March 19, 2024

Patricia Coyne

Reference: MVEIRB ORS Comment Responses ORS 64-143

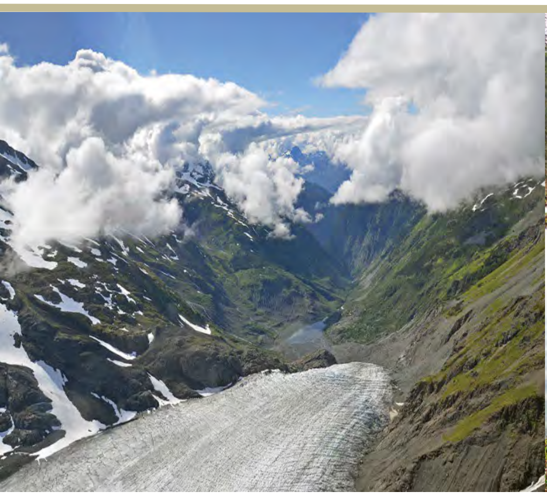
Attachment LKFN-33B

Mackenzie Valley Highway Sahtu South Segment Hydrotechnical Assessments (Tetra Tech 2022)

Kálo-Stantec

TETRA TECH

Mackenzie Valley Highway
Sahtu South Segment Hydrotechnical Assessments
GNWT Service Contract SC-5132



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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 Limited for K'alo-Stantec Limited (Stantec), was retained by the Government of the Northwest Territories (GNWT) to provide fish habitat and hydrotechnical assessments along a segment of the proposed Mackenzie Valley Highway (MVH) in the southern portion of the Sahtu Lands Administration Region (Sahtu South Segment). The assessed segment is approximately 150 km long, starting at the southern Sahtu border and extending north to Prohibition Creek. This work was done under a Standing Offer Agreement with the GNWT.

The alignment for the proposed MVH largely follows an existing winter road which has bridges at major watercourse crossings. The scope of work excludes the major crossings with existing bridges which have been evaluated previously.

The results of the fish habitat and hydrotechnical assessment are provided in separate discipline-specific reports. This report presents the hydrotechnical results.

Field Investigation

Twelve days of site investigation were completed from September 30 through October 11th, 2021, by two Tetra Tech field staff, accompanied by a wildlife monitor based out of Tulita, using helicopter services based in Norman Wells to access the sites. Approximately 40 predefined watercourses of potential interest were observed from the air to evaluate whether the watercourses were substantial enough to warrant a ground inspection. Ground inspections were made at 27 of these watercourses to measure flow rates, assess channel geometry and channel substrate, and to document other watercourse characteristics potentially pertinent to the design of appropriate drainage infrastructure.

Hydrologic Analysis

A hydrologic analysis was undertaken to estimate peak flows for various return periods. 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

Preliminary crossing structure recommendations are made for 27 crossing locations. Sizing assumed non-embedded circular corrugated culverts with inlet flow control at projecting inlets and a 100-year flow maximum allowable 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 3050 mm.

The sizing assumptions do not consider fish passage requirements and the preliminary sizes may therefore not be suitable for fish bearing streams. Alternative designs such as bridges or large arch culverts that preserve the natural channel hydraulic characteristics through the crossing should be considered for any watercourses subsequently deemed to be fish bearing.

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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.

ACRONYMS & ABBREVIATIONS

Acronyms/Abbreviations	Definition
%	percent
ASR	All Season Road
AT	Alberta Transportation
CSP	Corrugated Steel Pipe
DEM	Digital Elevation Model
ECCC	Environment and Climate Change Canada
ENR-ITI-Lands	Environment and Natural Resources - Industry, Tourism and Investment, and Lands
INF	Department of Infrastructure
GCM	Global Climate Model
GNWT	Government of the Northwest Territories
km	kilometre
KM	Kilometre marker
km^2	Square kilometres
LiDAR	Light Detection and Ranging
L/s	litres per second
m	metre
mm	millimetre
MVH	Mackenzie Valley Highway
MGAR	Mount Gaudet Access Road
NTS	National Topographic System (the system used by Natural Resources Canada for providing general purpose topographic maps of the country)
NWT	Northwest Territories
PCAR	Prohibition Creek Access Road
PDR	Project Description Report
SPCSP	Structural Plate Corrugated Steel Pipe
the Project	the Mackenzie Valley Highway Project

1.0 INTRODUCTION

Tetra Tech Canada Inc. (Tetra Tech), as a subconsultant to Stantec Architecture Limited for K'alo-Stantec Limited (Stantec), was retained by the Government of the Northwest Territories (GNWT) to provide field and hydrotechnical aspects of fish habitat and hydrotechnical assessments along portions of the proposed Mackenzie Valley Highway (MVH) Project which will upgrade the existing winter road to an All-Season Road (ASR). This work was authorized by multiple Service Contracts under Standing Offer Agreement 4034 with the GNWT.

This report describes hydrotechnical services provided in late 2021 under Service Contract 5132 for an approximately 150-kilometre segment of the MVH in the southern portion of the Sahtu Lands Administration Region (Sahtu South Segment). This segment starts at the southern Sahtu border and extends north to Prohibition Creek.

Figure 1-1 presents a regional location plan showing the location and extents of the current Sahtu South Segment and also the three segments for which minor watercourse hydrotechnical assessed were conducted in 2020: (1) Prohibition Creek Access Road (PCAR), (2) Mount Gaudet Access Road (MGAR) and (3) Dehcho Segment (Tetra Tech, 2021). In addition to the above, Tetra Tech provided hydrotechnical input in 2021 for a multi-disciplinary team, led by Stantec, for detailed design of bridge-size culverts and modifications of approaches to existing bridges along the PCAR segment.

The alignment for the proposed ASR largely follows the existing winter road which has bridges at major watercourse crossings. The scope of work excludes the major crossings with existing bridges which have been evaluated previously. The watercourse crossings assessed in this report are described as "minor watercourse crossings" to distinguish them from the excluded larger watercourses with existing bridges and bridge-size culverts.

Field inspections were conducted from September 30 through October 11th, 2021, by a team consisting of one Tetra Tech hydrotechnical engineer, one Tetra Tech fisheries biologist and a local wildlife/environmental monitor based out of Tulita. Sites were accessed via helicopter based in Norman Wells.

The results of the fish habitat and hydrotechnical assessments are provided in separate discipline-specific reports. This report presents the hydrotechnical results.

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LEGEND

- Water Survey of Canada Stream Gauge Station
- Mackenzie Valley Highway Project
- Mackenzie Valley Winter Road
- Mount Gaudet Access Road
- Prohibition Creek Access Road
- Region Boundary
- District Boundary

Base Data

- Populated Place
- Other Road
- Provincial/Territorial Boundary

NOTES
Base data source:
Natural Resources Canada
CanVec 1:5M scale
ESRI Data Maps
Imagery provided by ESRI; Maxar

STATUS
ISSUED FOR USE

MACKENZIE VALLEY HIGHWAY 2021 HYDROTECHNICAL ASSESSMENTS

Sahtu South Segment Regional Location Plan

PROJECTION	DATUM	CLIENT
Northwest Territories Lambert	NAD83	Northwest Territories

Scale: 1:4,000,000
50 25 0 50
Kilometres

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Figure 1-1

2.0 SCOPE OF WORK AND BACKGROUND INFORMATION

The original scope of work for the Sahtu South Segment anticipated the evaluation of 28 specific watercourses. Preliminary assessments made in preparation for field work determined that several watercourses appeared on the original list by error, such as watercourses not being crossed by the current proposed All Season Road (ASR) alignment or having been previously assessed, and that other pertinent watercourses had been omitted. To ensure timely completion of the field program, the work proceeded with a modified scope that included assessments of all relevant crossings from the original scope plus additional sites judged to be potentially significant based, in part, on aerial reconnaissance observations during the field program.

The additional sites selected for ground inspections and subsequent hydrotechnical assessment are believed to include all watercourses, excluding existing bridge crossings, substantial enough to contain fish and/or require a culvert greater than 1500mm in diameter, the cut-off diameter beyond which GNWT guidelines require bridge-size culverts to be designed in accordance with specific material and engineering criteria.

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
- Hydraulic analysis for preliminary crossing structure recommendations.

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

The ASR centreline was provided by Stantec for this project. This ASR alignment is understood to generally (but not exactly) match the alignment described in the Project Description Report (PDR) for the MVH Tulita District, Sahtu Settlement Area (EBA, 2011). The Kilometre Markers (KMs) used to describe the 2011 PDR alignment are used in this report to refer to the crossing locations.

Historical streamflow information from Water Survey Canada (WSC) stations in the vicinity of the study area, reflecting drainage from relatively-small basins in close proximity to the ASR, was obtained for the hydrologic analysis. The stations used in the analysis are identified in Figure 1-1 and described in Section 4.2.

Multiple forms of topographic mapping information were obtained, including: (1) bare earth Light Detection and Ranging (LiDAR) data acquired in 2010[1] by the GNWT for a corridor along the MVH alignment, (2) Government of Canada 1:50,000 scale National Topographic System (NTS) maps and companion CanVec data layers, (3) Government of Canada Geobase Digital Elevation Models, and 4) Polar Geospatial Centre ArcticDEM terrain models developed from satellite imagery. The LiDAR, NTS mapping, Geobase DEM and ArcticDEM data were used to determine watershed areas.

[1] GNWT acquired additional LiDAR data along the MVH alignment during 2019-2021 which was not available for the current assessment but should be used for subsequent detailed designs.

The methodology used for preliminary sizing of culverts at minor watercourse crossings incorporates knowledge gained during the preparation of detailed designs of culvert crossing along the PCAR segment in 2021 and is modified slightly from the methodology used for the PCAR and MGAR initial assessments in 2020.

It was learned during the PCAR detailed design that drainage crossing designs along the MVH ASR cannot rely on conventional ditching or grading along the road embankment, as initially assumed, to direct intercept runoff to designated cross-drainage locations. This is because of geotechnical recommendations for the embankment construction to be exclusively with fill, without grading of the native ground, to minimize ground disturbance in confirmed or potential permafrost areas. In a change from the prior initial assessments of the PCAR and MGAR segments which had assumed that all runoff intercepted by the road embankment would be directed to a designated cross drainage location, the minor crossing designs for the Dehcho and Sahtu assessments only consider the watershed areas that naturally drain to the specific minor crossing locations.

It was also learned during the PCAR detailed design it is not always possible to size a single culvert with sufficient capacity to convey the design flow that naturally drains to the culvert location. This condition occurs at drainages without a well-defined channel or gully deep enough to develop the headwater (depth of water at the culvert inlet) to pass the design flow without creating bypass flow along the toe of the road embankment. For example, if the native topography can only impound water to a depth of 0.5 m before bypass flow occurs, it is essentially not possible to utilize the full capacity of culverts with a diameter greater than 0.5 m. The minor crossing designs for the Dehcho and Sahtu assessments consider headwater constraints which need to be resolved with multiple culverts and sometimes eliminate the need for bridge-size culverts.

The current scope of work provides preliminary sizing recommendations for minor watercourse crossings and does not include preparation of detailed designs which will incorporate geotechnical, road design and other information not yet available. The 2011 PDR (EBA, 2011) included a relevant discussion of future detailed designs for minor stream crossings, copied below for reference.

> *Other minor stream crossings will utilize common culvert design and installation or minor bridges. The decision to use a culvert or a minor bridge structure is generally dependent on ground and soil conditions, availability of fill material, cost, and most importantly, requirements to protect fish habitat. Where large diameter culverts (greater than 1,400 mm dia.) are considered for minor crossings, the culverts will be traditional circular or arch culverts with closed bottoms as these are known to have better performance in permafrost regions than open bottom arch culverts. As the cost of shipping large diameter corrugated steel pipe culverts is prohibitive, structural plate corrugated steel pipe culverts will be considered.*
>
> *Designs for major and minor culverts will include requirements for bedding materials, geotextile, and insulation to provide strength in foundation and to protect the surrounding permafrost and ice rich soils from thaw. Detailed geotechnical information will be collected in field investigations in the next steps in development of the Highway and detailed design stages will incorporate the bedding and foundation requirements for culverts.*

3.0 FIELD INVESTIGATIONS

The field investigation along the MVH South Sahtu Segment was conducted from September 30 to October 11, 2021, by hydrotechnical engineer Mark Aylward-Nally, P.Eng. (BC) and aquatic biologist Theresa McCaffrey of Tetra Tech, accompanied by a local wildlife/environmental monitor based in Tulita. A total of 27 water crossings were accessed by helicopter to evaluate the drainage and fish habitat characteristics, reported separately.

The proposed ASR alignment largely follows the current winter road alignment with exceptions where deviations have been made to improve the alignment. The majority (18) of the watercourse crossings evaluated in this assessment are at locations where the two alignments match.

The terrain over the Sahtu South Segment can be characterized as gently rolling terrain that generally drains west towards the Mackenzie River. Ground cover along the alignment is predominantly muskeg, often wet and marshy in low-lying areas, vegetated with small trees and shrubs. Heavy beaver activity was noted along the entire Sahtu South Segment, creating blockages on many of the visited watercourses.

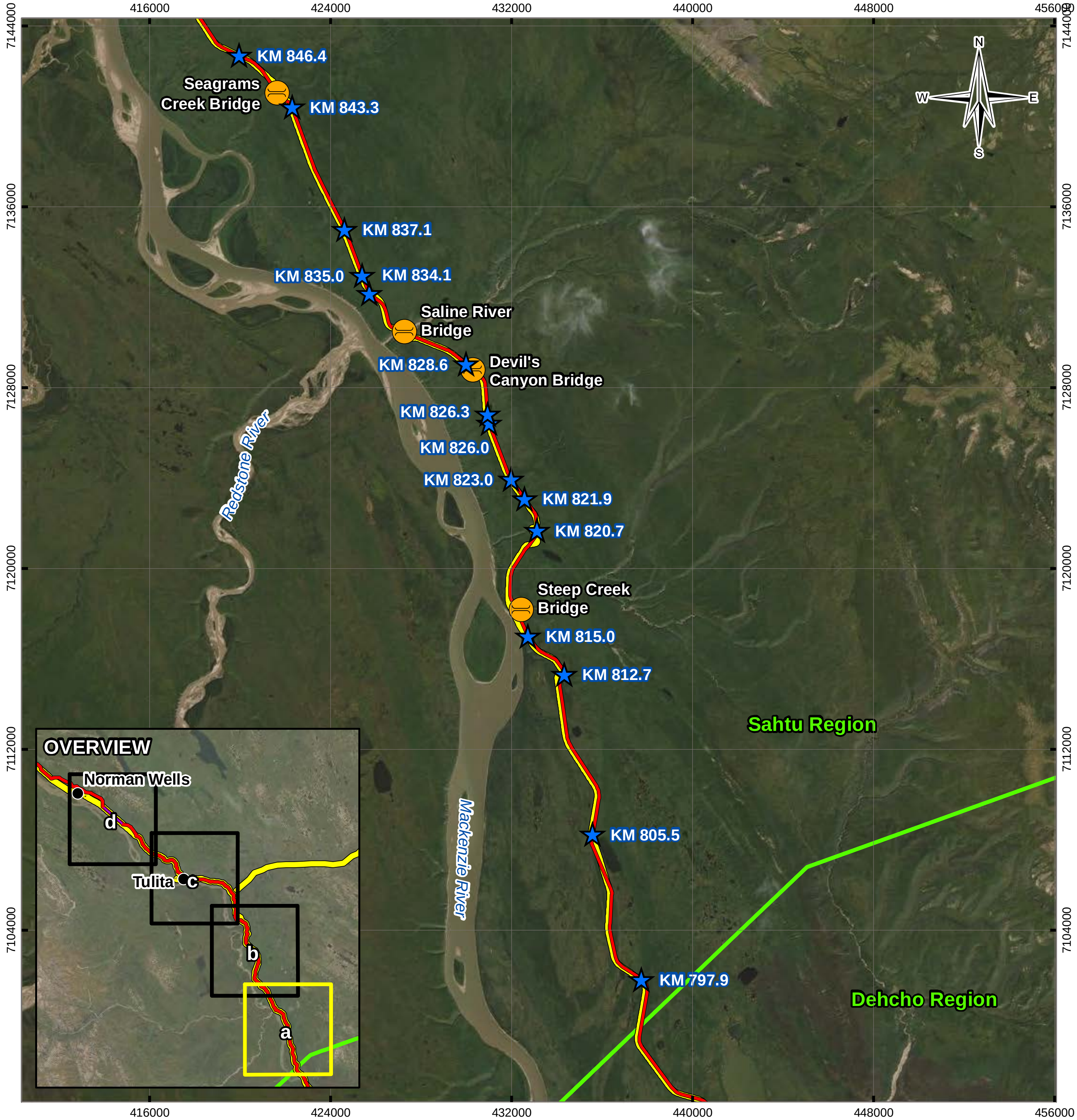
3.1 Watercourse Selection Methods

As described in Section 2.0, the watercourse crossing site list in the originally scope of work was modified to include some alternate crossings after it was determined that the original list, based on watercourses from the 2011 PDR (EBA, 2011), included several watercourses that were either avoided by the most current ASR alignment or had been previously assessed for a now-existing bridge or bridge culvert. The final list of sites was developed by a combination of desktop reviews and field aerial reconnaissance.

A review of background reports and topography data was completed prior to the field visit to prepare a list of watercourses of potential interest. This list included still-relevant watercourses identified in the 2011 PDR report plus additional potential watercourses identified through examination of LiDAR and ArcticDEM terrain models, NTS 1:50,000 topographic maps and aerial imagery to identify substantial drainage features. In total, 36 preliminary sites were identified. During the field program each of these sites was viewed from the air to determine whether a significant enough watercourse was present to warrant ground inspection.

Ground assessments were made at a total of 27 sites. The final site list includes every watercourse along the MVH Sahtu South Segment, without an existing bridge or bridge culvert, significant enough to possibly require an engineered bridge size culvert design. The site list also incudes many smaller watercourses. Although an effort was made to include the largest of the smaller watercourses, it was difficult to make this determination from the aerial assessment. The final list does not provide a comprehensive summary of locations where small channels (some larger than those where site inspections were made) or flowing wetlands exist and where cross-drainage will be required.

Figures 3-1a through 3-1d show the locations of the minor watercourse crossings which are evaluated in this report. Figures C-1 to C-8 in Appendix C show the crossings locations at a smaller scale, together with their drainage basin areas.



LEGEND

- Existing Bridge
- Minor Watercourse Crossing
- Mackenzie Valley Highway Project
- Mackenzie Valley Winter Road
- Region Boundary

NOTES
Kilometre Markers (KMs) based on All-Season Road KMs from the Tulita District Project Description Report (October 2011)

Base data source:
Natural Resources Canada
CanVec 1:250,000 scale
ESRI Data Maps
Imagery provided by ESRI; Maxar (various dates)

STATUS
ISSUED FOR USE

MACKENZIE VALLEY HIGHWAY 2021 HYDROTECHNICAL ASSESSMENTS

Sahtu South Segment Watercourse Crossings

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Northwest Territories

Scale: 1:250,000
5 2.5 0 5
Kilometres

FILE NO.
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Figure 3-1a

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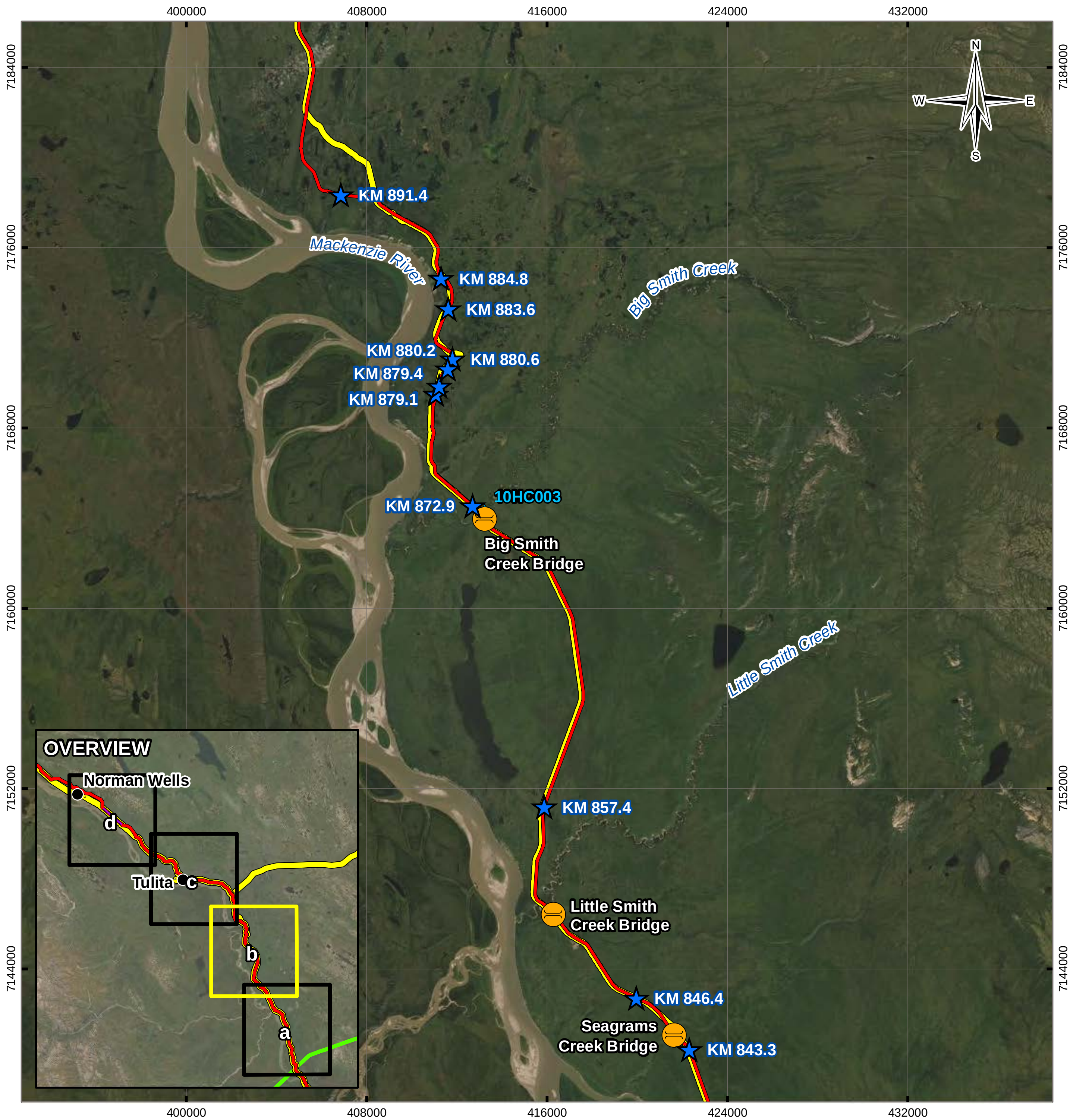

LEGEND

- Existing Bridge
- Minor Watercourse Crossing
- Water Survey of Canada Stream Gauge Station
- Mackenzie Valley Highway Project
- Mackenzie Valley Winter Road
- Region Boundary

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Kilometre Markers (KMs) based on All-Season Road KMs from the Tulita District Project Description Report (October 2011)

Base data source:
Natural Resources Canada
CanVec 1:250,000 scale
ESRI Data Maps
Imagery provided by ESRI; Maxar (various dates)

STATUS
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MACKENZIE VALLEY HIGHWAY 2021 HYDROTECHNICAL ASSESSMENTS

Sahtu South Segment Watercourse Crossings

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Northwest Territories

Scale: 1:250,000
5 2.5 0 5
Kilometres

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Figure 3-1b

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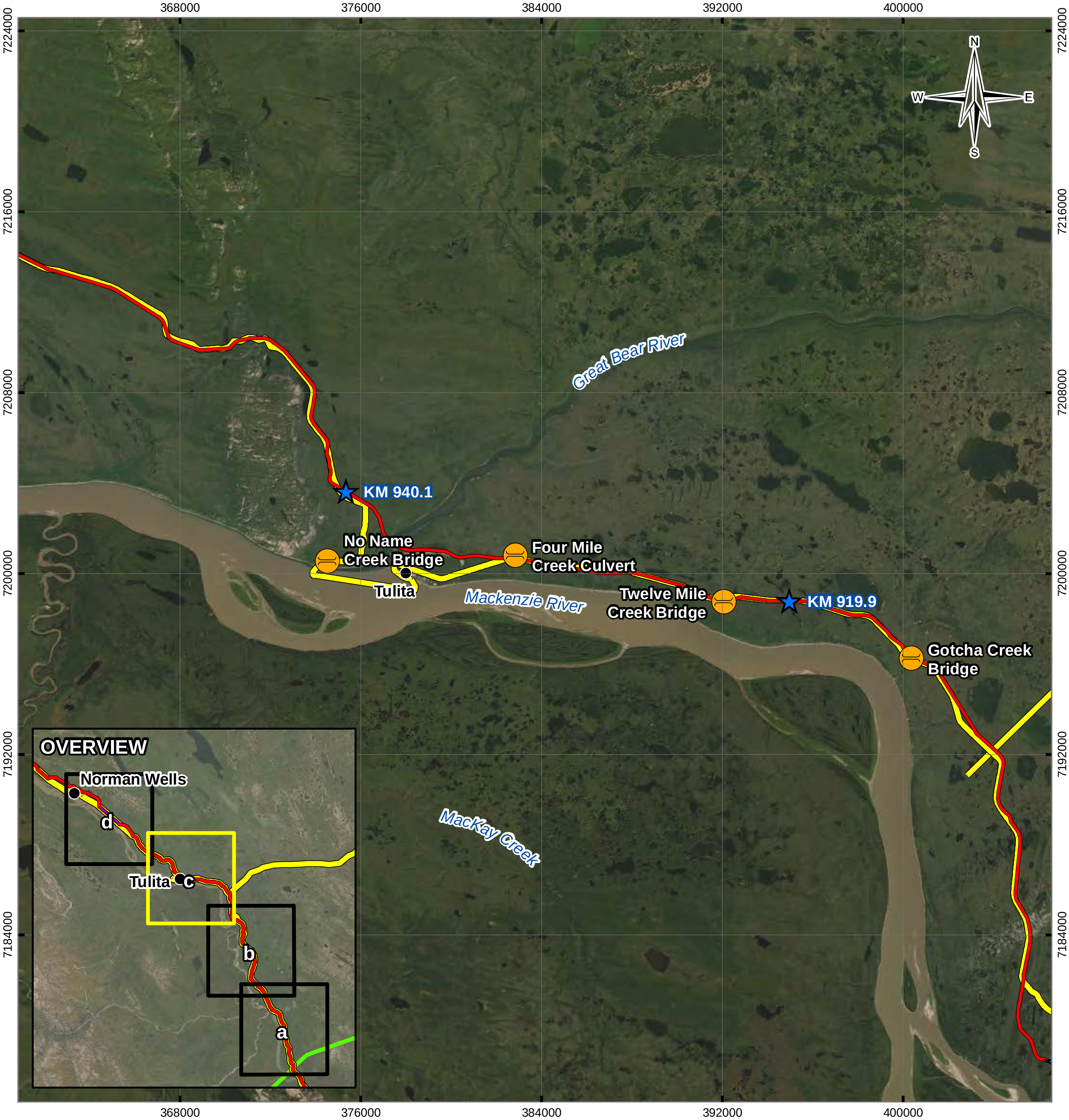

LEGEND

- Existing Bridge
- Minor Watercourse Crossing
- Mackenzie Valley Highway Project
- Mackenzie Valley Winter Road
- Region Boundary

Base Data

- Populated Place

NOTES

Kilometre Markers (KMs) based on All-Season Road KMs from the Tulita District Project Description Report (October 2011)

Base data source:
Natural Resources Canada
CanVec 1:250,000 scale
ESRI Data Maps
Imagery provided by ESRI; Maxar (various dates)

STATUS
ISSUED FOR USE

MACKENZIE VALLEY HIGHWAY 2021 HYDROTECHNICAL ASSESSMENTS

Sahtu South Segment Watercourse Crossings

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Northwest Territories

Scale: 1:250,000
5 2.5 0 5
Kilometres

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FILE NO.
WTRI03067-01_Fig3-1_WaterCrossings.mxd

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Figure 3-1c

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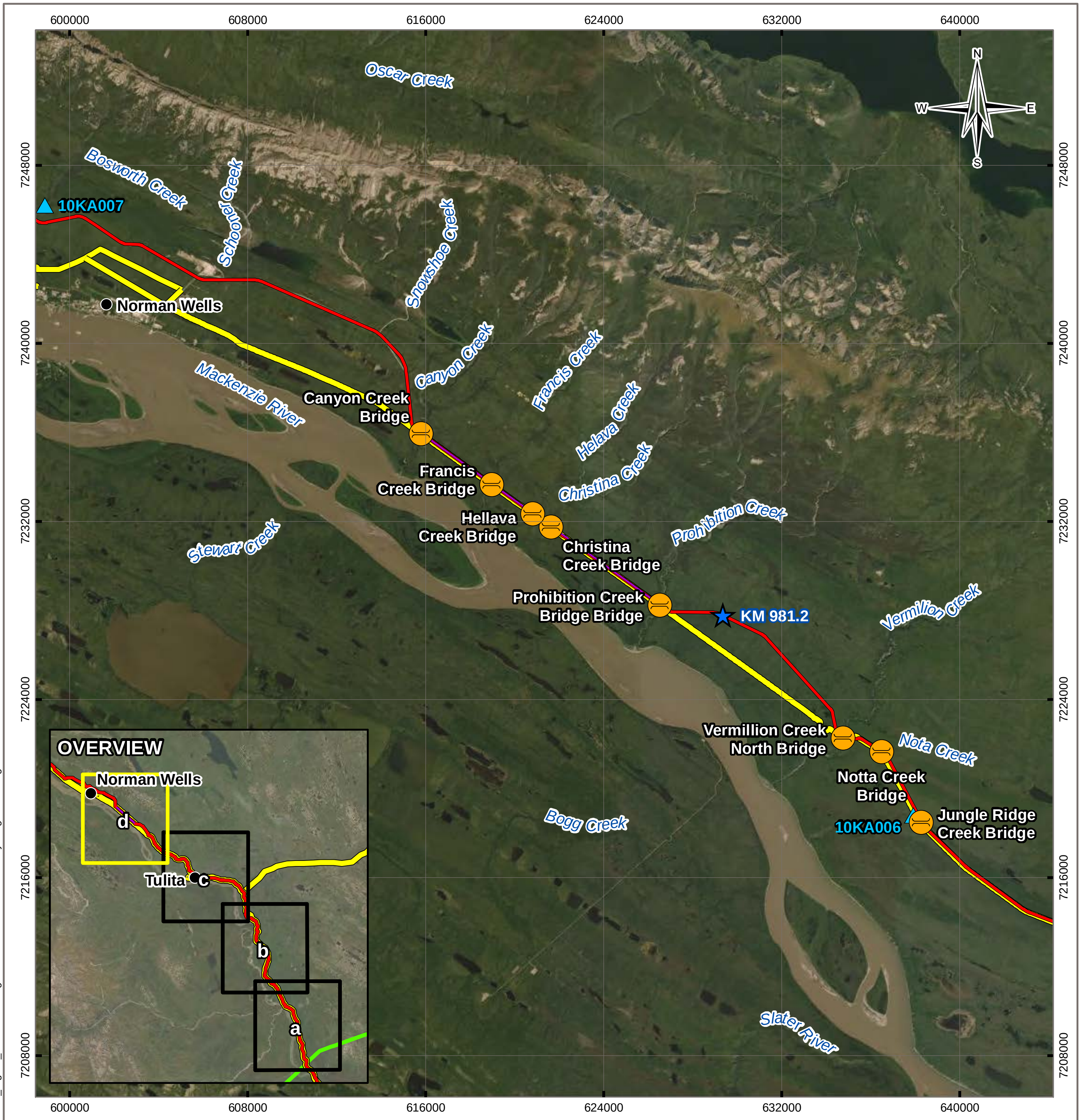

LEGEND

- Existing Bridge
- Minor Watercourse Crossing
- Water Survey of Canada Stream Gauge Station
- Mackenzie Valley Highway Project
- Mackenzie Valley Winter Road
- Prohibition Creek Access Road
- Region Boundary

Base Data

- Populated Place

NOTES

Kilometre Markers (KMs) based on All-Season Road KMs from the Tulita District Project Description Report (October 2011)

Base data source:
Natural Resources Canada
CanVec 1:250,000 scale
ESRI Data Maps
Imagery provided by ESRI; Maxar
(various dates)

STATUS
ISSUED FOR USE

MACKENZIE VALLEY HIGHWAY 2021 HYDROTECHNICAL ASSESSMENTS

Sahtu South Segment Watercourse Crossings

PROJECTION	DATUM	CLIENT
UTM Zone 9	NAD83	Northwest Territories

Scale: 1:250,000
5 2.5 0 5
Kilometres

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Figure 3-1d

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3.2 Site Assessment Summary

Ground inspections were made at each crossing to 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 and the velocity-area method or timed volumetric measurements when possible; visual estimates were made of flows too difficult to measure with metering equipment, such as shallow flow in vegetated areas.

Table 3-1 presents a summary of the assessments of each minor watercourse. Field photos are presented in Appendix B; drainage basins are presented in Appendix C.

Table 3-1: Site Assessment Summary; UTM Coordinates

Winter Road Crossing ID	Zone 10 Easting (m)	Zone 10 Northing (m)	Date Assessed	Flow (L/s)	Bankfull Width (m)	Bankfull Depth (m)	Channel Slope (%)	Substrate Composition	Site Notes	Photo Numbers in Appendix B
KM 797.9	437749	7101831	1-Oct-21	20	4.1	1.3	0.5	Fines and waterlogged woody debris	Wide and deep slow-moving channel, banks comprised of sand, silt, and clay. Numerous small beaver dams downstream of crossing have flooded the entire area. 100m upstream of the crossing location water is freely flowing in a defined channel filled with woody debris.	1 to 4
KM 805.5	435588	7108256	1-Oct-21	n/a	~30	~1.0	0.3	Fines	Proposed crossing location is an approximately 30-metre-wide strip of wetland containing two wide deep channels. No flow visible at crossing due to large wetted cross-sectional area. Soft substrate with some sunken woody debris. Downstream of crossing flow disperses across a 50 m wide wetland with many braids of flow.	5 and 6
KM 812.7	434330	7115335	1-Oct-21	2	1.3	0.55	2.4	Gravel and sand	Proposed crossing is approximately 100m upstream of present winter road crossing. Flow is only 2 L/s at the new proposed crossing while closer to 8 L/s downstream of the existing crossing suggesting that additional inflows are occurring. No obvious additional tributaries visible so it is assumed that this increase in flow is due to seepage. A large gully is present immediately south of this crossing which had stagnant water but no flow at the time of the visit.	7 to 11
KM 815.0	432726	7117027	2-Oct-21	5	1.9	0.4	6.5	Gravel and sand, some cobbles	Two culverts (1000 and 900mm) present at winter road. Both in poor structural condition and the outlets are perched by about 1 m. Defined but small channel at crossing with small amounts of woody debris. 200m downstream of crossing channel dissipates into multiple largely stagnant braids.	12 to 14
KM 820.7	433134	7121695	6-Oct-21	30	20-30	~1.0	0.1	Fines and organics	Proposed crossing is within a wetland that has a defined single flow path. Wetted top width was approximately 8 metres at time of visit, but it is likely that it increases to 20 or 30 metres during freshet. Wetland continues approximately 300m downstream of crossing where gradient increases and flow fully channelizes.	15 to 20
KM 821.9	432581	7123102	9-Oct-21	~0.1	1.3	0.7	2.0	Fines and gravel	Small but defined channel. Watercourse base data from CanVec are not accurate for the 1.4 km segment that includes this channel; LiDAR elevation data show additional, some larger, unmapped drainages where culverts will be required in this segment.	21 to 23
KM 823.0	431979	7123969	6-Oct-21	2	2.5	0.7	2.2	Boulders and cobbles	Well defined channel, boulder and cobble substrate at crossing. Gradient lessens immediately downstream of the crossing where substrate changes to gravel, sand, and organics	24 to 27
KM 826.0	431008	7126447	8-Oct-21	~0.5	1.8	0.7	<0.1	Fines and organics	Wide seemingly stagnant channel at PDR. Lake and wetland immediately upstream of crossing. Gradient increases downstream of proposed crossing, flow confined to small but defined channel with small but obvious flow.	28 to 31
KM 826.3	430947	7126835	8-Oct-21	2	1.2	0.4	1.4	Fines and organics	Small but defined channel. Large amounts of felled trees and woody debris along the entire watercourse.	32 to 35
KM 828.6	429994	7129068	9-Oct-21	~0.5	1.0	0.8	2.5	Fines and sand, some gravel	Small but defined channel. Heavily overgrown in parts.	36 to 39
KM 834.1	425726	7132183	10-Oct-21	<1	1.1	0.5	2.4	Fines and sand	Small but defined channel. Heavily overgrown in parts.	40 and 41
KM 835.0	425407	7132984	10-Oct-21	<1	1.5	0.55	5.8	Sand and gravel, some cobbles	Small but defined channel.	42 and 43
KM 837.1	424624	7135021	11-Oct-21	2	1.5	0.5	8.0	Cobbles and gravel	Well-defined channel. Gravel and cobble substrate throughout the entire length of channel walked.	44 to 47
KM 843.3	422302	7140425	11-Oct-21	4	25	0.25	2.1	Fines and organics	Two small channels present upstream of crossing which reach their confluence at the crossing location, beyond which flow dissipates and no defined channels are present. Area downstream of crossing area is flooded with water flowing in multiple braids.	48 to 53
KM 846.4	419957	7142711	11-Oct-21	50	12	0.2	1.0	Fines and organics	No discernable channel at or upstream of crossing. Water seeps across the winter road in multiple spots over an ~12 m wide section of winter road. Gradient marginally increases downstream of alignment resulting in flow consolidating in a slow-moving but defined channel overgrown by trees and other vegetation.	54 to 57

Table 3-1: Site Assessment Summary; UTM Coordinates

Winter Road Crossing ID	Zone 10 Easting (m)	Zone 10 Northing (m)	Date Assessed	Flow (L/s)	Bankfull Width (m)	Bankfull Depth (m)	Channel Slope (%)	Substrate Composition	Site Notes	Photo Numbers in Appendix B
KM 857.4	415860	7151193	11-Oct-21	5	2.3	0.6	1.9	Fines and organics	Two consecutive beaver dams are present immediately upstream (north) of the roadway alignment flooding a large area. Flow proceeds in a small channel across the alignment and continues about 50 m downstream before encountering another area completely flooded by multiple beaver dams. A separate small channel crosses the PDR alignment approximately 120m to the south of this crossing.	58 to 62
KM 872.9	412680	7164554	2-Oct-21	<5	40	~0.6	0.6	Fines and organics	Crossing is located within a strip of wetland that extends upstream and downstream with no defined channels. A wooden bridge structure and 500mm culvert are present on site for the winter road. No observable flow at crossing due to large, wetted area, a trickle seen in a braid downstream.	63 to 65
KM 879.1	411054	7169500	9-Oct-21	<1	~3	~1	0.2	Organics	Wide wetland type channel of seemingly stagnant water connecting lakes on each side of the alignment.	66 and 67
KM 879.4	411210	7169865	9-Oct-21	10	5.2	0.5	1.7	Organics	Crossing is approximately 50 metres downstream of a lake outlet. Wide wetted width (~5m) at alignment, lots of willows/reeds growing in channel. Downstream of roadway alignment gradient steepens and a well-defined channel exists.	68 and 69
KM 880.2	411595	7170626	2-Oct-21	1	1.2	0.4	2.0	Fines and organics	Tiny watercourse in a poorly defined channel, quite overgrown.	70 to 72
KM 880.6	411801	7171055	5-Oct-21	50	1.8	0.8	2.3	Cobbles and gravels	Larger watercourse contained within a well-defined channel crowded by lots of vegetation.	73 to 76
KM 883.6	411616	7173284	5-Oct-21	1	4.0	0.4	1.8	Fines and organics	Poorly defined channel. Flow spread over a couple metres of marshy ground at PDR alignment.	77 to 81
KM 884.8	411300	7174637	30-Sep-21	12	2.5	0.85	1.7	Fines	An uncovered 900mm culvert is present along the winter road alignment. PDR alignment is approximately 160m downstream of the winter road alignment. Entire area shows signs of being substantially flooded for a long period of time. Trees at the PDR crossing location are stained ~2m in height. Local wildlife monitor says a large beaver dam was removed here just last year which had created this flooding. Small amounts of woody debris present in channel.	82 to 86
KM 891.4	406838	7178354	11-Oct-21	500	15	>1.5 m	0.6	Fines	Crossing is at the outlet of a large lake. Large woody debris and a beaver dam have backwatered this crossing to ~0.3m higher than the bank height at time of site visit. ~150m downstream of PDR alignment channel is free of blockages and water flows freely in a well-defined channel (~7m wide).	87 to 91
KM 919.9	394957	7198774	30-Sep-21	15	~40	1.1	0.5	Fines and organics	Crossing is within a wetland backwatered by a 1m high beaver dam located ~50 metres downstream. A small lake is immediately upstream of crossing location. Winter road crosses this watercourse via a recently constructed crushed rock embankment with 600mm culvert installed.	92 to 95
KM 940.1	375328	7203624	7-Oct-21	3	1.5	0.9	3.0	Fines	Flow contained in a single defined channel highly overgrown by small trees and other vegetation.	96 to 99
KM 981.2	629355 (Zone 9)	7227772 (Zone 9)	7-Oct-21	5	2.26	0.8	3.0	Cobbles and gravel, some boulders	Well defined channel, small amounts of erosion and undercutting to both banks.	100 to 102

4.0 HYDROTECHNICAL ANALYSIS

The hydrotechnical assessment of highway drainage involved three basic components: (1) delineation of watershed areas; (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.

4.1 Watershed Delineation

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 Sahtu South Segment alignment. Digital watershed delineations were completed using the Global Mapper GIS software package. Lake areas within each watershed were calculated through use of the CanVec 1:50,000 Waterbodies dataset.

Tributary watersheds were delineated for the 27 crossings as listed in Table 4-1 and shown on Figures C-1 through C-8 in Appendix C. Watershed areas range between approximately 0.2 km^2 and 63 km^2.

Several very small watersheds are included in the assessment because of preliminary screening information that suggested a potentially large watershed. For example, at KM 879.1 (0.22 km^2), a defined watercourse connects two lakes on opposite sides of the alignment where east-to-west flow normally occurs towards the Mackenzie River. However, subsequent basin delineation with the project high-resolution LiDAR DEM identified that this defined channel actually flows from west to east and is part of a larger watershed to the crossing at KM 879.4 that drains east to west. In another example, at KM 880.2 (0.26 km^2) the crossing corresponds to the start of a deep gully and NTS/CanVec mapping shows a defined watercourse at this location. Basin delineation with the high-resolution LiDAR DEM however identified the small basin area. Here and in other locations along the ASR alignment, the presence of a well-defined gully, even with a mapped watercourse from NTS/CanVec, is not a reliable indicator of drainage from a large watershed.

Table 4-1: Minor Watercourse Crossing Locations and Watershed Areas

Crossing ID	Easting (m)	Northing (m)	UTM Zone	Watershed Area (sq km)	Lake Area (sq km)
KM 797.9	437749	7101831	10 W	50.22	1.21
KM 805.5	435588	7108256	10 W	37.94	2.09
KM 812.7	434330	7115335	10 W	6.41	0.00
KM 815.0	432726	7117027	10 W	3.83	0.00
KM 820.7	433134	7121695	10 W	15.64	0.25
KM 821.9	432581	7123102	10 W	0.30	0.00
KM 823.0	431979	7123969	10 W	8.84	0.00
KM 826.0	431008	7126447	10 W	1.41	0.02
KM 826.3	430947	7126835	10 W	4.30	0.03

Table 4-1: Minor Watercourse Crossing Locations and Watershed Areas

Crossing ID	Easting (m)	Northing (m)	UTM Zone	Watershed Area (sq km)	Lake Area (sq km)
KM 828.6	429994	7129068	10 W	2.12	0.00
KM 834.1	425726	7132183	10 W	3.05	0.01
KM 835.0	425407	7132984	10 W	1.32	0.00
KM 837.1	424624	7135021	10 W	2.43	0.00
KM 843.3	422302	7140425	10 W	2.67	0.00
KM 846.4	419957	7142711	10 W	4.25	0.00
KM 857.4	415860	7151193	10 W	0.75	0.02
KM 872.9	412680	7164554	10 W	1.36	0.00
KM 879.1	411054	7169500	10 W	0.22	0.04
KM 879.4	411210	7169865	10 W	1.63	0.23
KM 880.2	411595	7170626	10 W	0.26	0.10
KM 880.6	411801	7171055	10 W	11.40	1.73
KM 883.6	411616	7173284	10 W	0.42	0.01
KM 884.8	411300	7174637	10 W	8.63	1.16
KM 891.4	406838	7178354	10 W	62.26	7.31
KM 919.9	394957	7198774	10 W	1.85	0.13
KM 940.1	375328	7203624	10 W	2.77	0.06
KM 981.2	629355	7227772	9 W	5.36	0.17

4.2 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 2-year through 200-year peak flows estimates for each of the identified minor watercourses crossed by the Sahtu South Segment of the MVH alignment.

4.2.1 Hydrometric Station Selection

Water Survey of Canada (WSC) hydrometric stations draining basins in proximity to the MVH project site were reviewed to find gauged watercourses with similar watershed characteristics and sufficient data for meaningful statistical analysis. Eight stations on relatively small drainages situated within the Mackenzie Valley between Wrigley and Inuvik were selected for the analysis. Station information is included in Table 4-2 below. The WSC stations selected for analysis of the Sahtu South Segment are modified from those used for analysis of the prior PCAR, MGAR and Dehcho segments, primarily to include stations draining watersheds with significant lake attenuation effects that did not apply to the prior segments. Station locations are shown in the Figure 1-1 Regional Location Plan.

Watershed areas have been published by WSC for five of the eight stations selected for analysis. Stations which do not have a published area have typically been installed within complex watersheds which are challenging to accurately delineate due to shallow topography possibly creating multiple drainage outlets.

Additionally, Environment and Climate Change Canada (ECCC) has prepared the National Hydrometric Network Basin Polygon dataset which contains watershed polygons for all WSC stations. These polygons have been compiled from a number of contributing agencies, including provinces, territories and other government departments and have been delineated independently and thus may differ from, the WSC published areas.

Tetra Tech completed an independent delineation of all eight of the hydrometric stations based on 1:50,000 NTS elevation data. These delineations were then further refined through a review of: the most recent National Hydrometric Network Basin Polygon dataset and satellite imagery. The Tetra Tech delineations which considered all available information were used in all subsequent hydrological analysis.

Table 4-2: WSC Regional Stations

Station ID	Station Name	Watershed Area (km^2)			Period of Record	Data Available (years)
		WSC Reported	ECCC Delineation	Tetra Tech Delineation		
10LB005	Travaillant River above Travaillant Lake	n/a	1255	1214	2004-2016	13
10HC003	Big Smith Creek near Highway No. 1	980	920	932	1974-1994	21
10LB006	Thunder River near the Mouth	n/a	521	563	2006-2013	8
10HC007	Hodgson Creek near the Mouth	n/a	303	333	2006-2014	9
10KA007	Bosworth Creek near Norman Wells	125	111	110	1976-2017	27
10KA006	Jungle Ridge Creek near the Mouth	60	109	104	1980-2011	15
10LC010	Boot Creek near Inuvik	28.2	28.6	28.0	1981-1990	9
10LC017	Havikpak Creek near Inuvik	15.2	16.8	17.4	1995-2015	20

4.2.2 Statistical Flood Frequency Analysis

A peak flow 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 an average ratio of the two in years where both values were available.

The statistical frequency analysis software, HYFRANPLUS, was used to fit the flow data to commonly-used statistical distributions. Several probability distributions were tested from which a best distribution was selected for each station, usually Gumbel. A chart of the Gumbel fitting used for station 10KA007 (Bosworth Creek) is shown in Figure 4-3.

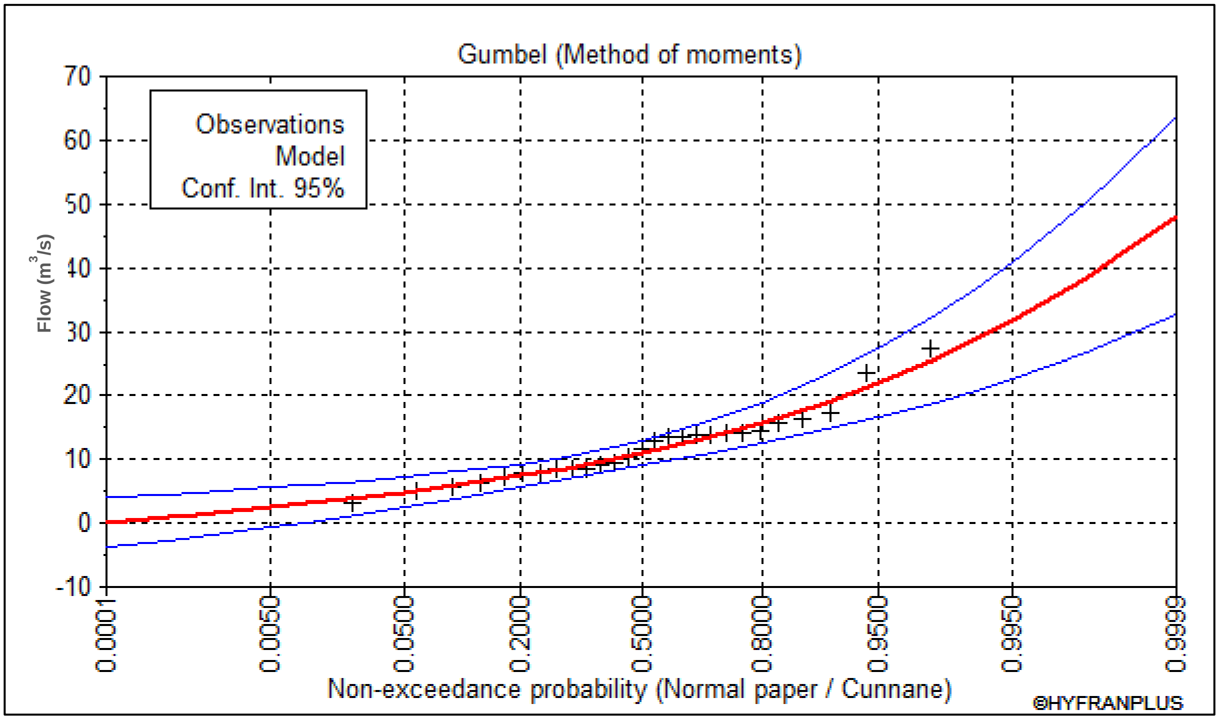

Figure 4-3: Peak Flow Frequency Distribution for Bosworth Creek (10KA007)

Results of the frequency analysis estimating 2-year through 200-year flows for each station are shown in Table 4-3. 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 4-3 includes 95% confidence lines for the Bosworth 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 estimates for larger return periods increases for data sets with longer periods of record.

Table 4-3: Frequency Analysis Results

Station	10LB005	10HC003	10LB006	10HC007	10KA007	10KA006	10LC010	10LC017
Area (km^2)	1214	932	563	333	110	104	28.0	17.4
Lake Area (km^2)	199	26.7	65.0	5.11	3.64	2.29	1.41	0.75
Years of Data	13	21	8	9	27	15	9	20
200-Year (m^3/s)	73.3	230	77.0	85.4	31.5	24.3	8.34	6.34
100-Year (m^3/s)	66.6	212	68.5	77.7	28.6	22.2	7.54	5.72
50-Year (m^3/s)	59.9	193	60.0	70.0	25.7	20.0	6.75	5.10
20-Year (m^3/s)	51.0	168	48.7	59.7	21.8	17.1	5.68	4.26
10-Year (m^3/s)	44.1	149	40.0	51.7	18.8	14.9	4.86	3.62
5-Year (m^3/s)	36.8	129	30.9	43.4	15.7	12.6	4.00	2.95
2-Year (m^3/s)	25.9	98.4	17.1	30.9	11.0	9.09	2.71	1.94

4.2.3 Regional Hydrological Analysis

Figure 4-4 depicts a preliminary relationship between watershed area and 5-year flow for the eight selected regional WSC stations. The 5-year flow was selected for this preliminary comparison because confidence in the peak flow estimates is higher for relatively frequent events than for more extreme events such as a 100-year flow.

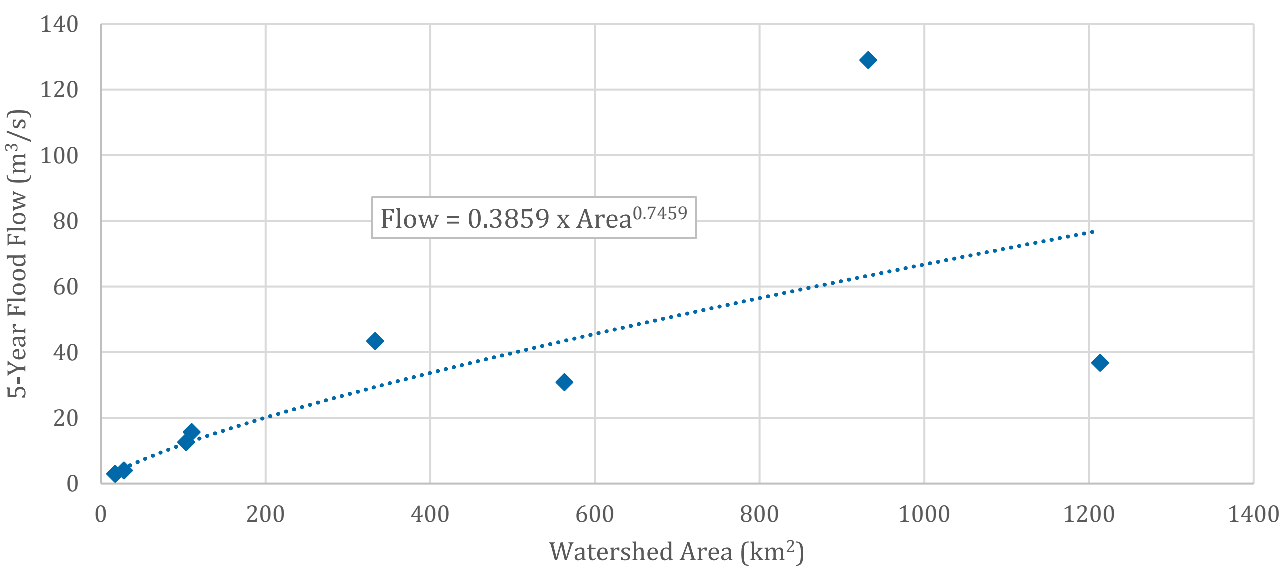

Figure 4-4: 5-Year Peak Flow versus Watershed Area for Regional WSC Stations

Though a visible trend can be observed across several of the stations, the overall scatter is unfavorable for establishing a relationship to define the hydrologic performance of all watercourses within the region. This scatter is predominately due to the different levels of flood attenuation that lakes provide in each watershed. Greater amounts of lake coverage, particularly within the lower parts of a watershed, translates to a greater amount of flood attenuation. Unsurprisingly we note in Figure 4-4 that the two datapoints furthest removed from the others are the two WSC stations with highest percentage of lake coverage, Travaillant and Thunder River, with 16.4 and 11.5 percent lake coverage respectively. The other six gauged watercourses all have less than 5 percent lake coverage within their watersheds. By temporarily removing the two stations with greatest lake coverage, a convincing relationship can be established across the remaining six (Figure 4-5).

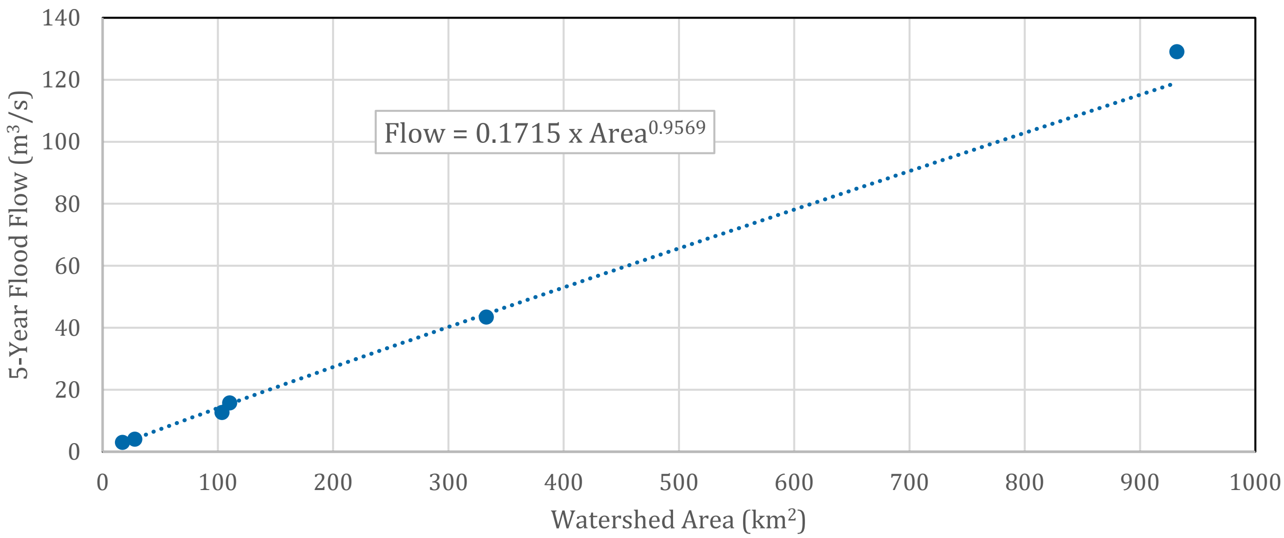

Figure 4-5: 5-Year Flow vs Watershed Area for WSC Stations < 5% Lake Area

The relationship presented in Figure 4-5 shows a strong correlation between watershed area and 5-year flow across the WSC stations for basins with a small percentage of lake area. The equation exponent of 0.957 suggests a near linear relationship between flood flow and watershed area (1.00 would be linear). This exponent is reasonable for arctic watersheds which will experience their peak annual flows during freshet, a largely homogenous runoff event where similar runoff rates can be expected across watersheds of a wide range of sizes. Given the strong correlation between the six plotted WSCs and this appropriate exponent magnitude, this equation is expected to produce good estimations of 5-year flood flows for basins with less than 5% lake coverage. An additional factor must be multiplied in for this equation to be appropriate for watersheds with substantial lake attenuation (Section 4.2.1).

With Figure 4-5 demonstrating the success of the approach, similar equations [Flow = coefficient x (Area)$^{\wedge \text{exponent}}$] were derived from the same six WSCs to estimate 2-year through 200-year floods as presented in Table 4-4.

Table 4-4: Regional Peak Flow Equation Variables (<5% Lake Coverage)

Return Period	Coefficient	Exponent
2-Year	0.1037	0.9895
5-Year	0.1715	0.9569
10-Year	0.218	0.9436
100-Year	0.3666	0.9209
200-Year	0.4118	0.9162

4.2.4 Lake Attenuation

Lake attenuation refers to the flood hydrograph attenuation (and peak flow reduction) that occurs due to lake storage effects. Several of the project watersheds have substantial lake attenuation, with lakes covering greater than 5% of their total watershed area. An additional "lake attenuation factor" was developed for these watersheds, to be applied as an adjustment to the results of small-percentage-lake equations presented in Table 4-4.

Lake attenuation factors were derived through analysis of the two WSC stations with substantial lake coverage. The dampening effects of the lakes on peak flows were estimated by comparing the statistically derived 5-year flow estimates of each station to the 5-year flow rates expected for basin of similar size but without lake effects as per the Figure 4-5 (and Table 4-4) regional equation. A lake attenuation factor was calculated for each station as the ratio between these two flows as presented in Table 4-5.

Table 4-5: Lake Attenuation Factors for WSC Stations with >5% Lake Area

Attribute	Travaillant River above Travaillant Lake	Thunder River near the Mouth
Watershed Area (km^2):	1214	563
Lake Area (km^2):	199	65.0
Percentage Lake Coverage (%):	16.4%	11.5%
Statistically Derived 5-Year Flow (m^3/s):	36.8	30.9
Regional Equation 5-Year Flow (m^3/s):	153.2	73.5
Lake Attenuation Factor:	0.240	0.420

Figure 4-6 shows the relationship and equation that was developed to calculate lake attenuation factor as a function of percent lake coverage within a catchment and applied for all return periods as discussed further below. The factor was accepted to be 1.0 for all watersheds with under 5% lake coverage.

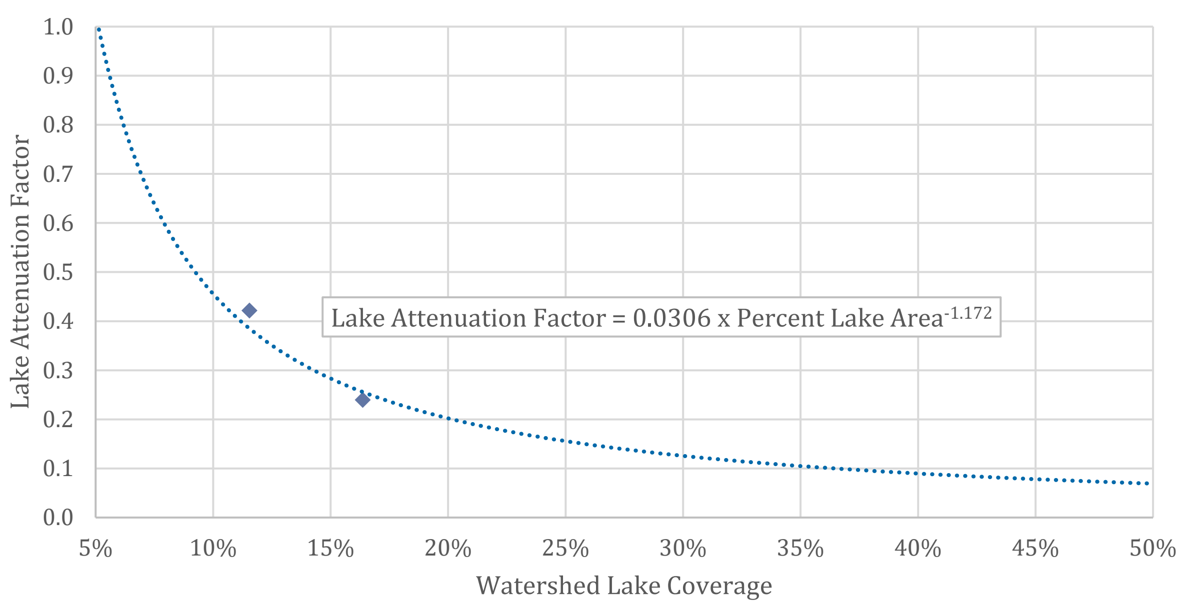

Figure 4-6: Lake Attenuation Factor by Watershed Lake Coverage

The lake attenuation factor equation derived from 5-Year flow observations was used to estimate flood flows for other return periods from 2-year to 200-year. This simplifying assumption was needed because historical flow data were too limited to allow for development of unique attenuation factors for different return periods. This method of quantifying the impact of lakes within a watershed as a function of lake area is further simplified as it does not capture the effects of the spatial distribution of lakes within a watershed. These simplifications are considered to be reasonable and appropriate in the context of sizing culverts for minor watercourse crossings.

4.2.5 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 (GCM) recommended by PCIC as appropriate for Western North America and selected for having seasonal precipitation outputs. Results applicable to the MVH Sahtu South Segment region are shown in Table 4-6.

Table 4-6: PCIC Ensemble GCM Winter Mean Daily Precipitation for Sahtu Region

Model Period	Min	Max	Mean	Median	Std. Dev	Units
1961 – 1990	0.537	0.738	0.602	0.600	0.040	mm/day
1971 – 2000	0.530	0.735	0.595	0.592	0.040	mm/day
1981 – 2010	0.540	0.743	0.600	0.598	0.040	mm/day
2010 – 2039	0.572	0.785	**0.642**	0.635	0.042	mm/day
2040 – 2069	0.602	0.818	0.668	0.660	0.042	mm/day
2070 – 2099	0.685	0.925	**0.757**	0.748	0.045	mm/day

From the highlighted (bold font) projections in Table 4-6, an increase in winter precipitation of 17.9 percent is estimated for the project area for the time period of 2070-2099 compared to the current time period of 2010-2039.

A separate check using the Climate Atlas of Canada[4] GCM-based projections for Norman Wells, representing the Sahtu South Segment, are shown in Table 4-7. A linear interpolation was applied to 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.

[2] https://services.pacificclimate.org/pcex/app
[2] The models selected for ensemble analysis were: GFDL-ESM2 m; GFDL-ESM2G; GFDL-CM3; CNRM-CM5; CanESM2; and MIROC5
[4] https://climateatlas.ca

Table 4-7: Climate Atlas of Canada Winter Precipitation for Norman Wells

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 17.9 percent increase in winter precipitation from the PCIC data. A linear relationship was assumed between cumulative winter precipitation and freshet magnitude resulting in initial flood flow estimates being increased by 17.9 percent.

4.2.6 Watercourse Crossing Flood Flow Estimates

Following the methods detailed in this report, flood flows for each of the 27 crossings were calculated for various return periods of interest as presented in Table 4-8. The 100-year flows estimates were used in the subsequent preliminary culvert designs discussed in Section 4.4.

Table 4-8: Return Period Flows for Minor Watercourse Crossings

Crossing ID	Watershed Area (km^2)	Lake Area (%)	Lake Attenuation Factor	Climate Change Adjusted Flood Flow (m^3/s)			
				2-Year	10-Year	100-Year	200-Year
KM 797.9	50.22	2.4%	1.00	5.89	10.35	15.92	17.56
KM 805.5	37.94	5.5%	0.92	4.09	7.28	11.27	12.45
KM 812.7	6.41	0.0%	1.00	0.77	1.48	2.39	2.66
KM 815.0	3.83	0.0%	1.00	0.46	0.91	1.49	1.66
KM 820.7	15.64	1.6%	1.00	1.86	3.44	5.44	6.03
KM 821.9	0.30	0.0%	1.00	0.04	0.08	0.14	0.16
KM 823.0	8.84	0.0%	1.00	1.06	2.01	3.21	3.57
KM 826.0	1.41	1.5%	1.00	0.17	0.36	0.59	0.67
KM 826.3	4.30	0.7%	1.00	0.52	1.02	1.66	1.85
KM 828.6	2.12	0.0%	1.00	0.26	0.52	0.86	0.97
KM 834.1	3.05	0.4%	1.00	0.37	0.74	1.21	1.35
KM 835.0	1.32	0.0%	1.00	0.16	0.33	0.56	0.62
KM 837.1	2.43	0.2%	1.00	0.29	0.59	0.98	1.09
KM 843.3	2.67	0.0%	1.00	0.32	0.65	1.07	1.20
KM 846.4	4.25	0.0%	1.00	0.51	1.01	1.64	1.83
KM 857.4	0.75	3.0%	1.00	0.09	0.20	0.33	0.37
KM 872.9	1.36	0.0%	1.00	0.17	0.34	0.57	0.64
KM 879.1	0.22	16.6%	0.25	0.01	0.02	0.03	0.03

Crossing ID	Watershed Area (km^2)	Lake Area (%)	Lake Attenuation Factor	Climate Change Adjusted Flood Flow (m^3/s)			
				2-Year	10-Year	100-Year	200-Year
KM 879.4	1.63	13.9%	0.31	0.06	0.13	0.21	0.23
KM 880.2	0.26	39.5%	0.09	0.00	0.01	0.01	0.01
KM 880.6	11.40	15.2%	0.28	0.38	0.71	1.13	1.26
KM 883.6	0.42	2.8%	1.00	0.05	0.11	0.20	0.22
KM 884.8	8.63	13.5%	0.32	0.33	0.63	1.01	1.12
KM 891.4	62.26	11.7%	0.38	2.75	4.78	7.32	8.06
KM 919.9	1.85	7.1%	0.68	0.15	0.31	0.52	0.58
KM 940.1	2.77	2.1%	1.00	0.34	0.67	1.11	1.24
KM 981.2	5.36	3.2%	1.00	0.64	1.25	2.03	2.26

4.2.7 Fish Passage Design Flows

A three-day one-in-ten year delay discharge, referred to as a 3Q10 flow, is sometimes considered for hydraulic designs of fishways and other fish passage structures. As described in Introduction to Fishway Design[5] (Katopodis, 1992) the method addresses a concern that certain fish species will only tolerate a delay of three days before giving up on their migration and reabsorbing their eggs. Statistically, 3Q10 flows are evaluated from analysis of recorded streamflow data, 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 hydrotechnical scopes of work for the current MVH Sahtu South Segment, and the prior PCAR, MGAR, and Dehcho Segments, identify 3Q10 flows as a deliverable. It was carried forward from prior GNWT requirements for a hydrotechnical study, awarded to Tetra Tech in 2018, for 31 existing culverts along the Mackenzie Highway, Ingraham Trail, Liard Highway and Dempster Highway. During the development of current 2020/21 hydrotechnical work scopes for the MVH studies, it was assumed that 3Q10 flows would again be required.

Current GNWT design guidelines for Bridges and Bridge Culverts do not specify or require the 3Q10 methodology. Tetra Tech became aware of the current guidelines in 2021 during the preparation of detailed designs for bridge culverts along the PCAR segment. Applicable fish passage requirements are found from Alberta Transportation (AT) publications, specifically Design Guidelines for Bridge Size Culverts[6] cited by GNWT, and companion AT Bridge Conceptual Design Guidelines[7] which reject the 3Q10 methodology and recommend a slope-based approach to determine fish passage design flows. The latter document includes appendices with detailed discussions of fish passage design flows and AT concerns with the 3Q10 methodology.

[5] https://www.engr.colostate.edu/~pierre/ce_old/classes/ce717/Manuals/Fishway%20design%20Katopodis/1992%20Katopodis%20Introduction%20to%20Fishway%20Design.pdf

[6] http://www.transportation.alberta.ca/content/doctype30/production/dsngdlclvapril2012.pdf
[7] https://open.alberta.ca/publications/bridge-conceptual-design-guidelines-version-3-0

When Tetra Tech applied the AT fish passage flow methodology for a bridge-size culvert along the PCAR segment, the design flow seemed to be unreasonably small compared to the separately-estimated 3Q10 values which are often comparable to a 2-year return period flow. That design was subsequently developed considering a fish passage discharge for a survey-determined bankfull stage, often also similar to a 2-year return period flow.

Because AT guidelines referenced by GNWT do not recommend the 3Q10 method, this report does not provide 3Q10 values for the watercourse crossings. Alternative AT slope-based fish passage flows are not provided because of initial unsatisfactory results using that method. While computed 2-year peak flows presented in this report may be suitable for fish passage designs, we recommend that fish passage flows be assessed on a case-by-case basis when needed, considering the fish species that are present and difficulty and cost of providing a bridge or open-bottom culvert solution to mitigate potential fish passage impacts.

The approach for determining fish passage flows to be used for culvert crossing designs should be confirmed by GNWT with input from fisheries specialists and possibly regulators. The 2-year peak flows such as provided in the present report can potentially be used as a defensible proxy for fish passage flows.

4.3 Preliminary Crossing Designs

The 100-year return period flows, inclusive of estimated climate change effects, developed through Tetra Tech's hydrologic analysis were used as the design events for culvert designs.

Preliminary culvert sizes for each crossing were determined from nomographs published in the Handbook of Steel Drainage and Highway Construction Projects[8] (Corrugated Steel Pipe Institute, 2007). Design assumed inlet control conditions for non-embedded circular culverts with projecting inlets and a minimum diameter of 800 mm. This minimum diameter is understood to be the present standard for the Northwest Territories. 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.

Culverts smaller than 1500 mm in diameter can be specified to be corrugated steel pipe (CSP), while culvert larger than 1500 mm will require structural plate corrugated steel pipe (SPCSP).

Summaries of preliminary culvert sizes are presented in Table 4-9.

Table 4-9: Preliminary Proposed Culverts for Minor Watercourse Crossings

Crossing ID	UTM 10 Easting (m)	UTM 10 Northing (m)	Watershed Area (sq km)	Climate Change Adjusted 100-Year Flow (m^3/s)	Preliminary Single-Culvert Diameter (mm)	Notes
KM 797.9	437749	7101831	50.22	15.92	3050	Significant beaver activity at crossing has impacted the ability to estimate maximum allowable headwater elevation from LiDAR and will impact culvert hydraulic performance. Recommend completing a site survey to confirm available headwater and hydraulic modelling to develop culvert crossing design cognizant of downstream backwatering effects.

[8] https://www.cspi.ca/sites/default/files/download/handbook_chapter04.pdf

Crossing ID	UTM 10 Easting (m)	UTM 10 Northing (m)	Watershed Area (sq km)	Climate Change Adjusted 100-Year Flow (m^3/s)	Preliminary Single-Culvert Diameter (mm)	Notes
KM 805.5	435588	7108256	37.94	11.27	2590	Insufficient head is available to utilize a single large culvert. Multiple smaller culverts are recommended (5 x 1400 mm)
KM 812.7	434330	7115335	6.41	2.39	1400	Single Culvert at main coordinates, supplemented by four additional culverts at minor drainages within the segment extending from 200 m south to 200 m north of the main culvert. This is needed to minimize concentration of flow entering the top of gully immediately downstream.
KM 815.0	432726	7117027	3.83	1.49	1200	Single Culvert
KM 820.7	433134	7121695	15.64	5.44	1970	Two 1400 mm culverts can be fit in 8 m wide channel and avoid bridge culvert requirements
KM 821.9	432581	7123102	0.30	0.14	800	Single Culvert; supplemented by six additional culverts at minor drainages within the segment extending from 700 m south to 700 m north of the designated culvert.
KM 823.0	431979	7123969	8.84	3.21	1600	Single Culvert
KM 826.0	431008	7126447	1.41	0.59	800	Single Culvert
KM 826.3	430947	7126835	4.30	1.66	1200	Single Culvert
KM 828.6	429994	7129068	2.12	0.86	900	Insufficient head (~ 0.7 m) to pass design flow at coordinates. Two 800 mm culverts are recommended instead. Overflow will drain north. An additional culvert will need to be sized for a terminal low point about 130 m northwest of the listed coordinates
KM 834.1	425726	7132183	3.05	1.21	1200	Single Culvert but recommend increasing capacity to accommodate potential bypass runoff from the 3 km of road north of KM 834.1, that may drain to the terminal low at this location. Additional cross drainage culverts should be added at minor low points along the segment.
KM 835.0	425407	7132984	1.32	0.56	800	Single Culvert. This watercourse is in the segment that will drain south along the alignment to KM 834.1 if culvert capacity is exceeded. About 1.1 m of head is available before overflow.
KM 837.1	424624	7135021	2.43	0.98	1000	Single Culvert
KM 843.3	422302	7140425	2.67	1.07	1000	Insufficient head (< 0.3 m) available prior to bypass flow north along the alignment. Recommend multiple (potentially four) 800 mm diameter culverts within the broad wet area.

Crossing ID	UTM 10 Easting (m)	UTM 10 Northing (m)	Watershed Area (sq km)	Climate Change Adjusted 100-Year Flow (m^3/s)	Preliminary Single-Culvert Diameter (mm)	Notes
KM 846.4	419957	7142711	4.25	1.64	1200	Single Culvert
KM 857.4	415860	7151193	0.75	0.33	800	Single Culvert, in a reach significantly affected by beaver activity. Install an additional 1200 mm culvert at a deeper low point located 120 m to the south, which will receive overflow
KM 872.9	412680	7164554	1.36	0.57	800	Single Culvert
KM 879.1	411054	7169500	0.22	0.03	800	Single Culvert
KM 879.4	411210	7169865	1.63	0.21	800	Single Culvert
KM 880.2	411595	7170626	0.26	0.01	800	Single Culvert
KM 880.6	411801	7171055	11.40	1.12	1000	Single Culvert
KM 883.6	411616	7173284	0.42	0.19	800	Single Culvert
KM 884.8	411300	7174637	8.63	1.00	1000	Single Culvert
KM 891.4	406838	7178354	62.26	7.29	2280	Single Culvert
KM 919.9	394957	7198774	1.85	0.51	800	Single Culvert
KM 940.1	375328	7203624	2.77	1.11	1000	Single Culvert
KM 981.2	629355 (Zone 9)	7227772 (Zone 9)	5.36	2.03	1400	Single Culvert

Following the completion of road and embankment design, crossing profiles should be developed for each of the proposed culvert crossings. Preliminary embankment heights are needed to assess available culvert cover heights and the location of the toe of upstream embankment. The preliminary toe of upstream embankment is required to: (1) identify the low areas where culvert inlets should be placed to minimize ponding in areas without defined channels; and (2) confirm the amount of head available before bypass flow occurs down the alignment.

Section profiles perpendicular to the alignment will allow for detailed hydraulic modelling which will provide accurate headwater depths, peak flows, and peak water 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.

5.0 CLOSURE

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

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PERMIT TO PRACTICE
TETRA TECH CANADA INC.
Signature ____________
Date May 26, 2021
PERMIT NUMBER: P 018
NT/NU Association of Professional
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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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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.

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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.

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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 explore, address or consider, and has not explored, 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 B

SAHTU SOUTH SEGMENT FIELD PHOTOS

Photo 1: KM 797.9 (1 of 4) - Looking north (upstream) at PDR alignment.

Photo 2: KM 797.9 (2 of 4) - Looking northeast (upstream) at PDR alignment.

Photo 3: KM 797.9 (3 of 4) - Looking southwest (downstream) from PDR alignment. Site is backwatered by beaver dams downstream.

Photo 4: KM 797.9 (4 of 4) - Looking southwest (downstream) approximately 30 m upstream of PDR alignment. Channelized watercourse with large amount of woody debris.

Photo 5: KM 805.5 (1 of 2) - Looking north along PDR alignment at crossing location. Two distinguishable channels within an approximately 30m wide wetland.

Photo 6: KM 805.5 (2 of 2) - Looking northeast (upstream) from PDR alignment. No defined channels within upstream wetland.

Photo 7: KM 812.7 (1 of 5) - Looking north (upstream) at PDR alignment. Channel is small at this location with only 2 L/s of flow observed.

Photo 8: KM 812.7 (2 of 5) – Looking southeast (downstream) at PDR alignment.

Photo 9: KM 812.7 (3 of 5) - Looking southeast (upstream) at downstream side of existing wooden bridge structure on winter road, downstream of proposed crossing.

Photo 10: KM 812.7 (4 of 5) – Looking east (upstream) approximately 200m downstream of proposed crossing. Flow ~8 L/s.

Photo 11: KM 812.7 (5 of 5) - Looking southeast (upstream) at a wide neighbouring channel approximately 150m southwest of 812.7. Stagnant water. No visible flow during site inspection.

Photo 12: KM 815 (1 of 3) - Looking west (upstream) approximately 25m upstream of proposed crossing. Defined channel with cobble + gravel substrate and above average levels of woody debris.

Photo 13: KM 815 (2 of 3) - Looking east (downstream) approximately 100m downstream of proposed crossing. 5 L/s, some woody debris, substrate gravel and sand.

Photo 14: KM 815 (3 of 3) – Looking east (downstream) approximately 200m downstream of proposed crossing. Water has dispersed into numerous braids. No defined channel.

Photo 15: KM 820.7 (1 of 6) - Looking west (downstream). Low flow is predominately contained within a single channel. Banks comprised of wetland type vegetation, likely inundated during freshet and summer.

Photo 16: KM 820.7 (2 of 6) – Looking east (upstream) at proposed crossing. Wetted width is 10m, but probably increases to 20-30m during freshet.

Photo 17: KM 820.7 (3 of 6) – Looking northeast (upstream) approximately 60m downstream of PDR alignment. Wide wetland area with a single main flowpath but no defined channel features.

Photo 18: KM 820.7 (4 of 6) – Looking north (upstream) approximately 150m downstream of PDR alignment. A 900 and 600mm culvert sit along winter road alignment. Flow rechannellizes at this location.

Photo 19: KM 820.7 (5 of 6) – Looking west (downstream) approximately 300m downstream of PDR alignment.

Photo 20: KM 820.7 (6 of 6) – Looking east (upstream) approximately 30m upstream of proposed crossing. No defined channel as flow emerges from this wetland area.

Photo 21: KM 821.9 (1 of 3) – Looking east (upstream) from PDR alignment. Small but defined channel. Trickle of flow.

Photo 22: KM 821.9 (2 of 3) – Looking east (upstream) approximately 300m downstream of PDR alignment.

Photo 23: KM 821.9 (3 of 3) – Looking east (upstream) approximately 50m upstream of PDR alignment.

Photo 24: KM 823 (1 of 4) – Looking south along PDR alignment at watercourse valley.

Photo 25: KM 823 (2 of 4) – Looking west (downstream) at existing culvert within crossing used for winter road.

Photo 26: KM 823 (3 of 4) – Looking east (upstream) immediately upstream of crossing. Small but defined channel. Substrate comprised of small rounded boulders and cobbles.

Photo 27: KM 823 (4 of 4) – Looking west (downstream) approximately 100m downstream of alignment.

Photo 28: KM 826 (1 of 4) – Looking east (upstream) at crossing location. Wetland and lake are upstream, stagnant flow channelized through the PDR alignment.

Photo 29: KM 826 (2 of 4) – Looking southwest (downstream) from crossing location. Stagnant 1.5m wide channel.

Photo 30: KM 826 (3 of 4) – Looking east (upstream) approximately 300m downstream of PDR alignment. Poorly defined channel. ~0.5 L/s.

Photo 31: KM 826 (4 of 4) – Looking east (upstream) at wetland and lake approximately 75m upstream of PDR alignment.

Photo 32: KM 826.3 (1 of 4) – Looking east (upstream) from PDR alignment. Overgrown and poorly defined channel.

Photo 33: KM 826.3 (2 of 4) – Looking west (downstream) from PDR alignment. Overgrown and poorly defined channel.

Photo 34: KM 826.3 (3 of 4) – Looking west (downstream) approximately 250m downstream of PDR alignment. Poorly defined channel with much woody debris.

Photo 35: KM 826.3 (4 of 4) – Looking east (upstream) approximately 100m upstream of PDR alignment. No defined channel.

Photo 36: KM 828.6 (1 of 4) – Looking northwest at watercourse crossing winter road and PDR alignments.

Photo 37: KM 828.6 (2 of 4) – Looking northeast (upstream) from PDR alignment. Small incised channel.

Photo 38: KM 828.6 (3 of 4) – Looking east (upstream) approximately 200m downstream of proposed crossing.

Photo 39: KM 828.6 (4 of 4) – Looking east (upstream) approximately 100m upstream of proposed crossing. Flow contained within defined channel.

Photo 40: KM 834.1 (1 of 2) – Looking east (upstream) from PDR alignment. Poorly defined channel.

Photo 41: KM 834.1 (2 of 2) – Looking west (downstream) from PDR alignment.

Photo 42: KM 835 (1 of 2) – Looking northwest (upstream) from PDR alignment. Channel covered in snow; no water visible.

Photo 43: KM 835 (2 of 2) – Looking east (upstream) approximately 100m upstream of PDR alignment. Small channel snowed over.

Photo 44: KM 837.1 (1 of 4) – Looking east (upstream) from PDR alignment.

Photo 45: KM 837.1 (2 of 4) – Looking west (downstream) from PDR alignment.

Photo 46: KM 837.1 (3 of 4) – Looking east (upstream) approximately 100m upstream of PDR alignment. Defined channel with rounded boulders and cobble substrate.

Photo 47: KM 837.1 (4 of 4) – Looking northeast (upstream) approximately 250m downstream of PDR alignment where watercourse crosses Enbridge pipeline. 1m wetted top width. Cobble and gravel substrate.

Photo 48: KM 843.3 (1 of 6) – Looking south along PDR alignment at crossing location. No defined channel, water is shallow and spread out as it seeps across the alignment.

Photo 49: KM 843.3 (2 of 6) – Looking northwest (downstream) from PDR alignment.

Photo 50: KM 843.3 (3 of 6) – Looking northwest (downstream) approximately 50m downstream of alignment. Area is flooded, no defined channel.

Photo 51: KM 843.3 (4 of 6) – Looking west (downstream) approximately 100m downstream of alignment. Area flooded ~25m wide, water split into many braids

Photo 52: KM 843.3 (5 of 6) – Looking east (upstream) immediately upstream of crossing location at one of two channels that approach the crossing. This one the northernmost of the two and stagnant.

Photo 53: KM 843.3 (6 of 6) – Looking southeast (upstream) upstream of crossing location at one of two channels that approach the crossing. This one the southernmost of the two, with a trickle of flow.

Photo 54: KM 846.4 (1 of 4) – Looking northwest (upstream) at PDR alignment. Water is spread 12m wide as it flows across alignment. No defined channel

Photo 55: KM 846.4 (2 of 4) – Looking east (upstream) from PDR alignment. Inflow spread out with no defined channels upstream of crossing.

Photo 56: KM 846.4 (3 of 4) – Looking west (downstream) at PDR alignment. Flow collects within a defined channel shortly downstream of alignment.

Photo 57: KM 846.4 (4 of 4) – Looking northeast (upstream) approximately 100m downstream of PDR alignment. Flow has channelized in slow moving channel. 2.2m wide x 0.6m deep

Photo 58: KM 857.4 (1 of 5) – Looking north (upstream) from PDR alignment. Two small beaver dams immediately upstream of crossing have flooded entire upstream area.

Photo 59: KM 857.4 (2 of 5) – Looking south (downstream) at beaver dam immediately upstream of PDR alignment and small channel crossing alignment.

Photo 60: KM 857.4 (3 of 5) – Looking southeast (downstream) from PDR alignment. Flow collects in small channel.

Photo 61: KM 857.4 (4 of 5) – Looking southeast (downstream) approximately 200m downstream. Entire downstream area is flooded by a series of beaver dams.

Photo 62: KM 857.4 (5 of 5) – Looking southwest (downstream) approximately 50m upstream of PDR alignment. Entire area flooded by beaver activity.

Photo 63: KM 872.9 (1 of 3) – Looking northeast (upstream) at watercourse from air. Entire area is wetland with no defined channel. 500mm culvert from winter road visible.

Photo 64: KM 872.9 (2 of 3) – Looking northeast (upstream) from PDR alignment at upstream wetland. Standing on existing wooden bridge structure.

Photo 65: KM 872.9 (3 of 3) – Looking southwest (downstream) within wetland approximately 60m upstream of PDR alignment.

Photo 66: KM 879.1 (1 of 2) – Looking west (upstream) from PDR alignment. Upstream area is entirely wetland/lake.

Photo 67: KM 879.1 (2 of 2) – Looking southeast (downstream) from PDR alignment. Water contained within a stagnant channel, enters a lake approximately 70m downstream of crossing.

Photo 68: KM 879.4 (1 of 2) – Looking east (upstream) from PDR alignment. Water is spread with approximately 5m top width. Lake outlet located approximately 100m upstream.

Photo 69: KM 879.4 (2 of 2) – Looking west (downstream) approximately 200m downstream of PDR alignment. Flow is channelized within small channel set in deep valley. ~10L/s

Photo 70: KM 880.2 (1 of 3) – Looking southeast (upstream) at PDR alignment. Flow is confined within small overgrown channel.

Photo 71: KM 880.2 (2 of 3) – Looking southeast (upstream) approximately 100m upstream of PDR alignment. Area is marshy with no defined channels.

Photo 72: KM 880.2 (3 of 3) – Looking southeast (upstream) from winter road approximately 25m downstream of PDR alignment.

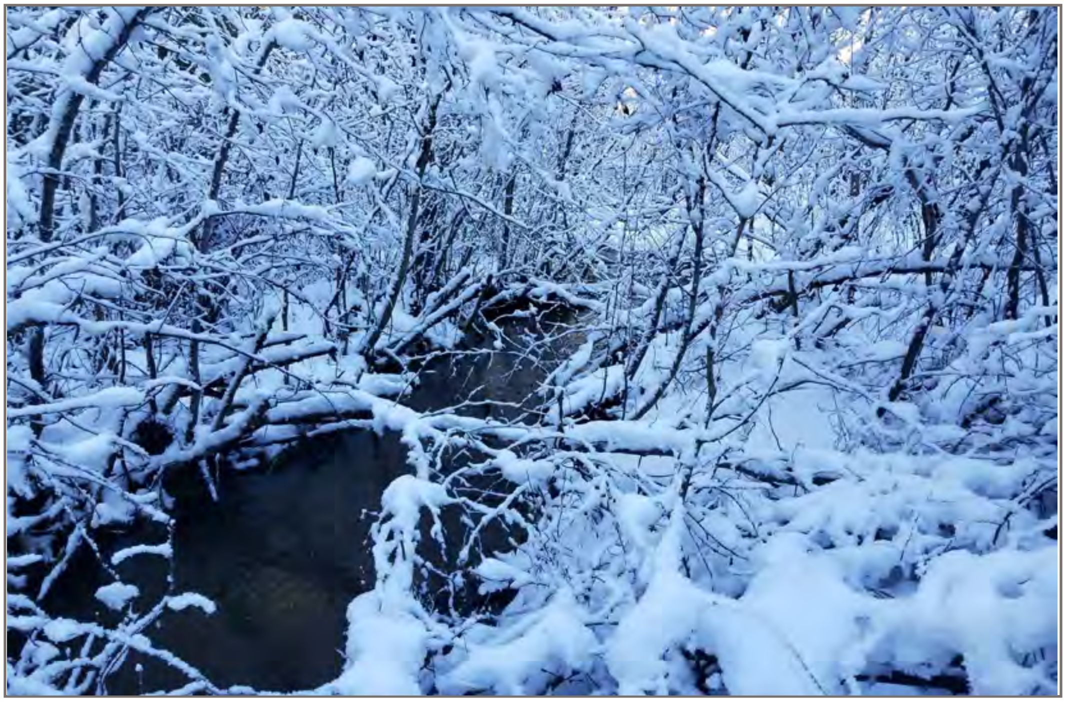

Photo 73: KM 880.6 (1 of 4) – Looking east (upstream) at PDR alignment.

Photo 74: KM 880.6 (2 of 4) – Looking southwest (downstream) approximately 100m downstream of PDR alignment at Enbridge pipeline alignment. Channellized flow ~50 L/s

Photo 75: KM 880.6 (3 of 4) – Looking west (downstream) approximately 300m downstream of PDR alignment. Flow channelized with minimal debris.

Photo 76: KM 880.6 (4 of 4) – Looking west (downstream) approximately 100m upstream of PDR alignment.

Photo 77: KM 883.6 (1 of 5) – Looking south along PDR alignment. Crossing 883.6 visible in foreground, a second minor drainage visible further south.

Photo 78: KM 883.6 (2 of 5) – Looking east (upstream) from PDR alignment.

Photo 79: KM 883.6 (3 of 5) – Looking west (downstream) from PDR alignment.

Photo 80: KM 883.6 (4 of 5) – Looking east (upstream) approximately 300m downstream of PDR alignment. Eroded banks and much debris in channel. ~~1.5 L/s.

Photo 81: KM 883.6 (5 of 5) – Looking southeast (upstream) approximately 50m upstream of PDR alignment, while on Enbridge pipeline alignment. Stagnant water with no defined channel.

Photo 82: KM 884.8 (1 of 5) – Looking southwest (downstream). PDR alignment is further downstream than the visible Enbridge and Winter Road alignments.

Photo 83: KM 884.8 (2 of 5) – Looking east (upstream) from winter road alignment, approximately 150m upstream of PDR alignment.

Photo 84: KM 884.8 (3 of 5) – Looking southwest (downstream) from winter road alignment. Area was flooded an extra 1.5m by a beaver dam which was removed last year.

Photo 85: KM 884.8 (4 of 5) – Looking west (downstream) at PDR alignment. Staining on trees indicates area was previously flooded by beaver dams ~2m higher than current water level.

Photo 86: KM 884.8 (5 of 5) – Looking west (downstream) approximately 200m downstream of PDR alignment. 12 L/s in defined 1m x 0.3m deep channel.

Photo 87: KM 891.4 (1 of 5) – Looking southwest (downstream). PDR crosses watercourse approximately 100m downstream of lake outlet.

Photo 88: KM 891.4 (2 of 5) – Looking southwest (downstream) from 25m upstream of PDR alignment. Beaver dam visible along PDR alignment Site is flooded as obvious banks are visible 30cm below the water surface.

Photo 89: KM 891.4 (3 of 5) – Looking south (downstream) at PDR alignment. Erosion on left bank immediately downstream of PDR alignment. Large woody debris present within channel.

Photo 90: KM 891.4 (4 of 5) – Looking northeast (upstream) at lake outlet PDR alignment.

Photo 91: KM 891.4 (5 of 5) – Looking south (downstream) approximately 100m downstream of alignment. Water is flowing freely, no longer backwatered

Photo 92: KM 919.9 (1 of 4) – Looking east along PDR alignment. A 600mm culvert backfilled with crushed rock span exists at this crossing.

Photo 93: KM 919.9 (2 of 4) – Looking southeast (upstream) from PDR at lake/wetland immediately upstream of crossing.

Photo 94: KM 919.9 (3 of 4) – Looking north (downstream) from PDR. Site is backwatered by a beaver dam ~50m downstream.

Photo 95: KM 919.9 (4 of 4) – Looking south (upstream) approximately 60m downstream of PDR. Beaver dam and impounded water visible through foliage.

Photo 96: KM 940.1 (1 of 4) – Looking north (upstream) across PDR and Enbridge alignments. Channel alignment visible by changes in vegetation.

Photo 97: KM 940.1 (2 of 4) – Looking north (upstream) at PDR alignment. Water channelized in a heavily overgrown channel.

Photo 98: KM 940.1 (3 of 4) – Looking south (downstream) at PDR alignment. Water channelized in a heavily overgrown channel.

Photo 99: KM 940.1 (4 of 4) – Looking north (upstream) approximately 100m upstream of PDR alignment. Water flowing in heavily vegetated creek valley.

Photo 100: KM 981.2 (1 of 3) – Looking northeast (upstream) at PDR alignment. Substrate comprised of cobbles and gravel with some boulders.

Photo 101: KM 981.2 (2 of 3) – Looking south (downstream) from PDR alignment. Defined channel 2.2m wide by 0.8m high at bank full.

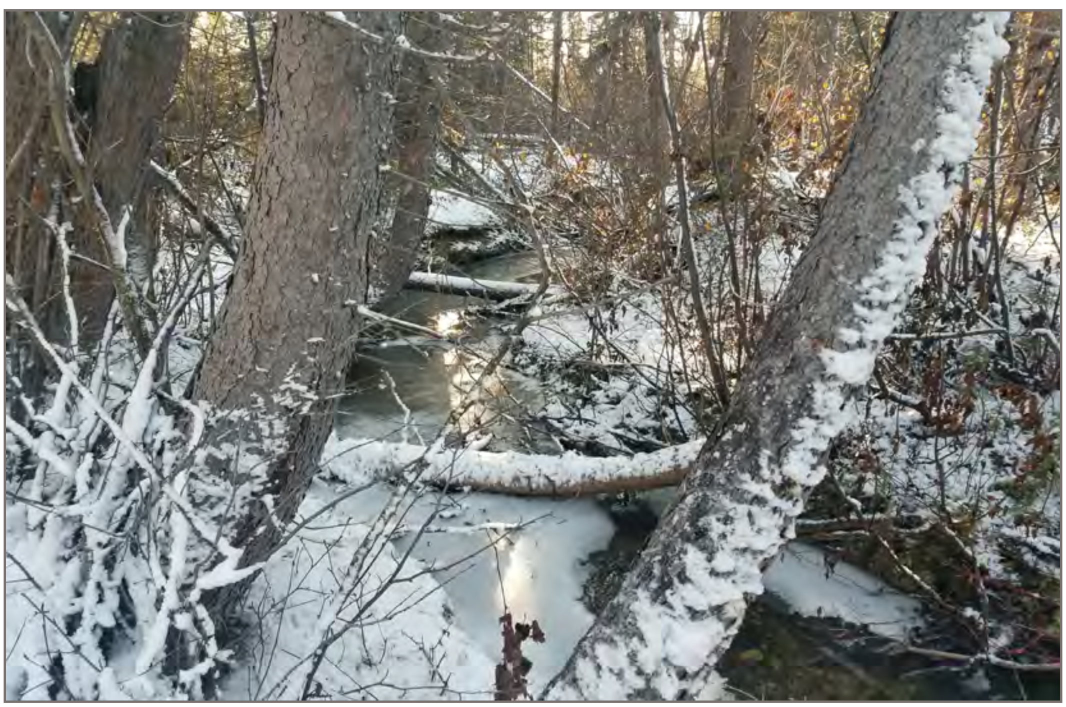

Photo 102: KM 981.2 (3 of 3) – Looking south (downstream) approximately 100m downstream of alignment. Wetted width = 1.35m, defined banks 2 to 2.5m wide.

APPENDIX C

MINOR WATERCOURSE DRAINAGE BASINS

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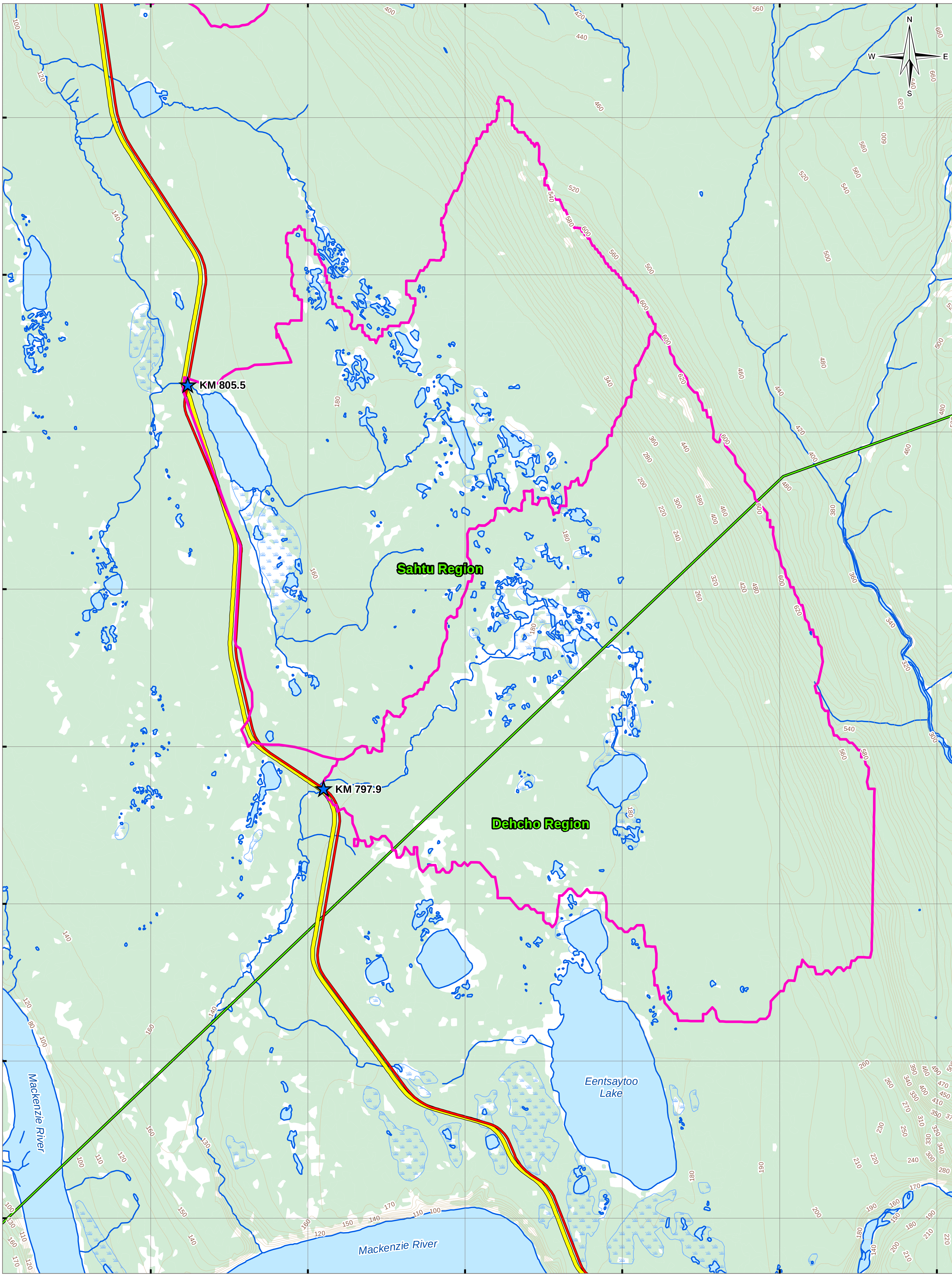

LEGEND

- Drainage Basin
- Minor Watercourse Crossing
- Mackenzie Valley Highway Project
- Mackenzie Valley Winter Road
- Region Boundary

Base Data

- Contour (10 or 20 m)
- Watercourse
- Waterbody
- Wetland
- Wooded Area

NOTES

Kilometre Markers (KMs) based on All-Season Road KMs from the Tulita District Project Description Report (October 2011)
Base data source:
Natural Resources Canada CanVec 1:50,000 scale
ESRI Data Maps
Imagery provided by ESRI; Maxar

STATUS
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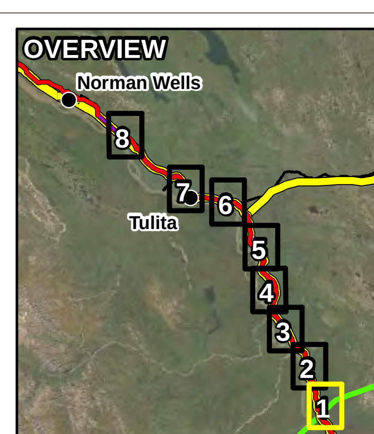

MACKENZIE VALLEY HIGHWAY 2021 HYDROTECHNICAL ASSESSMENTS

Sahtu South Segment Minor Watercourse Drainage Basins

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Northwest Territories

Scale: 1:60,000

1 0.5 0 1

Kilometres

TETRA TECH

FILE NO.				
WTRI03067-01_FigC_DrainageBasins.mxd				
OFFICE	DWN	CKD	APVD	REV
Tt-VANC	SL	BB	MAN	0
DATE	PROJECT NO.			
May 25, 2022	ENG.WTRI03067-01			

Figure C-1

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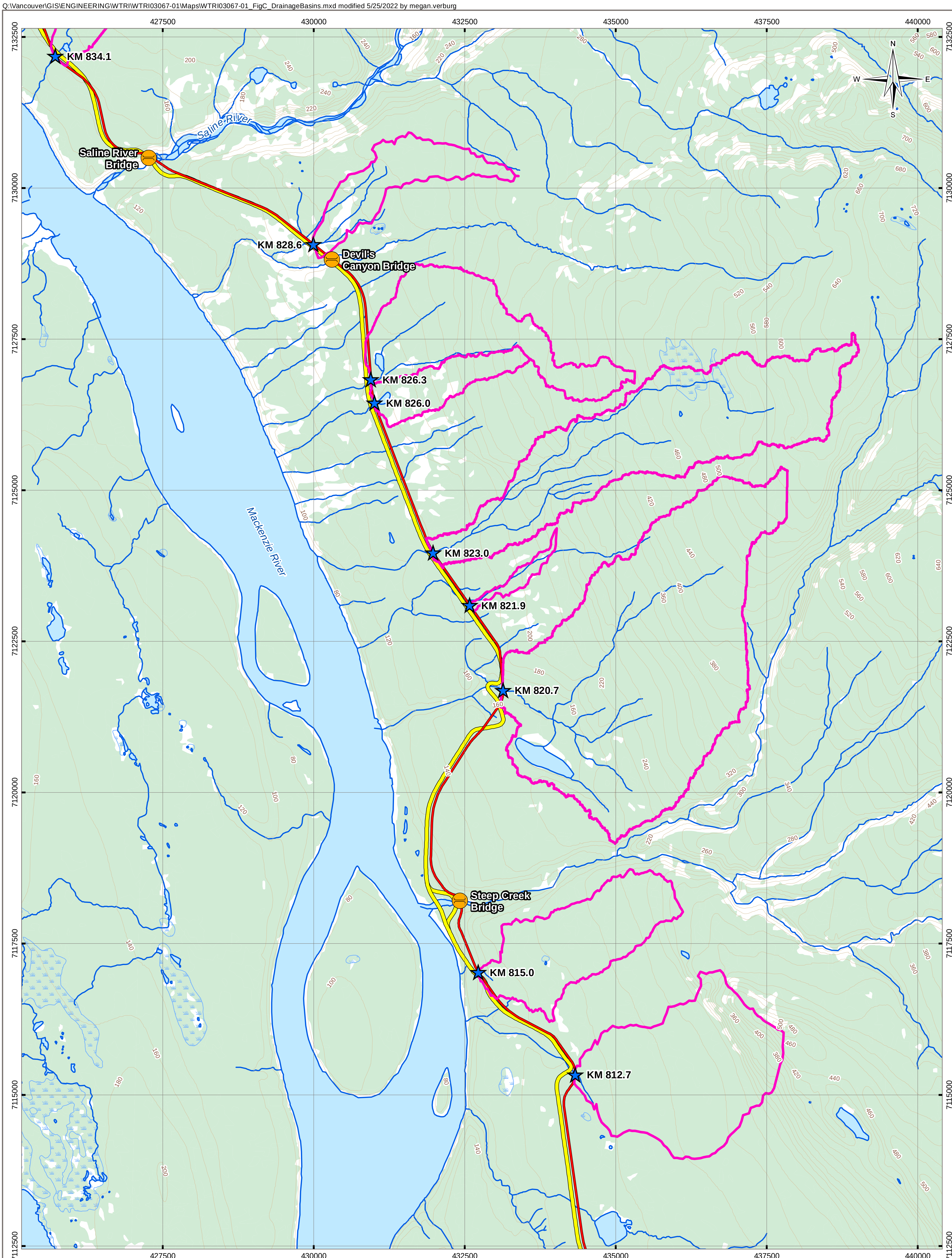

LEGEND

- Drainage Basin
- Existing Bridge
- Minor Watercourse Crossing
- Mackenzie Valley Highway Project
- Mackenzie Valley Winter Road
- Region Boundary

Base Data

- Contour (10 or 20 m)
- Watercourse
- Waterbody
- Wetland
- Wooded Area

NOTES

Kilometre Markers (KMs) based on All-Season Road KMs from the Tulita District Project Description Report (October 2011)
Base data source:
Natural Resources Canada CanVec 1:50,000 scale
ESRI Data Maps
Imagery provided by ESRI; Maxar

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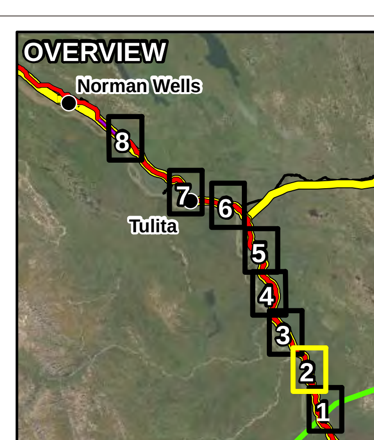

MACKENZIE VALLEY HIGHWAY
2021 HYDROTECHNICAL ASSESSMENTS

Sahtu South Segment
Minor Watercourse Drainage Basins

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Northwest Territories

Scale: 1:60,000
1 0.5 0 1
Kilometres

TETRA TECH

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Tt-VANC	SL	BB	MAN	0
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May 25, 2022	ENG.WTRI03067-01			

Figure C-2

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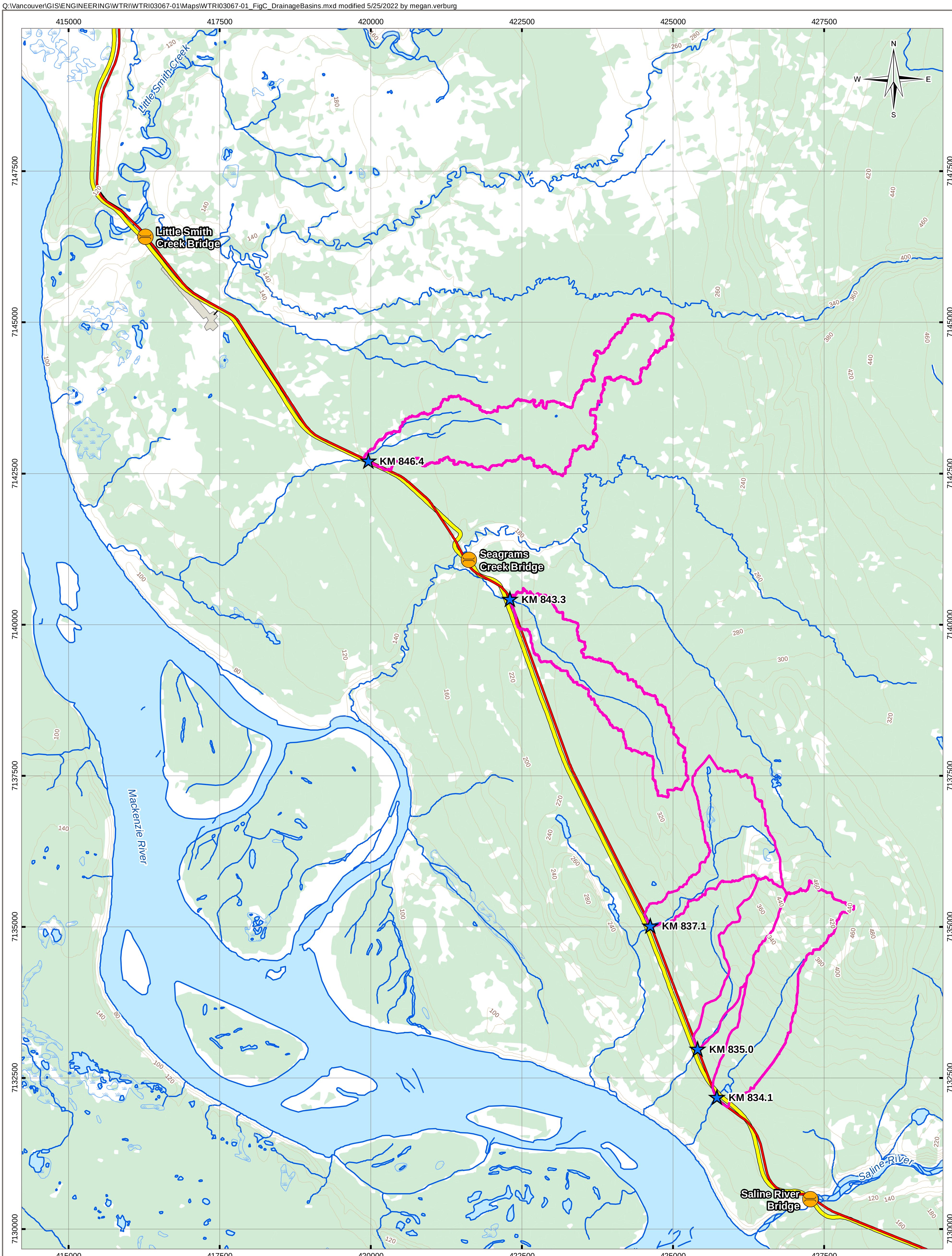

LEGEND

- Drainage Basin
- Existing Bridge
- Minor Watercourse Crossing
- Mackenzie Valley Highway Project
- Mackenzie Valley Winter Road
- Region Boundary

Base Data

- Contour (10 or 20 m)
- Watercourse
- Waterbody
- Wetland
- Wooded Area
- Other Road
- Runway

NOTES
Kilometre Markers (KMs) based on All-Season Road KMs from the Tulita District Project Description Report (October 2011)
Base data source:
Natural Resources Canada CanVec 1:50,000 scale
ESRI Data Maps
Imagery provided by ESRI; Maxar

STATUS
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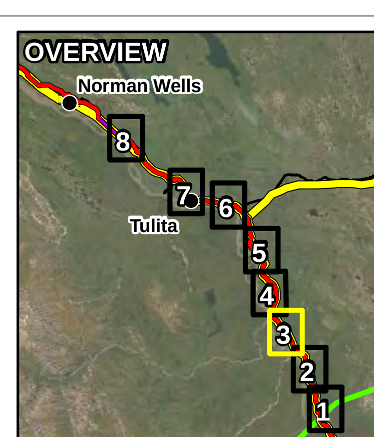
OVERVIEW



MACKENZIE VALLEY HIGHWAY
2021 HYDROTECHNICAL ASSESSMENTS

Sahtu South Segment
Minor Watercourse Drainage Basins

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Northwest Territories

Scale: 1:60,000
1 0.5 0 1
Kilometres

TETRA TECH

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Figure C-3

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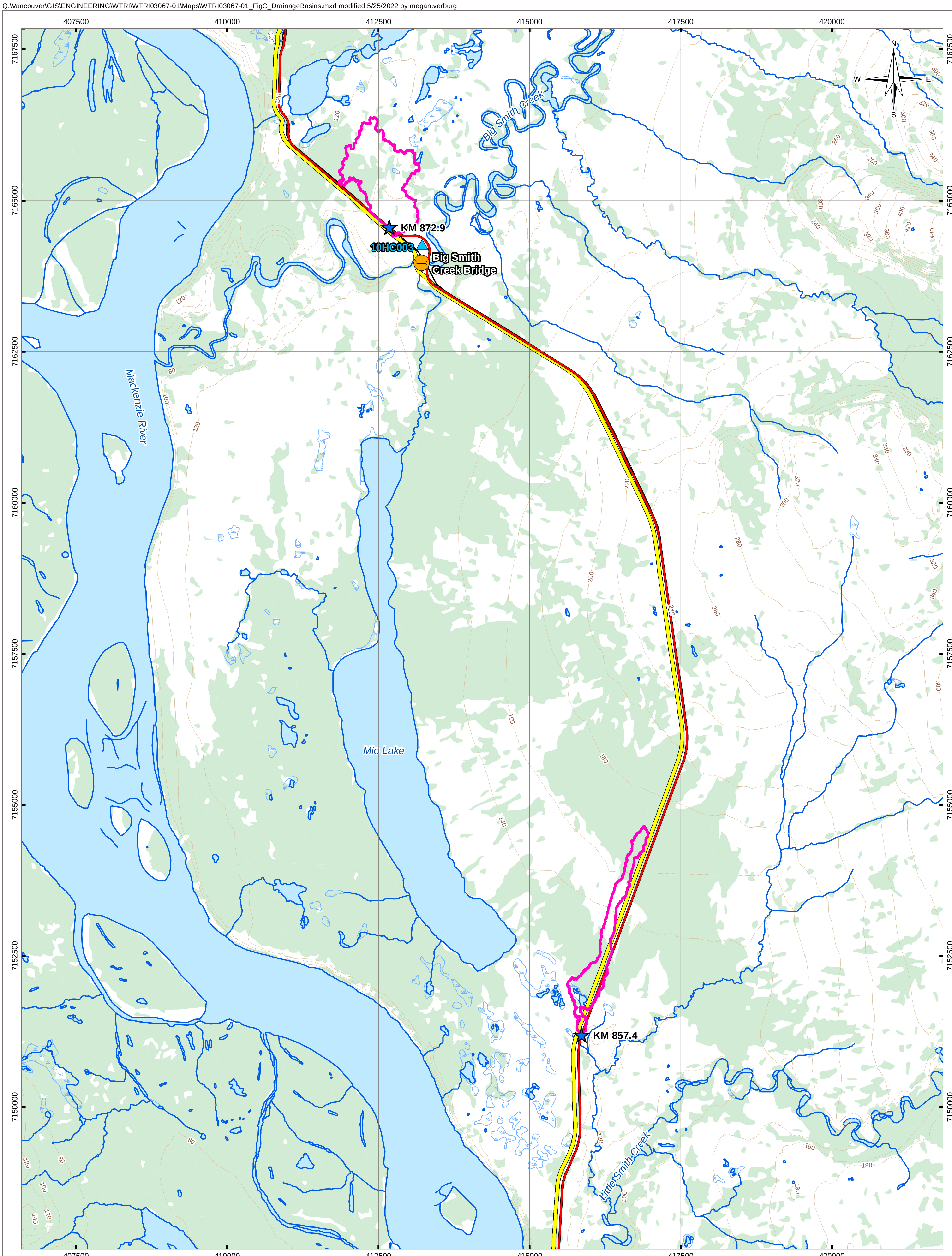

LEGEND

- Drainage Basin
- Existing Bridge
- Minor Watercourse Crossing
- Water Survey of Canada Stream Gauge Station
- Mackenzie Valley Highway Project
- Mackenzie Valley Winter Road
- Region Boundary

Base Data

- Contour (10 or 20 m)
- Watercourse
- Waterbody
- Wetland
- Wooded Area
- Other Road

NOTES
Kilometre Markers (KMs) based on All-Season Road KMs from the Tulita District Project Description Report (October 2011)
Base data source:
Natural Resources Canada CanVec 1:50,000 scale
ESRI Data Maps
Imagery provided by ESRI; Maxar

STATUS
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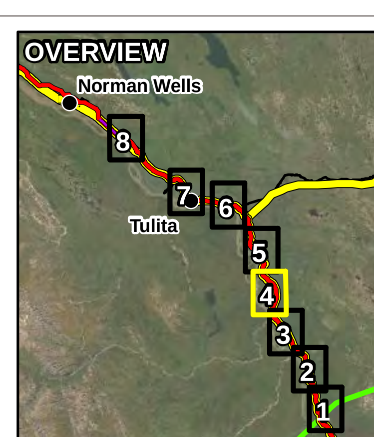
OVERVIEW



MACKENZIE VALLEY HIGHWAY
2021 HYDROTECHNICAL ASSESSMENTS

Sahtu South Segment
Minor Watercourse Drainage Basins

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Northwest Territories

Scale: 1:60,000
1 0.5 0 1
Kilometres

TETRA TECH

FILE NO.				
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DATE	PROJECT NO.			
May 25, 2022	ENG.WTRI03067-01			

Figure C-4

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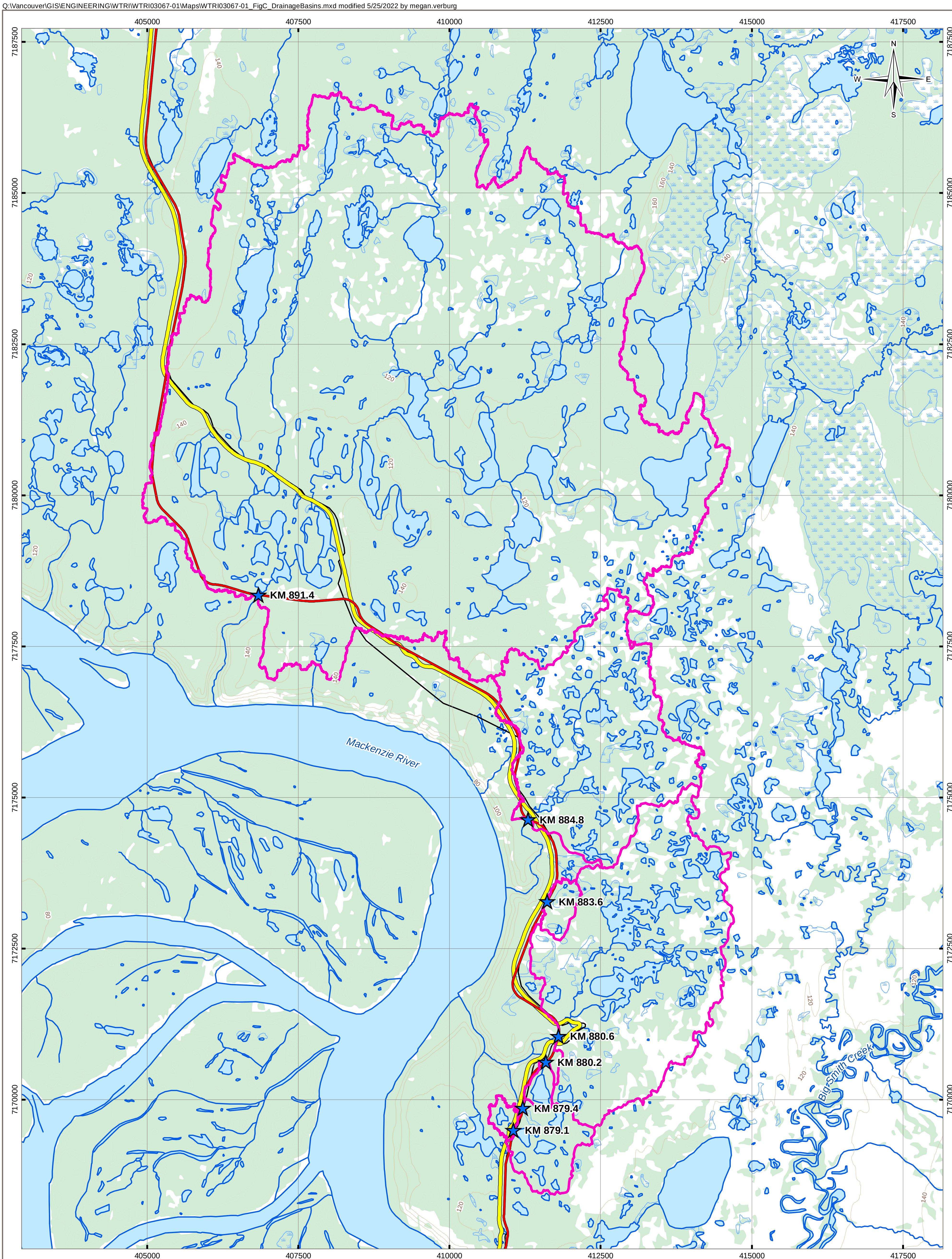

LEGEND

- Drainage Basin
- Minor Watercourse Crossing
- Mackenzie Valley Highway Project
- Mackenzie Valley Winter Road
- Region Boundary

Base Data

- Contour (10 or 20 m)
- Watercourse
- Waterbody
- Wetland
- Wooded Area
- Other Road

NOTES

Kilometre Markers (KMs) based on All-Season Road KMs from the Tulita District Project Description Report (October 2011)
Base data source:
Natural Resources Canada CanVec 1:50,000 scale
ESRI Data Maps
Imagery provided by ESRI; Maxar

STATUS
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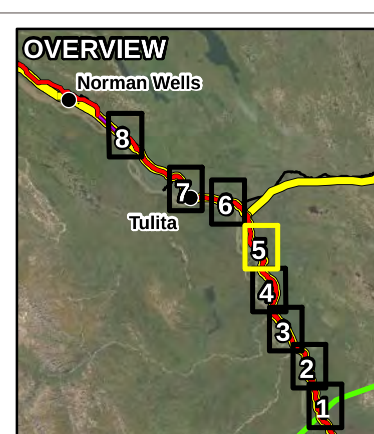
OVERVIEW



MACKENZIE VALLEY HIGHWAY 2021 HYDROTECHNICAL ASSESSMENTS

Sahtu South Segment Minor Watercourse Drainage Basins

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Northwest Territories

Scale: 1:60,000
1 0.5 0 1
Kilometres

TETRA TECH

FILE NO.
WTRI03067-01_FigC_DrainageBasins.mxd

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DATE	PROJECT NO.
May 25, 2022	ENG.WTRI03067-01

Figure C-5

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LEGEND

- Drainage Basin
- Existing Bridge
- Minor Watercourse Crossing
- Mackenzie Valley Highway Project
- Mackenzie Valley Winter Road
- Region Boundary

Base Data

- Contour (10 or 20 m)
- Watercourse
- Waterbody
- Wetland
- Wooded Area
- Other Road

NOTES
Kilometre Markers (KMs) based on All-Season Road KMs from the Tulita District Project Description Report (October 2011)
Base data source:
Natural Resources Canada CanVec 1:50,000 scale
ESRI Data Maps
Imagery provided by ESRI; Maxar

STATUS
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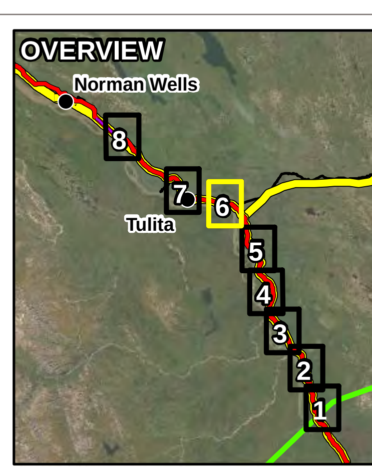

MACKENZIE VALLEY HIGHWAY
2021 HYDROTECHNICAL ASSESSMENTS

Sahtu South Segment
Minor Watercourse Drainage Basins

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Northwest Territories

Scale: 1:60,000
1 0.5 0 1
Kilometres

TETRA TECH

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WTRI03067-01_FigC_DrainageBasins.mxd				
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DATE	PROJECT NO.			
May 25, 2022	ENG.WTRI03067-01			

Figure C-6

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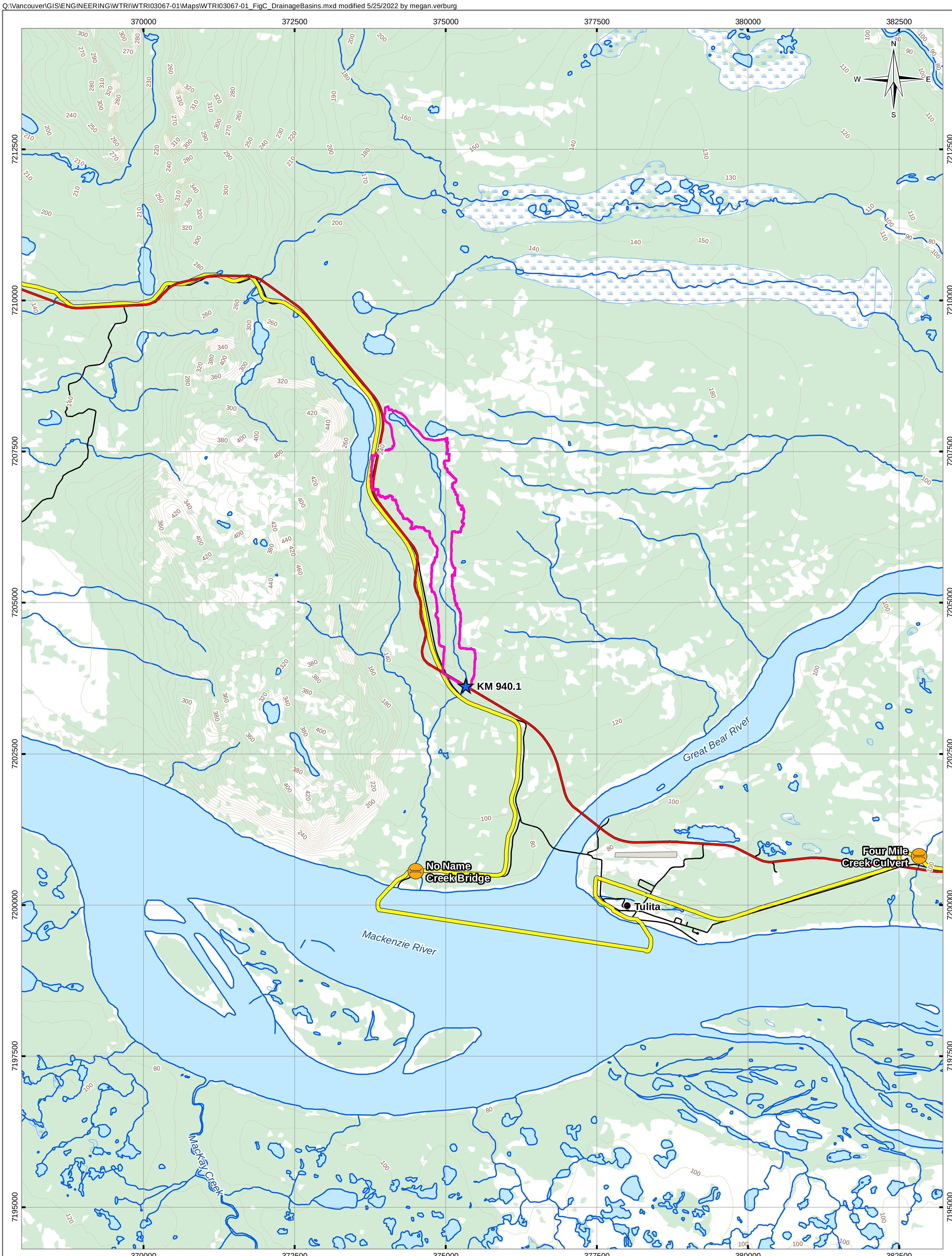

LEGEND

- Drainage Basin
- Existing Bridge
- Minor Watercourse Crossing
- Mackenzie Valley Highway Project
- Mackenzie Valley Winter Road
- Region Boundary

Base Data

- Contour (10 or 20 m)
- Watercourse
- Waterbody
- Wetland
- Wooded Area
- Other Road
- Runway
- Populated Place

NOTES
Kilometre Markers (KMs) based on All-Season Road KMs from the Tulita District Project Description Report (October 2011)
Base data source:
Natural Resources Canada CanVec 1:50,000 scale
ESRI Data Maps
Imagery provided by ESRI; Maxar

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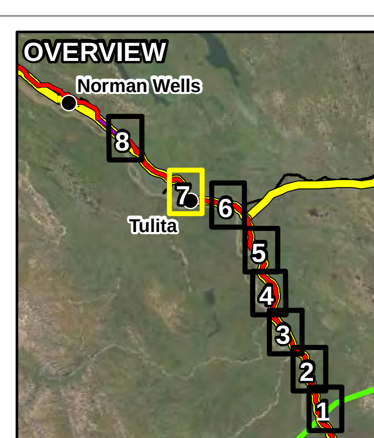

MACKENZIE VALLEY HIGHWAY 2021 HYDROTECHNICAL ASSESSMENTS

Sahtu South Segment Minor Watercourse Drainage Basins

PROJECTION	DATUM	CLIENT
UTM Zone 10	NAD83	Northwest Territories

Scale: 1:60,000
1 0.5 0 1
Kilometres

FILE NO.
WTRI03067-01_FigC_DrainageBasins.mxd

TETRA TECH

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Tt-VANC	SL	BB	MAN	0

DATE	PROJECT NO.
May 25, 2022	ENG.WTRI03067-01

Figure C-7

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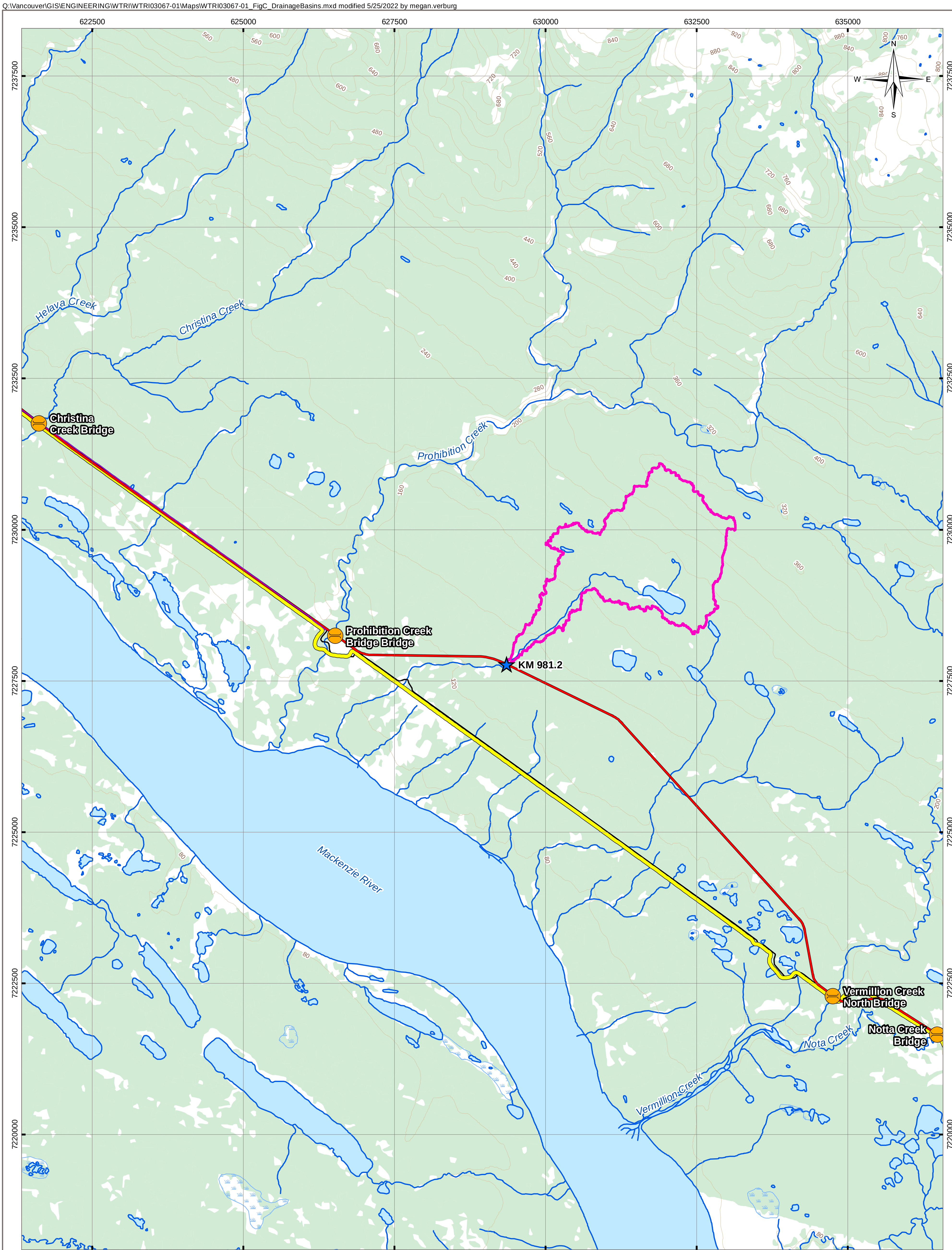

LEGEND

- Drainage Basin
- Existing Bridge
- Minor Watercourse Crossing
- Prohibition Creek Access Road
- Mackenzie Valley Highway Project
- Mackenzie Valley Winter Road
- Region Boundary

Base Data

- Contour (10 or 20 m)
- Watercourse
- Waterbody
- Wetland
- Wooded Area
- Other Road

NOTES

Kilometre Markers (KMs) based on All-Season Road KMs from the Tulita District Project Description Report (October 2011)
Base data source:
Natural Resources Canada CanVec 1:50,000 scale
ESRI Data Maps
Imagery provided by ESRI; Maxar

STATUS
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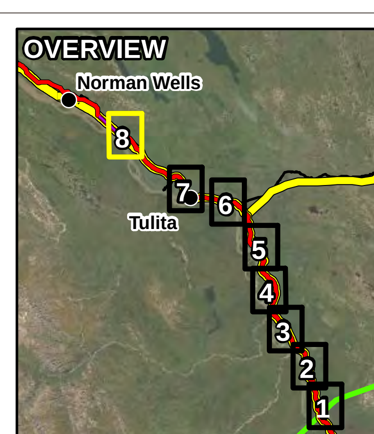

MACKENZIE VALLEY HIGHWAY 2021 HYDROTECHNICAL ASSESSMENTS

Sahtu South Segment Minor Watercourse Drainage Basins

PROJECTION	DATUM	CLIENT
UTM Zone 9	NAD83	Northwest Territories

Scale: 1:60,000
1 0.5 0 1
Kilometres

TETRA TECH

FILE NO.				
WTRI03067-01_FigC_DrainageBasins.mxd				
OFFICE	DWN	CKD	APVD	REV
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DATE	PROJECT NO.			
May 25, 2022	ENG.WTRI03067-01			

Figure C-8