APPENDIX F

GEOPHYSICAL FUNDAMENTALS

Resistivity Fundamentals

The physics of mapping permafrost have not changed over time. Many of the geophysical techniques which have been successfully employed in permafrost terrain have been available for some time. Fixed frequency electromagnetic (FEM) instrumentation was originally developed to map permafrost distribution for the Mackenzie Valley Pipeline in the mid 1970's. Ground penetrating radar (GPR) was initially used by the Geologic Survey of Canada in the Mackenzie Delta region, and by Northern Engineering in the Norman Wells and Fort Simpson regions in the mid 1970's. Electrical resistivity methods were used in the early 1970's, but suffered due to contact resistance problems due to the frozen ground. The instrumentation has undergone some improvements over time, but methods such as electrical resistivity are still hampered by contact resistance problems, particularly during winter exploration programs. Newly available systems such as the capacitively coupled resistivity systems (VCHEP and OhmMapper) offer a means to collect resistivity data without the contact resistance problems encountered by other resistivity systems.

For any geophysical technique to be successfully employed, there must be a mappable contrast in physical properties. For permafrost, the physical properties of interest include: electrical, acoustic, and dielectric constant. Previous research has provided good evidence of the contrasts in these properties with variations in temperature and ice content (Hoekstra et al, 1975, Rennie et al 1978, Rosenburg et al, 1984). In the case of the electrical properties, as the temperature of the subsurface decreases below 0 Centigrade (C), and/or as the ice content increases, the resistivity of subsurface materials increases substantially as illustrated in Figures 1a and 1b.

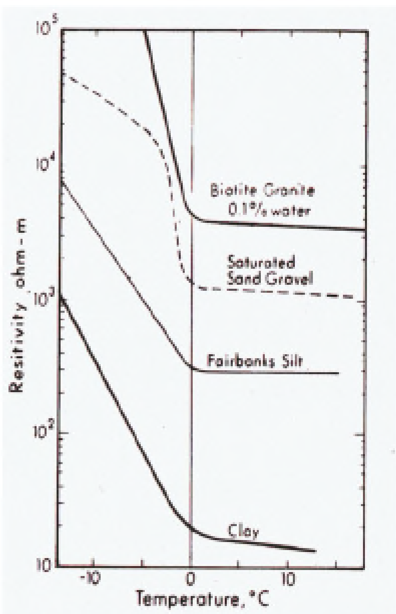

FIGURE 1a Relationship between

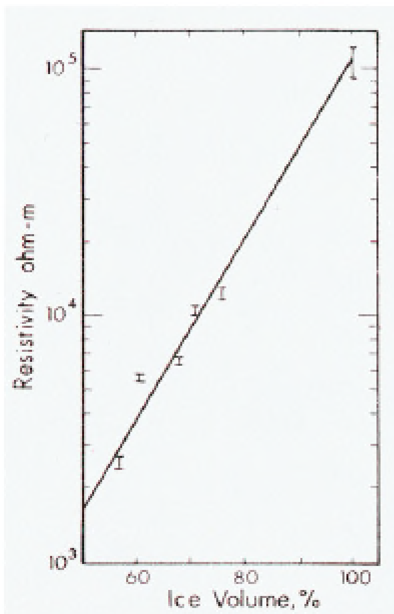

FIGURE 1b Relationship between

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Figure 2 illustrates ranges of resistivity for both frozen and unfrozen soil types in the vicinity of Fort Simpson, NT. It should be noted that there is considerable overlap of resistivity values for the various soil types.

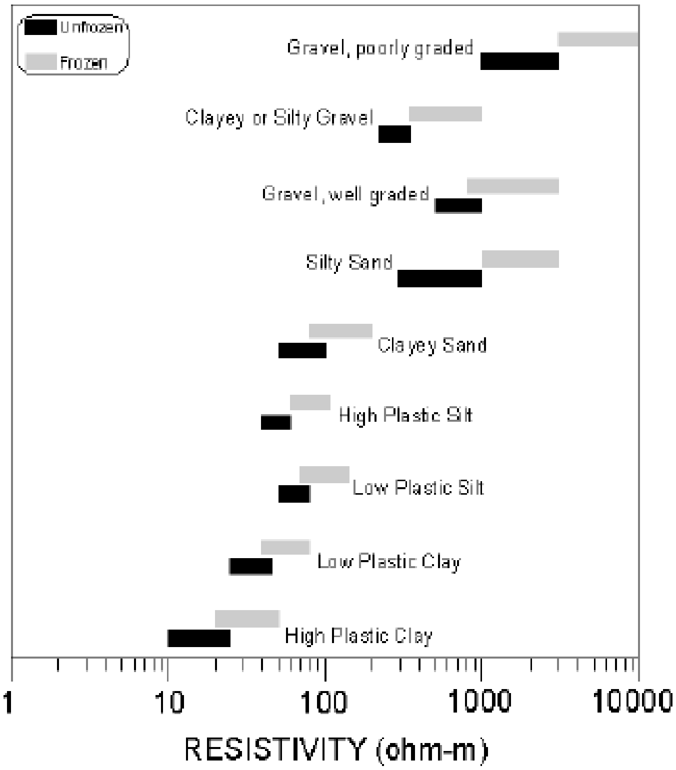


FIGURE 2 Range of resistivity values for frozen and unfrozen soils types in the Ft. Simpson, NT region (J.A. Rennie, D.E. Reid & J. Henderson; 1978)

This can make it difficult to distinguish between variations in soil/bedrock type and variations in ice content. Conversely, if one knows the nature of the soil/bedrock type, the resistivity measured can be used to determine whether it is frozen or not. Given a known soil/bedrock type, the areas showing higher resistivity values would be expected to be frozen.

GPR Fundamentals

Ground penetrating radar is a non-destructive geophysical technique capable of delineating materials that have contrasting bulk electrical properties. Operationally, GPR systems transmit a short duration electromagnetic (EM) pulse into the ground generating a downward propagating wave front. At each interface, a portion of the wave front energy is reflected back to the surface. A radar receiver, located at the surface, detects (and typically digitally samples and records) the reflected EM pulse. The detected pulse amplitude and delay time are a function of the subsurface electrical properties. The strength of the reflected signal is approximately proportional to the difference in dielectric contrasts at the reflecting interface. The pulse transmit/receive delay time is inversely proportional to the EM propagation velocity (determined by the bulk electrical properties), and proportional to the distance from the receiver at the surface to the reflecting stratigraphic interface (Davis and Annan, 1989). Changes in dielectric constants and electrical conductivity also affect signal attenuation. High conductivities, as found in fine-grained materials such as silts and clays, can increase signal attenuation and limit signal propagation to a few metres or less. Saline (salt water) pore water in otherwise resistive sediments can result in the same effect. Conversely, in areas not affected by excessive signal attenuation, interfaces deeper than 50 m can be detected.

Table 1 shows typical electrical properties of various materials. However, it should be noted that these properties of the materials do vary from site to site. The properties can be approximated site-specifically using ground truth information or by using techniques such as Wide Angle Reflection Refraction (WARR) Sounding.

Table 1: Electrical Properties of Materials (misc. sources)

Material Type	Dielectric Constant	Velocity (m/ns)	Conductivity (mS/m)	Attenuation (dB/m)
Wet Sand	10-30	0.05-0.09	0.2-10	0.03-0.3
Sand	3-5	0.13-0.17	0.01-1	0.01
Silts	5-30	0.05-0.13	0.5-100	1-100
Clay	5-40	0.05-0.13	5-1000	1-300
Ice	3-5	0.13-0.17	0.01-1	0.01-1
Granite	4-6	0.12-0.15	0.001-3	0.01-1
Fresh Water	80	0.033	0.5-2	0.1
Salt Water	80	0.033	$5x10^3$-$3x10^4$	1000

By exploiting the sensitivity to variations in bulk material electrical properties, GPR is an established method for detecting subsurface anomalies and voids, profiling complex geological stratigraphic components, and mapping natural phenomena.

REFERENCES

Davis, J. L. and Annan, A. P., 1989, Ground-penetrating radar for high-resolution mapping of soil and rock stratigraphy: Geophys. Prosp., Eur. Assn. Geosci. Eng., 37, 531-552.

Hoekstra, P.; McNeill J.D. (1973) "Electromagnetic Probing of Permafrost". Proc. Second Intl. Conference on Permafrost. Yakutsk. USSR. pp517-526

Rennie, J.A., Reid, D.E. and Henderson, J. (1978) “Permafrost Distribution on the Southern Fringe of the Discontinuous Zone, Fort Simpson, N.W.T.”. Proc. Fourth Intl. Permafrost Conference.

APPENDIX G

ROCK CORE PHOTOGRAPHS

Description: Borehole P13D-01, 0 m to 5.00m, Dry

Description: Borehole P13D-01, 0 m to 5.00m, Wet

Description: Borehole P13D-02, 0 m to 9.50m, Dry

Description: Borehole P13D-02, 0 m to 9.50m, Wet

TETRA TECH

Description: Borehole P13D-03, 0 m to 8.00m, Dry
Note: Whiteboard in photo is incorrectly labelled and should read as Borehole P13D-03

Description: Borehole P13D-03, 0 m to 8.00m, Wet
Note: Whiteboard in photo is incorrectly labelled and should read as Borehole P13D-03

TETRA TECH

Description: Borehole P13D-04, 0 m to 9.50m, Dry
Note: Whiteboard in photo is incorrectly labelled and should read as Borehole P13D-04

Description: Borehole P13D-04, 0 m to 9.50m, Wet
Note: Whiteboard in photo is incorrectly labelled and should read as Borehole P13D-04

TETRA TECH

Description: Borehole P13D-05, 0 m to 9.00m, Dry

Description: Borehole P13D-05, 0 m to 9.00m, Wet

Description: Borehole P29-01, 0 m to 9.50m, Dry

Description: Borehole P29-01, 0 m to 9.50m, Wet

TETRA TECH

Description: Borehole P29-03, 0 m to 8.00m, Dry

Description: Borehole P29-03, 0 m to 8.00m, Wet

Description: Borehole P29-04, 0 m to 9.50m, Dry

Description: Borehole P29-04, 0 m to 9.50m, Wet

Description: Borehole P29-05, 0 m to 9.50m, Dry

Description: Borehole P29-05, 0 m to 9.50m, Wet

Description: Borehole P29-06, 0 m to 8.00m, Dry

Description: Borehole P29-06, 0 m to 8.00m, Wet

Description: Borehole P29-07, 0 m to 9.50m, Dry

Description: Borehole P29-07, 0 m to 9.50m, Wet

Description: Borehole P29-08, 0 m to 4.30m, Dry

Description: Borehole P29-08, 0 m to 4.30m, Wet

TETRA TECH

Description: Borehole P33A-01, 0 m to 9.50m, Dry

Description: Borehole P33A-01, 0 m to 9.50m, Wet

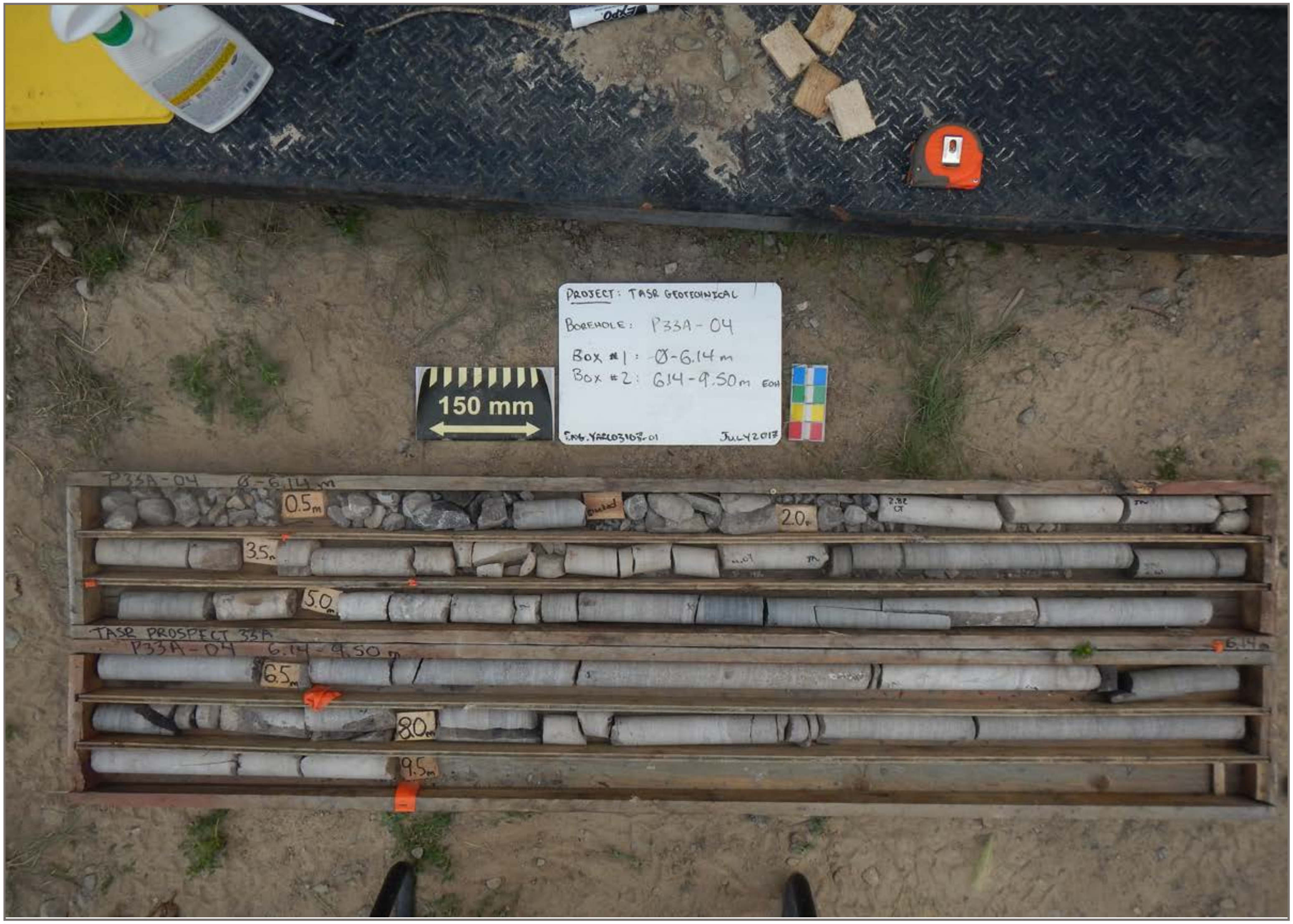
Description: Borehole P33A-02, 0 m to 9.50m, Dry
Note: Whiteboard in photo is incorrectly labelled and should read as Borehole P33A-02

Description: Borehole P33A-02, 0 m to 9.50m, Wet
Note: Whiteboard in photo is incorrectly labelled and should read as Borehole P33A-02

Description: Borehole P33A-03, 0 m to 9.50m, Dry

TETRA TECH

Description: Borehole P33A-03, 0 m to 9.50m, Wet



Description: Borehole P33A-04, 0 m to 9.50m, Dry

Description: Borehole P33A-04, 0 m to 9.50m, Wet

Description: Borehole P33A-05, 0 m to 9.50m, Dry

Description: Borehole P33A-05, 0 m to 9.50m, Wet

Description: Borehole P33A-06, 0 m to 9.50m, Dry

Description: Borehole P33A-06, 0 m to 9.50m, Wet

Description: Borehole P33A-07, 0 m to 9.50m, Dry

Description: Borehole P33A-07, 0 m to 9.50m, Wet

Description: Borehole P33A-08, 0 m to 9.50m, Dry

Description: Borehole P33A-08, 0 m to 9.50m, Wet

Description: Borehole P33A-10, 0 m to 9.50m, Dry

TETRA TECH

Description: Borehole P33A-10, 0 m to 9.50m, Wet

TETRA TECH

Description: Borehole P69-05, 0 m to 11.00m, Dry

Description: Borehole P69-05, 0 m to 11.00m, Wet

TETRA TECH

Description: Borehole P76-03, 0 m to 18.5m, Dry

TETRA TECH

Description: Borehole P76-03, 0 m to 18.5m, Wet

Description: Borehole P86-01A, 0 m to 5.00m, Dry

TETRA TECH

Description: Borehole P86-01A, 0 m to 5.00m, Wet

Description: Borehole P86-01B, 0 m to 3.5m, Dry

TETRA TECH

Description: Borehole P86-01B, 0 m to 3.5m, Wet

Description: Borehole P86-02, 0 m to 9.50m, Dry

TETRA TECH

Description: Borehole P86-02, 0 m to 9.50m, Wet

TETRA TECH

Description: Borehole P86-04, 0 m to 8.80m, Dry

Description: Borehole P86-04, 0 m to 8.80m, Wet

Description: Borehole P86-06, 0 m to 8.00m, Dry

Description: Borehole P86-06, 0 m to 8.00m, Wet

TETRA TECH

Description: Borehole P98-01, 0 m to 6.50m, Dry

TETRA TECH

Description: Borehole P98-01, 0 m to 6.50m, Wet

TETRA TECH

Description: Borehole P105-02, 0 m to 9.00m, Dry

Description: Borehole P105-02, 0 m to 9.00m, Wet

Note: P105-01, no rock core photos were collected, refer to P105-02

APPENDIX H

HYDROTECHNICAL SURVEY TECHNICAL MEMO CROSSING 10A

September 21, 2017

ISSUED FOR REVIEW
FILE: 704-ENG.YARC03107-01

Subject: Tlicho Road. Hydrotechnical Report – Crossing 10a

This 'Issued for Review' document is provided solely for the purpose of client review and presents our interim findings and recommendations to date. Our usable findings and recommendations are provided only through an 'Issued for Use' document, which will be issued subsequent to this review. Final design should not be undertaken based on the interim recommendations made herein. Once our report is issued for use, the 'Issued for Review' document should be either returned to Tetra Tech Canada Inc. (Tetra Tech) or destroyed.

1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech) was retained by the Government of the Northwest Territories, Department of Infrastructure (GNWT-INF) to undertake a hydrotechnical assessment of a watercourse crossing along the proposed Tlicho All-Season Road, specifically Crossing 10a, as specified in the Terms of Reference included as Appendix B. This crossing was identified by Stantec as part of the Tlicho Road Alignment Hydrologic and Hydraulic Study (Stantec, 2016).

Stantec had first identified Crossing 10, defined as "a low-lying area where ponding occurs during large rainfall events". A possible crossing location was identified where "a small, well-defined, meandering channel was observed just south of the proposed crossing area". This crossing was named as "Crossing 10a" and it is the subject study of this report. Photo 1 shows both crossing sites.

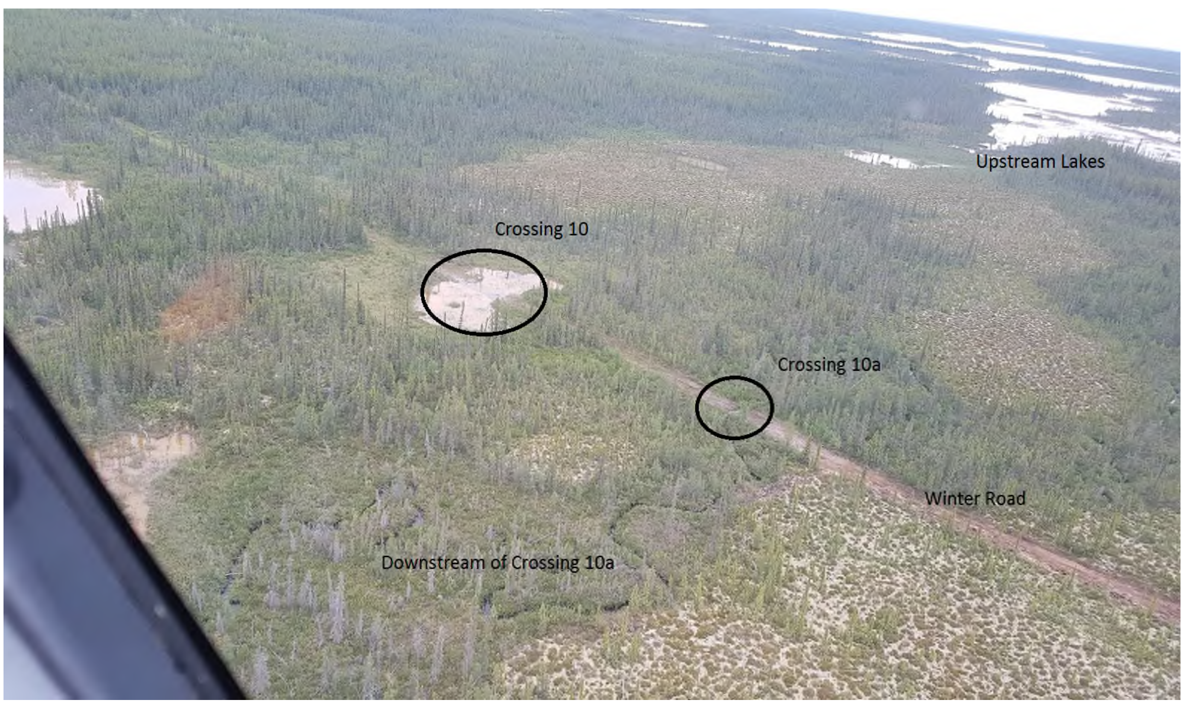


Photo 1 Aerial Photo Showing Crossing 10a

The objective of this hydrotechnical assessment is to provide a summary of the field inspection, detailed hydrologic and hydraulic analysis of the watercourse, and recommended drainage infrastructure sizing for Crossing 10a.

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Yellowknife, NT X1A 2P7 CANADA
Tel 867.920.2287 Fax 867.873.3324

2.0 SCOPE OF WORK

Tetra Tech was retained by the GNWT to conduct a hydrotechnical assessment of one crossing, identified as Crossing 10a. The objective of this technical memo is to summarize the field activities, hydrological assessment, hydraulic assessment, and recommended crossing structure. The following points are specifically addressed:

- Watershed delineation;
- Estimate of peak flow during the 100-year recurrence interval flood;
- Estimate of high water level at the stream crossing;
- Estimate of ice elevation level and ice characteristics;
- Measurement of channel geometry;
- Determine the potential for scour and recommended scour protection type, position and elevation;
- Recommend site specific structure options and optimal structure location.

3.0 SITE STUDY

A field investigation was conducted on June 27, 2017 by two hydrotechnical engineers (Mark Aylward-Nally, EIT and Mauricio Herrera, Ph.D., P.Eng) and a local wildlife/environmental monitor to observe and collect data for Crossing 10a along the proposed highway alignment. Information collected during the visit included a visual assessment of the watercourse and its immediate drainage area, measurement of channel bankfull width and depth, survey of channel slope, flow measurement at the crossing, and photographic inventory of the crossing. This information was subsequently used for desktop hydrologic and hydraulic analyses in developing recommended drainage infrastructure for the crossing.

The watercourse is described as a deep, well-defined, meandering channel with shallow slope (~0.2%). Banks are near-vertical and approximately 0.9 m high. A cross section of the crossing, measured during the site visit is shown in Figure 1. The surrounding floodplain is flat and densely vegetated by shrubs and small conifers with some grasses. Minimal vegetation was observed within the watercourse itself, with the channel bed consisting primarily of small cobbles. The flow in the watercourse was 34 L/s at the time of the field investigation. Site conditions are shown in the Photographs below.

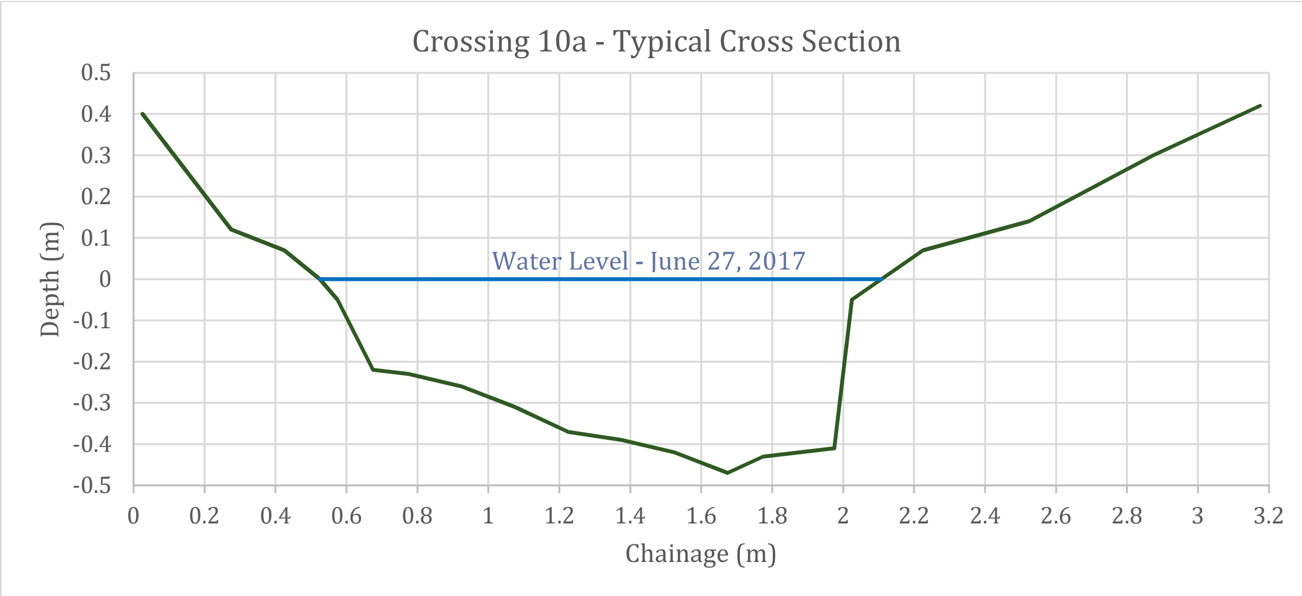

Figure 1. Surveyed Cross Section at Crossing 10a

Photo 2 ***Flow Measurement at Crossing 10a***

Photo 3 Stream at Crossing 10a. Looking Downstream

Photo 4 Winter Road. Looking South East

Photo 5 Winter Road. Looking North West. At Crossing 10 with Environmental Monitor.

4.0 DESIGN CRITERIA

4.1 Flood Passage Capacity

As it is required by the GNWT, the culvert crossing is to be designed to safely pass the 100-year peak flow, which is the same as the peak flow with a 1% chance of occurrence in any given year.

4.2 Water Depth at Culvert

Following Stantec's recommended criteria, based on Ontario Highway Drainage Design Standards (2008) and the Canadian Highway Bridge Design Code (2000), the headwater depth at the upstream face of a culvert to the diameter or rise of the culvert (HW/D) shall be less than 1.5 for closed bottom culverts with a diameter or rise less than 3.0 m.

5.0 HYDROLOGICAL ASSESSMENT

5.1 Watershed Delineation

The tributary watershed at the 10a crossing location was digitally delineated on ArcGIS, using a combination of publically available imagery and contour lines from ESRI, and LiDAR data (2 km width) along the proposed road alignment. Visual inspection of the available orthophotos was used to interpret lake connectivity and apparent flow paths. A total watershed area of 25 km² was identified, as shown in Figure 2. The delineated watershed represents the best judgement based on limited topographical information of what is likely the largest area that could drain under large flow conditions.

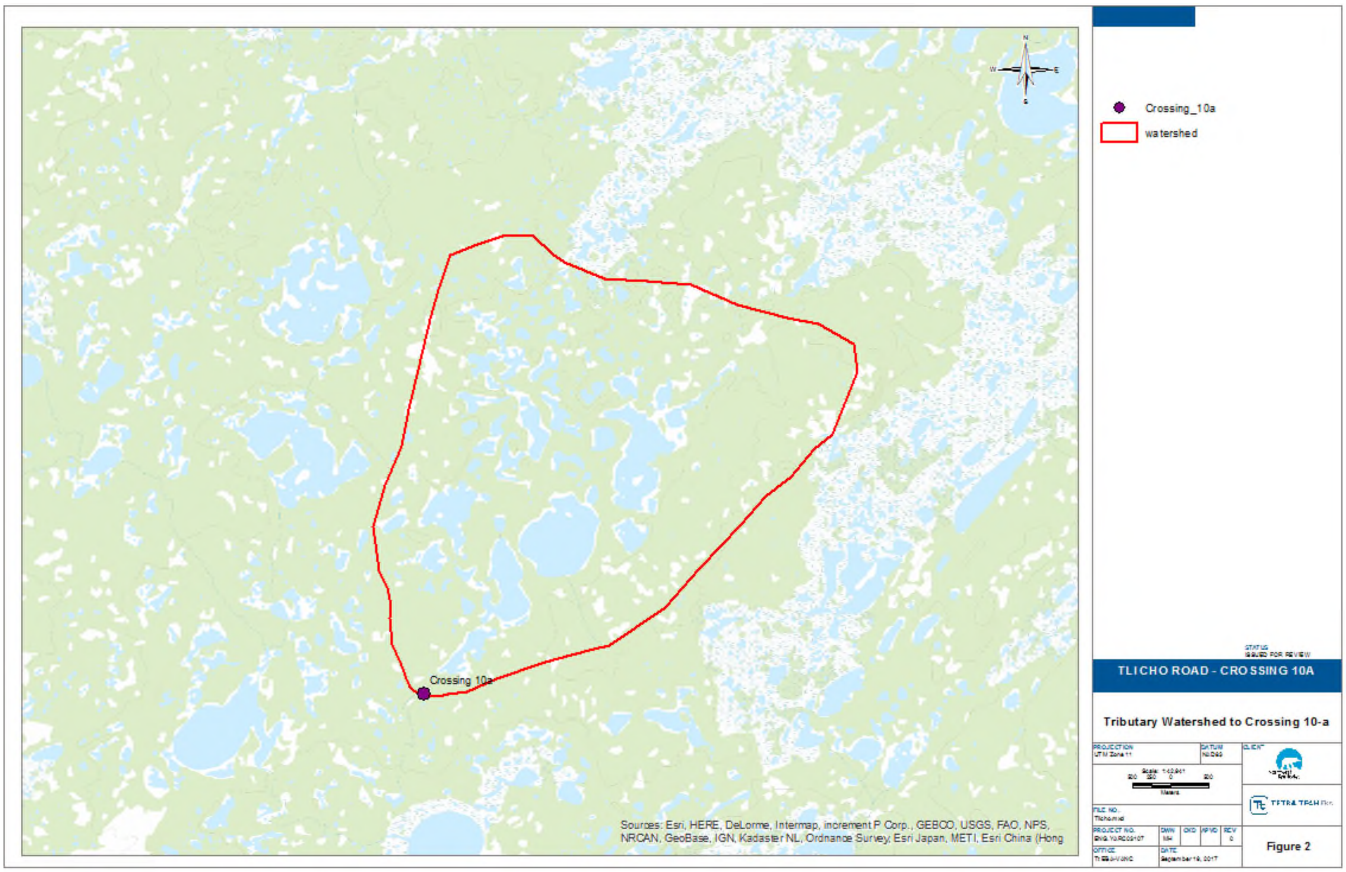

Figure 2: Tributary Watershed to Crossing 10-a

5.2 Peak Flow Estimate

Estimation of peak flows in ungauged watersheds requires the use and interpretation of hydrometric and climatic data from nearby stations. Typically, flow estimates are obtained from two main approaches, one statistically based where regional analysis are applied to estimate flows using hydrometric data from nearby watersheds, and a second, based on physically based hydrologic models, where hydroclimatic inputs are used to calculate hydrological outputs, such as runoff rates, streamflows, and water levels.

Stantec (2016) conducted a hydrotechnical engineering report for the Tlicho Road project. As part of this effort, they reviewed hydrometric data from nearby hydrometric stations and completed a regional analysis to estimate peak flows for all crossings along the proposed Tlicho All Season Road alignment. The result was a series of empirical relationships between the maximum discharge for various return periods and the watershed area, as shown below:

- 2-year maximum discharge (m^3/s) = $0.2297A^{0.6619}$
- 5-year maximum discharge (m^3/s) = $0.5077A^{0.6148}$
- 10-year maximum discharge (m^3/s) = $0.7871A^{0.5853}$
- 20-year maximum discharge (m^3/s) = $1.1435A^{0.5587}$
- 50-year maximum discharge (m^3/s) = $1.7604A^{0.5266}$
- 100-year maximum discharge (m^3/s) = $2.3604A^{0.5041}$

The 100-year peak flow formula was applied for the 10a crossing (25 km^2) obtaining a flow of 12 m^3/s.

A closer look at the data used to develop these set of equations reveals that the smaller watershed used for the analysis corresponds to hydrometric station 10FC001 (Plateau Creek near Willow Lake) with an area of 70 km^2, and a flow record length of 9 years. The rest of the stations have tributary watersheds ranging from 1,520 km^2 to 51,700 km^2. Both the short duration of the flow record and the significant difference in watershed sizes makes the estimate obtained from the above relationship for 10a suspect.

To supplement the flow estimation analysis, other nearby stations were examined. Two stations were identified on Baker Creek, Sta 07SB013 and Sta 07SB009. The first one at the outlet of Lower Martin Lake with an area of 121 km^2 and the second one near Yellowknife with an area of 126 km^2. The combined flow record spans from 1968 to 2016, which makes it more suitable for estimating larger return period flows. In this case, a higher weight is given to a single station, rather than the multi-station based regional analysis. It seems that the latter method results in significant extrapolation of the available data, with a large uncertainty. For this reason, the combined data from Baker Creek was selected as the preferred source of information to estimate flows at Crossing 10a.

A frequency analysis of the combined data set (stations 07SB013 and 07SB009) was conducted using the statistical package HYFRAN. A number of frequency distributions were tested and the best result was obtained with the Exponential distribution, as shown in Figure 3.

Peak flows from Baker Creek were adjusted to Crossing 10a using a simple area ratio adjustment factor. Accordingly, peak flows are shown in Table 1.

Table 1. Peak Flow Estimates for Crossing 10a

	Peak Flow estimates (m^3/s)	
Return Period	**Baker Creek**	**Crossing 10a**
200	10	2.0
100	8.69	1.7
50	7.38	1.5
20	5.65	1.1
10	4.33	0.9
5	3.02	0.6
3	2.05	0.4
2	1.28	0.3

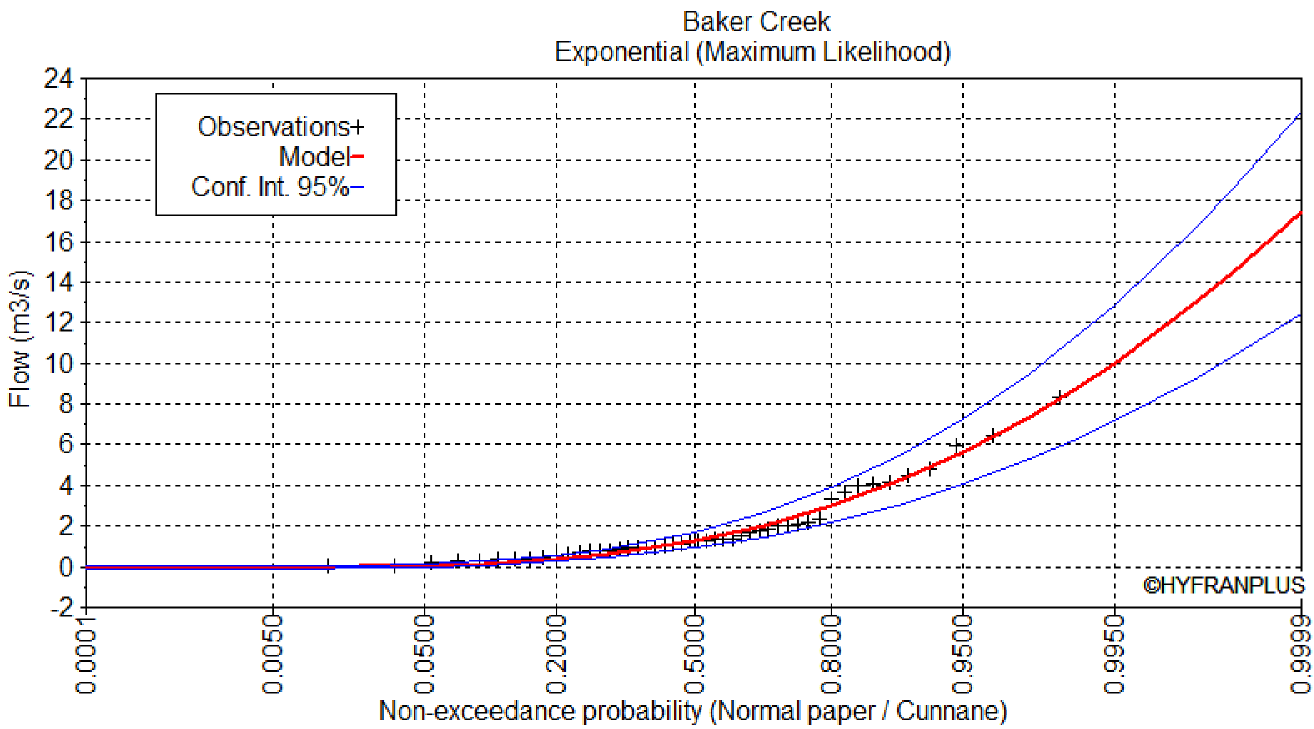

Figure 3. Baker Creek Peak Flows (stations 07SB013 and 07SB009). Frequency Distribution.

5.3 Climate Change Considerations

Estimating the effects of climate change on peak flows is complex. Hydrological modeling of the watershed system is perhaps one of the most complete methods to assess changes in flow conditions through the use of modified hydro-meteorological inputs that have been extracted and downscaled from General Circulation Models (GCMs). Such an approach requires a calibrated model that can be used to extrapolate flow conditions under climate change scenarios. In this case, for the tributary watershed to Crossing 10a, no model calibration was possible due to lack of long term hydrometric data. Therefore, a practical approach was adopted where climate change projections were interpreted and used to adjust the estimated flow for the 100-year flood.

Through the use of SWMM-CAT software (Rossman, 2014) developed by the United States Environmental Protection Agency (USEPA), expected changes in hydro-meteorological conditions were estimated for the project area. SWMM-CAT is a utility that adds location-specific climate change adjustments. As described by this software's documentation, "Adjustments can be applied on a monthly basis to air temperature, evaporation rates, and precipitation, as well as to the 24-hour design storm at different recurrence intervals". Furthermore, "The source of these adjustments are global climate change models run as part of the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project Phase 3 (CMIP3) archive. Downscaled results from this archive were generated and converted into changes with respect to historical values by USEPA's CREAT project (http://water.epa.gov/infrastructure/watersecurity/climate/creat.cfm)".

The software provided the following expected changes in climate conditions:

- Expected increase in July temperatures, up to 5.5 degrees Celsius for the far term (2045 – 2074);
- Expected increase in the 24-hr 100-year storm, up to 20% for the far term (2045 – 2074);
- Expected increase in May monthly rainfall, up to 32.8% for the far term (2045 – 2074).

A review of the maximum peak flows from the Baker Creek hydrometric data shows that the largest peak flow from the dataset corresponds to the largest spring precipitation rainfall for the corresponding flows. Accordingly, the projected increase in flows was assumed to be directly proportional to the expected increase in May monthly rainfall. This assumption can be further examined in the future, but based on the available data it was considered to be appropriate for this study. Thus, a multiplying factor of 1.32 was used to obtain a climate changed 100-year peak flow of 2.24 m^3/s.

6.0 HYDRAULIC ASSESSMENT

Hydraulic conditions at Crossing 10a were assessed and a culvert crossing is proposed. Hydraulic modeling with PCSWMM software was used to assess existing conditions and for the design of a proposed structure.

The cross sections at the proposed crossing and both upstream and downstream of it were obtained from field survey data and available LiDAR data. A Manning's number of 0.04 was selected for the main channel and 0.07 for the banks and floodplain. Downstream boundary conditions were set with normal flow depth.

Preliminary analysis suggested that a Circular CSP culvert with a diameter of 1.2 meters would be sufficient to pass the design flow, and to meet the design criteria for HW/D. However, based on experiences in the north, we recommend a larger size to accommodate ice blockages and potential debris loads.

6.1 Recommended Crossing Structure

To pass the 100-year design flow of 2.24 m^3/s, and to provide an allowance for potential ice blockages and potential debris loads, the following culvert options were identified:

Culvert Type	Culvert Dimensions	Number of Barrels	HW/D	Outlet Velocity (m/s)
Concrete Box Culvert	Span: 1.8 m x Rise: 0.9 m	1	0.75	1.9
Circular CSP	Diameter: 1.5 m.	2 (equal elevation)	0.56	1.6

6.1.1 Erosion Protection

A preliminary riprap sizing was conducted using the maximum outlet velocity obtained from the hydraulic analysis. Based on this, a D50 of 300 mm was identified as the required rock size to provide erosion protection downstream of the culvert crossing.

7.0 SUMMARY AND RECOMMENDATIONS

Based on the findings from the hydrotechnical assessment of Crossing 10a, presented in this Letter Report, the following can be concluded:

- A design flow for the 100-year (1%) event was estimated to be 2.24 m^3/s
- Both a box culvert with a span of 1.8 m and a height of 1.2 m; or two parallel CSP pipes with a diameter of 1.5 m would be able to pass the 100-year flow and provide additional capacity for potential ice blockages and debris loads.

Due to the timing of the field visit in June 2017, ice characteristics such as ice thickness, ice strength, ice loading elevation and break-up elevation could not be observed. It is recommended that an assessment of ice conditions and characteristics should to be conducted during the winter (if such investigation has not been conducted to date). Changes to the design should be accommodated as part of the detailed design.

8.0 LIMITATIONS OF REPORT

This report and its contents are intended for the sole use of the Government of Northwest Territories and their agents. Tetra Tech Canada Inc. (operating as 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, or for any Project other than the proposed development at the subject site. Tetra Tech's General Conditions are provided in Appendix A of this report. The Terms of Reference for this work is included in Appendix B.

9.0 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.

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/db

10.0 REFERENCES

Stantec (2016). Tli Cho Road Alignment, Hydrologic and Hydraulic Study. Prepared for Government of Northwest Territories. Department of Transportation Structures Section. Stantec Project No. 144902005.

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Rossman, L. SWMM-CAT User's Guide. US EPA Office of Research and Development, Washington, DC, EPA/600/R-14/428, 2014.

APPENDIX A

TETRA TECH'S GENERAL CONDITIONS

GENERAL CONDITIONS

HYDROTECHNICAL

This report incorporates and is subject to these "General Conditions".

1.1 USE OF REPORT AND OWNERSHIP

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

The Report is intended for the sole use of TETRA TECH's Client (the "Client") as specifically identified in the TETRA TECH Services Agreement or other Contract entered into with the Client (either of which is termed the "Services Agreement" herein). TETRA TECH does not accept any responsibility for the accuracy of any of the data, analyses, recommendations or other contents of the Report 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 Report 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 Report.

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1.2 ALTERNATIVE REPORT FORMAT

Where TETRA TECH submits both electronic file and hard copy versions of the Report 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 version archived by TETRA TECH shall be deemed to be the original. TETRA TECH will archive the original signed and/or sealed version for a maximum period of 10 years.

Both electronic file and 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 Report have been conducted in accordance with the Services Agreement, 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 Report. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of the Report.

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 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.

1.5 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 Services Agreement, TETRA TECH has relied upon the Client with respect to both the full disclosure and accuracy of any such information.

1.6 INFORMATION PROVIDED TO TETRA TECH BY OTHERS

During the performance of the work and the preparation of this Report, TETRA TECH may have relied on information provided by persons 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.

1.7 GENERAL LIMITATIONS OF REPORT

This Report is based solely on the conditions present and the data available to TETRA TECH at the time the Report was prepared.

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

The Report 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 at or the development proposed as of the date of the Report requires a supplementary investigation and assessment.

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.

The Client acknowledges that 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.

1.8 JOB SITE SAFETY

TETRA TECH is only responsible for the activities of its employees on the job site and was not and will not be responsible for the supervision of any other persons whatsoever. The presence of TETRA TECH personnel on site shall not be construed in any way to relieve the Client or any other persons on site from their responsibility for job site safety.

APPENDIX B

TERMS OF REFERENCE

APPENDIX B

SCOPE OF WORK FOR HYDROLOGICAL ASSESSMENT OF ONE (1) WATER CROSSING LOCATION.

INTRODUCTION

The Government of the Northwest Territories (GNWT) has begun pre-engineering work on the Tli Cho Road. The hydrological analysis detailed in this request is to provide design parameters for culverts and bridges where required.

The proposed Tli Cho Road will intersect Highway No. 3 at approximately kilometer 196 (62°28'50"N, 116°29'00"W) and will extend north and west to the community of Whati (63°08'39"N, 117°16'11"W).

The table attached lists the GPS coordinates of crossing 10a along the TASR alignment.

SCOPE

The following are general requirements. The hydrological engineer is required to assess the scope and deliverables using their experience and professional judgment to determine activities and resources not mentioned specifically.

1. Determine the water shed estimate.
2. Determine the stream flow during the 100-year recurrence interval flood.
3. Determine the high water level at the stream crossing.
4. Determine the ice elevation level and ice characteristics.
5. Determine the channel geometry.
6. Determine the potential for scour and recommend scour protection type, position, and elevation.
7. Recommend site specific structure options and optimal structure locations.

A proposal detailing the methodology of the entire hydrological study is required. The proposal must include, but is not limited to, field work procedures, data collection methods, field equipment to be used, post field work analysis methods, historical climate data to be used, a confidence valuation of final deliverables based on information currently available, an in-field time estimation for data collection, and a post-field time estimation for analysis and processing. The proposal must include a detailed and fully inclusive cost breakdown.

REPORTS AND DELIVERABLES

The following are required:

1. A report detailing the requirements stated in the scope.
2. A summary of hydrotechnical design parameters including, but not limited to:
    a. Hydrologic Characteristics
        i. Drainage Area
        ii. Design Discharge
    b. Ice Characteristics
        i. Ice Thickness
        ii. Ice Strength
        iii. Ice Load Elevation
    c. Hydraulic Characteristics
        i. Open Water Velocity
        ii. Open Water Elevation
        iii. Breakup Elevation

iv. Minimum Bridge Elevation
v. Minimum Scour Elevation

d. Slope Protection

i. Riprap Median Diameter
ii. Top of Riprap Elevation

e. Structure Recommendations

i. Site specific structure options.
ii. Optimal structure location to maximize crossing economics.

3. Markups of the maps (1:50 000) provided showing the watershed.
4. Markups of the maps (1:50 000) provided showing the structure location at the crossing.
5. Drawings detailing the cross section of the channel bed at the crossing.

Two bound **hardcopies** as well as softcopies (**PDF**, **DWG**, **shapefile**) of crossing 10a is required.

Crossing No.	Station	Crossing Description	Specifications	Geotechnical Investigation, March 2017	UTM Zone 11		Lat/Long	
					X	Y	Latitude	Longitude
10a	48+208.8	3660x1910 Arch culvert	Arch Culvert; corrugation profile and thickness to be determined	1 borehole	508606.6	6962701.5	62° 47' 40.1"	-116° 49' 52.6"