

March 19, 2024

Patricia Coyne

Reference: MVEIRB ORS Comment Responses ORS 64-143

Attachment LKFN-33A

**Mackenzie Valley Highway Dehcho Segment
Hydrotechnical Assessments (Tetra Tech 2021)**

Mackenzie Valley Highway Dehcho Segment Hydrotechnical Assessments GNWT Service Contract SC-4306



PRESENTED TO
**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 sections of the proposed Mackenzie Valley Highway (MVH). This work was done under a Standing Offer Agreement 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; and
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 excludes the major crossings with existing bridges which have been 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 Dehcho segment, which overlaps slightly with the MGAR segment which is reported separately.

Field Investigation

Seven days of site investigation were completed from September 18 through 24, 2020, using helicopter to access the Dehcho study area. Ground inspections were made at 23 predefined watercourses of interest 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. Several additional watercourses were inspected as could be accommodated within the field program's end-of-season schedule.

The number of watercourses being assessed was increased from 23 to 34 during final reporting in 2021, and an aerial inspection of the northernmost site was made on October 2, 2021, during field assessments of the adjacent Sahtu Region segment.

Hydrologic Analysis

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 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

Culverts sized to pass estimated 100-year flows are recommended for 34 crossing locations. Two of these reside within the MGAR alignment and had already been sized during prior MGAR study. 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 3670 mm. The proposed culvert geometries have been developed with the assumption that none of the subject watercourses are fish bearing. Alternative culvert design including the use of embedment or open-bottomed arch culverts should be considered if any watercourses are deemed to be fish bearing.

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LIMITATIONS OF REPORT

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ACRONYMS & ABBREVIATIONS

| Acronyms/Abbreviations | Definition |
|------------------------|---|
| % | percent |
| ASR | All Season Road |
| AT | Alberta Transportation |
| CSP | Corrugated Steel Pipe |
| DEM | Digital Elevation Model |
| ENR-ITI-Lands | Environment and Natural Resources - Industry, Tourism and Investment, and Lands |
| INF | Department of Infrastructure |
| GNWT | Government of the Northwest Territories |
| km | kilometre |
| 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 Extension Project |

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 portions of the proposed Mackenzie Valley Highway (MVH) Extension which will upgrade the existing winter road to an All Season Road (ASR). This work was done Standing Offer Agreement 4034 with the GNWT.

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

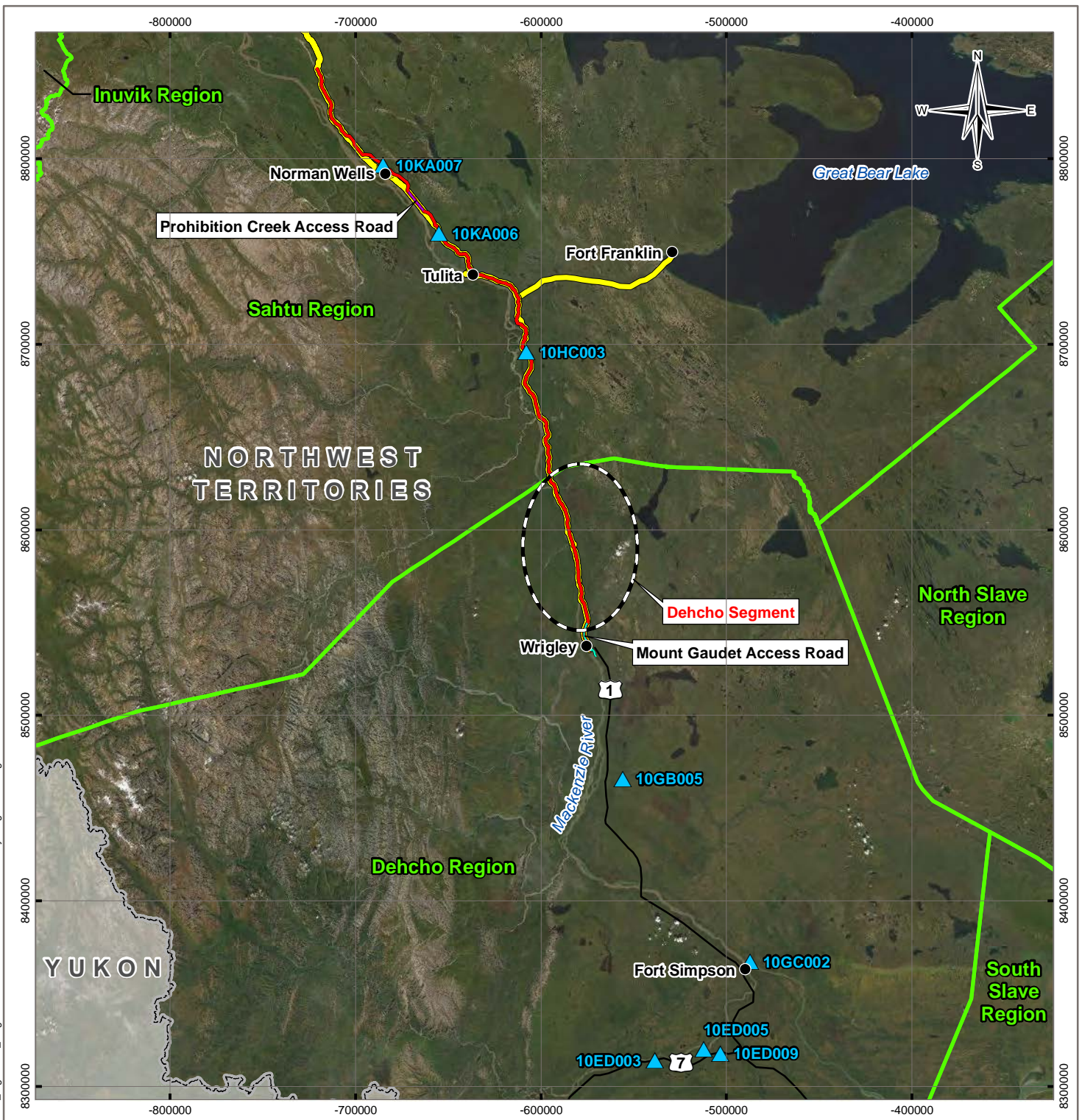
1. Prohibition Creek Access Road (PCAR), approximately 14 km long, accessed from Norman Wells;
2. Mount Gaudet Access Road (MGAR), approximately 21 km long, accessed from Wrigley; and
3. A segment through Dehcho Lands, approximately 83 km long, north of the MGAR, accessed from Wrigley.

Figure 1-1 presents a regional location plan showing the locations and extents of the above segments.

The alignment for the proposed ASR generally follows the existing winter road which has bridges at major crossings. The scope of work excludes the previously-assessed major crossings with existing bridges.

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 for sites accessed with ground transportation. An aerial inspection of the northernmost potential crossing was made during field assessments in 2021 of the southern portion of the adjoining Sahtu Region segment.

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 Dehcho segment.



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LEGEND

- ▲ Water Survey of Canada Stream Gauge Station
- Mackenzie Valley Highway Extension
- Mackenzie Valley Highway Public Winter Road
- Mount Gaudet Access Road
- Prohibition Creek Access Road
- ENR-ITI-Lands Administrative Boundary
- Base Data**
- Populated Place
- Other Road
- Provincial/Territorial Boundary

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

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**MACKENZIE VALLEY HIGHWAY
 2020-21 HYDROTECHNICAL ASSESSMENTS**

Regional Location Plan

| | | | |
|--|--|-----------------------|-------------------|
| PROJECTION Northwest Territories Lambert | | DATUM NAD83 | |
| Scale: 1:3,000,000 | | | |
| | | | |
| FILE NO. WTRI03043-01_Figure1-1_RegionalPlan.mxd | | | |
| OFFICE Tt-EDM | DWN MRV | CKD SL | APVD BR |
| DATE October 27, 2021 | PROJECT NO. ENG.WTRI03043-01 | | |

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Figure 1-1

2.0 INITIAL SCOPE OF WORK AND BACKGROUND INFORMATION

The initial hydrotechnical scope of work for the Dehcho segment was to provide an assessment of 23 watercourse locations that were predefined during the initial scoping of work. This differed in scope compared to the two other sections of highway (PCAR and MGAR) where drainages of interest were not predefined but rather identified during the field reconnaissance. The Dehcho Segment field program was a short-notice add-on to the scheduled 2020 field program then in progress and was constrained by short days, weather conditions and staff availability.

The predefined locations for the Dehcho Segment were a subset of potential watercourses listed in the Dessau (2012) Mackenzie Valley Highway Extension, Pehdzeh Ki Ndeh - Dehcho Region, Project Description Report (PDR).

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.

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 identified in Figure 1-1 and 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, and Polar Geospatial Centre ArcticDEM terrain models developed from satellite imagery. The NTS mapping and ArcticDEM data were used to determine watershed areas.

Bare earth Light Detection and Ranging (LiDAR) elevation data were obtained from the GNWT for a corridor along the MVH alignment. This information was obtained after the completion of the field investigations. It was used to identify additional crossing locations for a revised interpretation of the scope of work

3.0 REVISED LIST OF CROSSINGS

During the reporting stage, the list of crossings to be assessed was revised to include all watercourse crossings identified in the 2012 PDR, not limited to those identified in the original scope of work, plus additional drainage features which were identifiable from high-resolution LiDAR data for the PDR alignment. For completeness, an initial full list of potential crossings developed for screening purposes, presented in Appendix B, includes major watercourse crossings with existing bridges which are excluded from subsequent analyses. The watercourse crossings assessed in this report are described as “minor watercourse crossings” to distinguish them from the larger watercourses with bridges.

The screening table in Appendix B provides an extended list of potential watercourse crossings for the MVH Dehcho Segment and documents the adjustments made from KM identifiers (and coordinates) in the PDR to yield those subsequently used in the present report. The list was developed during the reporting stage and was not available at the time of the 2020 field inspections.

The screening list of crossings was developed with the procedures and methods listed below.

- Sites are identified by Winter Road Kilometre Markers (KMs) used in the Dehcho PDR to identify potential watercourse crossings. New (not in the PDR) watercourse crossings are referenced to the same winter road reference system, measured from the nearest identified drainage with a KM identifier. A georeferenced version of the Dessau winter road KM markers could not be located. Generally, the watercourses encountered along the winter road are the same as encountered along the proposed ASR, repositioned either upstream or downstream where the alignment is shifted.
- Watercourse crossing coordinates, referenced to UTM Zone 10, are at positions where LiDAR-confirmed watercourses cross the ASR road centreline provided by Stantec for this project. This ASR alignment is understood to match the PDR alignment. The KMs associated with this alignment are not used in the present report because the ASR alignment and corresponding KMs were under review in 2021 and expected to change.
- Most of the watercourses identified in the Dehcho PDR correspond to drainage courses identified on 1:50,000 National Topographic Survey (NTS) maps and successor Canvec digital topographic features. However, a combination of ground and desktop assessments determined that defined watercourses are sometimes not present along the winter road at the original (PDR) coordinates. Updated coordinates were determined for ASR crossings of LiDAR-confirmed drainages. The Winter Road KMs were updated or adjusted only when the LiDAR-derived location of the winter road channel crossing was more than 100 m from the KM identified in the PDR. Adjustments were sometimes complex as illustrated in Figure 3-1, presented below.
- Location of additional watercourse crossings, not listed in the Dehcho PDR, were identified by a desktop assessment of the LiDAR elevation data along the MVH corridor. An effort was made to identify all crossings with a LiDAR-derived gully depth greater than one metre. The final list of crossings includes several watercourses identified in the original PDR which do not meet the one metre depth threshold and would not have been assessed considering LiDAR alone. It should be noted that the LiDAR surface stops at the water surface and does not detect the depth of slow-moving water in muskeg or fen wetland areas.

Appendix B is the only location in this report which presents the full list of PDR KM identifiers used for planning and initial reporting of the 2020 field program and documents the adjustments made to the initial identifiers. Subsequent tables and figures are based on the adjusted values.

As mentioned above, the LiDAR-based identification of drainage channels considered the presence of an existing drainage feature which was sufficiently deep to accommodate a culvert at the watercourse crossing. This criterion was not considered during the preparation of the prior PCAR and MGAR assessments, but its importance became apparent during detailed designs developed in 2021 for the PCAR segment. Specifically, some crossings lacked sufficient depth to provide the headwater necessary for culverts to flow at their full design capacity. Water at the culvert inlets will produce bypass flow down the edge of road embankment with only shallow depth (or head) being developed at the culvert inlets.

Figure 3-1 shows drainage information for the crossing at PDR KP 769.66 and illustrates the challenge in identifying and sizing some of the minor watercourse crossings. In this example, a future road embankment will block the present flow of water at the mapped watercourse where there is insufficient head available to confine flood flows to a culvert crossing. Water will bypass the culvert by flowing along the embankment and potentially produce a cascade of overflows at sequential low points along the alignment

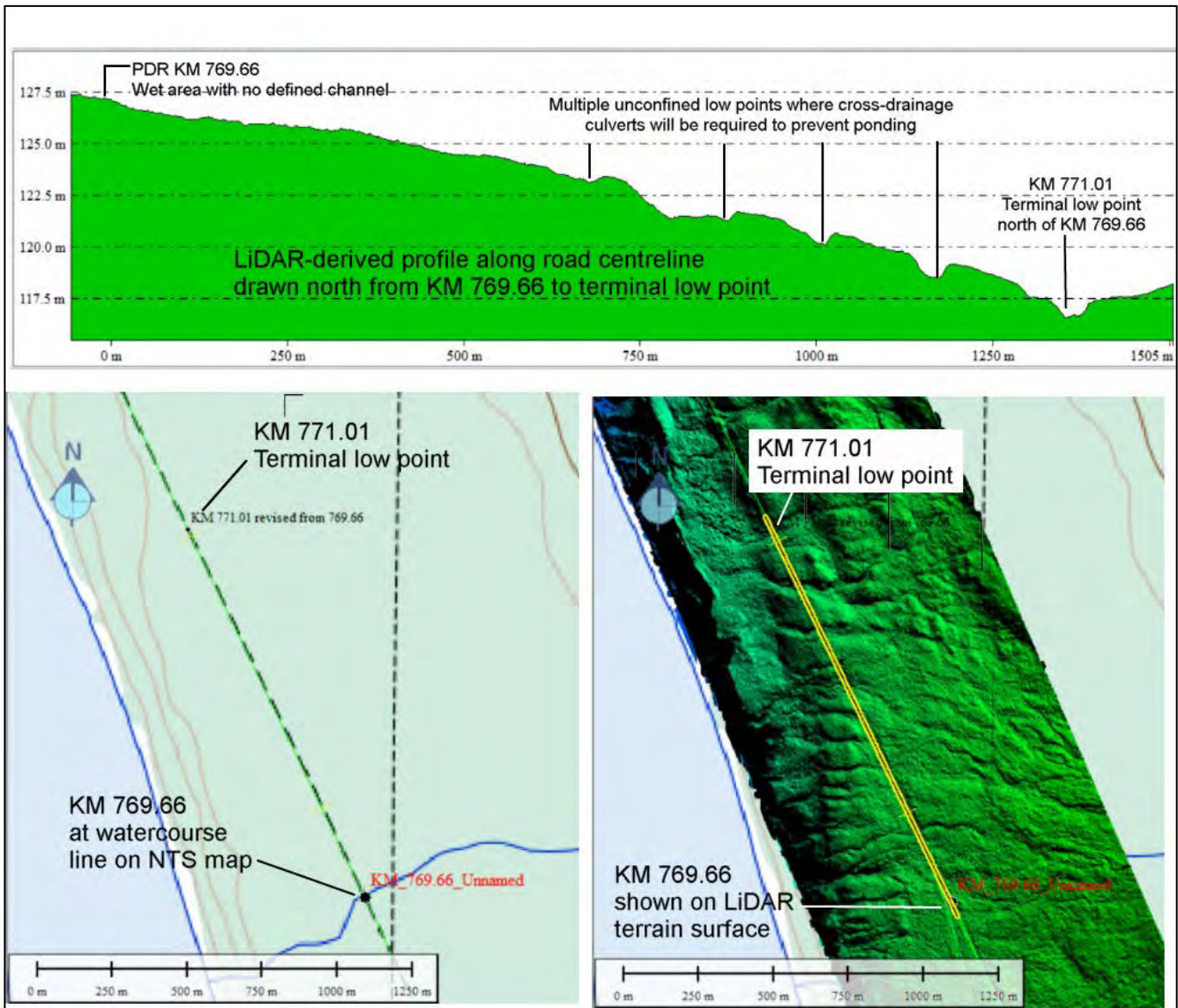


Figure 3-1: Watercourse Identification Example with NTS Mapping and LiDAR Data for PDR KM 769.66

Figure 3-1 shows the primary forms of desktop information used for desktop identification of watercourse crossings: (1) National Topographic Survey (NTS) 1:50,000 scale topographic mapping; (2) LiDAR-derived shaded terrain surface; and (3) LiDAR-derived elevation profiles.

Watercourses identified on NTS maps are generally a very reliable source of drainage information, but this was not the case for the MVH Dehcho segment. Many of the NTS mapped minor drainages, including but not limited to a mapped watercourse at PDR 769.66, are either offset from the mapped position or lack a defined channel within 100 m of the mapped position. A ground inspection confirmed wet conditions near the original KM 769.66, but the only identifiable channel was a short north-flowing segment within the cleared winter road corridor. No channels were observed in wet areas adjacent to the alignment.

Construction of the ASR road embankment is expected to utilize only fill, without excavation of roadside ditches which could cause impacts to underlying permafrost. This complicates the design of cross-drainage because the road embankment will block the present shallow flow without providing a way for water to fill a culvert to a nominal design condition such as an inlet water depth more than one half of the culvert diameter. Without the ability to

develop headwater to the culvert, water will bypass the culvert and follow the slope along the edge of alignment. In the above example, bypass water will drain to the north.

For purposes of tabulating culvert crossings, the original KM 769.66 has been augmented with a new crossing identifier at KM 771.01 at a “terminal low” where there is sufficient head (more than 2 m) and space available to install culverts capable of conveying the accumulated flow to that point. Additional relief culverts will be required at the original KM 769.66 and the other depressions indicated on Figure 3-1.

Design of the individual (or multiple) culverts at these depressions is complicated by the bypass flow conditions and will depend in part on the final road alignment and proposed geometry (especially embankment height and toe of fill) not known at this time. Further assessment of the segment draining to KM 701.01 and other watercourses that lack a defined channel is deferred to a final design stage when this information is available.

4.0 FIELD INVESTIGATIONS

The field investigation along the MVH Dehcho segment was conducted from September 18 to 24, 2020 by hydrotechnical engineer Mark Aylward-Nally, P.Eng. (BC) of Tetra Tech and aquatic biologist Lindsay Dowbush, P.Biol. of Stantec, accompanied by a local wildlife/environmental monitor. The findings are supplemented by an aerial assessment of the northernmost Dehcho crossing, KM 793.4, during the 2021 field assessment of the adjacent Sahtu Region segment. Each site was accessed using helicopter. This original field program was undertaken to evaluate the drainage and/or fish habitat characteristics of 23 watercourses along the proposed highway alignment. Two of these 23 watercourses were located within the MGAR segment assessed previously, with hydrotechnical results copied to the current report for ease of reference. The fish habitat assessment portion of this work is discussed in a separate report by Stantec.

The proposed all-weather highway alignment follows the current winter road alignment with a few discrete exceptions where deviations exist. Most watercourse crossings evaluated in this assessment are in locations where the two alignments match. Exceptions include KM 767.16, where the combination of an alignment shift and inaccurate NTS mapping led to the removal of that identifier from the list of assessed crossings. Another crossing, KM 774.09, is located approximately 100 metres downstream of the existing winter road.

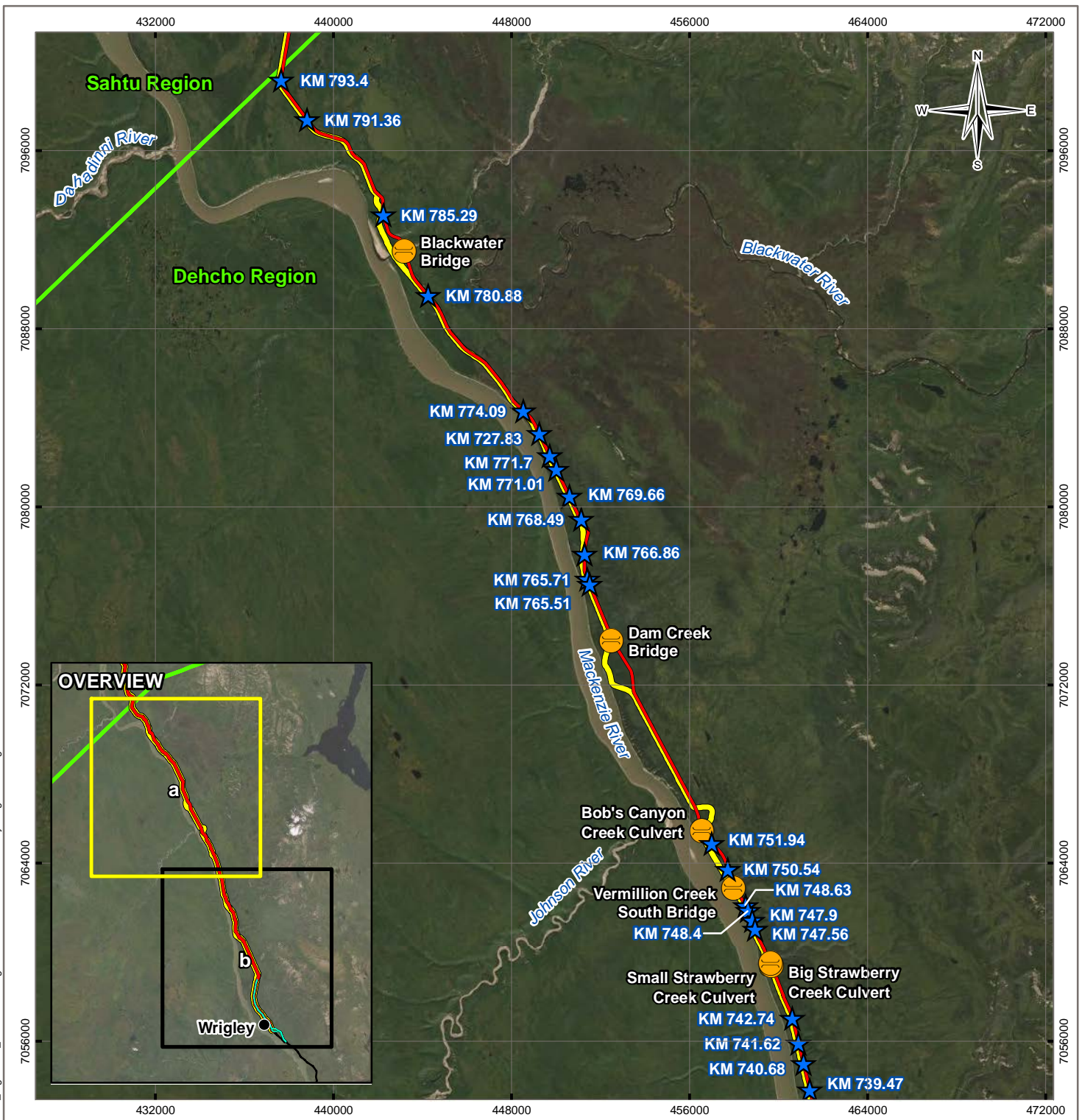
The terrain over the Dehcho segment can be characterized as gently rolling terrain with a consistent western slope towards the Mackenzie River. Ground cover along the alignment is predominantly muskeg, often wet and marshy in low-lying areas, vegetated with small trees and shrubs.

4.1 Watercourses Assessed and Assessment Methods

Unlike the PCAR and MGAR assessments, the initial 23 watercourses of interest for the Dehcho segment were predefined during the scoping of work, meaning no initial desktop GIS analysis of topographic data was conducted prior to the field program. Direct field inspections were made of each of the pre-defined watercourses. Ground assessments of additional sites identified from helicopter aerial observations were however made when they could be accommodated within the field program’s schedule constraints.

The expanded list of 34 watercourse sites, described in Section 3 and Appendix B, was developed after submittal of an initial report which was limited to the predefined sites. The present report includes all sites for which ground inspections were made, plus additional sites added after the completion of the field program. These watercourse assessments are therefore considered to be reasonably comprehensive and are based on the best information presently available from a combination of ground, aerial and desktop assessment methods.

Figures 4-1a and 4-1b show the locations of the minor watercourse crossings which are evaluated in this report. Figures A-1 to A-6 in Appendix D show the crossings locations at a smaller scale, together with drainage basin areas.



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LEGEND

- Existing Bridge
- Minor Watercourse Crossing
- Mackenzie Valley Highway Extension
- Mackenzie Valley Highway Public Winter Road
- ENR-ITI-Lands Administrative Boundary

NOTES
 Kilometre Markers (KMs) based on Winter Road KMs from the Dehcho Region Project Description Report, Dessau (March 2012)
 Base data source: CanVec 1:250,000
 ESRI Data Maps
 Imagery provided by ESRI; Maxar

STATUS
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**MACKENZIE VALLEY HIGHWAY
 2020-21 HYDROTECHNICAL ASSESSMENTS**

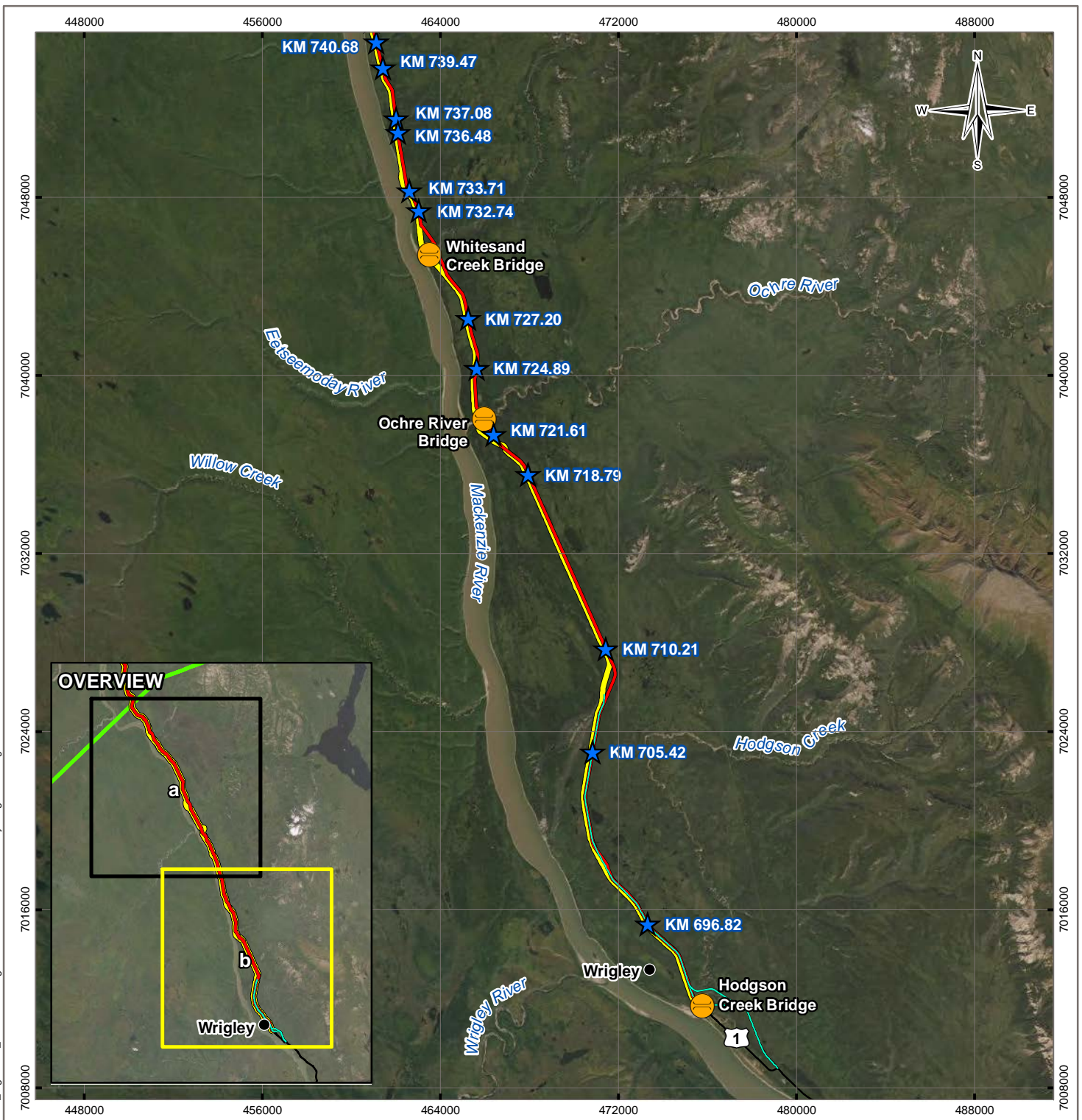
**Dehcho Segment
 Watercourse Crossings**

| | | | | |
|--|-------------------|--|-------------------|-------------------|
| PROJECTION UTM Zone 10 | | DATUM NAD83 | | CLIENT |
| Scale: 1:250,000 Kilometres | | | | |
| FILE NO. WTRI03043-01_Figure4-1_WaterCrossings.mxd | | | | |
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| DATE October 27, 2021 | | PROJECT NO. ENG.WTRI03043-01 | | |

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Figure 4-1a



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LEGEND

- Existing Bridge
- Minor Watercourse Crossing
- Mackenzie Valley Highway Extension
- Mackenzie Valley Highway Public Winter Road
- Mount Gaudet Access Road
- ENR-ITI-Lands Administrative Boundary
- Base Data**
- Populated Place
- Other Road

NOTES
 Kilometre Markers (KMs) based on Winter Road KMs from the Dehcho Region Project Description Report, Dessau (March 2012)
 Base data source: CanVec 1:250,000
 ESRI Data Maps
 Imagery provided by ESRI; Maxar

STATUS
 ISSUED FOR USE

MACKENZIE VALLEY HIGHWAY 2020-21 HYDROTECHNICAL ASSESSMENTS

Dehcho Segment Watercourse Crossings

| | | |
|--|-----------------------|---------------------|
| PROJECTION UTM Zone 10 | DATUM NAD83 | CLIENT |
| Scale: 1:250,000 | | |
| FILE NO. WTR103043-01_Figure4-1_WaterCrossings.mxd | | |
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| DATE October 27, 2021 | APVD BR BR | REV 0 |
| PROJECT NO. ENG.WTR103043-01 | | Figure 4-1b |

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4.2 Site Assessment Summary

Ground inspections were made at each of the originally-identified crossings 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.

Ground inspections were also conducted at three sites not on the original list but added during the field program. Aerial inspections were made at two additional sites.

Table 4-1 presents a summary of best available information from ground, aerial, and desktop assessments of each minor watercourse. Field photos are presented in Appendix C; drainage basins are presented in Appendix D.

The photo summary in Appendix C is based on the photo summary initially submitted with the draft report. The additional sites now included have been appended to the end of the initial photo summary. As a result, photos for the added sites appear to be out of sequence. Also, the original photo summary used KM markers identical to those in the original PDR. Where the KM marker has changed, both versions are noted in Table 4-1.

Table 4-1: Site Assessment Summary

| Winter Road Crossing ID | Easting (m) | Northing (m) | Date Assessed | Flow (L/s) | Bankfull Width (m) | Bankfull Depth (m) | Channel Slope (%) | Substrate Composition | Site Notes | Photo Numbers in Appendix A |
|-------------------------|-------------|--------------|---------------|---|--------------------|--------------------|-------------------|--|--|-----------------------------|
| KM 793.40 | 437654 | 7099183 | 2-Oct-21 | Aerial assessment: ground conditions not observed | | | | | A series of four beaver dams impound flow immediately upstream of the crossing location. | 90 to 92 |
| KM 791.36 | 438816 | 7097405 | 18-Sep-20 | < 10 | ~30 | 0.5 | 0.3 | Fines | 900 mm culvert from the winter road sits perched at this location. Crossing is wide and marshy with defined wetland immediately upstream. No observable flow but given the wide cross section flows of < 10 l/s very possible. | 93 to 95 |
| KM 785.29 | 442243 | 7093122 | n/a | Desktop assessment: field conditions not observed | | | | | No drainage shown on NTS maps. LiDAR shows a shallow gully feature approx. 1 m deep and 10 m wide. | none |
| KM 780.88 | 444249 | 7089511 | 18-Sep-20 | Aerial assessment: ground conditions not observed | | | | | Drainage shown on NTS maps. Aerial inspection identified improved road with existing culvert, size not determined. LiDAR shows drainage over a 30 m wide corridor with no defined channels. | none |
| KM 774.09 | 448526 | 7084328 | 18-Sep-20 | 408 | 4.5 | 0.6 | 1.3 | Boulders | The proposed highway alignment deviates from the current winter road alignment, crossing this watercourse approximately 100 metres downstream of the winter road alignment. Substantial woody debris present within the watercourse. Ice scarring noted on some trees approximately 1.3 metres higher than water level at time of visit (0.6 m higher than top of creek bank). | 1 to 5 |
| KM 772.83 | 449249 | 7083301 | 18-Sep-20 | 8 | n/a | n/a | 3.6 | Muskeg | Low gradient area with lots of ponding. No defined channel present. | 6 to 9 |
| KM 771.7 (and KM 771.6) | 449725 | 7082312 | n/a | Desktop assessment: field conditions not observed | | | | | Low points at KM 771.6 and 771.7 appear to share a common watershed and are separated by a ridge about 1.6 m high | none |
| KM 771.01 | 450016 | 7081707 | n/a | Desktop assessment: field conditions not observed | | | | | The deepest and northernmost of a series of five low points along a 2 km road segment originating from a wet area at KM 769.66 where there is insufficient head to provided culverted cross-drainage of high flow events. See Figure 3-1. | none |
| KM 769.66 | 450608 | 7080490 | 18-Sep-20 | 4 | n/a | n/a | 1.6 | Muskeg | No defined channels upstream or downstream of highway alignment, flow ponds and meanders through muskeg. Flow concentrates at the alignment and flows north for ~50 m before crossing the alignment and dissipating into the muskeg. | 10 to 13 |
| KM 768.49 | 451136 | 7079444 | 18-Sep-20 | ~1 | n/a | n/a | 2.8 | Muskeg | Site flows east to west, draining into a wetland immediately adjacent to the winter road alignment. No defined channel exists. | 96 and 97 |
| KM 767.16 | 451279 | 7078183 | 18-Sep-20 | 20 | 1.5 | 0.35 | 1.7 | Fines | Loosely defined channel, some small braids upstream and downstream of the crossing. Large vegetation growing within the channel at points. Banks are not well defined but approximately 0.35 m high. Downstream of alignment channel dissipates into small wetland. The ASR diverges from the winter road in this segment and conditions observed are not directly relevant to ASR design. | 14 to 17 |
| KM 766.86 | 451290 | 7077883 | n/a | Desktop assessment: field conditions not observed | | | | | New coordinates are initial drainage point from main basin incorrectly associated with KM 767.16 on NTS maps. Shallow available headwater will result in flood flow bypass down alignment to low spot at about KM 767.04. The low spot will also receive bypass flow from the drainage originally associated with KM 767.16. | none |
| KM 765.71 | 451418 | 7076765 | 19-Sep-20 | 20 | 2.0 | 0.6 | 2.6 | Fines and Boulders | New site identified when visiting KM 765.51. Similar characteristics with substrate consisting of boulders and fines. | 98 and 99 |
| KM 765.51 | 451511 | 7076538 | 18-Sep-20 | 31 | 1.9 | 0.45 | 3.7 | Fines at roadway alignment, boulder, and cobbles upstream downstream | Woody debris spanning watercourse outside of cleared road corridor. | 18 to 21 |

Table 4-1: Site Assessment Summary

| Winter Road Crossing ID | Easting (m) | Northing (m) | Date Assessed | Flow (L/s) | Bankfull Width (m) | Bankfull Depth (m) | Channel Slope (%) | Substrate Composition | Site Notes | Photo Numbers in Appendix A |
|--|-------------|--------------|---------------|---|--------------------|--------------------|-------------------|---|---|-----------------------------|
| KM 752.61 (Bobs Canyon Creek) | 456550 | 7065460 | 19-Sep-20 | 44 | 2.1 | 0.45 | 7.6 | Boulders | Watercourse crosses alignment through a recently installed open bottomed arch culvert. Culvert is 7 m wide and 3.4 m high with boulder substrate installed throughout. Mud lines along culvert walls indicate water levels have reached depths of approximately 1.0 m at the inlet and 0.65 m at the outlet. Culvert has MSE headwalls at both inlet and outlet ends. A boulder apron approximately 15 m long has been installed at the outlet. The channel upstream and downstream of the culvert is well defined. | 22 to 28 |
| KM 751.94 | 456996 | 7064881 | n/a | Desktop assessment: field conditions not observed | | | | | No drainage shown on NTS maps. LiDAR shows a shallow gully feature approx. 1.5 m deep and 10 m wide. | none |
| KM 750.54 | 457721 | 7063732 | n/a | Desktop assessment: field conditions not observed | | | | | No drainage shown on NTS maps. LiDAR shows a shallow gully feature approx. 0.9 m deep and 10 m wide. | none |
| KM 748.63 | 458521 | 7062099 | n/a | Desktop assessment: field conditions not observed | | | | | No drainage shown on NTS maps, but LiDAR shows a shallow gully feature about 1.5 m deep and 25 m wide immediately upstream of the winter road. The profile along the winter road suggests grading through the gully and possibly an existing culvert. | none |
| KM 748.40 | 45863 | 7061889 | n/a | Desktop assessment: field conditions not observed | | | | | No drainage shown on NTS maps, but LiDAR shows a shallow gully feature nearly 2 m deep and 25 m wide immediately upstream of the winter road. The profile along the winter road suggests grading through the gully and possibly an existing culvert. | none |
| KM 747.9 (KM 748.02 on photo captions) | 458828 | 7061444 | 19-Sep-20 | 20 | 1.4 | 0.3 | 7.8 | Sand, gravel, and cobble; some boulders | Watercourse crosses the alignment through a failed culvert. Culvert believed to be ~1.7 m diameter originally has been severely deformed (crushed) within embankment; inlet and outlet ends of the culvert have angled upwards as a result. Substantial erosion has occurred on the downstream slope of the highway embankment. This failure is likely a piping failure, attributed to both the blocked flowpath of the deformed culvert which will create heightened headwater depth upstream of the embankment and the potential exfiltration within the roadway embankment occurring at damage culvert joints. Channel well-defined with substantial woody debris. | 29 to 35 |
| KM 747.56 | 458944 | 7061043 | 19-Sep-20 | 15 | 0.6 | 0.3 | 7.8 | Cobbles and gravel | Watercourse crosses the alignment through a failed culvert. Culvert believed to be 1.5 m diameter originally has been severely deformed (crushed) within the embankment. Inlet end of the pipe has become angled and elevated as a result. Substantial erosion has occurred on the downstream slope of the highway embankment. This failure is likely a piping failure, attributed to both the blocked flowpath of the deformed culvert which will create heightened headwater depth upstream of the embankment, and potential exfiltration occurring at damaged culvert joints within the embankment. | 36 to 42 |
| KM 742.74 | 460630 | 7057036 | 20-Sep-20 | 8 | 1.2 | 0.6 | 3.7 | Fines | Water slow moving upstream and within alignment. Immediately downstream of alignment water has scoured a large (7 m diameter) pocket. Significant erosion has continued 300 m+ downstream of crossing, eroding a path up to 30 m wide in some areas claiming numerous large trees. | 43 to 47 |
| KM 741.62 (KM 741.62 on photo captions) | 460900 | 7055915 | 20-Sep-20 | 13 | 1.1 | 0.9 | 3.8 | Fines | Channel incised in multiple locations. Substrate composed almost entirely of fines. Woody debris scattered throughout channel. | 48 to 50 |
| KM 740.68 (KM 740.75 on photo captions) | 461120 | 7055000 | 21-Sep-20 | 17 | 1.8 | 0.25 | 3.6 | Fines | Woody debris present throughout watercourse. | 51 and 52 |
| KM 739.47 (KM 739.55 on photo captions) | 461401 | 7053830 | 21-Sep-20 | 26 | 1.5 | 0.4 | 3.1 | Cobbles and fines, some boulders | Remnants of an old culvert on the downstream side of the alignment. No other indication of a historical culvert crossing. Downstream of the alignment the channel takes a 135 degree turn to the north, reaching the toe of the winter road embankment before turning again to continue downslope to the west. Substantial woody debris present 100 m+ downstream. | 53 to 56 |
| KM 737.08 (KM 737.36 on photo captions) | 461998 | 7051551 | 23-Sep-20 | 3 | 1.6 | 0.6 | 3.2 | Boulders and fines | Small watercourse incised at times. Small amounts of woody debris throughout. | 57 to 59 |
| KM 736.48 | 462091 | 7050918 | 23-Sep-20 | 5 | 1.2 | 0.7 | 3.9 | Boulders and fines | Small watercourse incised at times. Small amounts of woody debris throughout. | 60 to 63 |
| KM 733.71 (Bonnie Creek) | 462594 | 7048305 | 23-Sep-20 | 45 | 3.1 | 0.6 | 4.3 | Boulders and cobbles | Stable channel with defined banks. Boulders and cobble substrate throughout. Small amounts of woody debris present | 64 to 68 |
| KM 732.74 | 463010 | 7047416 | 24-Sep-20 | 13 | 1.4 | 0.8 | 4.2 | Boulders | Small steep channel incised at times. Woody debris present throughout. | 69 to 72 |

Table 4-1: Site Assessment Summary

| Winter Road Crossing ID | Easting (m) | Northing (m) | Date Assessed | Flow (L/s) | Bankfull Width (m) | Bankfull Depth (m) | Channel Slope (%) | Substrate Composition | Site Notes | Photo Numbers in Appendix A |
|--|-------------|--------------|---------------|---|--------------------|--------------------|-------------------|---------------------------------|--|-----------------------------|
| KM 727.20 (KM 727.36 on photo captions) | 465242 | 7042568 | 22-Sep-20 | 18 | 1.4 | 0.5 | 3.0 | Fines and organics, few cobbles | Small watercourse with trees growing within it and woody debris at times. | 73 to 75 |
| KM 724.89 | 465535 | 7039921 | n/a | Desktop assessment: field conditions not observed | | | | | New coordinates receive drainage from basin incorrectly associated with KM 724.49 on NTS maps. Shallow main channel is perched in an alluvial fan feature with flood event bypass flow expected. | none |
| KM 724.49 | 465613 | 7040331 | 22-Sep-20 | 0 | n/a | n/a | 2.2 | n/a | No visible signs of a watercourse within 150 metres of this location. | 76 to 78 |
| KM 721.61 | 466376 | 7037359 | 22-Sep-20 | 21 | 2.1 | 0.5 | 1.4 | Boulder | Boulders and woody debris present throughout watercourse. | 79 to 82 |
| KM 718.79 | 467939 | 7035565 | 22-Sep-20 | 1 | n/a | n/a | 5.3 | Muskeg | Water has collected in a small channel within the alignment; however, no discernable channels exist upstream or downstream of highway alignment. Largely pooled water in muskeg. | 83 and 84 |
| KM 710.21 (KM 710.35 on photo captions) | 471424 | 7027729 | 16-Sep-20 | 1 | n/a | n/a | 0.3 | Muskeg | No defined channels upstream or downstream of highway alignment, flow ponds and meanders through muskeg. | 85 and 86 |
| KM 705.42 | 470833 | 7023101 | 16-Sep-20 | 4 | n/a | n/a | 0.1 | Muskeg | Water largely throughout area. 4L/s estimated across alignment. Muskeg and wetland upstream and downstream of alignment with no defined channels. | 87 and 88 |
| KM 696.82 | 473317 | 7015365 | 16-Sep-20 | 1 | n/a | n/a | 1.9 | Muskeg | Ponded water on alignment with small detectable flow. No defined channels upstream or downstream. | 89 |

5.0 HYDROTECHNICAL ANALYSIS

The hydrotechnical assessment for 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.

A total of 34 locations were analyzed for design flows and preliminary culvert sizing. These include two crossing locations (KM 705.42 and KM 696.82) previously assessed in the 2020 MGAR hydrotechnical report.

5.1 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 Dehcho alignment. Digital watershed delineations were completed using the Global Mapper GIS software package.

Tributary watersheds were delineated for the 34 crossings listed in Table 5-1 are shown on Figures D-1 through D-6 in Appendix D. Watershed areas range between approximately 0.2 km² and 42 km².

Table 5-1: Dehcho Minor Drainage Crossing Locations and Watershed Areas

| Crossing ID | Easting (m) | Northing (m) | Watershed Area (sq km) |
|-------------|-------------|--------------|------------------------|
| KM 793.4 | 437654 | 7099183 | 0.45 |
| KM 791.36 | 438816 | 7097405 | 19.70 |
| KM 785.29 | 442243 | 7093122 | 0.82 |
| KM 780.88 | 444249 | 7089511 | 10.00 |
| KM 774.09 | 448526 | 7084328 | 42.19 |
| KM 772.83 | 449249 | 7083301 | 7.45 |
| KM 771.7 | 449725 | 7082312 | 0.84 |
| KM 771.01 | 450016 | 7081707 | 12.44 |
| KM 768.49 | 451135 | 7079445 | 3.91 |
| KM 766.86 | 451290 | 7077883 | 5.88 |
| KM 765.71 | 451420 | 7076761 | 4.77 |
| KM 765.51 | 451511 | 7076538 | 7.23 |
| KM 751.94 | 456996 | 7064882 | 0.84 |
| KM 750.54 | 457721 | 7063732 | 1.14 |

Table 5-1: Dehcho Minor Drainage Crossing Locations and Watershed Areas

| Crossing ID | Easting (m) | Northing (m) | Watershed Area (sq km) |
|-------------------------------|-------------|--------------|------------------------|
| KM 748.63 | 458521 | 7062099 | 0.29 |
| KM 748.4 | 458630 | 7061889 | 0.19 |
| KM 747.9 | 458828 | 7061444 | 2.55 |
| KM 747.56 | 458944 | 7061043 | 1.08 |
| KM 742.74 | 460630 | 7057036 | 1.67 |
| KM 741.62 | 460900 | 7055915 | 2.18 |
| KM 740.68 | 461120 | 7055000 | 4.96 |
| KM 739.47 | 461401 | 7053830 | 6.64 |
| KM 737.08 | 461998 | 7051551 | 3.08 |
| KM 736.48 | 462091 | 7050918 | 2.91 |
| KM 733.71 (Bonnie Creek) | 462594 | 7048305 | 14.02 |
| KM 732.74 | 463010 | 7047416 | 1.09 |
| KM 727.20 | 465242 | 7042568 | 2.75 |
| KM 724.89 | 465613 | 7040331 | 1.47 |
| KM 721.61 | 466376 | 7037359 | 6.61 |
| KM 718.79 | 467939 | 7035565 | 0.66 |
| KM 710.21 | 471424 | 7027729 | 0.40 |
| KM 705.42 (MGAR Crossing C18) | 470833 | 7023101 | 1.63 |
| KM 696.82 (MGAR Crossing C11) | 473317 | 7015365 | 0.55 |

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 Dehcho segment of the MVH alignment.

The hydrologic assessment made estimates of 2-year through 200-year peak flows for each drainage crossing, and also 3-day 10-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 for meaningful statistical analysis. Seven stations on relatively small drainages were selected for the analysis prior to further screening for physiographic characteristics similar to the watersheds draining to the Dehcho Segment. Station information is included in Table 5-2 below. Station locations are shown in the Figure 1-1 Regional Location Plan.

Table 5-2: WSC Regional Station

| 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 |

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.

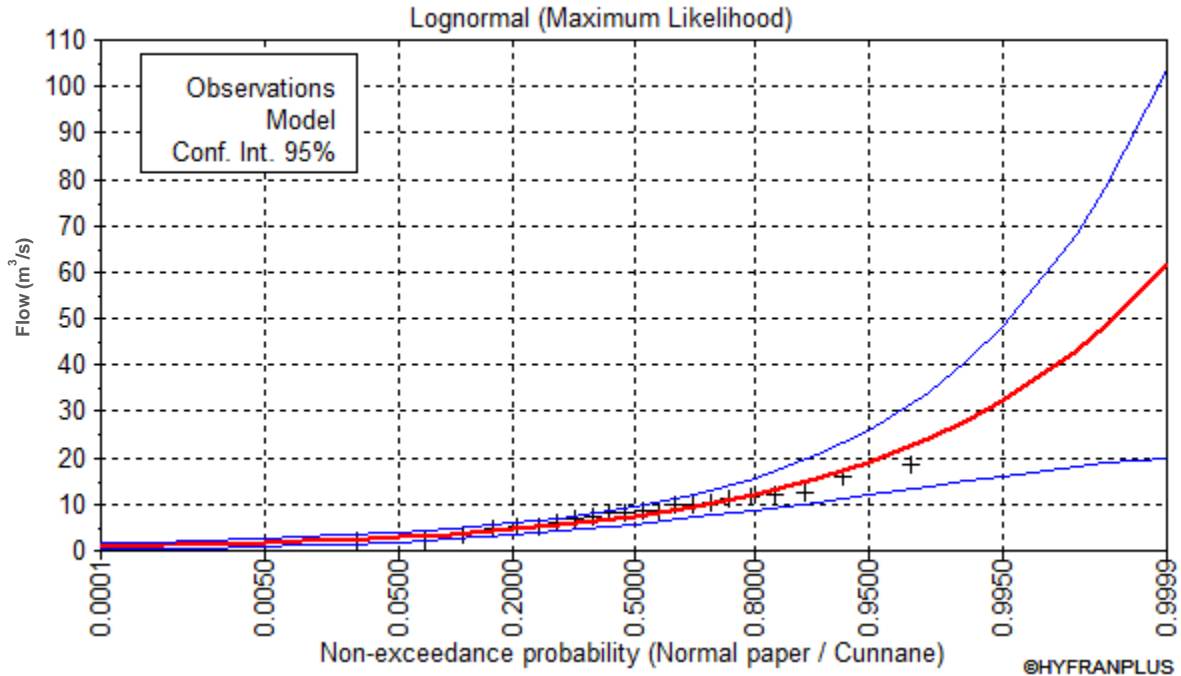


Figure 5-3: Frequency Distribution for Jungle Ridge Creek (10KA006) Instantaneous Flow Data

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

Table 5-3 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 estimates for larger return periods increases for data sets with longer periods of record.

Table 5-3: Frequency Analysis Results

| Station | 10HC003 | 10GC002 | 10ED003 | 10GB005 | 10ED009 | 10KA007 | 10KA006 |
|-------------------------------|---------|---------|---------|---------|-----------------|------------------|---------|
| Area (km ²) | 980 | 701 | 542 | 344 | 202 | 125 | 60 |
| Years of Data | 22 | 23 | 43 | 11 | 23 | 37 | 15 |
| 200-Year (m ³ /s) | 230 | 84 | 126 | 97.6 | 24.9 | 32.3 | 27 |
| 100-Year (m ³ /s) | 212 | 75.2 | 114 | 87 | 22.4 | 29.4 | 24.3 |
| 50-Year (m ³ /s) | 193 | 66.2 | 101 | 76.4 | 19.9 | 26.5 | 21.6 |
| 20-Year (m ³ /s) | 168 | 54.4 | 84.1 | 62.3 | 16.6 | 22.6 | 18.1 |
| 10-Year (m ³ /s) | 149 | 45.2 | 71 | 51.4 | 14 | 19.6 | 15.5 |
| 5-Year (m ³ /s) | 129 | 35.6 | 57.5 | 40 | 11.3 | 16.5 | 12.9 |
| 2-Year (m ³ /s) | 98.3 | 21.1 | 37 | 22.8 | 7.2 | 11.7 | 9 |
| 3Q10 (m ³ /s) | * | * | * | * | 10 | 10.4 | 10.2 |
| 200-Year/Area | 0.23 | 0.12 | 0.23 | 0.28 | 0.12 | 0.26 | 0.45 |
| 100-Year/Area | 0.22 | 0.11 | 0.21 | 0.25 | 0.11 | 0.24 | 0.41 |
| 200-Year/2-Year | 2.34 | 3.98 | 3.41 | 4.28 | 3.45 | 2.76 | 3.01 |
| 100-Year/2-Year | 2.16 | 3.56 | 3.08 | 3.82 | 3.1 | 2.51 | 2.71 |
| 50-Year/2-Year | 1.96 | 3.14 | 2.73 | 3.35 | 2.76 | 2.26 | 2.41 |
| 20-Year/2-Year | 1.71 | 2.58 | 2.27 | 2.73 | 2.3 | 1.93 | 2.02 |
| Observations | | | | | Flat headwaters | Lake attenuation | |
| * 3Q10 discharge not computed | | | | | | | |

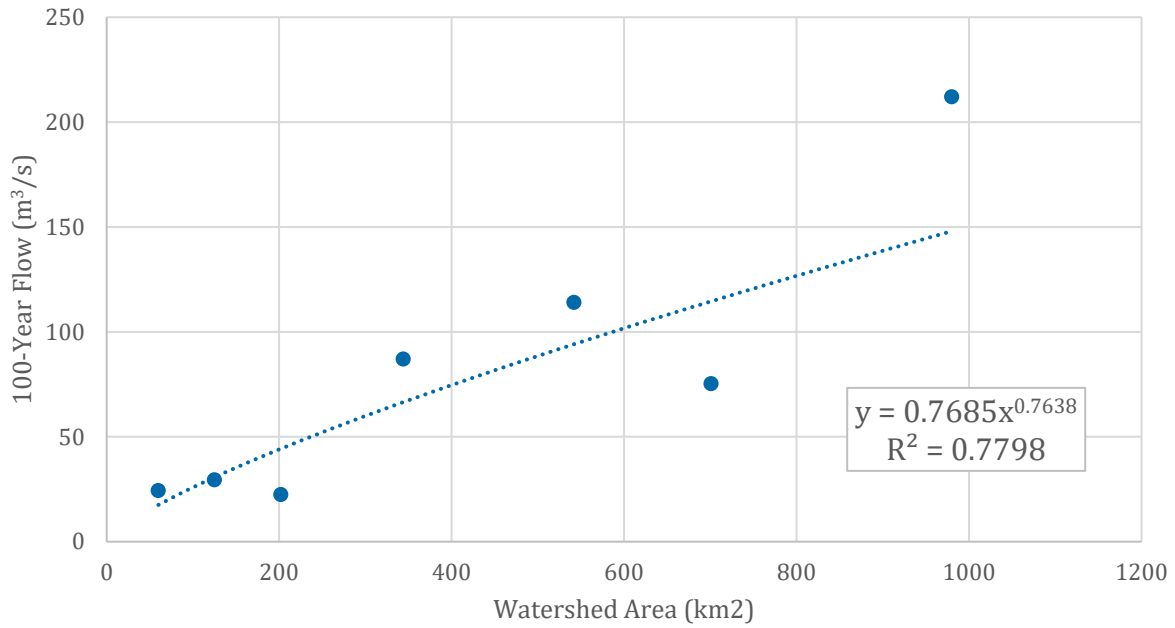


Figure 5-4: Computed 100-Year Peak Flow vs Watershed Area

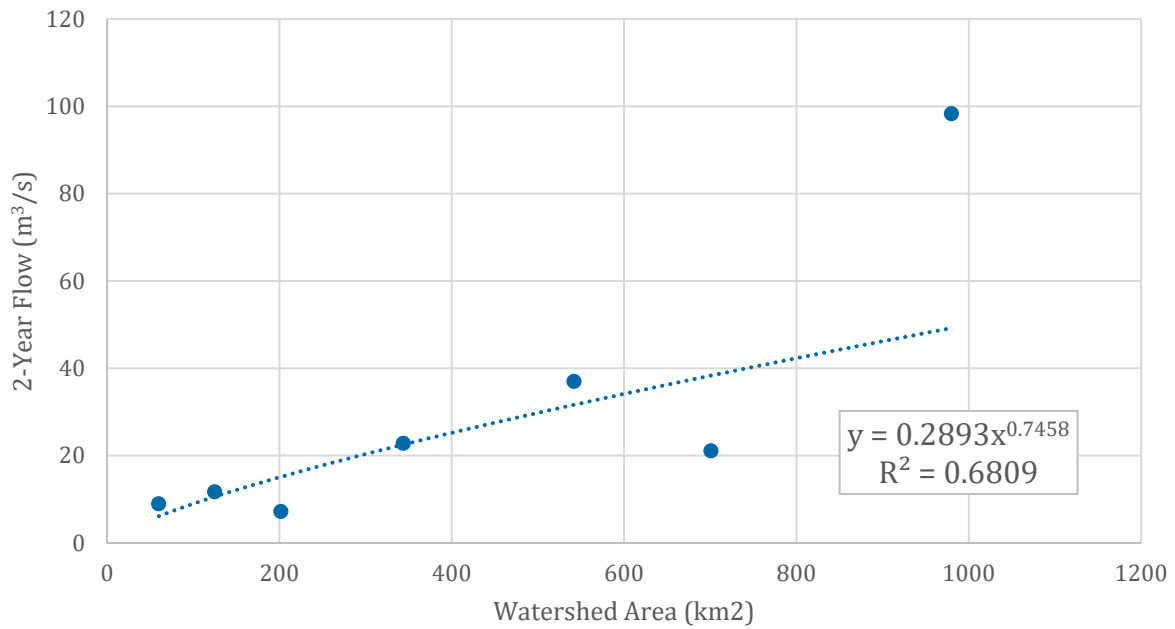


Figure 5-5: Computed 2-Year Peak Flow vs Watershed Area

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 km²) and Harris River (701 km²). The Jungle Ridge Creek gauge with the smallest of the gauged basins (60 km²) 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 Ridge Creek as an index station was made by comparing its historical recorded mid-September flows with the flows measured at each watercourse during the September 2020 site investigation. Normalizing for catchment size, these flows translate to unit flows as shown in Tables 5-4 and 5-5.

There is considerable variability in the Jungle Ridge Creek mean September flows ranging from 1.3 to 29.2 L/s/km² over a record length of 20 years. It is normal and expected that flows on different watersheds will have different responses even with the same climate inputs, this can be due to different lag-times for different basins sizes, different proportion of basin in lake or muskeg area, and different soil types; as such, spot measurements are a very coarse measure of similarity. Nonetheless, the unit flows of spot measurements during the September 2020 field investigation are mostly within the range of historical mean flows recorded on Jungle Ridge Creek. Several sites had unit flows lower than the minimum September mean flow for Jungle Ridge Creek. The lower flows are probably due in-part to a higher fraction of total flow occurring subsurface (shallow groundwater which would not be captured in a surface flow measurement) in the late-summer runoff of smaller watersheds. Other contributing factors could include beaver activity and wet areas which cease to drain when water levels drop to below the outlet level.

Notwithstanding the differences in the September flows, we would expect the Jungle Ridge index station and project watercourse flows to be more similar during freshet periods. This is because the effects of groundwater and local impoundments are less significant during freshet periods with high flow when the full basin is contributing.

Table 5-4: WSC Mean September Flow Rates for Jungle Ridge Creek (60 km²)

| Jungle Ridge Creek (20-Years of September Mean Flows) | WSC Reported Flow (L/s) | Unit Flow (L/s/km ²) |
|---|-------------------------|----------------------------------|
| Maximum of 20 mean September flows | 1,750 | 29.2 |
| Mean of 20 mean September flows | 427 | 7.1 |
| Minimum of 20 mean September flows | 76 | 1.3 |

Table 5-5: Watershed Areas with Spot Flow Rates during September 2020 Site Investigation

| Watercourse | Watershed Area (km ²) | Measured flow (L/s) | Unit Flow (L/s/km ²) |
|--|-----------------------------------|---------------------|----------------------------------|
| KM 774.09 | 42.19 | 408 | 8.8 |
| KM 772.83 | 7.45 | 8 | 1.1 |
| KM 771.01 | 12.44 | 4 | 1 |
| KM 767.16 | n/a | 20 | n/a |
| KM 765.51 | 5.88 | 31 | 7.2 |
| KM 752.61 (Bobs Canyon Creek) | 10.1 | 44 | 4.8 |
| KM 747.9 | 2.55 | 20 | 10.4 |
| KM 747.56 | 1.08 | 15 | 6.5 |
| KM 742.74 | 1.67 | 8 | 3.2 |
| KM 741.62 | 2.18 | 13 | 4.1 |
| KM 740.68 | 4.96 | 17 | 3.8 |
| KM 739.47 | 6.64 | 26 | 2.7 |
| KM 737.08 | 3.08 | 3 | 0.9 |
| KM 736.48 | 2.91 | 5 | 1.7 |
| KM 733.71 (Bonnie Creek) | 14.02 | 45 | 4 |
| KM 732.74 | 1.09 | 13 | 4.9 |
| KM 727.20 | 2.75 | 18 | 5.5 |
| KM 724.89 | 1.47 | 0 | 0 |
| KM 721.61 | 6.61 | 1 | 0.4 |
| KM 718.79 | 0.66 | 21 | 6.1 |
| KM 710.21 | 0.4 | 1 | 2.9 |
| KM 705.42 | 1.63 | 4 | 2.5 |
| KM 696.82 | 0.55 | 1 | 3.2 |
| Mean of September 2020 Spot Flow Measurements: | | | 3.6 |
| Standard Deviation of Spot Flow Measurements: | | | 2.5 |

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 5-6 presents the adjusted results, which are believed to be conservative.

Table 5-6: Adjusted Frequency Analysis Results for Jungle Ridge Creek (10KA006)

| Jungle Ridge Creek Near the Mouth (Station ID: 10KA006) | | | |
|---|---------------------|---------------------|--------------|
| Dataset | Initial Flow | Adjusted | |
| Return Period | (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:

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

Where:

- Q₁ and Q₂ denotes flows of two watersheds;
- A₁ and A₂ denote watershed areas of differing size (km²); 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 peaking factor of 0.8 was used in this analysis.

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 Explorer¹ for the Winter (Dec to Feb) Precipitation RCP 8.5 (high carbon) scenario. An ensemble² mean was calculated from six Global Climate Models recommended by PCIC as appropriate for Western North America and selected for having seasonal precipitation outputs. Results are shown in Table 5-7.

Table 5-7: 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 |

From the projections in Table 5-7, 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 Canada³ projections are shown in Table 5-8. 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.

Table 5-8: Climate Atlas of Canada Winter Precipitation Projections for the 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.

¹ <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

³<https://climateatlas.ca>

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 culvert designs.

Preliminary culvert sizes for each crossing were determined from nomographs published in the Handbook of Steel Drainage and Highway Construction Projects⁴ (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 across the 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 crossing design flows and preliminary culvert sizes are presented in Table 5-9 and 5-10 respectively.

Table 5-9: Design Flows (Coordinate System: NAD83, UTM 10)

| Crossing ID | Easting (m) | Northing (m) | Watershed Area (sq km) | 100-Year Flow (m ³ /s) | Climate Change Adjusted 100-Year Flow (m ³ /s) | 3Q10 (m ³ /s) | Climate Change Adjusted 3Q10 (m ³ /s) |
|-------------|-------------|--------------|------------------------|-----------------------------------|---|--------------------------|--|
| KM 793.4 | 437654 | 7099183 | 0.45 | 0.55 | 0.65 | 0.08 | 0.09 |
| KM 791.36 | 438816 | 7097405 | 19.70 | 11.34 | 13.37 | 3.35 | 3.95 |
| KM 785.29 | 442243 | 7093122 | 0.82 | 0.89 | 1.05 | 0.14 | 0.16 |
| KM 780.88 | 444249 | 7089511 | 10.00 | 6.59 | 7.77 | 1.70 | 2.00 |
| KM 774.09 | 448526 | 7084328 | 42.19 | 20.85 | 24.58 | 7.17 | 8.46 |
| KM 772.83 | 449249 | 7083301 | 7.45 | 5.21 | 6.14 | 1.27 | 1.49 |
| KM 771.7 | 449725 | 7082312 | 0.84 | 0.91 | 1.08 | 0.14 | 0.17 |
| KM 771.01 | 450016 | 7081707 | 12.44 | 7.85 | 9.25 | 2.11 | 2.49 |
| KM 768.49 | 451135 | 7079445 | 3.91 | 3.11 | 3.66 | 0.66 | 0.78 |
| KM 766.86 | 451290 | 7077883 | 5.88 | 4.31 | 5.08 | 1.00 | 1.18 |
| KM 765.71 | 451420 | 7076761 | 4.77 | 3.65 | 4.30 | 0.81 | 0.96 |
| KM 765.51 | 451511 | 7076538 | 7.23 | 5.08 | 6.00 | 1.23 | 1.45 |
| KM 751.94 | 456996 | 7064882 | 0.84 | 0.90 | 1.07 | 0.14 | 0.17 |
| KM 750.54 | 457721 | 7063732 | 1.14 | 1.16 | 1.37 | 0.19 | 0.23 |
| KM 748.63 | 458521 | 7062099 | 0.29 | 0.38 | 0.45 | 0.05 | 0.06 |

⁴https://www.cspi.ca/sites/default/files/download/handbook_chapter04.pdf

| Crossing ID | Easting (m) | Northing (m) | Watershed Area (sq km) | 100-Year Flow (m ³ /s) | Climate Change Adjusted 100-Year Flow (m ³ /s) | 3Q10 (m ³ /s) | Climate Change Adjusted 3Q10 (m ³ /s) |
|--------------------------|-------------|--------------|------------------------|-----------------------------------|---|--------------------------|--|
| KM 748.4 | 458630 | 7061889 | 0.19 | 0.28 | 0.33 | 0.03 | 0.04 |
| KM 747.9 | 458828 | 7061444 | 2.55 | 2.21 | 2.61 | 0.43 | 0.51 |
| KM 747.56 | 458944 | 7061043 | 1.08 | 1.11 | 1.31 | 0.18 | 0.22 |
| KM 742.74 | 460630 | 7057036 | 1.67 | 1.57 | 1.85 | 0.28 | 0.33 |
| KM 741.62 | 460900 | 7055915 | 2.18 | 1.95 | 2.29 | 0.37 | 0.44 |
| KM 740.68 | 461120 | 7055000 | 4.96 | 3.76 | 4.43 | 0.84 | 0.99 |
| KM 739.47 | 461401 | 7053830 | 6.64 | 4.75 | 5.60 | 1.13 | 1.33 |
| KM 737.08 | 461998 | 7051551 | 3.08 | 2.57 | 3.03 | 0.52 | 0.62 |
| KM 736.48 | 462091 | 7050918 | 2.91 | 2.46 | 2.90 | 0.49 | 0.58 |
| KM 733.71 (Bonnie Creek) | 462594 | 7048305 | 14.02 | 8.64 | 10.18 | 2.38 | 2.81 |
| KM 732.74 | 463010 | 7047416 | 1.09 | 1.12 | 1.31 | 0.18 | 0.22 |
| KM 727.20 | 465242 | 7042568 | 2.75 | 2.35 | 2.77 | 0.47 | 0.55 |
| KM 724.89 | 465613 | 7040331 | 1.47 | 1.42 | 1.67 | 0.25 | 0.29 |
| KM 721.61 | 466376 | 7037359 | 6.61 | 4.73 | 5.58 | 1.12 | 1.32 |
| KM 718.79 | 467939 | 7035565 | 0.66 | 0.75 | 0.88 | 0.11 | 0.13 |
| KM 710.21 | 471424 | 7027729 | 0.40 | 0.50 | 0.59 | 0.07 | 0.08 |
| KM 705.42 | 470833 | 7023101 | 1.63 | 1.54 | 1.82 | 0.28 | 0.33 |
| KM 696.82 | 473317 | 7015365 | 0.55 | 0.65 | 0.77 | 0.09 | 0.11 |

Table 5-10: Preliminary Proposed Culverts

| Winter Road 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 793.4 | 437654 | 7099183 | 0.45 | 0.65 | 800 | Significant beaver activity at crossing |
| KM 791.36 | 438816 | 7097405 | 19.70 | 13.37 | 2740 | Multiple culverts suggested over 50 m wide corridor without defined channels. Design flow does not account for upstream lake attenuation and is therefore presently over-estimated |

| Winter Road 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 785.29 | 442243 | 7093122 | 0.82 | 1.05 | 1000 | Single Culvert |
| KM 780.88 | 444249 | 7089511 | 10.00 | 7.77 | 2280 | Recently improved road with existing culvert – size to be determined |
| KM 774.09 | 448526 | 7084328 | 42.19 | 24.58 | 3670 | Single Culvert. Possible fish passage design required |
| KM 772.83 | 449249 | 7083301 | 7.45 | 6.14 | 2120 | Single Culvert |
| KM 771.7 | 449725 | 7082312 | 0.84 | 1.08 | 1000 | Dual Culverts at split flow low points KM 771.7 and 771.6 |
| KM 771.01 | 450016 | 7081707 | 12.44 | 9.25 | 2430 | Single Culverts at each of five low points north of KM 769.66. Additional may be required. See Figure 3-1. |
| KM 769.66 | 450608 | 7080490 | Included in KM 771.01 | | nominal | Minimum of one nominal (800 m) culvert to pass low flow. High flows will bypass north towards KM 771.01 |
| KM 768.49 | 451135 | 7079445 | 3.91 | 3.66 | 1660 | Multiple Culverts suggested over 80 m wide corridor without defined channels |
| KM 766.86 | 451290 | 7077883 | 5.88 | 5.08 | 1810 | Insufficient head (< 0.2 m) to pass design flow at coordinates. Two or three additional culverts required along overflow path ending at KM 767.04 low spot |
| KM 765.71 | 451420 | 7076761 | 4.77 | 4.30 | 1810 | Single Culvert |
| KM 765.51 | 451511 | 7076538 | 7.23 | 6.00 | 1970 | Single Culvert |
| KM 751.94 | 456996 | 7064882 | 0.84 | 1.07 | 1000 | Single Culvert |
| KM 750.54 | 457721 | 7063732 | 1.14 | 1.37 | 1200 | Single Culvert |
| KM 748.63 | 458521 | 7062099 | 0.29 | 0.45 | 800 | Single Culvert |
| KM 748.4 | 458630 | 7061889 | 0.19 | 0.33 | 800 | Single Culvert |
| KM 747.9 | 458828 | 7061444 | 2.55 | 2.61 | 1500 | Single Culvert |
| KM 747.56 | 458944 | 7061043 | 1.08 | 1.31 | 1200 | Single Culvert |
| KM 742.74 | 460630 | 7057036 | 1.67 | 1.85 | 1400 | Single Culvert |
| KM 741.62 | 460900 | 7055915 | 2.18 | 2.29 | 1400 | Single Culvert |
| KM 740.68 | 461120 | 7055000 | 4.96 | 4.43 | 1810 | Single Culvert |
| KM 739.47 | 461401 | 7053830 | 6.64 | 5.60 | 1970 | Single Culvert |

| Winter Road 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 737.08 | 461998 | 7051551 | 3.08 | 3.03 | 1660 | Low head available, will need one culvert at coordinates and an overflow culvert at low point about 100 m to the north |
| KM 736.48 | 462091 | 7050918 | 2.91 | 2.90 | 1660 | Single Culvert |
| KM 733.71 (Bonnie Creek) | 462594 | 7048305 | 14.02 | 10.18 | 2590 | Single Culvert |
| KM 732.74 | 463010 | 7047416 | 1.09 | 1.31 | 1200 | Single Culvert |
| KM 727.20 | 465242 | 7042568 | 2.75 | 2.77 | 1500 | Single Culvert |
| KM 724.89 | 465613 | 7040331 | 1.47 | 1.67 | 1200 | Low head available, three culverts suggested at low spots within 60 m segment |
| KM 721.61 | 466376 | 7037359 | 6.61 | 5.58 | 1970 | Single Culvert |
| KM 718.79 | 467939 | 7035565 | 0.66 | 0.88 | 900 | Low head available, suggest one nominal (800 mm) culvert at coordinates and a second at low point about 140 m to the north |
| KM 710.21 | 471424 | 7027729 | 0.40 | 0.59 | 800 | Single Culvert. Note, drainage is west to east, opposite that shown on NTS map. |
| KM 705.42 (previously assessed as C11 in MGAR report) | 470833 | 7023101 | 1.63 | 1.82 | 1400 | Low head available, suggest three culverts at low points within 250 m wide low segment |
| KM 696.82 (previously assessed as C11 in MGAR report) | 4733+1 7 | 7015365 | 0.55 | 0.77 | 900 | 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.

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.



FILE: 704-ENG.WTRI03043-01
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|---|---|
| PERMIT TO PRACTICE TETRA TECH CANADA INC. | |
| Signature |  |
| Date | December 8, 2021 |
| PERMIT NUMBER: P 018 NT/NU Association of Professional Engineers and Geoscientists | |

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APPENDIX A

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LIMITATIONS ON USE OF THIS DOCUMENT

HYDROTECHNICAL

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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.

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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

PDR PRELIMINARY STREAM CROSSINGS AND MASTER LIST DEVELOPMENT

APPENDIX B - CONTENTS

1. Three pages of excerpts from the Dessau (2012) Dehcho Region Project Description Report (PDR) with preliminary watercourse crossings which were the basis for the planning of the 2020 (and 2021) hydrotechnical assessments.
2. A Preliminary Screening List of Major and Minor watercourse crossings from Dessau (2012), augmented with additional drainage features identified by a desktop assessment of available 2010 LiDAR data.

The preliminary screening list was used to confirm and/or update Winter Road KM identifiers along the Dehcho segment, and to determine companion UTM (Zone 10) coordinates where these watercourses cross the proposed All Season Road from the PDR. The screening list is included to provide a means to backtrack from the KM markers used in the current hydrotechnical report to those in the Dehcho (2012) PDR, should that be needed.

DESSAU



Mackenzie Valley Highway Extension Pehdzeh Ki Ndeh – Dehcho Region

Project Description Report (PDR)



004-P037500-0200-EI-R200-00 | MARCH 2012

Final Report

Table 26: Fish Species Historically Captured in the Study Area (GeoNorth & Golder 2000; Stewart & Low 2000)

| FISH SPECIES COMMON NAME | FAMILY | SCIENTIFIC NAME |
|--------------------------|----------------|------------------------|
| Arctic Cisco | Salmonidae | Coregonus autumnalis |
| Arctic Grayling | Salmonidae | Thymallus arcticus |
| Broad Whitefish | Salmonidae | Coregonus nasus |
| Burbot | Lotidae | Lota lota |
| Emerald Shiner | Cyprinidae | Notropis atherinoides |
| Flathead Chub | Cyprinidae | Platygobio gracilis |
| Inconnu | Salmonidae | Stenodus leucichthys |
| Lake Chub | Cyprinidae | Couesius plumbeus |
| Lake Whitefish | Salmonidae | Coregonus clupeaformis |
| Longnose Sucker | Catostomidae | Catostomus catostomus |
| Mountain Whitefish | Salmonidae | Prosopium williamsoni |
| Ninespine Stickleback | Gasterosteidae | Pungitius pungitius |
| Northern Pike | Esocidae | Esox lucius |
| Round Whitefish | Salmonidae | Prosopium cylindraceum |
| Slimy Sculpin | Cottidae | Cottus cognatus |
| Spottail Shiner | Cyprinidae | Notropis hudsonius |
| Trout-Perch | Percopsidae | Percopsis omiscomaycus |
| Walleye | Percidae | Sander vitreus |

6.2.3.2 Stream Crossings

Based on review of available historical reports and examination of aerial photographs taken by Dessau in 2011, 34 potential watercourses have been identified to date as potentially intersecting the proposed highway alignment in the Pehdzeh Ki Ndeh - Dehcho region. A listing of these 34 watercourses is provided in Table 27, as well as approximate UTM coordinates for each potential crossing location. For the purposes of this document, watercourses have been named based on the distance, in kilometres, from kilometre marking (KM) 692.03 near Wrigley, Northwest Territories (UTM 475970, 7011620), to the location where the watercourse intersects with the proposed highway alignment.

Table 27: Preliminary Watercourse Crossing Locations Identified to Date

| WATERCOURSE ID (FOR THE PURPOSES OF THIS PDR) | HISTORICAL WATERCOURSE NAME(S) | APPROXIMATE CROSSING LOCATION | | HISTORICAL ASSESSMENT LOCATION | |
|---|--------------------------------------|----------------------------------|----------|-----------------------------------|----------|
| | | Easting | Northing | Easting | Northing |
| KM 692.30 | Hodgson Creek | 475736 | 7011728 | - | - |
| KM 696.82 | None | 473317 | 7015384 | - | - |
| KM705.42 | None | 470824 | 7023125 | - | - |
| KM 710.35 | None | 471369 | 7027862 | - | - |
| KM 718.79 | None | 467938 | 7035574 | - | - |
| KM 721.61 | None | 465978 | 7037414 | - | - |
| KM 722.45 | Ochre River | 465952 | 7038075 | 465762 | 7037632 |
| KM 724.49 | None | 465535 | 7039921 | - | - |
| KM 727.36 | None | 465206 | 7042721 | - | - |
| KM 730.66 | Whitesand Creek | 463489 | 7045444 | 463746 | 7045218 |
| KM 732.74 | Drainage 1 | 463001 | 7047419 | 463110 | 7047212 |
| KM 733.71 | Bonnie Creek | 462617 | 7048303 | 462673 | 7048309 |
| KM 736.48 | Drainage 2 | 462074 | 7050956 | 462221 | 7050738 |
| KM 737.36 | None | 461944 | 7051827 | - | - |
| KM 739.55 | Drainage 3 | 461379 | 7053905 | 461519 | 7063611 |
| KM 740.75 | None | 461097 | 7055069 | - | - |
| KM 741.74 | None | 460866 | 7056033 | - | - |
| KM 742.74 | None | 460633 | 7057006 | - | - |
| KM 745.72 | Strawberry Creek | 459359 | 7059422 | 459471 | 7059215 |
| KM 747.56 | None | 458926 | 7061092 | - | - |
| KM 748.02 | None | 458796 | 7061536 | - | - |
| KM 749.65 | Vermillion Creek South | 458005 | 7062948 | 458116 | 7062601 |
| KM 752.61 | Bobs Canyon Creek | 456532 | 7065508 | 456630 | 7065773 |
| KM 752.81 | Drainage 13 | 456629 | 7065715 | 456640.00 | 7065501 |
| KM 762.91 | Dam Creek | 452480 | 7074159 | 452653 | 7073890 |
| KM 765.51 | None | 451505 | 7076573 | - | - |
| KM 767.16 | None | 451279 | 7078183 | - | - |
| KM 769.66 | None | 450608 | 7080490 | - | - |
| KM 772.83 | None | 449252 | 7083358 | - | - |
| KM 774.09 | Drainage 4 | 448502 | 7084357 | 448605 | 7084494 |
| KM 780.88 | REV3-AK | 444236 | 7089533 | 444426 | 7089450 |
| KM 783.26 | Blackwater River | 442742 | 7091387 | 442829 | 7091192 |
| KM 785.29 | Drainage 5 | - | - | 442320 | 7093137 |
| KM 787.31 | Drainage 6 | - | - | 437629 | 7099230 |

Screening Assessment of PDR and LiDAR-derived Watercourse Crossings

| Winter Road Crossing ID | PDR Name | Initial UTM 10 Easting (m) | Initial UTM 10 Northing (m) | Inspection Method | Screening Notes |
|---|------------------|----------------------------|-----------------------------|-------------------|--|
| KM 787.31 but coordinates match KM 793.40 | Drainage 6 | 437629 | 7099230 | Aerial | The KM identifier from the PDR agree with the coordinates from the PDR. A 3 m deep gully near the PDR coordinates is apparent from LiDAR data; the PDR KM is therefore assumed to be incorrect. No drainage shown on NTS maps for this location. Update location to KM 793.40 at coordinates E 437654; N 7099183 |
| KM 791.36 | Not in PDR | 438816 | 7097405 | Ground | NTS maps show start of drainage originating from a wet area immediately upstream of the crossing. Drainage occurs over a 50 m wide corridor with no defined channels. Included as new site identified as NEW4 during 2020 field assessment. |
| KM 785.29 | Drainage 5 | 442320 | 7093137 | Desktop | No drainage shown on NTS maps. LiDAR shows a shallow gully feature approx. 1 m deep and 10 m wide. Update coordinates to E 442243 N 7093122 |
| KM 783.26 | Blackwater River | 442742 | 7091387 | None | Existing bridge excluded from scope |
| KM 780.88 | REV3-AK | 444236 | 7089533 | Aerial | Drainage shown on NTS maps; LiDAR shows drainage occurs over a 30 m wide corridor with no defined channels. Site identified as NEW3 during 2020 field assessment. Aerial inspection identified improved road with existing culvert. Update coordinates to E 444249 N 7089511. |
| KM 774.09 | Drainage 4 | 448502 | 7084357 | Ground | Drainage shown on NTS maps. LiDAR shows well-defined low area to collect flows Update coordinates to E 448526 N 7084328 |
| KM 772.83 | None (unnamed) | 449252 | 7083358 | Ground | Drainage shown on NTS maps but is about 50 m north of LiDAR-defined drainage feature about 30 m wide and up to 1.5 m deep. Update coordinates to E 449249 N 7083301. |
| KM 771.7 (and KM 771.6) | Not in PDR | 449725 | 7082312 | Desktop | Low points at KM 771.6 and 771.7 appear to share a common watershed and are separated by a ridge about 1.6 m high. Mapping and subsequent tables identify the slightly deeper northern drainage (KM 771.1) with coordinates E 449725 N 7082312. |
| KM 771.01 | Not in PDR) | 450016 | 7081707 | Desktop | The deepest and northernmost of a series of five low points along a 2 km road segment originating from a wet area at KM 769.66 where there is insufficient head to provided culverted cross-drainage of high flow events. See Figure 3-1 for locations of additional low points where culverts will be required. |
| KM 769.66 | None (unnamed) | 450608 | 7080490 | Ground | Drainage shown on NTS maps; but LiDAR shows no defined channels near the identified location. Freshet high flow intercepted by the ASR embankment will drain north where low spots are encountered where cross-drainage will occur, with a terminal low at KM 771.01 Update coordinates to E 450603 N 7080488. See Figure 3-1 for additional information. |
| KM 768.49 | Not in PDR | 451136 | 7079444 | Ground | Drainage shown on NTS maps west of alignment, but majority of watershed is from east and will be intercepted by the road as it flows towards the mapped drainage. LiDAR shows low area over an 80 m wide corridor with up to 4 m depth with no defined channels. Site identified as NEW2 during 2020 field assessment. |

| Winter Road Crossing ID | PDR Name | Initial UTM 10 Easting (m) | Initial UTM 10 Northing (m) | Inspection Method | Screening Notes |
|-------------------------------------|------------------------|----------------------------|-----------------------------|-------------------|--|
| KM 767.16 | None (unnamed) | 451279 | 7078183 | Ground | Drainage shown on NTS maps but is about 50 m north of LiDAR-defined low area about 30 m wide and up to 1.5 m deep, contained within longer 100 m wide low segment. This low segment will receive overflow from drainage to KM 767.16 and also KM 766.86. The proposed ASR is shifted from the winter road at this location and the new drainage crossing about 80 to the north, offset from ASR, has available head less than 0.3 m, with overflow draining down the alignment towards the same low area. Remove from list of assessed crossings. |
| KM 766.86 | Not in PDR | 451290 | 7077883 | Desktop | New site receives flow from main watershed that NTS maps incorrectly associated with KM 767.16. Low available head at new site will result in northward overflow along alignment, reaching low segment spot at about KM 767.04. The same low spot will also receive bypass flow from drainage associated with KM 767.16. |
| KM 765.71 | Not in PDR | 451418 | 7076765 | Ground | No drainage shown on NTS maps, but LiDAR shows a 130 m wide ravine with maximum depth over 3 m. Site identified as NEW1 during 2020 field assessment. |
| KM 765.51 | None (unnamed) | 451505 | 7076573 | Ground | Drainage shown on NTS maps is about 35 m north of LiDAR-defined drainage up to 4 m deep within 60 m wide ravine. Revise coordinates to LiDAR location E 451511 N 7076538. |
| KM 762.92 | Dam Creek | 452501 | 7074003 | None | Existing bridge excluded from scope |
| KM 752.81 | Drainage 13 | 456629 | 7065715 | Desktop | No drainage features could be identified near the PDR coordinates from NTS maps, LiDAR, or aerial inspection. Site not included in subsequent lists. |
| KM 752.61 | Bob's Canyon Creek | 456532 | 7065508 | Ground | Existing bridge culvert recently installed. Open bottomed arch culvert 7 m wide and 3.4 m high with boulder substrate. Existing bridge excluded from scope. |
| KM 751.94 | Not in PDR | 456996 | 7064881 | Desktop | No drainage shown on NTS maps. LiDAR shows a shallow gully feature approx. 1.5 m deep and 10 m wide. |
| KM 750.54 | Not in PDR | 457721 | 7063732 | Desktop | No drainage shown on NTS maps. LiDAR shows a shallow gully feature approx. 0.9 m deep and 10 m wide. |
| KM 749.65 | Vermillion Creek South | 458005 | 7062948 | None | Existing bridge excluded from scope. |
| KM 748.63 | Not in PDR | 458521 | 7062099 | Desktop | No drainage shown on NTS maps. LiDAR shows a shallow gully feature about 1.5 m deep and 25 m wide immediately upstream of the winter road. The profile along the winter road suggests grading through the gully and possibly an existing culvert. |
| KM 748.40 | Not in PDR | 45863 | 7061889 | Desktop | No drainage shown on NTS maps. LiDAR shows a shallow gully feature nearly 2 m deep and 25 m wide immediately upstream of the winter road. The profile along the winter road suggests grading through the gully and possibly an existing culvert. |
| KM 748.02 Revise to KM 747.90 | None (unnamed) | 458796 | 7061536 | Ground | Drainage shown on NTS maps about 100 m north of LiDAR-defined drainage feature about 10 m deep with top width about 200 m. Update coordinates to LiDAR location E 458828 N 7061444. In 2020, a failed culvert was observed at this crossing. |

| Winter Road Crossing ID | PDR Name | Initial UTM 10 Easting (m) | Initial UTM 10 Northing (m) | Inspection Method | Screening Notes |
|----------------------------------|------------------|----------------------------|-----------------------------|-------------------|---|
| KM 747.56 | None (unnamed) | 458926 | 7061092 | Ground | Drainage shown on NTS maps about 50 m north of LiDAR-defined drainage feature about 12 m deep with top width greater than 150 m. Update coordinates to LiDAR location E 458944 N 7061043. In 2020, a failed culvert was observed at this crossing. |
| KM 745.72 | Strawberry Creek | 459359 | 7059422 | None | Existing bridge excluded from scope |
| KM 742.74 | None (unnamed) | 460633 | 7057006 | Ground | Drainage shown on NTS maps about 30 m south of LiDAR-defined shallow drainage feature less than 0.2 m deep and apparently perched in the high central area of an alluvial fan deposit. Downstream (east) of the alignment, the channel becomes increasingly incised to depths up to 3 m. Update coordinates to E 460630 N 7057036. |
| KM 741.74 revise to KM 741.62 | None (unnamed) | 460866 | 7056033 | Ground | Drainage shown on NTS maps about 120 m north of LiDAR-defined drainage feature over 4 m deep within a 100-m wide ravine. Update coordinates to E 460900 N 7055915. |
| KM 740.75 revise to KM 740.68 | None (unnamed) | 461097 | 7055069 | Ground | Drainage shown on NTS maps is about 70 m north of LiDAR-defined drainage feature over 3 m deep within an 80 m wide ravine. Update coordinates to E 461120 N 7055000. |
| KM 739.55 revise to KM 739.47 | Drainage 3 | 461379 | 7053905 | Ground | Drainage shown on NTS maps is about 75 m north of LiDAR-defined drainage feature over 3 m deep within a 100-m wide gully. Update coordinates to LiDAR location E 461401 N 7053830. |
| KM 737.36 revise to KM 737.08 | None (unnamed) | 461944 | 7051827 | Ground | Drainage shown on NTS maps about 130 m north of the north end of a LiDAR-defined low area about 150 m wide with a maximum depth of about 0.7 m. Ground inspections were made at a very small (5 m wide, 0.2 m deep) channel near the south end of the low area. Channel is deeper upstream and downstream of alignment centreline. Update KM and coordinates to the small channel location E 461999 N 7051550. |
| KM 736.48 | Drainage 2 | 462074 | 7050956 | Ground | Drainage shown on NTS maps about 40 m north of a LiDAR-defined gully about 4 m deep and 70 m wide. Update coordinates to E 462091 N 7050918. |
| KM 733.71 | Bonnie Creek | 462617 | 7048303 | Ground | Drainage shown on NTS maps at original coordinates. Channel is within a ravine about 7 m deep. Update coordinates to E 462594 N 7048305. |
| KM 732.74 | Drainage 1 | 463001 | 7047419 | Ground | Drainage shown on NTS maps at original coordinates; depth about 1.5 m. Update coordinates to E 463010 N 7047416. |
| KM 730.66 | Whitesand Creek | 463489 | 7045444 | None | Existing bridge excluded from scope |
| KM 727.36 Revise to KM 727.20 | None (unnamed) | 465206 | 7042721 | Ground | Drainage shown on NTS maps about 160 m north of a LiDAR-determined small channel with a depth of about 0.5 m. Freshet and flood flows will be intercepted by the road embankment and flow to a low area about 600 m to the south where head can be established to provide cross-drainage. Update KM and coordinates to small channel location at E 465242 N 7042568. |

| Winter Road Crossing ID | PDR Name | Initial UTM 10 Easting (m) | Initial UTM 10 Northing (m) | Inspection Method | Screening Notes |
|----------------------------------|----------------|----------------------------|-----------------------------|------------------------|--|
| KM 724.49 Revise to 724.89 | None (unnamed) | 465535 | 7039921 | Ground | Drainage shown on NTS maps could not be located during field inspections. LiDAR analysis indicates that the water from the NTS upstream drainage feature would cross the alignment in multiple shallow (< 0.5 m) perched flow paths about 400 m north of the original coordinates. Overflow from the perched drainages will flow along the road embankment to eventual low areas which drain additional basins. Update KM and coordinates to the vicinity of small, perched channels at E 465613 N 7040331. |
| KM 722.45 | Ochre River | 465952 | 7038075 | None | Existing bridge excluded from scope |
| KM 721.61 | None (unnamed) | 465978 | 7037414 | Ground | Drainage shown on NTS maps at original coordinates. Preliminary all season road is located about 400 m upstream (east) from the winter road, Update coordinates to crossing location: E 466376 N 7037358. |
| KM 718.79 | None (unnamed) | 467938 | 7035574 | Ground | Drainage shown on NTS maps could not be located during field inspections. LiDAR suggests drainage at the original location but without a defined channel. Update coordinates to E 467939 N 7035565. |
| KM 710.35 Revise to KM 710.21 | None (unnamed) | 471369 | 7027862 | Ground | Drainage shown on NTS maps could not be located during field inspections. LiDAR analysis does not show a channel at the crossing. Also, the LiDAR-derived direction of drainage at the crossing is west to east, opposite of what is indicated by the NTS maps. Update KM to 710.21 at coordinates E 471424 N 7027729. |
| KM 705.42 | None (unnamed) | 470824 | 7023125 | MGAR C18 Drainage 5 | Drainage shown on NTS maps does not correspond to a defined channel at the alignment. A defined channel per NTS begins about 350 m downstream (NE) of the alignment. LiDAR indicates a low area about 40 m wide and up to 0.3 m deep that crosses the ASR alignment. High flows will bypass to the north with two additional lows within 250 m. Update coordinates to E 470833 N 7023101. |
| KM 696.82 | None (unnamed) | 473317 | 7015384 | MGAR C11 Drainage 1 | Drainage shown on NTS maps and LiDAR shows a swale about 2 m deep near the PDR coordinates. Update coordinates to ASR crossing location: E 473317 N 7015365. |
| KM 692.0 | Hodgson Creek | 475736 | 7011728 | None | Existing bridge excluded from scope. |

APPENDIX C

DEHCHO SEGMENT - SITE PHOTOGRAPHS



Photo 1: km 774.09 (1 of 5) – Looking upstream (north) from proposed crossing location.



Photo 2: km 774.09 (2 of 5) – Looking downstream (south) from proposed crossing location.



Photo 3: km 774.09 (3 of 5)– Looking east at boulders and woody debris, approximately 30 metres upstream of proposed crossing location.



Photo 4: km 774.09 (4 of 5) – Looking upstream (north) along main braid at winter road alignment. Channel substrate here is purely fines.



Photo 5: km 774.09 (5 of 5) – Looking at current winter road crossing at a point where the watercourse has split into two channels. Proposed alignment is approximately 100m downstream where all water is contained in a single defined channel.



Photo 6: km 772.83 (1 of 4) – Looking upstream (east) upstream of proposed highway alignment. No defined channel. Water is spread out and ponded throughout.



Photo 7: km 772.83 (2 of 4) – Looking north along winter road alignment at crossing location. No defined channel, flow is spread out and trickling over an approximately 5 metre wide wetted section of the alignment.



Photo 8: km 772.83 (3 of 4) – Looking east at proposed crossing location. No defined channels, flow spread out over an approximately 5 metre wide wetted section of the alignment.



Photo 9: km 722.83 (4 of 4) – Looking west (downstream) from proposed crossing location. No defined channel, flow continues to be spread over a wide area.



Photo 10: km 769.66 (1 of 4) – Looking downstream (west) towards highway alignment. Flow is dispersed through muskeg.



Photo 11: km 769.66 (2 of 4) – Looking south along alignment. Flow has collected in a small channel and flows north along alignment, eventually crossing the alignment and dispersing into the muskeg downstream.



Photo 12: km 769.66 (3 of 4) – Looking south along alignment. Flow spread over a wide area as it crosses the alignment.



Photo 13: km 769.66 (4 of 4) – Looking north at pools downstream of highway alignment. No defined channels downstream of the alignment. Flow is dispersed over a wide area with frequent pooling.



Photo 14: km 767.16 (1 of 4) – Looking upstream (east) from proposed crossing location.



Photo 15: km 767.16 (2 of 4)– Looking upstream (east) upstream of proposed crossing location.



Photo 16: km 767.16 (3 of 4) – Looking downstream (west) upstream of proposed crossing location. Small trees within the channel common for this watercourse.



Photo 17: km 767.16 (4 of 4) – Flow disperses into small wetland downstream of proposed crossing location.



Photo 18: km 765.51 (1 of 4) – Looking south along highway alignment at watercourse crossing.



Photo 19: km 765.51 (2 of 4) – Looking west (downstream) at channel within winter highway alignment. Channel substrate in the alignment is fines with boulders and cobbles. Upstream and downstream substrate is generally boulder and cobbles.



Photo 20: km 765.51 (3 of 4) – Looking southeast (upstream) at channel approximately 100 metres downstream of alignment. Channel is well defined with boulder and cobble substrate. Woody debris present throughout channel.



Photo 21: km 765.51 (4 of 4) – Looking upstream (east) approximately 20 metres downstream of highway alignment. Boulders and woody debris present in channel.



Photo 22: km 752.61 (1 of 7) – Looking upstream (east) from winter road alignment. MSE walls installed as headwalls for existing culvert.



Photo 23: km 752.61 (2 of 7) – Looking upstream (east) at culvert outlet. Culvert is 7 m wide by 3.4 m high with MSE headwall. Boulders installed throughout culvert and boulder apron present.



Photo 24: km 752.61 (3 of 7) – Looking upstream within culvert. Boulders throughout culvert with low flow channel centred within culvert.



Photo 25: km 752.61 (4 of 7) – Looking at north wall at culvert outlet. Culvert in good condition. Mud lines indicate water has reached 0.65m outlet depth.



Photo 26: km 752.61 (5 of 7) – Looking at north wall at culvert inlet. Mud lines indicate water has reached 1.0m inlet depth.



Photo 27: km 752.61 (6 of 7) – Looking upstream (east) at channel approaching existing culvert. Water confined within a well-defined and stable channel.



Photo 28: km 752.61 (7 of 7) – Looking downstream (west) approximately 100 m downstream of existing culvert crossing. Water confined within a well-defined and stable channel.



Photo 29: km 748.02 (1 of 7) – Looking upstream (east) at outlet end of existing culvert. Significant loss of embankment is visible, extending all the way to the crest of the embankment



Photo 30: km 748.02 (2 of 7) – Looking east within the culvert outlet. Culvert severely crushed, but all flow at the time of the field visit seemingly still conveyed through damaged pipe.



Photo 31: km 748.02 (3 of 7) – Looking north along embankment at embankment loss on downstream end of existing watercourse crossing.



Photo 32: km 748.02 (4 of 7) – Looking at culvert inlet. Inlet has become angled due to internal damage to remainder of culvert within embankment.



Photo 33: km 748.02 (5 of 7) – Looking downstream from inlet of culvert. Culvert severely damaged.



Photo 34: km 748.02 (6 of 7) – Looking upstream (northeast) from culvert inlet. Channel well defined with woody debris present.



Photo 35: km 748.02 (7 of 7) – Looking downstream approximately 75 metres downstream of existing damaged culvert crossing.



Photo 36: km 747.56 (1 of 7) – Looking east at damage to embankment at outlet end of existing crossing.



Photo 37: km 747.56 (2 of 7) – Looking north along winter road alignment. Downstream embankment erosion extends to crest and is diminishing available roadway width.



Photo 38: km 747.56 (3 of 7) – Looking east at outlet end of existing culvert. Culvert 40% full of sediment. All flow at the time of the site visit was conveyed through the culvert outlet.



Photo 39: km 747.56 (4 of 7) – Looking north at inlet end of existing culvert. Damage to the culvert within the embankment has forced the inlet to lift. Flow goes underneath inlet, appearing to enter the culvert at the first culvert joint.



Photo 40: km 747.56 (5 of 7) – Looking west within inlet end of culvert. Culvert is severely deformed, and most joints have been damaged, allowing piping. As the inlet of the culvert is raised above the channel, flow enters the culvert at the first and second joints.



Photo 41: km 747.56 (6 of 7) – Looking upstream (east) approximately 50 m upstream of existing culvert crossing.



Photo 42: km 747.56 (7 of 7) – Looking downstream (west) approximately 40 metres downstream of existing culvert crossing.



Photo 43: km 742.74 (1 of 5) – Looking east at watercourse crossing winter road alignment.



Photo 44: km 742.74 (2 of 5) – Upstream of alignment. Gradual slope with substrate entirely fines.



Photo 45: km 742.74 (3 of 5) – Looking north, immediately downstream of highway alignment. Large scour pocket.



Photo 46: km 742.74 (4 of 5) – Looking west (downstream), approximately 100m downstream of highway alignment. Substantial erosion to both banks with many trees fallen across channel.



Photo 47: km 742.74 (5 of 5) – Looking west (downstream), approximately 200m downstream of highway alignment. Substantial erosion to both banks with many trees fallen across channel.



Photo 48: km 741.74 (1 of 3) – Looking east (upstream) approximately 75 metres upstream of the highway alignment. Woody debris present in a small channel.



Photo 49: km 741.74 (2 of 3) – Looking west (downstream) from highway alignment.



Photo 50: km 741.74 (3 of 3) – Looking east (upstream) approximately 40 metres downstream of the highway alignment.



Photo 51: km 740.75 (1 of 2) – Looking east (upstream) approximately 50 metres upstream of the highway alignment. Small amount of woody debris present in channel.



Photo 52: km 740.75 (2 of 2) – Looking east (upstream) approximately 50 metres downstream of the highway alignment. Woody debris present in channel.



Photo 53: km 739.55 (1 of 4) – Looking upstream (southeast) at watercourse as it crosses the highway alignment.



Photo 54: km 739.55 (2 of 4) – Looking downstream (west) at watercourse from highway alignment. A single piece of destroyed culvert present. There are no other indications that this crossing was once serviced by a culvert



Photo 55: km 739.55 (3 of 4) – Looking south along highway alignment. Blue arrows indicate flow path. Downstream of the alignment the channel takes a 135 degree turn north, coming back to the toe of the existing roadway.



Photo 56: km 739.55 (4 of 4) – Looking east (upstream) approximately 30m west of highway alignment.



Photo 57: km 737.36 (1 of 3) – Looking east (upstream) at watercourse crossing highway alignment.



Photo 58: km 737.36 (2 of 3) – Looking east (upstream) at watercourse crossing approximately 25 metres upstream of highway alignment. Small amounts of woody debris present throughout channel.



Photo 59: km 737.36 (3 of 3) – Looking east (upstream) at watercourse approximately 100 metres downstream of highway alignment. Incised channel at times.



Photo 60: km 736.48 (1 of 4) – Looking east (upstream) at watercourse crossing highway alignment.



Photo 61: km 736.48 (2 of 4) – Looking east (upstream) approximately 200 metres downstream of highway alignment. Steep riffle sections and woody debris periodically throughout channel.



Photo 62: km 736.48 (3 of 4) – Looking east (upstream) approximately 250 metres downstream of highway alignment. Small slightly incised channel.



Photo 63: km 736.48 (4 of 4) – Looking east (upstream) approximately 50 metres upstream of highway alignment.



Photo 64: km 733.71 (Bonnie Creek) (1 of 5) – Looking east (upstream) at watercourse crossing highway alignment.



Photo 65: km 733.71 (Bonnie Creek) (2 of 5) – Looking west (downstream) at watercourse crossing highway alignment.



Photo 66: km 733.71 (Bonnie Creek) (3 of 5) – Looking east (upstream) approximately 25 metres upstream of highway alignment.



Photo 67: km 733.71 (Bonnie Creek) (4 of 5) – Looking downstream (west) approximately 75 metres downstream of highway alignment. Woody debris present throughout channel.



Photo 68: km 733.71 (Bonnie Creek) (5 of 5) – Looking upstream (east) immediately upstream of confluence with Mackenzie River.



Photo 69: km 732.74 (1 of 4) – Looking north as watercourse crosses highway alignment.



Photo 70: km 732.74 (2 of 4) – Looking east (upstream) from highway alignment.



Photo 71: km 732.74 (3 of 4) – Looking east (upstream) approximately 25 metres downstream of alignment. Steep section of channel.



Photo 72: km 732.74 (4 of 4) – Looking east (upstream) approximately 100 metres downstream of alignment. Steep section of channel, small amounts of woody debris.



Photo 73: km 727.36 (1 of 3) – Looking north along highway alignment as watercourse crosses (flow direction right to left)



Photo 74: km 727.36 (2 of 3) – Looking east (upstream) approximately 50 metres upstream of highway alignment.



Photo 75: km 727.36 (3 of 3) – Looking west (downstream) approximately 100 metres downstream of highway alignment.



Photo 76: km 724.49 (1 of 3) – Looking north along highway alignment, no signs of watercourse.



Photo 77: km 724.49 (2 of 3) – Looking east upgradient from highway alignment, no signs of watercourse.



Photo 78: km 724.49 (3 of 3) – Looking south along highway alignment, no signs of watercourse.



Photo 79: km 721.61 (1 of 4) – Looking upstream (east) from proposed crossing location.



Photo 80: km 721.61 (2 of 4) – Looking downstream (west) from proposed crossing location.



Photo 81: km 721.61 (3 of 4) – Looking upstream (east) approximately 25 metres upstream of proposed crossing.



Photo 82: km 721.61 (4 of 4) – Looking downstream (west) approximately 200 metres downstream of highway alignment. Channel slightly incised.



Photo 83: km 718.79 (1 of 2) – Looking up-gradient (northeast) at slow moving water on highway alignment. No defined channels upstream or downstream of alignment.



Photo 84: km 718.79 (2 of 2) – Looking down-gradient (west) at slow moving water across highway alignment. No defined channels upstream or downstream of alignment.



Photo 85: km 710.35 (1 of 2) – Looking south along alignment as water seeps through muskeg at this location.



Photo 86: km 710.35 (2 of 2) – Looking north at standing water to the west of the highway alignment.



Photo 87: km 705.42 (1 of 2) – Looking upstream (northwest) at slow moving water ponded across alignment. Flow estimated at 4 L/s.



Photo 88: km 705.42 (2 of 2) – Looking north at slow moving water ponded across alignment. Flow estimated at 4 L/s.



Photo 89: km 696.82 (1 of 1) – Looking south at ponded water along alignment at this location.



Photo 90: km 793.40 (1 of 3) – Looking east (upstream) at a series of four beaver dams immediately upstream of crossing location.



Photo 91: km 793.40 (2 of 3) – Looking downstream (west) at beaver dam impounding water at crossing location.



Photo 92: km 793.40 (3 of 3) – Looking down at beaver dam immediately east of proposed crossing location. No defined channel seems to be present downstream of the dam.



Photo 93: km 791.36 (1 of 3) – Looking west (downstream) at crossing location. Lake/wetland crosses the alignment in an approximately 30m wide crossing. Perched 900mm culvert visible from usage on the winter road.



Photo 94: km 791.36 (2 of 3) – Looking east (upstream) at crossing location. Standing water with no visible signs of flow.



Photo 95: km 791.36 (3 of 3) – Looking south at crossing location. Flow is from left to right. Wetted top width is approximately 30m and depths are consistently 0.5m across. No discernable signs of flow.



Photo 96: km 768.49 (1 of 2) – Looking east (upstream) at small watercourse draining across alignment into a wetland. No defined channel exists upstream of the crossing. Flow estimated < 1 L/s.



Photo 97: km 768.49 (2 of 2) – Looking northwest (downstream) at small watercourse draining into wetland.



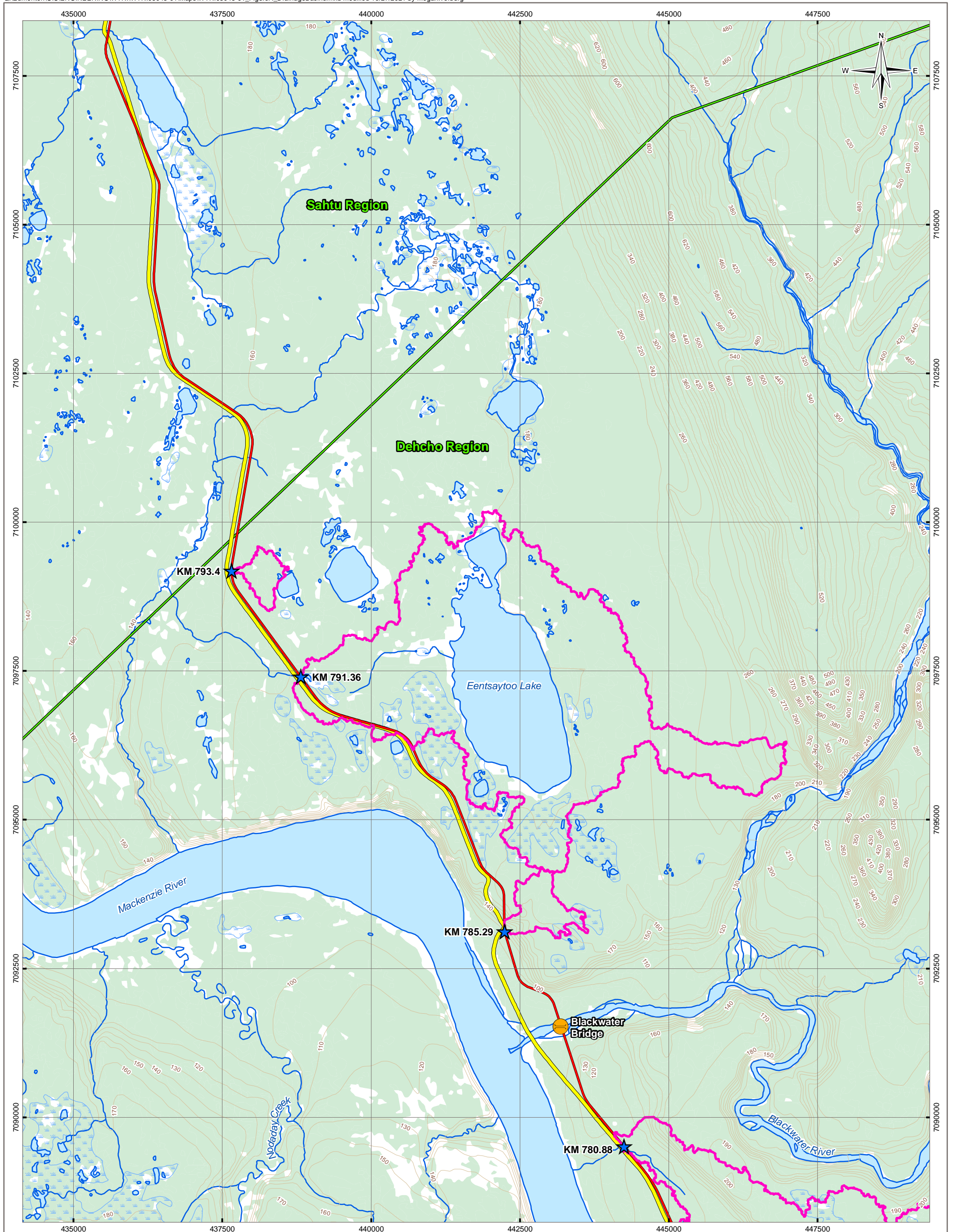
Photo 98: km 765.71 (1 of 2) – Looking east (upstream) from proposed crossing location. Flow estimated at 20 L/s.



Photo 99: km 765.71 (2 of 2) – Looking downstream (west) from proposed crossing location.

APPENDIX D

MINOR WATERCOURSE DRAINAGE BASINS



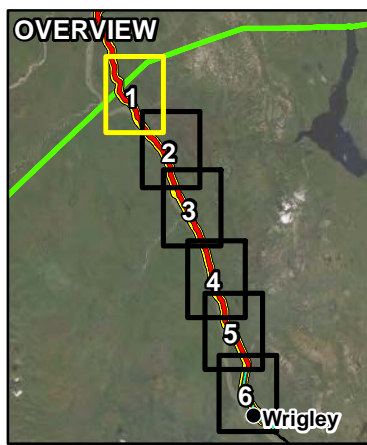
LEGEND

- Drainage Basin
- Existing Bridge
- Minor Watercourse Crossing
- Mackenzie Valley Highway Extension
- Mackenzie Valley Highway Public Winter Road
- ENR-ITI-Lands Administrative Boundary

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

NOTES
 Kilometre Markers (KMs) based on Winter Road KMs from the Dehcho Region Project Description Report, Dessau (March 2012)
 Base data source: CanVec 1:50,000
 ESRI Data Maps
 Imagery provided by ESRI; Maxar

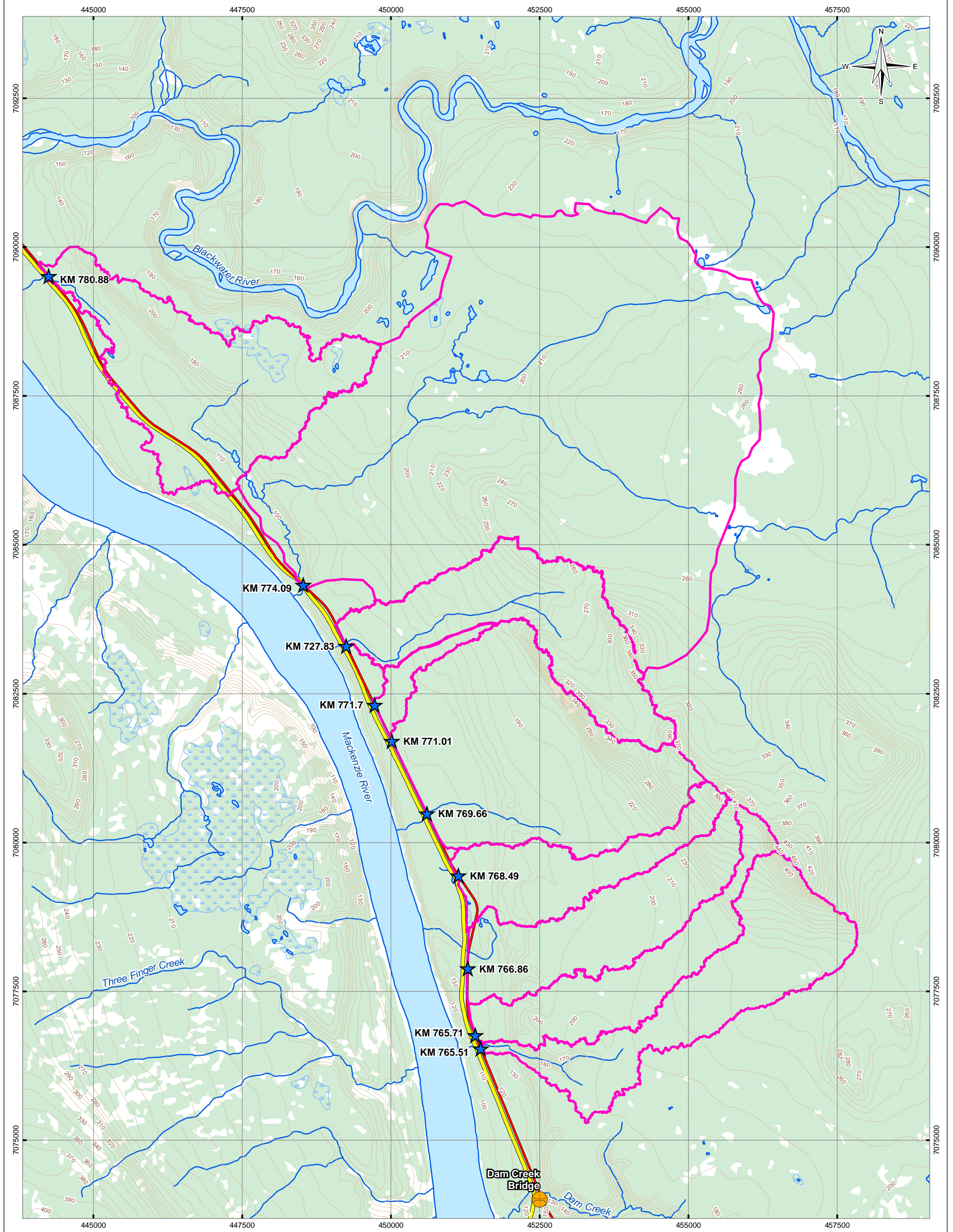
STATUS
 ISSUED FOR USE



**MACKENZIE VALLEY HIGHWAY
 2020-21 HYDROTECHNICAL ASSESSMENTS**

**Dehcho Segment
 Minor Watercourse Drainage Basins**

| | | |
|--|--|-------------------|
| PROJECTION UTM Zone 10 | DATUM NAD83 | CLIENT |
| Scale: 1:60,000 | | TETRA TECH |
| FILE NO. WTRI03043-01_FigureA_DrainageBasins.mxd | | |
| OFFICE Tl-EDM | DWN MRV | CKD SL |
| APVD BR | REV 0 | |
| DATE October 27, 2021 | PROJECT NO. ENG.WTRI03043-01 | |
| Figure D-1 | | |

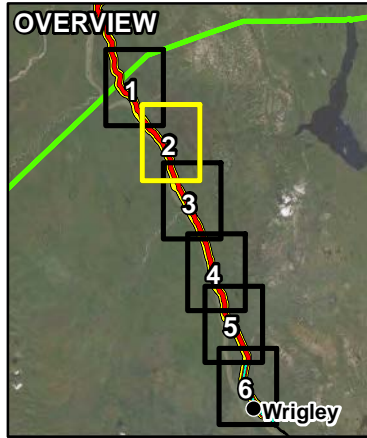


LEGEND

- Drainage Basin
 - Existing Bridge
 - Minor Watercourse Crossing
 - Mackenzie Valley Highway Extension
 - Mackenzie Valley Highway Public Winter Road
 - ENR-ITI-Lands Administrative Boundary
- Base Data**
- Contour (10 or 20 m)
 - Watercourse
 - Waterbody
 - Wetland
 - Wooded Area

NOTES
 Kilometre Markers (KMs) based on Winter Road KMs from the Dehcho Region Project Description Report, Dessau (March 2012)
 Base data source: CanVec 1:50,000
 ESRI Data Maps
 Imagery provided by ESRI; Maxar

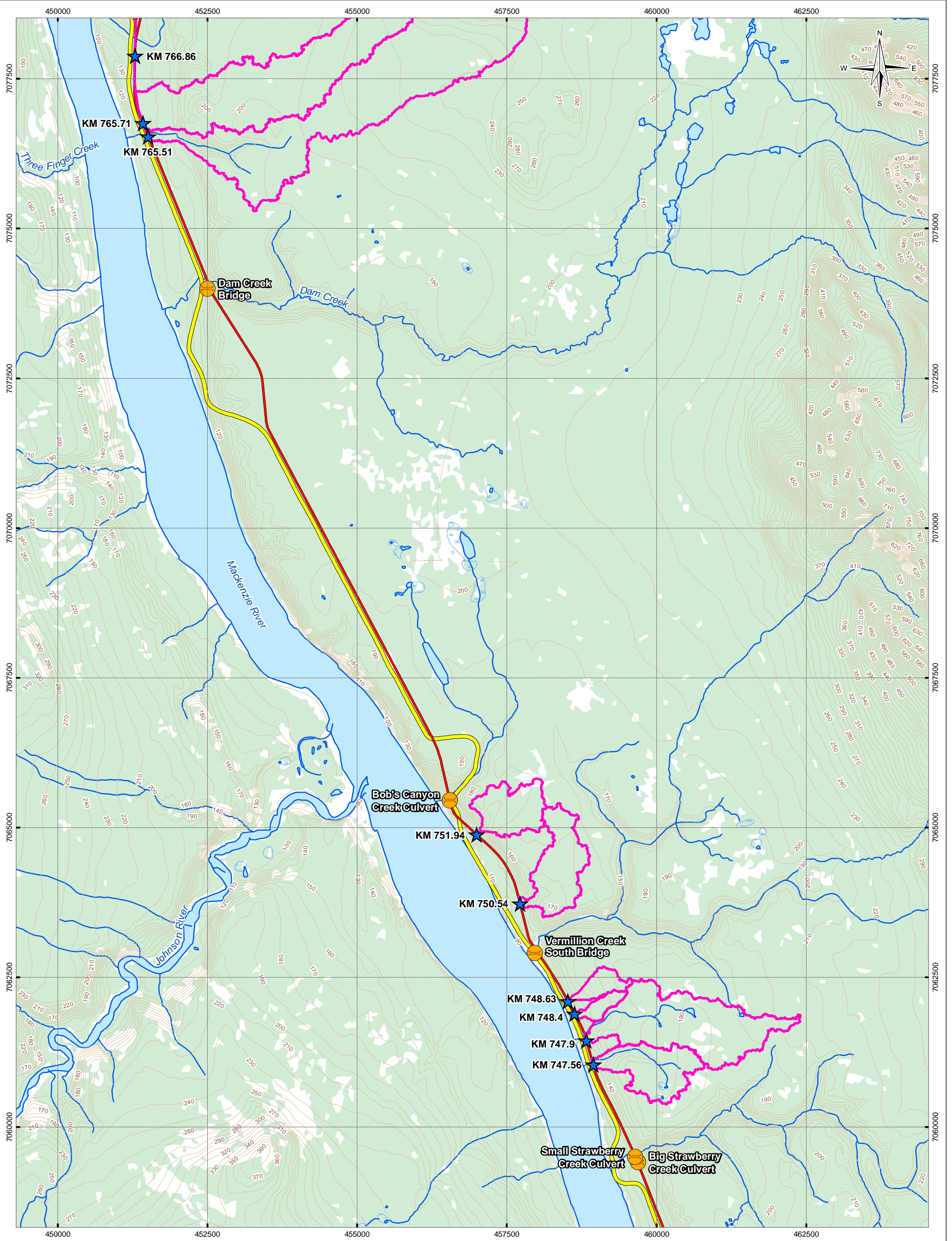
STATUS
 ISSUED FOR USE



**MACKENZIE VALLEY HIGHWAY
 2020-21 HYDROTECHNICAL ASSESSMENTS**

**Dehcho Segment
 Minor Watercourse Drainage Basins**

| | | |
|---|----------------|-------------------|
| PROJECTION UTM Zone 10 | DATUM NAD83 | CLIENT |
| Scale: 1:60,000 | | |
| FILE NO. WTRI03043-01_FigureA_DrainageBasins.mxd | | |
| OFFICE Tr-EDM | DWN MRV | CKD SL |
| DATE October 27, 2021 | APVD BR | REV 0 |
| PROJECT NO. ENG.WTRI03043-01 | | Figure D-2 |

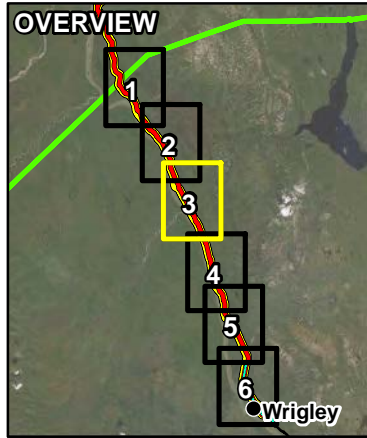


LEGEND

- | | |
|---|----------------------|
| Drainage Basin | Contour (10 or 20 m) |
| Existing Bridge | Watercourse |
| Minor Watercourse Crossing | Waterbody |
| Mackenzie Valley Highway Extension | Wetland |
| Mackenzie Valley Highway Public Winter Road | Wooded Area |
| ENR-ITI-Lands Administrative Boundary | |

NOTES
 Kilometre Markers (KMs) based on Winter Road KMs from the Dehcho Region Project Description Report, Dessau (March 2012)
 Base data source: CanVec 1:50,000
 ESRI Data Maps
 Imagery provided by ESRI; Maxar

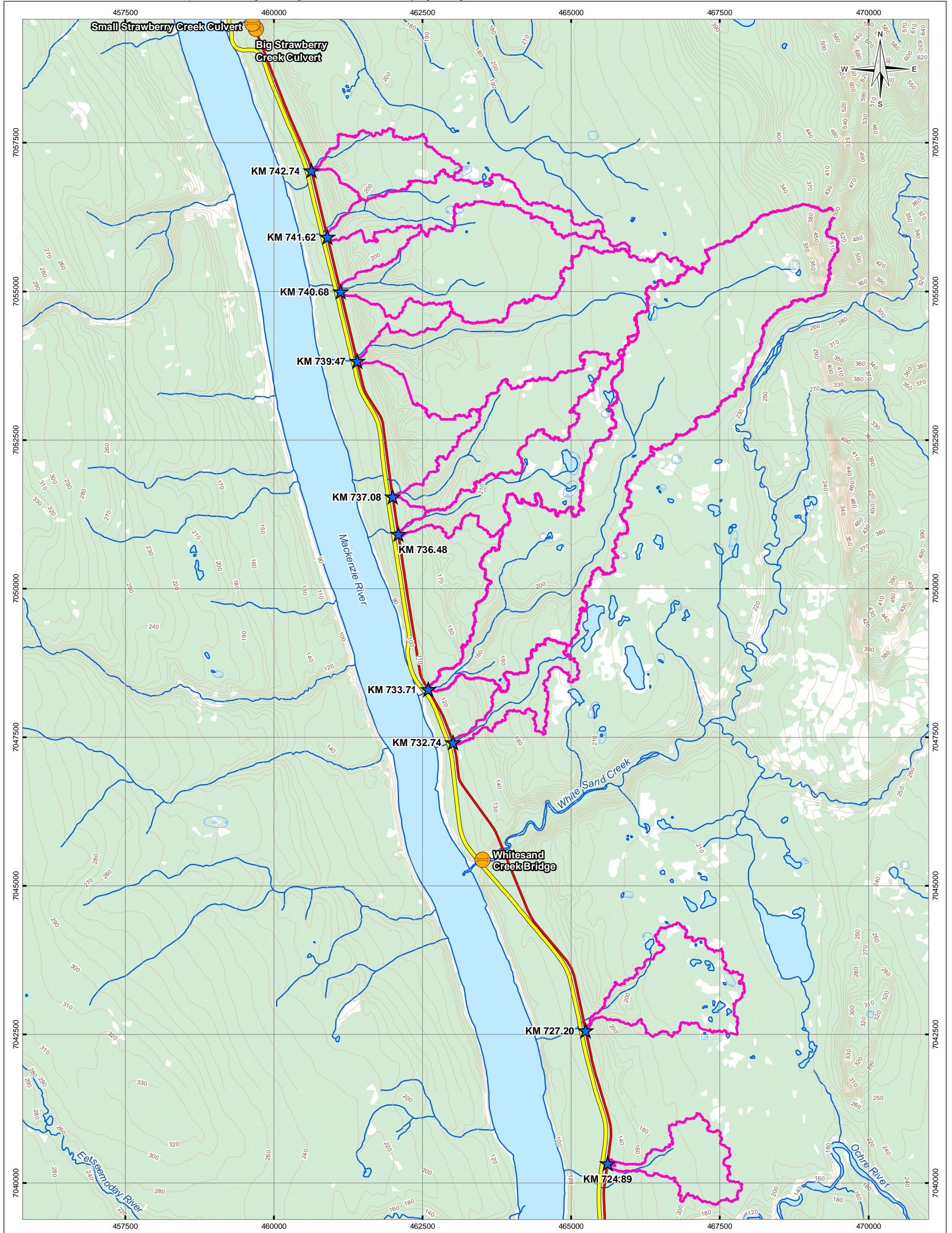
STATUS
 ISSUED FOR USE



**MACKENZIE VALLEY HIGHWAY
 2020-21 HYDROTECHNICAL ASSESSMENTS**

**Dehcho Segment
 Minor Watercourse Drainage Basins**

| | | |
|---|-------------------|-------------------|
| PROJECTION UTM Zone 10 | DATUM NAD83 | CLIENT |
| Scale: 1:60,000 | | |
| FILE NO. WTRI03043-01_FigureA_DrainageBasins.mxd | TETRA TECH | |
| OFFICE Tr-EDM | DWN MRV | CKD SL |
| DATE October 27, 2021 | APVD BR | REV 0 |
| PROJECT NO. ENG.WTRI03043-01 | | Figure D-3 |



LEGEND

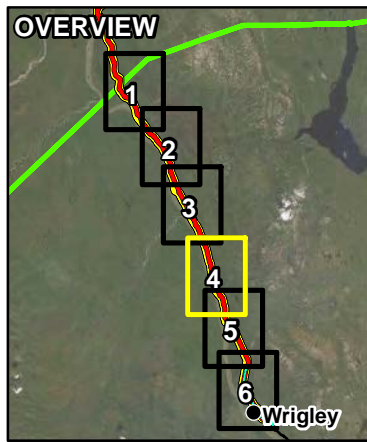
- Drainage Basin
- Existing Bridge
- Minor Watercourse Crossing
- Mackenzie Valley Highway Extension
- Mackenzie Valley Highway Public Winter Road
- ENR-ITI-Lands Administrative Boundary

Base Data

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

NOTES
 Kilometre Markers (KMs) based on Winter Road KMs from the Dehcho Region Project Description Report, Dessau (March 2012)
 Base data source: CanVec 1:50,000
 ESRI Data Maps
 Imagery provided by ESRI; Maxar

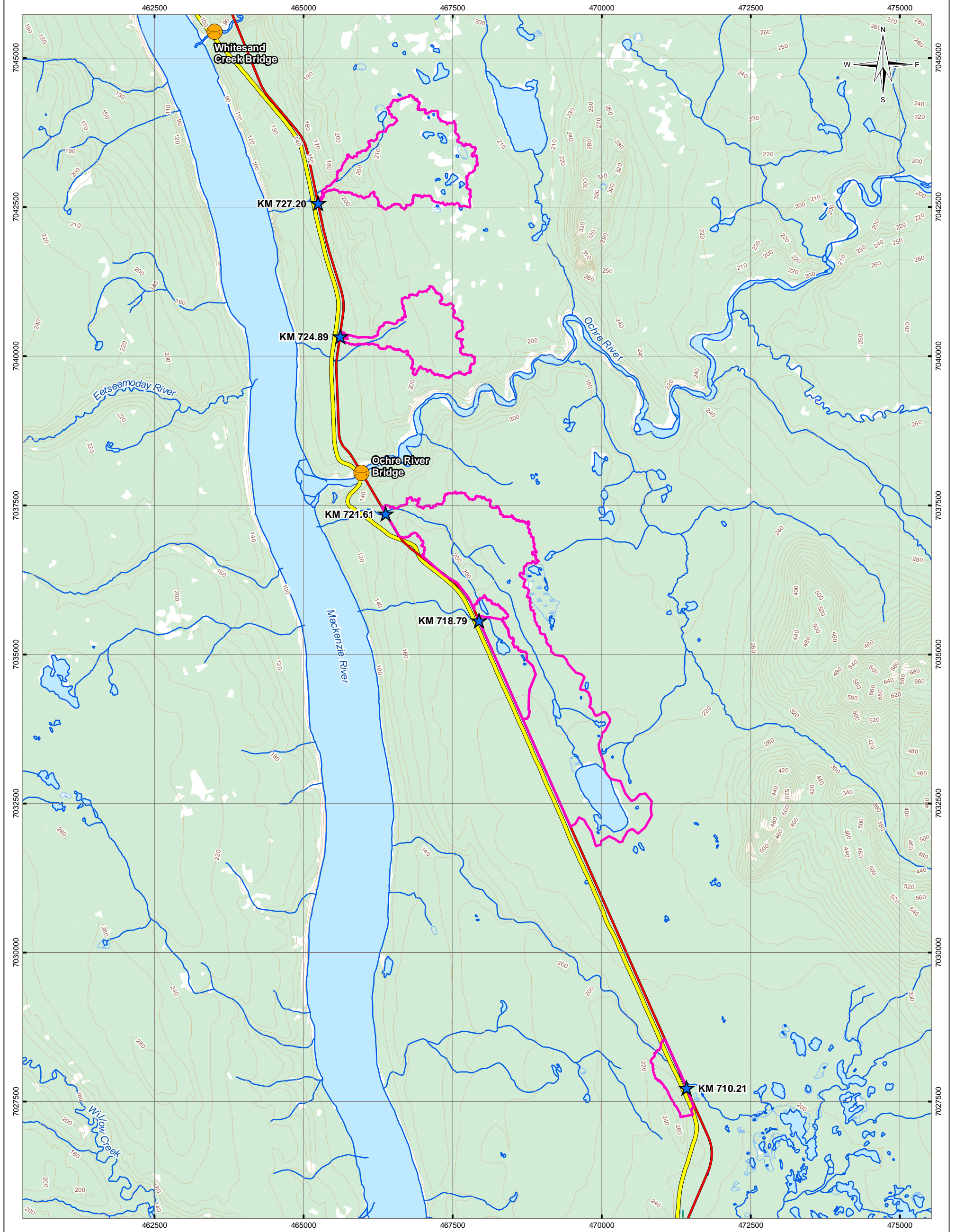
STATUS
 ISSUED FOR USE



**MACKENZIE VALLEY HIGHWAY
 2020-21 HYDROTECHNICAL ASSESSMENTS**

**Dehcho Segment
 Minor Watercourse Drainage Basins**

| | | |
|---|----------------|-------------------|
| PROJECTION UTM Zone 10 | DATUM NAD83 | CLIENT |
| Scale: 1:60,000 | | |
| FILE NO. WTRI03043-01_FigureA_DrainageBasins.mxd | | |
| OFFICE Tl-EDM | DWN MRV | CKD SL |
| DATE October 27, 2021 | APVD BR | REV 0 |
| PROJECT NO. ENG.WTRI03043-01 | | Figure D-4 |



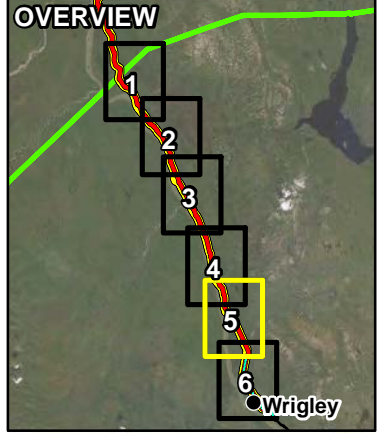
LEGEND

- Drainage Basin
- Existing Bridge
- Minor Watercourse Crossing
- Mount Gaudet Access Road
- Mackenzie Valley Highway Extension
- Mackenzie Valley Highway Public Winter Road
- ENR-ITI-Lands Administrative Boundary

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

NOTES
 Kilometre Markers (KMs) based on Winter Road KMs from the Dehcho Region Project Description Report, Dessau (March 2012)
 Base data source: CanVec 1:50,000
 ESRI Data Maps
 Imagery provided by ESRI; Maxar

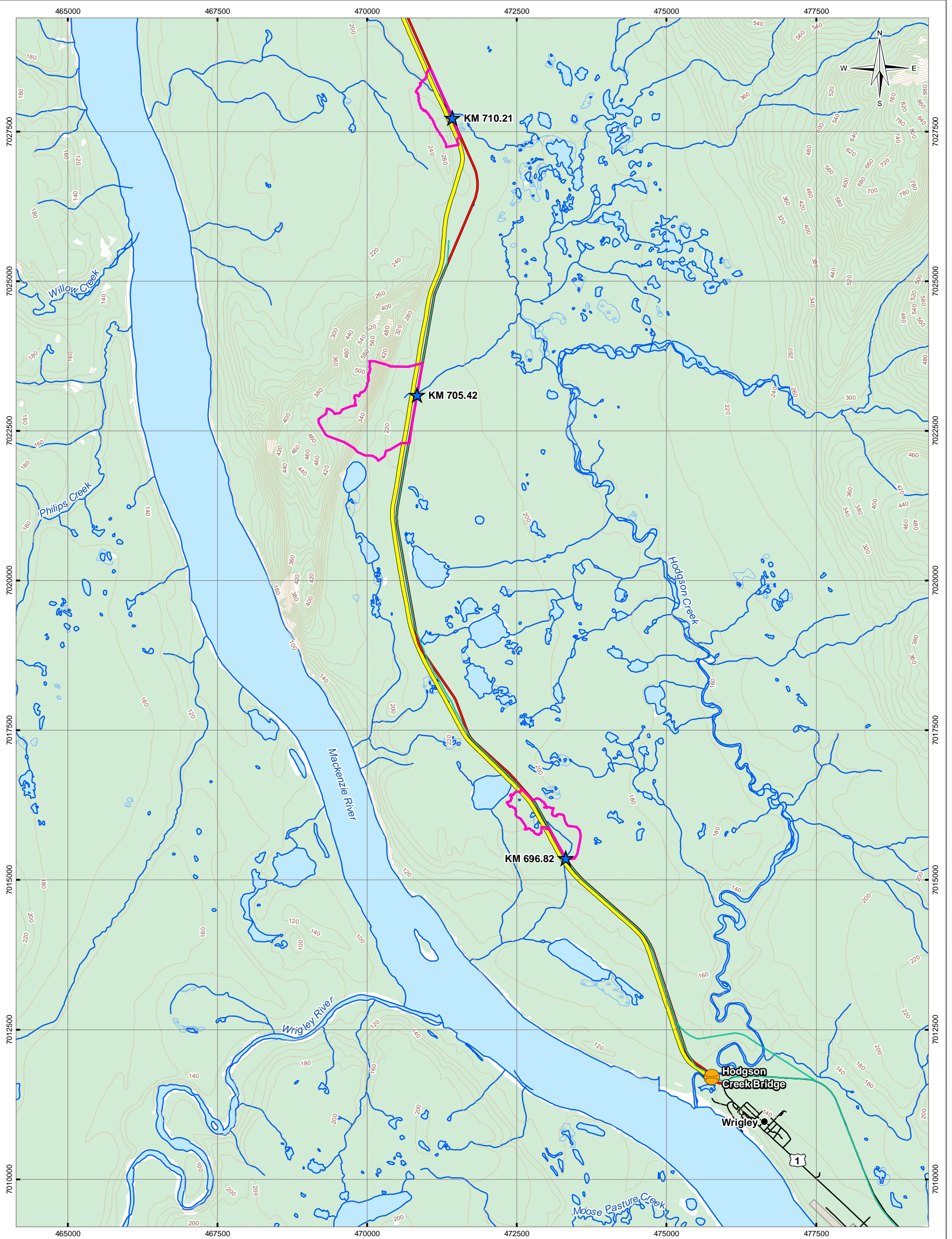
STATUS
 ISSUED FOR USE



**MACKENZIE VALLEY HIGHWAY
 2020-21 HYDROTECHNICAL ASSESSMENTS**

**Dehcho Segment
 Minor Watercourse Drainage Basins**

| | | |
|---|----------------|-------------------|
| PROJECTION UTM Zone 10 | DATUM NAD83 | CLIENT |
| Scale: 1:60,000 | | |
| FILE NO. WTRI03043-01_FigureA_DrainageBasins.mxd | | |
| OFFICE Tt-EDM | DWN MRV | CKD SL |
| DATE October 27, 2021 | APVD BR | REV 0 |
| PROJECT NO. ENG.WTRI03043-01 | | Figure D-5 |



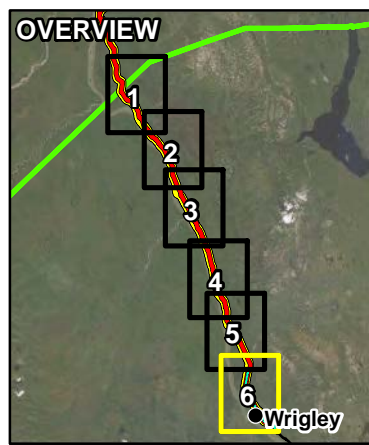
LEGEND

- Drainage Basin
- Existing Bridge
- Minor Watercourse Crossing
- Mount Gaudet Access Road
- Mackenzie Valley Highway Extension
- Mackenzie Valley Highway Public Winter Road
- ENR-ITI-Lands Administrative Boundary

- Base Data**
- Contour (10 or 20 m)
 - Watercourse
 - Waterbody
 - Wetland
 - Wooded Area
 - Residential Area
 - Building
 - Other Road
 - Runway
 - Populated Place

NOTES
 Kilometre Markers (KMs) based on Winter Road KMs from the Dehcho Region Project Description Report, Dessau (March 2012)
 Base data source: CanVec 1:50,000
 ESRI Data Maps
 Imagery provided by ESRI; Maxar

STATUS
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**MACKENZIE VALLEY HIGHWAY
 2020-21 HYDROTECHNICAL ASSESSMENTS**

**Dehcho Segment
 Minor Watercourse Drainage Basins**

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|---|----------------|-------------------|
| PROJECTION UTM Zone 10 | DATUM NAD83 | CLIENT |
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| FILE NO. WTR\03043-01_FigureA_DrainageBasins.mxd | | |
| OFFICE Tl-EDM | DWN MRV | CKD SL |
| DATE October 27, 2021 | APVD BR | REV 0 |
| PROJECT NO. ENG.WTR\03043-01 | | Figure D-6 |