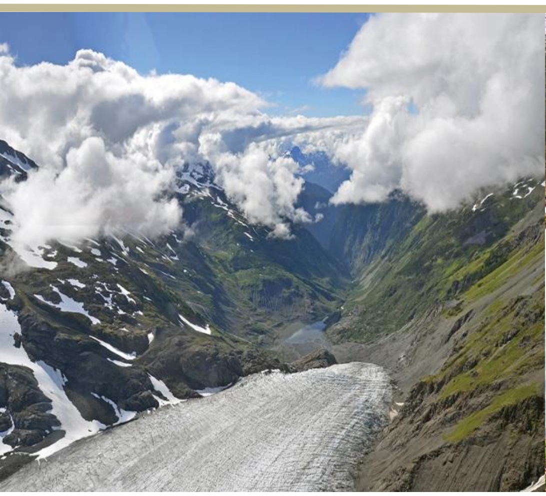
TETRA TECH

Mackenzie Valley Highway
Mount Gaudet Access Road Hydrotechnical Assessments



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Government of the Northwest Territories
Department of Infrastructure

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EXECUTIVE SUMMARY

Tetra Tech Canada Inc. (Tetra Tech), as a subconsultant to Stantec Architecture Ltd. (Stantec), was retained by the Government of the Northwest Territories (GNWT) to provide the hydrotechnical aspects of fish habitat and hydrotechnical assessments along the proposed Mackenzie Valley Highway (MVH). This work was done under Standing Offer Agreement 4034 with the GNWT.

Services were provided in late 2020 for three segments of the MVH, as follows:

1. Prohibition Creek Access Road (PCAR), approximately 14 kilometres (km) long, accessed from Norman Wells
2. Mount Gaudet Access Road (MGAR), approximately 21 km long, accessed from Wrigley
3. A segment through Dehcho Lands, approximately 83 km long, north of the MGAR, accessed from Wrigley

The alignment for the proposed MVH follows an existing winter road which has bridges at major watercourse crossings. The scope of work generally excludes the major crossings which the GNWT had evaluated previously.

The results of the fish habitat and hydrotechnical reports are provided in separate discipline-specific reports for each of the three road segments. This report presents the hydrotechnical results for the MGAR.

Field Investigation

Three days of site investigation were completed from September 16 through 18, 2020, using a helicopter to access the study area. One major creek crossing with a defined channel and five minor drainage crossings with visible surface water were identified from a low altitude reconnaissance of the entire alignment. Ground inspections were subsequently made at these identified sites, plus at Quarry Pond where a habitat assessment was required at the northern end of the segment. The Quarry Pond drains via shallow groundwater flow through a marshy area at the north end of the pond and crosses the MVH at a location beyond the northern extent of the MGAR segment.

Drainage Crossing Identification

Additional minor drainage crossings, without a defined channel or visible water during the field inspection, were identified from a desktop review of available topographic information, predominantly LiDAR elevation data, and companion watershed delineations completed using Global Mapper GIS software. Drainage crossings were located at all significant low points crossing the alignment and at a minimum spacing of 1500 metres (m) through segments with sheet flow drainage that would be intercepted by the highway embankment. A total of 22 drainage crossing locations were identified along the MGAR alignment, including those inspected during the field investigation. Sixteen of the crossings were at low points which did not have visible water during the field surveys and were not inspected.

Hydrologic Analysis and Results

A hydrologic analysis was undertaken to estimate peak flows, for various return periods, and a 3Q10 flow sometimes used for fish passage assessments, at each of the 22 drainage crossings. The methodology utilized a regional hydrologic approach to transpose flow quantiles of historical flow data for Water Survey of Canada (WSC) gauged watercourses in the study area vicinity to subject watercourses of interest.

Hydraulic Analysis and Crossing Structure Recommendations

Single culverts sized to pass estimated 100-year flows are recommended for all of the 22 crossing locations. Sizing assumed non-embedded circular corrugated culverts with inlet flow control at projecting inlets and a 100-year flow maximum headwater elevation equal to the top of culvert. Recommended sizes range from a nominal minimum diameter of 800 millimetres (mm) to a maximum diameter of 1400 mm for circular culverts. For the largest channel, which is fish bearing, an open bottom arch culvert 2700 mm wide x 1350 mm high is recommended to minimize disturbance to the existing channel and substrate. The sizes and shapes are preliminary and should be revisited once the highway design is finalized as roadway grading and available embankment heights may alter drainage patterns or increase maximum allowable headwater depths. Hydraulically-equivalent alternatives such as substituting multiple small culverts for specified large culverts may be preferred for final design where there is a cost or design advantage in doing so.

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APPENDIX

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 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 A or Contractual Terms and Conditions executed by both parties.

1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech), as a subconsultant to Stantec Architecture Ltd. (Stantec), was retained by the Government of the Northwest Territories (GNWT) to provide hydrotechnical aspects of fish habitat and hydrotechnical assessments along the proposed Mackenzie Valley Highway (MVH). This work was done under Standing Offer Agreement 4034 with the GNWT.

Services were provided in late 2020 for three segments of the MVH, as follows:

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3. A segment through Dehcho Lands, approximately 83 km long, north of the MGAR, accessed from Wrigley

The alignment for the proposed MVH follows an existing winter road which has bridges at major crossings. The scope of work generally excludes the major crossings which the GNWT had evaluated previously.

Field inspections for all three segments were conducted from September 8 to September 24, 2020 by a team consisting of one Tetra Tech hydrotechnical engineer, one Stantec fisheries biologist and a local wildlife/environmental monitor. The MGAR segment was inspected from September 16 to 18, 2020

The results of the fish habitat and hydrotechnical reports are provided in separate discipline-specific reports for each of the three road segments. This report presents the hydrotechnical results for the MGAR.

2.0 SCOPE OF WORK AND METHODOLOGY

The hydrotechnical scope of work for the MGAR segment was to provide assessments at up to seven drainages to be confirmed during field surveys, and for a pond, referred to as "Quarry Pond" located near Hodgson Creek. A site assessment of Hodgson Creek was made for fish and fish habitat assessments only.

Scope of work elements included:

- Collection of relevant background information;
- Field investigation to assess watercourse crossing characteristics;
- Hydrologic desktop assessment for design flow determination and equalization culverts;
- Hydraulic analysis for preliminary crossing structure recommendations; and
- Highlight outstanding issues that require investigation.

3.0 BACKGROUND INFORMATION

Background information obtained for desktop hydrologic studies consisted of regional streamflow data and topographic mapping information.

Historical streamflow information from Water Survey Canada (WSC) stations in the vicinity of the study area(s) was obtained for the hydrologic analysis. The stations used in the analysis are described in Section 5.2.

Multiple forms of topographic mapping information were obtained, including Government of Canada 1:50,000 scale National Topographic System (NTS) maps and companion Digital Elevation Models (DEMs), and Polar Geospatial Centre ArcticDEM terrain models developed from satellite imagery. The NTS mapping and ArcticDEM data were used to identify locations to be evaluated during the field inspections and subsequently to determine watershed areas to all crossings.

NTS 1:50,000 mapping is used as the base image for Figures 4-1 and 5-1 in this report, copped to areas of interest and scaled (shrunk) to fit the report page size. This map source provides a valuable compilation of topographic contours, land cover (glaciers, wooded areas), and water features including rivers, streams, braided steams, disappearing streams, dry river beds, canals, ditches, lakes, intermittent lakes, and wetlands (marsh, swamp, muskeg), all at high resolution. The mapping shows what is present and, equally important, what is not present. Its index identifies more than 100 features and, due to its large size, was normally printed on the back side of the hard copy map sheet. It is also available online[1].

Bare earth Light Detection and Ranging (LiDAR) elevation data were obtained from the GNWT for a corridor typically 1.0 m wide along the MVH alignment. The LiDAR data points for a representative site of interest were determined to be were spaced at irregular intervals ranging from one (1) m to about eight (8) m. This information was obtained after the completion of the field investigations. It was used to identify low segments along the alignment without defined drainages where cross-drainage or equalization culverts will be required to prevent water from ponding along a future highway embankment.

4.0 FIELD INVESTIGATIONS

The field investigation along the MVH MGAR segment was conducted from September 16 to 18, 2020 by hydrotechnical engineer Mark Aylward-Nally, P.Eng. (BC) of Tetra Tech, and aquatic biologist Lindsay Dowbush, P.Biol. of Stantec. This field program was undertaken to evaluate the drainage and/or fish habitat characteristics of watercourses and waterbodies encountered along the highway alignment. The fish habitat assessment portion of this work is discussed in a separate report by K'alo-Stantec.

The terrain over the MGAR alignment can be characterized as flat or gently rolling terrain, dense with small trees, shrubs and low-lying vegetation with numerous small lakes and wetlands. Mount Gaudet, a steep 350 m high mountain at the northern end of the alignment, is the only pronounced feature on the otherwise flat landscape. Ground cover along the alignment is predominantly muskeg, often wet and marshy in low-lying areas.

4.1 Watercourse Assessment Methods

Watercourse sites for field inspections were identified and assessed in a multi-step process. First, a desktop GIS analysis of topographic data was conducted to identify locations of possible watercourse crossings. Second, an aerial inspection of the entire alignment was made by helicopter to confirm the desktop-identified sites and to identify any additional crossings. A total of six crossings of interest were identified: a single watercourse with a defined channel plus five locations with visible surface water across the alignment. These sites have been presented on Figure 4-1 as Creek #1 and Drainages #1 through #5 respectively. While no other locations were identified as having visible drainage at the time of the field visit, it is likely that other smaller drainages exist which only flow during spring melt.

[1] https://ftp.maps.canada.ca/pub/nrcan_rncan/raster/topographic/doc/endos_legend_back.pdf

Ground inspections were conducted at the six locations of interest identified from the initial aerial survey and at a Quarry Pond identified in the initial scope of work. The goal of the ground inspections was to confirm the presence of drainage across the alignment, measure flow rates, assess channel geometry and channel substrate, and to document other watercourse characteristics potentially pertinent to the design of appropriate drainage infrastructure. Flow rates were measured using a Swoffer meter. The inspection at Quarry Pond was to identify the pond's natural outlet and assess if the pond will present any design constraints to the highway alignment.

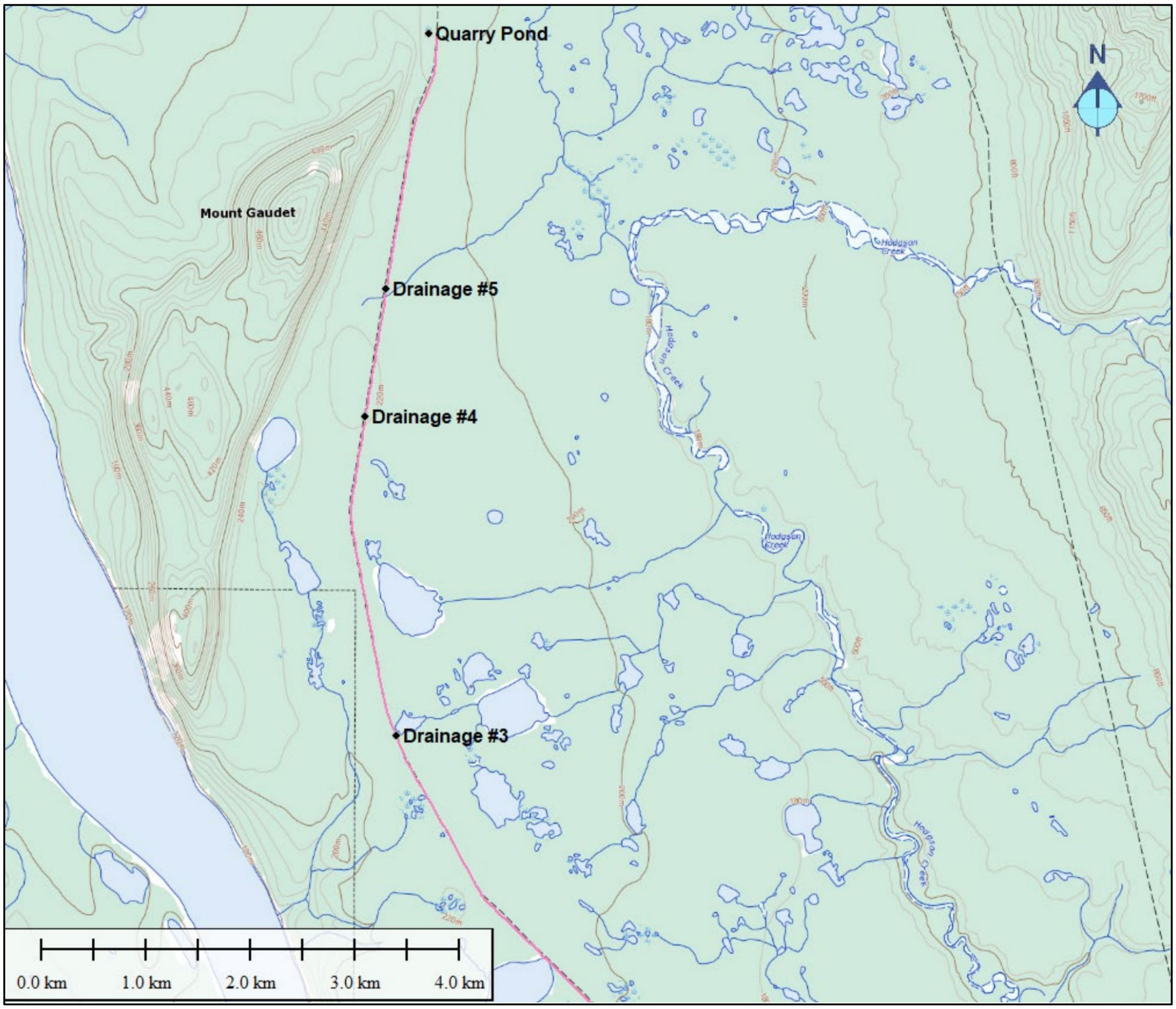

Figure 4-1a: MGAR Water Features Assessed During Field Program – North Panel (1 of 2)

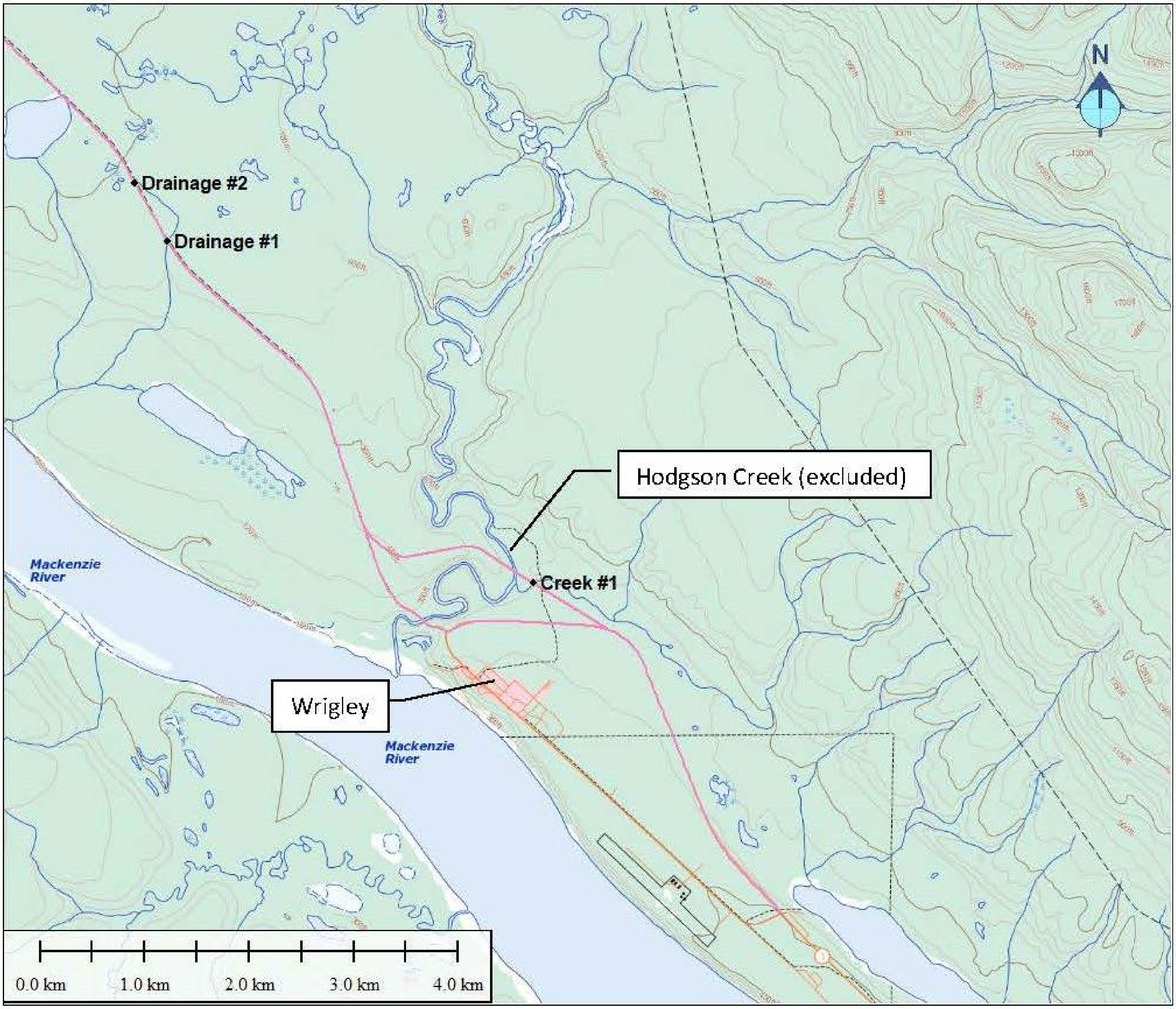

Figure 4-1b: MGAR Water Features Assessed During Field Program – South Panel (2 of 2)

4.2 Watercourse Crossings with a Defined Channel

With Hodgson Creek being excluded from the present hydrotechnical assessment, only one substantial watercourse was encountered along the MGAR alignment with measurable flow and defined channel geometry. This location has been identified as Creek #1 on Figure 4-1 and is discussed below.

4.2.1 Creek #1

Creek #1 is a tributary to Hodgson Creek, reaching its confluence with Hodgson approximately 300 m downstream of the MVH alignment. The watercourse is a well-defined channel with dense vegetation on both banks. Defined channel banks are approximately 0.4 m high at the crossing location, increasing to 0.8 m immediately upstream of confluence with Hodgson Creek. The floodplain outside these banks is flat and wide. No signs of historical high water or ice marks were noted within the floodplain. Bankfull width varies along the channel, averaging close to 2.0 m. Channel substrate is predominantly comprised of small boulders with cobbles. Small quantities of woody debris are present within the watercourse but are not obstructing the flow. The creek at this crossing does not show evidence of substantial erosion or aggradation. The watercourse is considered generally stable at this location and there are no specific concerns or issues related to this crossing

Table 4-1 presents a summary of field information for the crossing. Representative photographs of the watercourse taken on September 17, 2020 are presented as Photos 1 and 2.

Table 4-1: Creek #1 Field Summary

Parameter	Measurement/Observation
Coordinates	476789 E, 7012091 N, UTM Zone 10
Measured Flow	~60 L/s
Bankfull Width	Varies: 1.8 – 2.5 m
Bankfull Depth	Varies: 0.4 to 0.6 m
Channel Slope	2.5%
Substrate Composition	Small Boulders w/Cobble

Photo 1: Creek #1
Looking Upstream from Alignment Crossing

Photo 2: Creek #1
Looking Downstream from Alignment Crossing

4.3 Drainages without a Defined Channel

All remaining watercourse crossings with visible water at the time of field surveys are minor in nature, generally consisting of muskeg with either stagnant or slow-moving shallow water coverage with no defined channel. Flow measurements were not possible at these locations due to the lack of concentrated flow paths but were estimated to be between 0 and 4 L/s at each site. These sites have been identified on Figure 4-1, location coordinates for each site are listed in Table 4-2.

Table 4-2: UTM Coordinates of Inspected Drainages

Drainage	UTM Zone 10 Coordinates (m)
Drainage #1	473247 E, 7015472 N
Drainage #2	472984 E, 7015941 N
Drainage #3	470888 E, 7018953 N
Drainage #4	470643 E, 7021998 N
Drainage #5	470851 E, 7023206 N

Photos 3 through 8 present representative photographs of each site taken September 16 and field notes made during the visit.

Photo 3: Drainage #1 Looking south
Boggy area with no defined channel upstream or downstream of the alignment. Less than 0.5 L/s of flow moving through this area

Photo 4: Drainage #2 looking east
Approximately 1 L/s flowing to the east. Scattered 0.5 m deep stagnant pools upstream of the alignment. Flow disperses downstream of the alignment with no defined channel

Photo 5: Drainage #3 looking north
Approximately 0.5 L/s flowing to the east. No defined channel upstream or downstream. Fed by a small marsh 20m to the west

Photo 6: Drainage #4 looking west
Approximately 1 L/s flowing to the east. No defined channels upstream or downstream of the alignment.

Photo 7: Drainage #5 looking north
Approximately 4 L/s flowing to the east. Pooling of water extends downstream (east) of the alignment as no defined channel exists

Photo 8: Drainage #5 looking northwest
Wide ponded area on and east of alignment. Wide marsh area west of alignment with dispersed water.

4.4 Quarry Pond

The Quarry Pond situated at the northern limit of the MGAR alignment was circumnavigated during the field assessment. No obvious pond inlets or outlet were observed during the investigation, though marshy terrain in the north was noted as a probably shallow groundwater outlet and potential surface water outlet. Supplementary analysis of LiDAR datasets after the field investigation confirms that surface outflow if any, would occur at the northern end of the pond (Figure 4-2) where the marshy terrain was encountered. This outflow would continue to the northeast, crossing the winter highway alignment at a location outside of the 12-kilometer extent of the MGAR segment.

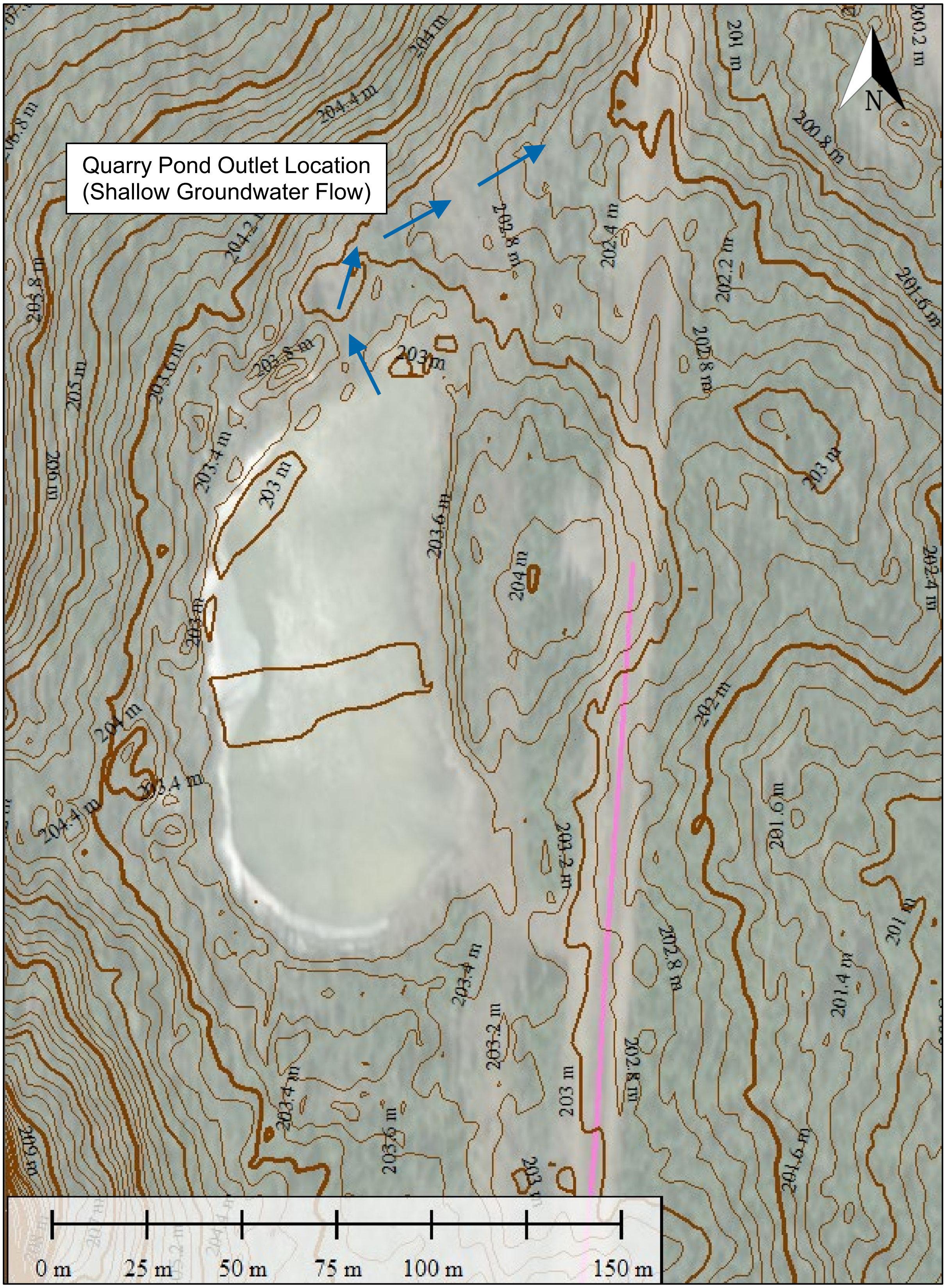

Figure 4-2: Quarry Pond Contour Delineation and Outlet Identification

5.0 HYDROTECHNICAL ANALYSIS

The hydrotechnical assessment for highway drainage involved three basic components: (1) identification of and watershed mapping for cross-drainage sites including but not limited to segments with unconcentrated flow that will be blocked by road construction; (2) hydrologic analysis to determine a design discharge for each site; and (3) hydraulic design and sizing of drainage openings of sufficient size to pass the design discharge. These components are described below.

5.1 Crossing Identification and Watershed Delineation

Preliminary crossing locations were identified through a desktop review of available topographic information and observations of the September 2020 site visit. Available LiDAR surface data was combined with ArcticDEM surface data to synthesize a Digital Elevation Model (DEM) that covers the entirety of the watershed areas crossing the MGAR alignment and was used to determine crossing coordinates. A digital watershed delineation was completed using the Global Mapper GIS software package.

The watershed delineation was interpreted in conjunction with field observations to identify crossing locations where the flow is naturally concentrated to an identifiable flow path where a culvert would be required. Additional culverts were then added at all significant low points where water might pond in the absence of a culvert. Outside of these low points, the MGAR alignment does not encounter any wet areas where culverts would be required to equalize ponded water levels on opposite sides of the alignment, or areas of sheet flow perpendicular to the alignment where culverts would be required to prevent ponding.

A total of 22 crossing locations were identified and tributary watersheds were delineated as shown in in Figure 5-1 and listed in Table 5-1. The catchment sizes have watershed areas ranging between approximately 0.1 km^2 and 9.6 km^2. The number of crossings and their coordinates are preliminary as cross drainage locations may be affected by grading activities to achieve the final highway design.

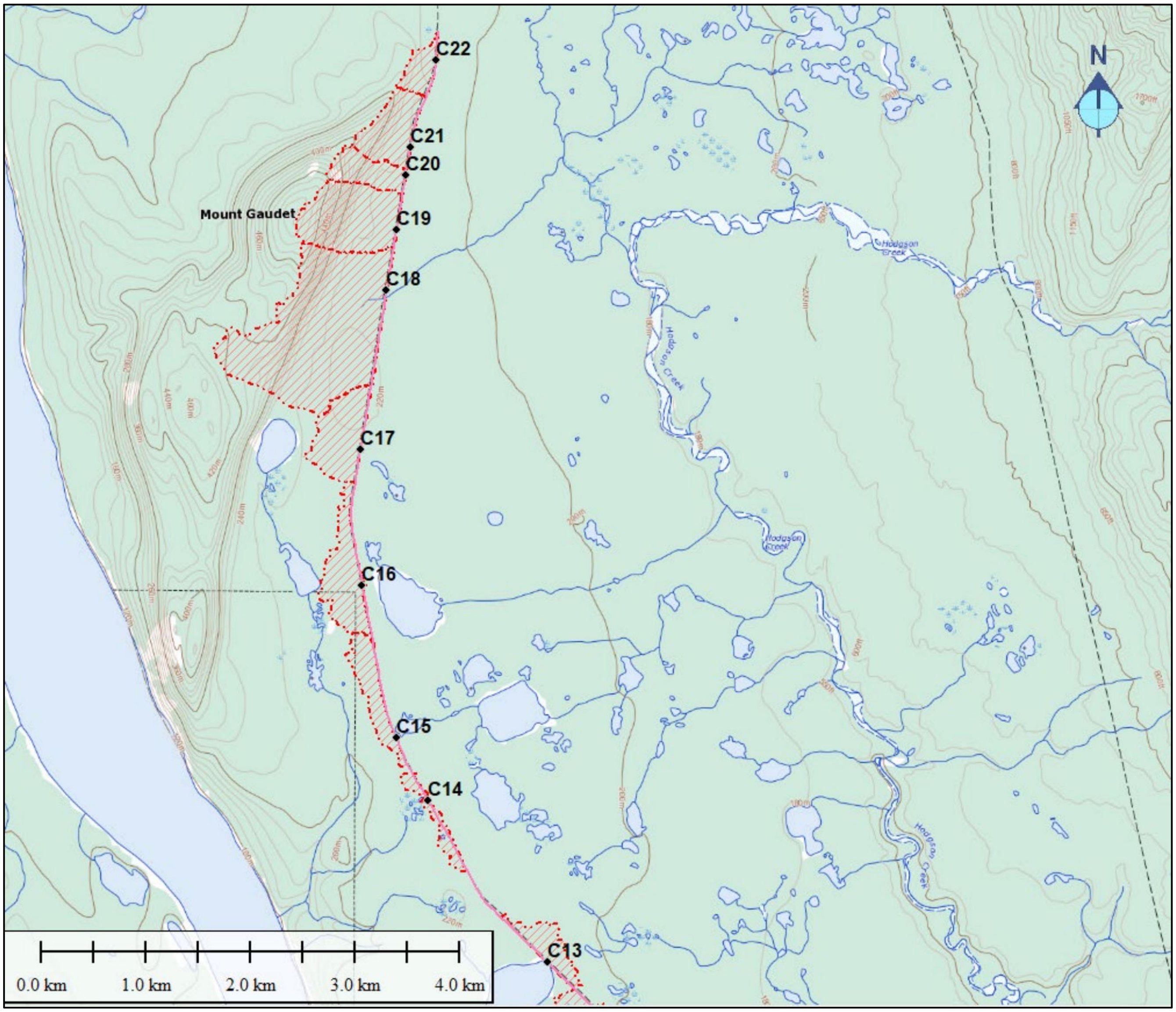

Figure 5-1a: MGAR Proposed Culvert Crossing Watersheds – North Panel (1 of 2)

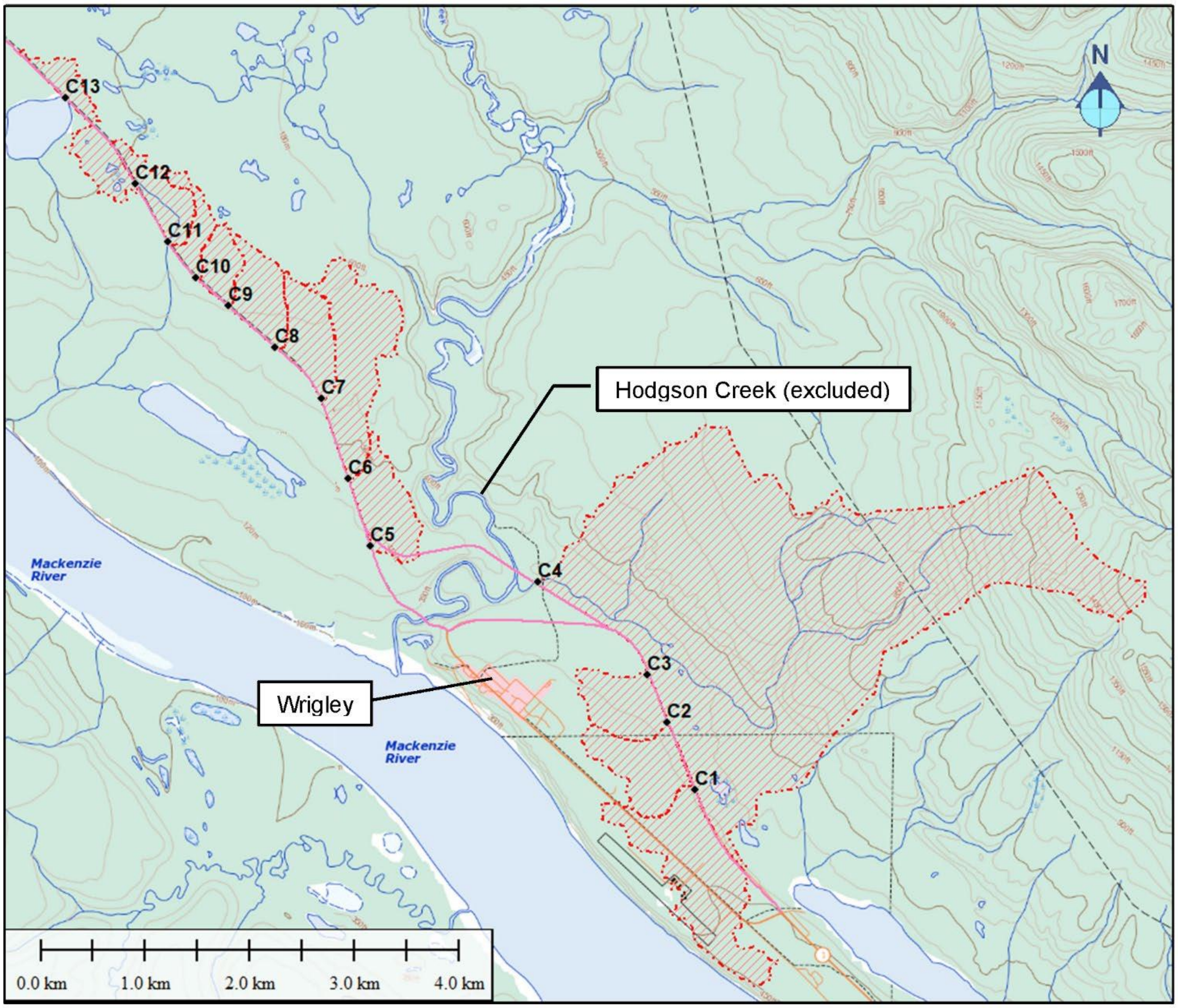

Figure 5-1b: MGAR Proposed Culvert Crossing Watersheds – South Panel (2 of 2)

Table 5-1: MGAR Drainage Crossing Locations and Watershed Areas

Crossing	UTM Zone 10 Easting (m)	UTM Zone 10 Northing (m)	Geographic Latitude	Geographic Longitude	Watershed Area (km^2)	Field Investigation Site
C1	478311	7010082	63° 13' 09.02" N	123° 25' 53.17" W	1.11	
C2	478056	7010724	63° 13' 29.71" N	123° 26' 11.70" W	0.52	
C3	477870	7011188	63° 13' 44.66" N	123° 26' 25.25" W	0.43	
C4	476822	7012085	63° 14' 13.40" N	123° 27' 40.80" W	9.57	Creek #1
C5	475226	7012442	63° 14' 24.54" N	123° 29' 35.36" W	0.46	
C6	475013	7013087	63° 14' 45.33" N	123° 29' 50.96" W	0.91	
C7	474764	7013858	63° 15' 10.17" N	123° 30' 09.29" W	0.41	
C8	474325	7014352	63° 15' 26.02" N	123° 30' 41.04" W	0.37	
C9	473874	7014762	63° 15' 39.15" N	123° 31' 13.59" W	0.21	
C10	473569	7015028	63° 15' 47.66" N	123° 31' 35.65" W	0.18	
C11	473309	7015378	63° 15' 58.90" N	123° 31' 54.46" W	0.31	Drainage #1
C12	472996	7015942	63° 16' 17.04" N	123° 32' 17.28" W	0.25	Drainage #2
C13	472341	7016764	63° 16' 43.44" N	123° 33' 04.77" W	0.16	
C14	471201	7018324	63° 17' 33.50" N	123° 34' 27.59" W	0.11	
C15	470904	7018933	63° 17' 53.11" N	123° 34' 49.25" W	0.23	Drainage #3
C16	470586	7020392	63° 18' 40.12" N	123° 35' 13.06" W	0.36	
C17	470587	7021689	63° 19' 22.05" N	123° 35' 13.87" W	0.35	300 m from Drainage #4
C18	470852	7023215	63° 20' 11.44" N	123° 34' 55.82" W	1.63	Drainage #5
C19	470951	7023792	63° 20' 30.10" N	123° 34' 49.05" W	0.55	
C20	471043	7024312	63° 20' 46.91" N	123° 34' 42.80" W	0.20	
C21	471088	7024576	63° 20' 55.45" N	123° 34' 39.68" W	0.29	
C22	471344	7025408	63° 21' 22.41" N	123° 34' 21.86" W	0.12	

5.2 Hydrologic Analysis

The goal of the hydrologic analysis was to estimate the flow, for various return periods, at drainage crossings along the proposed highway alignment.

The hydrology was evaluated using a regional analysis approach. Regional analyses are used to estimate flow in ungauged watersheds by using relationships based on measured flows in gauged watersheds with similar physiographic characteristics. This approach was used to develop flow estimates for each of the catchments crossed by the MGAR alignment.

The hydrologic assessment made estimates of two year through 200-year peak flows for each drainage crossing, and also three day ten year delay flows sometimes 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.

Water Survey of Canada (WSC) hydrometric stations in the vicinity of the project site were reviewed to find gauged watercourses with similar watershed characteristics and sufficient data (more than ten years) for meaningful statistical analysis. Seven stations on relatively small drainages (less than 1,000 km^2) were selected for analysis prior to further screening for physiographic characteristics similar to the watershed draining to the MGAR. Station information is included in Table 5-2 below.

Table 5-2: WSC Regional Stations

Station ID	Station Name	Watershed Area (km^2)	Period of Record	Data Available (years)
10HC003	Big Smith Creek near Highway No. 1	980	1972-1994	22
10GC002	Harris River near The Mouth	701	1972-1995	23
10ED003	Birch River at Highway No. 7	542	1974-2017	43
10GB005	Metahdali Creek above Willowlake River	344	1976-1987	11
10ED009	Scotty Creek at Highway No. 7	202	1994-2017	23
10KA007	Bosworth Creek near Norman Wells	125	1980-2017	37
10KA006	Jungle Ridge Creek near The Mouth	60	1980-2011	15

Figure 5-2 below presents the Project Location in relation to the Hydrometric Stations Identified in Table 5-2.

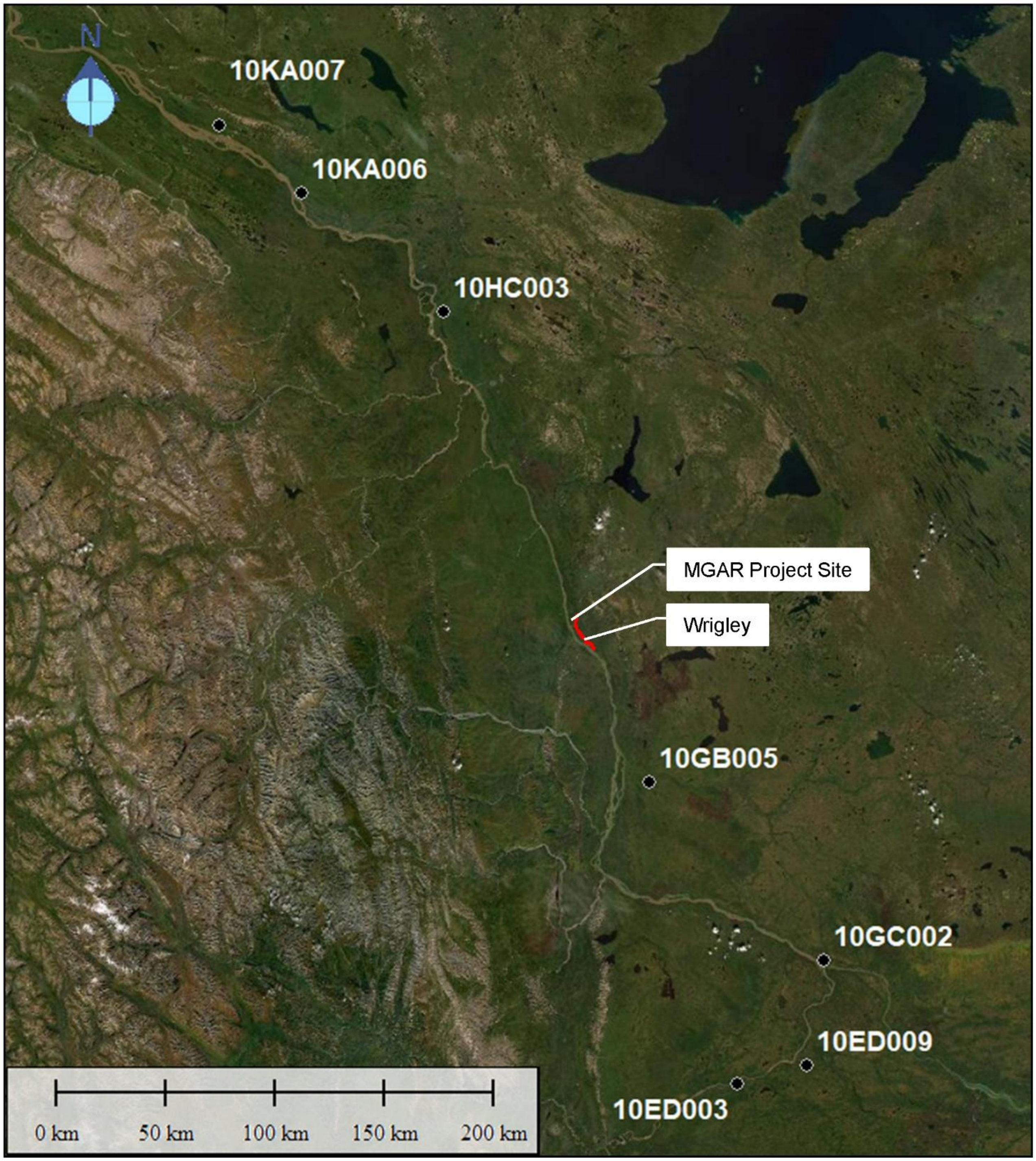

Figure 5-2: Water Survey of Canada Hydrometric Stations and MGAR Project Location

A frequency analysis was completed 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 from the maximum daily value based on a linear-regression analysis of years where both values were available.

In addition, the 3Q10 flow (the 1 in 10-year 3-day delay discharge) was computed for the three gauges with the smallest basins of the gauged regional streams. The 3Q10 flow is sometimes used to assess 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.

The statistical frequency analysis software, HYFRANPLUS, was used to fit the flow data to selected best fit statistical distributions. Several probability distributions were tested and used to select the best distribution for each station. A chart of the Lognormal fitting used for station 10KA006 (Jungle Ridge Creek) is shown in Figure 5-3.

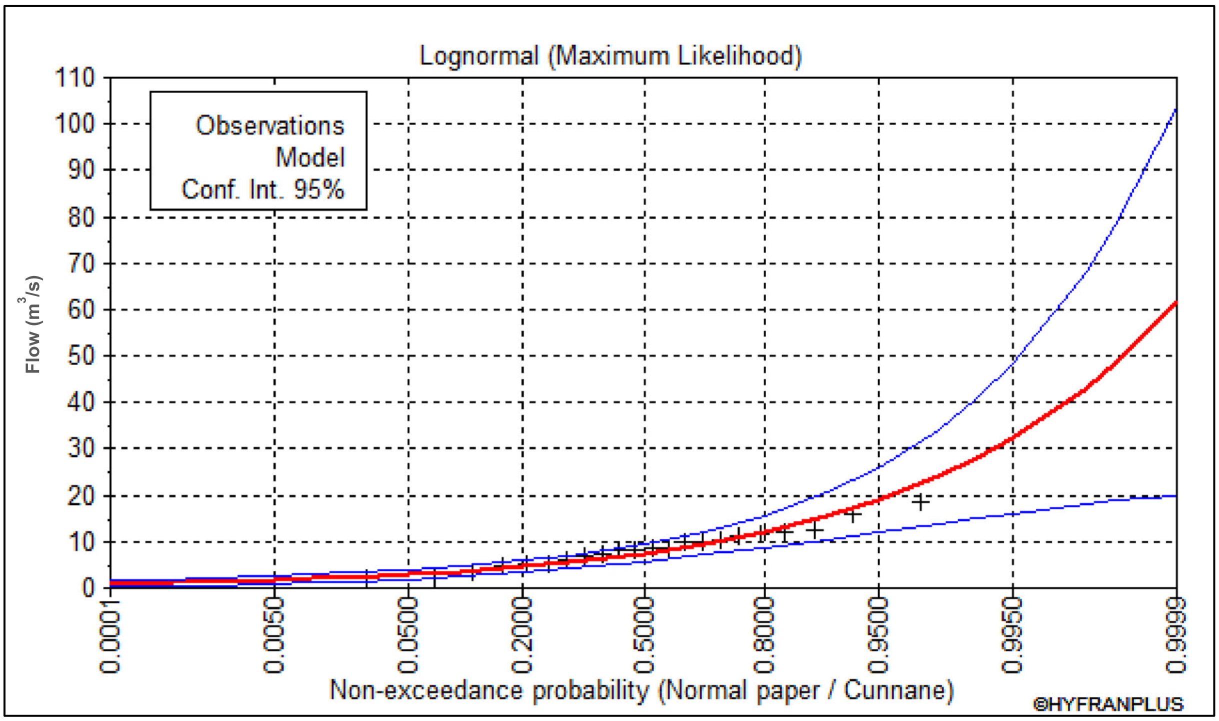

Figure 5-3: Frequency Distribution for Jungle Ridge Creek (10KA006) Instantaneous Flow Data

Results of the frequency analysis are shown in Table 5-3 and Figures 5-4 and 5-5 below.

Table 5-3: Frequency Analysis Results

Station	10HC003	10ED003	10GC002	10GB005	10ED009	10KA007	10KA006
Area (km^2)	980	542	701	344	202	125	60
Years of Data	22	43	23	11	23	37	15
200-Year (m^3/s)	230.0	126.0	84.0	97.6	24.9	32.3	27.0
100-Year (m^3/s)	212.0	114.0	75.2	87.0	22.4	29.4	24.3
50-Year (m^3/s)	193.0	101.0	66.2	76.4	19.9	26.5	21.6
20-Year (m^3/s)	168.0	84.1	54.4	62.3	16.6	22.6	18.1
10-Year (m^3/s)	149.0	71.0	45.2	51.4	14.0	19.6	15.5
5-Year (m^3/s)	129.0	57.5	35.6	40.0	11.3	16.5	12.9
2-Year (m^3/s)	98.3	37.0	21.1	22.8	7.2	11.7	9.0
3Q10 (m^3/s)	*	*	*	*	10.0	10.4	10.2
200-Year/Area	0.23	0.23	0.12	0.28	0.12	0.26	0.45
100-Year/Area	0.22	0.21	0.11	0.25	0.11	0.24	0.41
200-Year/2-Year	2.34	3.41	3.98	4.28	3.45	2.76	3.01
100-Year/2-Year	2.16	3.08	3.56	3.82	3.10	2.51	2.71
50-Year/2-Year	1.96	2.73	3.14	3.35	2.76	2.26	2.41
20-Year/2-Year	1.71	2.27	2.58	2.73	2.30	1.93	2.02
Observations					flat headwaters	lake attenuation	

* 3Q10 discharge not computed

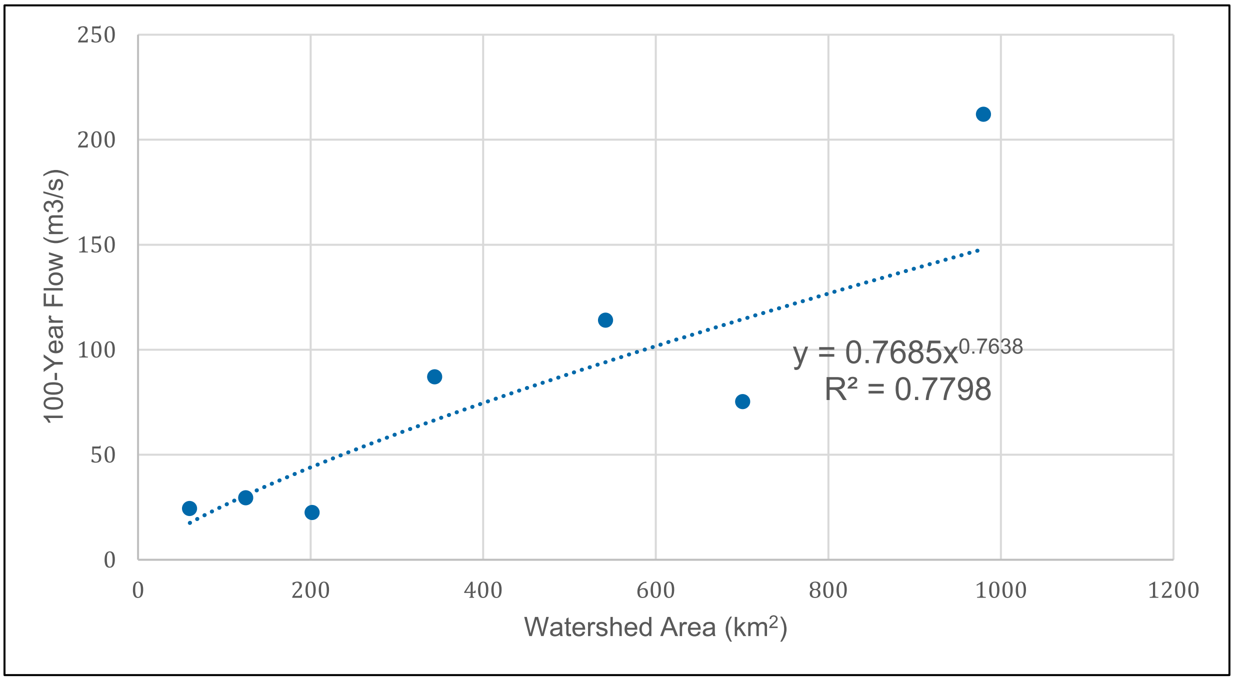

Figure 5-4: Computed 100-Year Peak Flow vs Watershed Area

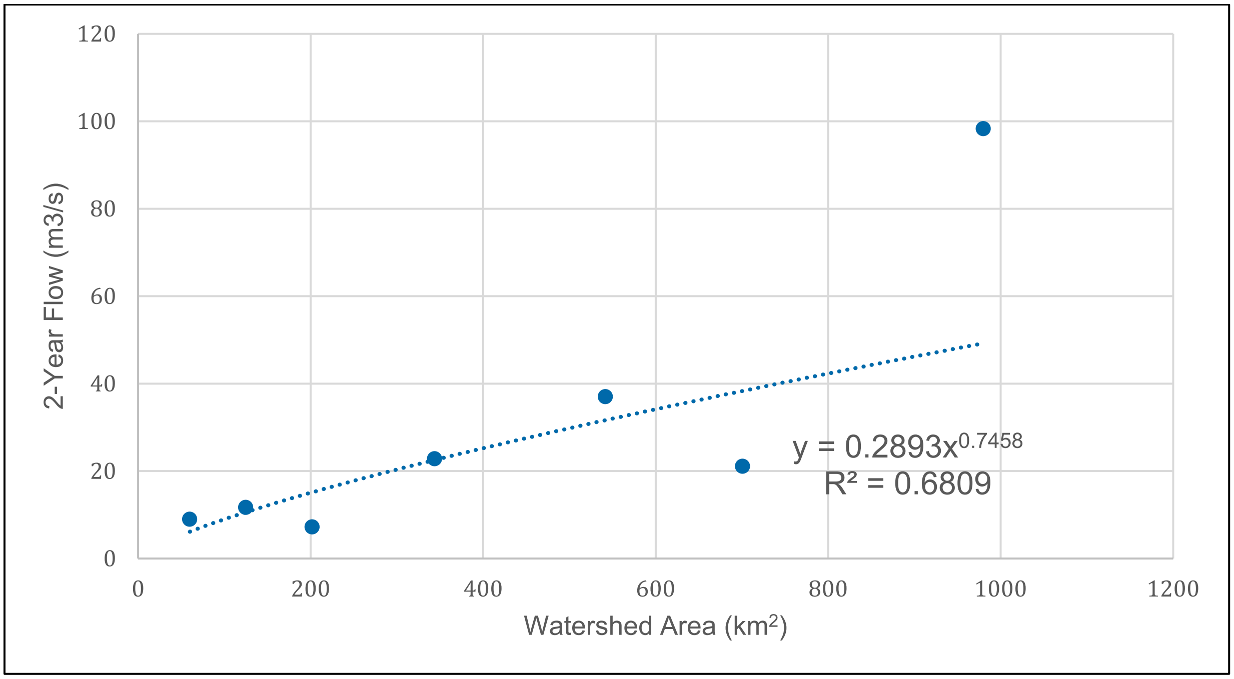

Figure 5-5: Computed 2-Year Peak Flow vs Watershed Area

Figures 5-4 and 5-5 show considerable scatter in the data relative to a best fit regression line. Two stations in particular have flows that are lower than the other stations: Scotty Creek (202 km^2) and Harris River (701 km^2). The Jungle Ridge Creek gauge with the smallest of the gauged basins (60 km^2) plots slightly above the best fit regressions and was selected as an index station for conservative extrapolation of flows to the smaller basin sizes encountered along the MGAR. Reliance on the Jungle Creek Ridge station yields higher design flows than the regression line that provides a best fit for all the regional stations regardless of physiographic characteristics.

A check on the suitability of the Jungle Creek Ridge as an index station was made by comparing its historical recorded mid-September flow which averaged 438 L/s with the 60 L/s flow measured at MGAR Creek #1 (Crossing C4) during the September 2020 site inspection. Normalizing for catchment size, these flows translate to unit flows of 7.3 L/s/km^2 and 6.3 L/s/km^2 for Jungle Ridge Creek and Creek #1 respectively. The consistency of these flow data supports the use of Jungle Ridge Creek for assessment of project area watercourses.

Table 5-3 includes ratios of 2-year flows to 20- through 200-year flows for each station. The accuracy of individual quantiles is dependent on the years of record for each station, with longer records yielding greater confidence in the results. Figure 5-4 includes 95% confidence lines for the Jungle Ridge Creek frequency curve, from which it is apparent that the confidence in a particular estimate decreases with increasing return period (larger non-exceedance probability). In other words, the confidence in a 2-year estimate (0.5 probability) is higher than for a 200-year (0.995 probability). The confidence in the larger return periods increases for data sets with longer periods of record.

The Jungle Ridge Creek gauge has 15 years of record, resulting in relatively low confidence for estimates of high return period floods. To provide a more conservative estimate of the flows, adjustments were made considering the ratios of flood flows to 2-year flows from the other regional stations. Adjustments were made to the Jungle Creek 20- through 200-year estimates using the multipliers for Birch River which has the longest period of record of the regional stations (43 years) and also the highest multipliers. Table 5-4 presents the adjusted results, which are believed to be conservative.

Table 5-4: Adjusted Frequency Analysis Results for Jungle Ridge Creek (10KA006)

Jungle Ridge Creek Near the Mouth (Station ID: 10KA006)			
Dataset	Initial Flow	Adjusted	
Return Period (years)	(m^3/s)	(m^3/s)	Scale Factor
200	27.0	30.5	3.41/3.01
100	24.3	27.6	3.08/2.71
50	21.6	24.5	2.73/2.41
20	18.1	20.4	2.27/2.02
10	15.5	15.5	*
5	12.9	12.9	*
2	9.0	9.0	*
3Q10	10.2	10.2	*

* Value not scaled.

As Jungle Ridge Creek has a larger watershed area than the highway crossing watershed areas, peak flows were adjusted using the equation:

$$Q_2 = Q_1 \times \frac{A_2}{A_1}^k$$

Where:

- Q_1 and Q_2 denotes flows of two watersheds;
- A_1 and A_2 denote watershed areas of differing size (km^2); and
- k is a peaking factor, recognizing heightened unitized runoff within smaller catchments. Commonly 0.785 is used for the B.C. region (Coulson and Obedkoff, 1998); a rounded value of 0.8 was used for the present study.

5.3 Climate Change Effects

Due to freshet flows being the dominant high flow events for gauged streams for the project region, it was assumed that peak flows are related to winter precipitation depths. Climate change effects on peak flows were assessed with a simplifying assumption that the magnitude of these effects will be similar to modelled climate change effects on winter precipitation.

Climate model data was obtained from the Pacific Climate Impacts Consortium (PCIC) Climate Explorer[2] for the Winter (Dec to Feb) Precipitation RCP 8.5 (high carbon) scenario. An ensemble[3] mean was calculated from six Global Climate Models recommended by PCIC for western North America and selected for having seasonal precipitation outputs. Results are shown in Table 5-5.

Table 5-5: Ensemble Global Climate Model Winter December to February Mean Daily Precipitation for Region Including Project Site

Model Period	Min	Max	Mean	Median	Std. Dev	Units
1961 - 1990	0.54	0.74	0.60	0.60	0.04	mm/day
1971 - 2000	0.53	0.74	0.60	0.59	0.04	mm/day
1981 - 2010	0.54	0.74	0.60	0.60	0.04	mm/day
2010 - 2039	0.57	0.79	**0.64**	0.64	0.04	mm/day
2040 - 2069	0.60	0.82	0.67	0.66	0.04	mm/day
2070 - 2099	0.69	0.93	**0.76**	0.75	0.05	mm/day

Using the above projections in Table 5-5, an increase in winter precipitation of 17.9 percent is estimated for the project area for the time period of 2070-2099 versus the current time period of 2010-2039.

[2] https://services.pacificclimate.org/pcex/app

[2] The models selected for ensemble analysis were: GFDL-ESM2M; GFDL-ESM2G; GFDL-CM3; CNRM-CM5; CanESM2; and MIROC5

A separate check using the Climate Atlas of Canada[4] projections are shown in Table 5-6. A linear interpolation was used on the winter precipitation depths between the two time periods of 1976-2005 and 2021-2050 to estimate a 2020 depth of 63.3 mm. An increase in winter precipitation of 15.2 percent is estimated for the project area for the time period of 2051-2080 versus the interpolated precipitation depth for 2020.

Table 5-6: Climate Atlas of Canada Winter Precipitation Projections for Norman Wells Region

Time Period	Winter Precipitation (mm)
1976-2005	58.0
2021-2050	66.0
2020, (Interpolated)	63.3
2051-2080	73.0

The PCIC Climate Explorer and Climate Atlas of Canada projections are reasonably consistent. Climate change effects on project area peak flows were estimated using the more conservative 17.9 percent increase in winter precipitation from the PCIC data.

5.4 Preliminary Crossing Designs

The 100-year return period flows developed through Tetra Tech's hydrologic analysis were used as the design events for crossing designs. Because major crossings requiring bridges have been assessed previously and are excluded from the current assessment, culverts are assumed to be sufficient for all crossings.

Preliminary culvert sizes for each crossing were determined assuming a single non-embedded circular culvert with inlet control conditions, a projecting inlet and a minimum diameter of 800 mm. This minimum diameter is specified in the GNWT 2010 Highway Maintenance Manual. The culverts were sized such that the inlet headwater depth for the 100-year peak flow does not exceed the culvert diameter (a headwater to diameter ratio (HW/D) of 1.0) and is independent of the road embankment height. Different assumptions including but not limited to the culvert shape and number of barrels may apply for final design when site survey and road geometry information is available.

Additional hydraulic analysis was completed for culvert C4 (Creek #1) which was the only MGAR watercourse crossing identified as being fish-bearing during the site investigation. Crossings designed for fish passage are typically open-bottomed and attempt to preserve the natural cross-section and substrate of the original channel. An open-bottomed arch culvert is recommended for crossing C4 to minimize channel disturbance and to accommodate passage of the 100-year event. This recommendation does not preclude a different shape or dimensions being specified for the final design.

A summary of culvert design flows and preliminary sizes is presented in Table 5-7. Geographic coordinates for these crossings are available from Table 5-1.

[4] https://climateatlas.ca

Table 5-7: MGAR Culvert Crossing Design Flows and Preliminary Sizes

Crossing	UTM Zone 10 Easting (m)	UTM Zone 10 Northing (m)	Watershed Area (sq km)	100-Year Flow (m^3/s)	Climate Change Adjusted 100-Year Flow (m^3/s)	Culvert Diameter (mm)
C1	478311	7010082	1.11	1.13	1.34	1200
C2	478056	7010724	0.52	0.62	0.73	900
C3	477870	7011188	0.43	0.53	0.62	800
C4	476822	7012085	9.57	6.36	7.5	Arch: 3100w x 1980h
C5	475226	7012442	0.46	0.56	0.66	900
C6	475013	7013087	0.91	0.97	1.14	1200
C7	474764	7013858	0.41	0.51	0.6	800
C8	474325	7014352	0.37	0.47	0.55	800
C9	473874	7014762	0.21	0.3	0.35	800
C10	473569	7015028	0.18	0.27	0.32	800
C11	473309	7015378	0.31	0.41	0.48	800
C12	472996	7015942	0.25	0.34	0.4	800
C13	472341	7016764	0.16	0.24	0.29	800
C14	471201	7018324	0.11	0.17	0.21	800
C15	470904	7018933	0.23	0.32	0.37	800
C16	470586	7020392	0.36	0.46	0.54	800
C17	470587	7021689	0.35	0.45	0.53	800
C18	470852	7023215	1.63	1.54	1.82	1400
C19	470951	7023792	0.55	0.65	0.76	900
C20	471043	7024312	0.2	0.29	0.34	800
C21	471088	7024576	0.29	0.39	0.46	800
C22	471344	7025408	0.12	0.19	0.23	800

The recommended sizes and shapes are preliminary and should be revisited once the highway design is finalized as roadway grading and preferred embankment heights may alter drainage patterns, increase maximum allowable headwater depths, or create cover height constraints. Hydraulically-equivalent alternatives such as substituting multiple small culverts for specified large culverts may be preferred for final design where there is a cost or design advantage in doing so.

Following the completion of road and embankment design, crossing profiles should be developed for each of the proposed culvert crossings. Crossing profiles will allow for detailed hydraulic modelling which will provide accurate headwater depths, peak flows, and peak velocities through the proposed culverts. This is required for confirmation of design sizes and design of scour and erosion protection measures, both of which should be completed prior to tendering and construction.

6.0 CLOSURE

We trust this document 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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PERMIT TO PRACTICE
TETRA TECH CANADA INC.
Signature
Date April 26, 2021
PERMIT NUMBER: P 018
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APPENDIX A

TETRA TECH'S LIMITATIONS ON THE USE OF THIS DOCUMENT

LIMITATIONS ON USE OF THIS DOCUMENT

HYDROTECHNICAL

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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.