for this culvert crossing were both estimated based on hydrometric data collected on *Eagle River at Dempster Highway*. 3Q10 and Q100 values for Eagle River were scaled to Crossing 32/24's watershed area based on the following scaling: $$Q_{C24} = Q_{Eagle} \times \left(\frac{WSA_{C32/24}}{WSA_{Eagle}}\right)^{0.785}$$ An additional factor of 0.2 was then applied to account for the estimated distribution of flows between Crossing 31/23 and Crossing 32/24, which are both located 100 m apart on the same watercourse. Based on visual inspection of the two braids of the watercourse and 1D hydraulic modelling of the channel geometries we estimate 20% of the flow will be directed towards Crossing 32/24.

Crossing 33/25	
Watershed Area:	4.70 km^2
3Q10:	1.40 m^3/s
Q100:	4.20 m^3/s
Methodology:	3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The Q2 for this crossing was estimated to be 1.4 m^3/s, which was the flow necessary to achieve bankfull flow in a 1D model of the watercourse. The factors relating Q2 to 3Q10 and Q2 to Q100 were selected as 1.0 and 3.0 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Fort Resolution area, particularly *Eagle River at Dempster Highway*.

Crossing 34/26	
Watershed Area:	n/a
3Q10:	0 m^3/s
Q100:	0 m^3/s
Methodology:	Crossing 26 is located within an unusual geological feature which may potentially drain towards the south, away from the road. No flow was observed during the September 2018 site visit and rust marks on the culvert exterior indicate that historical water levels do not go much higher (0.2 m) than the water level during the site visit. We believe the existing culvert is primarily an equalization culvert. No flood flow estimates were possible for this crossing.

Crossing 35/27	
Watershed Area:	1300 km^2
3Q10:	95.6 m^3/s (19.1 m^3/s per culvert)
Q100:	210 m^3/s (42 m^3/s per culvert)
Methodology:	Crossing 35/27 is located on the Rengleng River. WSC have operated a hydrometric station on Rengleng River at the highway crossing since 1974. 3Q10 and Q100 estimates for this culvert crossing were both calculated directly from the dataset of flow values from the hydrometric station.

Crossing 36/28	
Watershed Area:	65.6 km^2
3Q10:	10.2 m^3/s
Q100:	25.5 m^3/s
Methodology:	3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The Q2 for this crossing was estimated to be 10.2 m^3/s, which calculated through scaling Q2 values for the WSC on Cabin Creek to Crossing 36/28 watershed area based on the following equation: $$Q_{C28} = Q_{Cabin} \times \left(\frac{WSA_{C36/28}}{WSA_{Cabin}}\right)^{0.785}$$ The factors relating Q2 to 3Q10 and Q2 to Q100 were selected as 1.0 and 2.5 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Inuvik area.

Crossing 37/29	
Watershed Area:	44.2 km^2
3Q10:	7.48 m^3/s
Q100:	18.71 m^3/s
Methodology:	3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The Q2 for this crossing was estimated to be 7.5 m^3/s, which calculated through scaling Q2 values for the WSC on Cabin Creek to Crossing 29's watershed area based on the following equation: $$Q_{C29} = Q_{Cabin} \times \left(\frac{WSA_{C37/29}}{WSA_{Cabin}}\right)^{0.785}$$ The factors relating Q2 to 3Q10 and Q2 to Q100 were selected as 1.0 and 2.5 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Inuvik area.

Crossing 38/30	
Watershed Area:	9.9 km^2
3Q10:	2.31 m^3/s
Q100:	5.78 m^3/s
Methodology:	3Q10 and Q100 values for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The Q2 for this crossing was estimated to be 2.3 m^3/s, which calculated through scaling Q2 values for the WSC on Cabin Creek to Crossing 30's watershed area based on the following equation: $$Q_{C29} = Q_{Cabin} \times \left(\frac{WSA_{C38/29}}{WSA_{Cabin}}\right)^{0.785}$$ The factors relating Q2 to 3Q10 and Q2 to Q100 were selected as 1.0 and 2.5 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Inuvik area.

Crossing 39/31	
Watershed Area:	121 km^2
3Q10:	16.5 m^3/s
Q100:	41.3 m^3/s
Methodology:	Crossing #31 is located on the Cabin Creek. WSC operated a hydrometric station on Cabin Creek at the highway crossing between 1984 and 1995. This 12-year period of record was adequate to provide an estimate of Q2, but insufficient to adequately extrapolate 3Q10 and Q100 values. As such, 3Q10 and Q100 estimates for this culvert crossing were both estimated by applying factors to the Q2 for the crossing. The factors relating Q2 to 3Q10 and Q2 to Q100 were selected as 1.0 and 2.5 respectively which are based on statistical analysis of similar WSC gauged watercourses in the Inuvik area.

Table 6: Culvert Crossing Design Flows

Crossing #	Watershed Area (km^2)	3Q10 (m^3/s)	Q2 (m^3/s)	Q100 (m^3/s)
1/1	31.9	1.88	1.05	3.95
2/2	43	1.07	0.60	2.25
3/3	17.7	1.87	1.10	3.85
4/4	9.2	1.70	1.0	3.5
7/5	56.0	11.4	4.88	40.2
8/6	97.5	17.6	7.60	62.2
10/7	7.35	2.31	0.96	8.16
14/8	0.7	0.49	0.29	0.8
15/9	2.45	0.48	0.28	0.85
16/10	128	4.35	1.36	8.38
17/11	1	0.90	0.53	1.6
18/na	1.6	1.14	0.67	2
19/13	9.75	1.87	1.10	3.85
20/14	5.3	1.36	0.80	2.80
21/15	32.6	5.89	3.47	12.15
22/16	2.4	1.19	0.70	2.45
23/17	5.1	1.37	0.81	2.85
25/18	16.6	3.47	2.04	7.15
26/19	48.3	8.02	4.72	16.5
27/20	2.45	0.68	0.40	1.40
29/21	1.73	2.60	2.60	7.80
30/22	1.30	0.80	0.80	2.40
31/23	42.2	9.45	9.80	27.6
32/24	42.2	2.36	2.40	6.91
33/25	4.70	1.40	1.40	4.20
34/26	157	n/a	n/a	n/a
35/27	1545	95.6	43	210
36/28	46.8	7.95	6.61	16.5
37/29	44.2	7.48	6.32	18.7
38/30	9.90	2.31	1.95	5.78
39/31	150	19.8	16.5	49.5

5.0 HYDRAULIC ANALYSIS

Hydraulic analysis and modelling is used to simulate the physical parameters of water flowing through a given channel. The water surface elevation and the average water velocity for various return period flows were modelled at each crossing location. This information is useful for assessing the structural and environmental components of each crossing.

The hydraulic model HEC-RAS V5.0.5 developed by US Army Corps of Engineers was used to model the hydraulics at each crossing. HEC-RAS is designed to perform one-dimensional and two-dimensional hydraulic calculations for a full network of natural and constructed channels, overbank/floodplain areas, levee protected areas.

The models were developed using steady flow conditions to calculate water surface profiles for the specified flows (2-year, 100-year, etc.). The steady flow computational procedures are capable of modelling subcritical, supercritical, and mixed flow regime water surface profiles. The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied.

The hydrologic results described in Section 5 were input to the HEC-RAS model to assess channel and culvert performance. The model downstream boundary condition was, for most of the crossings, specified to be the normal depth computed from the channel geometry, downstream slope, and assigned roughness values. For crossings where “ponding” existed on the downstream end of the models, estimated water surface elevations were used as the downstream boundary condition.

Model geometries were generated from the surveyed cross sections and data points collected by White Bear Geomatics Ltd. A terrain surface was built upon the surveyed data in Civil 3D software, and the corresponding cross sections were exported from the terrain surface into the HEC-RAS model. Where needed for purposes of hydraulic modelling, additional sections were interpolated or manually added. Additional sections were added at the culvert inlets and outlets, based on the nearest (upstream or downstream) section with a vertical adjustment to match the bed level shown in the stream survey profile. In other cases, additional sections were added to represent obstructions observed in site photos and/or the surveyor plan drawings, but not captured by the surveyed sections.

All existing culverts are made of corrugated metal, with either projecting or mitered inlets. Culvert inlet loss coefficients and Manning’s n roughness coefficients were assigned following guidance in the US Federal Highway Association (FHWA) Publication Number HIF-12-026, Hydraulic Design of Highway Culverts, Third Edition. For crossings with sharp bends or skew such as crossings 16/10, 30/22, and 37/29, a 2D hydraulic model was applied to validate the results of the 1D analysis.

Hydraulic analyses for culvert crossings were also completed using standard culvert design nomographs per U.S. Department of Transportation Federal Highway Administration (2012) assuming inlet control and headwater depth at the inlet equal to the culvert diameter.

5.1 Model Setup and Calibration

Channel bank stations, representing the transition from channel flow to overbank (vegetated) flow conditions, were determined from field investigation photographs and surveyor estimates of bankfull width and depth. Channel slope was estimated using the surveyed stream profiles, sometimes supplemented with Google Earth elevation data if the profile data were inadequate. Initial estimates of hydraulic roughness coefficients for the channel and floodplain areas were based on professional judgement considering field observations and guidance provided in US

Geological Survey Water Supply Paper 1849, Roughness Characteristics of Natural Channels, and Water Supply Paper 2339, Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains.

The published roughness and inlet loss coefficients used in the models are understood to be based on full flow and/or submerged inlet conditions which may be applicable to major design flood events (e.g., 100-year). For lesser events, such as a 2-year or bankfull flow, the inlet losses may be significantly over-estimated because there will be less constriction and less of an orifice effect; this in turn results in over-estimation of (too high) water levels upstream of the culvert. Accordingly, calibration achieve bankfull width and depths for the estimated 2-year flow gave low weight to the upstream results and focussed on model results for the channel downstream from the culverts.

Calibration to reasonably achieve 2-year flow bankfull hydraulic conditions for model downstream sections was achieved by review of initial results and then adjusting some defensible combination of:

- estimated channel and bank roughness values;
- downstream boundary conditions (channel slope and/or water level);
- 2-year discharge estimate;
- upstream split flow assumptions (in cases where a portion of the watershed does not drain to culvert); and
- additional approximate cross sections added if needed to represent hydraulic controls not captured by the surveyed sections.

The slope and roughness parameters used in the calibrated hydraulic models are presented in Table 7. Where two values are presented for the channel or roughness, the lower value is applied to the cleared right of way where the absence of vegetation reduces the roughness.

Table 7: Hydraulic Model Parameters

Crossing	Channel Slope (%)	Channel Roughness (Manning's 'n')	Floodplain Roughness (Manning's 'n')
1/1	0.5	0.04/0.08	0.04/0.1
2/2	1.5	0.04	0.06
3/3	2	0.06/0.08	0.1
4/4	9	0.05/0.08	0.1/0.2
7/5	0.5	0.04	0.1
8/6	1.5	0.08	0.1
10/7	3	0.07	0.2
14/8	6	0.1	0.15
15/9	3	0.05/0.2	0.05/0.2
16/10	0.5	0.04	0.06
17/11	2	0.04	0.06
18/na	4	0.1/0.06	0.2/0.06
19/13	0.7	0.08	0.15
20/14	2	0.06/0.08/0.15	0.06/0.08

Crossing	Channel Slope (%)	Channel Roughness (Manning's 'n')	Floodplain Roughness (Manning's 'n')
21/15	0.5	0.2	0.06
22/16	3	0.08	0.08/0.1
23/17	4	0.05/0.08	0.05/0.2
25/18	1	0.05	0.2
26/19	0.5	.06	0.2
27/20	1.5	0.04/0.06	0.05/0.1
29/21	4	0.06	0.1
30/22	2.5	0.06	0.08
31/23	1.5	0.04 /0.07-0.08	0.08
32/24	1.5	0.045	0.1
33/25	3	0.05/0.08	0.08
34/26	0.001	0.035, 0.055	0.06
35/27	0.5	0.032	0.1
36/28	0.5	0.035	0.1
37/29	0.2	0.035	0.1
38/30	3	0.05	0.1
39/31	0.3	0.035	0.15

5.2 Hydraulic Results

The calibrated models were run under flow scenarios corresponding to the 3Q10 delay flow and 100-year design flood for each crossing. Resulting water velocities and water surface elevations are presented in Table 8 together with clearance and freeboard amounts used to assess culvert adequacy.

To estimate the freeboard and clearance (Figure 3), the water level was extracted just upstream of the culvert inlet. The clearance is the difference between culvert crown and water surface elevations, and freeboard is the difference between road and water surface elevations.

The downstream velocity refers to the velocity of the channel at 10 m downstream of the culvert location, whereas, the culvert velocity is the velocity estimated through the culvert adjacent to the outlet.

The key results for the 3Q10 flow are the velocity through the culvert and the channel velocity. The methodology considers that fish passage for migration may be impaired if culvert velocity is significantly greater than the channel velocity. As mentioned earlier, 3Q10 flows have been computed as required by the RFT, but determination of actual fish presence, suitability of the 3Q10 methodology and the need for culvert designs to accommodate fish passage are all beyond the scope of the present assignment.

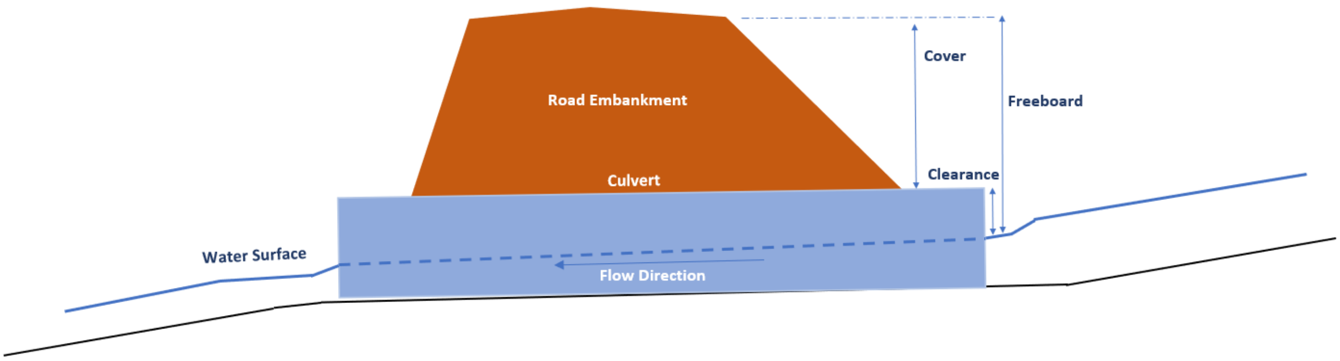


Figure 3: Definition of Clearance and Freeboard

Table 8: Hydraulic Model Results

ID	Return Event	Upstream Invert Elevation (m)	Road Elevation (m)	Water Surface Elevation at Inlet (m)	Channel velocity 10 m Down-stream	Velocity Through the Culvert (m/s)	Head Water to Diameter Ratio (Hw/D)	Clearance (m)	Freeboard (m)
1/1	3Q10	285.2	289.6	286.2	0.9	2.4	0.63	0.6	3.4
	100-yr	285.2	289.6	286.65	1.3	2.8	0.9	0.15	2.95
2/2	3Q10	248.95	250.5	250.0	1.4	3	0.9	0.1	0.6
	100-yr	248.95	250.5	250.5	1.8	3.5	1.4	-0.5	0
3/3	3Q10	272.4	273.95	272.4	0.85	2.75	0.8	0.4	1.6
	100-yr	272.4	273.95	273.0	1.1	3.3	1.2	-0.25	0.95
4/4	3Q10	132.4	134.7	132.4	1.85	3.75	0.7	0.4	2.3
	100-yr	132.4	134.7	133.0	2.35	4.55	1.1	-0.2	1.7
7/5	3Q10	140.95	147.85	143.5	0.25	1.45	0.4	3.2	4.4
	100-yr	140.95	147.85	144.9	0.65	3.1	0.7	1.8.	3
8/6	3Q10	151.2	163.25	153.95	1	1.7	0.5	2	10.3
	100-yr	151.2	163.25	156.0	1.8	4.4	1.3	-1	7.3
9/7	3Q10	158.6	169.5	159.85	0.4	0.5	0.3	2.4	9.7
	100-yr	158.6	169.5	160.3	0.55	1.05	0.5	2	9.3
14/8	3Q10	190.1	197.6	190.6	0.8	2.7	0.2	1.7	7.0
	100-yr	190.1	197.6	190.7	1	3.2	0.3	1.5	6.9
15/9	3Q10	285.2	171.5	166.75	0.3	0.7	0.3	1.55	4.75
	100-yr	285.2	171.5	166.85	0.4	1.05	0.33	1.5	4.65
16/10	3Q10	157.1	161.9	158.3	0.65	2.75	0.4	1.7	4.4
	100-yr	157.1	161.9	158.8	0.85	3.3	0.6	1.1	3.9
17/11	3Q10	457.65	466.61	458.4	0.4	1.9	0.5	0.8	8.3

ID	Return Event	Upstream Invert Elevation (m)	Road Elevation (m)	Water Surface Elevation at Inlet (m)	Channel velocity 10 m Down-stream	Velocity Through the Culvert (m/s)	Head Water to Diameter Ratio (Hw/D)	Clearance (m)	Freeboard (m)
	100-yr	457.65	466.61	458.5	0.5	2.25	0.6	0.6	8.1
18/na	3Q10	243.3	251.9	244.15	1.1	3.3	0.6	0.7	7.8
	100-yr	243.3	251.9	244.45	1.2	3.85	0.8	0.3	7.4
19/13	3Q10	316.25	318.7	317.6	0.65	2.3	0.9	0.2	1.2
	100-yr	316.25	318.7	318.3	0.1	0.75	1.4	-0.6	0.4
20/14	3Q10	277.95	286.95	279	0.9	1	0.6	0.7	8
	100-yr	277.95	286.95	279.55	1	1.95	0.9	0.05	7.4
21/15	3Q10	276.4	280.5	278.3	0.75	1.35	0.6	1.1	2.2
	100-yr	276.4	280.5	278.8	1.1	2.5	0.8	0.7	1.7
22/16	3Q10	345.5	349.85	346.3	1.3	2	0.5	0.7	3.6
	100-yr	345.5	349.85	346.8	1.85	2.5	0.8	0.2	3.1
23/17	3Q10	213.1	217.5	214.05	0.7	2.3	0.6	0.6	3.5
	100-yr	213.1	217.5	214.5	0.95	2.8	1	0.1	3.0
25/18	3Q10	209.3	215.4	210.35	1.6	1.65	0.3	2	5.1
	100-yr	209.3	215.4	211.05	1.95	3.4	0.6	1.2	4.3
26/19	3Q10	188.8	196.3	191.15	1.0	1.55	0.5	2.5	5.1
	100-yr	188.8	196.3	191.9	1.25	3.25	0.6	1.8	4.4
27/20	3Q10	196.4	200.05	197.1	1.4	1.8	0.4	0.8	3.0
	100-yr	196.4	200.05	197.4	1.85	2.25	0.6	0.5	2.7
29/21	3Q10	643.9	647.5	645.1	1.1	4.1	0.65	0.6	2.4
	100-yr	643.9	647.5	646.15	1.75	5.15	1.25	-0.45	1.35
30/22	3Q10	655.2	659.9	655.75	1.1	0.7	0.2	2.3	4.15
	100-yr	655.2	659.9	656.25	1.75	3.4	0.37	1.75	3.6
31/23	3Q10	654.4	660.3	655.2	2.1	4.95	0.2	3.3	4.9
	100-yr	654.4	660.3	656.0	2.9	5.7	0.4	2.55	4.17
32/24	3Q10	655.2	659.8	656.15	0.5	2.05	0.25	3.15	3.65
	100-yr	655.2	659.8	656.8	0.8	2.75	0.4	2.5	3
33/25	3Q10	339.85	350.15	340.65	1.25	1	0.45	1.05	9.5
	100-yr	339.85	350.15	342.15	2.0	3.2	1.25	-0.5	8
34/26	3Q10	7	15	N/A	N/A	N/A	N/A	N/A	5.5 – 6.5*
	100-yr	7	15	N/A	N/A	N/A	N/A	N/A	3.0 – 3.5*

ID	Return Event	Upstream Invert Elevation (m)	Road Elevation (m)	Water Surface Elevation at Inlet (m)	Channel velocity 10 m Down-stream	Velocity Through the Culvert (m/s)	Head Water to Diameter Ratio (Hw/D)	Clearance (m)	Freeboard (m)
35/27	3Q10	34.65	47.95	37.65	0.7	2.75	0.65	1.7	10.3
	100-yr	34.65	47.95	39.1	1.0	3.5	0.95	0.2	8.8
36/28	3Q10	61.9	66.85	63.5	0.5	2.6	0.4	2.2	3.35
	100-yr	61.9	66.85	64.5	1.05	3.5	0.67	1.25	2.35
37/29	3Q10	62.55	65.7	63.5	2.0	1.2	0.6	1	1.75
	100-yr	62.55	65.7	64.55	2.65	2.65	0.85	0.4	1.2
38/30	3Q10	40.9	44.5	42.05	1.15	3.5	0.75	0.35	0.45
	100-yr	40.9	44.5	43.2	1.7	4.6	1.5	-0.76	1.35
39/31	3Q10	8.55	13.3	10.35	1.1	2.6	0.46	2.15	2.95
	100-yr	8.55	13.3	12.35	1.9	4.85	0.96	0.16	0.95

NOTES:

* Culvert 34/26 is identified to be an equalizing culvert. The normal and flooding freeboard for this crossing is estimated to be within the range of 3 m to 6.5 m.

5.3 Two-Dimensional Modelling

Crossings with some level of complexity including sharp bends or skew in the flood path to or from the culvert(s) were also modeled using HEC-RAS 2D. The two-dimensional modelling considers velocity distribution in both x and y directions and provides a more accurate capacity assessment compared to the 1D modelling for complex systems.

Crossings 16/10, 30/22, and 37/29 were identified to levels of complexity that warranted a 2D analysis. Compared to the 1D model, the results of the 2D modelling were to have up to 20% difference in flood level at spot locations. The design recommendations for these crossings were updated accordingly.

Figure 4 to 6 show the simulated flood depth and inundation extents during the 1:100-year flood event for crossings 16/10, 30/22, and 37/29, respectively.

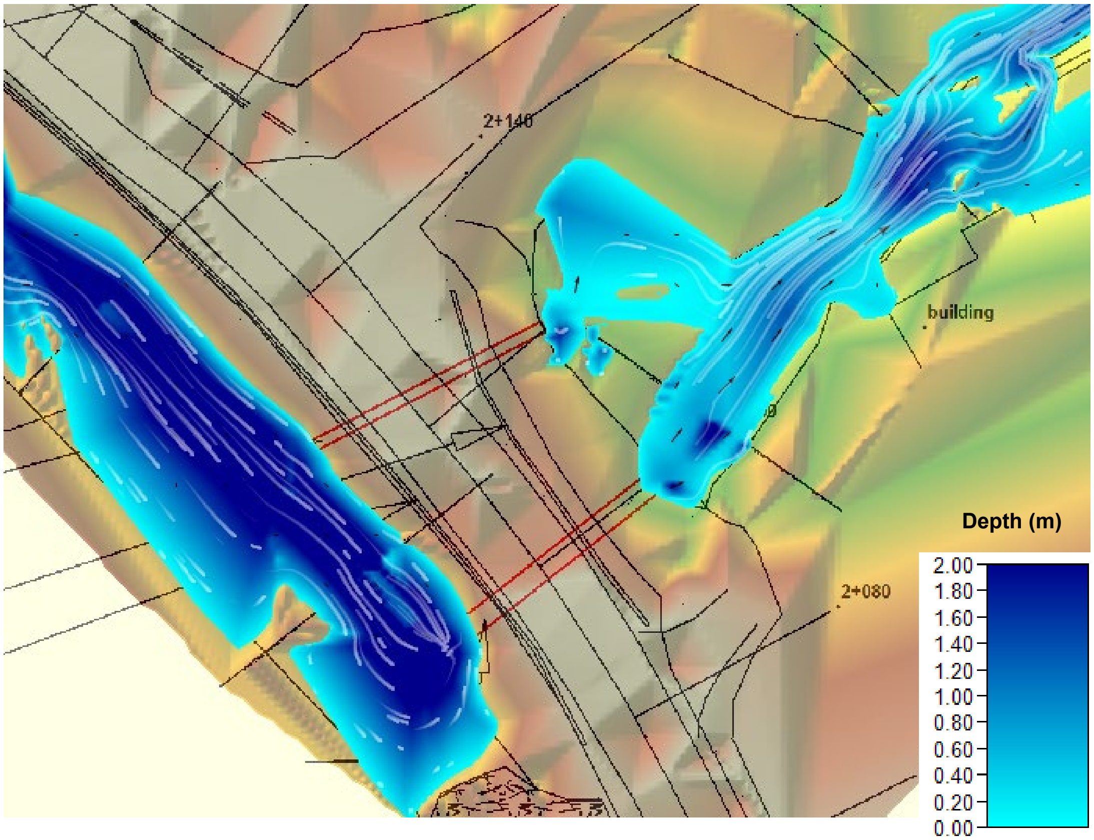


Figure 4: Crossing 16/10 100-year Flood Depth and Flow Lines

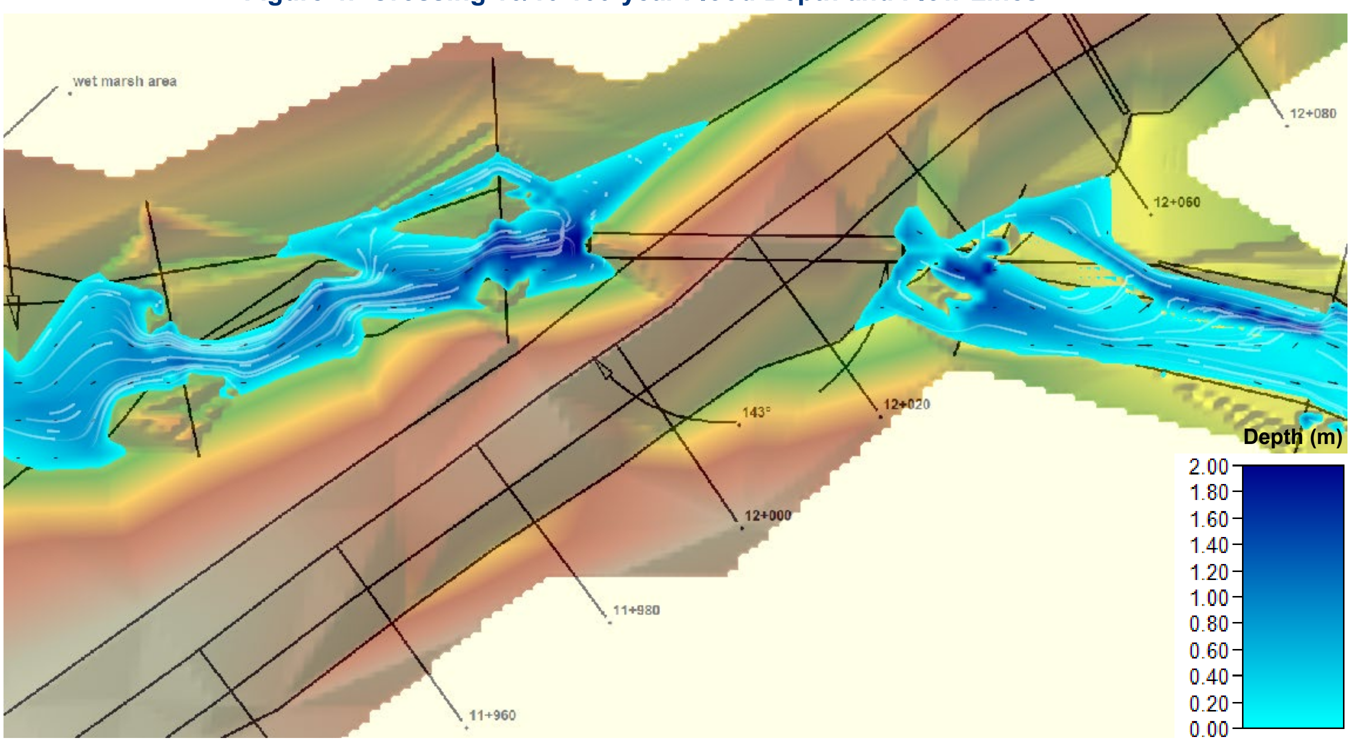


Figure 5: Crossing 30/22 100-year Flood Depth and Flow Lines

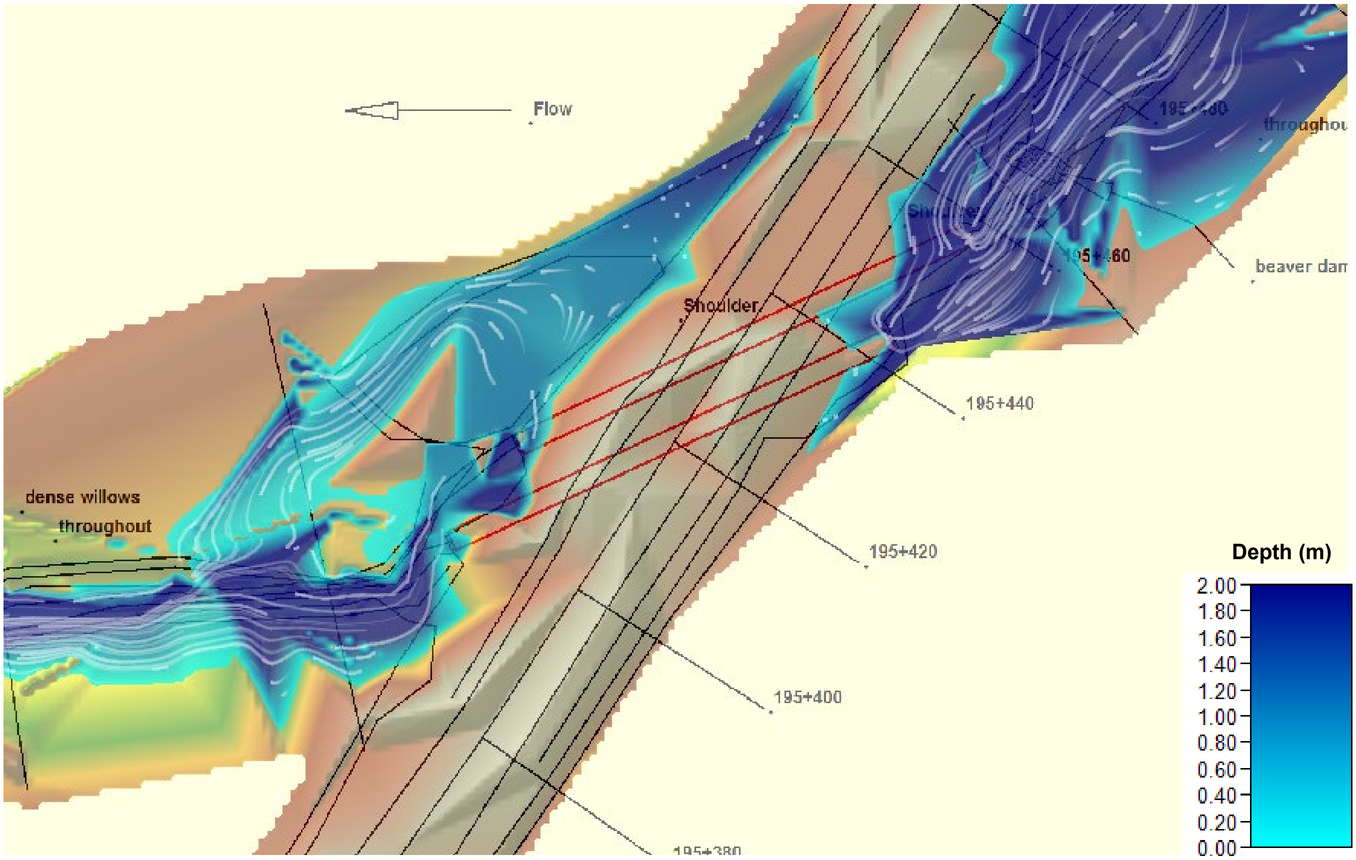


Figure 6: Crossing 37/29 100-year Flood Depth and Flow Lines

5.4 Sensitivity Analysis

To assess some of the uncertainties within the hydrologic and hydraulic results, sensitivity analyses were performed to review the separate impacts of uncertainty in Manning's n coefficients and design flows.

5.4.1 Manning's Roughness Coefficient Sensitivity Analysis

A series of hydraulic models with 20% increase in Manning's roughness coefficient were run to assess the sensitivity of flood levels to the channel friction coefficients. Results are summarized in Table 9.

Water level was highly insensitive to Manning's n for all crossings except for 7/5, 8/6, 19/13 and 31/23, where the difference in water level was in the order of 0.2 m.

Table 9: Sensitivity Results for Manning's n Channel and Floodplain Roughness

Crossing	100-year Water Surface Elevation					
	At the Inlet			At the Outlet		
	Base Scenario	Manning's n 20% Increased	Difference (m)	Base Scenario	Manning's n 20% Increased	Difference (m)
1/1	286.63	286.63	0	284.54	284.54	0
2/2	250.01	250.01	0	248.82	248.84	0.02
3/3	273.02	273.02	0	271.48	271.48	0
4/4	132.99	132.99	0	127.64	127.7	0.06
7/5	144.88	144.89	0.01	144.26	144.27	0.01
8/6	155.99	155.99	0	154.04	154.04	0
10/7	160.27	160.27	0	159.72	159.93	0.21
14/8	190.70	190.70	0	187.46	187.49	0.03
15/9	166.83	166.83	0	166.35	166.35	0
16/10	158.81	158.95	0.14	157.66	157.66	0
17/11	458.49	458.49	0	457.42	457.42	0
18/na	244.43	244.43	0	241.53	241.6	0.07
19/13	318.29	318.29	0	316.93	317.18	0.25
20/14	279.54	279.54	0	278.67	278.67	0
21/15	279.00	279.00	0	278.43	278.43	0
22/16	346.79	346.79	0	345.64	345.7	0.06
23/17	214.51	214.51	0	211.96	212.02	0.06
25/18	211.06	211.06	0	210.15	210.22	0.07
26/19	191.87	191.87	0	190.61	190.75	0.14
27/20	197.38	197.38	0	196.05	196.05	0
29/21	646.14	646.14	0	643.68	643.68	0
30/22	656.25	656.25	0	654.89	654.97	0.08
31/23	656.11	656.11	0	654.44	654.55	0.11
32/24	656.81	656.81	0	655.86	655.94	0.08
33/25	342.14	342.14	0	340.73	340.73	0
35/27	39.1	39.14	0.04	38.12	38.22	0.1
36/28	64.47	64.47	0	63.41	63.52	0.11
37/29	64.56	64.58	0.02	63.97	64.04	0.07
38/30	43.16	43.16	0	39.37	39.41	0.04
39/31	12.34	12.34	0	10.11	10.31	0.2

5.4.2 Hydrology Sensitivity Analysis

There is unavoidable uncertainty in the accuracy of estimated 100-year flows for the ungauged streams assessed in this study. For many of these, our approach was to apply a 3.5 multiplier to the estimated 2-year flow (Q2). The Q2 was based on our professional judgement assessment of methods that included HEC-RAS calibration to bankfull estimate, transposition of WSC gauge results based on an area adjustment exponent developed for British Columbia, culvert rust line (unknown recurrence) or rational method for very small basins.

We generally applied a 3.5 multiplier to the 2-year flows to develop a defensible estimate of the 100-year design flow. However, as shown in Table 5, there were several WSC gauges with much higher multipliers, up to nearly nine. Our review of the basins with high multipliers identified one basin with numerous small lakes and we hypothesized that the larger multiplier was the result of large portions of the watershed that were ineffective for frequent (i.e., Q2) events. In two other cases, the higher multipliers were the result of single extreme flow outlier events within the period of gauge record that did not fit the pattern from the other peak measurements and distorted the frequency curves.

For purposes of sensitivity analysis, simulations were made for design flows that are 25% higher than the original 100-year peak flow estimates. This same multiplier was used to develop design flows to represent a climate change scenario, considering comparable climate change multipliers presently used in British Columbia.

Model results are presented in Table 10.

The peak flow sensitivity analysis results show that impacts to water surface elevations are less on the downstream side of the culvert as compared to the upstream side. A 25% increase to the peak flows did not increase the water surface elevation beyond 0.5 m on the downstream for all the crossings.

On the upstream side of the culverts, a 25% increase to the peak flows did not increase the water surface elevation above 0.5 m except for crossings 8/6, 35/27, 38/30, and 39/31. The water surface increase for crossing 27,30 and 31 were on the order of 0.6 m to 0.7 m, whereas that for the crossing 6 was on the order of 1.4 m. The reason for such a large difference in water surface elevation could be because of the large flow through the system combined with the fact that the peak flow for the base case scenario was close to the culvert capacity.

Table 10: Sensitivity Results for 100-year Discharges

Crossing	100-year Water Surface Elevation					
	At the Inlet			At the Outlet		
	Base Scenario	25% increase 100 Year Peak Flow	Difference (m)	Base Scenario	25% increase 100 Year Peak Flow	Difference (m)
1/1	286.63	286.81	0.18	284.54	284.67	0.13
2/2	250.53	250.57	0.04	248.82	248.90	0.08
3/3	273.02	273.50	0.48	271.48	271.58	0.10
4/4	132.99	133.26	0.27	127.64	127.75	0.11
7/5	144.88	145.30	0.42	144.26	144.49	0.23
8/6	155.99	157.40	1.41	154.04	154.41	0.37
10/7	160.27	160.39	0.12	159.72	159.98	0.26
14/8	190.96	190.99	0.03	187.12	187.14	0.02
15/9	166.83	166.86	0.03	166.35	166.38	0.03

Crossing	100-year Water Surface Elevation					
	At the Inlet			At the Outlet		
	Base Scenario	25% increase 100 Year Peak Flow	Difference (m)	Base Scenario	25% increase 100 Year Peak Flow	Difference (m)
16/10	158.81	159.03	0.22	157.66	157.82	0.16
17/11	458.49	458.69	0.20	457.42	457.48	0.06
18/12	244.43	244.60	0.17	241.53	241.58	0.05
19/13	318.29	318.72	0.43	316.93	317.03	0.10
20/14	279.54	279.83	0.29	278.67	278.69	0.02
21/15	278.77	279.04	0.27	278.37	278.40	0.03
22/16	346.79	346.99	0.2	345.64	345.69	0.05
23/17	214.42	214.65	0.23	212.25	212.39	0.14
25/18	211.06	211.29	0.23	210.15	210.21	0.06
26/19	191.87	192.17	0.30	190.61	190.77	0.16
27/20	197.38	197.51	0.13	196.05	196.10	0.05
29/21	646.14	646.62	0.48	643.68	643.82	0.14
30/22	656.25	656.38	0.13	654.92	654.98	0.06
31/23	655.97	656.13	0.16	653.82	653.96	0.14
32/24	656.81	657.01	0.20	655.86	655.93	0.07
33/25	342.14	342.64	0.50	340.73	340.90	0.17
35/27	39.10	39.72	0.62	38.12	38.49	0.37
36/28	64.48	64.82	0.34	63.55	63.73	0.18
37/29	64.56	64.85	0.29	63.97	64.05	0.08
38/30	43.16	43.82	0.66	39.37	39.41	0.04
39/31	12.34	13.00	0.66	10.11	10.25	0.14

6.0 EXISTING PERFORMANCE AND PRELIMINARY RECOMMENDATIONS

The adequacy of the existing culverts to convey the 100-year peak flow was assessed based on modelled freeboard and clearance. The culverts were flagged for insufficient capacity if the freeboard (before road overtopping) was less than 1.0 m or if the culvert inlet was submerged by more than 0.5 m during passage of the 100-year flow. These thresholds are considered reasonable but are subject to reconsideration and do not consider possible mitigating conditions such as upstream ponding which would attenuate (and reduce) the peak flow. Culvert submergence is indicated by negative clearance values in Table 8.

The adequacy of potential fish passage performance was assessed based on comparison of culvert flow mean velocity and channel mean flow velocity for 3-day 10-year delay flows. This is provided for information purposes only. As discussed earlier, determination of actual fish presence, suitability of the 3Q10 methodology and the need for culvert designs to accommodate fish passage are beyond the scope of the present assignment.

Performance results summarized in Table 11 indicate that most of the existing culverts have adequate capacity to convey the 100-year flows. Possible fish passage concerns are flagged for most culverts.

Table 11 also presents preliminary culvert sizes to convey 100-year peak flows with a headwater depth equal to the culvert diameter (e.g., full flow at the inlet), based on published inlet control nomographs for circular corrugated culverts with projecting inlets. Sizes are presented for three scenarios: (1) existing hydrology with no embedment; (2) existing hydrology with 25% embedment for fish passage or other environmental enhancement; and (3) peak flows increased by 25%, representing possible climate change impacts, plus 25% embedment.

For Crossing 35/27 at Rengling River, the recommended culverts are based on a single culvert passing one fifth of total flow. A similar approach was used in other instances with multiple culverts.

Table 11 provides a summary comparing existing culvert geometries against required equivalent circular diameter. This is followed by Table 12 suggesting the required crossing type (bridges versus arches or circular) based on various parameters.

Table 11: Existing Culvert Performance and Preliminary Replacement Sizing for 100-year Flows

Mackenzie Highway (No. 1) Culverts								
ID	Existing Culvert Geometry (m) Diameter or Span x Height	Performance with Existing Geometry		Upgrades Required in Terms of		Nomograph Based Recommended Minimum Diameter (m)		
		Freeboard 100-Year (m)	Clearance 100-year (m)	Capacity	Fish Friendly	No Embedment	With 25% Embedment	With 25% Embedment + 25% increase in Design Inflow
Mackenzie Highway (No. 1) Culverts								
1/1	1.6 + 1.0*	2.95	0.15	-	x	1.4 + 1.0	2.0 + 1.0	2.2 + 1.0
2/2	1.1 x 1.85	0	-0.5	x	x	1.0	1.4	1.6
3/3	1.5	1.5	-0.3	-	x	1.8	2.0	2.2
4/4	1.5	1.7	-0.2	-	x	1.6	2.0	2.2

Mackenzie Highway (No. 1) Culverts								
ID	Existing Culvert Geometry (m)	Performance with Existing Geometry		Upgrades Required in Terms of		Nomograph Based Recommended Minimum Diameter (m)		
	Diameter or Span x Height	Freeboard 100-Year (m)	Clearance 100-year (m)	Capacity	Fish Friendly	No Embedment	With 25% Embedment	With 25% Embedment + 25% increase in Design Inflow
7/5	5.73	3.0	1.8	-	x	4.3	5.2	5.85
8/6	3.8 (2)	7.3	-1	x	x	4.0 (2)	4.6 (2)	5.3 (2)
10/7	3.1 x 3.7	9.3	2	-	-	2.2	2.7	3.0
14/8	2.3 x 2.6	6.9	1.5	-	x	0.9	1.2	1.35
15/9	2.3	4.65	1.5	-	x	2.2	2.7	3.0
Ingraham Trail (No. 4) Culverts								
16/10	3.05	3.1	1.3	-	x	2.2	2.7	3.0
Liard Highway (No. 7) Culverts								
17/11	1.55	8.1	0.6	-	x	1.2	1.4	1.6
18/na	1.3 x 1.7	7.4	0.3	-	x	1.4	1.6	1.8
19/13	1.5 x 1.65	0.4	-0.6	x	x	1.8	2.0	2.2
20/14	1.4 x 1.7	7.4	0.05	-	x	1.6	1.8	2.0
21/15	3.0	1.7	0.7	-	x	2.7	3.3	3.6
22/16	1.45 x 1.65	3.1	0.2	-	x	1.4	1.6	1.8
23/17	1.55	3.0	0.1	-	x	1.6	1.8	2.0
25/18	3.0	4.3	1.2	-	x	2.2	2.7	3.0
26/19	4.8	4.4	1.8	-	x	3.0	3.6	4.0
27/20	1.6	2.7	0.5	-	x	1.2	1.4	1.6
Dempster Highway (No. 8) Culverts								
29/21	1.8	1.35	-0.45	x	x	2.2	2.7	3.0
30/22	2.8	3.6	1.75	-	-	1.4	1.6	1.8
31/23	4.26 (2)	4.17	2.55	-	x	2.7 (2)	3.3 (2)	4.0 (2)
32/24	3.8 x 4.1	3	2.5	-	x	2.2	2.7	3.0
33/25	1.83	8	-0.5	x	-	1.6	2.0	2.2
34/26**	3.95	3	0	-	x	4.0	5.0	5.0
35/27	4.7 (5)	8.8	0.2	-	x	4.6 (5)	5.3 (5)	5.6 (5)
36/28	3.8	2.35	1.25	-	x	3.0	3.6	4.0
37/29	2.4 (2)	1.2	0.4	-	-	2.4 (2)	3.0 (2)	3.3 (2)
38/30	1.5	1.35	-0.76	x	x	2.0	2.4	2.7
39/31	4.0 + 1.7	0.95	0.16	-	x	4.6	5.6	6.2

NOTES for Nomograph Derived Preliminary Recommendations:

- Circular culvert(s) with projecting inlet

- Inlet headwater to diameter ratio of 1.0 (HW/D =1) for design flow.
- A quarter depth embedment for fish passage or environmental enhancement; approximated using nomograph HW/D target of 0.75
- * A secondary smaller culvert
- ** Equalizing Culvert

Considering the available cover, culvert dimension, embedment depth and crossing geometry, preliminary recommendations were made for crossings which should be upgraded to a bridge or arch/box culvert as shown in Table 12. The following assumptions were made:

- All crossings are fish bearing and require 25% embedment.
- Climate change scenario assumed with 100-year design flows increased by 25%.
- Circular culverts require a minimum cover of 1.0 m from road surface to culvert crown.
- Potential permafrost conditions may occur at 0.75 m depth which will be encountered with 25% embedment of a 3.0 m diameter circular culvert assumed to be the threshold for requiring an alternative design.
- Alternate designs may include (1) multiple circular culverts not exceeding 3.0 m diameter, (2) box or arch culverts, and (3) bridges. Our recommendations are for single opening alternatives only, which we prefer for hydraulic efficiency and greater capacity for debris passage.
- Bridges are recommended for crossings requiring cumulative open spans of 6.0 m or greater.
- The preliminary recommendations of crossing type should be reviewed further during the detailed design phase.

Table 12: Preliminary Recommended Crossing Type

ID	Preliminary Culvert Diameter, m (if circular)	Available Cover, m (if circular)	Preliminary Recommended Crossing Type		
			Bridge	Arch or Box Culvert	Circular Culvert
Mackenzie Highway (No. 1) Culverts					
1/1	2.2 + 1.0	2.85			x
2/2	1.6	0.95		x	
3/3	2.2	1.0			x
4/4	2.2	1.85			x
7/5	5.9	2.5		x	
8/6	5.3 (2)	8.0	x		
10/7	3.0	8.85			x
14/8	1.35	6.6			x
15/9	3.0	3.15			x
Ingraham Trail (No. 4) Culverts					
16/10	3.0	1.9			x
Liard Highway (No. 7) Culverts					
17/11	1.6	7.4			x

ID	Preliminary Culvert Diameter, m (if circular)	Available Cover, m (if circular)	Preliminary Recommended Crossing Type		
			Bridge	Arch or Box Culvert	Circular Culvert
18/12	1.8	7			x
19/13	2.2	1			x
20/14	2.0	7.4			x
21/15	3.6	1		x	
22/16	1.8	2.85			x
23/17	2.0	2.95			x
25/18	3.0	3.1			x
26/19	4.0	2.6		x	
27/20	1.6	2.2			x
Dempster Highway (No. 8) Culverts					
29/21	3.0	1.85			x
30/22	1.8	1.95			x
31/23	4.0 (2)	1.65	x		
32/24	3.0	0.55			x
33/25	2.2	8.7			x
34/26	5.0	3.1		x	
35/27	5.6 (5)	8.7	x		
36/28	4.0	1.15		x	
37/29	3.3 (2)	0.75	x		
38/30	2.7	2.2			x
39/31	6.2	0.8	x		

Additional considerations need to be addressed to refine the preliminary sizing recommendations above. These considerations should include but are not limited to consultation with maintenance personnel to identify past design approaches which may have provided best results. Fish presence, geotechnical consideration (permafrost, bedrock depth) will also influence the designs. The combination of these and other site-specific factors such as height of road embankment and installation complexity may influence the selection of culvert shape (circular, oval, open bottom) material type (metal, concrete) and end treatments.

Our objective with the current analysis is to have provided sufficient hydrotechnical inputs to guide the future design and decision process.

CLOSURE

We trust this report meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech Canada Inc.

Prepared by:
Davood Hasanloo, MSc, MASc, P.Eng. (B.C.)
Project Manager - Senior Hydrotechnical Engineer
Water and Marine Engineering
Direct Line: 778.945.5811
Davood.Hasanloo@tetratech.com

Prepared by:
Mark Aylward Nally, B.A.Sc., E.I.T. (B.C.)
Hydrotechnical Engineer in Training
Water and Marine Engineering
Direct Line: 778.945.5894
Mark.AylwardNally@tetratech.com

Prepared by:
Josh Weidner, M.Eng., E.I.T. (B.C.)
Hydrotechnical Engineer in Training
Water and Marine Engineering
Direct Line: 604.945.5905
Josh.Weidner@tetratech.com

REGISTERED PROFESSIONAL ENGINEER
W. A. ROZEBOOM
LICENSEE
NT/NU

April 11, 2019

Reviewed by:
Bill Rozeboom, MBA, P.Eng.
Principal Specialist, Water Resources
Water and Marine Engineering
Direct Line: 587.460.3611
Bill.Rozeboom@tetratech.com

Reviewed by:
David Moschini, B.A.Sc., P.Eng (B.C.)
Senior Hydrotechnical Engineer
Water & Marine Engineering
Direct Line: 778.945.5798
David.Moschini@tetratech.com

PERMIT TO PRACTICE
TETRA TECH CANADA INC.

Signature ____________________

Date APRIL 11, 2019

PERMIT NUMBER: P 018
NT/NU Association of Professional Engineers and Geoscientists

/tv

REFERENCES

Canadian Institute of Steel Construction, 2016. CAN/CSA S6-14 Canadian Highway Bridge Design Code (CHBDC).

Transportation Association of Canada, 2017. Geometric Design Guide for Canadian Roads.

Coulson and Obedkoff, 1998. Province of British Columbia Ministry of Environment, Land and Parks. Stream Flow Inventory.

Transportation Association of Canada, 2001. Guide to Bridge Hydraulics.

U.S. Army Corps of Engineers Hydrologic Engineering Center, 2016. HEC-RAS River Analysis System User Manual.

U.S. Department of Transportation Federal Highway Administration, 2012.

APPENDIX A

CROSSING SITE PHOTOS

1.1.25 *KM 40.2 Dempster Hwy No. 8 (Crossing 33/25)*

Photo 99: Crossing 33/25 distorted outlet.

Photo 100: Crossing 33/25 auxiliary raised culvert.

Photo 101: Crossing 33/25 looking downstream at condition of channel and bank vegetation.

Photo 102: Crossing 33/25 looking upstream at condition of channel and bank vegetation.

APPENDIX B

SURVEYOR SITE PLANS WITH PLAN VIEWS

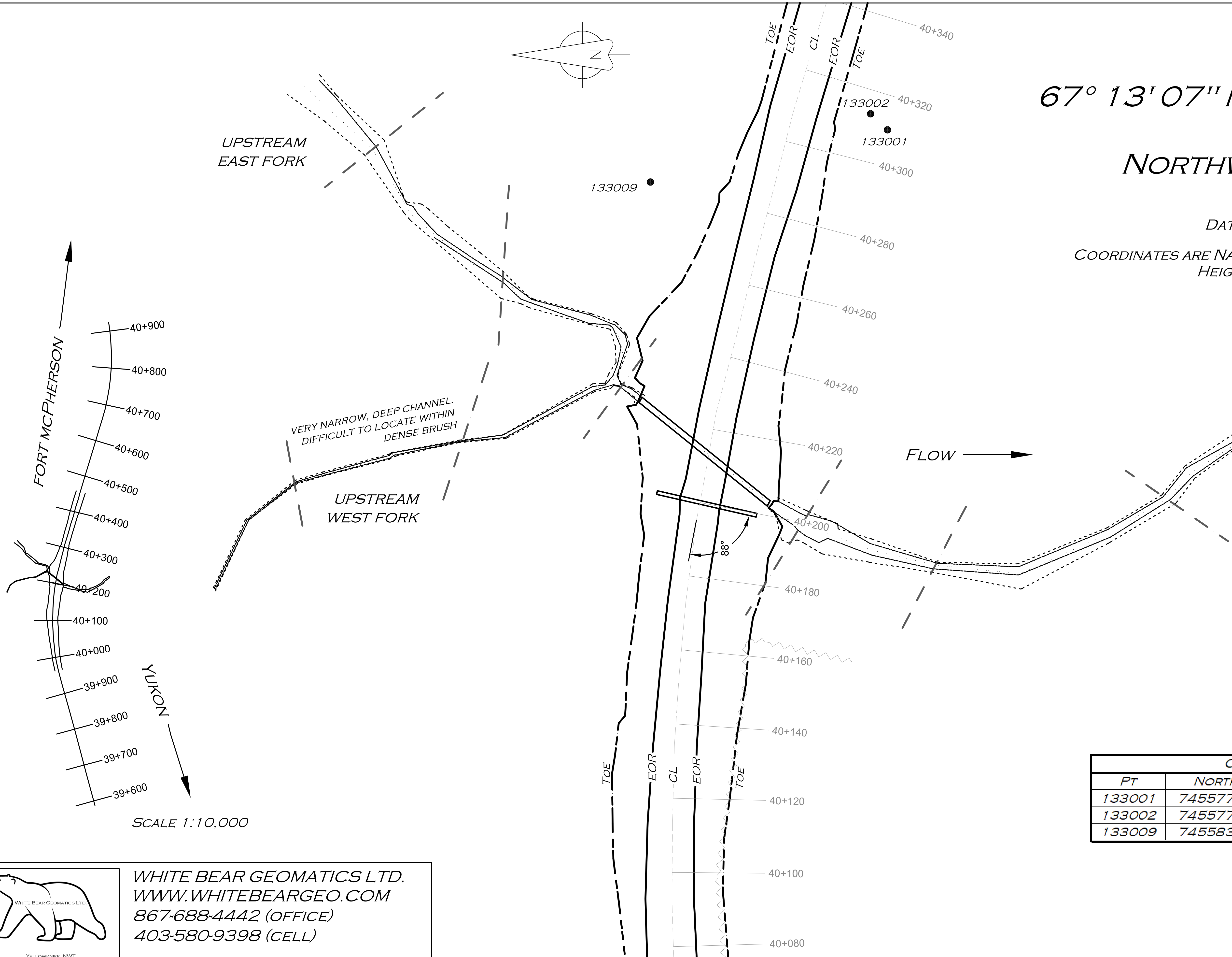
Survey of Crossing No. 33
67° 13' 07" N, 135°30'15" W
KM 40.2, HWY 8
Northwest Territories

Data Collected on August 21 2018

Coordinates are NAD83 CSRS (2010.0), UTM zone 8
Heights are Orthometric - CGG 2013

Local scale factor: 0.999551
Units are Metres

Notes:



Control Monument ●
Feature
CL Creek
CL Road
Edge of Road
Edge of Water
Top of Bank
Toe
Culvert
Treeline
Cross-Section Line
Shoulder

Culvert Diameter: 2m height upstream. 1.8m height downstream
Culvert Length: 44.3
Culvert Angle to Road: 88°
Typ. Road Width: 10.5
Typ. Shoulder Width: N/A

Control Stations			
Pt	Northing	Easting	Elevation
133001	7455773.407	478295.498	350.889
133002	7455777.970	478299.808	351.386
133009	7455837.265	478281.428	346.667

White Bear Geomatics Ltd.
Yellowknife, NWT
WHITE BEAR GEOMATICS LTD.
WWW.WHITEBEARGEO.COM
867-688-4442 (office)
403-580-9398 (cell)

Scale: 1:1,000

Rev: 0
File: 18-216 33.dwg
Date: October 25 2018

SURVEYOR CROSS SECTION ESTIMATES CROSSING 1/1						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	47.56	32.70	54.04	22.84	17.81	14.17
BANKFILL WIDTH	43.31	21.55	12.89	3.46	8.55	4.03
WATER SURFACE	39.47	19.84	2.77	2.72	3.80	2.42
BANKFILL DEPTH	2.33	2.67	1.53	0.93	1.56	1.16
FLOOD PRONE DEPTH	3.02	3.41	2.65	3.98	3.29	3.46
SURVEYOR CROSS SECTION ESTIMATES CROSSING 2/2						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	7.92	14.75	6.10	6.83	9.48	10.22
BANKFILL WIDTH	2.59	2.16	2.14	2.17	2.25	6.16
WATER SURFACE	1.94	1.76	1.29	1.84	1.04	1.34
BANKFILL DEPTH	0.31	0.34	0.22	0.23	0.46	0.63
FLOOD PRONE DEPTH	0.64	0.67	0.66	1.16	1.77	2.18
SURVEYOR CROSS SECTION ESTIMATES CROSSING 3/3						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	20.36	8.43	12.37	14.09	15.98	21.54
BANKFILL WIDTH	8.89	4.05	4.60	8.75	7.19	2.95
WATER SURFACE	1.32	1.25	1.12	0.78	1.19	1.10
BANKFILL DEPTH	0.72	0.93	0.44	0.48	1.41	2.84
FLOOD PRONE DEPTH	0.98	1.19	1.00	2.05	2.60	5.09
SURVEYOR CROSS SECTION ESTIMATES CROSSING 4/4						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	24.28	24.72	34.40	6.62	8.01	-
BANKFILL WIDTH	21.78	20.73	14.31	2.94	4.40	-
WATER SURFACE	16.36	2.95	2.32	1.04	1.73	-
BANKFILL DEPTH	0.65	0.82	0.58	1.07	0.76	-
FLOOD PRONE DEPTH	1.63	0.46	1.42	2.31	7.23	-

SURVEYOR CROSS SECTION ESTIMATES CROSSING 7/5						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	-	11.52	19.62	23.32	12.10	8.39
BANKFILL WIDTH	-	8.16	15.56	18.99	8.31	5.77
WATER SURFACE	-	5.68	11.28	17.50	5.66	5.20
BANKFILL DEPTH	-	1.31	1.59	3.45	1.07	0.73
FLOOD PRONE DEPTH	-	1.80	1.97	3.82	1.57	1.59
SURVEYOR CROSS SECTION ESTIMATES CROSSING 8/6						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	13.91	13.07	15.66	26.78	16.37	-
SANISFIL WIDTH	10.53	10.15	12.03	20.18	10.15	-
WATER SURFACE	6.65	0.97	3.01	5.77	5.16	-
BANKFILL DEPTH	I. 17	1.01	1.31	0.99	0.98	-
FLOOD PRONE DEPTH	1.71	2.18	1.98	1.72	1.63	-
SURVEYOR CROSS SECTION ESTIMATES CROSSING 10/7						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	-	-		-	-	-
BANKFILL WIDTH	-	-	9.25	-	-	-
WATER SURFACE	-	-	2.57	-	-	-
BANKFILL DEPTH	-	-	0.63	-	-	-
FLOOD PRONE DEPTH	-	-	2.05	-	-	-
SURVEYOR CROSS SECTION ESTIMATES CROSSING 14/8						
DESCRIPTION	UP 100	UP 50	Up 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	17.27	14.07	14.00	9.53	7.44	7.65
BANKFILL WIDTH	3.01	3.30	6.68	7.02	5.23	2.99
WATER SURFACE	0.50	1.11	0.57	0.63	1.27	2.1 1
BANKFILL DEPTH	0.91	1.14	0.75	0.97	0.75	0.89
FLOOD PRONE DEPTH	1.92	1.85	1.18	1.67	1.52	1.78

SURVEYOR CROSS SECTION ESTIMATES CROSSING 15/9						
DESCRIPTION	Up 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	26.88	29.39	29.98	17.65	-	-
BANKFILL WIDTH	1 5.89	6.05	14.67	11.35	-	-
WATER SURFACE	0.90	0.79	0.25	0.20	-	-
BANKFILL DEPTH	0.56	0.34	0.93	0.90	-	-
FLOOD PRONE DEPTH	1.86	1.06	2.36	1.42	-	-
SURVEYOR CROSS SECTION ESTIMATES CROSSING 16/10						
DESCRIPTION	UP 100	UP 50	UP 1 0	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	4.76	9.34	9.82	13.01	8.35	12.26
BANKFILL WIDTH	3.96	3.88	4.60	10.04	5.39	8.52
WATER SURFACE	2.41	2.33	1.93	6.16	3.18	4.79
BANKFILL DEPTH	0.84	0.78	0.65	0.62	0.55	0.83
FLOOD PRONE DEPTH	1.62	2.16	2.34	1.18	1.11	1.22
SURVEYOR CROSS SECTION ESTIMATES CROSSING 17/11						
DESCRIPTION	UP 100	UP 50	UP 1 0	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	-	-	25.02	11.33	-	-
BANKFILL WIDTH	-	-	7.80	1.49	-	-
WATER SUR-FACE	-	-	N/A	N/A	-	-
BANKFILL DEPTH	-	-	0.21	0.12	-	-
FLOOD PRONE DEPTH	-	-	0.58	0.17	-	-
SURVEYOR CROSS SECTION ESTIMATES CROSSING 18/NA						
DESCRIPTION	UP 100	UP 50	UP 1 0	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	-	-	9.43	9.24	-	-
BANKFILL WIDTH	-	-	3.94	3.99	-	-
WATER SUR-FACE	-	-	0.67	0.72	-	-
BANKFILL DEPTH	-	-	0.82	0.64	-	-

FLOOD PRONE DEPTH	-	-	1.34	1.06	-	-
SURVEYOR CROSS SECTION ESTIMATES CROSSING 19/13						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	26.92	27.74	28.07	32.65	19.49	30.18
BANKFILL WIDTH	12.90	5.76	4.85	5.22	3.78	14.56
WATER SURFACE	2.57	1.94	2.13	2.30	2.33	120
BANKFILL DEPTH	0.74	0.74	0.51	0.65	0.74	0.90
FLOOD PRONE DEPTH	1.41	0.94	1.18	1.28	1.16	1.13
SURVEYOR CROSS SECTION ESTIMATES CROSSING 20/14						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	28.46	28.96	12.92	36.33	-	-
BANKFILL WIDTH	5.08	19.95	8.13	2.54	-	-
WATER SURFACE	1 .16	0.50	1.87	1.26	-	-
BANKFILL DEPTH	0.71	0.63	0.67	0.59	-	-
FLOOD PRONE DEPTH	1.30	0.97	1.52	1.50	-	-
SURVEYOR CROSS SECTION ESTIMATES CROSSING 21/15						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	9.84	6.59	9.93	36.33	27.96	N/A
BANKFILL WIDTH	3.47	3.38	5.19	2.54	8.24	14.49
WATER SURFACE	2.65	2.19	3.95	1.26	4.31	5.04
BANKFILL DEPTH	1.08	0.81	0.99	0.61	1.28	1.73
FLOOD PRONE DEPTH	1.47	1.17	1.27	1.50	1.49	N/A
SURVEYOR CROSS SECTION ESTIMATES CROSSING 22/16						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	-	9.20	32.60	17.55	-	-
BANKFILL WIDTH	-	2.60	5.60	3.96	-	-
WATER SURFACE	-	1.05	0.88	0.87	-	-

BANKFILL DEPTH	-	0.68	0.90	0.67	-	-
FLOOD PRONE DEPTH	-	0.91	1.90	1.27	-	-
SURVEYOR CROSS SECTION ESTIMATES CROSSING 23/17						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	-	-	28.88	8.48	-	-
BANKFILL WIDTH	-	-	18.81	4.66	-	-
WATER SUR-FACE	-	-	0.50	1.00	-	-
BANKFILL DEPTH	-	-	1.00	0.55	-	-
FLOOD PRONE DEPTH	-	-	1.69	0.88	-	-
SURVEYOR CROSS SECTION ESTIMATES CROSSING 25/18						
DESCRIPTION	UP 100	UP 50	Up 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	19.01	8.24	17.22	11.34	10.07	19.11
BANKFILL WIDTH	4.89	4.61	14.08	4.17	3.31	3.52
WATER SURFACE	2.60	2.90	1.38	2.20	1.74	2.25
BANKFILL DEPTH	0.86	0.74	1.13	0.76	0.76	0.56
FLOOD PRONE DEPTH	1.16	1.10	1.49	1.08	1.23	1.16
SURVEYOR CROSS SECTION ESTIMATES CROSSING 26/19						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	14.99	10.53	16.00	14.05	38.25	15.29
BANKFILL WIDTH	5.63	7.05	12.94	10.86	6.61	10.03
WATER SURFACE	4.84	5.12	5.39	9.35	5.56	2.94
BANKFILL DEPTH	1.59	1.54	1.34	0.86	1.14	1.24
FLOOD PRONE DEPTH	1.95	1.99	1.85	1.43	1.84	1.75
SURVEYOR CROSS SECTION ESTIMATES CROSSING 27/20						
No Data Available						

SURVEYOR CROSS SECTION ESTIMATES CROSSING 29/21						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	Down 100
FLOOD PRONE WIDTH	11.66	15.96	22.32	15.37	14.82	13.70
BANKFILL WIDTH	1.85	9.05	8.74	11.12	5.37	4.95
WATER SURFACE	1.19	2.51	3.66	5.92	1.69	3.05
BANKFILL DEPTH	0.22	0.70	0.37	0.42	0.56	0.65
FLOOD PRONE DEPTH	0.69	1.44	1.18	1.06	1.18	1.39
SURVEYOR CROSS SECTION ESTIMATES CROSSING 30/22						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	26.93	20.95	17.02	9.55	15.13	14.04
BANKFILL WIDTH	12.32	12.82	9.34	3.23	10.01	10.27
WATER SURFACE	10.23	0.96	1.13	2.02	8.75	8.94
BANKFILL DEPTH	0.62	1.00	1.09	0.46	0.42	0.72
FLOOD PRONE DEPTH	2.60	1.99	2.05	0.79	1.15	1.24
SURVEYOR CROSS SECTION ESTIMATES CROSSING 31/23						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	26.93	20.95	17.02	9.55	15.13	14.04
BANKFILL WIDTH	12.32	12.82	9.34	3.23	10.01	10.27
WATER SURFACE	10.23	0.96	1.13	2.02	8.75	8.94
BANKFILL DEPTH	0.62	1.00	1.09	0.46	0.42	0.72
FLOOD PRONE DEPTH	2.60	1.99	2.05	0.79	1.15	1.24
SURVEYOR CROSS SECTION ESTIMATES CROSSING 32/24						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	7.66	10.15	10.31	10.23	9.64	7.70
BANKFILL WIDTH	5.50	4.66	6.97	7.78	4.94	4.49
WATER SURFACE	4.93	3.53	6.51	6.34	3.63	2.47
BANKFILL DEPTH	0.35	0.62	0.29	0.84	0.51	0.59
FLOOD PRONE DEPTH	0.85	0.88	0.75	1.35	1.01	1.15

SURVEYOR CROSS SECTION ESTIMATES CROSSING 33/25								
DESCRIPTION	UP 100 WEST	UP 50 WEST	UP 100 EAST	UP 50 EAST	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	3.04	15.5	17.95	21.24	9.88	19.39	14.86	11.49
BANKFILL VV1DTH	0.94	0.95	4.90	9.02	1.24	10.17	4.75	4.16
WATER SURFACE	0.35	0.57	2.27	1.47	0.64	4.43	1.94	1.96
BANKFILL DEPTH	0.61	0.43	0.48	1.08	0.87	0.81	0.75	0.75
FLOOD PRONE DEPTH	0.7	0.82	1.33	1.77	1.82	2.42	2.13	1.67

SURVEYOR CROSS SECTION ESTIMATES CROSSING 34/26						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	-	-	31.60	26.99	29.06	-
BANKFILL WIDTH	-	-	19.72	18.60	25.18	-
WATER SURFACE	-	-	17.84	13.98	22.00	-
BANKFILL DEPTH	-	-	3.30	3.83	2.95	-
FLOOD PRONE DEPTH	-	-	4.05	6.78	4.51	-

SURVEYOR CROSS SECTION ESTIMATES CROSSING 35/27						
DESCRIPTION	UP 100	UP 50	UPP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	43.64	23.31	25.04	70.35	34.60	26.32
BANKFILL WIDTH	27.30	20.34	19.79	67.47	21.60	20.23
WATER SURFACE	14.73	17.46	14.99	38.24	19.29	15.84
BANKFILL DEPTH	3.45	1.37	2.18	2.77	1.30	1.73
FLOOD PRONE DEPTH	3.80	1.57	2.82	3.28	2.15	2.47

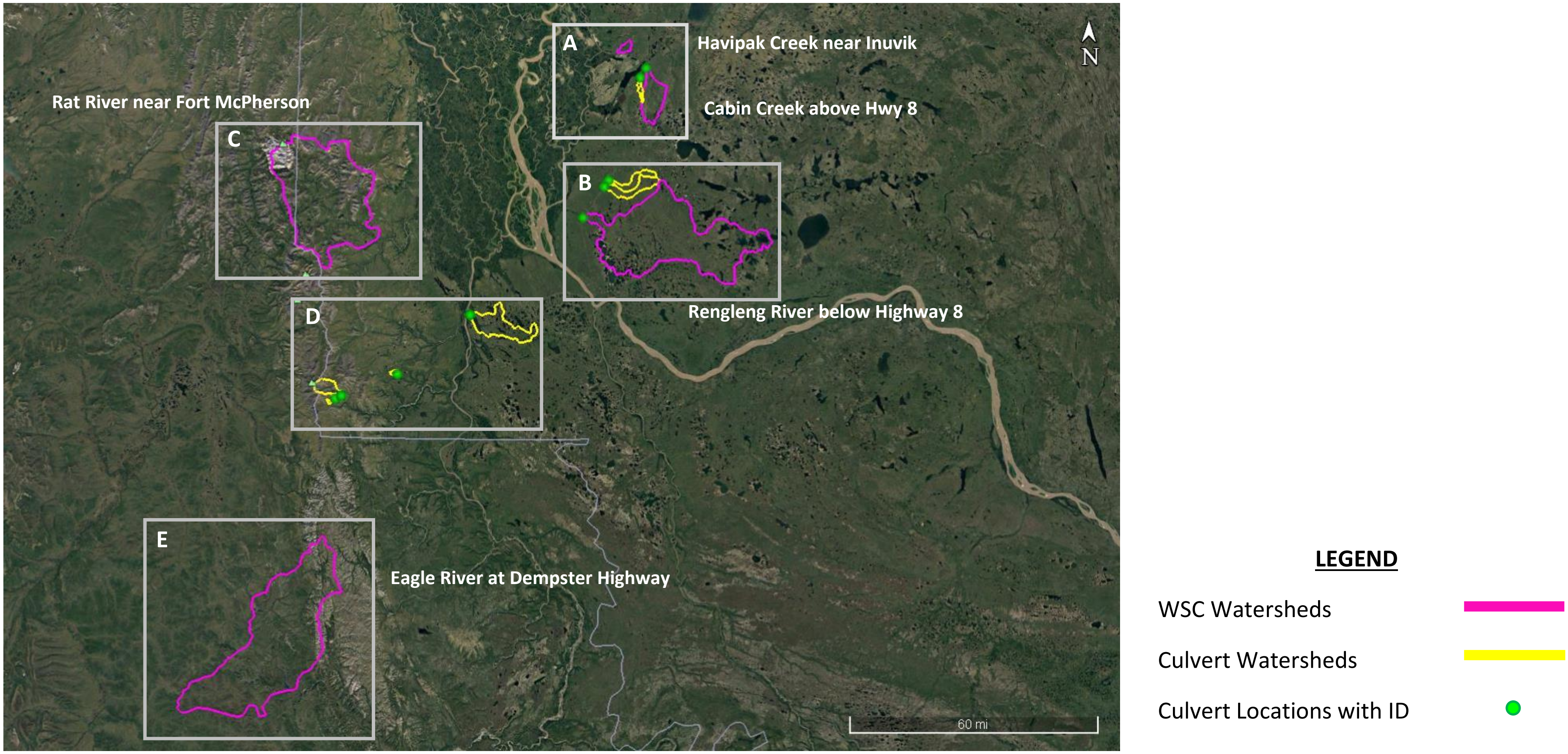
SURVEYOR CROSS SECTION ESTIMATES CROSSING 36/28						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	13.87	11.06	7.20	17.34	11.86	12.67
BANKFILL WIDTH	6.67	4.68	2.26	13.71	6.66	6.09
WATER SURFACE	5.49	3.45	1.15	11.10	4.42	3.04
BANKFILL DEPTH	0.98	0.64	0.73	3.04	1.37	0.99
FLOOD PRONE DEPTH	1.48	1.34	1.07	3.39	2.38	1.51

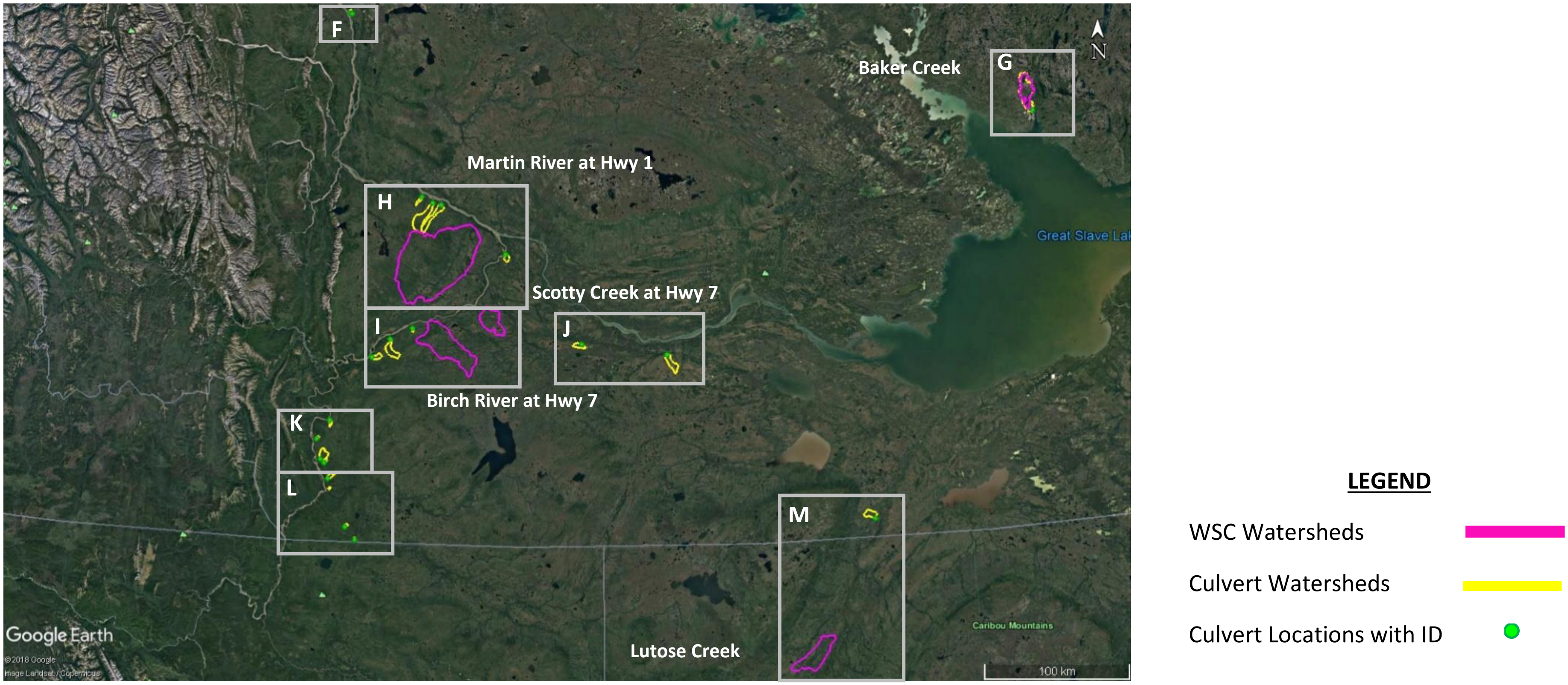
SURVEYOR CROSS SECTION ESTIMATES CROSSING 37/29						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	-	21.66	17.76	25.72	20.83	-
BANKFILL WIDTH	-	11.40	4.12	2.83	14.83	-
WATER SURFACE	-	10.40	2.57	2.26	7.05	-
BANKFILL DEPTH	-	1.04	0.89	0.50	1.17	-
FLOOD PRONE DEPTH	-	2.23	2.00	0.98	1.63	-
SURVEYOR CROSS SECTION ESTIMATES CROSSING 38/30						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH	-	-	36.99	14.83	-	-
BANKFILL WIDTH	-	-	1.74	5.91	-	-
WATER SURFACE	-	-	1.49	5.47	-	-
BANKFILL DEPTH	-	-	0.79	0.54	-	-
FLOOD PRONE DEPTH	-	-	1.26	0.79	-	-
SURVEYOR CROSS SECTION ESTIMATES CROSSING 39/31						
DESCRIPTION	UP 100	UP 50	UP 10	DOWN 10	DOWN 50	DOWN 100
FLOOD PRONE WIDTH			20.3	25.3	18.0	-
BANKFILL WIDTH	-	-	12.9	15.7	10.5	-
WATER SURFACE	-	-	9.3	10.7	10.1	-
BANKFILL DEPTH	-	-	0.8	1.7	0.7	-
FLOOD PRONE DEPTH	-	-	1.7	3.0	1.4	-

NOTE:
* Water Surface refers to the water level at the time of survey

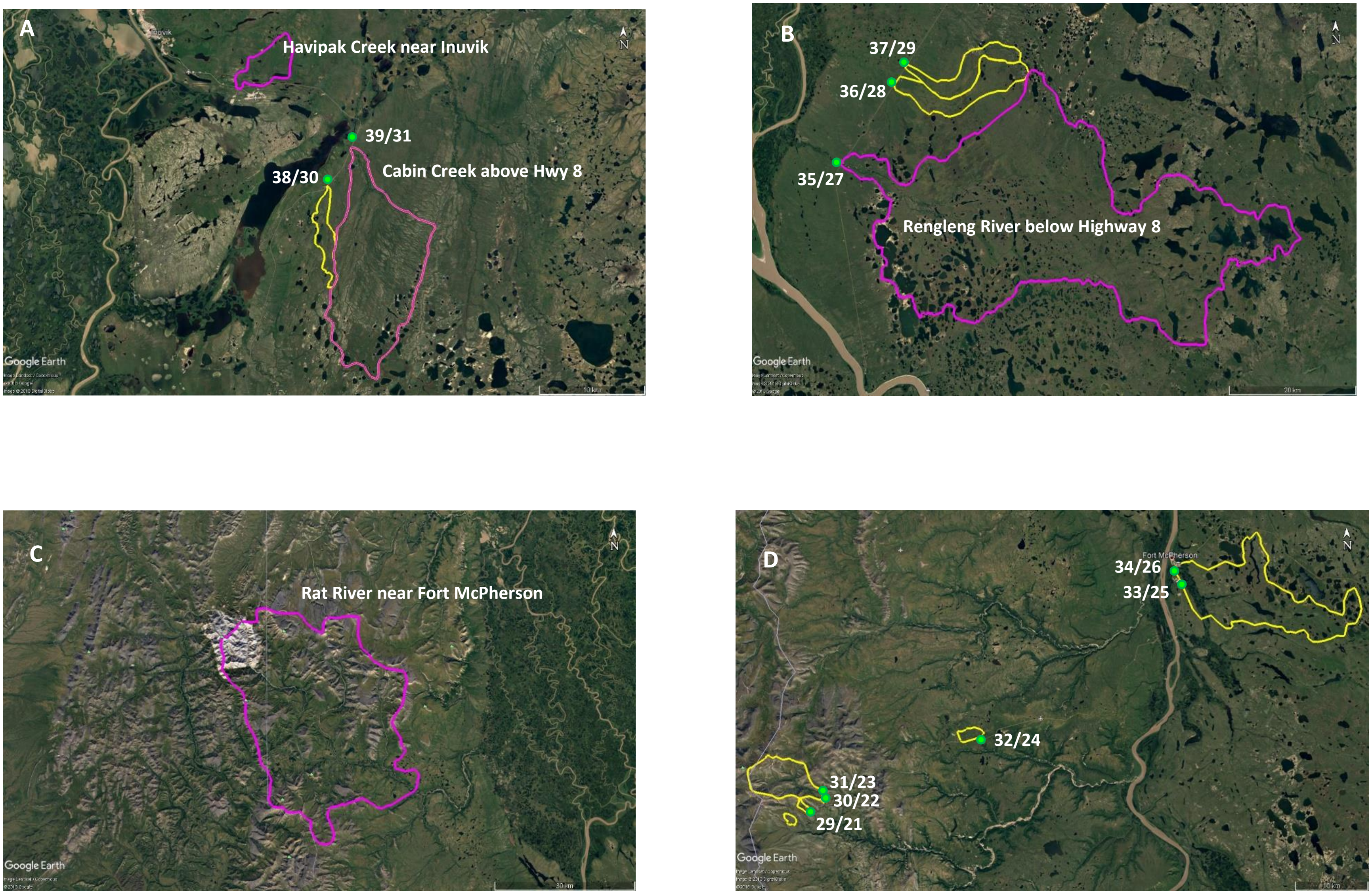
APPENDIX D

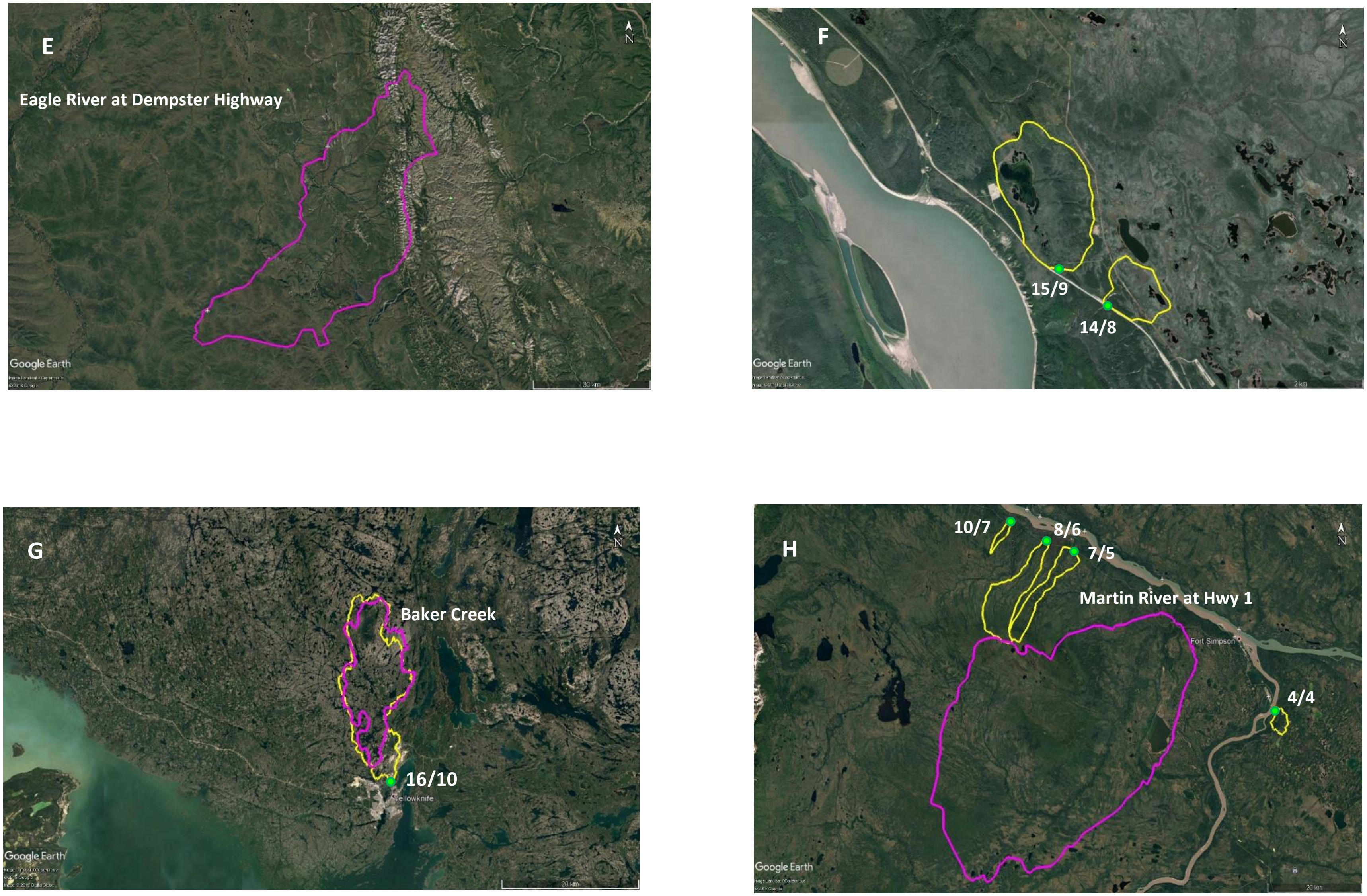
CULVERT CATCHMENT– EXPANDED VIEW

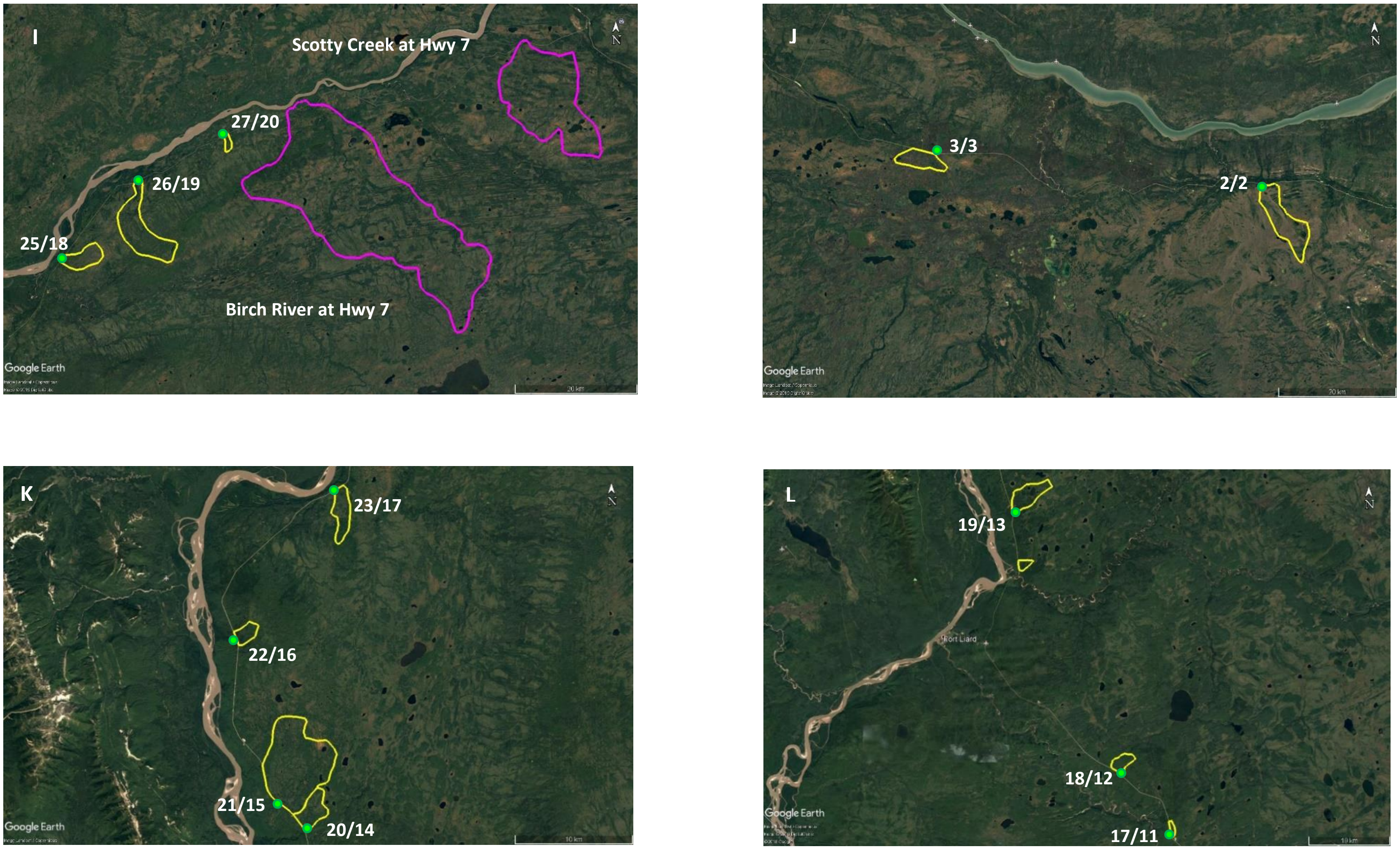

A
Havipak Creek near Inuvik
Cabin Creek above Hwy 8
Rat River near Fort McPherson
C
B
D
Rengleng River below Highway 8
E
Eagle River at Dempster Highway
N
60 mi
LEGEND
WSC Watersheds
Culvert Watersheds
Culvert Locations with ID

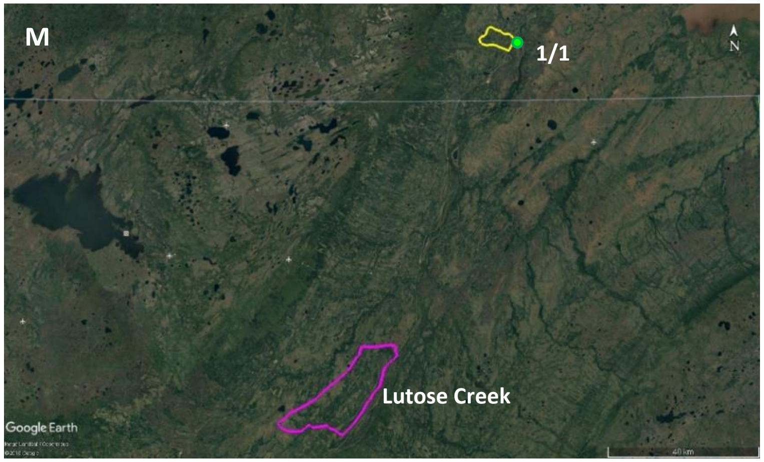


F
Baker Creek
G
N
Martin River at Hwy 1
H
Great Slave Lak
Scotty Creek at Hwy 7
I
J
Birch River at Hwy 7
K
L
M
Google Earth
Lutose Creek
Caribou Mountains
100 km
LEGEND
WSC Watersheds
Culvert Watersheds
Culvert Locations with ID


A
Havipak Creek near Inuvik
39/31
38/30
Cabin Creek above Hwy 8
Google Earth
B
37/29
36/28
35/27
Rengleng River below Highway 8
Google Earth
C
Rat River near Fort McPherson
Google Earth
D
Fort McPherson
34/26
33/25
32/24
31/23
30/22
29/21
Google Earth


E
Eagle River at Dempster Highway
Google Earth
F
15/9
14/8
Google Earth
G
Baker Creek
16/10
Yellowknife
Google Earth
H
10/7
8/6
7/5
Martin River at Hwy 1
Fort Simpson
4/4
Google Earth

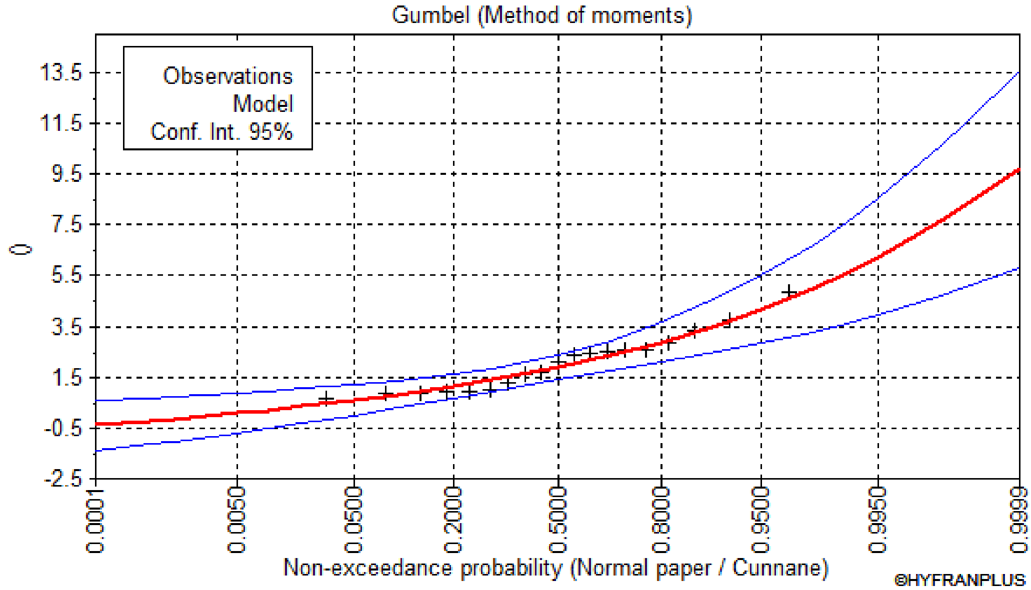

I
Scotty Creek at Hwy 7
27/20
26/19
25/18
Birch River at Hwy 7
Google Earth
J
3/3
2/2
Google Earth
K
23/17
22/16
21/15
20/14
Google Earth
L
19/13
Fort Liard
18/12
17/11
Google Earth


M
1/1
N
Lutose Creek
Google Earth

APPENDIX E

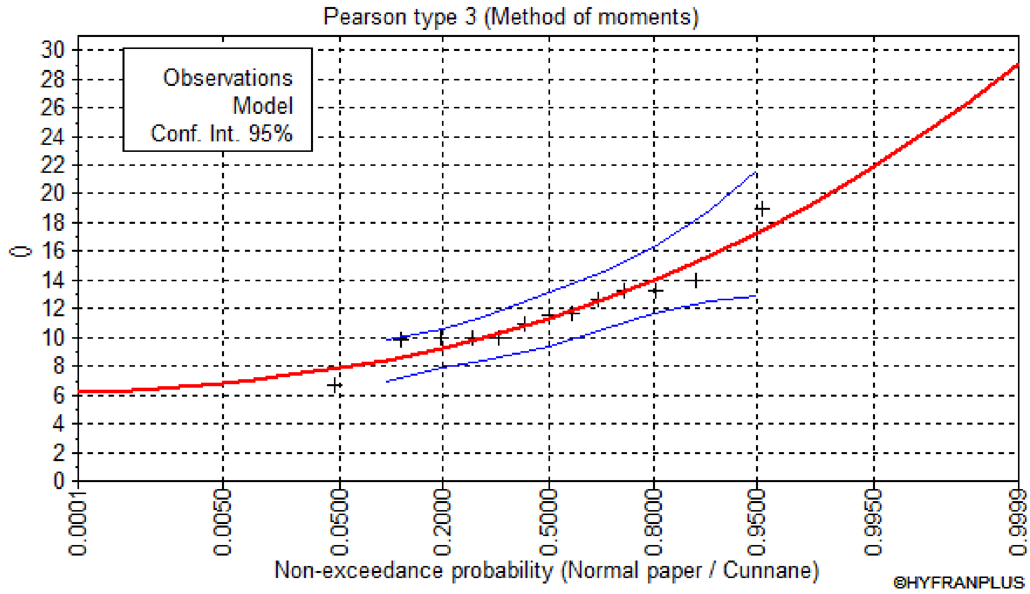
FLOOD FREQUENCY AND RAINFALL IDF CURVES

This appendix presents rainfall Intensity Frequency Duration (IDF) curves obtained from Environment Canada and frequency curves developed from statistical analysis of Water Survey of Canada peak flow data.



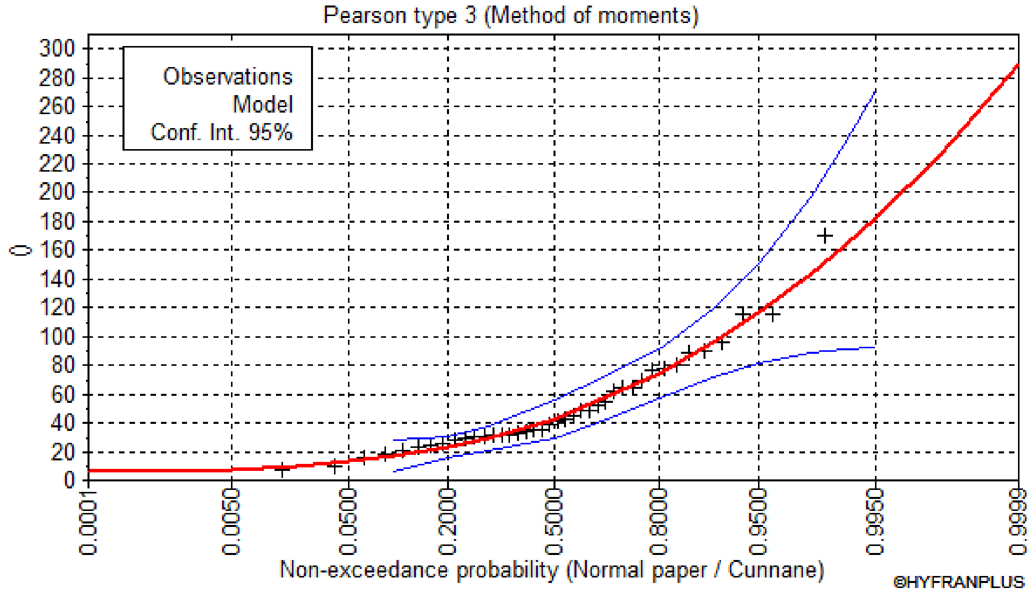
10LC017 – Havipak Creek near Inuvik – Return Period Flood Flows (m³/s)

3Q10	Q2	Q5	Q10	Q20	Q50	Q100	Q200
2.1	1.9	2.9	3.6	4.2	5.0	5.6	6.2



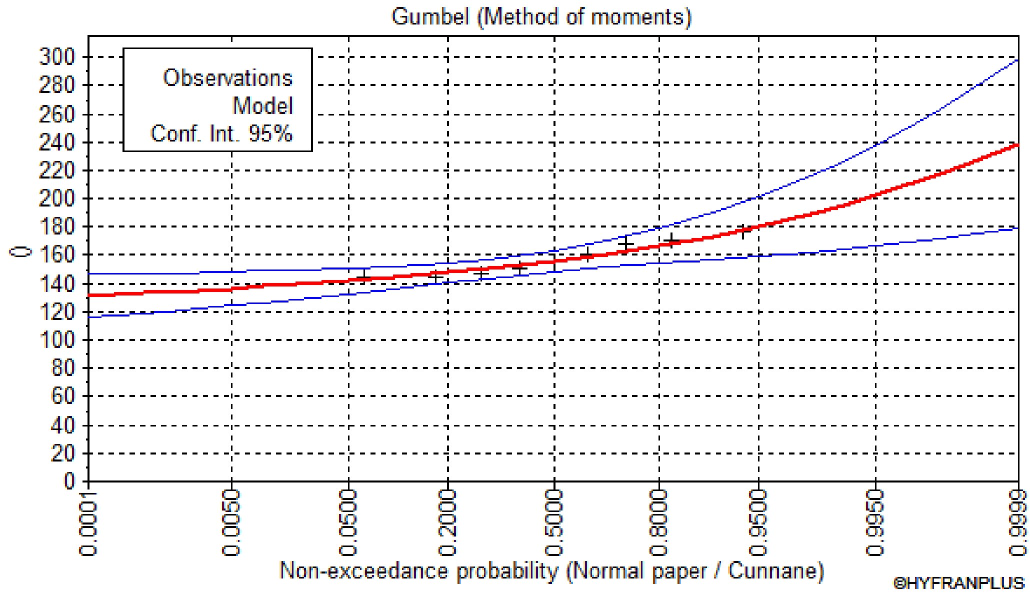
10LC009 – Cabin Creek above Highway No. 8 – Return Period Flood Flows (m³/s)

3Q10	Q2	Q5	Q10	Q20	Q50	Q100	Q200
15.7	33.6	54.3	68.0	81.2	98.2	111	124



10LC003 – Rengleng River below Highway No.8 – Return Period Flood Flows (m^3/s)

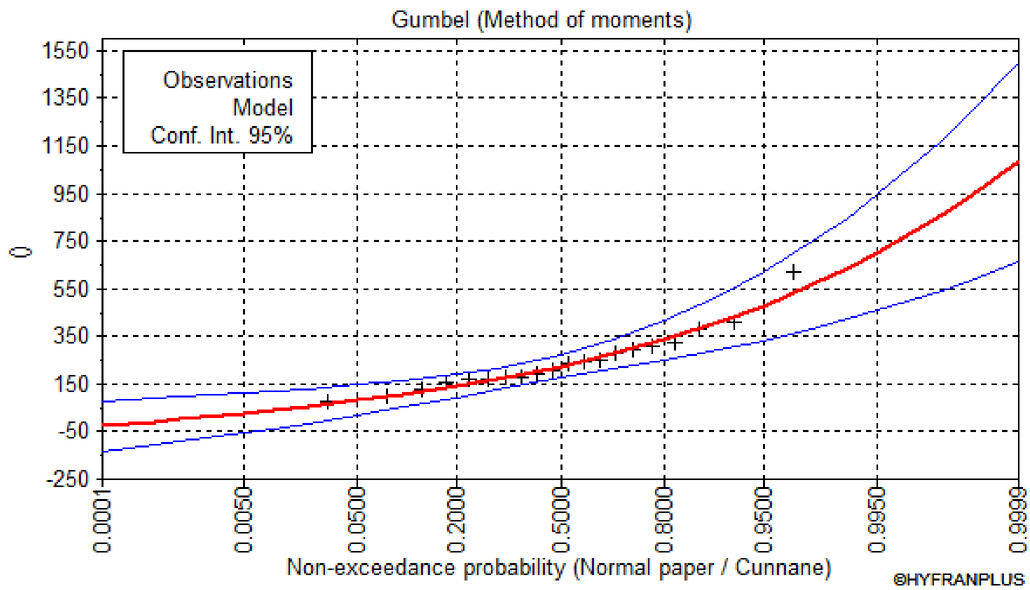
3Q10	Q2	Q5	Q10	Q20	Q50	Q100	Q200
95.6	50.4	91.4	120	149	184	210	235



10MC007 – Rat River near Fort McPherson – Return Period Flood Flows (m^3/s)

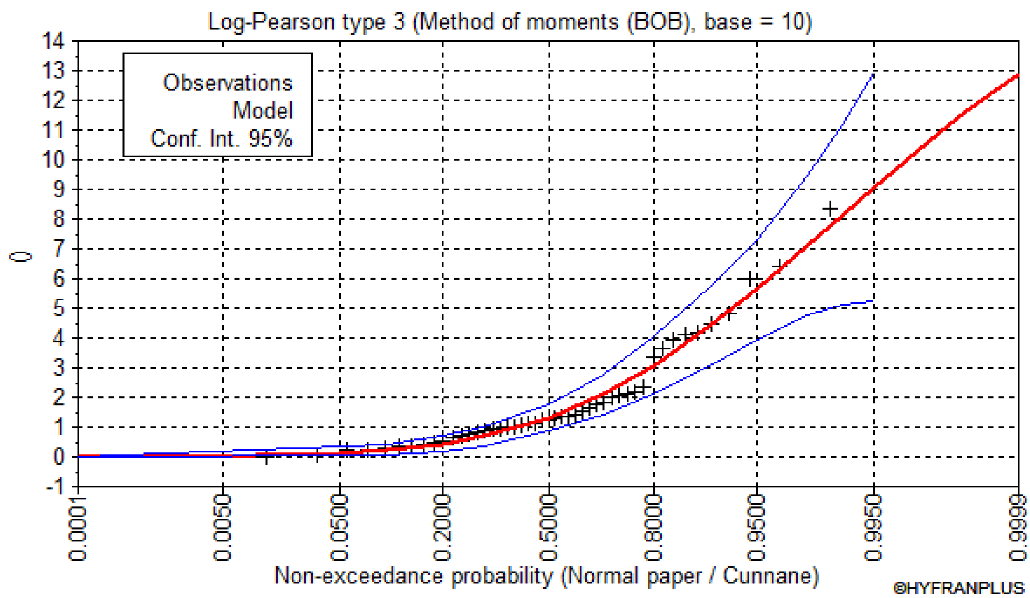
3Q10	Q2	Q5	Q10	Q20	Q50	Q100	Q200
-	156	166	-	-	-	-	-

* Q10 thru Q200 were not calculated due to less than 10 years of maximum daily flow record.



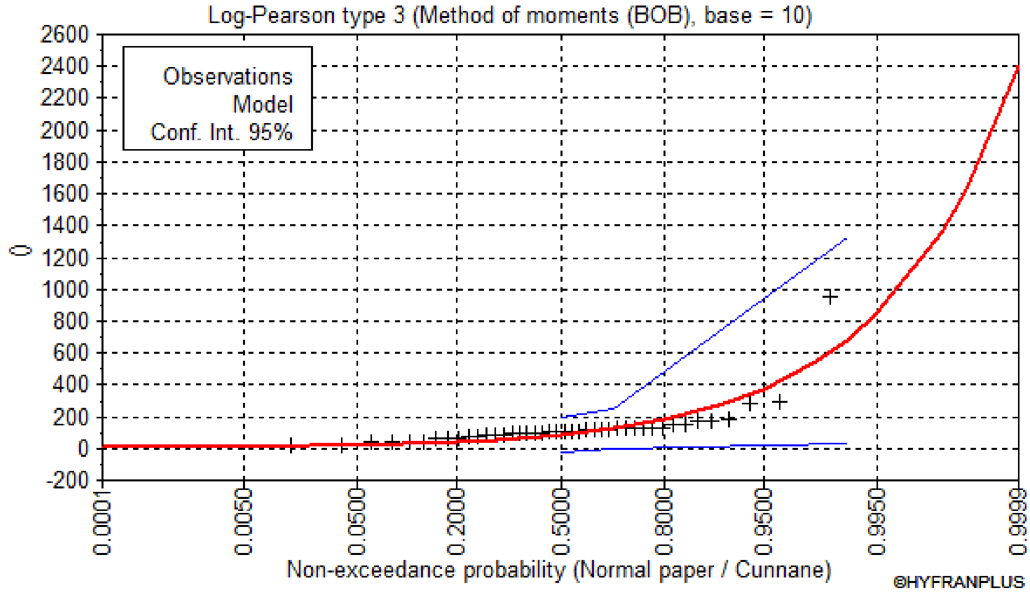
09FB002 – Eagle River at Dempster Highway Bridge – Return Period Flood Flows (m^3/s)

3Q10	Q2	Q5	Q10	Q20	Q50	Q100	Q200
217	225	335	408	477	568	635	703



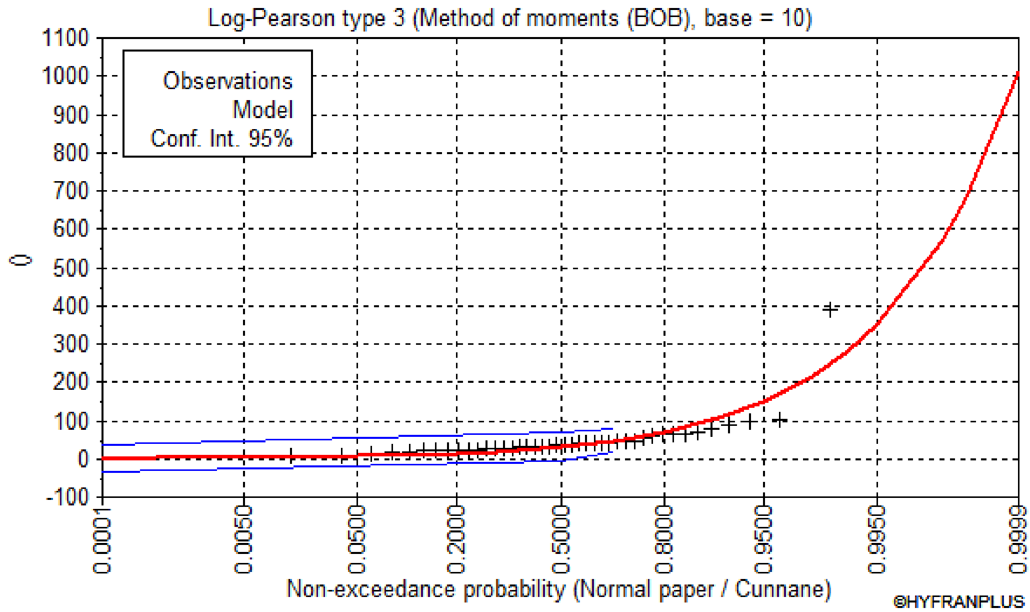
07SB013/07SB009 – Baker Creek at Outlet of Lower Martin Lake / Baker Creek near Yellowknife – Return Period Flood Flows (m^3/s)

3Q10	Q2	Q5	Q10	Q20	Q50	Q100	Q200
4.2	1.3	3.1	4.4	5.6	7.1	8.1	9.1



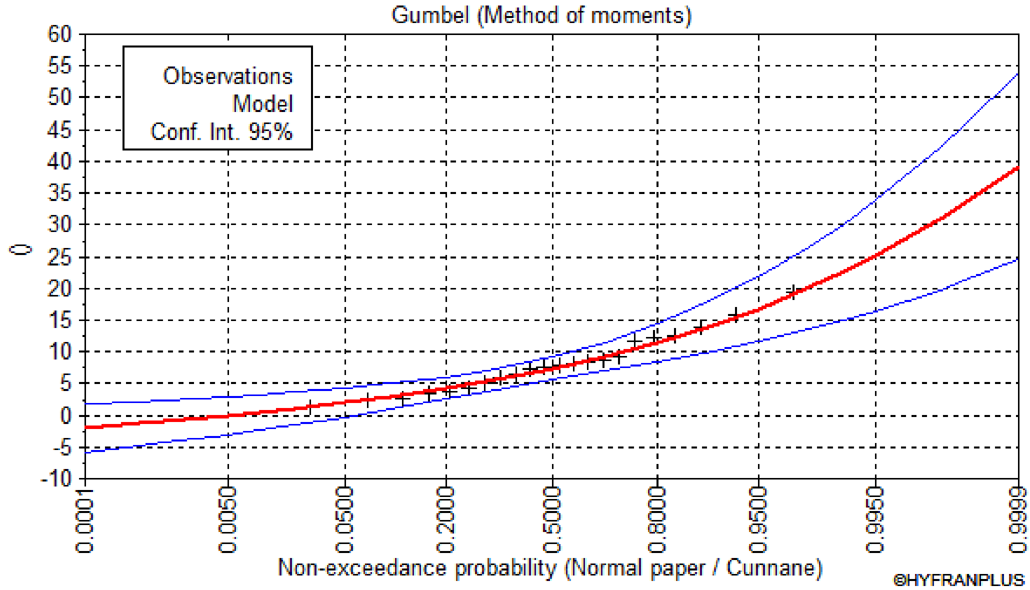
10GC003 – Martin River at Highway No. 1 – Return Period Flood Flows (m³/s)

3Q10	Q2	Q5	Q10	Q20	Q50	Q100	Q200
192	86.9	181	267	369	531	679	850



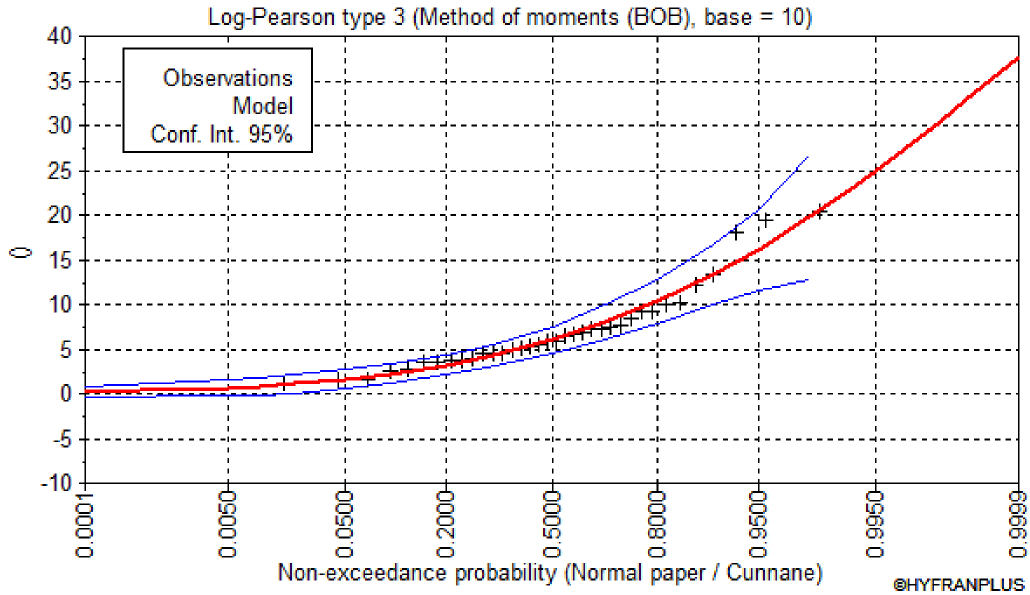
10ED003 –Birch River at Highway No. 7 – Return Period Flood Flows (m³/s)

3Q10	Q2	Q5	Q10	Q20	Q50	Q100	Q200
57.4	31.5	70.0	106	148	217	279	352



10ED009 – Scotty Creek at Highway No. 7 – Return Period Flood Flows (m³/s)

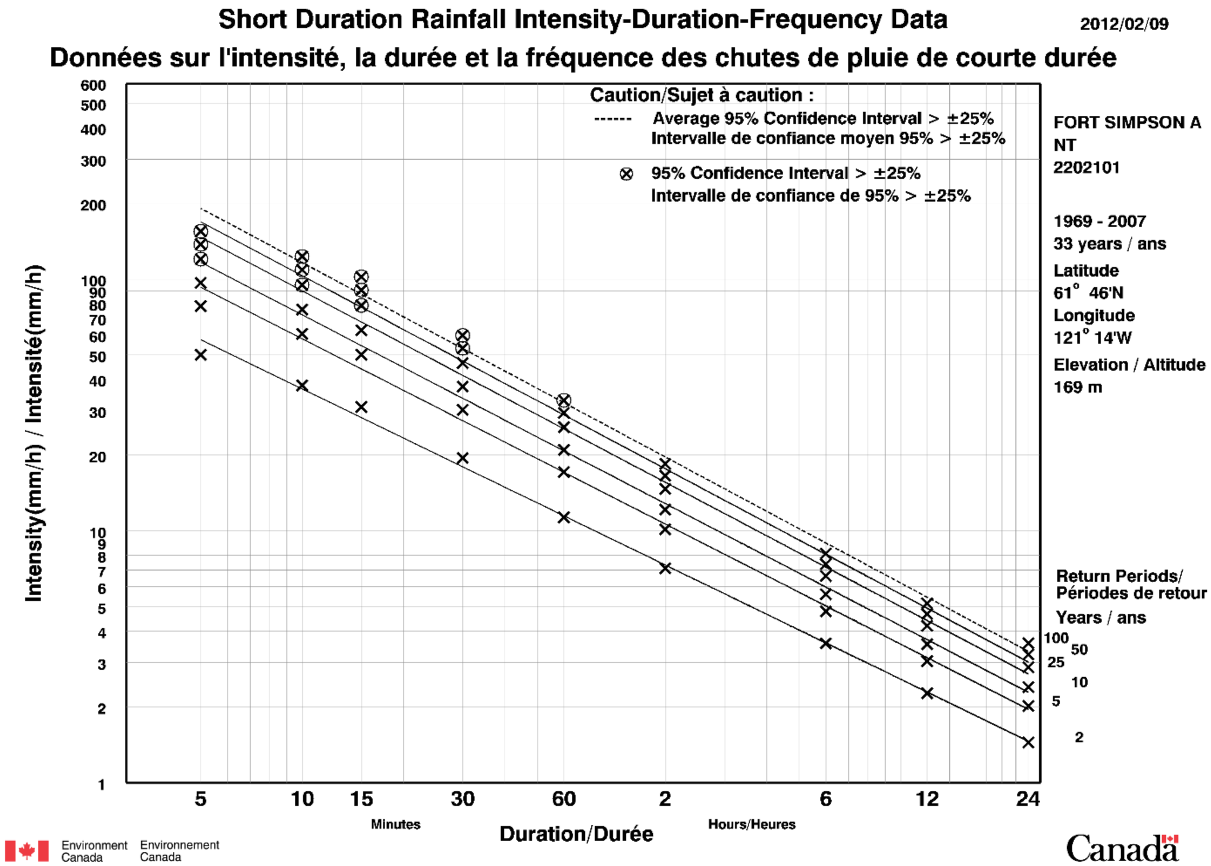
3Q10	Q2	Q5	Q10	Q20	Q50	Q100	Q200
10.9	7.3	11.4	14.1	16.7	20.1	22.6	25.1



07OB006 – Lutose Creek Near Steen River – Return Period Flood Flows (m³/s)

3Q10	Q2	Q5	Q10	Q20	Q50	Q100	Q200
10.7	6.0	10.3	13.3	16.1	19.8	22.4	24.9

Fort Simpson Airport, Environment Canada IDF: (1969 – 2007)



Fort Simpson Airport, Environment Canada IDF Rainfall Depth (mm)

Duration	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr
5 min	4.2	6.5	8.1	10.0	11.5	12.9
10 min	6.3	110.1	12.6	15.8	18.2	20.5
15 min	7.8	12.6	15.7	19.7	22.7	25.6
30 min	9.8	15.2	18.8	23.3	26.6	30.0
1 hour	11.3	17.2	21.0	25.9	29.5	33.1
2 hour	14.2	20.3	24.4	29.4	33.2	37.0
6 hour	21.5	28.8	33.7	39.8	44.3	48.9
12 hour	27.2	36.5	42.7	50.5	56.2	62.0
24 hour	34.7	48.5	57.6	69.1	77.6	86.1

APPENDIX F

TETRA TECH'S LIMITATIONS ON THE USE OF THIS DOCUMENT

LIMITATIONS ON USE OF THIS DOCUMENT

HYDROTECHNICAL

1.1 USE OF DOCUMENT AND OWNERSHIP

This document pertains to a specific site, a specific development, and a specific scope of work. The document may include plans, drawings, profiles and other supporting documents that collectively constitute the document (the "Professional Document").

The Professional Document is intended for the sole use of TETRA TECH's Client (the "Client") as specifically identified in the TETRA TECH Services Agreement or other Contractual Agreement entered into with the Client (either of which is termed the "Contract" herein). TETRA TECH does not accept any responsibility for the accuracy of any of the data, analyses, recommendations or other contents of the Professional Document when it is used or relied upon by any party other than the Client, unless authorized in writing by TETRA TECH.

Any unauthorized use of the Professional Document is at the sole risk of the user. TETRA TECH accepts no responsibility whatsoever for any loss or damage where such loss or damage is alleged to be or, is in fact, caused by the unauthorized use of the Professional Document.

Where TETRA TECH has expressly authorized the use of the Professional Document by a third party (an "Authorized Party"), consideration for such authorization is the Authorized Party's acceptance of these Limitations on Use of this Document as well as any limitations on liability contained in the Contract with the Client (all of which is collectively termed the "Limitations on Liability"). The Authorized Party should carefully review both these Limitations on Use of this Document and the Contract prior to making any use of the Professional Document. Any use made of the Professional Document by an Authorized Party constitutes the Authorized Party's express acceptance of, and agreement to, the Limitations on Liability.

The Professional Document and any other form or type of data or documents generated by TETRA TECH during the performance of the work are TETRA TECH's professional work product and shall remain the copyright property of TETRA TECH.

The Professional Document is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of TETRA TECH. Additional copies of the Document, if required, may be obtained upon request.

1.2 ALTERNATIVE DOCUMENT FORMAT

Where TETRA TECH submits electronic file and/or hard copy versions of the Professional Document or any drawings or other project-related documents and deliverables (collectively termed TETRA TECH's "Instruments of Professional Service"), only the signed and/or sealed versions shall be considered final. The original signed and/or sealed electronic file and/or hard copy version archived by TETRA TECH shall be deemed to be the original. TETRA TECH will archive a protected digital copy of the original signed and/or sealed version for a period of 10 years.

Both electronic file and/or hard copy versions of TETRA TECH's Instruments of Professional Service shall not, under any circumstances, be altered by any party except TETRA TECH. TETRA TECH's Instruments of Professional Service will be used only and exactly as submitted by TETRA TECH.

Electronic files submitted by TETRA TECH have been prepared and submitted using specific software and hardware systems. TETRA TECH makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.

1.3 STANDARD OF CARE

Services performed by TETRA TECH for the Professional Document have been conducted in accordance with the Contract, in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Professional judgment has been applied in developing the conclusions and/or recommendations provided in this Professional Document. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of the Professional Document.

If any error or omission is detected by the Client or an Authorized Party, the error or omission must be immediately brought to the attention of TETRA TECH.

1.4 DISCLOSURE OF INFORMATION BY CLIENT

The Client acknowledges that it has fully cooperated with TETRA TECH with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The Client further acknowledges that in order for TETRA TECH to properly provide the services contracted for in the Contract, TETRA TECH has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

1.5 INFORMATION PROVIDED TO TETRA TECH BY OTHERS

During the performance of the work and the preparation of this Professional Document, TETRA TECH may have relied on information provided by third parties other than the Client.

While TETRA TECH endeavours to verify the accuracy of such information, TETRA TECH accepts no responsibility for the accuracy or the reliability of such information even where inaccurate or unreliable information impacts any recommendations, design or other deliverables and causes the Client or an Authorized Party loss or damage.

1.6 GENERAL LIMITATIONS OF DOCUMENT

This Professional Document is based solely on the conditions presented and the data available to TETRA TECH at the time the data were collected in the field or gathered from available databases.

The Client, and any Authorized Party, acknowledges that the Professional Document is based on limited data and that the conclusions, opinions, and recommendations contained in the Professional Document are the result of the application of professional judgment to such limited data.

The Professional Document is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site conditions present, or variation in assumed conditions which might form the basis of design or recommendations as outlined in this report, at or on the development proposed as of the date of the Professional Document requires a supplementary exploration, investigation, and assessment.

TETRA TECH is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the Client.

1.7 ENVIRONMENTAL AND REGULATORY ISSUES

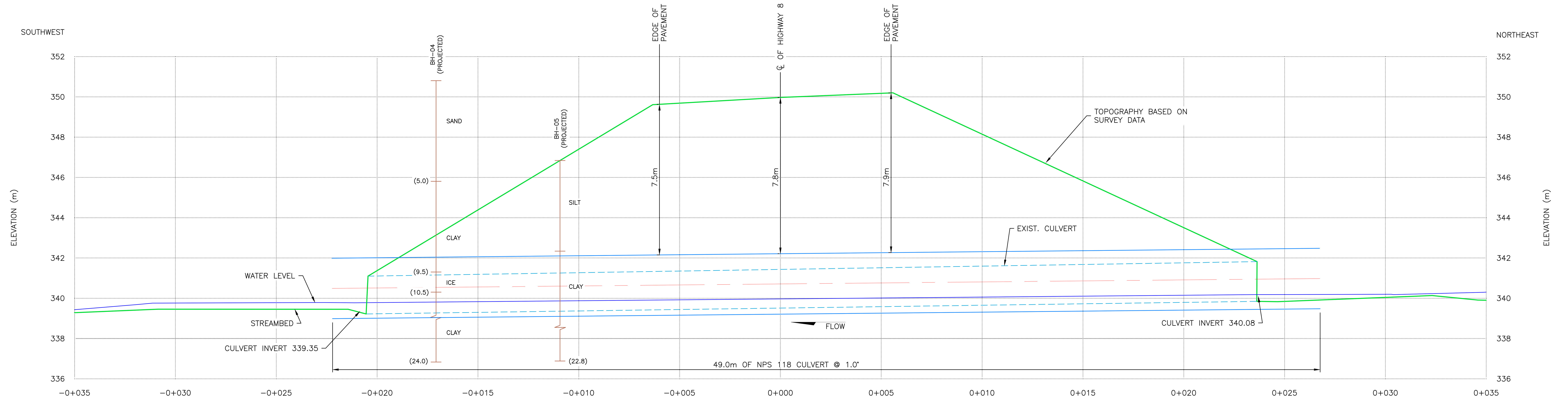
Unless expressly agreed to in the Services Agreement, TETRA TECH was not retained to investigate, address or consider, and has not investigated, addressed or considered any environmental or regulatory issues associated with the project.

1.8 LEVEL OF RISK

It is incumbent upon the Client and any Authorized Party, to be knowledgeable of the level of risk that has been incorporated into the project design, in consideration of the level of the hydrotechnical information that was reasonably acquired to facilitate completion of the design.

APPENDIX D – DESIGN DRAWINGS

PLAN □IE□
S□ALE 1:100



TOTAL T□NNEL LEN□T□ □1□m
TOTAL □□L□ERT LEN□T□ □□0m

PROFILE ALON□ □ENTRELINE OF EXISTIN□ □□L□ERT
S□ALE 1:100 □ORI□ONTAL
S□ALE 1:100 □ERTI□AL

REFEREN□E DO□□MENT NO□	DATE
1□ □0□5□KM□0	□0□1□0□1□
□□ □5□□0□□a□i□□ For□e□00	□0□□0□□1
□□ □5□□0□□API 110□□01	□0□□0□□1

EN□INEER AND PERMIT STAMPS

PRELIMINARY NOT FOR CONSTRUCTION

PIPELINE SPE□IFI□ATIONS

	NPS 11□
O□TSIDE DIAMETER (OD)(mm)	3000
□ALL T□I□KNESS (□ T)(mm)	25.4
□RADE	GRADE 3
PROD□□T	CULVERT
MATERIAL	STEEL
SPE□IFI□ATIONS	ASTM A252

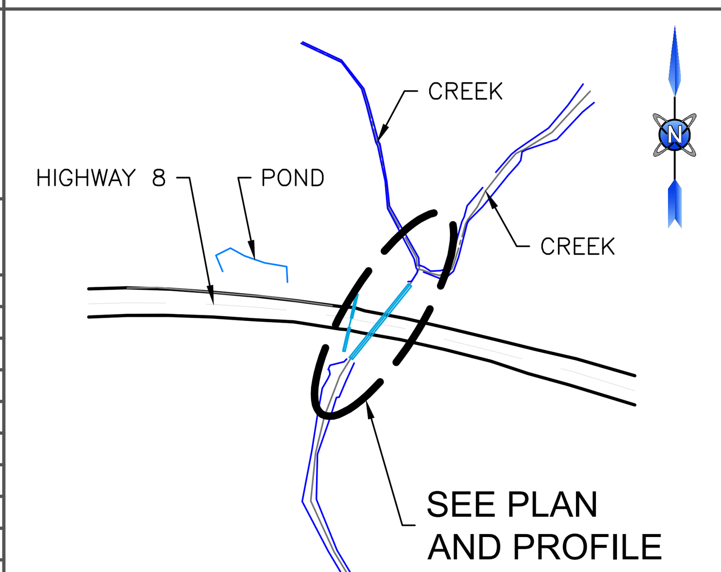
1:100
M 0 5 10
FT 0 10 20 30

P□LL FOR□E □RI□ SI□E □STRESS

□A□KIN□ FOR□E (□o B□OYAN□Y □ONTROL):	□□□000 □□(□□□)
MINIM□M RE□OMMENDED RI□ SI□E:	500 TONNE

DRA□ IN□ STAT□S	DATE	DRN	□□K	DES	□EO	APR	□R
ISS□ED FOR PERMIT	□0□□0□0□	AN	MAL	A□	N/A	□LT	ES
ISS□ED FOR RE□IE□	□0□□0□0□	AN	MAL	A□	N/A	□LT	ES

LO□ATION PLAN (1:□000)

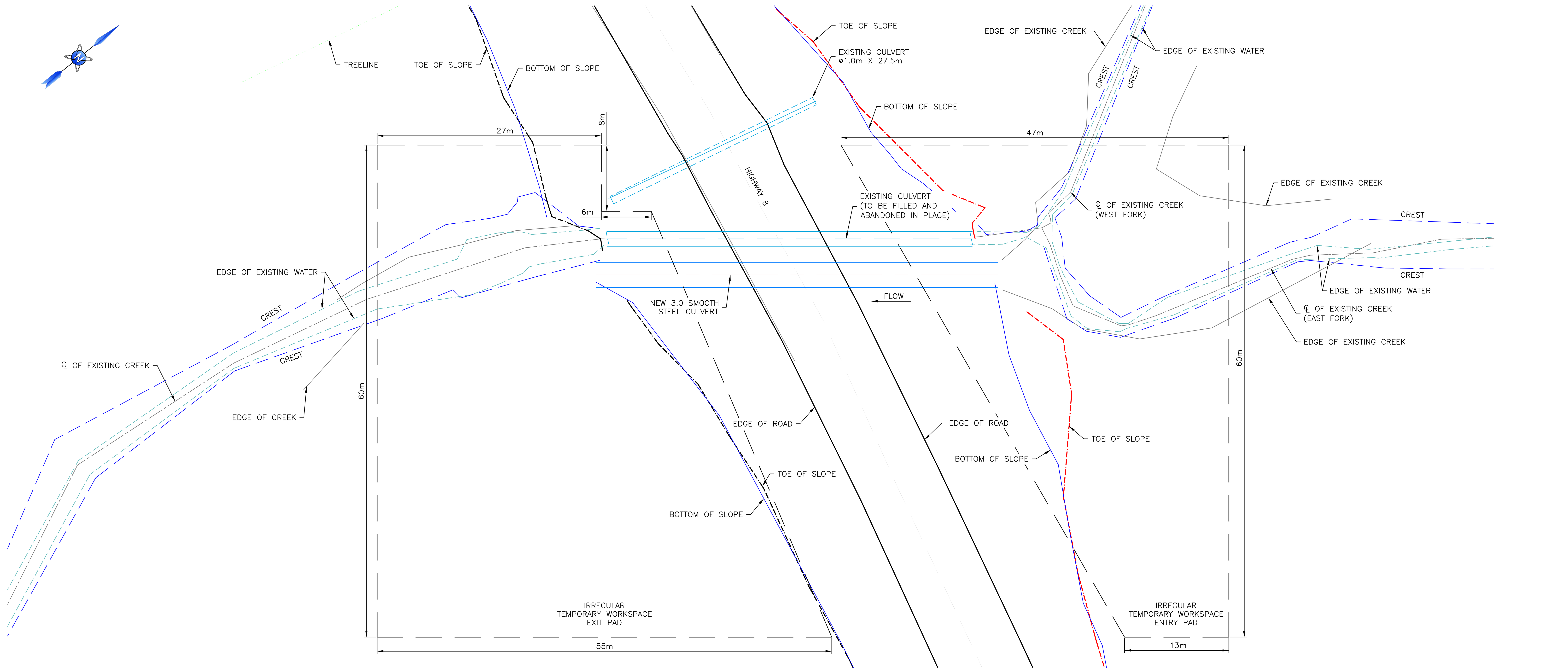


□TM □□ONE □□NAD □□(□SRS)

GOVERNMENT OF THE NWT
DEPARTMENT OF INFRASTRUCTURE

□I□□□ AY □□□L□ERT REPLA□EMENT PRO□E□T
□I□□□ AY □□KM □0□A□□ER BORE □ROSSIN□
PLAN AND PROFILE □NPS 11□
IN□□IK □N□T

S□ALE	D□ □□□	RE□ISION	S□EET
AS S□O□N	□5□□E□0□01	B	1 OF □



SITE PLAN

S□ALE 1:□50

NOTES

□ONSTR□□TION

1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE SPECIFIED.
2. ALL LENGTHS ARE ROUNDED TO THE NEAREST METRE AND ALL ANGLES ARE ROUNDED TO THE NEAREST DEGREE UNLESS OTHERWISE SPECIFIED.
3. THE CONTRACTOR SHALL VERIFY ALL TOPOGRAPHICAL SURVEY INFORMATION REPRESENTED ON THIS DRAWING IN THE FIELD PRIOR TO CONSTRUCTION.
4. THIS DRAWING IS BASED ON INFORMATION PROVIDED FROM VARIOUS SOURCES. CCI DOES NOT TAKE RESPONSIBILITY FOR THE ACCURACY OF INFORMATION PROVIDED BY OTHERS.
5. ALL EXISTING UTILITY DEPTHS ARE APPROXIMATE AND SHALL BE VERIFIED IN THE FIELD BY THE CONTRACTOR PRIOR TO ANY GROUND DISTURBANCE. VERIFICATION SHALL BE IN ACCORDANCE WITH OWNER SPECIFICATIONS AND GROUND DISTURBANCE PROCEDURES. LOCATION, WHEN SHOWN ON PLANS, IS APPROXIMATE AND SOME UTILITIES MAY NOT BE DISPLAYED. DEPTHS SHOWN IN RED ARE ASSUMED.
6. THE CONTRACTOR MUST TAKE ALL NECESSARY PRECAUTIONS DURING THE WORK TO AVOID DAMAGING EXISTING AT–SURFACE AND UNDERGROUND FACILITIES, PIPELINES, UTILITIES, OR CABLES AND ADJACENT PROPERTIES. IT IS HIS RESPONSIBILITY TO PROTECT THESE UTILITIES THROUGHOUT THE DURATION OF THE WORK.
7. CONTRACTOR SHALL PREPARE ENTRY LOCATIONS FOR SAFE WORK AND MANAGE GROUNDWATER IN THE AREA AS REQUIRED.
8. THE CONTRACTOR MUST REPORT ANY CHANGES IN THE NATURE OF THE SOIL DURING THE WORK, IN RELATION TO THE GEOTECHNICAL STUDY.
9. THIS ENGINEERED DESIGN IS BASED ON THE FOLLOWING MINIMUM EQUIPMENT REQUIREMENTS:
   A. MINIMUM TBM DIAMETER SHALL BE 3038mm;
   B. JACKING FRAME THRUST CAPACITY SHALL BE 500 TONNE;
   C. THE CONTRACTOR IS RESPONSIBLE FOR THE EXECUTION OF THE WORK UNDER THEIR APPROVED EXECUTION PLAN AND SHALL SUPPLY ALL ADDITIONAL EQUIPMENT TO COMPLETE THEIR PLAN AT THEIR COST. ALL EQUIPMENT SHALL BE SUPPLIED IN GOOD WORKING ORDER, MAINTAINED, FUELED AND SERVICED;
   D. ANY EQUIPMENT NOT OPERATIONAL OR FULFILLING THE REQUIREMENTS OUTLINED IN THE CONTRACT SHALL BE REPAIRED OR REPLACED AT THE CONTRACTORS COST. COST OF EQUIPMENT REPAIR OR REPLACEMENT AND STANDBY OF EQUIPMENT AND PERSONNEL DURING DOWNTIME DUE TO UNSUITABLE OR INOPERABLE EQUIPMENT SHALL BE SOLELY BORNE BY CONTRACTOR.
10. THE TOTAL THEORETICAL THRUST FORCE FOR THE ENTIRE LENGTH OF THIS TUNNEL CROSSING IS 402 TONNES / 887,000lbs (INCLUDING A SAFETY FACTOR OF 1.25). CONTRACTOR SHALL PROVIDE THE MAXIMUM THRUST FORCE EXPECTED BASED UPON THEIR APPROVED EXECUTION PLAN.

EN□IRONMENTAL

11. DISPOSAL OF SPOIL SHALL BE IN ACCORDANCE WITH THE GOVERNMENT OF NORTHWEST TERRITORIES (GNWT) GUIDELINES AND THE PROJECT ENVIRONMENTAL MANAGEMENT PLAN.
12. NO REFUELING OF PUMPS OR EQUIPMENT WITHIN, AROUND, OR AMONGST THE RIPARIAN ZONE SHALL BE COMPLETED.
13. EMERGENCY RESPONSE SPILL KITS MUST BE ON–SITE AND AVAILABLE FOR USE FOR THE DURATION OF THE PROJECT AND SHOULD ADHERE TO PROTOCOLS SET FORTH BY FISHERIES & OCEANS CANADA (DFO) OPERATIONAL STATEMENTS.
14. THE CONTRACTOR SHALL ENSURE THAT THE FOLLOWING DOCUMENTATION IS ON–SITE AND READILY AVAILABLE AT ALL TIMES (AT A MINIMUM):
   A. EMERGENCY RESPONSE PROCEDURE (ERP);
   B. ENVIRONMENTAL PROTECTION PLAN (EPP);
   C. MSDS FOR ALL ON–SITE MATERIAL;
   D. CROSSING AND PROXIMITY AGREEMENTS;
   E. COPIES OF TEMPORARY FIELD AUTHORIZATIONS AND/OR LAND USE AGREEMENTS.

□EOTE□□NI□AL

15. A GEOTECHNICAL EVALUATION WAS COMPLETED AT THIS SITE BY TETRA TECH AND CAN BE REFERENCED FROM PROJECT NO: ENG.YARC03234–01.
16. SUBSURFACE CONDITIONS ARE BELIEVED TO BE SUITABLE FOR CONSTRUCTION OF THE PROPOSED INSTALLATION BASED ON THE DATA AVAILABLE.
17. IT IS RECOMMENDED THAT THE CONTRACTOR INDEPENDENTLY EVALUATE THE FEASIBILITY OF CONSTRUCTING THE CROSSINGS WITH DUE CONSIDERATION GIVEN TO SUBSURFACE CONDITIONS AND THE SUITABILITY OF THEIR EQUIPMENT AND PROPOSED CONSTRUCTION PROCEDURES.

REFEREN□E DO□□MENT NO□	DATE
1□ □0□5□KM□0	□0□1□0□1□
□□ □5□□0□□a□i□□ For□e□00	□0□□0□□1
□□ □5□□0□□API 110□□01	□0□□0□□1

CCI

EN□INEER AND PERMIT STAMPS

PRELIMINARY NOT FOR CONSTRUCTION

PIPE SPE□IFI□ATIONS

	NPS 11□
O□TSIDE DIAMETER (OD)(mm)	3000
□ ALL T□I□KNESS (□ T)(mm)	25.4
□RADE	GRADE 3
PROD□□T	CULVERT
MATERIAL	STEEL
SPE□IFI□ATIONS	ASTM A252

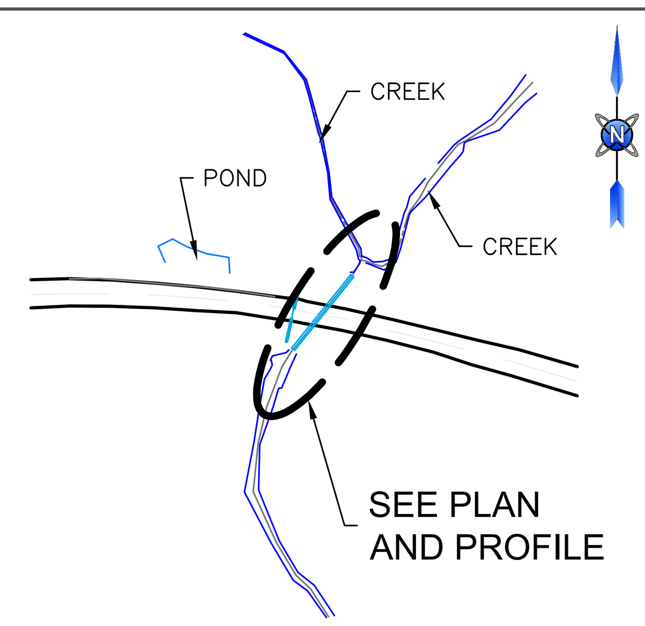
1:250
M 0 5 10 15 20 25
FT 0 10 20 30 40 50 60 70 80 90

□A□KIN□ FOR□E

□A□KIN□ FOR□E (□□o B□OYAN□Y □ONTROL):	□□□000 □□(□□□)
MINIM□M RE□OMMENDED RI□ SI□E:	500 TONNE

ISS□ED FOR PERMIT	□0□□0□0□	AN	MAL	A□	N□A	□LT	ES
ISS□ED FOR RE□IE□	□0□□0□0□	AN	MAL	A□	N□A	□LT	ES

LO□ATION PLAN (1:□□000)



□TM □□ONE □ □NAD □□ (□SRS)

Northwest Territories

GOVERNMENT OF THE NWT
DEPARTMENT OF INFRASTRUCTURE

□I□□□ AY □□□L□ERT REPLA□EMENT PRO□E□T

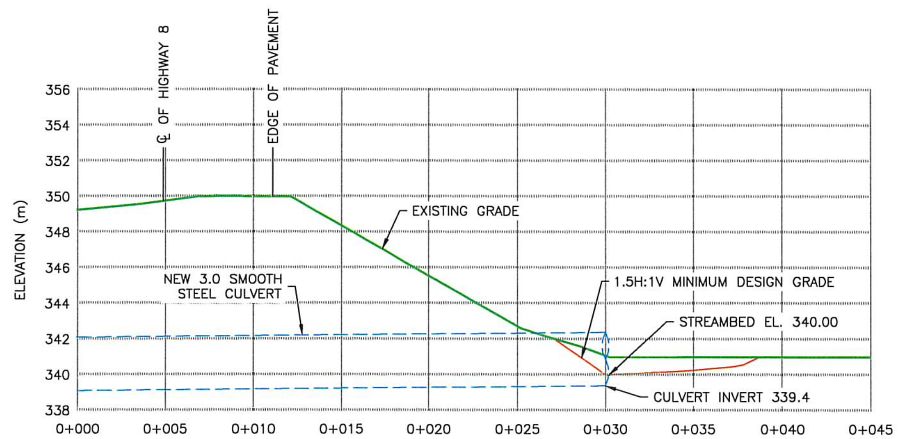
□I□□□ AY □□KM □0□□A□□ER BORE □ROSSIN□
□ONSTR□□TION LAYO□T AND NOTES

IN□□IK □N□T

S□ALE	D□ □□□	RE□ISION	S□EET
AS S□O□N	□5□□E□0□0□	B	□OF □

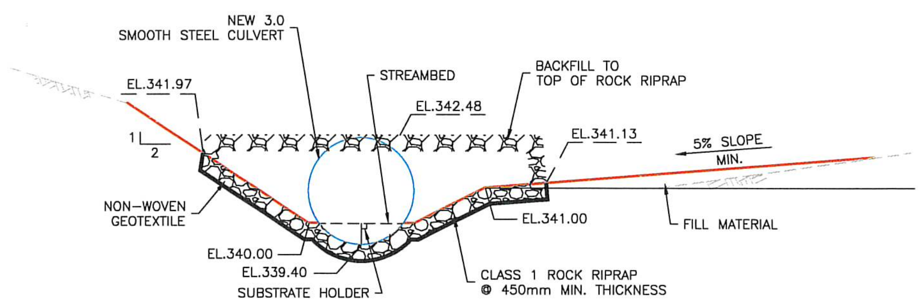
File Name: S:\Current Jobs\2567–Gov of NWT–CulvertDesign\Eng\Drawings\03–Highway 8 – KM 40.2\IFP\2567–EG–0301–B BORE_PHASES_NOTES.dwg Date/Time: 2022–04–22 / 2:01:09 PM Last Saved By: Abdulkodir.Nur

• FOR DESIGN AND MATERIAL NOTES, SEE DRAWING# 2567-EG-0305.



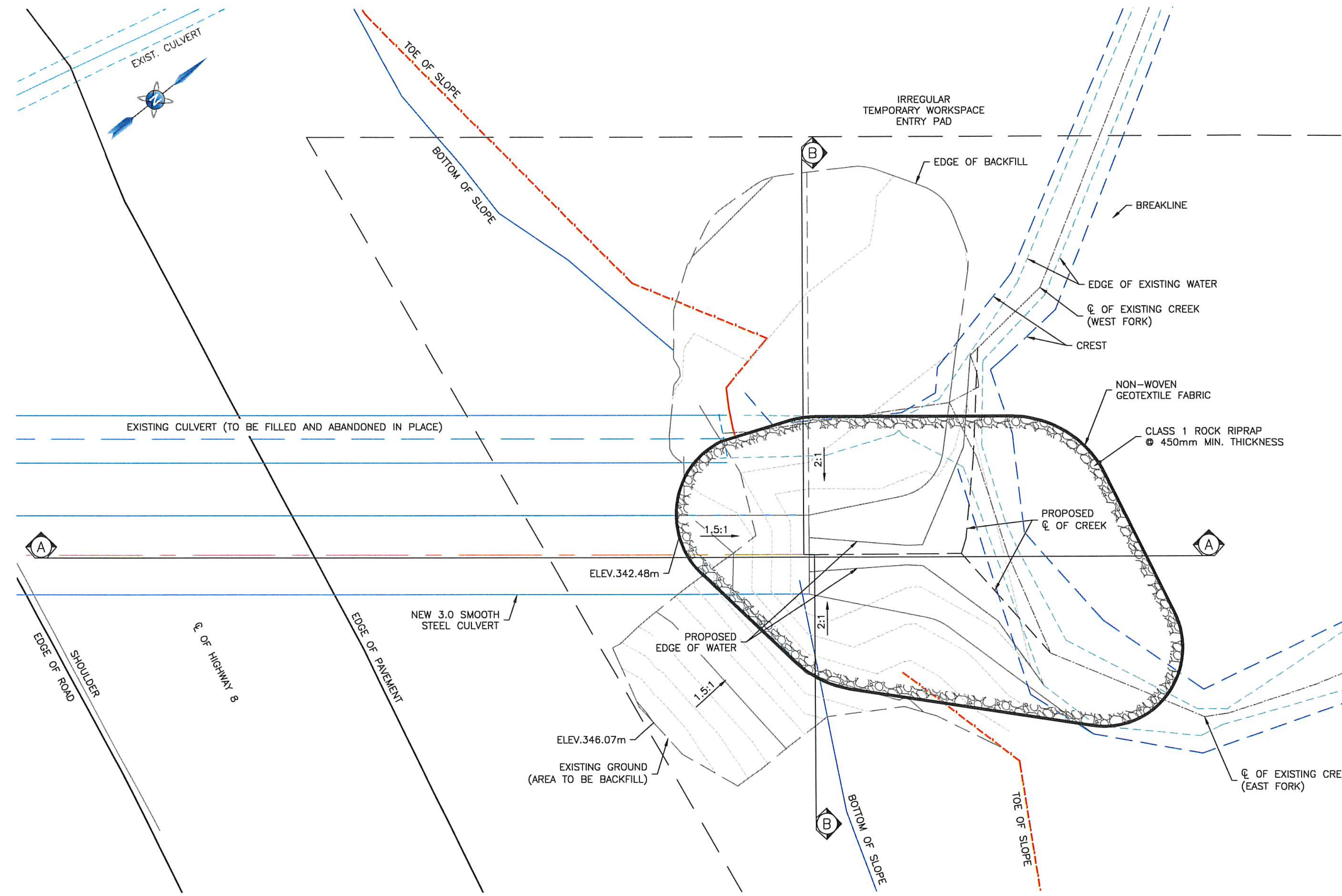
A-A SLOPE CROSS-SECTION

SCALE 1:200



B-B SECTION DETAIL

SCALE 1:100



CULVERT INLET

SCALE 1:100

REFERENCE DOCUMENT NO.	DATE
1. 80754 KM40	2021-09-16
2. 2567-EG-0304	2022-04-08
3. 2567-EG-0305	2022-04-08
4. 2567-EG-0306	2022-04-08
5. 2567-EG-0307	2022-04-08
6. 2567-EG-0308	2022-04-08

CCI

ENGINEER AND PERMIT STAMPS

REGISTERED PROFESSIONAL GEOSCIENTIST
N.P. BOELHOUWER
LICENSEE
NT/NU

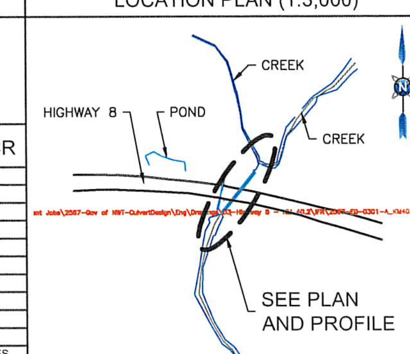
#L4934
2022-05-11

1:100
M 0 5 10
FT 0 10 20 30

1:200
M 0 5 10 15 20
FT 0 10 20 30 40 50 60 70

DRAWING STATUS	DATE	DRN	CHK	DES	GEO	APR	CR
ISSUED FOR PERMIT	2022-04-08	AN	MAL	NB	N/A	JLT	ES
ISSUED FOR REVIEW	2022-04-06	AN	MAL	NB	N/A	JLT	ES

LOCATION PLAN (1:3,000)



UTM - ZONE 8 - NAD 83 (CSRS)

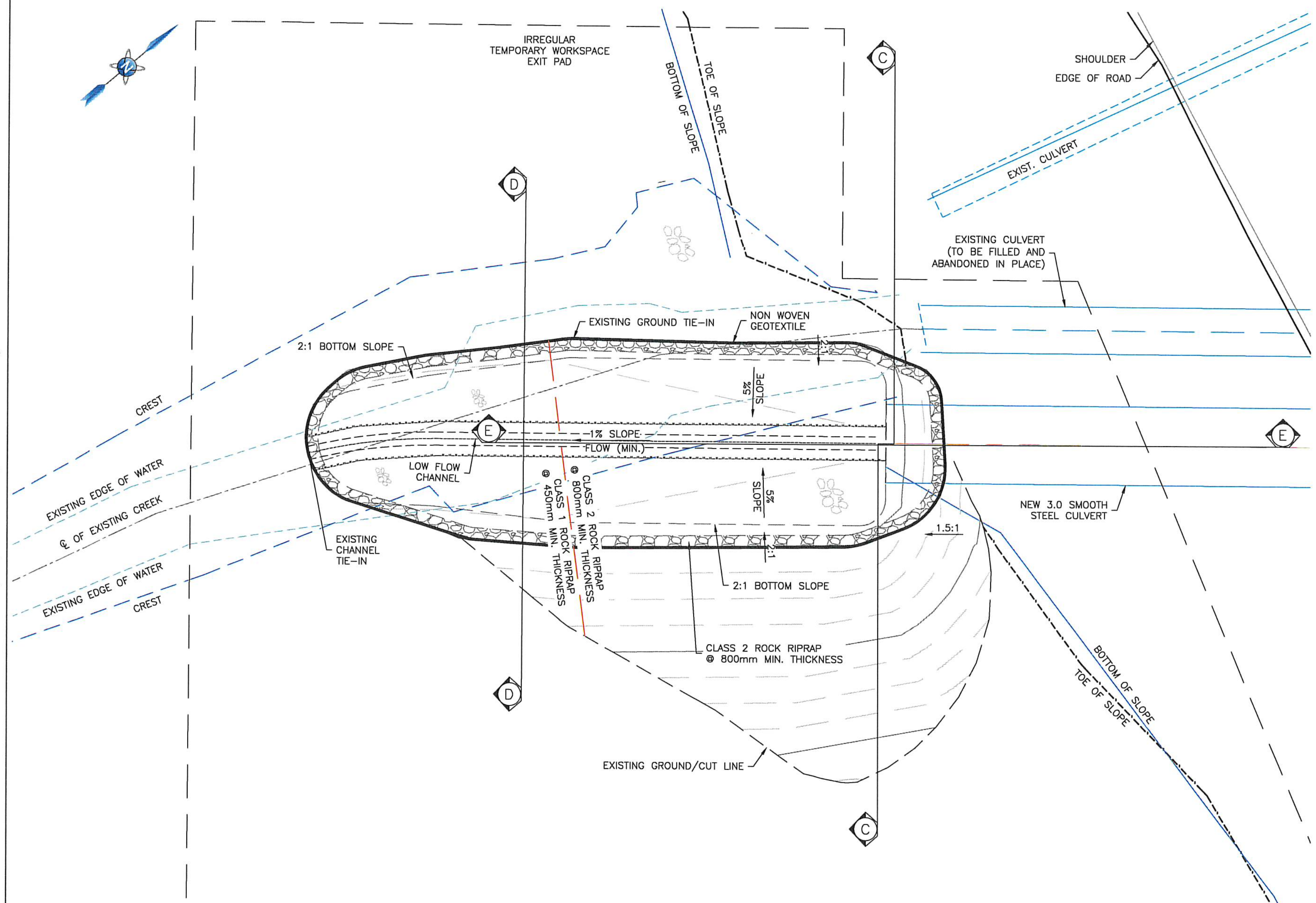
GOVERNMENT OF THE NWT
DEPARTMENT OF INFRASTRUCTURE

HIGHWAY 8 CULVERT REPLACEMENT PROJECT
HIGHWAY 8 - KM 40.2 AUGER BORE CROSSING
INLET PLAN AND DETAIL
INUVIK - NWT

SCALE	DWG. #	REVISION	SHEET
AS SHOWN	2567-EG-0303	B	3 OF 8

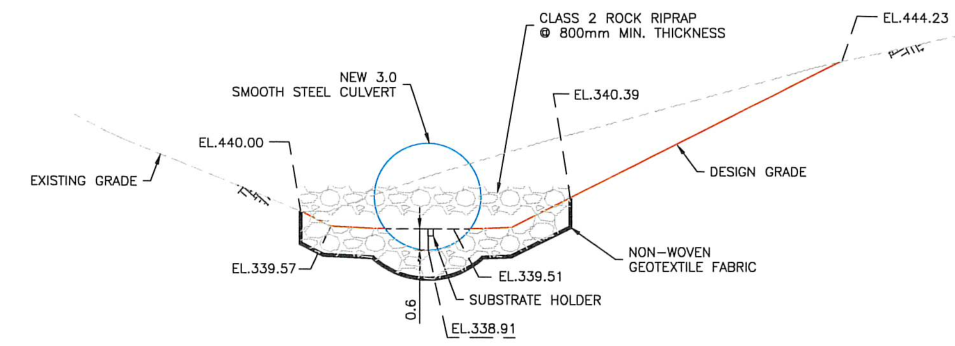
File Name: S:\Current Jobs\2567-Gov of NWT-CulvertDesign\Eng\Drawings\03-Highway 8 - KM 40.2\IFP\2567-EG-0301-B INLET_OUTLET_HYDO NOTES.dwg Date/Time: 2022-04-25 / 8:36:06 AM Last Saved By: Abdulkadir.Nur

- FOR DESIGN AND MATERIAL NOTES, SEE DRAWING# 2567-EG-0305.



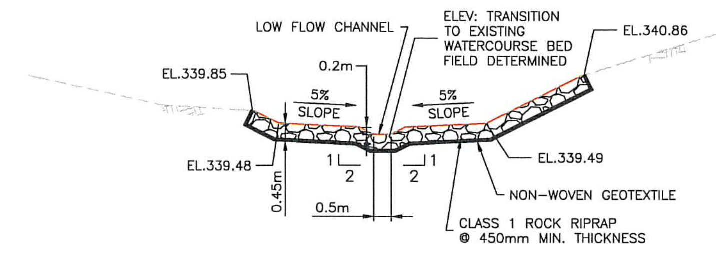
CULVERT OUTLET

SCALE 1:100



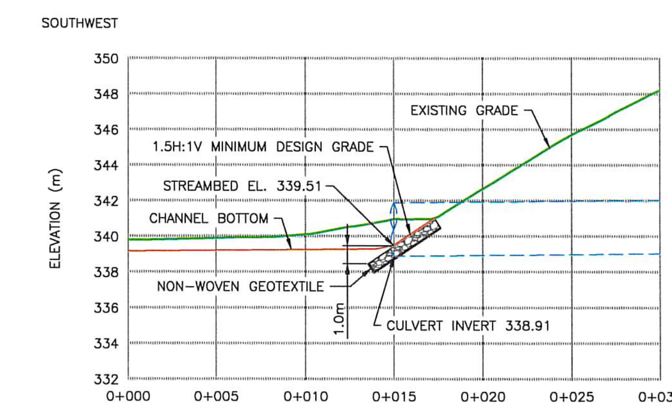
C-C OUTLET SECTION DETAIL

SCALE 1:100



D-D SECTION DETAIL

SCALE 1:100



E-E TYPICAL SLOPE STABILIZATION DETAIL

SCALE 1:200

File Name: S:\Current Jobs\2567-Gov of NWT-CulvertDesign\Eng\Drawings\03-Highway 8 - KM 40.2\VFP\2567-EG-0301-B INLET_OUTLET_HYDO NOTES.dwg Date/Time: 2022-04-25 / 8:36:06 AM Last Saved By: Abdulkadir.Nur

REFERENCE DOCUMENT NO.	DATE
1. 80754 KM40	2021-09-16
2. 2567-EG-0303	2022-04-08
3. 2567-EG-0305	2022-04-08
4. 2567-EG-0306	2022-04-08
5. 2567-EG-0307	2022-04-08
6. 2567-EG-0308	2022-04-08

CCI

ENGINEER AND PERMIT STAMPS

REGISTERED PROFESSIONAL GEOSCIENTIST
N.P. BOELHOUWER
LICENSEE
NT/NU

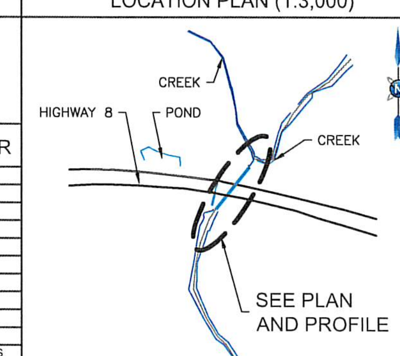
#L4934
2022-05-11

1:100 M 0 5 10 FT 0 10 20 30

1:200 M 0 5 10 15 20 FT 0 10 20 30 40 50 60 70

DRAWING STATUS	DATE	DRN	CHK	DES	GEO	APR	CR
ISSUED FOR PERMIT	2022-04-08	AN	MAL	NB	N/A	JLT	ES
ISSUED FOR REVIEW	2022-04-06	AN	MAL	NB	N/A	JLT	ES

LOCATION PLAN (1:3,000)



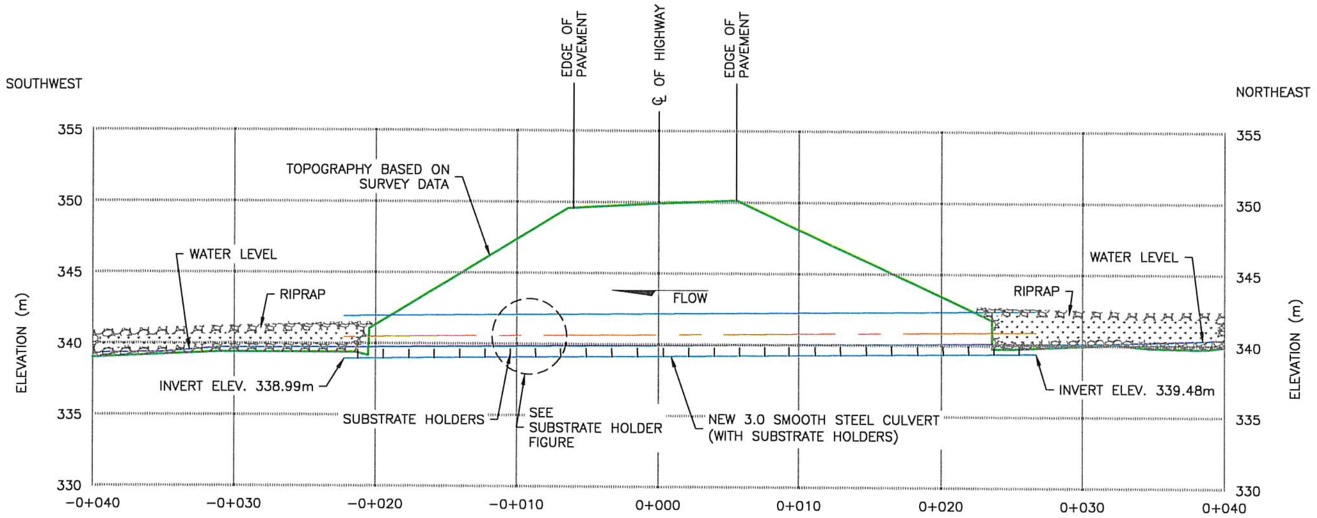
UTM - ZONE 8 - NAD 83 (CSRS)

Northwest Territories

GOVERNMENT OF THE NWT
DEPARTMENT OF INFRASTRUCTURE

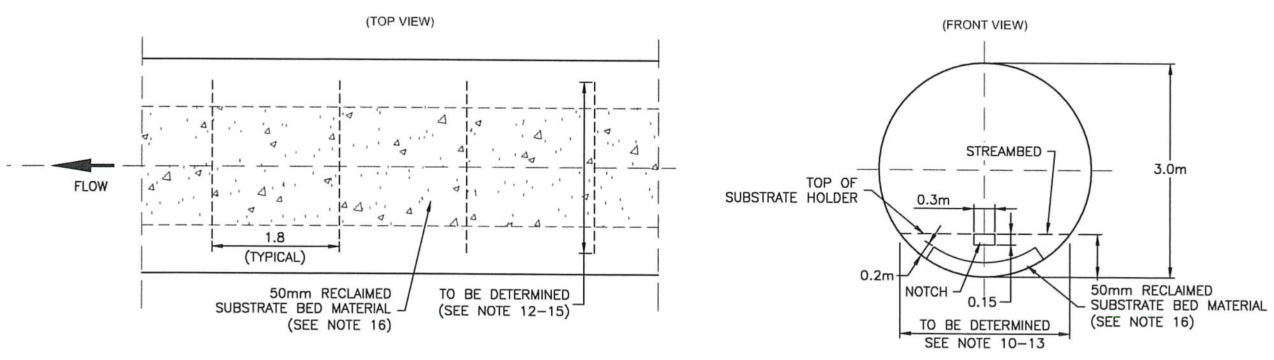
HIGHWAY 8 CULVERT REPLACEMENT PROJECT
HIGHWAY 8 - KM 40.2 AUGER BORE CROSSING
OUTLET PLAN AND DETAIL
INUVIK - NWT

SCALE	DWG #	REVISION	SHEET
AS SHOWN	2567-EG-0304	B	4 OF 8



LONGITUDINAL SECTION THROUGH 3.0 CULVERT CENTRELINE

SCALE 1:250



SUBSTRATE HOLDER FIGURE

NTS

HYDROTECHNICAL DESIGN SUMMARY

- DRAINAGE AREA = 4.7km²
- FLOOD DESIGN DISCHARGE = 5.5m³/s
- FISH PASSAGE DESIGN DISCHARGE = 1.40m³/s

GENERAL NOTES

1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. ALL WORK SHALL BE DONE IN ACCORDANCE WITH ALBERTA TRANSPORTATION STANDARD SPECIFICATIONS FOR BRIDGE CONSTRUCTION.
3. CONTRACTOR TO VERIFY ALL INVERTS OF EXISTING STRUCTURES PRIOR TO COMMENCING WORK. CONTRACTOR TO REPORT TO THE OWNER'S AUTHORIZED REPRESENTATIVE ANY DISCREPANCIES BETWEEN THE MEASURED INVERTS AND THE PIPE LOCATIONS SHOWN ON DRAWINGS PRIOR TO COMMENCING WORK.
4. BEFORE CONSTRUCTION ACTIVITIES COMMENCE, ALL WATER DIVERSION MEASURES AND EROSION CONTROL STRUCTURES SHALL BE INSTALLED ON BOTH SIDES OF THE WATERCOURSE.
5. ALL WORK SHALL BE DONE IN ACCORDANCE WITH PROJECT AGREEMENTS, REGULATORY APPROVALS, ENVIRONMENTAL PROTECTION PLAN AND SITE SPECIFIC REQUIREMENTS.

HEAVY ROCK RIPRAP AND NON-WOVEN GEOTEXTILE FABRIC

6. PRIOR TO INSTALLATION OF THE ROCK RIPRAP, THE APPROXIMATE 100mm OF SUBSTRATE BED MATERIAL SHALL BE STRIPPED AND STOCKPILED SEPARATELY. THE SUBSTRATE BED MATERIAL WILL BE PLACED ALONG THE LOW FLOW CHANNEL AND BETWEEN THE SUBSTRATE HOLDERS UPON COMPLETION OF THE ROCK RIPRAP.
7. HEAVY ROCK RIPRAP AND THE NON−WOVEN GEOTEXTILE SHALL BE SUPPLIED, DELIVERED, AND INSTALLED IN ACCORDANCE WITH THE ALBERTA TRANSPORTATION STANDARD SPECIFICATIONS FOR BRIDGE CONSTRUCTION.
8. PREPARE THE SUBGRADE FOR GEOTEXTILE AND RIPRAP TO THE REQUIRED LINES AND GRADES. COMPACT ANY FILL REQUIRED IN THE SUBGRADE TO A DENSITY OF APPROXIMATELY THAT OF THE SURROUNDING UNDISTURBED SOIL.
9. PLACE NON−WOVEN GEOTEXTILE FILTER FABRIC UNDER ALL HEAVY ROCK RIPRAP. PROVIDE A MINIMUM OF 400mm OVERLAP FOR JOINING TWO PIECES OF GEOTEXTILE TOGETHER. EXTEND GEOTEXTILE AT A MINIMUM OF 150mm BEYOND EDGES OF RIPRAP AND EMBED AT A MINIMUM 100mm AT SIDES OF RIPRAP.
10. AT THE CULVERT INLET, THREE LARGE CLASS 2 ROCK RIPRAP WILL BE PLACED IN ACCORDANCE WITH THE OWNER'S AUTHORIZED REPRESENTATIVE DIRECTION. THE INTENT OF THE CLASS 2 RIPRAP ROCKS IS TO PROVIDE A RESTING AREA FOR FISH. THE ROCK RIPRAP SHALL BE PLACED SO THAT THE TOP OF THE ROCKS ARE AT ELEVATION OF APPROXIMATELY 340.45m AND WILL BE PLACED TO MINIMIZE IMPACT TO THE FLOW.
11. IN THE OUTLET LOW FLOW CHANNEL, RECLAIMED SUBSTRATE BED MATERIAL SHALL BE PLACED WITHIN THE INTERSTITIAL SPACES BETWEEN THE ROCKS TO PROVIDE A CHANNEL FOR FISH MIGRATION. RECLAIMED SUBSTRATE BED MATERIAL SHALL ALSO BE PLACED WITHIN THE CULVERT.
    A. ESTIMATED SURFACE AREA COVERED BY FILTER FABRIC – 244m²
    B. ESTIMATED QUANTITY OF CLASS 1 ROCK RIPRAP – 60.2m³
    C. ESTIMATED QUANTITY OF CLASS 2 ROCK RIPRAP – 88.3m³

SUBSTRATE HOLDERS

12. SUBSTRATE HOLDERS TO BE PLACED AT A SPACING OF 1.8m. THE FIRST INTERIOR SUBSTRATE HOLDER AT THE OUTLET SHOULD BE LOCATED AS CLOSE TO THE DOWNSTREAM CULVERT OUTLET AS POSSIBLE AND SPACED ACCORDINGLY FROM THAT POINT TO THE INLET.
13. THE TOP OF THE SUBSTRATE HOLDERS HAVE BEEN DESIGNED TO BE APPROXIMATELY 0.6m ABOVE THE CULVERT INVERT AND ALIGNED WITH THE NATURAL WATERCOURSE BED AT THE INLET AND OUTLET. THE FINAL HEIGHT OF THE SUBSTRATE HOLDERS (INLET=340.0m AND OUTLET=339.51m) WILL PARALLEL THE NATURAL WATERCOURSE BED. TO ENSURE THE TOP OF THE SUBSTRATE HOLDERS ARE ALIGNED WITH THE NATURAL WATERCOURSE BED AT THE INLET AND OUTLET, THE HEIGHT OF EACH SUBSTRATE HOLDER SHALL BE MEASURED AND CUT UPON COMPLETION OF THE INSTALLATION OF THE NEW 3.0m BORED CULVERT.
14. A NOTCH IS TO BE INSTALLED IN THE SUBSTRATE HOLDERS TO PROVIDE FOR FISH PASSAGE DURING LOW FLOWS. THE NOTCH SHALL BE CENTERED IN THE SUBSTRATE HOLDER AND MEASURE 200mm DEPTH BY 300mm WIDTH.
15. SUBSTRATE HOLDERS SHALL BE A MINIMUM OF 10mm THICK CARBON STEEL PLATE AND TO BE CONTINUOUSLY WELDED ALONG THE EDGE OF THE PLATE TO THE CULVERT PIPE BODY. THE WELD SHALL BE A MIN. 10mm FILLET WELD.
16. RECLAIMED SUBSTRATE BED MATERIAL SHALL BE PLACED TO A THICKNESS OF 50mm ALONG THE BOTTOM OF THE CULVERT BETWEEN THE SUBSTRATE HOLDERS.

HIGHWAY EMBANKMENT STABILIZATION AND BACKFILL AREAS

17. ALL EMBANKMENTS SHALL BE GRADED TO A SLOPE OF 1.5 HORIZONTAL TO 1 VERTICAL OR SHALLOWER UNLESS OTHERWISE NOTED.
18. NON−ORGANIC CLAY SHALL BE USED FOR THE BACKFILL MATERIAL. ALL BACKFILL MATERIAL SHALL BE FREE FROM FROZEN LUMPS AND ORGANIC MATERIAL. BACKFILL MATERIAL SHALL BE APPROVED BY OWNER'S AUTHORIZED REPRESENTATIVE PRIOR TO CONSTRUCTION.
19. THE AMOUNT OF FILL REQUIRED WILL VARY ACCORDING TO THE TYPICAL CROSS−SECTION SHOWN ON THE DRAWING.
20. TO ENSURE A PROPER BOND BETWEEN THE EXISTING AND NEW MATERIAL, VEGETATION ALONG THE SIDESLOPE SHALL BE REMOVED AND THE TOPSOIL EXCAVATED AND SALVAGED. THE SURFACE SHALL BE SCARIFIED TO A DEPTH OF 0.15m.
21. ALL MATERIAL PLACED IN EMBANKMENTS SHALL BE SPREAD AND BLADED SMOOTH IN SUCCESSIVE LAYERS, NOT TO EXCEED 0.15m WHEN COMPACTED AND TO THE FULL WIDTH OF THE CROSS−SECTION. EACH LAYER SHALL BE COMPACTED TO A MINIMUM OF 95 PERCENT OF STANDARD PROCTOR DENSITY AT OPTIMUM MOISTURE CONTENT.

NON−WOVEN GEOTEXTILE FILTER FABRIC	
SPECIFICATIONS AND PHYSICAL PROPERTIES	
	CLASS 1M, 1, 2, 3
GRAB STRENGTH	900 N
ELONGATION (FAILURE)	50%
CBR PUNCTURE STRENGTH	550 N
TRAPEZOIDAL TEAR	350 N
MINIMUM FABRIC LAP TO BE 400mm	

REFERENCE DOCUMENT NO.	DATE
1. 80754 KM40	2021-09-16
2. 2567-EG-0303	2022-04-08
3. 2567-EG-0304	2022-04-08
4. 2567-EG-0306	2022-04-08
5. 2567-EG-0307	2022-04-08
6. 2567-EG-0308	2022-04-08

CCI

ENGINEER AND PERMIT STAMPS

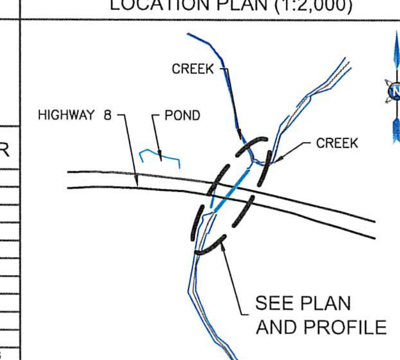
PROFESSIONAL GEOSCIENTIST
N.P. BOELHOUWER
LICENSEE
REGISTERED
NT/NU

#L4934
2022-05-11

1:250
M 0 5 10 15 20 25
FT 0 10 20 30 40 50 60 70 80 90

DRAWING STATUS	DATE	DRN	CHK	DES	GEO	APR	CR
ISSUED FOR PERMIT	2022-04-08	AN	MAL	NB	N/A	JLT	ES
ISSUED FOR REVIEW	2022-04-06	AN	MAL	NB	N/A	JLT	ES

LOCATION PLAN (1:2,000)



UTM - ZONE 8 - NAD 83 (CSRS)

Northwest Territories

GOVERNMENT OF THE NWT
DEPARTMENT OF INFRASTRUCTURE

HIGHWAY 8 CULVERT REPLACEMENT PROJECT
HIGHWAY 8 - KM 266.1 CULVERT INSTALLATION
SUBSTRATE DETAIL AND NOTES
INUVIK - NWT

SCALE	DWG. #	REVISION	SHEET
AS SHOWN	2567-EG-0305	B	5 OF 8

File Name: S:\Current Jobs\2567-Gov of NWT-CulvertDesign\Eng\Drawings\03-Highway 8 – KM 40.2\VFP\2567-EG-0301-B BORE_PHASES_NOTES.dwg Date/Time: 2022-04-22 / 2:01:09 PM Last Saved By: Abdulkadir.Nur

REFEREN□E DO□□MENT NO□	DATE
1□ □0□5□KM□0	□0□1□0□1□
□□ □5□□E□□0□0□	□0□□□0□□0□
□□ □5□□E□□0□0□	□0□□□0□□0□
□□ □5□□E□□0□05	□0□□□0□□0□
5□ □5□□E□□0□0□	□0□□□0□□0□
□□ □5□□E□□0□0□	□0□□□0□□0□

CCI

EN□INEER AND PERMIT STAMPS

PRELIMINARY NOT FOR CONSTRUCTION

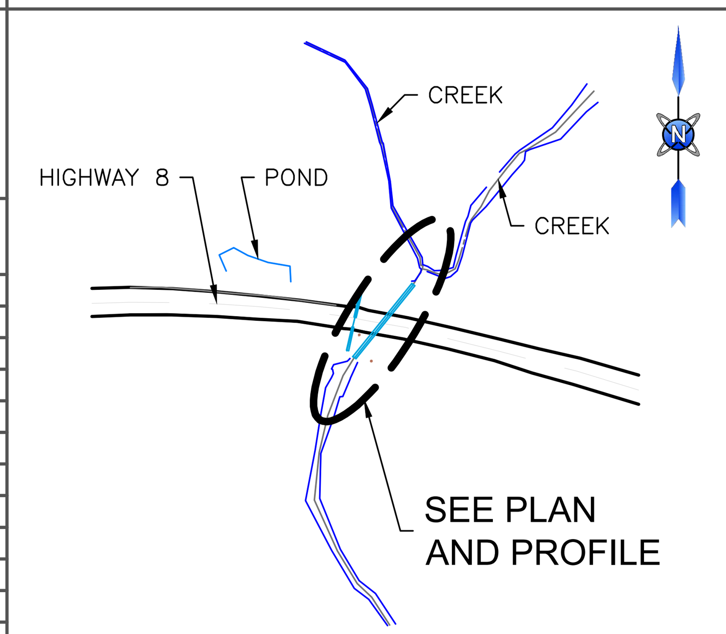
PIPELINE SPE□IFI□ATIONS

	NPS 11□
O□TSIDE DIAMETER (OD)(mm)	3000
□ALL T□I□KNESS (□T)(mm)	25.4
□RADE	GRADE 3
PROD□□T	CULVERT
MATERIAL	STEEL
SPE□IFI□ATIONS	ASTM A252

1:200
M 0 5 10 15 20
FT 0 10 20 30 40 50 60 70

DRA□ IN□ STAT□S	DATE	DRN	□□K	DES	□EO	APR	□R
ISS□ED FOR PERMIT	□0□□□0□□0□	AN	MAL	NB	N□A	□LT	ES
ISS□ED FOR RE□IE□	□0□□□0□□0□	AN	MAL	NB	N□A	□LT	ES

LO□ATION PLAN (1:□000)



□TM □□ONE □ □NAD □□ (□SRS)

Northwest Territories

GOVERNMENT OF THE NWT
DEPARTMENT OF INFRASTRUCTURE

□I□□□ AY □ □□L□ERT REPLA□EMENT PRO□E□T
□I□□□ AY □ □KM □0□□A□□ER BORE □ROSSIN□
P□ASE I □ II
IN□□IK □N□T

S□ALE	D□ □□□	RE□ISION	S□EET
AS S□O□N	□5□□E□□0□0□	B	□OF □

PLAN : P□ASE III

S□ALE 1:□00

□ENERAL NOTES

1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE SPECIFIED.
2. THE ISOLATION SHALL BE CONSTRUCTED TO MANAGE A MINIMUM CONSTRUCTION DESIGN DISCHARGE OF $0.5m^3/s$.
3. ALL WORK SHALL BE DONE IN ACCORDANCE WITH GOVERNMENT OF THE NORTHWEST TERRITORIES, DEPARTMENT OF TRANSPORTATION – EROSION AND SEDIMENT CONTROL MANUAL.
4. CONTRACTOR TO VERIFY ALL INVERTS OF EXISTING STRUCTURES PRIOR TO COMMENCING WORK. CONTRACTOR TO REPORT TO THE OWNER'S REPRESENTATIVE ANY DISCREPANCIES BETWEEN THE MEASURED INVERTS AND THE PIPE LOCATIONS SHOWN ON DRAWINGS PRIOR TO COMMENCING WORK.
5. CONTRACTOR TO PROVIDE ALL CONSTRUCTION EXECUTION PLANS, INCLUDING THE ENVIRONMENTAL MANAGEMENT PLAN AND EROSION AND SEDIMENT CONTROL PLAN, FOR REVIEW AND ACCEPTANCE PRIOR TO CONSTRUCTION.

P□ASE I: □□L□ERT INSTALLATION SITE PREPARATION

6. INSTALL PUMPS ON THE INLET (NORTH) SIDE OF THE CROSSING, IN THE EAST FORK OF THE CHANNEL, THAT WILL ACCOMMODATE THE VOLUME OF FLOW IN THE WATERCOURSE, EAST OF THE JACKING FRAME LOCATION.
7. STRING HOSES FROM THE EAST FORK TO THE WEST FORK OF THE WATERCOURSE AT A LOCATION WHERE SCOURING AND DOWNSTREAM SEDIMENTATION FROM DISCHARGE ENERGY IS MITIGATED.
8. DAM THE EAST FORK OF THE WATERCOURSE AND INITIATE BYPASS OPERATIONS TO THE WEST FORK OF THE WATERCOURSE. ENSURE PUMP CAPACITY IS EQUAL TO THE VOLUME OF WATER TRAVELING THROUGH THE WATERCOURSE.
9. CONSTRUCT AN ISOLATION DAM ON THE INLET (NORTH) SIDE OF THE CROSSING IMMEDIATELY EAST OF THE EXISTING CULVERT. KEY THE DAM INTO THE ROAD EMBANKMENT BESIDE THE CULVERT TO THE NORTH EDGE OF THE CHANNEL DIRECTLY ACROSS FROM THE CULVERT. ALL ADVICE AND BEST PRACTICES CONTAINED IN DEPARTMENT OF FISHERIES AND OCEANS CANADA'S (DFO) INTERIM CODE OF PRACTICE: TEMPORARY COFFERDAMS AND DIVERSION CHANNELS WILL BE APPLIED.
10. CONSTRUCT A WORK AREA ON THE INLET (NORTH) SIDE OF THE CROSSING.
    - A. STAKE OUT THE LOCATION OF THE JACKING FRAME.
    - B. SALVAGE SURFICIAL SOILS FROM THE JACKING FRAME WORK AREA AND STOCKPILE AWAY FROM THE WATERCOURSE.
    - C. REMOVE GRADE CUTS FROM THE WORK AREA AND STOCKPILE AWAY FROM THE CROSSING SEPARATELY FROM THE SALVAGED SURFICIAL SOILS.
    - D. CONSTRUCT THE JACKING FRAME.
    - E. WHEN THE JACKING FRAME IS COMPLETE, CONSTRUCT A DIVERSION CHANNEL AROUND THE NORTH SIDE OF THE FRAME AND LINE WITH ROCK COBBLE.
    - F. WITH THE DIVERSION CHANNEL COMPLETE, REMOVE THE DAM, DISCONTINUE PUMP AROUND OPERATIONS AND ALLOW WATER TO FLOW AROUND THE JACKING FRAME TO THE WEST FORK AND THROUGH THE EXISTING CULVERT.
    - G. PLACE EQUIPMENT ON THE WORK AREA.
    - H. INSTALL SILT FENCING WHERE REQUIRED ON THE EDGE OF THE WORK AREA TO MITIGATE POTENTIAL SEDIMENTATION INTO THE WATERCOURSE.
11. CONSTRUCT AN ISOLATION DAM ON THE OUTLET (SOUTH) SIDE OF THE CROSSING. ALL ADVICE AND BEST PRACTICES CONTAINED IN THE DFO'S INTERIM CODE OF PRACTICE: TEMPORARY COFFERDAMS AND DIVERSION CHANNELS WILL BE APPLIED.
12. CONSTRUCT A WORK AREA ON THE OUTLET SIDE OF THE CROSSING.
    - A. INSTALL THE ISOLATION DAM FROM THE EAST EDGE OF THE EXISTING CULVERT, EXTENDING ACROSS THE WATERCOURSE AND KEY INTO THE EAST BANK OF THE CHANNEL, DIRECTLY ACROSS FROM THE EAST EDGE OF THE CULVERT.

P□ASE II: □□L□ERT INSTALLATION

13. INSTALL 3m CULVERT (2567–EG–0301).
14. COMPLETE THE RECLAMATION OF THE INLET AND OUTLET SIDES OF THE 3m CULVERT WHILE STILL ISOLATED.
15. REMOVE ANY DEPOSITED SEDIMENT FROM WITHIN THE ISOLATED WORKSITE AND ENSURE ANY DISTURBED INSTREAM AREAS HAVE BEEN STABILIZED PRIOR TO REMOVAL.
16. MAINTAIN SEDIMENT CONTROL MEASURES DURING REMOVAL AND RE–WATERING OF INSTREAM WORKSITE.
    - A. INLET SIDE:
        - REMOVE THE TRENCHLESS EQUIPMENT AND JACKING FRAME ON THE INLET SIDE OF THE 3m CULVERT.
        - INSTALL PUMPS IN THE EAST FORK OF THE WATERCOURSE, NORTHEAST OF THE JACKING FRAME LOCATION, THAT WILL HANDLE THE VOLUME OF FLOW IN THE WATERCOURSE.
        - STRING HOSES FROM THE PUMP LOCATION TO THE WEST FOR OF THE WATERCOURSE TO A LOCATION WHERE SCOURING AND DOWNSTREAM SEDIMENTATION FROM DISCHARGE ENERGY IS MITIGATED.
        - INSTALL A DAM ON THE SOUTH SIDE OF THE JACKING FRAME AND INITIATE PUMP AROUND OF WATER FROM TO THE WEST FORK.
        - WIDEN THE CHANNEL ON THE INLET SIDE TO ACCOMMODATE FLOW TO THE INSTALLED 3m CULVERT.
        - RECONTOUR THE CHANNEL OF THE ORIGINAL EAST FORK OF THE CREEK CHANNEL.
        - RE–ESTABLISH FLOW THROUGH THE EAST FORK OF THE CREEK CHANNEL
        - INSTALL ROCK RIP RAP AND ARMOUR THE CHANNEL AND CONTOURED BANK TO THE WATER LINE.
        - SEED AND PLACE COCONUT MATTING OVER THE BANK ABOVE THE WATER LINE (2567–EG–0303).
    - B. OUTLET SIDE:
        - COMPLETE THE OUTLET APRON ON THE OUTLET END OF THE 3m CULVERT.
        - INSTALL ROCK RIP RAP AND ARMOUR THE CHANNEL AND CONTOURED BANKS TO THE WATER LINE (2567–EG–0304).
        - SEED AND PLACE COCONUT MATTING OVER THE BANK ABOVE THE WATER LINE.

P□ASE III: EXISTIN□ □□L□ERT DE□OMMISSIONIN□

17. MOVE THE ISOLATION DAM ON THE INLET (NORTH) SIDE OF THE CROSSING, ISOLATING THE EXISTING CULVERT AND ALLOWING THE WATER TO MOVE FROM THE ISOLATED AREA THROUGH THE INSTALLED 3m CULVERT, PRIOR TO COMPLETING THE ISOLATION TO THE EDGE OF THE 3m CULVERT.
18. INSTALL THE ISOLATION DAM ALONG THE EAST EDGE OF THE NEWLY CONTOURED OUTLET CHANNEL, EAST OF THE 3m CULVERT.
19. CONSTRUCT A WORK AREA ON THE OUTLET SIDE OF THE CROSSING.
    - A. LEVEL THE OUTLET SIDE OF THE EXISTING CULVERT.
    - B. PLACE GROUTING EQUIPMENT ON THE WORK AREA.
    - C. INSTALL SILT FENCING WHERE REQUIRED ON THE EDGE OF THE WORK AREA TO MITIGATE POTENTIAL SEDIMENTATION INTO THE WATERCOURSE.
20. GROUT THE EXISTING CULVERT.
21. COMPLETE THE RECLAMATION OF THE OUTLET SIDE OF THE DECOMMISSIONED EXISTING CULVERT WHILE STILL ISOLATED.
22. REMOVE ANY DEPOSITED SEDIMENT FROM WITHIN THE ISOLATED WORKSITE AND ENSURE ANY DISTURBED INSTREAM AREAS HAVE BEEN STABILIZED PRIOR TO REMOVAL.
23. MAINTAIN SEDIMENT CONTROL MEASURES DURING REMOVAL AND RE–WATERING OF INSTREAM WORKSITE.
    - A. OUTLET SIDE:
        - REMOVE EQUIPMENT ON OUTLET SIDE OF THE EXISTING CULVERT.
        - COMPLETE THE OUTLET APRON ON THE OUTLET END OF THE EXISTING CULVERT.
        - INSTALL ROCK RIP RAP AND ARMOUR THE CHANNEL AND CONTOURED BANKS TO THE WATER LINE.
        - INSTALL SILT FENCING ALONG THE TOE OF THE ROAD SLOPE, BETWEEN THE ROAD FILL AND THE ROCK ARMOUR.
        - REMOVE ISOLATION DAM ON THE OUTLET SIDE.
        - COMPLETE THE REMAINDER OF THE OUTLET APRON THROUGH THE PLACEMENT OF ROCK RIP RAP, WHERE REQUIRED.
    - B. INLET SIDE
        - COMPLETE FINAL RECONTOURING AND CHANNEL/BANK ARMOURING ON THE INLET SIDE OF THE EXISTING CULVERT.
        - INSTALL SILT FENCING AND SEED DISTURBED AREAS ON THE INLET SIDE OF THE CROSSING.
        - INSTALL SILT FENCING ALONG THE OUTLET APRON EDGE.
        - COMPLETE SEEDING AND COCONUT MATTING INSTALLATION OVER WORK AREA ON THE OUTLET SIDE.

P□ASE I□ □FINAL RE□LAMATION

24. DEPENDING ON THE SOIL TYPES AND THE PROJECT FOOTPRINT LOCATED AT THE CROSSING LOCATION, ADDITIONAL RECLAMATION MEASURES MAY BE REQUIRED ON THE OUTLET AND INLET SIDE OF THE CROSSING. THESE ADDITIONAL MEASURES CAN INCLUDE:
    - A. STREAMBANK RESTORATION THROUGH THE INSTALLATION OF LIFTS AND JUTE WRAP, WITH WILLOWS PLACED BETWEEN LIFTS.
    - B. WILLOW STAKING ON THE WATERCOURSE BANKS TO STABILIZE DISTURBED AREAS AND PROMOTE REGROWTH.
    - C. ADDITIONAL SILT FENCING WILL BE INSTALLED TO AVOID THE POTENTIAL MOVEMENT OF SOILS AND SEDIMENTATION OF THE WATERCOURSE.
    - D. ADDITIONAL SEEDING OR INSTALLATION OF COCONUT MATTING TO PROMOTE EXPEDITED REGROWTH AND STABILIZATION OF THE PROJECT FOOTPRINT.

REFEREN□E DO□□MENT NO□	DATE
1□ 1□□0□PPP Dra□ti□□	□0□0□0□□1□
□□ □5□□0□□API 110□□00	□0□0□05□1□
□□ □5□□E□□0□0□	□0□□□0□□0□
□□ □5□□E□□0□0□	□0□□□0□□0□
5□ □5□□E□□0□05	□0□□□0□□0□
□□ □5□□E□□0□0□	□0□□□0□□0□
□□ □5□□E□□0□0□	□0□□□0□□0□

CCI

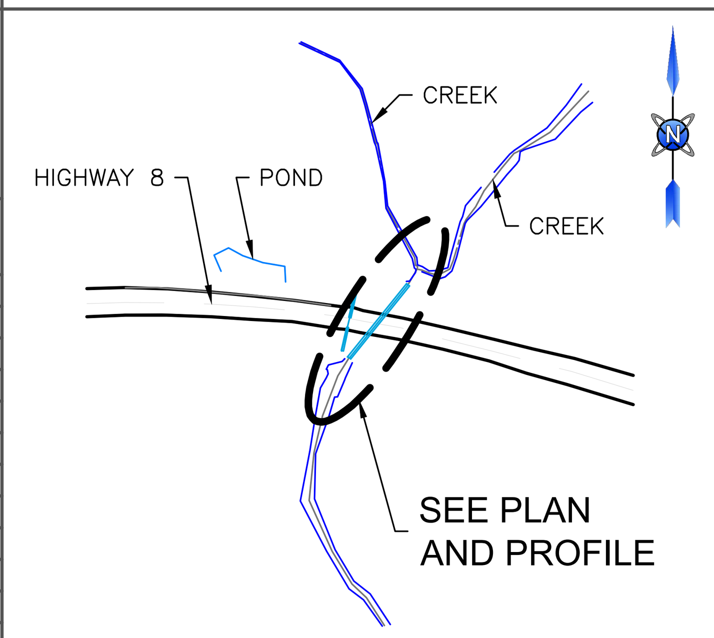
EN□INEER AND PERMIT STAMPS

PRELIMINARY NOT FOR CONSTRUCTION

1:200
M 0 5 10 15 20
FT 0 10 20 30 40 50 60 70

DRA□ IN□ STAT□S	DATE	DRN	□□K	DES	□EO	APR	□R
ISS□ED FOR PERMIT	□0□□0□0□	AN	MAL	NB	N□A	□LT	ES
ISS□ED FOR RE□IE□	□0□□0□0□	AN	MAL	NB	N□A	□LT	ES

LO□ATION PLAN (1:□000)



□TM □□ONE □ □NAD □□ (□SRS)

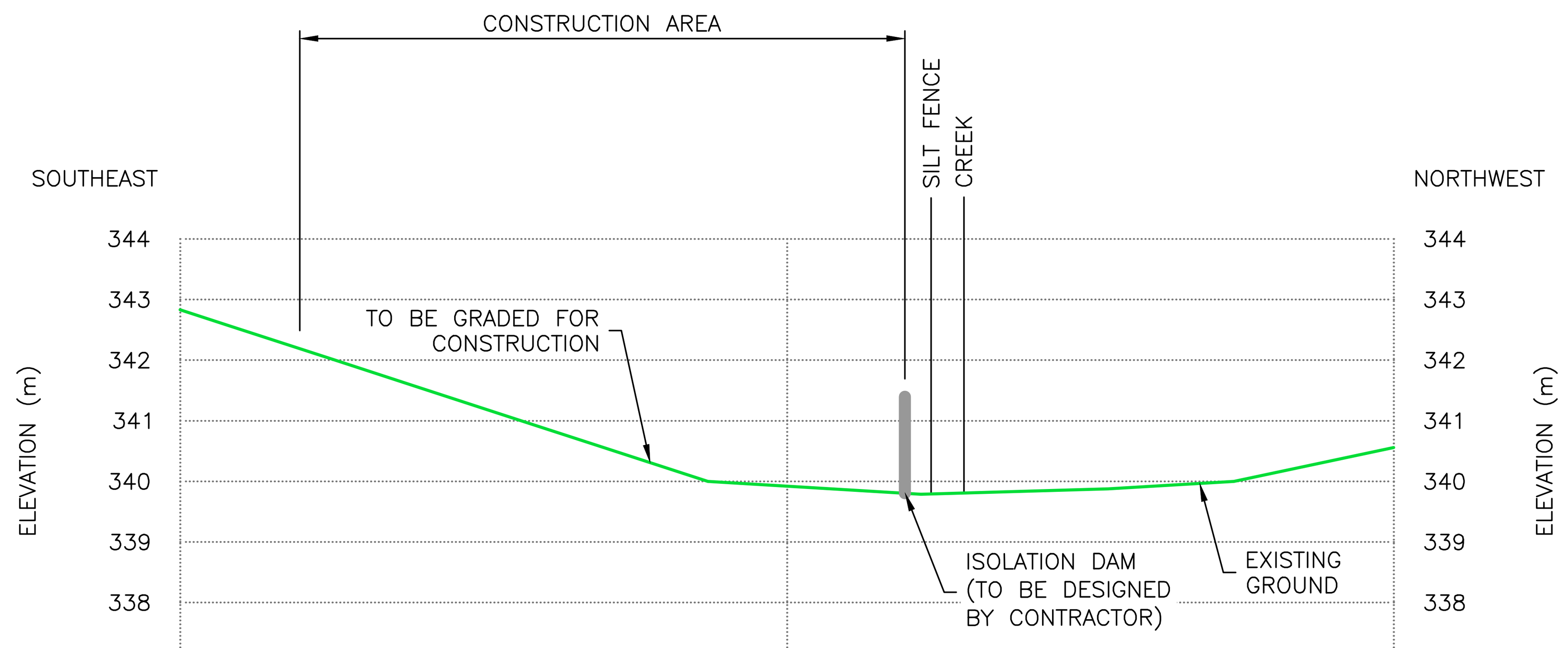
Northwest Territories

GOVERNMENT OF THE NWT
DEPARTMENT OF INFRASTRUCTURE

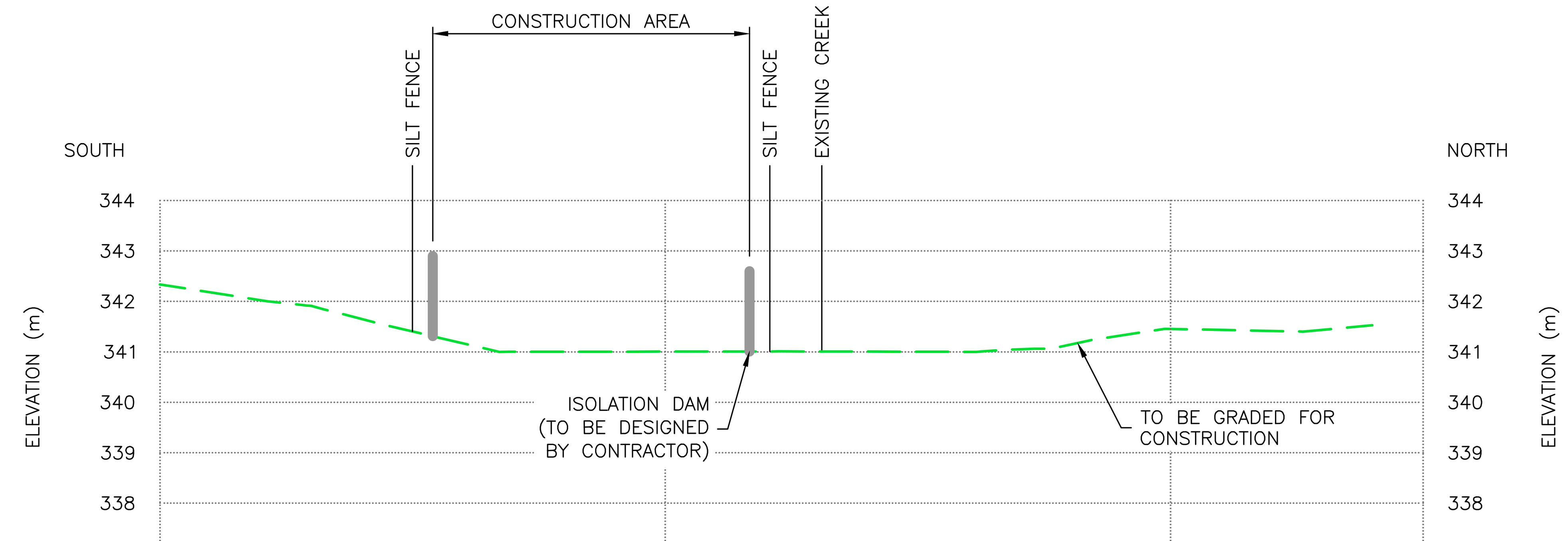
□I□□□ AY □ □□L□ERT REPLA□EMENT PRO□E□T
□I□□□ AY □ □KM □0□□A□□ER BORE □ROSSIN□
P□ASE III AND NOTES
IN□□IK □N□ T

S□ALE	D□ □□□	RE□ISION	S□EET
AS S□O□ N	□5□□E□□0□0□	B	□OF □

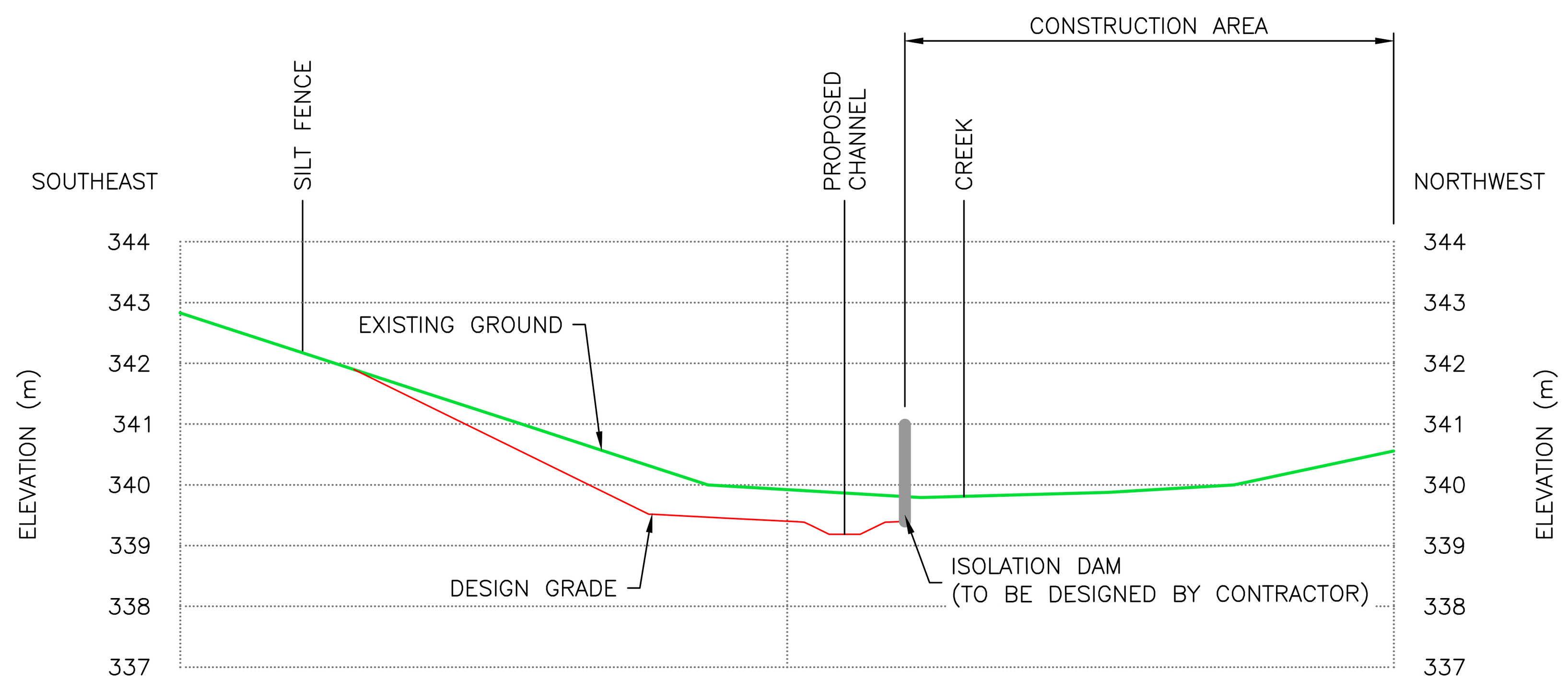
File Name: S:\Current Jobs\2567–Gov of NWT–CulvertDesign\Eng\Drawings\03–Highway 8 – KM 40.2\VFP\2567–EG–0301–B BORE_PHASES_NOTES.dwg Date/Time: 2022–05–03 / 10:41:33 AM Last Saved By: Abdulkadir.Nur



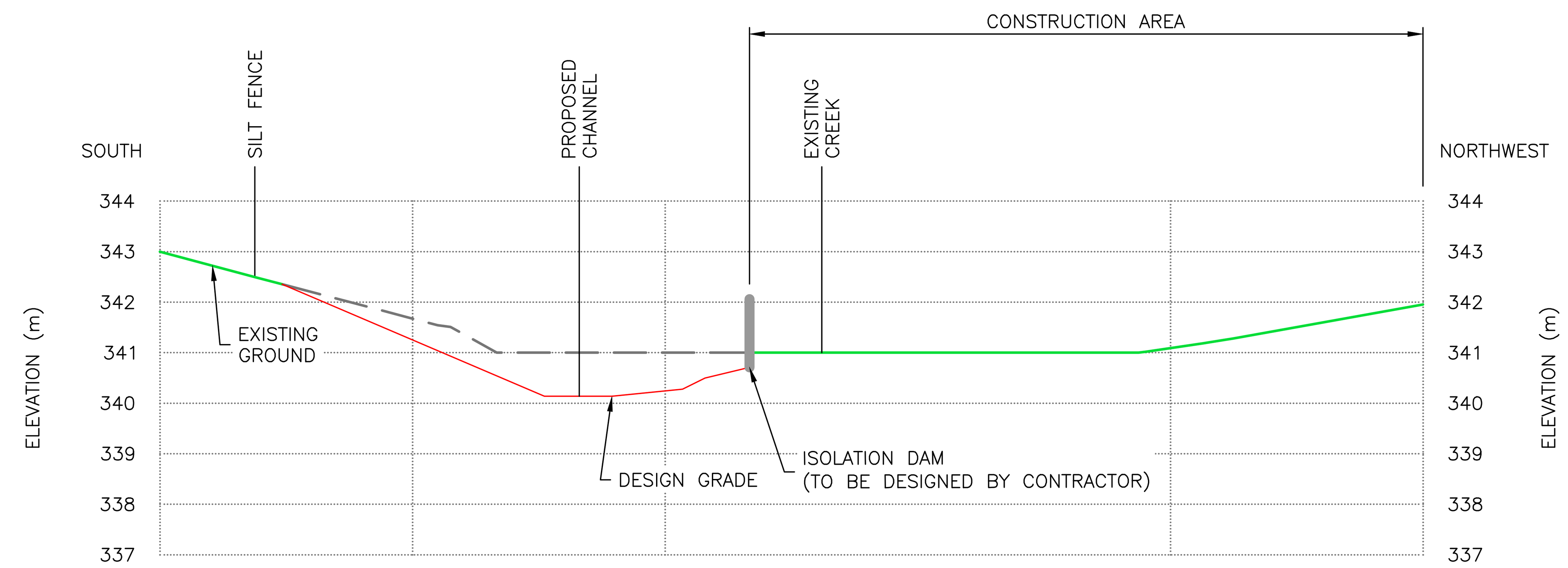
F□F P□ASE I O□TLET DETAIL
S□ALE 1:100



□□ P□ASE I INLET DETAIL
S□ALE 1:100



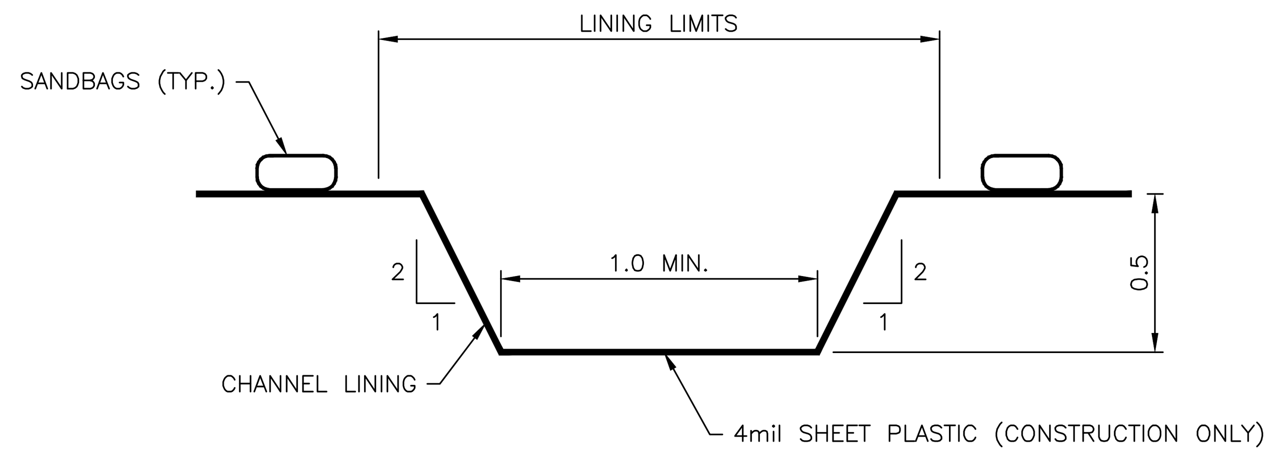
□□ P□ASE II O□TLET DETAIL
S□ALE 1:100



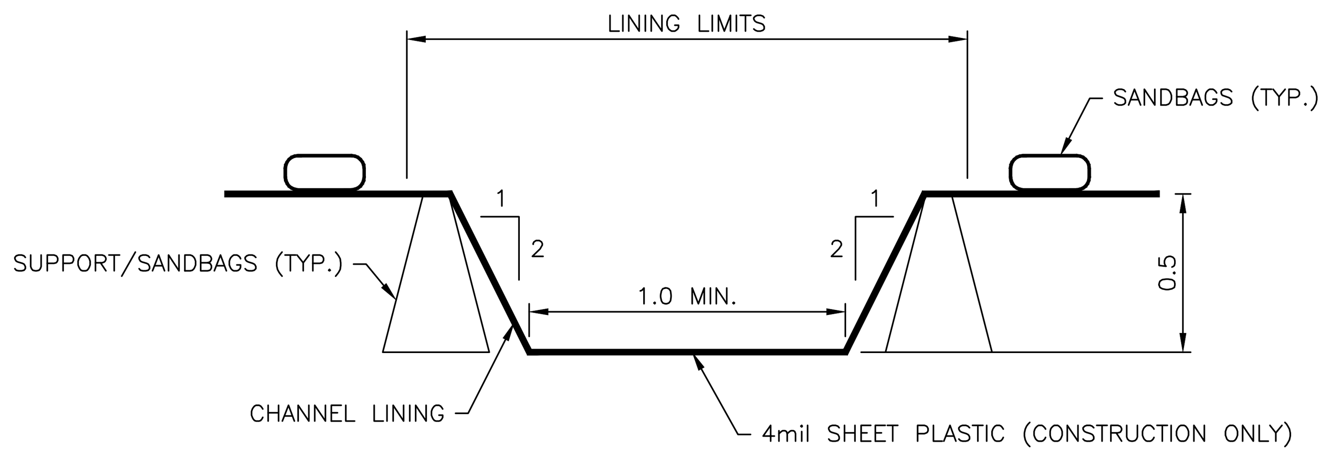
I-I P□ASE II INLET DETAIL
S□ALE 1:100

- FOR PLAN DETAIL, SEE DRAWING# 2567-EG-0206.

□ENERAL NOTES
- CHANNEL MUST MAINTAIN FLOW AT A MINIMUM GRADE OF 1%.
- CONTRACTOR PLANS ARE TO BE SUBMITTED FOR APPROVAL PRIOR TO CONSTRUCTION (SEE NOTE 5 ON DRAWING 2567-EG-0307).



ISOLATION OPTION A
S□ALE 1:□0



ISOLATION OPTION B
S□ALE 1:□0

REFEREN□E DO□□MENT NO□	DATE
1□ 1□□0□PPP Dra□i□□	□0□0□1□
□□ □5□□0□API 110□00	□0□0□5□1□
□□ □5□□E□0□0□	□0□□0□0□
□□ □5□□E□0□0□	□0□□0□0□
5□ □5□□E□0□05	□0□□0□0□
□□ □5□□E□0□0□	□0□□0□0□
□□ □5□□E□0□0□	□0□□0□0□

CCI

EN□INEER AND PERMIT STAMPS

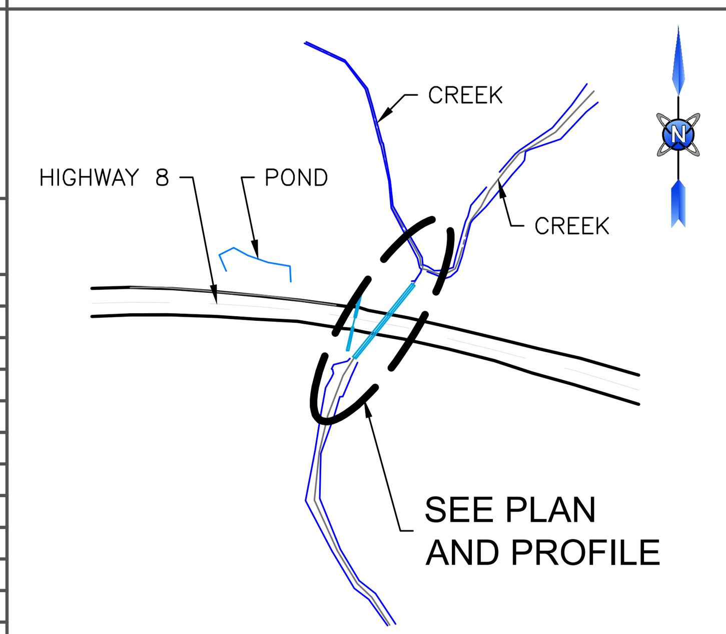
PRELIMINARY NOT FOR CONSTRUCTION

1:20 M 0 1 2 FT 0 1 2 3 4 5 6

1:100 M 0 5 10 FT 0 10 20 30

DRA□IN□ STAT□S	DATE	DRN	□□K	DES	□EO	APR	□R
ISS□ED FOR PERMIT	□0□□0□0□	AN	MAL	NB	N/A	□LT	ES
ISS□ED FOR RE□IE□	□0□□0□0□	AN	MAL	NB	N/A	□LT	ES

LO□ATION PLAN (1:□000)



□TM □□ONE □ □NAD □□ (□SRS)

Northwest Territories

GOVERNMENT OF THE NWT
DEPARTMENT OF INFRASTRUCTURE

□I□□□ AY □□□L□ERT REPLA□EMENT PRO□E□T
□I□□□ AY □□KM □0□A□□ER BORE □ROSSIN□
P□ASE I □ II PROFILES
IN□□IK □N□T

S□ALE	D□ □□□	RE□ISION	S□EET
AS S□O□N	□5□□E□0□0□	B	□OF □

File Name: S:\Current Jobs\2567-Gov of NWT-CulvertDesign\Eng\Drawings\03-Highway 8 - KM 40.2\FP\2567-EG-0301-B BORE_PHASES_NOTES.dwg Date/Time: 2022-04-22 / 2:01:09 PM Last Saved By: Abdulkadir.Nur