APPENDIX 15B

Hydrogeology Technical Data Report

Mackenzie Valley Highway Project
Technical Data Report—Hydrogeology

Prepared for:

Government of the Northwest Territories

Prepared by:

K'alo-Stantec Limited

December 2022

Project No.: 144903025

Limitations and Sign-off

This document entitled Mackenzie Valley Highway Project Technical Data Report—Hydrogeology was prepared by K'alo-Stantec Limited ("K'alo-Stantec") for the account of Government of the Northwest Territories (the "Client") to support the regulatory review process for its Developer's Assessment Report (the "DAR") for the Mackenzie Valley Highway (Wrigley to Norman Wells) Project (the "Project"). In connection therewith, this document may be reviewed and used by the Government of the Northwest Territories Department of Infrastructure participating in the review process in the normal course of its duties. Except as set forth in the previous sentence, any reliance on this document by any other party or use of it for any other purpose is strictly prohibited. The material in it reflects K'alo-Stantec's professional judgment in light of the scope, schedule and other limitations stated in the document and in the contract between K'alo-Stantec and the Client. The information and conclusions in the document are based on the conditions existing at the time the document was published and does not take into account any subsequent changes. In preparing the document, K'alo-Stantec did not verify information supplied to it by the Client or others, unless expressly stated otherwise in the document. Any use which another party makes of this document is the responsibility and risk of such party. Such party agrees that K'alo-Stantec shall not be responsible for costs or damages of any kind, if any, suffered by it or any other party as a result of decisions made or actions taken based on this document.

Prepared by ______________________
(signature)

Eric Westberg, M.Sc., P.Geo.
Hydrogeologist

Reviewed by ______________________ Digitally signed by Yoshisaka, Dan
(signature)

Dan Yoshisaka, M. Sc., P.Eng.
Managing Senior Principal

Approved by ______________________ Digitally signed by Bonhomme, Erica
(signature)

Erica Bonhomme, M.Sc., P.Geo.
Principal, Environmental Services

K'alo-Stantec

Executive Summary

The Government of the Northwest Territories (GNWT) is proposing the Mackenzie Valley Highway Project (the Project) that will extend the Mackenzie Valley Highway (MVH) from Wrigley to Norman Wells. The Project consists of a 321 kilometre (km) all-season highway that largely follows the route of the existing Mackenzie Valley Winter Road (MVWR), and the construction and operation of temporary and permanent quarries and borrow sources. The project highway alignment will pass through the Dehcho Region and a portion of the Tulita District of the Sahtu Region within the Northwest Territories (NT).

This technical data report (TDR) presents existing groundwater quantity and quality conditions to support the Developer's Assessment Report (DAR). Based on existing available data, conceptual models of regional and local groundwater flow within the RSA and LSA were developed. Effects of the Project on groundwater within the LSA and RSfA will be assessed in the DAR using the conceptual framework provided by these models. Potential quarries and borrow sources have yet to be identified and, therefore, characterization of these areas has not been included in this TDR.

East of the Mackenzie River, regional groundwater systems flow from the Franklin Mountains to the Mackenzie River. Permafrost, where it exists, acts as a confining layer and a barrier to groundwater recharge. Within limestone, dolostone, and evaporite lithologies of the Franklin Mountains, however, recharge can occur by infiltration through taliks beneath high-permeability weathered bedrock exposures and karst landforms including sinkholes, ponors, and dry valleys (Van Everdingen, 1981; Hamilton, 1995).

Regional groundwater discharge occurs along the western slopes of the Franklin Mountains and along stream channels draining these slopes. Depending on the scale of discharge, streams crossed by the project highway alignment are perennially ice-free, experience icings, or annually freeze to ground surface (IORVL, 2004). In contrast to recharge, permafrost is not a barrier to regional groundwater discharge because the discharge temperature likely maintains perennial open taliks (Michel, 1986). Discharge from regional flow paths tend to have high concentrations of major ions that reflect the solubility of the bedrock encountered along the groundwater flow path.

Local groundwater flow in the LSA and RSA is strongly impacted by the distribution of permafrost and low-permeability sediments that act as barriers to groundwater flow. Where permafrost exists, local groundwater flow paths in the LSA and RSA are generally limited to seasonal supra-permafrost flow in the active layer. However, the Bear Rock Conservation Zone is one area within the LSA and RSA where deeper localized groundwater flow paths have developed.

Table of Contents

List of Tables

List of Figures

List of Appendices

Abbreviations

% .... percent
°C .... degrees Celsius
µS/cm .... microsiemens per centimetre
‰ .... permil
CMV… .... Central Mackenzie Valley
DAR .... Developer's Assessment Report
EC .... electrical conductivity
GNWT .... Government of the Northwest Territories
INF .... Department of Infrastructure
ka BP .... thousand years before present
km .... kilometre
km^2 .... square kilometre
L/s .... litres per second
LSA .... local study area
m .... metre
ma BP .... million years before present
masl .... metres above sea level
mg/L .... milligrams per litre
MVEIRB .... Mackenzie Valley Environmental Impact Review Board
MVH .... Mackenzie Valley Highway
NT .... Northwest Territories
PDA .... Project Development Area
PDR .... Project Description Report
RSA .... regional study area
SMOW .... standard mean ocean water
SSA .... Sahtu Settlement Area
TDLC .... Tulita District Land Corporation

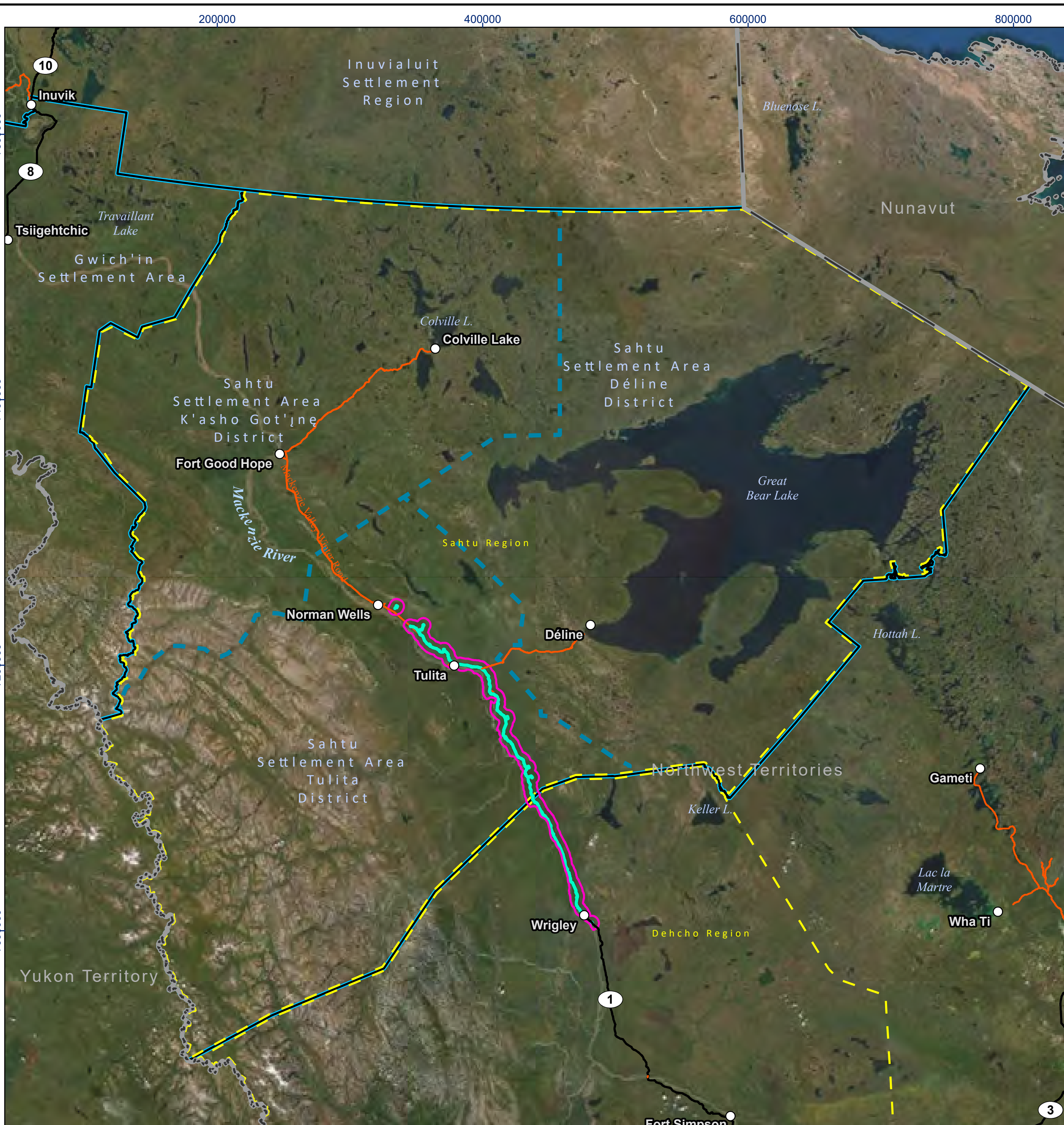
TDR .... Technical Data Report

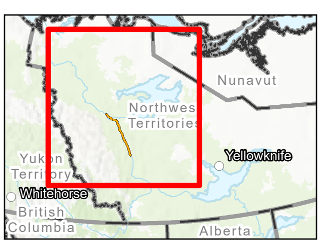
the Project .... Mackenzie Valley Highway Project

1 Introduction

The Government of the Northwest Territories (GNWT) is proposing the Mackenzie Valley Highway Project (the "Project") that will extend the Mackenzie Highway from Wrigley to Norman Wells, Northwest Territories (NT). The Project consists of a planned 321 kilometre (km) all-season gravel highway that largely follows the route of the existing Mackenzie Valley Winter Road (MVWR). The project highway alignment will pass through the Dehcho Region and a portion of the Tulita District of the Sahtu Region within the NT (Figure 1.1).

The Project is subject to an environmental assessment and the requirements of Part 5 of *the Mackenzie Valley Resource Management Act*. This Technical Data Report (TDR) presents a description of existing hydrogeological (groundwater) conditions to support the information required to be presented in the Project's Developer's Assessment Report (DAR), as described in the Terms of Reference (MVEIRB, 2015).





- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- Community
- All-Season Road
- Winter Road
- District Boundary
- Settlement Area Boundary
- Region Boundary
- Territorial Boundary

0 40 80 Kilometres

(At original document size of 8.5x11)
1:4,500,000

N

Kálo-Stantec

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Centre for Geomatics Government of NWT, Government of Canada, Stantec
3. Background: World Imagery: Earthstar Geographics
World Topographic Map: Esri, FAO, NOAA, NRCan
World Hillshade: Esri, USGS
Name: NAD 1983 UTM Zone 10N
PCS: NAD 1983 UTM Zone 10N

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2022-04-08
TR by AJ on 2022-04-08

Client/Project
144903025-0061 REVB

Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
1.1

Title
MVH Project Overview

2 Study Area

The Project is located in the Mackenzie Valley region of the NT between the current terminus of the existing all-weather highway in Wrigley (Highway #1, KM 690) and Norman Wells (MVWR, KM 1,011). The project highway alignment generally follows the MVWR along the east side of the Mackenzie River within the Mackenzie Plain physiographic region and passes through the community of Tulita (MVWR, KM 938; Figure 2.1).

The Project Development Area (PDA) is the area of direct Project disturbance within which works and activities will occur (footprint). This includes a new two-lane gravel highway, 60 m wide highway right-of-way (ROW), laydown and staging areas, maintenance yards, construction camps and quarry/borrow sites with access roads on a 30 m ROW. The PDA is defined as the area to be used by the Project from Wrigley to approximately 25 km Southeast of Norman Wells. The PDA does not include a section of Project (less than 10 km in length) that passes through the hamlet of Tulita.

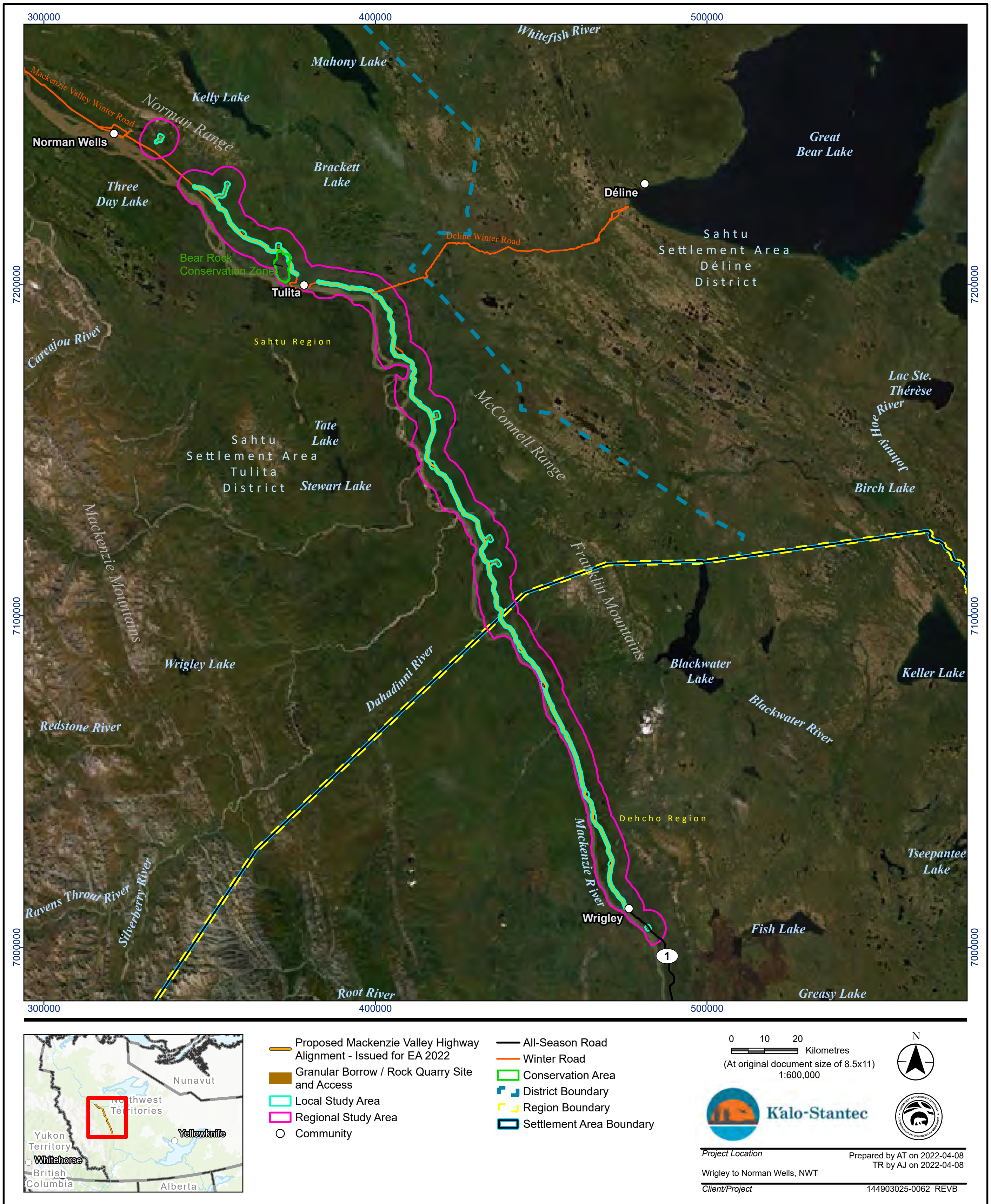
The local and regional study areas presented in this TDR are where K'alo-Stantec focused data compilation/collection efforts to understand groundwater conditions in support of the project-specific effects assessment and the cumulative effects assessment. However, some groundwater-related studies completed within the larger Central Mackenzie Valley (CMV) provide important context on regional groundwater flow conditions. These studies have been included in the literature review. The area of the CMV varies depending on the reference (e.g., Michel, 1986 vs. Golder, 2015), but for this TDR the CMV extends east-to-west from the Franklin to the Mackenzie Mountains and north-to-south from Norman Wells to Wrigley (Figure 2.1).

2.1 Local Study Area

The Local Study Area (LSA) is a 1 km buffer centred on the PDA, which is the alignment of the MVWR (Figure 2.1). Observable, Project-related direct and indirect effects to groundwater and groundwater-influenced valued components (VCs) are expected to be limited to this area.

2.2 Regional Study Area

The Regional Study Area (RSA) is a 10 km buffer centred on the PDA (Figure 2.1). The RSA was selected to include groundwater-related features and groundwater-influenced VCs that could be affected by the effects of project activities interacting with the effects of other existing, past or reasonably foreseeable projects in the area.



Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Centre for Geomatics Government of NWT, Government of Canada, Stantec
3. Background: World Imagery: Earthstar Geographics World Topographic Map: Esri, FAO, NOAA, NRCan World Hillshade: Esri, USGS

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2022-04-08
TR by AJ on 2022-04-08

Client/Project
144903025-0062 REVB

Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
2.1

Title
Regional and Local Study Area for Hydrogeology

3 Methods

K’alo-Stantec completed a review of existing traditional knowledge (TK) and traditional land and resource use (TLRU) and a literature review of groundwater-related information to characterize existing hydrogeological conditions within the LSA and RSA.

Based on the data compiled during the TK, TLRU, and literature review, K’alo-Stantec completed hydrostratigraphic interpretations of soils and bedrock geological units intersected by the project highway alignment and developed a conceptual hydrogeological model. The objective of the model is to provide a simplified but defensible representation of local and regional groundwater flow systems that will help with the identification of potential environmental effects and effect pathways of the Project on groundwater quality and quantity.

3.1 Traditional Knowledge and Traditional Land and Resource Use

Groundwater-related TK and TLRU in the Sahtu and Dehcho regions are summarized in the following sections. Section 3.1, Traditional Knowledge and Traditional Land and Resource Use, will be updated as additional information TK and TLRU information relevant to the Project becomes available.

3.1.1 Sahtu Region

The Petınıʔah (Bear Rock) Conservation Zone is an important sacred site in Denendeh and is of cultural value to Dene groups within and outside of the Sahtu (SLUB, 2013). Physically, it is composed of exposed karst landforms of considerable importance to the local groundwater system, and local groundwater discharge zones are crossed by the PDA, LSA, and RSA (Figure 2.1). The groundwater flow system at Petınıʔah (Bear Rock) Conservation Zone is discussed in Section 4.4.3, Karst, and in Section 5.2, RSA and LSA Groundwater Flow.

3.1.2 Dehcho Region

K’alo-Stantec did not find any documentation of groundwater-related TK or TLRU in the Dehcho Region.

Until 2014, the community water source for Wrigley was reported as a groundwater well (GNWT, 2013). The well diverted groundwater from glaciofluvial sands and gravels beneath a 40 m to 50 m thick permafrost horizon (IORVL, 2004). In 2015, the community water source for Wrigley was reported as the Mackenzie River (GNWT, 2015).

3.2 Literature Review

K'alo-Stantec completed a literature review to understand existing groundwater conditions along the project highway alignment. Primary sources reviewed for groundwater information in the Sahtu and Dehcho regions included:

- Hydrogeology of the Central Mackenzie Valley (Michel, 1986)
- Morphology, Hydrology, and Hydrochemistry of Karst in Permafrost Terrain near Great Bear Lake, Northwest Territories (Van Everdingen, 1981)
- Karst Geomorphology and Hydrogeology of the Northeastern Mackenzie Mountains (Hamilton, 1995)
- The Physical Environment of the Mackenzie Valley, Northwest Territories: A Base Line for the Assessment of Environmental Change (Dyke and Brooks, 2000)
- Environmental Impact Statement for Mackenzie Gas Project Volume 3, Part B – Aquatic Resources: Groundwater, Hydrology, and Water Quality (IORVL, 2004)
- Mapping Known and Potential Karst Areas in the Northwest Territories, Canada (Ford, 2009)
- Mackenzie Valley Highway Extension Pehdzéh Kį Ndeh – Dehcho Region. Project Description Report (PDR) (Dessau, 2012)
- Central Mackenzie Valley Subsurface Groundwater Baseline Study (AMEC, 2014; NWT Open File 2014-07).
- Geological Compilation of the Western Mainland and Southern Arctic Islands Regions, Northwest Territories (Okulitch and Irwin, 2014)
- Central Mackenzie Surface Water and Groundwater Baseline Assessment. Report 1: Technical State of Knowledge (Golder, 2015)
- Hydrologic Impacts of Thawing Permafrost – A Review (Walvoord and Kurylyk, 2016).

The complete list of literature reviewed, including files retrieved from Northwest Territories Open Files for the TDR is provided in Section 7, References.

3.3 Hydrostratigraphic Interpretations

Hydrostratigraphic interpretations are the classification of units of subsurface material and their associated characteristics (e.g., lithologies, geologic facies, permafrost distribution) into groups of similar hydrogeologic behavior. Regional and local assessments of groundwater flow conditions can then be made based on the distribution of these hydrostratigraphic units. Subsurface materials identified within the LSA, RSA, and CMV have been classified as a confining layer or as potential aquifer material (Section 4, Review of Existing Data).

A confining layer is a low-permeability hydrostratigraphic unit that acts as a barrier to groundwater flow. Higher permeability units below a confining layer will be hydraulically uncoupled, to various degrees, to overlying higher permeability units and to surface water features.

Potential aquifers are higher-permeability hydrostratigraphic units of sufficient extent and thickness to be considered for groundwater extraction.

3.4 Conceptual Groundwater Flow Models

A conceptual groundwater flow model is a summary of inferred groundwater system characteristics, including hydrostratigraphic units, groundwater flow boundaries, preferential flow paths, and recharge and discharge conditions (Beale and Read, 2013). Based on the information compiled during the literature review, conceptual models of groundwater flow within the LSA and RSA were developed. Effects of the Project on groundwater within the LSA and RSA will be assessed in the DAR using the conceptual framework provided by these models.

4 Review of Existing Data

The results of the literature review are organized by subject in the following sections. Some subjects are discussed in greater detail in other TDRs; here, they are discussed as they relate to existing groundwater conditions. Hydrology is discussed in the TDR, Surface Water Quantity (K’alo-Stantec, 2022a), and the water quality of surface water bodies is discussed in the TDR, Surface Water Quality (K’alo-Stantec, 2022b). Bedrock geology, surficial geology and permafrost is discussed in the TDR, Soils, Terrain and Permafrost (K’alo-Stantec, 2021).

4.1 Physiography

The project highway alignment follows the MVWR east of the Mackenzie River within the Mackenzie Plain physiographic region (Figure 2.1). Topography is a key driver of groundwater flow. Elevations within the Mackenzie Plain, in the CMV, range from about 100 metres above sea level (m asl) to 350 m asl. The Mackenzie River and major tributaries are incised approximately 50 m to 150 m below the plain (Hamilton, 1995). Topography within the plain consists of gently undulating hills, hummocks and plateaus. Elevation decreases from south to north along the mainstem of the Mackenzie River (IORVL, 2004).

The Mackenzie Plain is bound to the west and east by the Mackenzie and Franklin Mountains, respectively. The Franklin Mountains are series of northwest to southeast trending thrust and fold ranges consisting of the Norman Range north of Great Bear River, and the McConnell Range south of Great Bear River (Figure 2.1). The maximum elevation along the Norman Range is approximately 975 m asl, while Clark Mountain within the McConnell Range rises to approximately 1,500 m asl (NRCan, 2016).

4.2 Permafrost

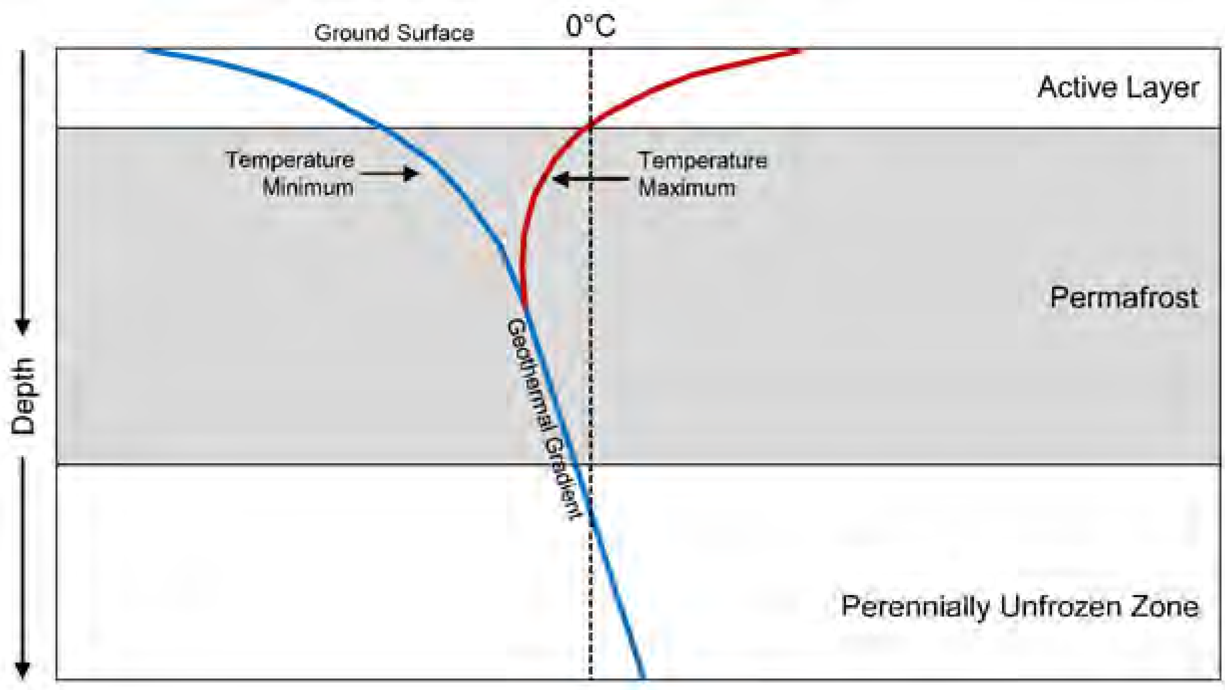
4.2.1 Thermal Ground Regime

A simplified ground thermal regime typical in permafrost regions is provided on Figure 4.1. The vertical temperature profile results from the long-term balance between incident solar radiation and reflected and re-radiated radiation from the ground surface (i.e., climate), and the input of geothermal heat from the Earth’s interior. Other factors influencing the ground thermal regime include elevation, soil type, soil moisture content, slope aspect, overlying vegetation, and snow cover (Burgess and Smith, 2000).

Permafrost is soil or rock with a temperature below zero degrees Celsius (0°C) for at least two consecutive years (Dobinski, 2011). In permafrost terrain, the active layer is the horizon immediately below ground surface that freezes and thaws each year, coincident with annual atmospheric temperature variations (Burgess and Smith, 2000). Permafrost is the zone below the active layer and above the perennially unfrozen zone.

The thickness of the permafrost zone can range from less than a metre to hundreds of metres at depending on location and conditions (Walvoord and Kurylyk, 2016). The permafrost zone is thin or absent at Fort Simpson, about 185 km southeast of Wrigley, and it ranges from 35 m to 135 m thick near Norman Wells (Taylor et al., 2000).

Figure 4.1 Typical Ground Thermal Profile



The thickness of the active layer depends on seasonal atmospheric temperature variations, longer-term climate trends, topography of the ground surface, the heat conductivity and water content of the subsurface material, and ground cover conditions (Burgess and Smith, 2000).

Between 1993 and 1998, the active layer thickness in the Mackenzie Valley, at monitoring sites instrumented with thaw tubes by the Geological Survey of Canada (GSC), ranged from 0.38 m to 1.82 m (Nixon, 2000). In 2017, the active layer thickness at monitoring sites, where permafrost was encountered and instrumented with thaw tubes and thermistor strings, ranged from 0.78 m to 7.68 m (Duchesne et al., 2020).

There is broad consensus among authors that climate change will result in a decrease in permafrost thickness and, potentially, an increase in the thickness of the active layer (Nixon, 2000; Wright et al., 2000, Bense et al., 2009, Walvoord and Kurylyk, 2016). The active layer at sites instrumented by Nixon (2000) generally increased in thickness between 1993 and 1998 but, due to thaw settlement, not always.

The hydrogeological effects of a thicker active layer are discussed in Section 5.3, Climate Change.

4.2.2 Distribution

The regional distributions of permafrost and of ice-content within the Mackenzie Plain were mapped by Heginbottom et al. (1995) and Heginbottom (2000) and are provided on Figure 4.2 (from K'alo-Stantec, 2021). The distribution of permafrost is classified as *extensive*, *intermediate*, or *sporadic discontinuous permafrost*. Extensive permafrost is generally associated with the higher altitudes of the Norman and McConnell Ranges (Heginbottom, 2000). Sporadic permafrost occurs primarily east of the Mackenzie River and to about 50 km north of Wrigley (Figure 4.2).

The distribution of ground ice content near the project highway alignment has been reported as low or moderate, indicating distributions of 0 percent (%) to 5% or 5% to 15%, respectively (Heginbottom, 2000). Higher moisture content is associated with flatter, lower permeability surficial sediments blanketing the Mackenzie Plain. Lower moisture content is associated with higher permeability surficial sediments, where they exist, and with higher permeability bedrock exposures and better-drained terrain of the Norman and McConnell Ranges (Figure 4.2).

4.2.3 Permafrost Influence on Groundwater Flow

4.2.3.1 Confining Layer

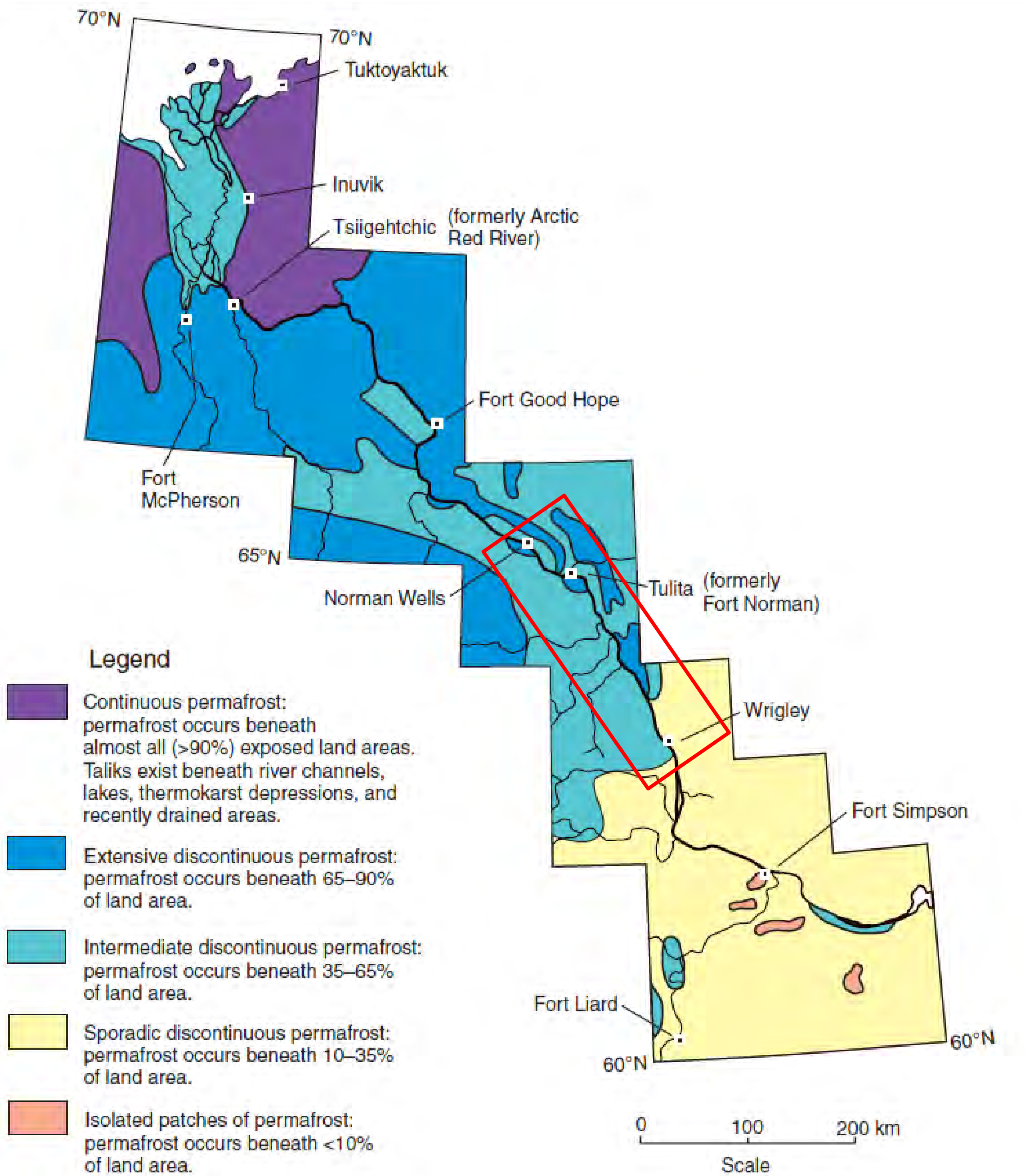
The distribution of permafrost and moisture content has a considerable impact on surface and groundwater hydrological processes in northern climates (Walvoord and Kurylyk, 2016). Moisture content is particularly important because the transition from unfrozen to frozen ground and the associated phase change from liquid to ice reduces the permeability of saturated porous media by several orders of magnitude (McCauley et al., 2002 *in* Walvoord and Kurylyk, 2016; Bense et al., 2009, 2012). As a result, ice-saturated permafrost is generally regarded as a confining layer and a barrier to groundwater flow (Bense et al., 2009, 2012; Walvoord et al., 2012). Groundwater flow that occurs seasonally or perennially above the permafrost horizon is supra-permafrost flow, while flow that occurs in the perennially thawed zone below permafrost is sub-permafrost flow (Walvoord and Kurylyk, 2016).

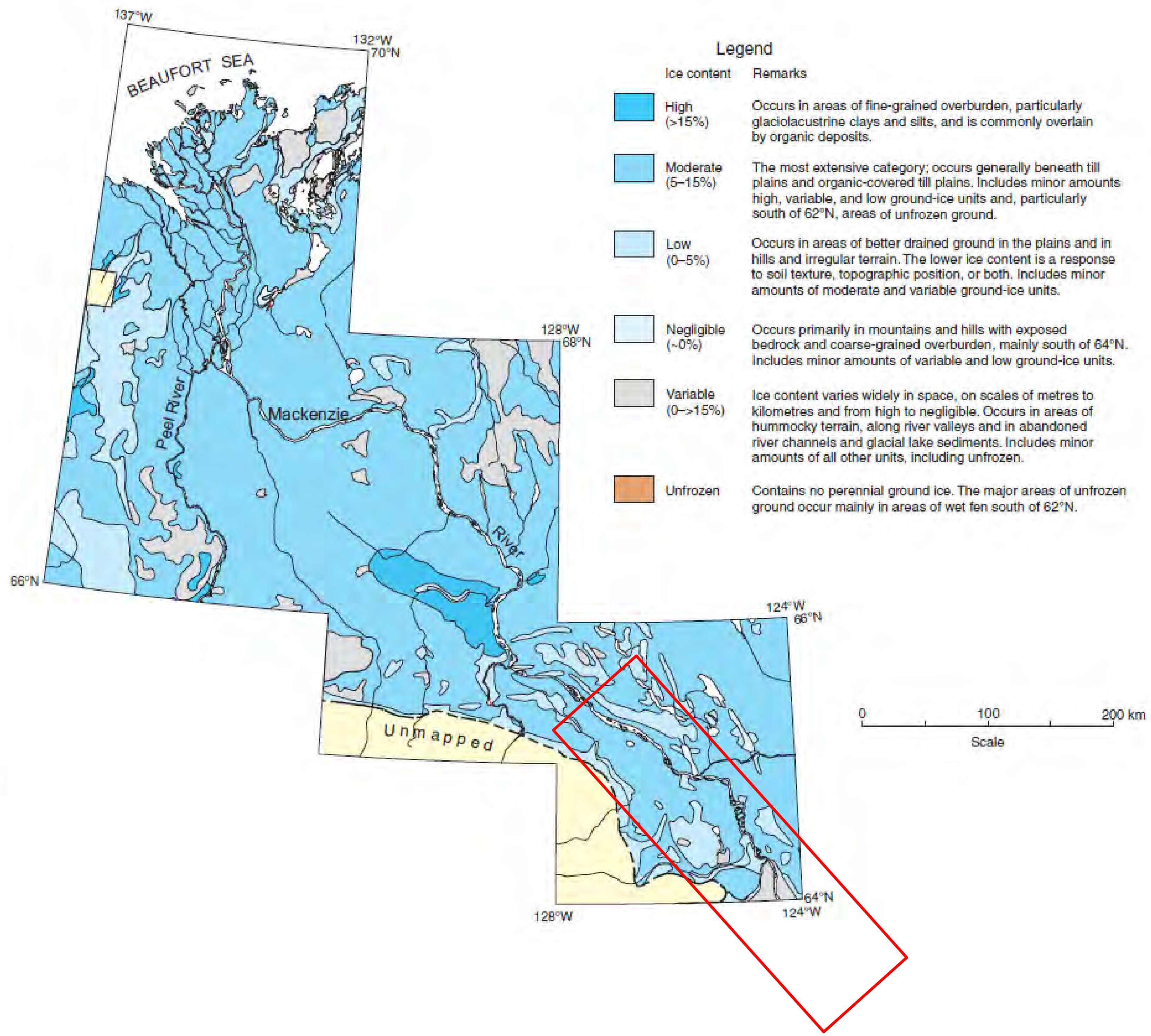
Figure 4.2 presents the permafrost distribution and the expected distribution of ground-ice within the Mackenzie Valley, based on mapping by Heginbottom (2000). The red rectangles indicate the approximate location of the project highway alignment.

The effect of permafrost as a confining layer and barrier to groundwater flow will be greater along the northern two thirds of the project highway alignment than along the southern third: permafrost is expected to underlie 35% to 90% of the land surface (northern two thirds) compared to 10% to 35% of the land surface (southern third); see Figure 4.2.

The degree to which permafrost acts as a confining layer depends on the direction of groundwater flow, the permeability of the hydrostratigraphic unit where flow occurs, and the magnitude of the flow gradient. Where flow has a downward component (i.e., recharge areas), permafrost may considerably limit vertical flow (Michel, 1986). Where flow has a minor upward component (i.e., local discharge areas) permafrost may act as a confining layer. Where flow gradients have a stronger upward component in relatively permeable material (i.e., regional discharge areas) advective heat transport from upwelling groundwater can produce and maintain open taliks (Bense et al., 2012).

Figure 4.2 Permafrost and Ice Content Distribution in the Mackenzie Plain





Notes:

1. The red polygons show the approximate location of the Project
2. From Heginbottom (2000).

4.2.3.2 Supra-Permafrost Flow in the Active Layer

Where permafrost exists, the seasonal active layer exerts control on surface and near-surface water storage, drainage, and routing (Walvoord and Kurylyk, 2016). In general, the active layer begins to thaw after snowmelt. Due to the limited thickness of the layer, most of the initial melt is rejected as recharge, which results in extensive surface ponding and runoff (Woo, 1986). As the thawing front advances and the active layer deepens, the storage capacity of the active layer increases and water levels may decline below ground surface. Key drivers in the maximum thickness of the active layer include climate, vegetation, and soil conditions (grainsize distribution and ice-content) (Walvoord and Kurylyk, 2016).

Water held in the active layer includes snowmelt, precipitation, and subsurface ice contributions (Woo, 1986). Groundwater flow within the active layer is governed by permeability and gradient. Shallow or near flow gradients are generally topography driven, and minor changes in slope may cause groundwater–surface water exchange: water will fluctuate from just above to just below ground surface as it moves downslope (Nielson et al., 2018). Minor topographic lows or areas where slope drainage is obstructed may cause ponding (Woo, 1986). Ponding, in turn, may result in a deepened active layer, increased ground-ice melting, and settlement of thaw (Mu et al., 2018). Thermokarst are processes and landforms that result from collapse of the ground surface due to melting ground ice (Kokelj and Jorgenson, 2013).

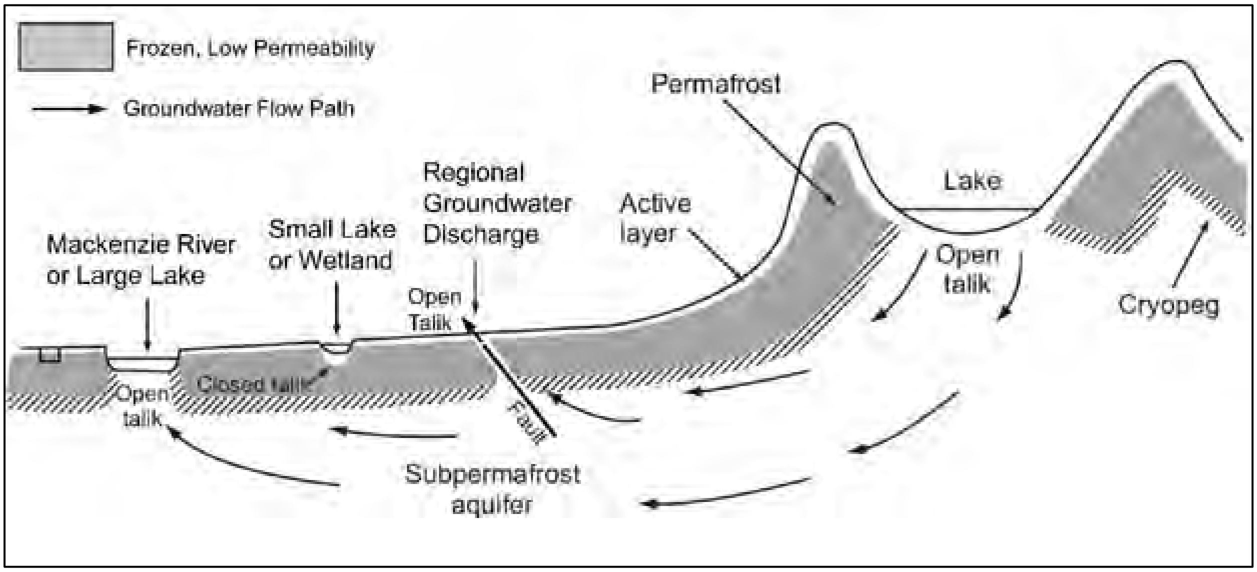
Summer precipitation events may rapidly exceed the limited storage capacity of the active layer and precipitation rapidly drains as surface runoff, forming shallow drainage features as a result (Mu et al., 2018). Within the LSA, apparent drainage flow paths (gullies) were mapped at a 1:10,000 scale using available aerial photography, ortho-imagery, and LiDAR-derived data available for the project (Appendix B, K'alo-Stantec, 2021).

Supra-permafrost groundwater begins to freeze in fall as the freezing front penetrates the ground surface. Groundwater can be confined between underlying permafrost and the descending freezing front, which causes groundwater to flow to areas of lowest hydraulic potential (pressure). Where pressure exceeds overlying lithostatic pressure, the ground surface may be lifted at points of weakness and frost blisters may form (Woo, 1986).

4.2.3.3 Taliks

Taliks are areas of unfrozen, saturated subsurface material beneath surface water features in regions underlain by extensive permafrost (Walvoord and Kurylyk, 2016). Closed taliks are unfrozen areas that penetrate deeper into the permafrost horizon than the surrounding active layer. Open taliks are unfrozen areas that completely penetrate the permafrost horizon and are hydraulically connected to the underlying sub-permafrost groundwater system. A schematic adapted from Lemieux et al. (2016) illustrating open and closed taliks in continuous permafrost is provided on Figure 4.3. In those parts of the LSA and RSA where permafrost is discontinuous, sub and supra-permafrost groundwater flow systems are considerably more hydraulically connected.

Figure 4.3 Schematic of Open and Closed Taliks (Adapted from Lemieux et al., 2016)



An open talik underlies the mainstem of the Mackenzie River (Taylor et al., 1998; Dyke, 2000) and connects the river to regional groundwater flow paths. Other open taliks in the region and within the RSA likely exist beneath streams and lakes of sufficient size. Open taliks may exist where there is regional groundwater discharge along the base of the Franklin Mountains (Michel, 1986). Closed taliks likely exist beneath smaller lakes and wetlands and, at these features, groundwater-interactions may be limited to the supra-permafrost flow.

4.2.3.4 Baseflow

Permafrost minimizes spring melt or precipitation event storage in the subsurface by restricting water storage to the active layer, and stream hydrographs in permafrost regions may show rapid streamflow response to these events (Brooks, 2000). Baseflow may also be severely limited where regional groundwater discharge pathways are absent and, in the CMV, many streams seasonally freeze to ground surface during the winter. In general, IORVL (2004) showed that streams draining watershed areas greater than 100 square kilometres (km^2) sustain perennial flow. Streams draining watershed areas less than 100 km^2 may be perennial or seasonal (i.e., freeze to the bottom in winter), depending on the scale of groundwater discharge.

IORVL (2004) completed visual surveys along the Mackenzie Gas Project route in April 2002 and noted that if streams at right-of-way crossings were frozen to ground, then they contained icings (accumulations of layered ice formed by continuous freezing of slow discharge water) or ice jams or contained open water. Ice jams and open water were considered strong evidence of groundwater contribution to baseflow.

Visual survey results completed by IORVL (2004) at right-of-way stream crossings are summarized in Appendix A.

Open water was observed at Hodgson, Steep, and Vermillion Creeks. Icings were noted at Ochre and Blackwater Rivers, and at White Sand, Big Smith, Christina, Hellava, Francis, and Canyon Creeks (Appendix A, Table A.1).

4.3 Surficial Geology

The surficial geology within the RSA includes till, glaciolacustrine, glaciofluvial, alluvial, eolian, colluvium and organic deposits that have formed during and since the last continental glaciation (Alysworth et al., 2000; Duk-Rodkin and Lemmen, 2000). The maximum extent of the Laurentide ice sheet in the Mackenzie Valley reached the Beaufort Sea about 30 thousand years before present (30 ka BP), depositing ice-contact till and glaciofluvial sediments as it moved northward (Duk-Rodkin and Lemmen, 2000). Subsequent glacial retreat to 13 ka BP resulted in the formation of Glacial Lake Mackenzie, which extended from about Fort Good Hope to south of Wrigley. By 10 ka BP the lake was completely drained, leaving extensive deposits of glaciolacustrine silts and clays overlying the till deposited by the glacial advance (Duk-Rodkin and Lemmen, 2000).

Subsequent erosion through these glacial and glaciolacustrine materials by the Mackenzie River and tributaries resulted in alluvial sediment deposition along their channels. Mass wasting processes resulted in colluvium deposition along escarpments and steeper topography. Organic bog and fen materials have gradually accumulated in areas of flatter topography (K’alo-Stantec, 2021).

Sediment descriptions, thickness, qualitative permeability estimates, and hydrostratigraphic interpretations of these deposits are summarized in Table 4.1. K’alo-Stantec has inferred hydrogeological characteristics from the general grainsize distribution implied by each sediment description.

The distribution of surficial geology within the RSA is provided in Appendix B, Figures B.1 to B.16, based on maps released by the GSC (Rutter et al., 1993; Duk-Rodkin, 2002; Duk-Rodkin and Couch, 2004; Duk-Rodkin and Huntley, 2009; Côté et al., 2013; GSC, 2019a, 2019b). Brief descriptions of these sediments based on the GSC maps are provided below, focusing on their distribution and relationship to groundwater flow paths. More detailed mapping and descriptions of these sediments are provided in the TDR, Soils, Terrain, and Permafrost (K’alo-Stantec, 2021).

Table 4.1 RSA Sediment Hydrostratigraphy

Deposit[1]	Sediment Description[1]	Thickness[2]	Qualitative Saturated Permeability[3]	Hydrostratigraphic Interpretation
Glaciolacustrine	Silt, sand, minor clay	to 50 m	Low	Confining layer
Till	Dominantly silt and clay-matrix till	To 30 m	Very low to low	Confining layer
Colluvium	Rubble, gravel, sand	to 10's of metres	Moderate to very high	Potential aquifer
Alluvial	Gravel, sand, silt	-[4]	Moderate to high	Potential aquifer
Glaciofluvial	Gravel, sand, silt	to >30 m	Moderate	Potential aquifer
Organic	Fens and bogs	1.5 m to 7 m	Low to high	-
Eolian	Sand, minor silt	to 20 m	Moderate	Potential aquifer

Notes:

1. Deposit types and sediment descriptions from Rutter et al., 1993.
2. Thickness from maps and reports by the GSC.
3. Qualitative permeability based on permeability ranges for sediment types in Freeze and Cherry (1979).
4. "-"denotes not available or applicable.

4.3.1 Low Permeability Sediments

Till deposits are found over a large portion the Mackenzie Plain (Rutter et al., 1993). These deposits cover 19% of the area within the RSA, generally overly bedrock and are up to 30 m thick (K'alo-Stantec, 2021). These tills are clay-and-silt matrix supported and compact (Savigny, 1989) and, based on literature values of permeability for similar tills (Freeze and Cherry, 1979), likely low-permeability.

Glaciolacustrine deposits are found over a large portion of the Mackenzie Plain (Rutter et al., 1993). These deposits cover 38% of the area within the RSA, generally overlie till, and are up to 50 m thick. Deposits of silt and fine sand are common in the south and central portions of the RSA, while clay sediment is more common in the northern portion (K'alo-Stantec, 2021). Clay-dominated deposits generally have very low permeabilities. Silt and fine sand deposits will tend to have low-to-moderate permeabilities that decrease with the increasing fraction of silt (Freeze and Cherry, 1979).

Due to their low permeability and broad distribution across the Mackenzie Plain and RSA, till and glaciolacustrine deposits likely act as regional confining layers and barriers to groundwater flow. Locally, these sediments will restrict groundwater recharge and encourage ponding and near-surface saturated conditions, conditions that will be exacerbated where permafrost exists. Regionally, these sediments will restrict groundwater discharge and artesian pressures may form in underlying aquifer units.

4.3.2 Moderate Permeability Sediments

Glaciofluvial deposits are found sporadically across the Mackenzie Plain (Rutter et al., 1993). These deposits cover about 5% of the area within the RSA (K'alo Stantec, 2021) and are up to more than 30 m thick. Deposition directly or close to glacial ice tends to produce a well-graded deposit; there is a distributed range of silt, sand, and gravel grainsize fractions. As a result, the permeability of glaciofluvial sediments will decrease with increasing silt fraction and increase with increasing sand and gravel fractions (Freeze and Cherry, 1979).

The limited distribution of glaciofluvial sediment within the RSA and the Mackenzie Plain will limit the effect these sediments have on regional groundwater flow. Locally, deposits with higher silt content may act as confining layers and barriers to groundwater flow. Deposits with higher sand and gravel content may encourage groundwater recharge and, where permafrost is limited or where these deposits exist beneath permafrost, may constitute good-quality aquifers for potable water.

Eolian deposits are found to a limited extent within the Mackenzie Plain and cover less than one percent of the RSA (K'alo-Stantec, 2021). Transport by wind energy limits these deposits to silt and fine sand, and, as a result, permeabilities tend to be low to moderate (Freeze and Cherry, 1979). Due to their limited extent, these deposits will have minimal influence on the regional and local hydrogeology within the LSA and RSA.

4.3.3 High Permeability Sediments

Alluvial sediments are found along modern stream channels and valley floors within Mackenzie Plain, covering about 14% of the RSA (K'alo Stantec, 2021). These sediments are poorly graded relative to glaciofluvial sediments and till, and permeabilities will depend on primary grain size fractions. Deposits dominated by silt and fine sand will have moderately low permeability. Deposits with primarily sand and/or gravel grainsize fractions will have high and potentially very high permeabilities (Freeze and Cherry, 1979).

Locally, alluvial sediments will encourage groundwater recharge where permafrost is limited and may constitute good-quality aquifers for potable water. Sand and gravel deposits will be substantially better aquifers than silt dominated deposits. The degree of hydraulic connection with nearby surface water bodies will generally need to be considered.

Colluvium deposits cover about 8% of the RSA and are generally found along the base of slopes in the Franklin Mountains (K'alo-Stantec, 2021). These deposits include surficial material that has reached its present position from gravity-induced movement: by slow mass movement or slow-to-fast moving landslides. Colluvium is derived from both bedrock and from pre-existing deposits of other surficial materials.

Also mapped in the RSA, as colluvium on level to gently sloping surfaces, are materials that could be more appropriately identified as in-situ weathered bedrock. Karst features have developed in areas where dolostone or limestone bedrock is weathering, and these materials may have very high permeabilities (Michel, 1986; Ford, 2009).

The hydrostratigraphic properties of colluvium will depend on the parent material and local depositional setting. Regionally, because of their exposure across higher elevations and association with karst landforms, colluvium deposits are important areas of regional groundwater recharge (Ford, 2009).

Organic deposits cover about 2% of the RSA and are mainly composed of organic materials resulting from the accumulation of vegetative matter, typically in poorly to very poorly drained, level and depressional areas (K'alo-Stantec, 2021). These materials may have a range of permeabilities depending on the material structure and degree of decomposition (Attila et al., 2005).

4.4 Bedrock Geology

4.4.1 Structure

Bedrock near the project highway alignment comprise clastic and chemical sedimentary rocks of the Mackenzie Fold Belt, which includes the Mackenzie Mountains, the Mackenzie Plain, and the Franklin Mountains (Douglas et al., 1970, *in* Michel, 1986). Large-scale, regional folding during the Cretaceous is the main structural stress that has folded Cambrian to Cretaceous strata into a broad, asymmetric, northwest-southeast oriented syncline beneath the Mackenzie Plain. The western limb forms the eastern margin of the Mackenzie Mountains, and the eastern limb forms the western slopes of the Franklin Mountains (Hayes and Dunn, 2012; Golder, 2015).

Faulting has also occurred: the Franklin mountains largely consist of isolated ridges of sedimentary stratigraphy thrust upwards and exposed at surface (Hannigan et al., 2011). Exposed bedding planes strike approximately northwest to southeast and dip westwards towards the Mackenzie River (i.e., the eastern limb of the regional syncline). Exposed bedding planes and associated thrust faults are regionally important for groundwater recharge and movement (Van Everdingen, 1981; Michel, 1986; Hamilton, 1995; Ford, 2009).

4.4.2 Outcrop

Bedrock formations within the RSA and the Mackenzie Plain are generally covered by surficial deposits and only about one percent of the RSA area is exposed bedrock (K'alo-Stantec, 2021). The Bear Rock Conservation Zone, immediately north of the confluence of the Great Bear and Mackenzie Rivers, is the location of the largest area of outcrop within the RSA (Appendix B, Figure B.13), although smaller exposures have been mapped throughout the RSA (K'alo-Stantec, 2021). Outcropping bedrock formations include the Bear Rock Group and the Hume, Franklin Mountain, and Saline River formations (Appendix B, Figures B.1 to B.16).

4.4.3 Karst

The Franklin Mountains contains formations with thick sequences of limestone, dolostone, and evaporites that have undergone dissolution weathering and produced extensive karst sinkhole and ponor landforms (Ford, 2008, 2009). These landforms exert considerable influence on the regional groundwater system and on baseflow in streams east of the Mackenzie River (Michel, 1977 *in* Michel, 1986; Heginbottom, 2000; IORVL, 2004; Ford, 2009; Dessau, 2012; Golder, 2015). As a result, karst hydrogeology has a considerable influence on local groundwater conditions within the groundwater LSA and RSA.

In well-developed karst regions, a large percentage of precipitation commonly infiltrates the subsurface as recharge (Van Everdingen, 1981). In colder climates, permafrost can reduce recharge into karst and in many areas of widespread or continuous permafrost karst groundwater recharge conduits become inert (Ford, 2008). However, inert karst features within the Franklin Mountains were covered by the Laurentide ice sheet during the last glaciation, which may have resulted in permafrost degradation (Hamilton, 1995). As a result, numerous karst recharge features and groundwater flow paths have been re-activated since the last glaciation and, at these locations, permafrost has not re-established as a barrier to groundwater flow (Hamilton, 1995).

An important karst environment is located within the Bear Rock Conservation Zone (SLUB, 2013) where pinnacle, ponor, and sinkhole karst landforms have developed (Ford, 2008). Permafrost locally perches surface water in small ponds, but these ponds generally drain through summer and fall, indicating that the permafrost is only a partial confining layer. Many of the sinkholes and ponors apparently function as seasonal recharge taliks to sub-permafrost groundwater systems (Hamilton, 1995).

4.4.4 Stratigraphy

A general stratigraphic column and lithologic descriptions of the sedimentary bedrock formations underlying the CMV in the RSA is provided in Table 4.1. The complete Cambrian to Tertiary stratigraphy in the area is approximately 3,000 m thick.

A summary of permeability and a hydrostratigraphic interpretation, where possible, of each bedrock formation is also provided in Table 4.1. The distribution of bedrock formations in the RSA is shown in Appendix C, Figures C.1 to C.16.

The Saline River, Franklin, and Mount Kindle Formations and the Bear Rock Group inferred by K'alo-Stantec as important to groundwater flow in the LSA and RSA are described in more detail in the following sections. The development of extensive karst landforms and preferential dissolution flow paths considerably influences the hydrostratigraphic interpretations of these units (Table 4.2).

Other formations, in particular the Early Cretaceous to Paleocene stratigraphy outlined in Table 4.2, may be regionally important aquifers (Hayes and Dunn, 2012). However, these formations within the RSA and LSA are generally covered by low permeability till, glaciolacustrine deposits, and permafrost. K'alo-Stantec infers potential effects from the Project on these potential bedrock aquifers will be negligible; therefore, these formations are not currently described in further detail in this TDR.

Table 4.2 RSA Bedrock Hydrostratigraphy

Age (Ma BP)[1]	Period[2]	Formation or *Group*[2,3,4]	Lithology[2]	Maximum thickness[2]	Permeability[2]	Hydrostratigraphy[2]
100 to 56	Late Cretaceous and Paleocene	Summit Creek	Conglomerate, sandstone, coal	400	Moderate to High	Potential regional aquifer
100 to 68	Late Cretaceous	East Fork	Shale	500	-[6]	Confining layer[5]
Unconformity[8]						
100 to 68	Late Cretaceous	Little Bear	Sandstone, coal	560	High	Potential regional aquifer
		Slater River	Shale, sandstone	400	Low[5]	Confining layer[5]
Unconformity[8]						
145 to 100	Early Cretaceous	Mahony Lake	Sandstone, siltstone, shale	-	-	-
		Sans Sault Member	Sandstone, siltstone, shale	100	-	-
		Arctic Red	sandstone, shale, interbedded siltstone	400	-	Potential regional aquifer in sandstone units. Confining layer in shale units[5]
		Martin House	Interbedded sandstone, siltstone, shale	100	-	Potential regional aquifer
Unconformity[8]						
385 to 355	Late Devonian	Imperial	shale, sandstone, minor limestone	400	Low[5]	Confining layer[5]
395 to 355	Middle to Late Devonian	*Horn River*	Shale, siltstone, limestone,	565	Low	Contains porous intervals[5]
		Hume	Limestone and shale	300	Low[5]	Confining layer[5]
420 to 385	Early to Middle Devonian	***Bear Rock***[5]	Limestone, dolostone, gypsum, and anhydrite breccias	470	High (Karst)[7]	Karst Features. Presence of dissolution channels. The major bedrock aquifer in the CMV.
		Tsetso	Siltstone, sandstone, dolostone	100	-	-

Age (Ma BP)[1]	Period[2]	Formation or ***Group***[2,3,4]	Lithology[2]	Maximum thickness[2]	Permeability[2]	Hydrostratigraphy[2]
Unconformity[8]						
460 to 440	Middle Ordovician to Early Silurian	**Mount Kindle[5]**	Dolostone, sandstone	250	High, (Karst)[7]	Potential regional aquifer
Unconformity[8]						
540 to 450	Cambrian to Ordovician	**Franklin Mountain[5]**	Dolostone	300	Low to High (Karst)[7]	Potential regional aquifer
510 to 490	Middle to Late Cambrian	**Saline River[5]**	Gypsum, anhydrite, halite, shale, siltstone, dolostone	500 to 750[7]	Low to High (Karst)[7]	Potential regional aquifer
Unconformity[8]						
540 to 500	Early to Middle Cambrian	Mount Cap	Shale, siltstone, dolostone, sandstone	-	Low to High (Karst)[7]	Potential local aquifer
		Nainlin	Shale, sandstone, conglomerate	-	-	-
		Mount Clark	Sandstone	50	-	-

Notes:

1. "Ma" is million years before present; approximate age ranges only; provided for context; based on the formation period age.
2. Based on Tables 3-8 and 3-10 in Golder (2015). Information from Golder (2015) unless otherwise noted.
3. ***Underlined and italicized*** indicates a group rather than a formation.
4. **Bolded** formations indicate those K'alo-Stantec infer are important for groundwater flow pathways within the LSA and RSA.
5. Identified as an aquifer or confining layer in AMEC, 2014 (Figure 5).
6. "-" denotes information not available or interpretation was not possible.
7. From on Michel (1986) and Hamilton (1995).
8. "Unconformity" is a break in an otherwise continuous rock record caused by erosion or a pause in sediment accumulation.

4.4.4.1 Saline River Formation

North of Great Bear River, the Saline River Formation outcrops along the east slopes of the Norman Range. South of Great Bear River, the formation outcrops on the west flank of the McConnell Range. Within the groundwater LSA and RSA, the formation is largely covered by till or colluvium, and it is composed of evaporites (halite and gypsum), shale, dolomite, and anhydrite (Serié et al., 2013). Beneath the western slopes of Norman Range, the evaporite sequences are more than 750 m thick (Michel, 1986).

Recessive weathering where the evaporites outcrop indicates that regional dissolution is occurring that likely produces high-permeability preferential flow paths (Michel, 1986). Halite (sodium chloride) is "*hypersoluble*" (Van Everdingen, 1981), and dissolution of thick halite sequences tend to markedly increase sodium and chloride ions in solution. As a result, the Saline River Formation is generally regarded as a major but poor-quality bedrock aquifer in the region (Golder, 2015).

4.4.4.2 Franklin Mountain Formation

The Franklin Mountain Formation is composed of about 300 m thickness of dolostone and displays considerable development of sinkhole, ponor, and river-sink karst landforms where the formation intersects ground surface. The formation primarily outcrops east of the Norman Range, but also outcrops within the Bear Rock Conservation Zone and within the Norman Range north of Great Bear River (Michel, 1986; Hamilton, 1995). The formation outcrops along the project highway alignment in the Bear Rock Conservation Zone (Appendix C, Figure C.13). The aquifer potential of this formation is primarily a result of karst feature development and dissolution weathering.

4.4.4.3 Mount Kindle Formation

The Mount Kindle Formation is composed of about 500 m thickness of thick-bedded, fossiliferous dark grey dolostone (Hannigan et al., 2011) that develops considerable karst landforms (Van Everdingen, 1981) The aquifer potential of this formation is primarily a result of karst feature development and dissolution weathering. The Mount Kindle Formation does not outcrop within the groundwater LSA or RSA.

4.4.4.4 Bear Rock Group

The Bear Rock Group summarized in Table 4.2 combines the Arnica, Landry, and Fort Norman Formations (Golder, 2015). These formations are composed of limestone, dolomite, gypsum, and solution breccia (Morrell et al., 1995). The Bear Rock Group is described as having "*cavernous porosity*" in the subsurface (Hume, 1954 *in* Hamilton, 1995) and the Bear Rock Group is generally regarded as a major bedrock aquifer in the region (Golder, 2015). The aquifer potential of this formation is primarily a result of karst feature development and dissolution weathering.

The Bear Rock Group outcrops within the groundwater LSA and RSA, primarily within the Bear Rock Conservation Zone (Appendix B, Figure B.13), and sporadic outcrop has also been mapped within the LSA and RSA along the project highway alignment (Appendix B, Figure B.1 to B.16). The largest exposures outside of the Bear Rock Conservation Zone are near Wrigley (Appendix B, Figures B.1 and B.2).

4.5 Groundwater Quality

Groundwater sampling completed within the CMV include efforts to understand karst hydrology (e.g., Van Everdingen, 1981; Michel, 1986; Hamilton, 1995), efforts to assess effects from the Mackenzie Gas Project (IORVL, 2004) , and efforts to characterize deep groundwater aquifers for oil and gas exploration support (AMEC, 2014).

Summaries of the chemistry analyses reported by Michel (1986) and by IORVL (2004) are provided in Appendix D1, Table D1.1 and Table D1.2, respectively.

Michel (1986) reported major ion and environmental isotope chemistry analyses from 12 groundwater discharge locations sampled by Michel (1977) between the Mackenzie River and the Franklin Mountains, from Wrigley to Norman Wells (Table 4.3). Figure D2.1 in Appendix D2 provides a plan map of the sampled locations.

Concentrations of major ions in seep discharge are relatively high, reflecting the solubility of the bedrock minerals encountered along the groundwater flow path. Michel (1986) showed that the concentrations of sodium (Na^+) and chloride (Cl^-), calcium (Ca^{2+}), and sulfate (SO_4^{2-}) ions closely approximate linear relationships. This suggests the source of these ions are primarily halite ($NaCl_{(s)}$) and gypsum ($CaSO_4 \cdot 2H_2O_{(s)}$) and anhydrite ($CaSO_{4(s)}$), respectively, which occur within the Saline River Formation and Bear Rock Group (Appendix D1, Table D1.1).

Oxygen-18 (^{18}O) and Deuterium (^2H) isotope fractionation ratios for the springs sampled by Michel (1986) ranged from -22.8 permil (‰) to -23.7 ‰, consistent with modern precipitation values for cooler climates (Appendix D1, Table D1.1). This indicates the springs were sourced from relatively recent recharge events after the last glacial period. In contrast, Michel (1982), as reported in Michel (1986), showed that ground ice from drill core retrieved from four locations between Wrigley and Norman Wells contained oxygen-18 fractionation ratios depleted to about -31‰, indicating recharge that took place during a cooler climate, inferred to be late Wisconsian age (about 10 ka BP). These oxygen-18 vs. depth profiles from Michel (1982), as reported in Michel (1986), are provided in Appendix D2 for context.

IORVL (2004) sampled springs between Wrigley and Norman Wells in spring and summer 2002 and 2003, aiming to re-sample locations first sampled by Michel (1977). Tabulated chemistry analysis results were not provided, but the groundwater quality of various springs was discussed in some detail. Appendix D1, Table D1.2 provides a summary of the groundwater quality information provided in IORVL (2004), including water type, discharge rate measurements, and concentrations of total dissolved solids (TDS). Location maps for the springs are provided in Appendix D3.

Chemistry analyses reported by AMEC (2014) are provided in Appendix D4, Table D4.1. These samples were generally collected from wells installed at a considerable depth below ground surface and within early cretaceous and younger stratigraphy west of the Mackenzie River (outside the groundwater RSA). As discussed in Section 4.4.4, Stratigraphy, the potential aquifers within these formations are not expected to be affected by the Project and these samples are not discussed in further detail in this TDR.

4.6 The Groundwater Resource

4.6.1 Potable Water

Until 2014, Wrigley relied on a groundwater for the community water source (GNWT, 2013). Michel (1986) and IROVL (2004) indicated that two wells have been drilled for the community. Both are completed in surficial sediments. The "*airport*" well is screened in unfrozen sand and gravel and provides high-quality potable water (Michel, 1986). The Wrigley town well is screened in glaciolacustrine silts and produces much lower-quality water (Michel, 1986). IORVL (2004) notes "*a deeper well was drilled for the community in about 1970*", which may be the well screened in glaciolacustrine silts referenced by Michel (1986). This "*deeper well*" is 48.8 m deep, produces 0.92 litres per second (L/s) groundwater with chloride concentrations between 539 mg/L and 573 mg/L, which was described as unsuitable for community use (IORVL, 2004).

There are no references to bedrock aquifers exploited for potable water in the literature K'alo-Stantec reviewed.

4.6.2 Groundwater for Oil and Gas Exploration

Various desktop assessments have been completed with the aim of developing groundwater resources to support oil and gas exploration (Hayes and Dunn, 2012; AMEC, 2014; Golder, 2015). Table 4.3 summarizes the qualitative conclusions made by these authors on the viability and quality of specific bedrock formations for groundwater extraction, presumably for oil and gas exploration support.

Table 4.3 General Quality of Select Bedrock Aquifers in the CMV

Formation	Hayes and Dunn (2012)	AMEC (2014)	Golder (2015)
Summit Creek	Relatively fresh groundwater.	-	Most viable aquifer for fresh water, low TDS.
Little Bear	Formation waters are fresh to brackish. Optimal aquifer quality and water chemistry is found in Upper Cretaceous Little Bear sandstones that occur in the southern CMV.	Exceedances for some heavy metal parameters. Exceedances and detections of hydrocarbon parameters.	Optimal water quality and chemistry.
Martin House and Arctic Fox	Water analyses indicate variable salinity, with total dissolved solids ranging from 3,208 to 40,212 mg/L. Inferred that some units in these formations are exposed to recharge by meteroric waters while others are relatively isolated.	Exceedances for some heavy metal parameters. Exceedances and detections of hydrocarbon parameters.	Highly variable water quality.
Franklin Mountain	-	-	Generally poor water quality
Saline River	-	-	Major aquifer but generally poor water quality

Note:

1. "-" indicates formation was not discussed in the referenced report.

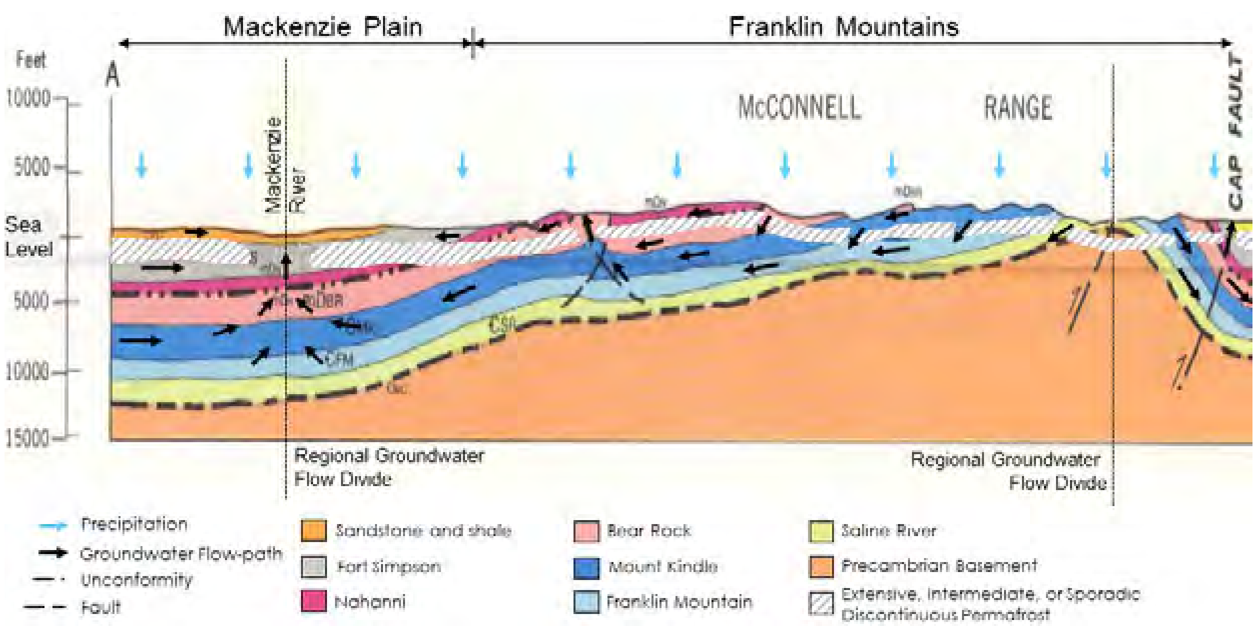
5 Conceptual Groundwater Flow Model

Groundwater flow systems are conceptualized as nested regional, intermediate, and local scale systems (Toth, 1963). Regional groundwater flow develops from large-scale topographic, physiographic, and geologic features: these features on the scale of the CMV. Local groundwater flow systems develop from smaller-scale variation of topography and geologic features; they are local flow, often dominated by one component of the regional flow system (Freeze and Cherry, 1979).

5.1 Regional CMV Groundwater Flow

Figure 5.1 (adapted from Map 1373A, GSC, 1993) summarizes K'alo-Stantec's general understanding of regional CMV groundwater flow along the project highway alignment.

Figure 5.1 Regional Groundwater Flow Schematic



5.1.1 Hydrostratigraphic Units

The major regional hydrostratigraphic units are bedrock units affected by dissolution weathering including the Saline River, Franklin, and Mount Kindle formations and the Bear Rock Group. Secondary porosity and permeability have been increased by continual groundwater circulation and dissolution of fractures, joints, and fault features in these units, therefore, they are expected to be the major conduits for regional groundwater flow.

Surficial deposits are much less important to regional groundwater flow because surficial deposits across the CMV are primarily low permeability till and glaciolacustrine sediments. Also, permafrost acts as a near-ground-surface barrier to groundwater flow and, therefore, primarily affects surficial deposits (Section 5.1.3, Groundwater Recharge).

5.1.2 Regional Flow Boundaries

The regional groundwater flow system relevant to the project highway alignment is bound by the Mackenzie River to the west and the Franklin Mountains to the east.

The Mackenzie River is a major surface water feature occupying the lowest topography within the Mackenzie Plain and is a regional groundwater discharge area and flow boundary. The Mackenzie River is underlain by an open talik (Taylor et al., 1998; Dyke, 2000) that connects the river to deeper sub-permafrost groundwater systems (Figure 5.1).

Regional groundwater flow from the west (Mackenzie Mountains) and from the east (Franklin Mountains) will converge at the Mackenzie River. Regional flow will not pass beneath the Mackenzie River unless induced by an artificial hydraulic gradient (e.g., pumping from a well) in a hydrostratigraphic unit disconnected from the overlying river (i.e., beneath a confining layer).

The Franklin Mountains is another regional groundwater flow divide. Groundwater flow paths diverge east and west along the mountain ranges following declining elevations. Groundwater discharge along the project highway alignment, where it occurs, likely will not originate from recharge areas farther eastward than the topographic highs of the Franklin Mountains (Figure 5.1).

5.1.3 Groundwater Recharge

Groundwater within the regional flow system will recharge primarily from melt and precipitation through karst landforms (e.g., sinkholes, ponors) within the Franklin Mountains. Recharge occurs through taliks beneath rapidly-draining weathered bedrock and karst landforms that perforate permafrost to underlying groundwater flow systems. These taliks may have been ice-filled and inert before the last glacial period, but they have been re-activated due to permafrost degradation from the insulating effect of the Laurentide ice sheet (Hamilton, 1995). The permeability of these taliks may be high enough that permafrost has not re-established a barrier to groundwater flow (Figure 5.1).

Groundwater recharge at lower elevations will be limited by extensive veneers/blankets of low permeability till and glaciolacustrine sediments covering much of the Mackenzie Plain. Where permafrost exists, groundwater recharge will be further reduced. Because groundwater recharge and subsurface storage is restricted by permafrost, many streamflow hydrographs in the area show a rapid increase to, and decline from, peak spring melt and peak summer precipitation events.

5.1.4 Groundwater Flow Paths

The permeability of sedimentary bedrock formations depends on the depositional environment, consolidation and cementation, and on subsequent deformational events that produce folds and faulting. In general, permeability along bedding planes will be higher than permeability across bedding planes (Freeze and Cherry, 1979). Between the Franklin Mountains and the Mackenzie River, the dominant structural feature is the eastern limb of the large-scale syncline underlying the Mackenzie Plain (Figure 5.1).

Regional groundwater flow paths are, therefore, down the eastern limb of the syncline, along western dipping stratigraphy, towards the Mackenzie River. Pore pressures increase along this flow path, and groundwater will flow upwards, following vertical joints and faulting upwards to areas of lower pressure. As a result, seep discharge at surface is often concentrated along fault traces, and thrust faults are a major mechanism by which deeper, regional groundwater flow paths discharge at surface (Michel, 1986).

The concentrations of chemical constituents increase along regional flow paths as bedrock dissolves and, in general, higher concentrations of major ions in seep discharge indicate a longer flow path and a greater “age” of groundwater recharge (Freeze and Cherry, 1979). Michel (1986) inferred from isotopic data that all the seeps sampled by Michel (1977) along the slopes of the Franklin Mountains were recharged since the last glacial period (about 10 ka BP).

5.1.5 Groundwater Discharge

Regional groundwater flow paths will discharge to surface through lower-elevation bedrock outcrops and higher permeability colluvial and/or alluvial deposits. Low permeability till and glaciomarine deposits, if present, will act as a barrier to discharge and artesian (above ground surface) pressure conditions may develop in underlying aquifer units. Permafrost, however, may not considerably impact regional groundwater discharge. Even where extensive discontinuous permafrost exists, the relatively higher temperature of groundwater discharge likely creates and maintains open taliks that connect deeper groundwater flow paths to the receiving surface environment. Areas of considerable regional groundwater discharge include the Mackenzie River and the western slopes and drainage channels of the Franklin Mountains.

5.2 RSA and LSA Groundwater Flow

Local groundwater recharge within the RSA is limited by the confining nature of extensive, low permeability till, glaciolacustrine sediments, and permafrost (where it exists). The confining effects of permafrost will be more important in the northern portion of the LSA than the southern due to its more extensive presence in northern areas of the LSA. Where it exists, permafrost will limit local groundwater flow paths and discharge to the supra-permafrost active layer.

Groundwater flow in the active layer is seasonal. In the spring, when the active layer is thinnest, slope drainage occurs as surface runoff that rapidly drains a large fraction of snowmelt (Woo, 1986). As the thawing front penetration continues, the active layer storage capacity increases and more flow occurs below ground surface. Summer precipitation events cause the water table in the active layer to rise, often rapidly. When the water table in the active zone rises above ground surface, surface runoff is generated, and ponding may occur in topographic lows or where slope drainage is obstructed. Where ponding occurs, the thawing front may advance deeper into permafrost, increasing the thickness of the active layer and potentially resulting in thaw settlement.

Regional groundwater discharge is also important within the LSA and RSA. Streams with considerable regional groundwater discharge may remain perennially ice free. These streams include Steep Creek in the Dehcho Region and Vermillion Creek in the Sahtu Region. Streams with smaller regional groundwater discharge contributions may experience the formations of icings. These streams include Ochre River, White Sand Creek and Blackwater River in the Dehcho Region and Big Smith Creek, Christina Creek, Hellava Creek, Francis Creek, and Canyon Creek in the Sahtu Region (IORVL, 2004).

The Bear Rock Conservation Zone has a local groundwater flow system where deeper, sub-permafrost flow paths have not been completely de-activated by permafrost or restricted by low permeability surficial sediments. Extensive weathered bedrock and karst sinkholes and ponors across a local topographic high composed of Saline River, Franklin, Kindle, and Hume formations, and the Bear Rock Group, resulting in groundwater recharge across a large local area (Hamilton, 1995). The PDA crosses a topographic saddle of exposed bedrock north of the Bear Rock recharge area, between Bear Rock and the greater extent of the Norman Range (Appendix B, Figure B.13). Groundwater discharge near the PDA may, therefore, consist of local recharge from Bear Rock mixed with deeper, regional groundwater discharge from the Franklin Mountains.

Estimates of groundwater travel time from recharge to discharge location are available for the Bear Rock Conservation Zone. Using dye tracer tests, Hamilton (1995) estimated groundwater travel time along shallow groundwater flow paths to be on the order of weeks. Van Everdingen (1981) constrained the travel time of deeper, regional flow paths in the area to be within the range of modern climactic conditions (e.g., less than 10 ka BP) using oxygen isotope tracers.

5.3 Climate Change

A warming climate (climate change) will likely affect both regional and local groundwater systems. The distribution of permafrost may be reduced, and regional recharge may increase, particularly along exposed bedrock in the Franklin Mountains and in areas not covered by till or glaciolacustrine sediments.

The local groundwater system, limited by permafrost (where it exists), is specifically susceptible to impacts of a warming climate. There is broad consensus among researchers that climate change will result in a decrease in permafrost thickness and, potentially, an increase in the thickness of the active layer (Nixon, 2000; Wright et al., 2000; Bense et al., 2009; Walvoord and Kurylyk, 2016). The thawing front, the depth at which frozen ground seasonally thaws, affects the distribution of runoff and baseflow (groundwater input) to streams from the shallow, supra-permafrost active layer (Yamazaki et al., 2005; Koch et al., 2014). As the thawing front deepens and the active layer becomes thicker, the direct runoff ratio may decrease (Yamazaki et al., 2005) and delayed contribution from baseflow may increase (Koch et al., 2014). This may fundamentally change streamflow in the North.

6 Closure

This TDR was prepared for the sole benefit of GNWT to describe existing conditions related to hydrogeology within the groundwater LSA and RSA. If you have any questions, please do not hesitate to contact the undersigned.

Respectfully submitted,

K'alo-Stantec Limited

7 References

7.1 Literature Cited

AMEC (AMEC Environmental & Infrastructure). 2014. Central Mackenzie Valley Subsurface Baseline Study. NWT Open File 2014-07, NWT Geoscience Office, Yellowknife, 99 p.

Attila, N., W.J. Rawls, and Y.A. Pachepsky. 2005. Influence of Organic Matter on the Estimation of Saturated Hydraulic Conductivity. Soil Science Society of America Journal 69: 1330-1337.

Aylsworth, J.M., M.M. Burgess, D.T. Desrochers, A. Duk-Rodkin, T. Robertson, and J.A. Traynor. 2000. Surficial Geology, Subsurface Materials, and Thaw Sensitivity of Sediments, in The Physical Environment of the Mackenzie Valley, Northwest Territories: a Base Line for the Assessment of Environmental Change. Geological Survey of Canada, Bulletin 547, p. 153-158.

Beale, G., and J. Read. 2013. Guidelines for evaluating water in pit slope stability. CSIRO Publishing, 150 Oxford Street, Collingwood VIC 3066. Australia.

Bense, V.F., G. Ferguson, and H. Kooi. 2009. Evolution of Shallow Groundwater Flow Systems in Areas of Degrading Permafrost. Geophysical Research Letters, Vol. 36, L22401.

Bense, V.F., H. Kooi, G. Ferguson, and T. Read. 2012. Permafrost Degradation as a Control on Hydrogeological Regime Shifts in a Warming Climate. Journal of Geophysical Research, Vol. 117, F03036.

Brooks, G.R. 2000. Streamflow in the Mackenzie Valley, in The Physical Environment of the Mackenzie Valley, Northwest Territories: a Base Line for the Assessment of Environmental Change. Geological Survey of Canada, Bulletin 547, p. 153-158.

Burgess, M.M. and S.L. Smith. 2000. Shallow Ground Temperatures, in The Physical Environment of the Mackenzie Valley, Northwest Territories: a Base Line for the Assessment of Environmental Change. Geological Survey of Canada, Bulletin 547, p. 89-104.

Côté, M.M., C. Duchesne, J.F. Wright, and M. Ednie. 2013. Digital compilation of the surficial sediments of the Mackenzie Valley corridor, Yukon Coastal Plain, and the Tuktoyaktuk Peninsula; Geological Survey of Canada, Open File 7289. doi:10.4095/292494

Dessau. 2012. Mackenzie Valley Highway Extension Pehdzéh Kį Ndeh – Dehcho Region. Project Description Report (PDR). 004-P037500-0200-EI-R200-00. March 2012.

Dobinski, W. 2011. Permafrost. Earth Sci. Rev. 108:158-169.

Duchesne, C; J. Chartrand, and S.L. Smith. 2020. Report on 2018 field activities and collection of ground-thermal and active-layer data in the Mackenzie corridor, Northwest Territories. Geological Survey of Canada, Open File 8707, 84 pages, Duk-Rodkin, A. 2002. Surficial geology, Norman Wells, District of Mackenzie, Northwest Territories; Geological Survey of Canada, Map 1989A, scale 1:250,000. doi:10.4095/213617

Duk-Rodkin, A., and A. Couch. 2004. Surficial Geology, Fort Norman, Northwest Territories; Geological Survey of Canada, Open File 4662, Scale 1: 100,000.

Duk-Rodkin, A., and D. Huntley. 2009. Surficial Geology, Wrigley (95O/SW), Northwest Territories; Geological Survey of Canada, Open File 6014, Scale 1: 100,000.

Duk-Rodkin, A., and D.S. Lemmen. 2000. Glacial history of the Mackenzie region; in The Physical Environment of the Mackenzie Valley, Northwest Territories: a Base Line for the Assessment of Environmental Change. Geological Survey of Canada, Bulletin 547, p.11-20.

Dyke, L.D. 2000. Shoreline Permafrost along the Mackenzie River, in The Physical Environment of the Mackenzie Valley, Northwest Territories: a Base Line for the Assessment of Environmental Change. Geological Survey of Canada, Bulletin 547, p. 143-152.

Dyke, L.D., and G.R. Brooks. 2000. Introduction, in The Physical Environment of the Mackenzie Valley, Northwest Territories: a Base Line for the Assessment of Environmental Change. Geological Survey of Canada, Bulletin 547, p. 7-10.

Ford, D. 2008. Report upon a Survey of Karst Landforms around Norman Wells, Northwest Territories for the NWT protected Areas Strategy Department of Environment and Natural Resources Government of the Northwest Territories. March 2008.

Ford, D. 2009. Mapping Known and Potential Karst Areas in the Northwest Territories, Canada. Prepared for Environment and Natural Resources Government of the Northwest Territories. August 2009.

Freeze, R.A., and J.A. Cherry. 1979. Groundwater. Prentice Hall, Inc. Englewood Cliffs, New Jersey.

Golder. 2015. Central Mackenzie Surface Water and Groundwater Baseline Assessment. Report 1: Technical State of Knowledge. Report Number: 1401835 Final Report 1. May 21, 2015.

GNWT (Government of the Northwest Territories). 2013. 2013 Water Quality Summary. Available at: https://www.maca.gov.nt.ca/en/services/drinking-water-nwt/gnwt-report-drinking-water-quality. Accessed November 21, 2021.

GNWT. 2015. 2015 Water Quality Summary. Available at: https://www.maca.gov.nt.ca/en/services/drinking-water-nwt/gnwt-report-drinking-water-quality. Accessed November 21, 2021.

GSC (Geological Survey of Canada). 1993. The Devonian Succession in the Subsurface of the Great Slave and Great Bear Plains, Northwest Territories. Bulletin 393.

GSC. 2019a. Reconnaissance surficial geology, Wrigley Lake, Northwest Territories, NT S95-O; Geological Survey of Canada, Canadian Geoscience Map 371 (Surficial Data Model v.2.3.14 conversion of Map 13-1978), scale 1:125 000.

GSC. 2019b. Reconnaissance surficial geology, Dahadinni River, Northwest Territories, NT S95-N; Geological Survey of Canada, Canadian Geoscience Map 375 (Surficial Data Model v.2.3.14 conversion of Map 18-1979), scale 1:125 000.

Hamilton, J.P. 1995. Karst Geomorphology and Hydrogeology of the Northeastern Mackenzie Mountains, District of Mackenzie, N.W.T., Canada. P.hD. Thesis, Department of Geography, McMaster University.

Hannigan, P.K., D.W. Morrow, and B.C. MacLean. 2011. Petroleum resource potential of the northern mainland of Canada (Mackenzie Corridor). Geological Survey of Canada, Open File, 6757(1).

Hayes B.R. and J. Dunn. 2012. Deep Subsurface Saline Aquifer Characterization, Central Mackenzie Valley, Northwest Territories, Northwest Territories Geoscience Office, NWT Open File 2012-07, 52p, 39 Figs., 4 Appendices.

Heginbottom, J.A., M.A. Dubreuil, and P.T. Harker. 1995. Canada: Permafrost. National Atlas of Canada Fifth Edition. Natural Resources Canada, MCR 4177. Scale 1:7,500,000, Department of Energy, Mines and Resources Canada. Available at: https://doi.org/10.4095/294672.

Heginbottom, J.A. 2000. Permafrost Distribution and Ground Ice in Surficial Materials. In L.D. Dyke and G.R. Brooks (ed). The Physical Environment of the Mackenzie River Valley, Northwest Territories: A Base Line for the Assessment of Environmental Change. Geological Survey of Canada, Bulletin 547:31–40.

IORVL (Imperial Oil Resources Ventures Limited). 2004. Environmental Impact Statement. Volume 5: Biophysical Impact Assessment. Part B – Aquatic Resources. Groundwater, Hydrology and Water Quality. Section 4 Groundwater.

K'alo-Stantec (K'alo-Stantec Limited). 2022a. Mackenzie Valley Highway Project. Technical Data Report—Surface Water Quantity. Prepared for the Department of Infrastructure, the Government of the Northwest Territories, Yellowknife, Northwest Territories.

K'alo-Stantec. 2022b. Mackenzie Valley Highway Project. Technical Data Report—Surface Water and Sediment Quality. Prepared for the Department of Infrastructure, the Government of the Northwest Territories, Yellowknife, Northwest Territories.

K'alo-Stantec. 2021. Mackenzie Valley Highway Extension Project, Technical Data Report—Soils, Terrain, and Permafrost. Draft. Project No.: 144903025. Prepared for the Government of the Northwest Territories July 2021.

Kokelj, S.V., and M.T. Jorgenson. 2013. Advances in Thermokarst Research. Permafrost and Periglacial Processes. Special Issue: Transactions of the International Permafrost Association. Vol. 24-2. Pages 108-119. Available at: https://doi.org/10.1002/ppp.1779

Koch, J.C., C.P. Kikuchi, K.P. Wickland, and P. Schuster. 2014. Runoff Sources and Flow Paths in a Partially Burned Upland Boreal Catchment Underlain by Permafrost. Water Resour. Res., 50, doi:10.1002/2014WR015586.

Lemieux, J., R. Fortier, M. Talbot-Poulin, J. Molson, R. Therrien, M. Ouellet, D. Banville, M. Cochand, and R. Murray. 2016. Groundwater Occurrence in Cold Environments: Examples from Nunavik, Canada. Hydrogeology Journal. 24, 1497-1513.

Michel, F.A. 1977. Hydrogeologic studies of springs in the central Mackenzie Valley, North-West Territories, Canada. M.S. Thesis, Univ. of Waterloo, Waterloo, Ont., 185 pp.

Michel, F.A. 1982. Isotope Investigations of Permafrost Waters in Northern Canada. Ph.D. Thesis, Univ. of Waterloo, Ont., 424 pp.

Michel, F.A. 1986. Hydrogeology of the central Mackenzie Valley. J. Hydrol., 85: 379-405.

Morrell G.R., M. Fortier, P.R. Price, and R. Polt. 1995. Petroleum Exploration in Northern Canada. A Guide to Oil and Gas Exploration and Potential. Northern and Gas Directorate. Indian and Northern Affairs Canada. Ottawa.

MVEIRB (Mackenzie Valley Environmental Impact Review Board). 2015. Terms of Reference EA1213-02 Mackenzie Valley Highway Extension Project Wrigley to Norman Wells Government of Northwest Territories. February 13, 2015. PR#66.

Mu, Y., W. Ma, G. Li, F. Niu, Y. Liu, and Y. Mao. 2018. Impacts of supa-permafrost water ponding and drainage on a railway embankment in continuous permafrost zone, the interior of the Qinghai-Tibet Plateau. Cold Regions Science and Technology, Vol. 154, pp 23-31.

Nielson, B.T., M.B. Cardenas, M.T. O'Connor, M.T. Rasmussen, T.V. King, and G.W. Kling. 2018. Groundwater Flow and Exchange Across the Land Surface Explain Carbon Export Patters in Continuous Permafrost Watersheds. Geophysical Research Letters, 45, 7596-7605. Available at: https://doi.org/10.1029/2018GL078140.

Nixon, F,M. 2000. Thaw-depth monitoring. The Physical Environment of the Mackenzie Valley, Northwest Territories: a Base Line for the Assessment of Environmental Change, (ed.) L.D. Dyke and G.R. Brooks; Geological Survey of Canada, Bulletin 547, p. 41-48.

NRCan (Natural Resources Canada). 2016. 50 K Elevation Contours, CanVec Dataset. Available at: https://maps.canada.ca/czs/index-en.html. Accessed September 2021.

Okulitch A.V., and D. Irwin. 2014. Geological Compilation of the Western Mainland and Southern Arctic Islands Regions, Northwest Territories; Northwest Territories Geoscience Office, NWT Open File 2014-01, ERSI® digital files.

Rutter, N.W., R.J. Hawes, and N.R. Catto. 1993. Surficial Geology, Southern Mackenzie River Valley, District of Mackenzie, Northwest Territories, Geological Survey of Canada Map 1693A, scale 1:500,000.

Savigny, K.W. 1989. Engineering geology of the Great Bear River area, Northwest Territories. Geological Survey of Canada, Paper 88-23.

Serié, C., C.l. Bergquist, and L.J. Pyle. 2013. Seventeen Measured Sections of Cambrian Mount Clark and Mount Cap Formations, Northern Mackenzie Mountains and Franklin Mountains, Northwest Territories. Geological Survey of Canada, Open File 6148 (Revised).

SLUB (Sahtu Land Use Planning Board). 2013. Sahtu Land Use Plan. Government of Northwest Territories. Good Hope

Taylor, A., M. Nixon, J. Eley, M. Burgess, and P. Egginton. 1998. Effect of Atmospheric Temperature Inversions on Ground Surface Temperatures and Discontinuous Permafrost, Norman Wells, Mackenzie Valley, Canada. Permafrost – Seventh International Conference Proceedings, Yellowknife, Canada. Collection Nordicana No 55, 1998.

Taylor A.E., M.M. Burgess, A.S. Judge, and V.S. Allen. 2000. Deep Ground Temperatures, in The Physical Environment of the Mackenzie Valley, Northwest Territories: a Base Line for the Assessment of Environmental Change. Geological Survey of Canada, Bulletin 547, p. 105-110.

Toth, J. 1963. A theoretical analysis of groundwater flow in small drainage basins. *J. Geophys. Res.*, 68, pp. 4795-4812.

Van Everdingen, R.O. 1981. Morphology, Hydrology and Hydrochemistry of Karst in Permafrost Terrain near Great Bear Lake, Northwest Territories. National Hydrology Research Institute Paper. 11.

Walvoord, M.A., and B.K. Kurylyk. 2016. Hydrologic Impacts of Thawing Permafrost – A Review. Vadose Zone Journal Vol. 15, Iss, 6., 2016.

Walvoord, M.A., C.I. Voss, and T.P. Wellman. 2012. Influence of Permafrost Distribution on Groundwwater Flow in the Context of Climate-Driven Permafrost Thaw: Example from Yukon Flats Basin, Alaska, United Sates. Water Resources Research, Vol 48, W07524, doi: 10.1029/2011 WR011 1595.

Wright, J.F., M.W. Smith, and A.E. Taylor. 2000. Potential Changes in Permafrost Distribution in the Fort Simpson and Norman Wells Regions. The Physical Environment of the Mackenzie Valley, Northwest Territories: a Base Line for the Assessment of Environmental Change, (ed.) L.D. Dyke and G.R. Brooks; Geological Survey of Canada, Bulletin 547, p. 197-207.

Woo, Ming-ko. 1986. Permafrost Hydrology in North America. Atmosphere-Ocean, 24:3 201-234. Doi: 10.1080/07055900.1986.9649248.

Yamazaki, Y., J. Kubota, T. Ohata, V. Vuglinksy, and T. Mizuyama. 2005. Seasonal Changes in Runoff Characteristics on a Permafrost Watershed in the Southern Mountainous Region of Easter Siberia. Hydrological Processes 20, 453-467.

Appendix A IORVL (2004) Stream Open Water and Icings

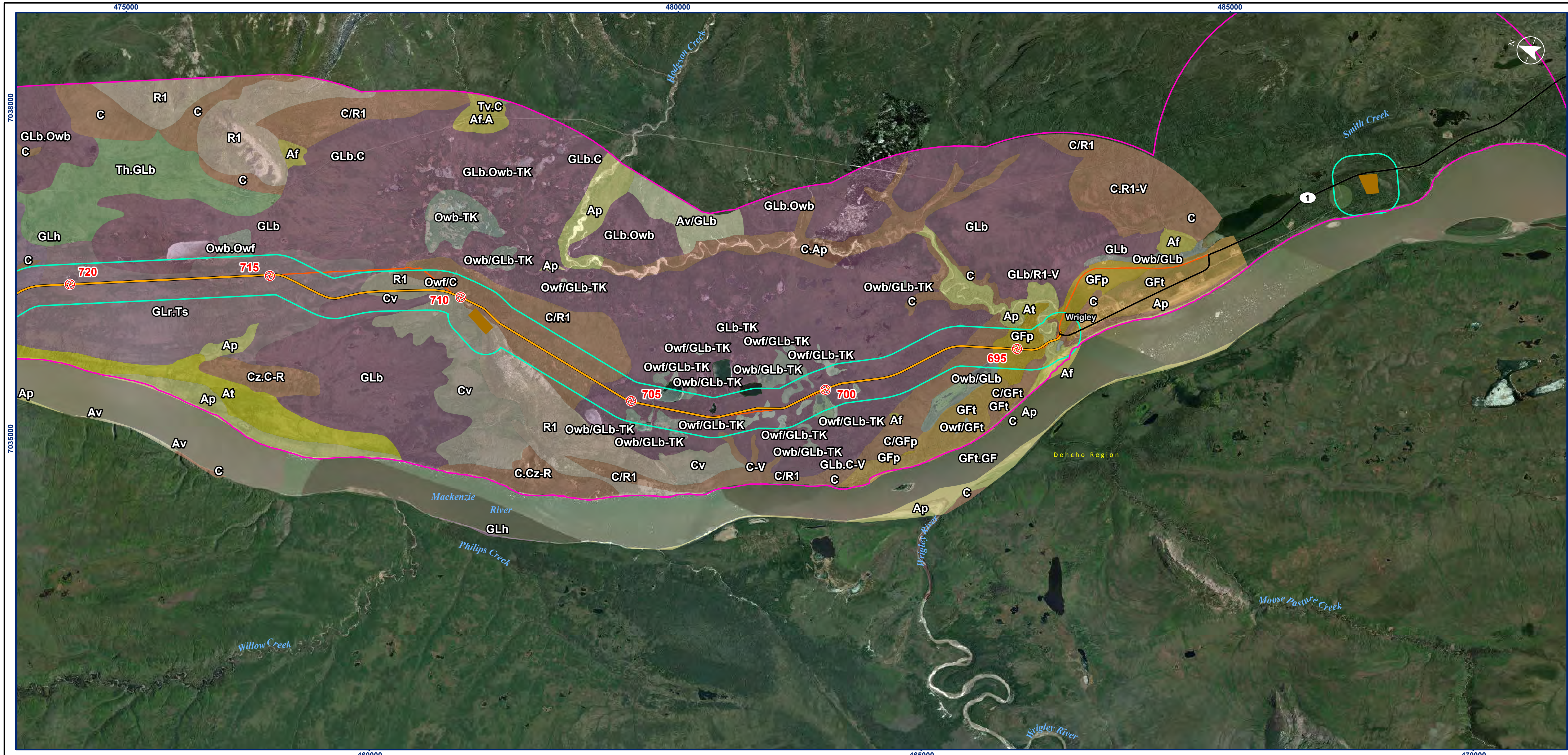
Table A.1 Observations of Open Water and Stream Icings from IORVL (2004)

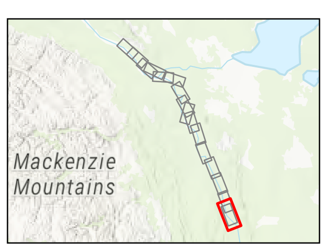
Stream[1]	Mid-April 2002 Observations
Great Bear River	-
Hodgson Creek	open water above crossing
Ochre River	Icings noted
White Sand Creek	Icings noted; substantial water on ice surface
Strawberry Creek	-
Vermillion Creek South	-
Bob's Canyon	-
Dam Creek	-
Blackwater River	Locals report icings common; not inspected
Steep Creek	2+ km open water; polynyas extending downstream; perennial flow ~0.47 m3/s
Devil's Creek	-
Saline Creek	Snow covered, no icings
Seagrams Creek	-
Little Smith Creek	Snow covered, no icings
Big Smith Creek	Icings noted
Gotcha Creek	-
Four Miles Creek	-
No name creek	Frozen to bottom
Bluefish Creek	-
Jungle Ridge Creek	Snow covered, no icings
Nota Creek	Snow covered, no icings
Vermillion Creek North	2+ km open water; polynyas extending downstream
Prohibition Creek	Not Augered; snow covered, no ice buildup
Christina Creek	Frozen to bottom; icings noted
Hellava Creek	Ice > 1.58 m thick; icings noted
Francis Creek	Standing water; icings noted
Canyon Creek	Ice > 1.58 m thick; icings noted
Bosworth Creek	Frozen to bottom

Note:

1. Streams are sorted south to north, following Table 3.1 in TDR – Surface Water Quantity (K'alo-Stantec, 2022a).

Appendix B Surficial Geology in the LSA and RSA





Surficial Geology [4]

- Af: Alluvial fan
- Ap: Alluvial floodplain sediment
- At: Alluvial terraced sediment
- Av: Alluvial veneer
- C: Colluvial deposit, undifferentiated
- Cv: Colluvial veneer
- Cz: Landslide deposit
- E: Eolian deposit, undifferentiated
- GFf: Glaciofluvial outwash-fan sediment
- GFh: Glaciofluvial hummocky sediment
- GFp: Glaciofluvial outwash-plain sediment
- GFr: Glaciofluvial esker sediment
- GFt: Glaciofluvial terraced sediment
- GFv: Glaciofluvial veneer
- GLb: Glaciolacustrine blanket
- GLh: Glaciolacustrine hummocky sediment
- GLr: Glaciolacustrine beach sediment
- GLv: Glaciolacustrine veneer
- Owb: Bog deposit
- Owf: Fen deposit
- R1: Sedimentary bedrock
- Tb: Till blanket
- Th: Hummocky till
- Tp: Till plain (all)
- Ts: Streamlined till
- Tv: Till veneer
- Mackenzie Valley Highway Kilometre Post

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Local Study Area
- Regional Study Area
- Granular Borrow / Rock Quarry Site and Access
- Canyon Creek All Season Access Road
- Prohibition Creek Access Road
- Proposed Great Bear River Bridge Project
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Geomorphological Process

R: Mass movement
TK: Thermokarst
V: Gullied

Example of terrain map unit symbol

Dominant surficial material and surface expression: Alluvial fan ⟹ AF/Tp - TK ⟸ Geomorphological process: Thermokarst (TK)

Dominant subsurface material and expression: till (M); plain (p)

Complex units
Two map-unit designators separated by a dot (.) are used where the surficial cover forms a complex area and the units are too small to be mapped individually (e.g. Ap.C designates an area of alluvial plain sediments with colluvial deposits).

Stratigraphic relationship
Two map-unit designators separated by a slash (/) are used where the stratigraphic relationship is observed or confidently inferred (e.g. GLv/T indicates glaciolacustrine veneer overlying till.)

0 1.5 3 Kilometres
1:100,000 (at original document size of 11x17)

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-20
TR by AJ on 2023-03-20

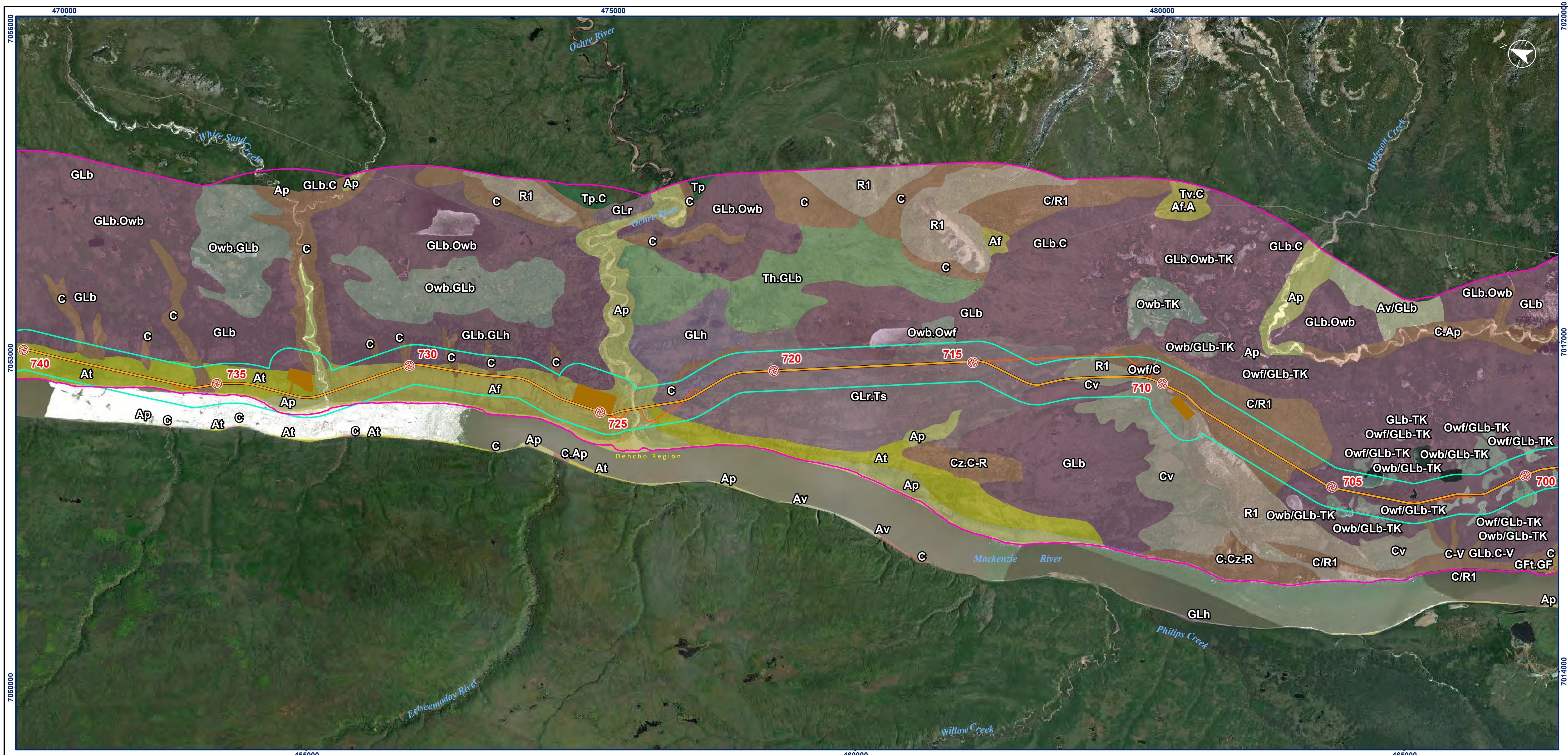
Client/Project
144903025-0080 REVC

Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
B.1

Title
RSA Surficial Geology

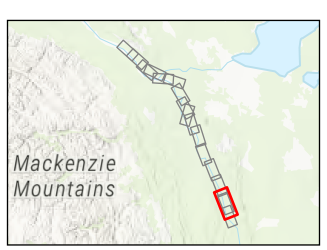
Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Terrain mapping was compiled and modified based on a series of maps including OpenFile 7289 - middle east section from Côté et al. (2013), maps 371 and 375 from GSC (2019), and MGAR and Great bear prohibition mapping from G.V.M. Geological Consultant Ltd. (2016, 2019). Some data gaps occur.



Surficial Geology [4]

- Af: Alluvial fan
- Ap: Alluvial floodplain sediment
- At: Alluvial terraced sediment
- Av: Alluvial veneer
- C: Colluvial deposit, undfferentiated
- Cv: Colluvial veneer
- Cz: Landslide deposit
- E: Eolian deposit, undifferentiated
- GFf: Glaciofluvial outwash-fan sediment
- GFh: Glaciofluvial hummocky sediment
- GFp: Glaciofluvial outwash-plain sediment
- GFr: Glaciofluvial esker sediment
- GFt: Glaciofluvial terraced sediment
- GFv: Glaciofluvial veneer
- GLb: Glaciolacustrine blanket
- GLh: Glaciolacustrine hummocky sediment
- GLr: Glaciolacustrine beach sediment
- GLv: Glaciolacustrine veneer
- Owb: Bog deposit
- Owf: Fen deposit
- R1: Sedimentary bedrock
- Tb: Till blanket
- Th: Hummocky till
- Tp: Till plain (all)
- Ts: Streamlined till
- Tv: Till veneer
- Mackenzie Valley Highway Kilometre Post

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Local Study Area
- Regional Study Area
- Granular Borrow / Rock Quarry Site and Access
- Canyon Creek All Season Access Road
- Prohibition Creek Access Road
- Proposed Great Bear River Bridge Project
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary



Geomorphological Process
R: Mass movement
TK: Thermokarst
V: Gullied

Example of terrain map unit symbol

Dominant surficial material and surface expression: Alluvial fan ⟹ AF/Tp - TK ⟸ Geomorphological process: Thermokarst (TK)

Dominant subsurface material and expression: till (M); plain (p)

Complex units
Two map-unit designators separated by a dot (.) are used where the surficial cover forms a complex area and the units are too small to be mapped individually (e.g. Ap.C designates an area of alluvial plain sediments with colluvial deposits).

Stratigraphic relationship
Two map-unit designators separated by a slash (/) are used where the stratigraphic relationship is observed or confidently inferred (e.g. GLv/T indicates glaciolacustrine veneer overlying till.)

0 1.5 3 Kilometres
1:100,000 (at original document size of 11x17)

Kalo-Stantec

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-20
TR by AJ on 2023-03-20

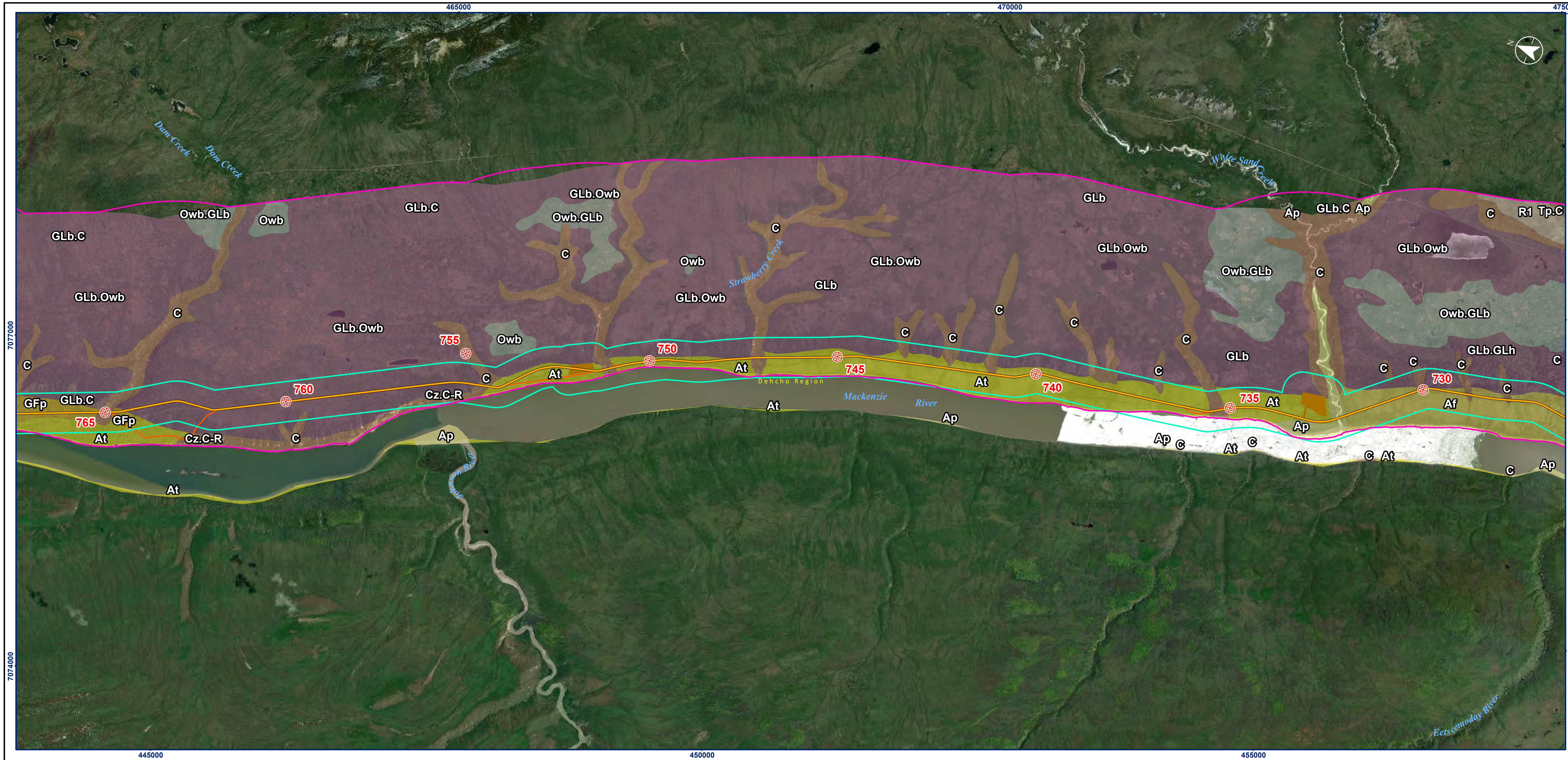
Client/Project
144903025-0080 REVC

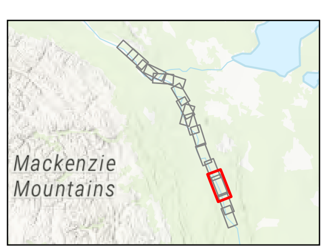
Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
B.2

Title
RSA Surficial Geology

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Terrain mapping was compiled and modified based on a series of maps including OpenFile 7289 - middle east section from Côté et al. (2013), maps 371 and 375 from GSC (2019), and MGAR and Great bear prohibition mapping from G.V.M. Geological Consultant Ltd. (2016, 2019). Some data gaps occur.





Surficial Geology [4]

- Af: Alluvial fan
- Ap: Alluvial floodplain sediment
- At: Alluvial terraced sediment
- Av: Alluvial veneer
- C: Colluvial deposit, undfferentiated
- Cv: Colluvial veneer
- Cz: Landslide deposit
- E: Eolian deposit, undifferentiated
- GFf: Glaciofluvial outwash-fan sediment
- GFh: Glaciofluvial hummocky sediment
- GFp: Glaciofluvial outwash-plain sediment
- GFr: Glaciofluvial esker sediment
- GFt: Glaciofluvial terraced sediment
- GFv: Glaciofluvial veneer
- GLb: Glaciolacustrine blanket
- GLh: Glaciolacustrine hummocky sediment
- GLr: Glaciolacustrine beach sediment
- GLv: Glaciolacustrine veneer
- Owb: Bog deposit
- Owf: Fen deposit
- R1: Sedimentary bedrock
- Tb: Till blanket
- Th: Hummocky till
- Tp: Till plain (all)
- Ts: Streamlined till
- Tv: Till veneer
- Mackenzie Valley Highway Kilometre Post

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Local Study Area
- Regional Study Area
- Granular Borrow / Rock Quarry Site and Access
- Canyon Creek All Season Access Road
- Prohibition Creek Access Road
- Proposed Great Bear River Bridge Project
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Geomorphological Process

R: Mass movement
TK: Thermokarst
V: Gullied

Example of terrain map unit symbol

Dominant surficial material and surface expression: Alluvial fan ⟹ AF/Tp - TK ⟸ Geomorphological process: Thermokarst (TK)

Dominant subsurface material and expression: till (M); plain (p)

Complex units
Two map-unit designators separated by a dot (.) are used where the surficial cover forms a complex area and the units are too small to be mapped individually (e.g. Ap.C designates an area of alluvial plain sediments with colluvial deposits).

Stratigraphic relationship
Two map-unit designators separated by a slash (/) are used where the stratigraphic relationship is observed or confidently inferred (e.g. GLv/T indicates glaciolacustrine veneer overlying till.)

0 1.5 3 Kilometres
1:100,000 (at original document size of 11x17)

K'alo-Stantec

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-20
TR by AJ on 2023-03-20

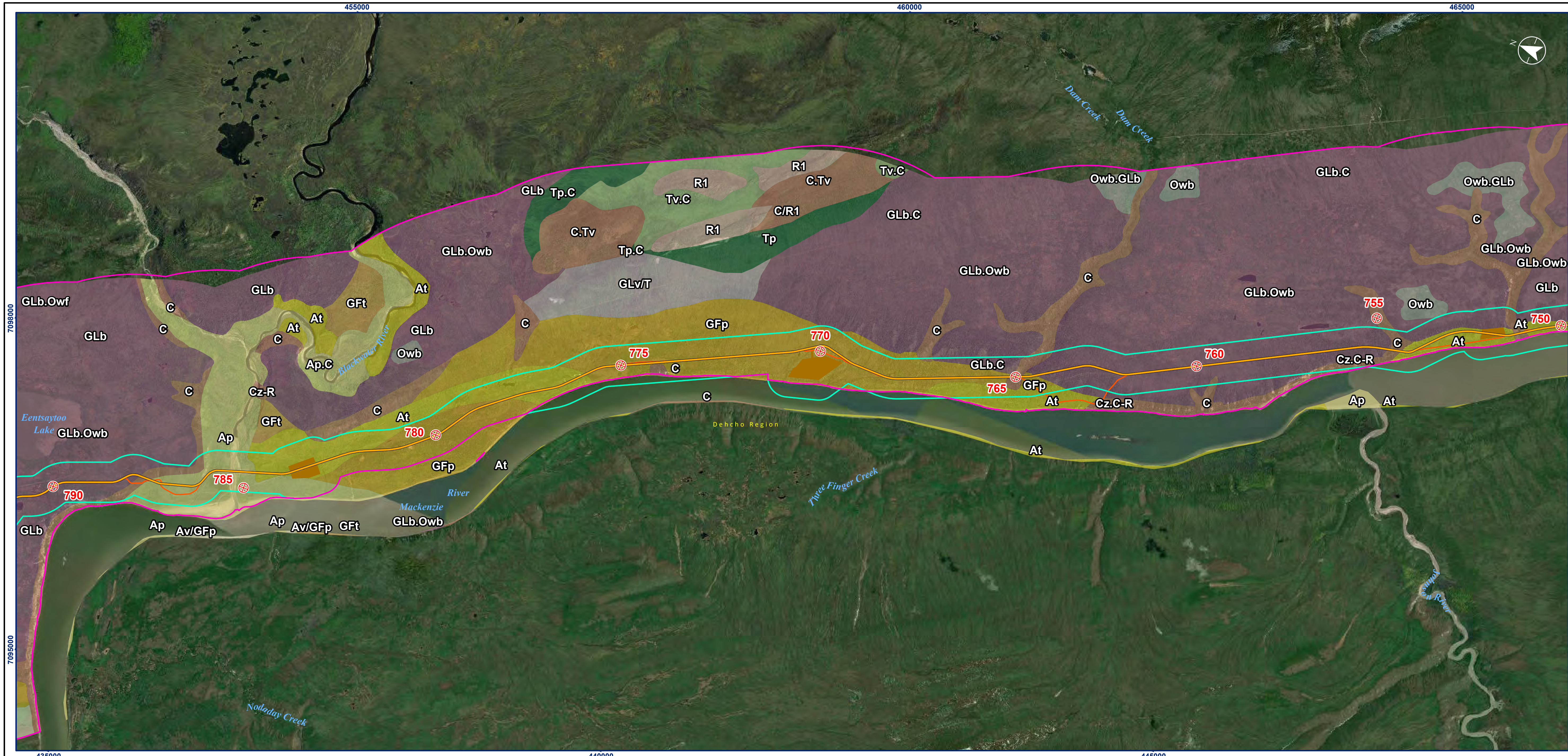
Client/Project
144903025-0080 REVC

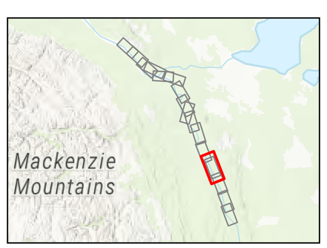
Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
B.3

Title
RSA Surficial Geology

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Terrain mapping was compiled and modified based on a series of maps including OpenFile 7289 - middle east section from Côté et al. (2013), maps 371 and 375 from GSC (2019), and MGAR and Great bear prohibition mapping from G.V.M. Geological Consultant Ltd. (2016, 2019). Some data gaps occur.





Surficial Geology [4]

- Af: Alluvial fan
- Ap: Alluvial floodplain sediment
- At: Alluvial terraced sediment
- Av: Alluvial veneer
- C: Colluvial deposit, undifferentiated
- Cv: Colluvial veneer
- Cz: Landslide deposit
- E: Eolian deposit, undifferentiated
- GFf: Glaciofluvial outwash-fan sediment
- GFh: Glaciofluvial hummocky sediment
- GFp: Glaciofluvial outwash-plain sediment
- GFr: Glaciofluvial esker sediment
- GFt: Glaciofluvial terraced sediment
- GFv: Glaciofluvial veneer
- GLb: Glaciolacustrine blanket
- GLh: Glaciolacustrine hummocky sediment
- GLr: Glaciolacustrine beach sediment
- GLv: Glaciolacustrine veneer
- Owb: Bog deposit
- Owf: Fen deposit
- R1: Sedimentary bedrock
- Tb: Till blanket
- Th: Hummocky till
- Tp: Till plain (all)
- Ts: Streamlined till
- Tv: Till veneer
- Mackenzie Valley Highway Kilometre Post

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Local Study Area
- Regional Study Area
- Granular Borrow / Rock Quarry Site and Access
- Canyon Creek All Season Access Road
- Prohibition Creek Access Road
- Proposed Great Bear River Bridge Project
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Geomorphological Process

R: Mass movement
TK: Thermokarst
V: Gullied

Example of terrain map unit symbol

Dominant surficial material and surface expression: Alluvial fan ⟹ AF/Tp - TK ⟸ Geomorphological process: Thermokarst (TK)

Dominant subsurface material and expression: till (M); plain (p)

Complex units
Two map-unit designators separated by a dot (.) are used where the surficial cover forms a complex area and the units are too small to be mapped individually (e.g. Ap.C designates an area of alluvial plain sediments with colluvial deposits).

Stratigraphic relationship
Two map-unit designators separated by a slash (/) are used where the stratigraphic relationship is observed or confidently inferred (e.g. GLv/T indicates glaciolacustrine veneer overlying till.)

0 1.5 3 Kilometres
1:100,000 (at original document size of 11x17)

Kálo-Stantec

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-20
TR by AJ on 2023-03-20

Client/Project
144903025-0080 REVC

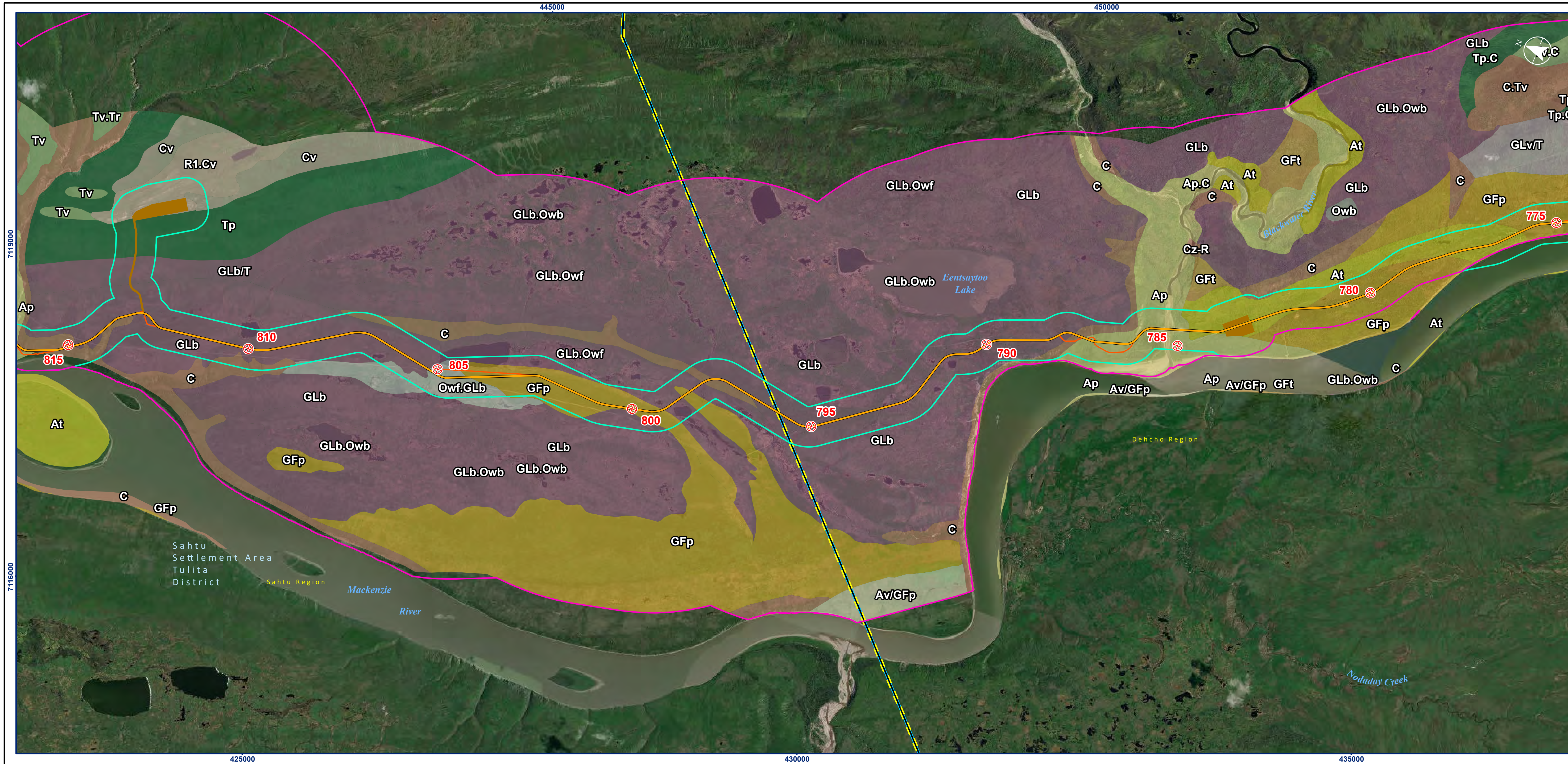
Government of Northwest Territories
Mackenzie Valley Highway Project

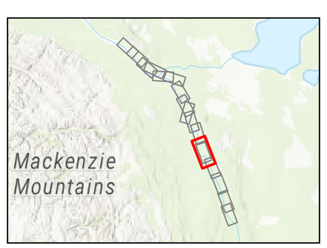
Figure No.
B.4

Title
RSA Surficial Geology

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Terrain mapping was compiled and modified based on a series of maps including OpenFile 7289 - middle east section from Côté et al. (2013), maps 371 and 375 from GSC (2019), and MGAR and Great bear prohibition mapping from G.V.M. Geological Consultant Ltd. (2016, 2019). Some data gaps occur.





Surficial Geology [4]

- Af: Alluvial fan
- Ap: Alluvial floodplain sediment
- At: Alluvial terraced sediment
- Av: Alluvial veneer
- C: Colluvial deposit, undifferentiated
- Cv: Colluvial veneer
- Cz: Landslide deposit
- E: Eolian deposit, undifferentiated
- GFf: Glaciofluvial outwash-fan sediment
- GFh: Glaciofluvial hummocky sediment
- GFp: Glaciofluvial outwash-plain sediment
- GFr: Glaciofluvial esker sediment
- GFt: Glaciofluvial terraced sediment
- GFv: Glaciofluvial veneer
- GLb: Glaciolacustrine blanket
- GLh: Glaciolacustrine hummocky sediment
- GLr: Glaciolacustrine beach sediment
- GLv: Glaciolacustrine veneer
- Owb: Bog deposit
- Owf: Fen deposit
- R1: Sedimentary bedrock
- Tb: Till blanket
- Th: Hummocky till
- Tp: Till plain (all)
- Ts: Streamlined till
- Tv: Till veneer
- Mackenzie Valley Highway Kilometre Post

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Local Study Area
- Regional Study Area
- Granular Borrow / Rock Quarry Site and Access
- Canyon Creek All Season Access Road
- Prohibition Creek Access Road
- Proposed Great Bear River Bridge Project
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Geomorphological Process

R: Mass movement
TK: Thermokarst
V: Gullied

Example of terrain map unit symbol

Dominant surficial material and surface expression: Alluvial fan ⟹ AF/Tp - TK ⟸ Geomorphological process: Thermokarst (TK)

Dominant subsurface material and expression: till (M); plain (p)

Complex units
Two map-unit designators separated by a dot (.) are used where the surficial cover forms a complex area and the units are too small to be mapped individually (e.g. Ap.C designates an area of alluvial plain sediments with colluvial deposits).

Stratigraphic relationship
Two map-unit designators separated by a slash (/) are used where the stratigraphic relationship is observed or confidently inferred (e.g. GLv/T indicates glaciolacustrine veneer overlying till.)

0 1.5 3 Kilometres
1:100,000 (at original document size of 11x17)

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-20
TR by AJ on 2023-03-20

Client/Project
144903025-0080 REVC

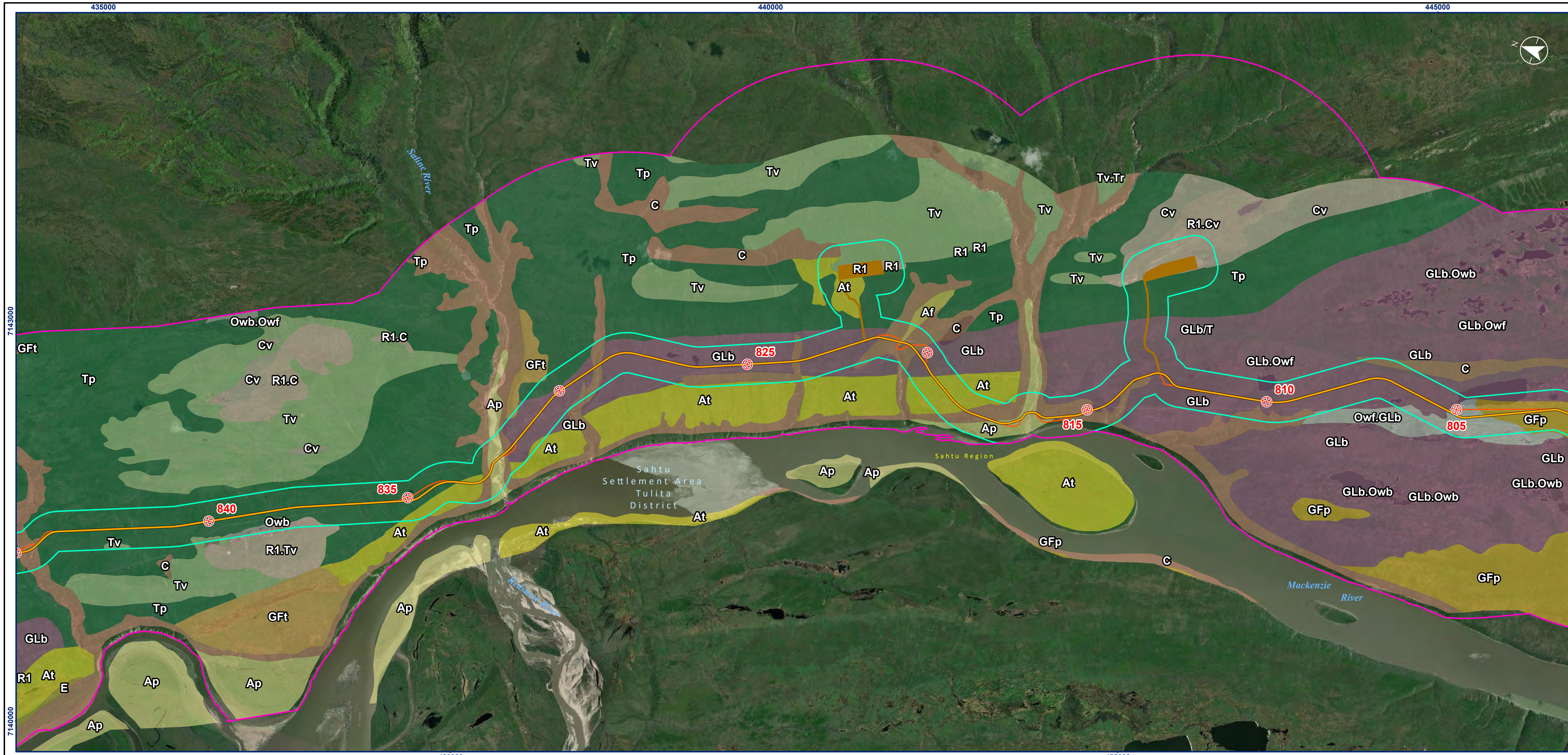
Government of Northwest Territories
Mackenzie Valley Highway Project

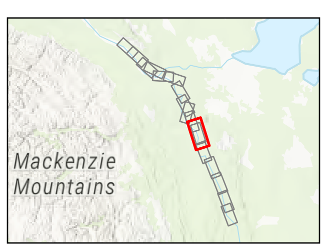
Figure No.
B.5

Title
RSA Surficial Geology

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Terrain mapping was compiled and modified based on a series of maps including OpenFile 7289 - middle east section from Côté et al. (2013), maps 371 and 375 from GSC (2019), and MGAR and Great bear prohibition mapping from G.V.M. Geological Consultant Ltd. (2016, 2019). Some data gaps occur.





Surficial Geology [4]

- Af: Alluvial fan
- Ap: Alluvial floodplain sediment
- At: Alluvial terraced sediment
- Av: Alluvial veneer
- C: Colluvial deposit, undifferentiated
- Cv: Colluvial veneer
- Cz: Landslide deposit
- E: Eolian deposit, undifferentiated
- GFf: Glaciofluvial outwash-fan sediment
- GFh: Glaciofluvial hummocky sediment
- GFp: Glaciofluvial outwash-plain sediment
- GFr: Glaciofluvial esker sediment
- GFt: Glaciofluvial terraced sediment
- GFv: Glaciofluvial veneer
- GLb: Glaciolacustrine blanket
- GLh: Glaciolacustrine hummocky sediment
- GLr: Glaciolacustrine beach sediment
- GLv: Glaciolacustrine veneer
- Owb: Bog deposit
- Owf: Fen deposit
- R1: Sedimentary bedrock
- Tb: Till blanket
- Th: Hummocky till
- Tp: Till plain (all)
- Ts: Streamlined till
- Tv: Till veneer
- Mackenzie Valley Highway Kilometre Post

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Local Study Area
- Regional Study Area
- Granular Borrow / Rock Quarry Site and Access
- Canyon Creek All Season Access Road
- Prohibition Creek Access Road
- Proposed Great Bear River Bridge Project
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Geomorphological Process

R: Mass movement
TK: Thermokarst
V: Gullied

Example of terrain map unit symbol

Dominant surficial material and surface expression: Alluvial fan ⇒ AF/Tp - TK ⇐ Geomorphological process: Thermokarst (TK)

Dominant subsurface material and expression: till (M); plain (p)

Complex units
Two map-unit designators separated by a dot (.) are used where the surficial cover forms a complex area and the units are too small to be mapped individually (e.g. Ap.C designates an area of alluvial plain sediments with colluvial deposits).

Stratigraphic relationship
Two map-unit designators separated by a slash (/) are used where the stratigraphic relationship is observed or confidently inferred (e.g. GLv/T indicates glaciolacustrine veneer overlying till.)

0 1.5 3 Kilometres
1:100,000 (at original document size of 11x17)

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-20
TR by AJ on 2023-03-20

Client/Project
144903025-0080 REVC

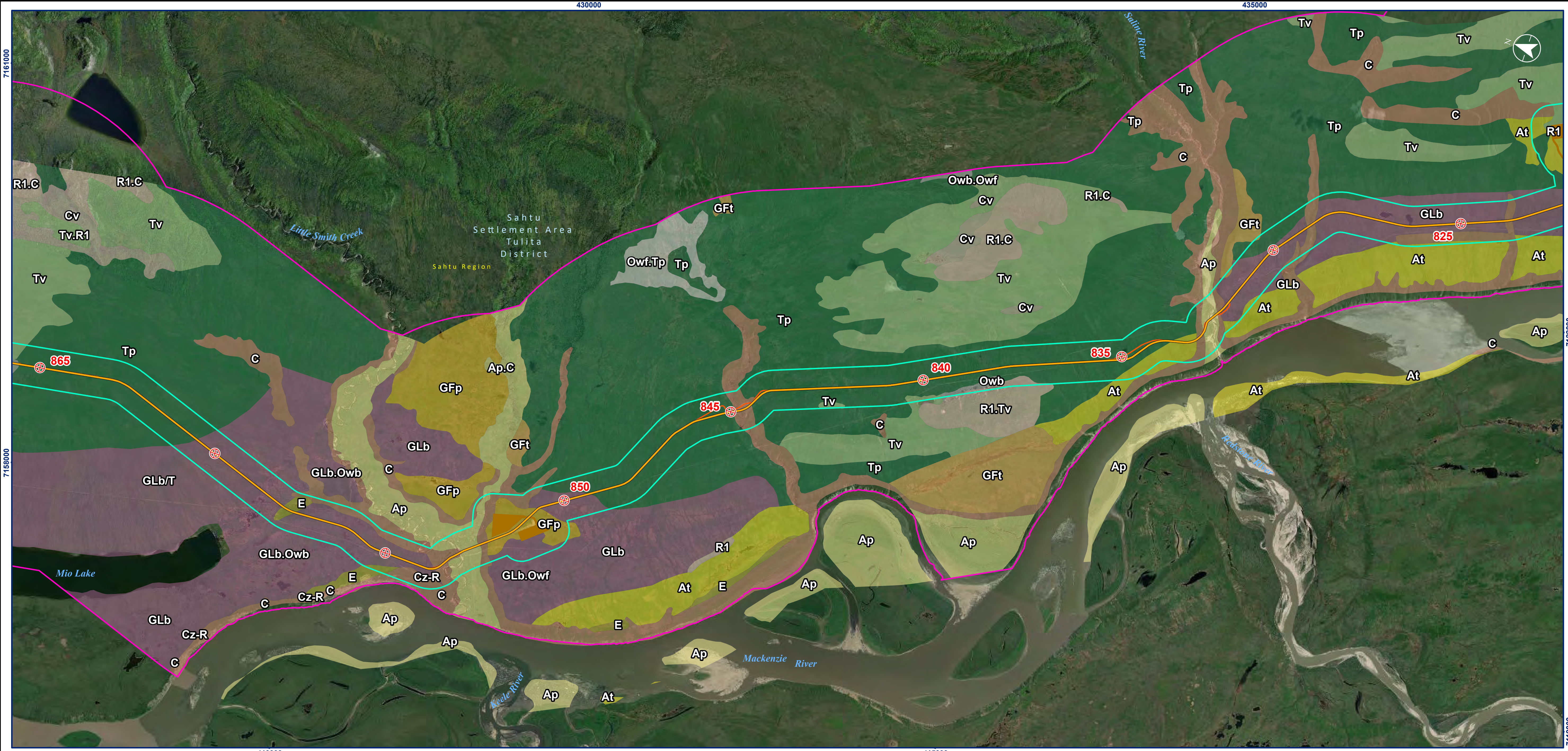
Government of Northwest Territories
Mackenzie Valley Highway Project

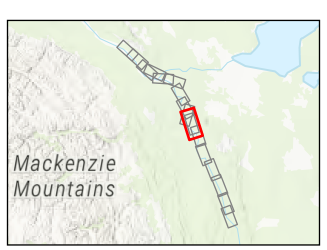
Figure No.
B.6

Title
RSA Surficial Geology

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Terrain mapping was compiled and modified based on a series of maps including OpenFile 7289 - middle east section from Côté et al. (2013), maps 371 and 375 from GSC (2019), and MGAR and Great bear prohibition mapping from G.V.M. Geological Consultant Ltd. (2016, 2019). Some data gaps occur.





Surficial Geology [4]

- Af: Alluvial fan
- Ap: Alluvial floodplain sediment
- At: Alluvial terraced sediment
- Av: Alluvial veneer
- C: Colluvial deposit, undifferentiated
- Cv: Colluvial veneer
- Cz: Landslide deposit
- E: Eolian deposit, undifferentiated
- GFf: Glaciofluvial outwash-fan sediment
- GFh: Glaciofluvial hummocky sediment
- GFp: Glaciofluvial outwash-plain sediment
- GFr: Glaciofluvial esker sediment
- GFt: Glaciofluvial terraced sediment
- GFv: Glaciofluvial veneer
- GLb: Glaciolacustrine blanket
- GLh: Glaciolacustrine hummocky sediment
- GLr: Glaciolacustrine beach sediment
- GLv: Glaciolacustrine veneer
- Owb: Bog deposit
- Owf: Fen deposit
- R1: Sedimentary bedrock
- Tb: Till blanket
- Th: Hummocky till
- Tp: Till plain (all)
- Ts: Streamlined till
- Tv: Till veneer
- Mackenzie Valley Highway Kilometre Post

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Local Study Area
- Regional Study Area
- Granular Borrow / Rock Quarry Site and Access
- Canyon Creek All Season Access Road
- Prohibition Creek Access Road
- Proposed Great Bear River Bridge Project
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Geomorphological Process

R: Mass movement
TK: Thermokarst
V: Gullied

Example of terrain map unit symbol

Dominant surficial material and surface expression: Alluvial fan ⟹ AF/Tp - TK ⟸ Geomorphological process: Thermokarst (TK)

Dominant subsurface material and expression: till (M); plain (p)

Complex units
Two map-unit designators separated by a dot (.) are used where the surficial cover forms a complex area and the units are too small to be mapped individually (e.g. Ap.C designates an area of alluvial plain sediments with colluvial deposits).

Stratigraphic relationship
Two map-unit designators separated by a slash (/) are used where the stratigraphic relationship is observed or confidently inferred (e.g. GLv/T indicates glaciolacustrine veneer overlying till.)

0 1.5 3 Kilometres
1:100,000 (at original document size of 11x17)

Kálo-Stantec

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-20
TR by AJ on 2023-03-20

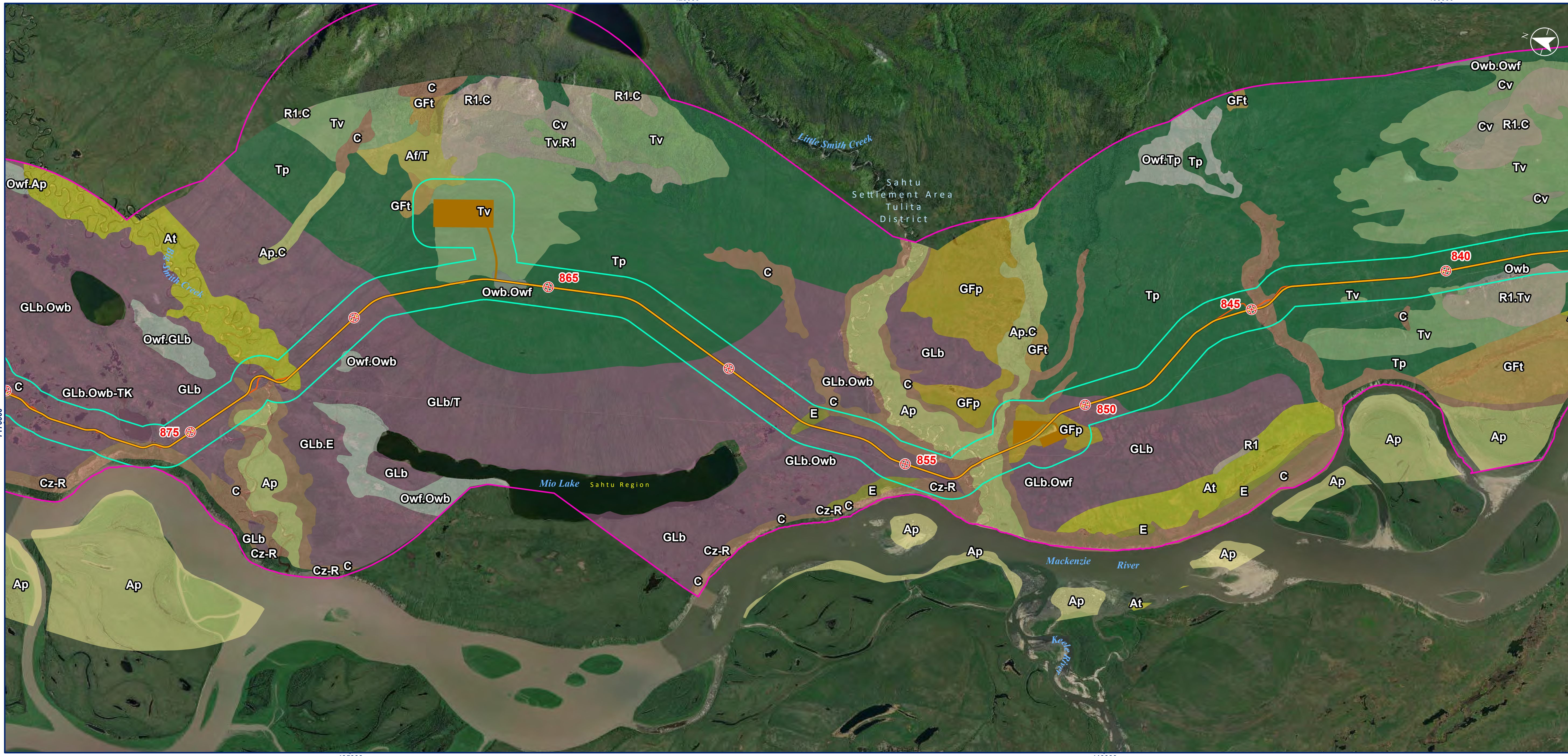
Client/Project
144903025-0080 REVC

Government of Northwest Territories
Mackenzie Valley Highway Project

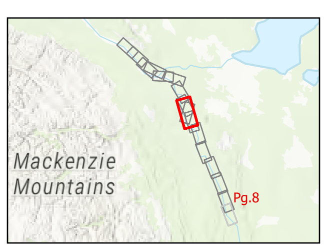
Figure No.
B.7

Title
RSA Surficial Geology

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Terrain mapping was compiled and modified based on a series of maps including OpenFile 7289 - middle east section from Côté et al. (2013), maps 371 and 375 from GSC (2019), and MGAR and Great bear prohibition mapping from G.V.M. Geological Consultant Ltd. (2016, 2019). Some data gaps occur.



Surficial Geology [4]



- Af: Alluvial fan
- Ap: Alluvial floodplain sediment
- At: Alluvial terraced sediment
- Av: Alluvial veneer
- C: Colluvial deposit, undfferentiated
- Cv: Colluvial veneer
- Cz: Landslide deposit
- E: Eolian deposit, undifferentiated
- GFf: Glaciofluvial outwash-fan sediment
- GFh: Glaciofluvial hummocky sediment
- GFp: Glaciofluvial outwash-plain sediment
- GFr: Glaciofluvial esker sediment
- GFt: Glaciofluvial terraced sediment
- GFv: Glaciofluvial veneer
- GLb: Glaciolacustrine blanket
- GLh: Glaciolacustrine hummocky sediment
- GLr: Glaciolacustrine beach sediment
- GLv: Glaciolacustrine veneer
- Owb: Bog deposit
- Owf: Fen deposit
- R1: Sedimentary bedrock
- Tb: Till blanket
- Th: Hummocky till
- Tp: Till plain (all)
- Ts: Streamlined till
- Tv: Till veneer
- Mackenzie Valley Highway Kilometre Post

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Local Study Area
- Regional Study Area
- Granular Borrow / Rock Quarry Site and Access
- Canyon Creek All Season Access Road
- Prohibition Creek Access Road
- Proposed Great Bear River Bridge Project
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Geomorphological Process

R: Mass movement
TK: Thermokarst
V: Gullied

Example of terrain map unit symbol

Dominant surficial material and surface expression: Alluvial fan ⟹ AF/Tp - TK ⟸ Geomorphological process: Thermokarst (TK)

Dominant subsurface material and expression: till (M); plain (p)

Complex units
Two map-unit designators separated by a dot (.) are used where the surficial cover forms a complex area and the units are too small to be mapped individually (e.g. Ap.C designates an area of alluvial plain sediments with colluvial deposits).

Stratigraphic relationship
Two map-unit designators separated by a slash (/) are used where the stratigraphic relationship is observed or confidently inferred (e.g. GLv/T indicates glaciolacustrine veneer overlying till.)

0 1.5 3 Kilometres
1:100,000 (at original document size of 11x17)

K'alo-Stantec

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-20
TR by AJ on 2023-03-20

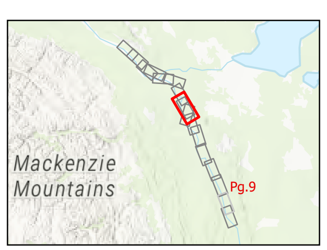
Client/Project
144903025-0080 REVC

Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
B.8

Title
RSA Surficial Geology

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Terrain mapping was compiled and modified based on a series of maps including OpenFile 7289 - middle east section from Côté et al. (2013), maps 371 and 375 from GSC (2019), and MGAR and Great bear prohibition mapping from G.V.M. Geological Consultant Ltd. (2016, 2019). Some data gaps occur.



Surficial Geology [4]

- Af: Alluvial fan
- Ap: Alluvial floodplain sediment
- At: Alluvial terraced sediment
- Av: Alluvial veneer
- C: Colluvial deposit, undfferentiated
- Cv: Colluvial veneer
- Cz: Landslide deposit
- E: Eolian deposit, undifferentiated
- GFf: Glaciofluvial outwash-fan sediment
- GFh: Glaciofluvial hummocky sediment
- GFp: Glaciofluvial outwash-plain sediment
- GFr: Glaciofluvial esker sediment
- GFt: Glaciofluvial terraced sediment
- GFv: Glaciofluvial veneer
- GLb: Glaciolacustrine blanket
- GLh: Glaciolacustrine hummocky sediment
- GLr: Glaciolacustrine beach sediment
- GLv: Glaciolacustrine veneer
- Owb: Bog deposit
- Owf: Fen deposit
- R1: Sedimentary bedrock
- Tb: Till blanket
- Th: Hummocky till
- Tp: Till plain (all)
- Ts: Streamlined till
- Tv: Till veneer
- Mackenzie Valley Highway Kilometre Post

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Local Study Area
- Regional Study Area
- Granular Borrow / Rock Quarry Site and Access
- Canyon Creek All Season Access Road
- Prohibition Creek Access Road
- Proposed Great Bear River Bridge Project
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Geomorphological Process

R: Mass movement
TK: Thermokarst
V: Gullied

Example of terrain map unit symbol

Dominant surficial material and surface expression: Alluvial fan ⟹ AF/Tp - TK ⟸ Geomorphological process: Thermokarst (TK)

Dominant subsurface material and expression: till (M); plain (p)

Complex units
Two map-unit designators separated by a dot (.) are used where the surficial cover forms a complex area and the units are too small to be mapped individually (e.g. Ap.C designates an area of alluvial plain sediments with colluvial deposits).

Stratigraphic relationship
Two map-unit designators separated by a slash (/) are used where the stratigraphic relationship is observed or confidently inferred (e.g. GLv/T indicates glaciolacustrine veneer overlying till.)

0 1.5 3 Kilometres
1:100,000 (at original document size of 11x17)

Kálo-Stantec

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-20
TR by AJ on 2023-03-20

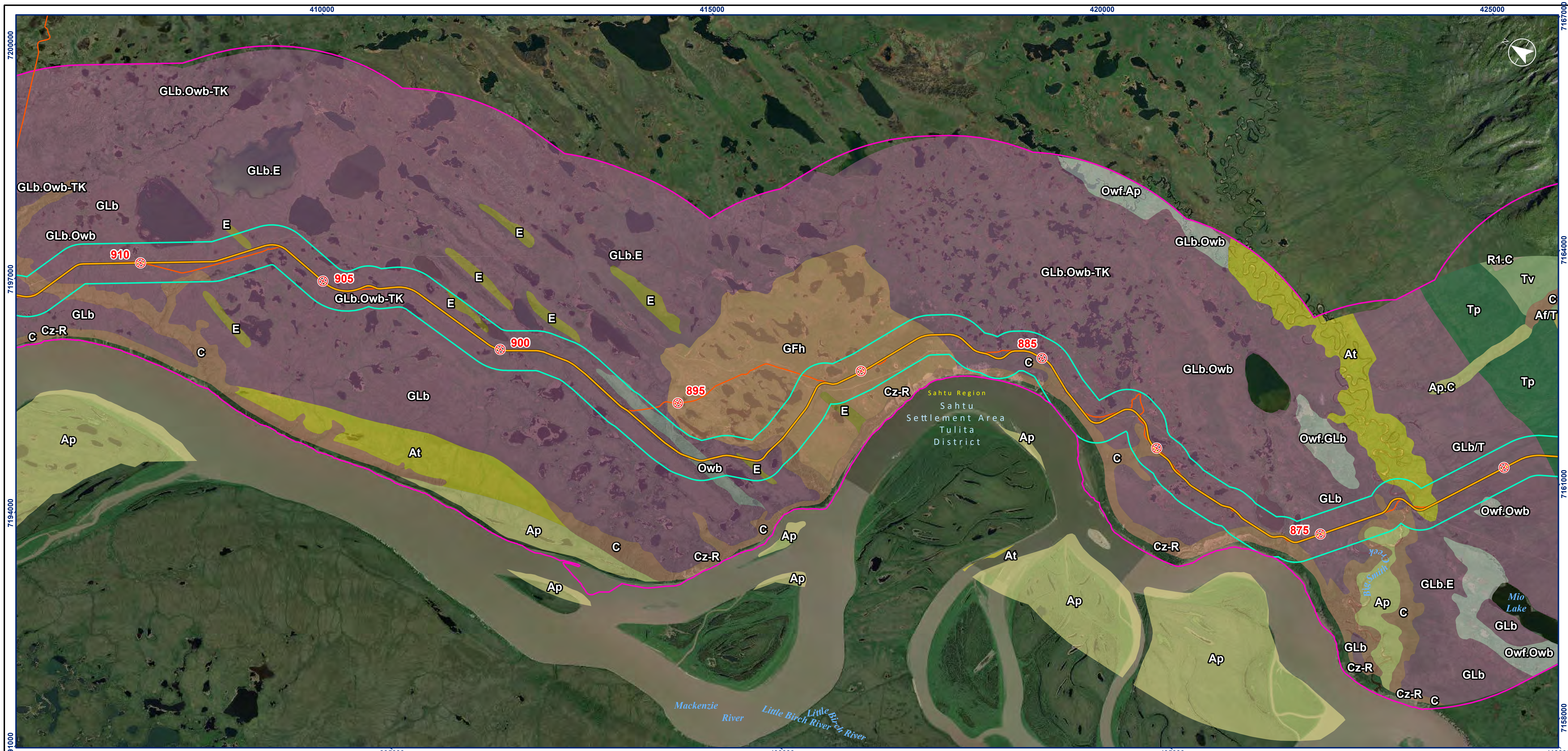
Client/Project
144903025-0080 REVC

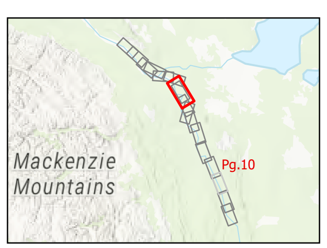
Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
B.9

Title
RSA Surficial Geology

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Terrain mapping was compiled and modified based on a series of maps including OpenFile 7289 - middle east section from Côté et al. (2013), maps 371 and 375 from GSC (2019), and MGAR and Great bear prohibition mapping from G.V.M. Geological Consultant Ltd. (2016, 2019). Some data gaps occur.





Surficial Geology [4]

- Af: Alluvial fan
- Ap: Alluvial floodplain sediment
- At: Alluvial terraced sediment
- Av: Alluvial veneer
- C: Colluvial deposit, undifferentiated
- Cv: Colluvial veneer
- Cz: Landslide deposit
- E: Eolian deposit, undifferentiated
- GFf: Glaciofluvial outwash-fan sediment
- GFh: Glaciofluvial hummocky sediment
- GFp: Glaciofluvial outwash-plain sediment
- GFr: Glaciofluvial esker sediment
- GFt: Glaciofluvial terraced sediment
- GFv: Glaciofluvial veneer
- GLb: Glaciolacustrine blanket
- GLh: Glaciolacustrine hummocky sediment
- GLr: Glaciolacustrine beach sediment
- GLv: Glaciolacustrine veneer
- Owb: Bog deposit
- Owf: Fen deposit
- R1: Sedimentary bedrock
- Tb: Till blanket
- Th: Hummocky till
- Tp: Till plain (all)
- Ts: Streamlined till
- Tv: Till veneer
- Mackenzie Valley Highway Kilometre Post

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Local Study Area
- Regional Study Area
- Granular Borrow / Rock Quarry Site and Access
- Canyon Creek All Season Access Road
- Prohibition Creek Access Road
- Proposed Great Bear River Bridge Project
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Geomorphological Process

R: Mass movement
TK: Thermokarst
V: Gullied

Example of terrain map unit symbol

Dominant surficial material and surface expression: Alluvial fan ⟹ AF/Tp - TK ⟸ Geomorphological process: Thermokarst (TK)

Dominant subsurface material and expression: till (M); plain (p)

Complex units
Two map-unit designators separated by a dot (.) are used where the surficial cover forms a complex area and the units are too small to be mapped individually (e.g. Ap.C designates an area of alluvial plain sediments with colluvial deposits).

Stratigraphic relationship
Two map-unit designators separated by a slash (/) are used where the stratigraphic relationship is observed or confidently inferred (e.g. GLv/T indicates glaciolacustrine veneer overlying till.)

0 1.5 3 Kilometres
1:100,000 (at original document size of 11x17)

Kálo-Stantec

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-20
TR by AJ on 2023-03-20

Client/Project
144903025-0080 REVC

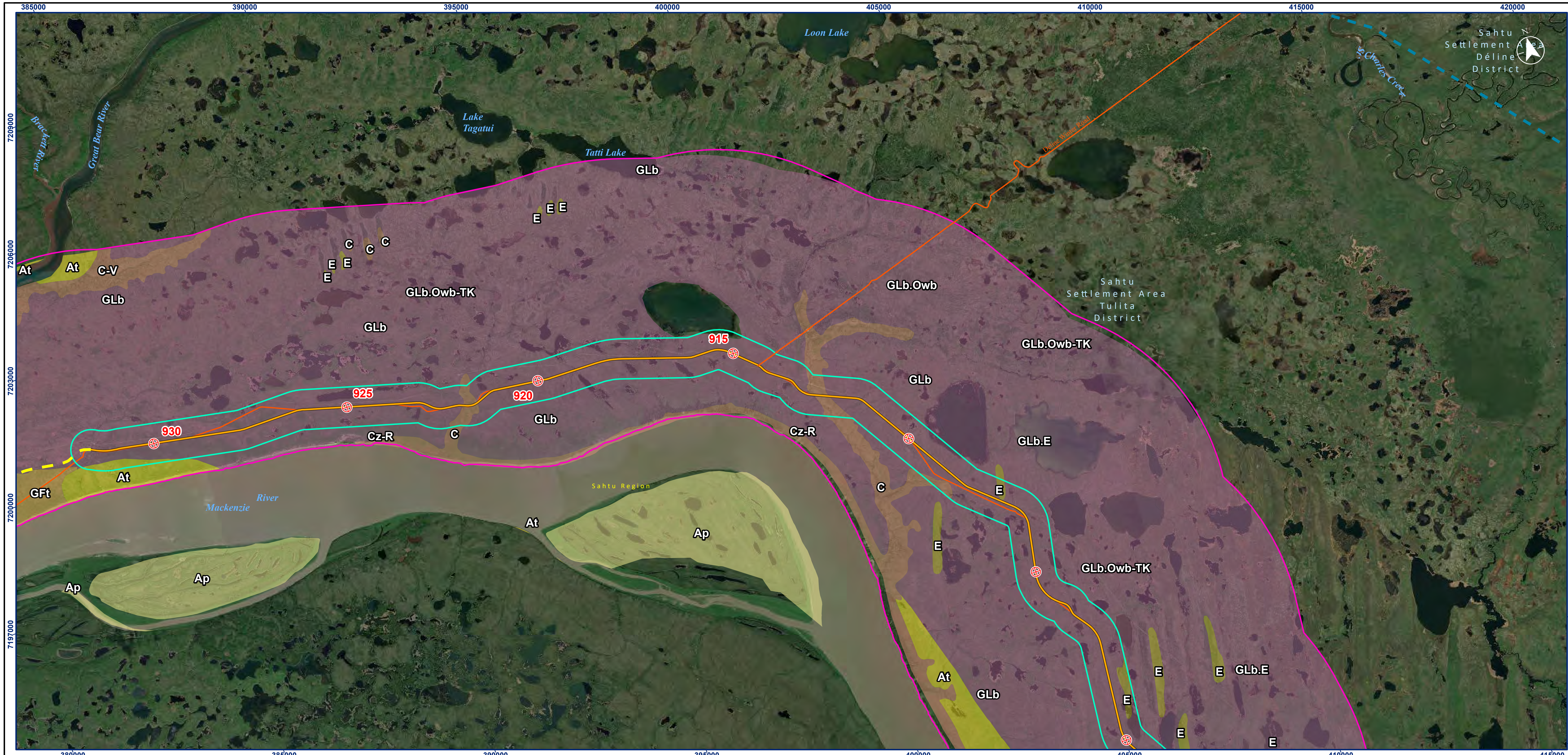
Government of Northwest Territories
Mackenzie Valley Highway Project

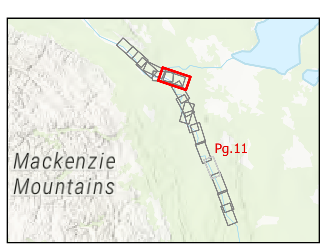
Figure No.
B.10

Title
RSA Surficial Geology

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Terrain mapping was compiled and modified based on a series of maps including OpenFile 7289 - middle east section from Côté et al. (2013), maps 371 and 375 from GSC (2019), and MGAR and Great bear prohibition mapping from G.V.M. Geological Consultant Ltd. (2016, 2019). Some data gaps occur.





Surficial Geology [4]

- Af: Alluvial fan
- Ap: Alluvial floodplain sediment
- At: Alluvial terraced sediment
- Av: Alluvial veneer
- C: Colluvial deposit, undfferentiated
- Cv: Colluvial veneer
- Cz: Landslide deposit
- E: Eolian deposit, undifferentiated
- GFf: Glaciofluvial outwash-fan sediment
- GFh: Glaciofluvial hummocky sediment
- GFp: Glaciofluvial outwash-plain sediment
- GFr: Glaciofluvial esker sediment
- GFt: Glaciofluvial terraced sediment
- GFv: Glaciofluvial veneer
- GLb: Glaciolacustrine blanket
- GLh: Glaciolacustrine hummocky sediment
- GLr: Glaciolacustrine beach sediment
- GLv: Glaciolacustrine veneer
- Owb: Bog deposit
- Owf: Fen deposit
- R1: Sedimentary bedrock
- Tb: Till blanket
- Th: Hummocky till
- Tp: Till plain (all)
- Ts: Streamlined till
- Tv: Till veneer
- Mackenzie Valley Highway Kilometre Post

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Local Study Area
- Regional Study Area
- Granular Borrow / Rock Quarry Site and Access
- Canyon Creek All Season Access Road
- Prohibition Creek Access Road
- Proposed Great Bear River Bridge Project
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Geomorphological Process

R: Mass movement
TK: Thermokarst
V: Gullied

Example of terrain map unit symbol

Dominant surficial material and surface expression: Alluvial fan ⇒ AF/Tp - TK ⇐ Geomorphological process: Thermokarst (TK)

Dominant subsurface material and expression: till (M); plain (p)

Complex units
Two map-unit designators separated by a dot (.) are used where the surficial cover forms a complex area and the units are too small to be mapped individually (e.g. Ap.C designates an area of alluvial plain sediments with colluvial deposits).

Stratigraphic relationship
Two map-unit designators separated by a slash (/) are used where the stratigraphic relationship is observed or confidently inferred (e.g. GLv/T indicates glaciolacustrine veneer overlying till.)

0 1.5 3 Kilometres
1:100,000 (at original document size of 11x17)

Kálo-Stantec

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-20
TR by AJ on 2023-03-20

Client/Project
144903025-0080 REVC

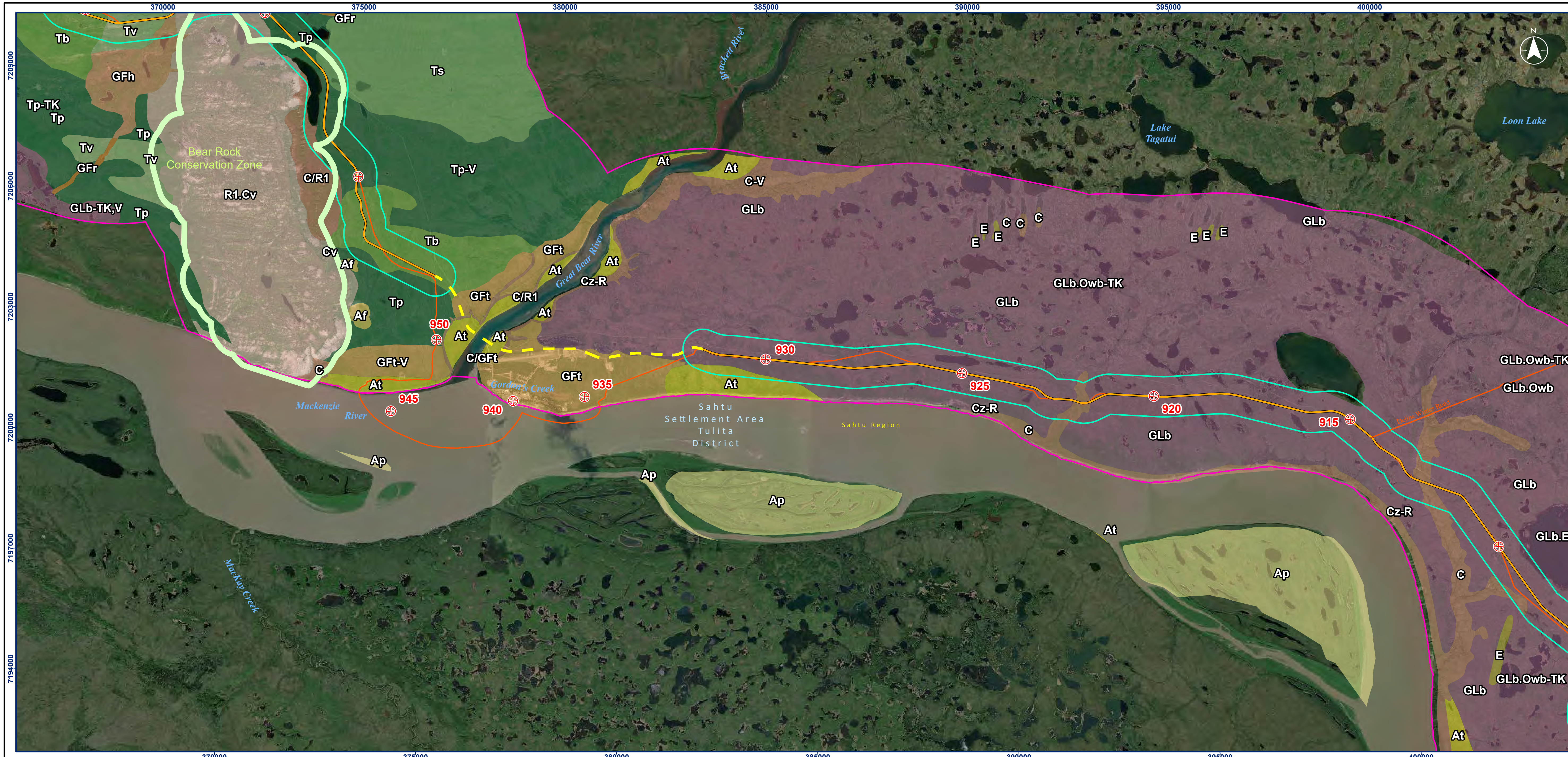
Government of Northwest Territories
Mackenzie Valley Highway Project

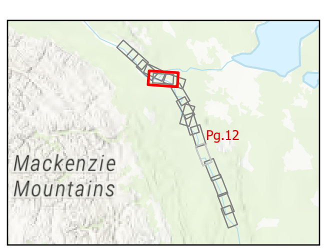
Figure No.
B.11

Title
RSA Surficial Geology

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Terrain mapping was compiled and modified based on a series of maps including OpenFile 7289 - middle east section from Côté et al. (2013), maps 371 and 375 from GSC (2019), and MGAR and Great bear prohibition mapping from G.V.M. Geological Consultant Ltd. (2016, 2019). Some data gaps occur.





Surficial Geology [4]

- Af: Alluvial fan
- Ap: Alluvial floodplain sediment
- At: Alluvial terraced sediment
- Av: Alluvial veneer
- C: Colluvial deposit, undifferentiated
- Cv: Colluvial veneer
- Cz: Landslide deposit
- E: Eolian deposit, undifferentiated
- GFf: Glaciofluvial outwash-fan sediment
- GFh: Glaciofluvial hummocky sediment
- GFp: Glaciofluvial outwash-plain sediment
- GFr: Glaciofluvial esker sediment
- GFt: Glaciofluvial terraced sediment
- GFv: Glaciofluvial veneer
- GLb: Glaciolacustrine blanket
- GLh: Glaciolacustrine hummocky sediment
- GLr: Glaciolacustrine beach sediment
- GLv: Glaciolacustrine veneer
- Owb: Bog deposit
- Owf: Fen deposit
- R1: Sedimentary bedrock
- Tb: Till blanket
- Th: Hummocky till
- Tp: Till plain (all)
- Ts: Streamlined till
- Tv: Till veneer

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Local Study Area
- Regional Study Area
- Granular Borrow / Rock Quarry Site and Access
- Canyon Creek All Season Access Road
- Prohibition Creek Access Road
- Proposed Great Bear River Bridge Project
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary
- Mackenzie Valley Highway Kilometre Post

Geomorphological Process

R: Mass movement
TK: Thermokarst
V: Gullied

Example of terrain map unit symbol

Dominant surficial material and surface expression: Alluvial fan ⟹ AF/Tp - TK ⟸ Geomorphological process: Thermokarst (TK)

Dominant subsurface material and expression: till (M); plain (p)

Complex units
Two map-unit designators separated by a dot (.) are used where the surficial cover forms a complex area and the units are too small to be mapped individually (e.g. Ap.C designates an area of alluvial plain sediments with colluvial deposits).

Stratigraphic relationship
Two map-unit designators separated by a slash (/) are used where the stratigraphic relationship is observed or confidently inferred (e.g. GLv/T indicates glaciolacustrine veneer overlying till.)

0 1.5 3 Kilometres
1:100,000 (at original document size of 11x17)

Kalo-Stantec

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-20
TR by AJ on 2023-03-20

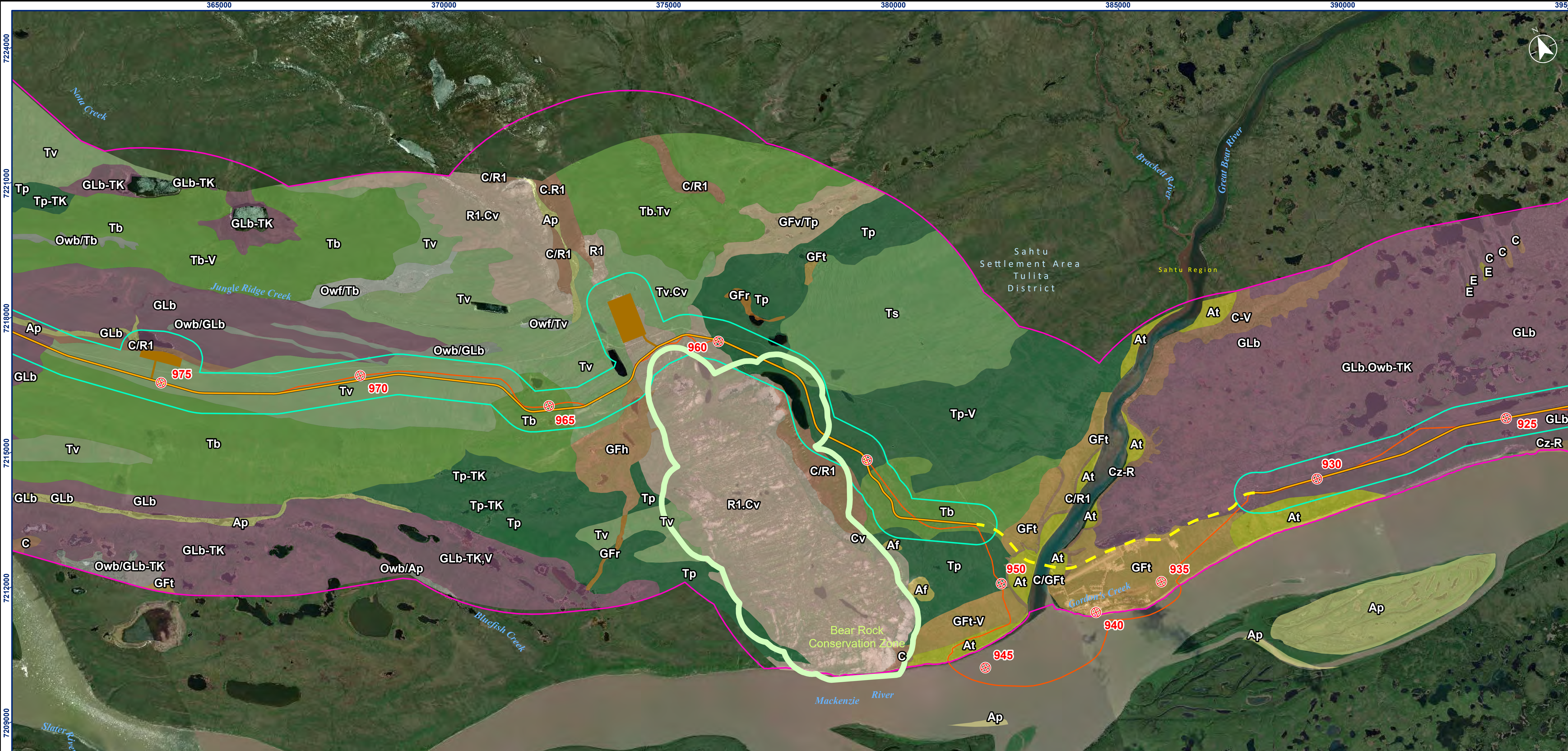
Client/Project
144903025-0080 REVC

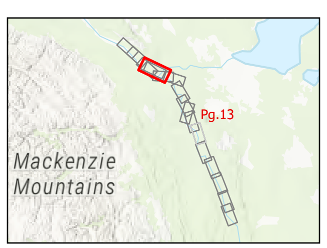
Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
B.12

Title
RSA Surficial Geology

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Terrain mapping was compiled and modified based on a series of maps including OpenFile 7289 - middle east section from Côté et al. (2013), maps 371 and 375 from GSC (2019), and MGAR and Great bear prohibition mapping from G.V.M. Geological Consultant Ltd. (2016, 2019). Some data gaps occur.





Surficial Geology [4]

- Af: Alluvial fan
- Ap: Alluvial floodplain sediment
- At: Alluvial terraced sediment
- Av: Alluvial veneer
- C: Colluvial deposit, undfferentiated
- Cv: Colluvial veneer
- Cz: Landslide deposit
- E: Eolian deposit, undifferentiated
- GFf: Glaciofluvial outwash-fan sediment
- GFh: Glaciofluvial hummocky sediment
- GFp: Glaciofluvial outwash-plain sediment
- GFr: Glaciofluvial esker sediment
- GFt: Glaciofluvial terraced sediment
- GFv: Glaciofluvial veneer
- GLb: Glaciolacustrine blanket
- GLh: Glaciolacustrine hummocky sediment
- GLr: Glaciolacustrine beach sediment
- GLv: Glaciolacustrine veneer
- Owb: Bog deposit
- Owf: Fen deposit
- R1: Sedimentary bedrock
- Tb: Till blanket
- Th: Hummocky till
- Tp: Till plain (all)
- Ts: Streamlined till
- Tv: Till veneer
- Mackenzie Valley Highway Kilometre Post

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Local Study Area
- Regional Study Area
- Granular Borrow / Rock Quarry Site and Access
- Canyon Creek All Season Access Road
- Prohibition Creek Access Road
- Proposed Great Bear River Bridge Project
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Geomorphological Process

R: Mass movement
TK: Thermokarst
V: Gullied

Example of terrain map unit symbol

Dominant surficial material and surface expression: Alluvial fan ⟹ AF/Tp - TK ⟸ Geomorphological process: Thermokarst (TK)

Dominant subsurface material and expression: till (M); plain (p)

Complex units
Two map-unit designators separated by a dot (.) are used where the surficial cover forms a complex area and the units are too small to be mapped individually (e.g. Ap.C designates an area of alluvial plain sediments with colluvial deposits).

Stratigraphic relationship
Two map-unit designators separated by a slash (/) are used where the stratigraphic relationship is observed or confidently inferred (e.g. GLv/T indicates glaciolacustrine veneer overlying till.)

0 1.5 3 Kilometres
1:100,000 (at original document size of 11x17)

Kálo-Stantec

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-20
TR by AJ on 2023-03-20

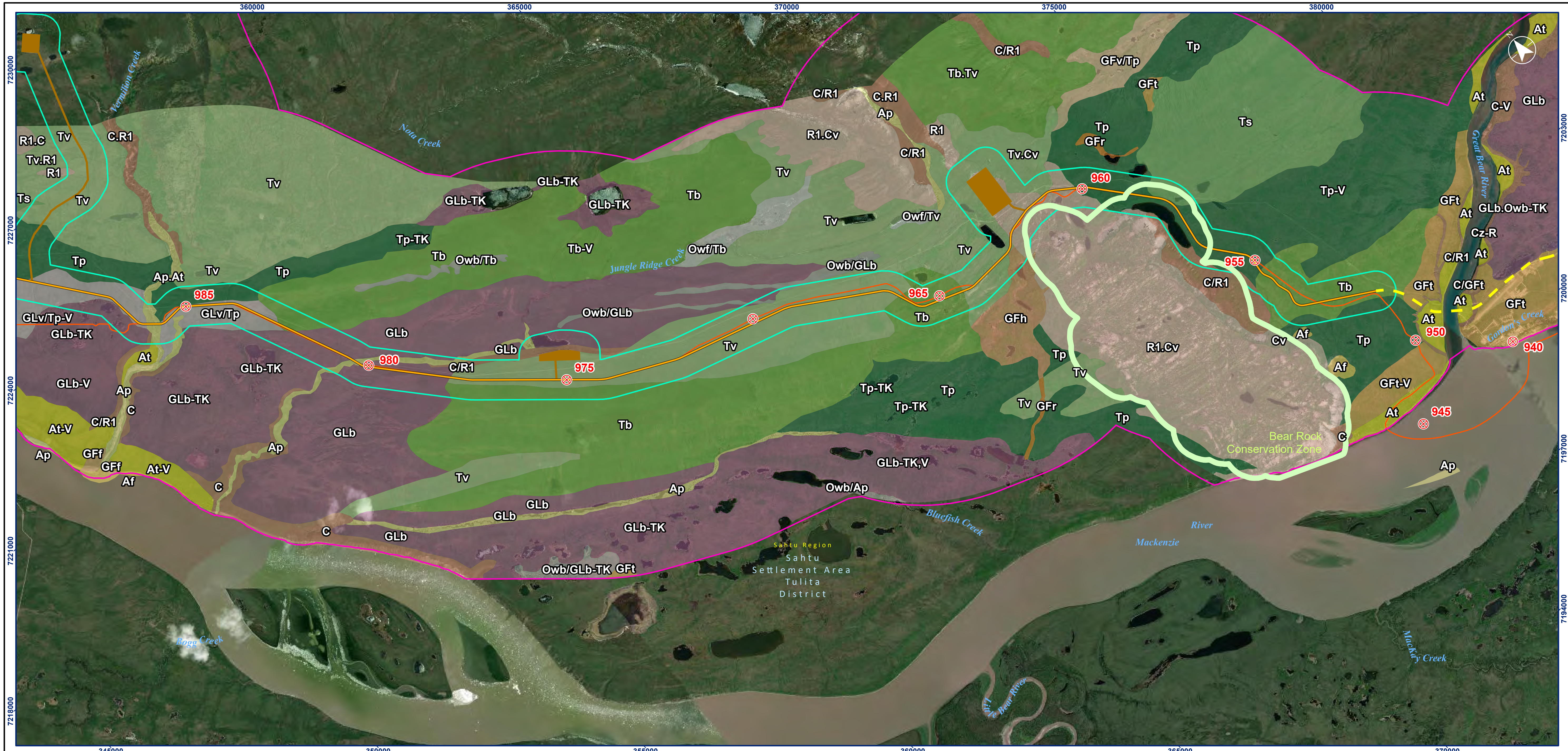
Client/Project
144903025-0080 REVC

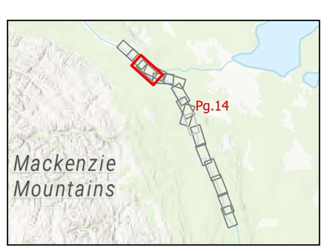
Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
B.13

Title
RSA Surficial Geology

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Terrain mapping was compiled and modified based on a series of maps including OpenFile 7289 - middle east section from Côté et al. (2013), maps 371 and 375 from GSC (2019), and MGAR and Great bear prohibition mapping from G.V.M. Geological Consultant Ltd. (2016, 2019). Some data gaps occur.





Surficial Geology [4]

- Af: Alluvial fan
- Ap: Alluvial floodplain sediment
- At: Alluvial terraced sediment
- Av: Alluvial veneer
- C: Colluvial deposit, undifferentiated
- Cv: Colluvial veneer
- Cz: Landslide deposit
- E: Eolian deposit, undifferentiated
- GFf: Glaciofluvial outwash-fan sediment
- GFh: Glaciofluvial hummocky sediment
- GFp: Glaciofluvial outwash-plain sediment
- GFr: Glaciofluvial esker sediment
- GFt: Glaciofluvial terraced sediment
- GFv: Glaciofluvial veneer
- GLb: Glaciolacustrine blanket
- GLh: Glaciolacustrine hummocky sediment
- GLr: Glaciolacustrine beach sediment
- GLv: Glaciolacustrine veneer
- Owb: Bog deposit
- Owf: Fen deposit
- R1: Sedimentary bedrock
- Tb: Till blanket
- Th: Hummocky till
- Tp: Till plain (all)
- Ts: Streamlined till
- Tv: Till veneer
- Mackenzie Valley Highway Kilometre Post

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Local Study Area
- Regional Study Area
- Granular Borrow / Rock Quarry Site and Access
- Canyon Creek All Season Access Road
- Prohibition Creek Access Road
- Proposed Great Bear River Bridge Project
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Geomorphological Process

R: Mass movement
TK: Thermokarst
V: Gullied

Example of terrain map unit symbol

Dominant surficial material and surface expression: Alluvial fan ⟹ AF/Tp - TK ⟸ Geomorphological process: Thermokarst (TK)

Dominant subsurface material and expression: till (M); plain (p)

Complex units
Two map-unit designators separated by a dot (.) are used where the surficial cover forms a complex area and the units are too small to be mapped individually (e.g. Ap.C designates an area of alluvial plain sediments with colluvial deposits).

Stratigraphic relationship
Two map-unit designators separated by a slash (/) are used where the stratigraphic relationship is observed or confidently inferred (e.g. GLv/T indicates glaciolacustrine veneer overlying till.)

0 1.5 3 Kilometres
1:100,000 (at original document size of 11x17)

Kalo-Stantec

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-20
TR by AJ on 2023-03-20

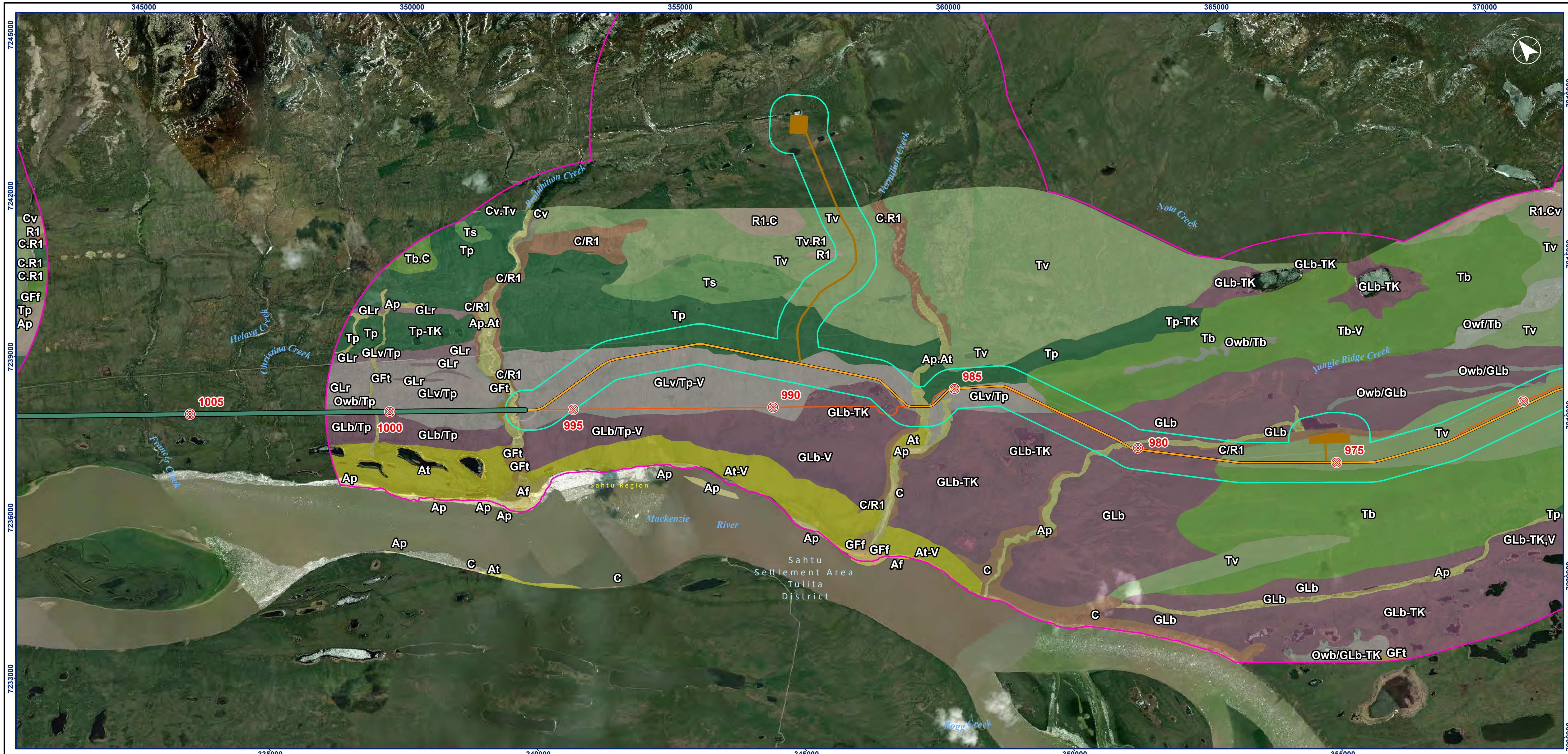
Client/Project
144903025-0080 REVC

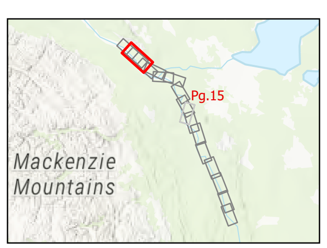
Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
B.14

Title
RSA Surficial Geology

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Terrain mapping was compiled and modified based on a series of maps including OpenFile 7289 - middle east section from Côté et al. (2013), maps 371 and 375 from GSC (2019), and MGAR and Great bear prohibition mapping from G.V.M. Geological Consultant Ltd. (2016, 2019). Some data gaps occur.





Surficial Geology [4]

- Af: Alluvial fan
- Ap: Alluvial floodplain sediment
- At: Alluvial terraced sediment
- Av: Alluvial veneer
- C: Colluvial deposit, undifferentiated
- Cv: Colluvial veneer
- Cz: Landslide deposit
- E: Eolian deposit, undifferentiated
- GFf: Glaciofluvial outwash-fan sediment
- GFh: Glaciofluvial hummocky sediment
- GFp: Glaciofluvial outwash-plain sediment
- GFr: Glaciofluvial esker sediment
- GFt: Glaciofluvial terraced sediment
- GFv: Glaciofluvial veneer
- GLb: Glaciolacustrine blanket
- GLh: Glaciolacustrine hummocky sediment
- GLr: Glaciolacustrine beach sediment
- GLv: Glaciolacustrine veneer
- Owb: Bog deposit
- Owf: Fen deposit
- R1: Sedimentary bedrock
- Tb: Till blanket
- Th: Hummocky till
- Tp: Till plain (all)
- Ts: Streamlined till
- Tv: Till veneer
- Mackenzie Valley Highway Kilometre Post

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Local Study Area
- Regional Study Area
- Granular Borrow / Rock Quarry Site and Access
- Canyon Creek All Season Access Road
- Prohibition Creek Access Road
- Proposed Great Bear River Bridge Project
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Geomorphological Process

R: Mass movement
TK: Thermokarst
V: Gullied

Example of terrain map unit symbol

Dominant surficial material and surface expression: Alluvial fan ⟹ AF/Tp - TK ⟸ Geomorphological process: Thermokarst (TK)

Dominant subsurface material and expression: till (M); plain (p)

Complex units
Two map-unit designators separated by a dot (.) are used where the surficial cover forms a complex area and the units are too small to be mapped individually (e.g. Ap.C designates an area of alluvial plain sediments with colluvial deposits).

Stratigraphic relationship
Two map-unit designators separated by a slash (/) are used where the stratigraphic relationship is observed or confidently inferred (e.g. GLv/T indicates glaciolacustrine veneer overlying till.)

0 1.5 3 Kilometres
1:100,000 (at original document size of 11x17)

Kálo-Stantec

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-20
TR by AJ on 2023-03-20

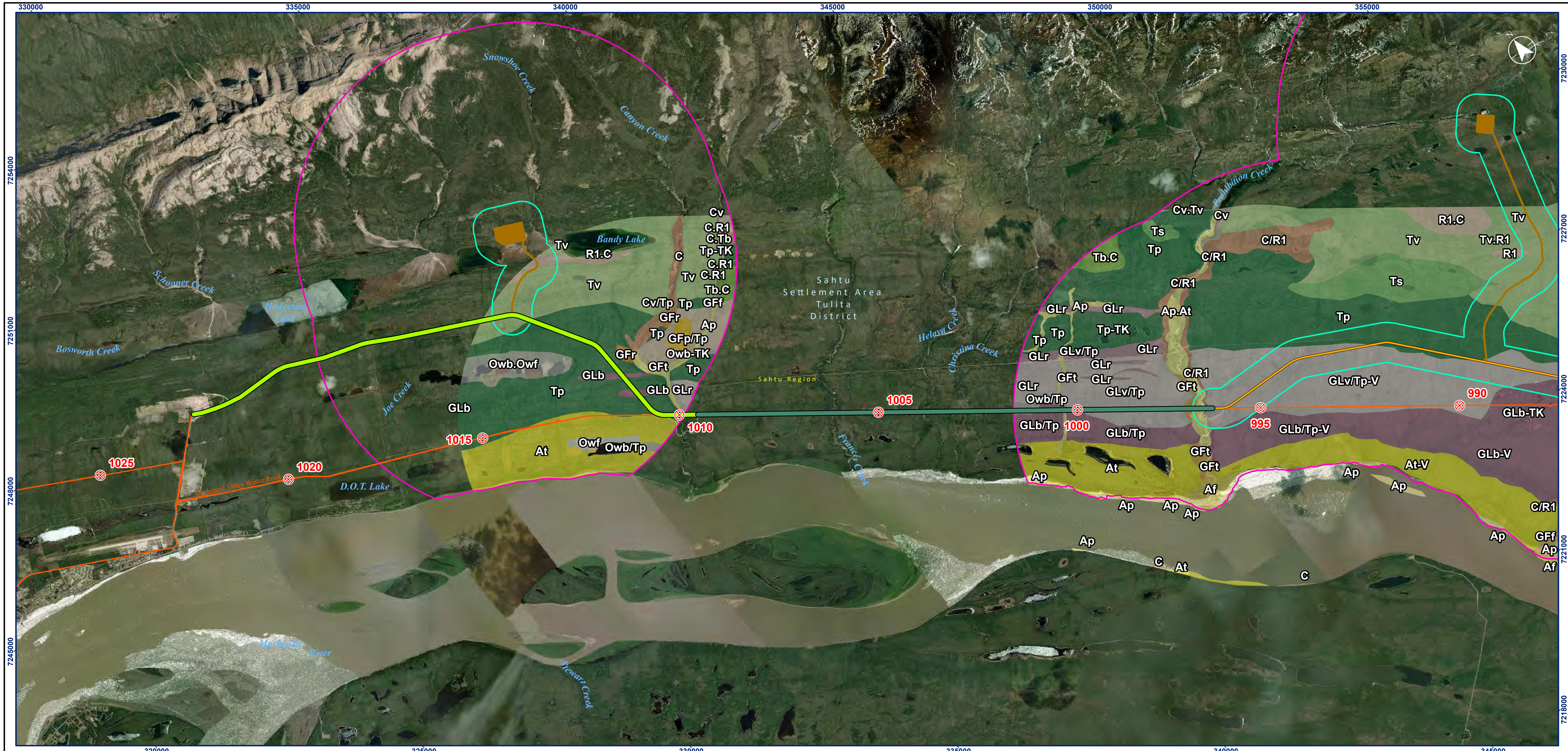
Client/Project
144903025-0080 REVC

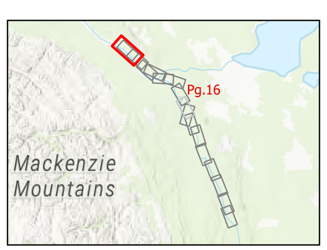
Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
B.15

Title
RSA Surficial Geology

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Terrain mapping was compiled and modified based on a series of maps including OpenFile 7289 - middle east section from Côté et al. (2013), maps 371 and 375 from GSC (2019), and MGAR and Great bear prohibition mapping from G.V.M. Geological Consultant Ltd. (2016, 2019). Some data gaps occur.





Surficial Geology [4]

- Af: Alluvial fan
- Ap: Alluvial floodplain sediment
- At: Alluvial terraced sediment
- Av: Alluvial veneer
- C: Colluvial deposit, undifferentiated
- Cv: Colluvial veneer
- Cz: Landslide deposit
- E: Eolian deposit, undifferentiated
- GFf: Glaciofluvial outwash-fan sediment
- GFh: Glaciofluvial hummocky sediment
- GFp: Glaciofluvial outwash-plain sediment
- GFr: Glaciofluvial esker sediment
- GFt: Glaciofluvial terraced sediment
- GFv: Glaciofluvial veneer
- GLb: Glaciolacustrine blanket
- GLh: Glaciolacustrine hummocky sediment
- GLr: Glaciolacustrine beach sediment
- GLv: Glaciolacustrine veneer
- Owb: Bog deposit
- Owf: Fen deposit
- R1: Sedimentary bedrock
- Tb: Till blanket
- Th: Hummocky till
- Tp: Till plain (all)
- Ts: Streamlined till
- Tv: Till veneer
- Mackenzie Valley Highway Kilometre Post

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Local Study Area
- Regional Study Area
- Granular Borrow / Rock Quarry Site and Access
- Canyon Creek All Season Access Road
- Prohibition Creek Access Road
- Proposed Great Bear River Bridge Project
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Geomorphological Process

R: Mass movement
TK: Thermokarst
V: Gullied

Example of terrain map unit symbol

Dominant surficial material and surface expression: Alluvial fan ⟹ AF/Tp - TK ⟸ Geomorphological process: Thermokarst (TK)

Dominant subsurface material and expression: till (M); plain (p)

Complex units
Two map-unit designators separated by a dot (.) are used where the surficial cover forms a complex area and the units are too small to be mapped individually (e.g. Ap.C designates an area of alluvial plain sediments with colluvial deposits).

Stratigraphic relationship
Two map-unit designators separated by a slash (/) are used where the stratigraphic relationship is observed or confidently inferred (e.g. GLv/T indicates glaciolacustrine veneer overlying till.)

0 1.5 3 Kilometres
1:100,000 (at original document size of 11x17)

Kálo-Stantec

Project Location
Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-20
TR by AJ on 2023-03-20

Client/Project
144903025-0080 REVC

Government of Northwest Territories
Mackenzie Valley Highway Project

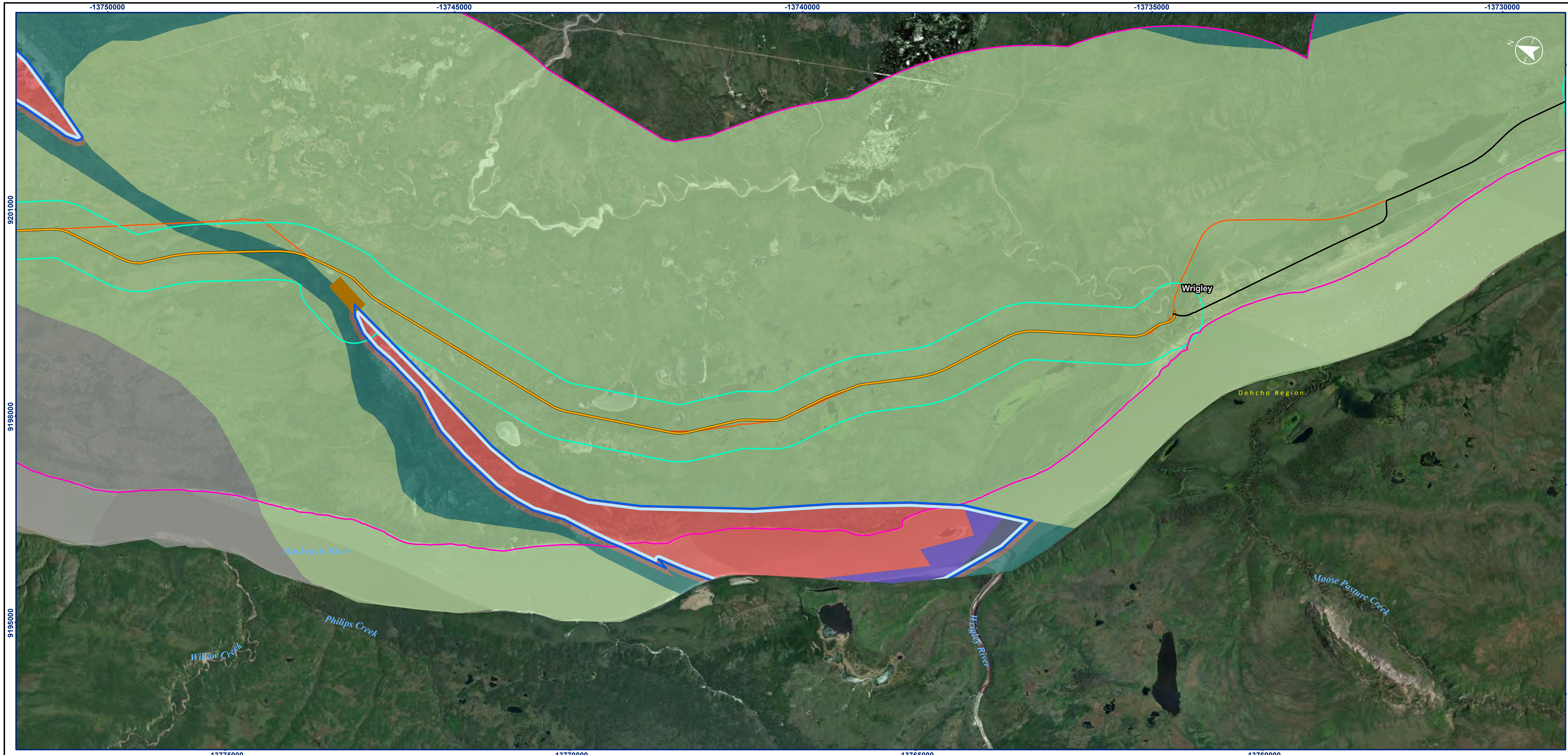
Figure No.
B.16

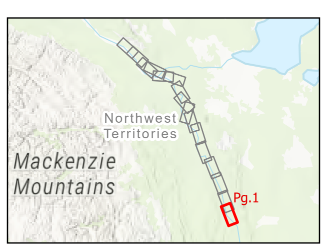
Title
RSA Surficial Geology

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Terrain mapping was compiled and modified based on a series of maps including OpenFile 7289 - middle east section from Côté et al. (2013), maps 371 and 375 from GSC (2019), and MGAR and Great bear prohibition mapping from G.V.M. Geological Consultant Ltd. (2016, 2019). Some data gaps occur.

Appendix C Bedrock Geology in the LSA and RSA





Aquifer[4]

Geologic Formation

- Summit Creek
- East Fork
- Little Bear
- Slater River
- Arctic Red
- Fort Simpson
- Unnamed
- Imperial
- Canol
- Ramparts
- Hare Indian
- Hume
- Nahanni
- Headless
- Landry (Bear Rock Group)
- Arnica (Bear Rock Group)
- Fort Norman (Bear Rock Group)
- Mount Kindle
- Franklin Mountain
- Saline River
- Mount Cap

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Bedrock formations Stantec infers are important aquifer hydrostratigraphic units relative to the Project LSA and RSA include the Saline River, Franklin Mountain, and Mount Kindle Formations and the Fort Norman, Arnica, and Landry Formations that constitute the Bear Rock Group.

0 1 2 Kilometres

1:70,000 (at original document size of 11x17)

Kálo-Stantec

Project Location

Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-07
TR by AJ on 2023-03-07

Client/Project

144903025-0072 REVB

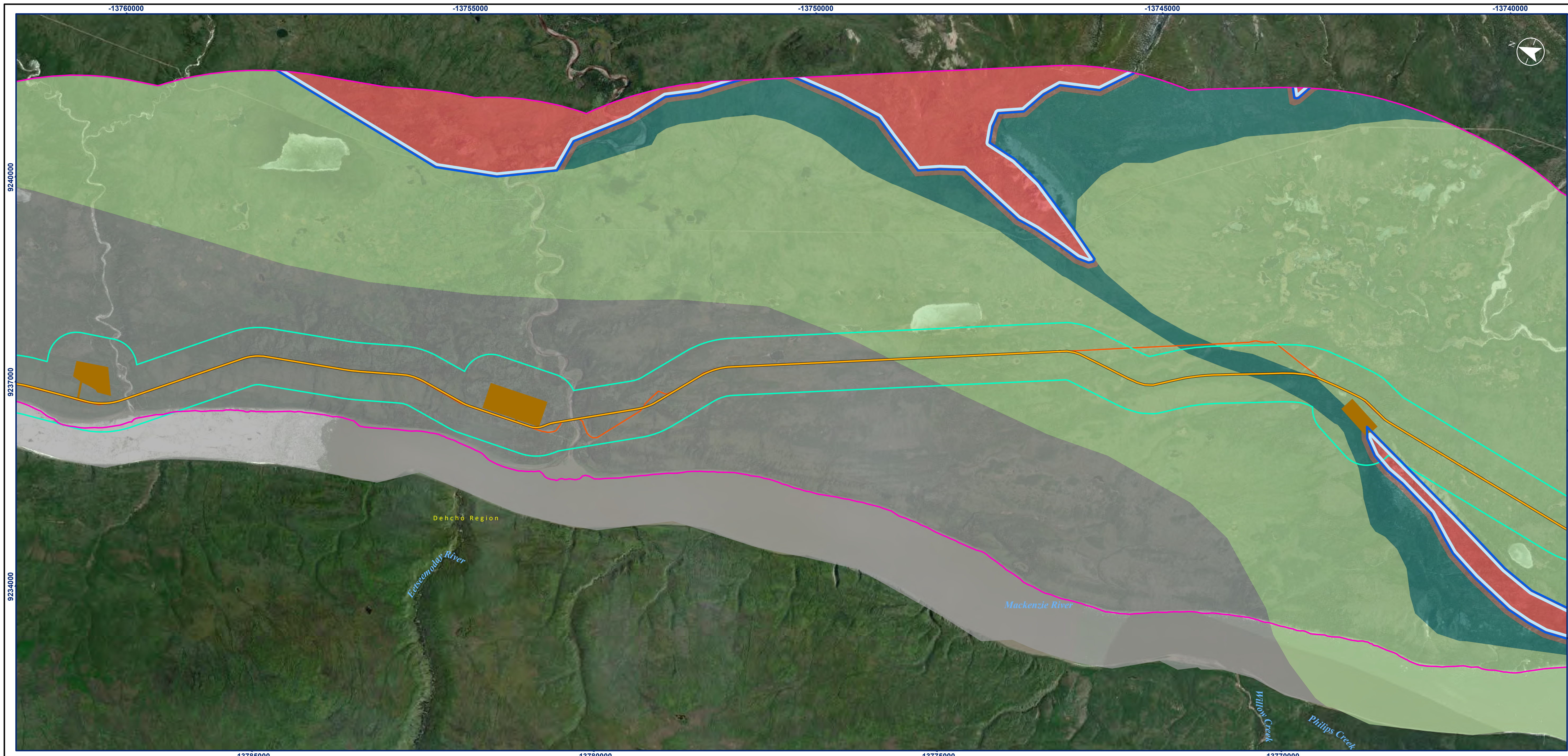
Government of Northwest Territories
Mackenzie Valley Highway Project

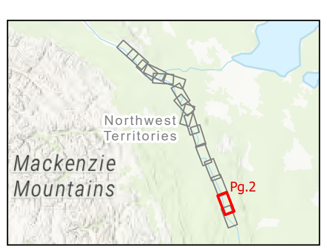
Figure No.

C.1

Title

RSA Geologic Formations with Aquifers Noted





Aquifer[4]

Geologic Formation

- Summit Creek
- East Fork
- Little Bear
- Slater River
- Arctic Red
- Fort Simpson
- Unnamed
- Imperial
- Canol
- Ramparts
- Hare Indian
- Hume
- Nahanni
- Headless
- Landry (Bear Rock Group)
- Arnica (Bear Rock Group)
- Fort Norman (Bear Rock Group)
- Mount Kindle
- Franklin Mountain
- Saline River
- Mount Cap

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Bedrock formations Stantec infers are important aquifer hydrostratigraphic units relative to the Project LSA and RSA include the Saline River, Franklin Mountain, and Mount Kindle Formations and the Fort Norman, Arnica, and Landry Formations that constitute the Bear Rock Group.

0 1 2 Kilometres
1:70,000 (at original document size of 11x17)

Project Location
Wrigley to Norman Wells, NWT

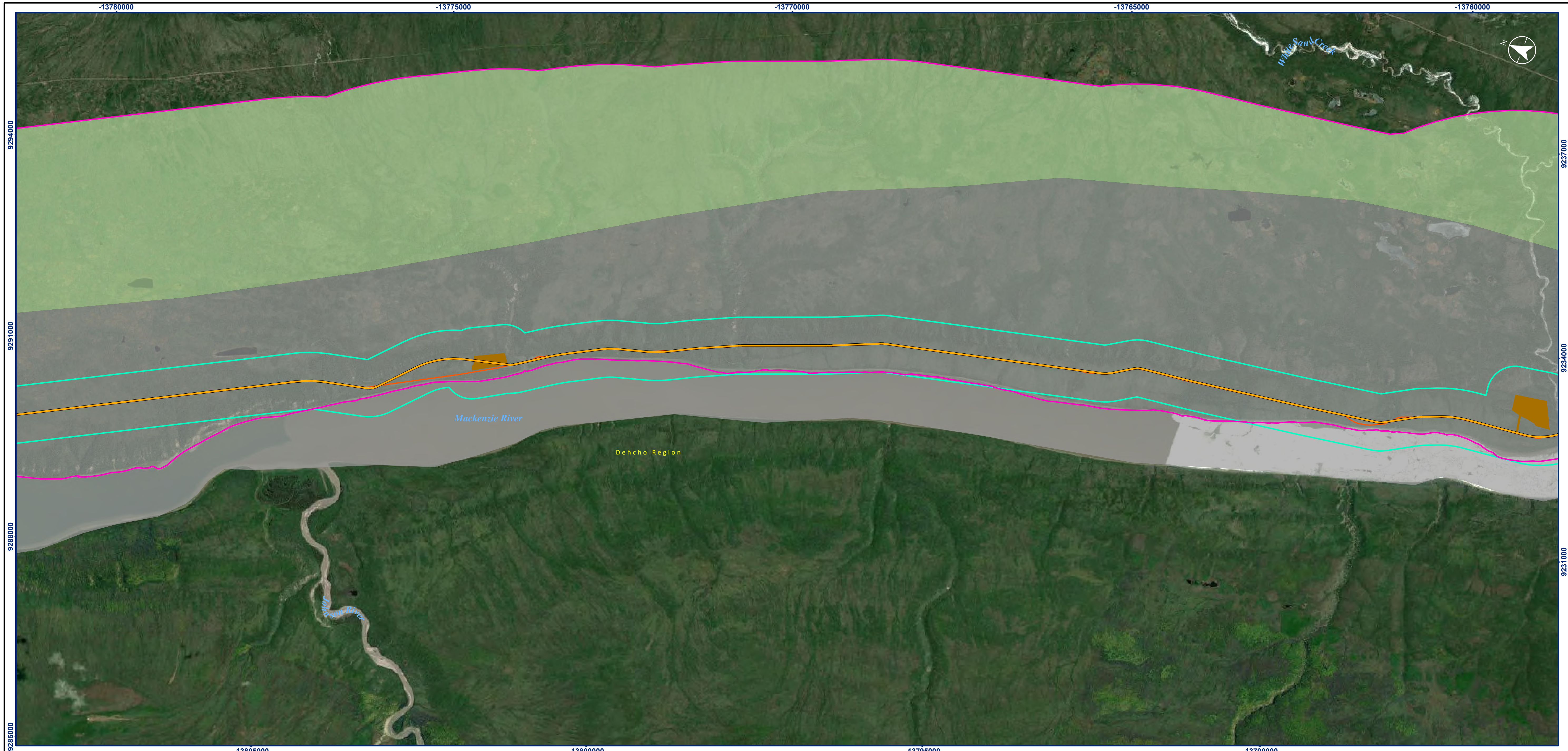
Prepared by AT on 2023-03-07
TR by AJ on 2023-03-07

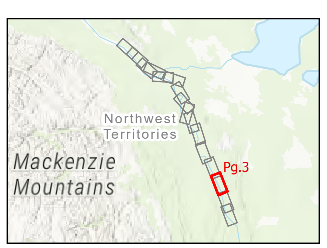
Client/Project
144903025-0072 REVB

Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
C.2

Title
RSA Geologic Formations with Aquifers Noted





Aquifer[4]

Geologic Formation

- Summit Creek
- East Fork
- Little Bear
- Slater River
- Arctic Red
- Fort Simpson
- Unnamed
- Imperial
- Canol
- Ramparts
- Hare Indian
- Hume
- Nahanni
- Headless
- Landry (Bear Rock Group)
- Arnica (Bear Rock Group)
- Fort Norman (Bear Rock Group)
- Mount Kindle
- Franklin Mountain
- Saline River
- Mount Cap

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Bedrock formations Stantec infers are important aquifer hydrostratigraphic units relative to the Project LSA and RSA include the Saline River, Franklin Mountain, and Mount Kindle Formations and the Fort Norman, Arnica, and Landry Formations that constitute the Bear Rock Group.

0 1 2 Kilometres

1:70,000 (at original document size of 11x17)

Kálo-Stantec

Project Location

Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-07
TR by AJ on 2023-03-07

Client/Project

144903025-0072 REVB

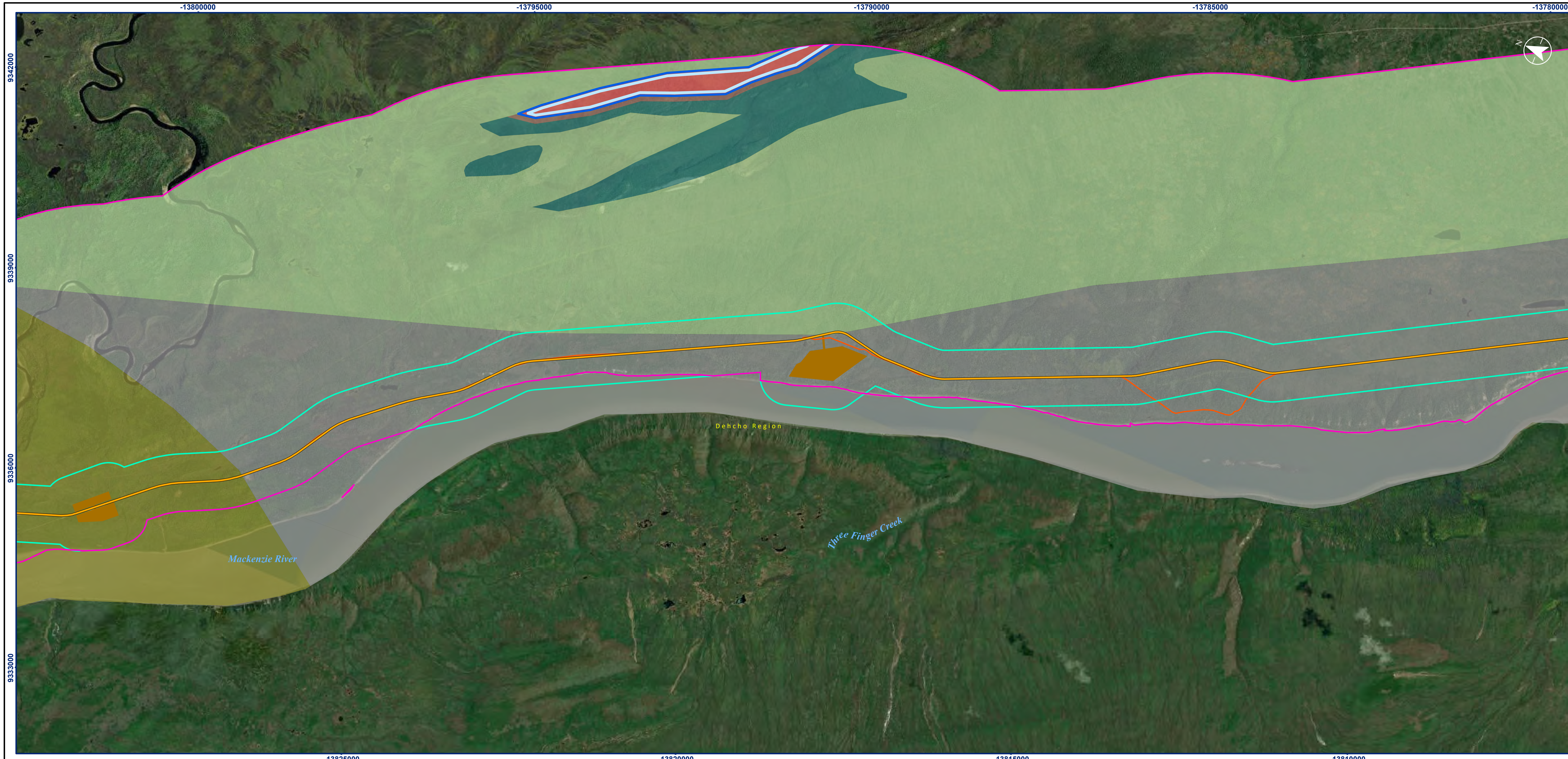
Government of Northwest Territories
Mackenzie Valley Highway Project

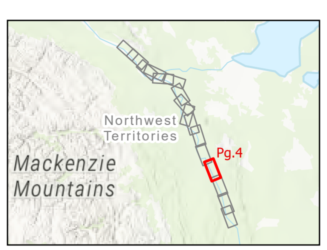
Figure No.

C.3

Title

RSA Geologic Formations with Aquifers Noted





Aquifer[4]

Geologic Formation

- Summit Creek
- East Fork
- Little Bear
- Slater River
- Arctic Red
- Fort Simpson
- Unnamed
- Imperial
- Canol
- Ramparts
- Hare Indian
- Hume
- Nahanni
- Headless
- Landry (Bear Rock Group)
- Arnica (Bear Rock Group)
- Fort Norman (Bear Rock Group)
- Mount Kindle
- Franklin Mountain
- Saline River
- Mount Cap

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

0 1 2 Kilometres

1:70,000 (at original document size of 11x17)

Project Location

Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-07
TR by AJ on 2023-03-07

Client/Project

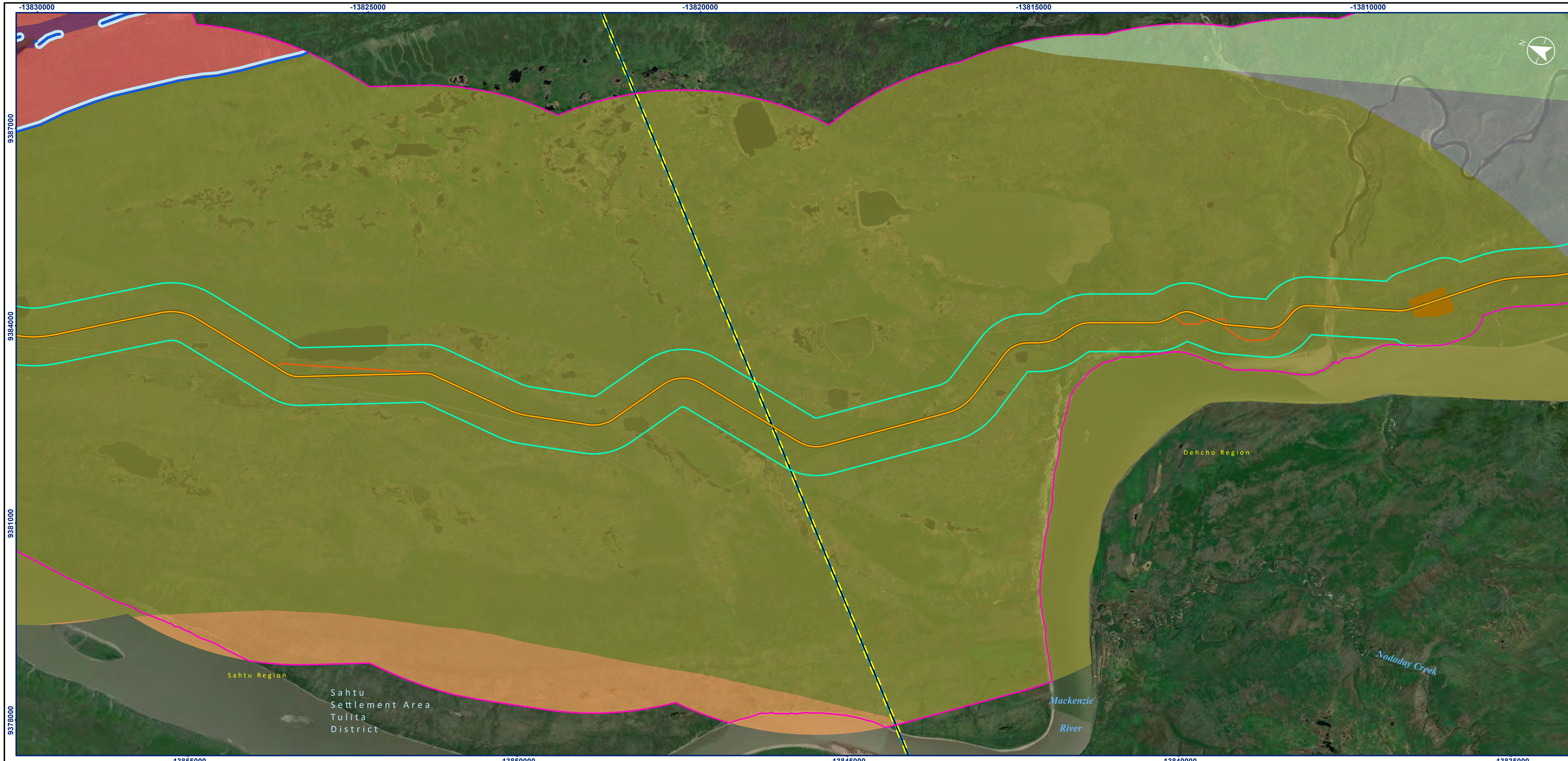
144903025-0072 REVB

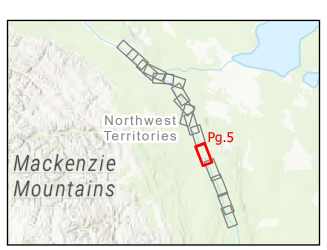
Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
C.4

Title
RSA Geologic Formations with Aquifers Noted

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Bedrock formations Stantec infers are important aquifer hydrostratigraphic units relative to the Project LSA and RSA include the Saline River, Franklin Mountain, and Mount Kindle Formations and the Fort Norman, Arnica, and Landry Formations that constitute the Bear Rock Group.





Aquifer[4]

Geologic Formation

- Summit Creek
- East Fork
- Little Bear
- Slater River
- Arctic Red
- Fort Simpson
- Unnamed
- Imperial
- Canol
- Ramparts
- Hare Indian
- Hume
- Nahanni
- Headless
- Landry (Bear Rock Group)
- Arnica (Bear Rock Group)
- Fort Norman (Bear Rock Group)
- Mount Kindle
- Franklin Mountain
- Saline River
- Mount Cap

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Bedrock formations Stantec infers are important aquifer hydrostratigraphic units relative to the Project LSA and RSA include the Saline River, Franklin Mountain, and Mount Kindle Formations and the Fort Norman, Arnica, and Landry Formations that constitute the Bear Rock Group.

0 1 2 Kilometres
1:70,000 (at original document size of 11x17)

Kálo-Stantec

Project Location
Wrigley to Norman Wells, NWT

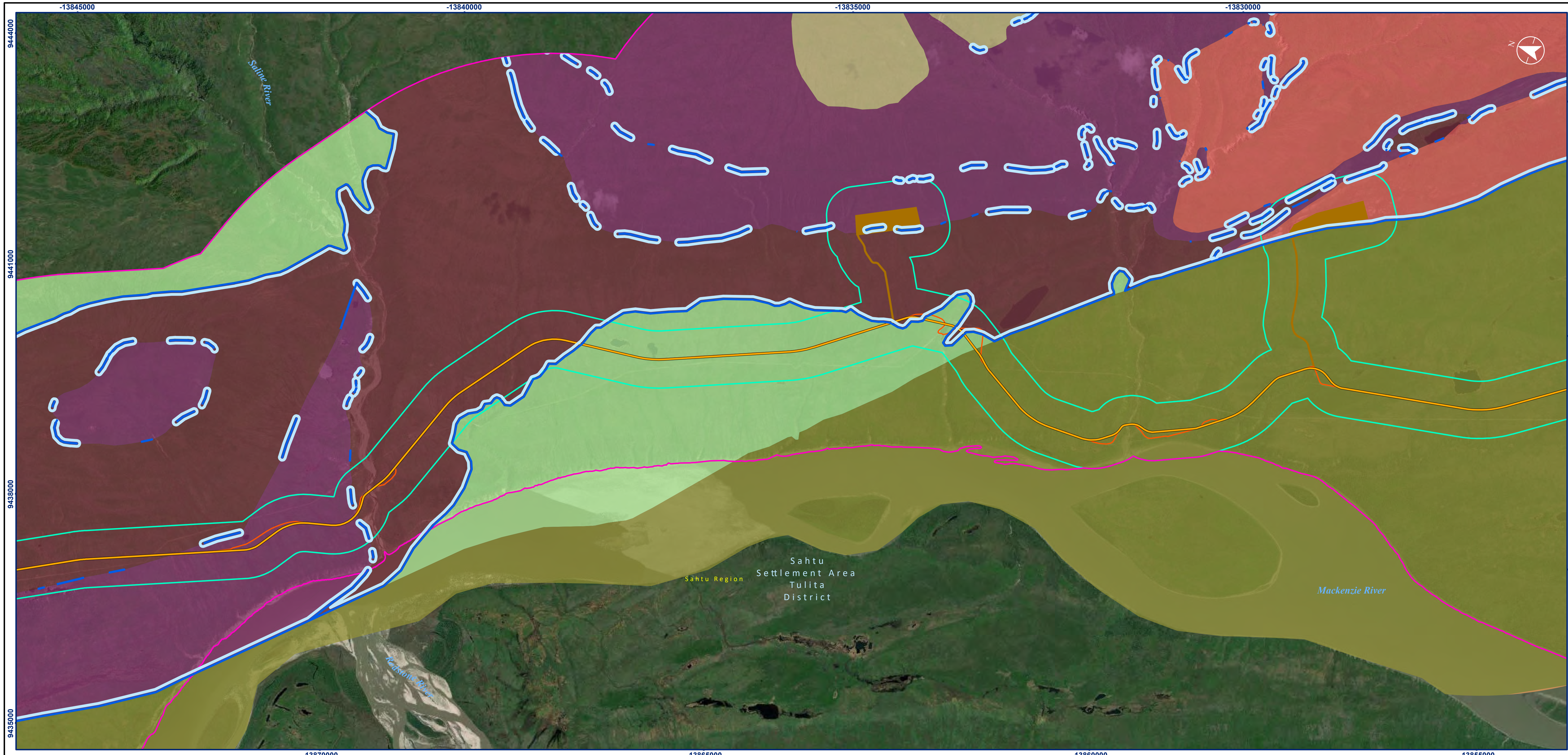
Prepared by AT on 2023-03-07
TR by AJ on 2023-03-07

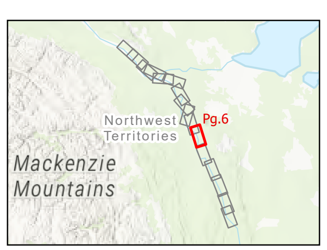
Client/Project
144903025-0072 REVB

Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
C.5

Title
RSA Geologic Formations with Aquifers Noted





- Aquifer[4]

Geologic Formation

- Summit Creek
- East Fork
- Little Bear
- Slater River
- Arctic Red
- Fort Simpson
- Unnamed
- Imperial
- Canol
- Ramparts
- Hare Indian
- Hume
- Nahanni
- Headless
- Landry (Bear Rock Group)
- Arnica (Bear Rock Group)
- Fort Norman (Bear Rock Group)
- Mount Kindle
- Franklin Mountain
- Saline River
- Mount Cap
- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Bedrock formations Stantec infers are important aquifer hydrostratigraphic units relative to the Project LSA and RSA include the Saline River, Franklin Mountain, and Mount Kindle Formations and the Fort Norman, Arnica, and Landry Formations that constitute the Bear Rock Group.

0 1 2 Kilometres
1:70,000 (at original document size of 11x17)

Kálo-Stantec

Project Location
Wrigley to Norman Wells, NWT

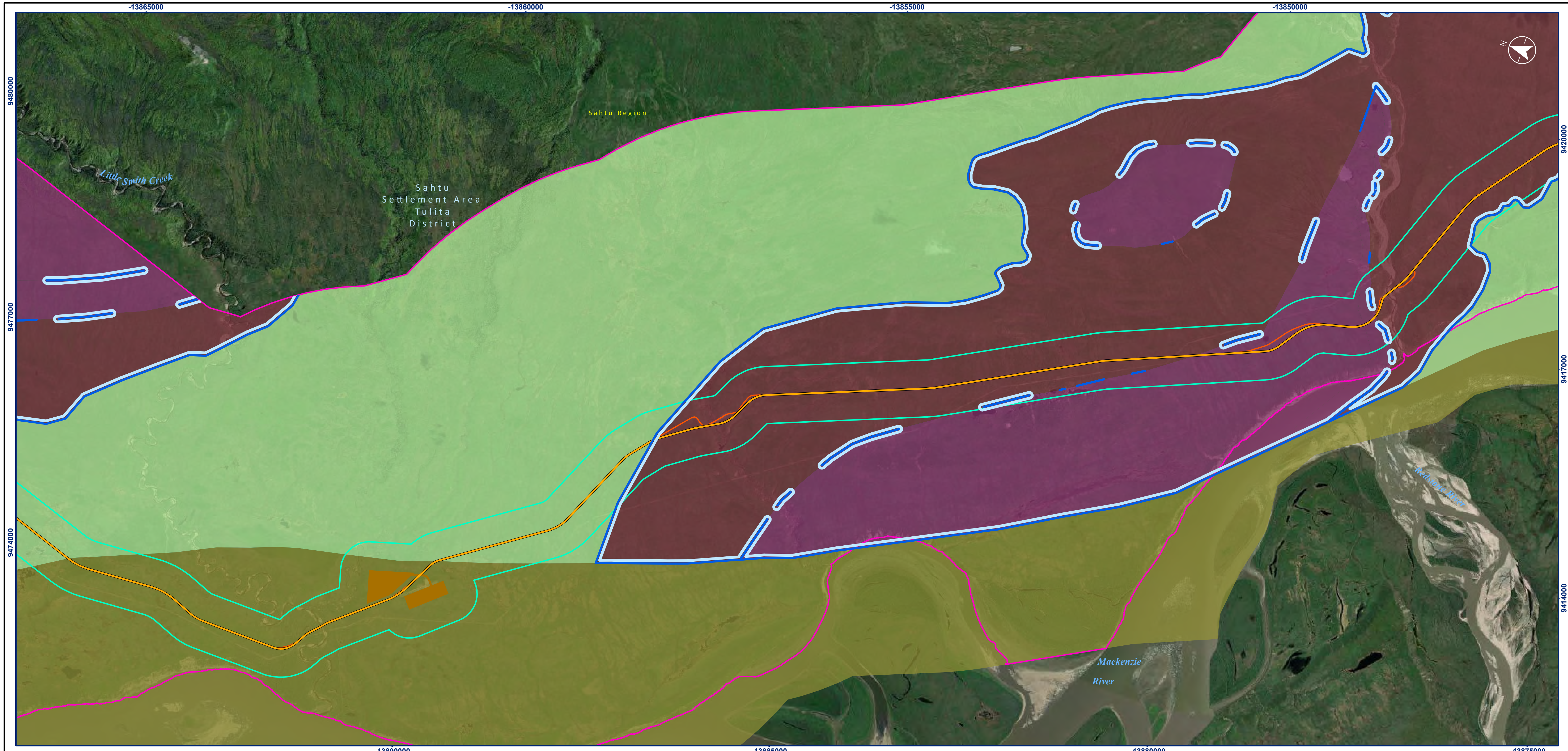
Prepared by AT on 2023-03-07
TR by AJ on 2023-03-07

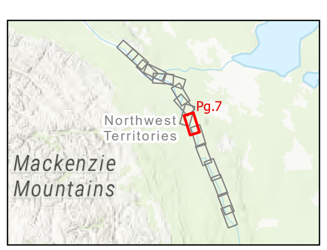
Client/Project
144903025-0072 REVB

Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
C.6

Title
RSA Geologic Formations with Aquifers Noted





Aquifer[4]

Geologic Formation

- Summit Creek
- East Fork
- Little Bear
- Slater River
- Arctic Red
- Fort Simpson
- Unnamed
- Imperial
- Canol
- Ramparts
- Hare Indian
- Hume
- Nahanni
- Headless
- Landry (Bear Rock Group)
- Arnica (Bear Rock Group)
- Fort Norman (Bear Rock Group)
- Mount Kindle
- Franklin Mountain
- Saline River
- Mount Cap

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Bedrock formations Stantec infers are important aquifer hydrostratigraphic units relative to the Project LSA and RSA include the Saline River, Franklin Mountain, and Mount Kindle Formations and the Fort Norman, Arnica, and Landry Formations that constitute the Bear Rock Group.

0 1 2 Kilometres
1:70,000 (at original document size of 11x17)

Kálo-Stantec

Project Location
Wrigley to Norman Wells, NWT

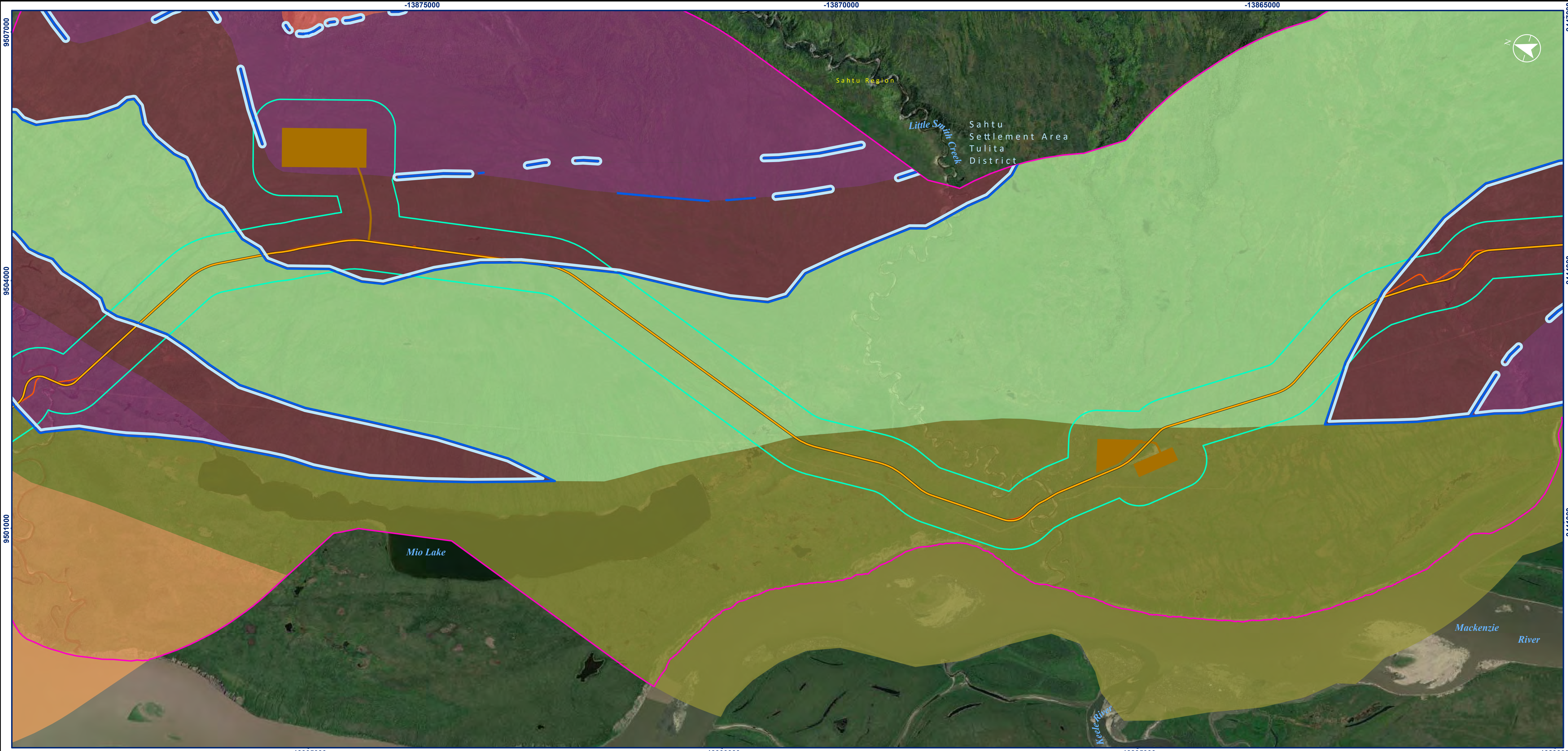
Prepared by AT on 2023-03-07
TR by AJ on 2023-03-07

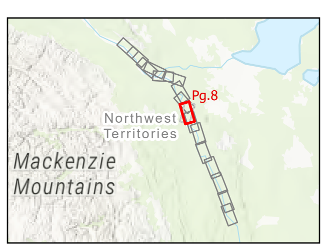
Client/Project
144903025-0072 REVB

Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
C.7

Title
RSA Geologic Formations with Aquifers Noted





Aquifer[4]

Geologic Formation

- Summit Creek
- East Fork
- Little Bear
- Slater River
- Arctic Red
- Fort Simpson
- Unnamed
- Imperial
- Canol
- Ramparts
- Hare Indian
- Hume
- Nahanni
- Headless
- Landry (Bear Rock Group)
- Arnica (Bear Rock Group)
- Fort Norman (Bear Rock Group)
- Mount Kindle
- Franklin Mountain
- Saline River
- Mount Cap

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Bedrock formations Stantec infers are important aquifer hydrostratigraphic units relative to the Project LSA and RSA include the Saline River, Franklin Mountain, and Mount Kindle Formations and the Fort Norman, Arnica, and Landry Formations that constitute the Bear Rock Group.

0 1 2 Kilometres
1:70,000 (at original document size of 11x17)

Kálo-Stantec

Project Location
Wrigley to Norman Wells, NWT

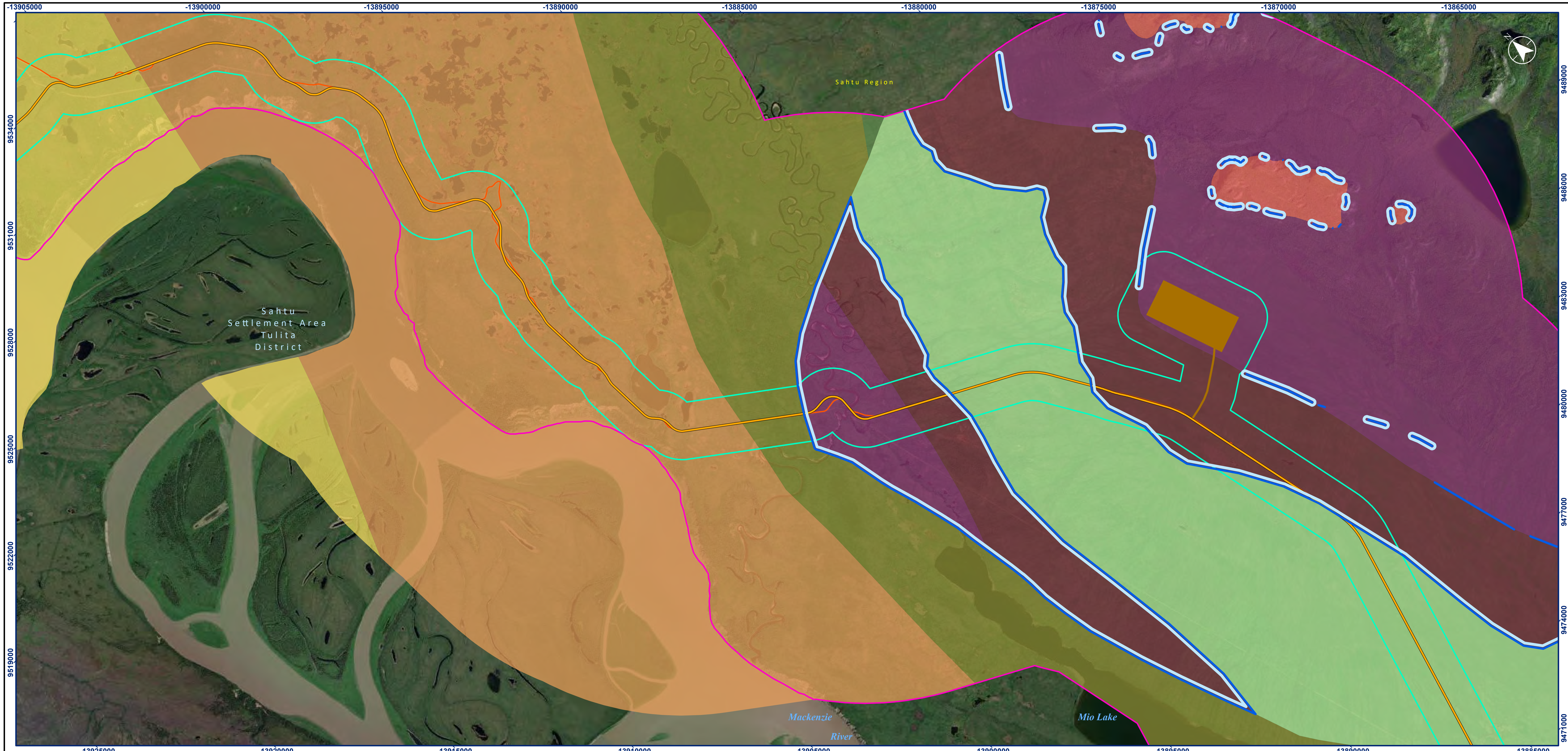
Prepared by AT on 2023-03-07
TR by AJ on 2023-03-07

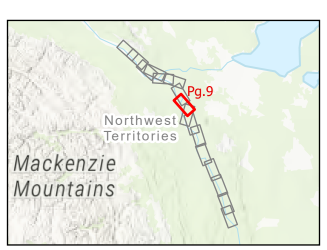
Client/Project
144903025-0072 REVB

Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
C.8

Title
RSA Geologic Formations with Aquifers Noted





Aquifer[4]

Geologic Formation

- Summit Creek
- East Fork
- Little Bear
- Slater River
- Arctic Red
- Fort Simpson
- Unnamed
- Imperial
- Canol
- Ramparts
- Hare Indian
- Hume
- Nahanni
- Headless
- Landry (Bear Rock Group)
- Arnica (Bear Rock Group)
- Fort Norman (Bear Rock Group)
- Mount Kindle
- Franklin Mountain
- Saline River
- Mount Cap

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Bedrock formations Stantec infers are important aquifer hydrostratigraphic units relative to the Project LSA and RSA include the Saline River, Franklin Mountain, and Mount Kindle Formations and the Fort Norman, Arnica, and Landry Formations that constitute the Bear Rock Group.

0 1 2 Kilometres
1:70,000 (at original document size of 11x17)

K'alo-Stantec

Project Location
Wrigley to Norman Wells, NWT

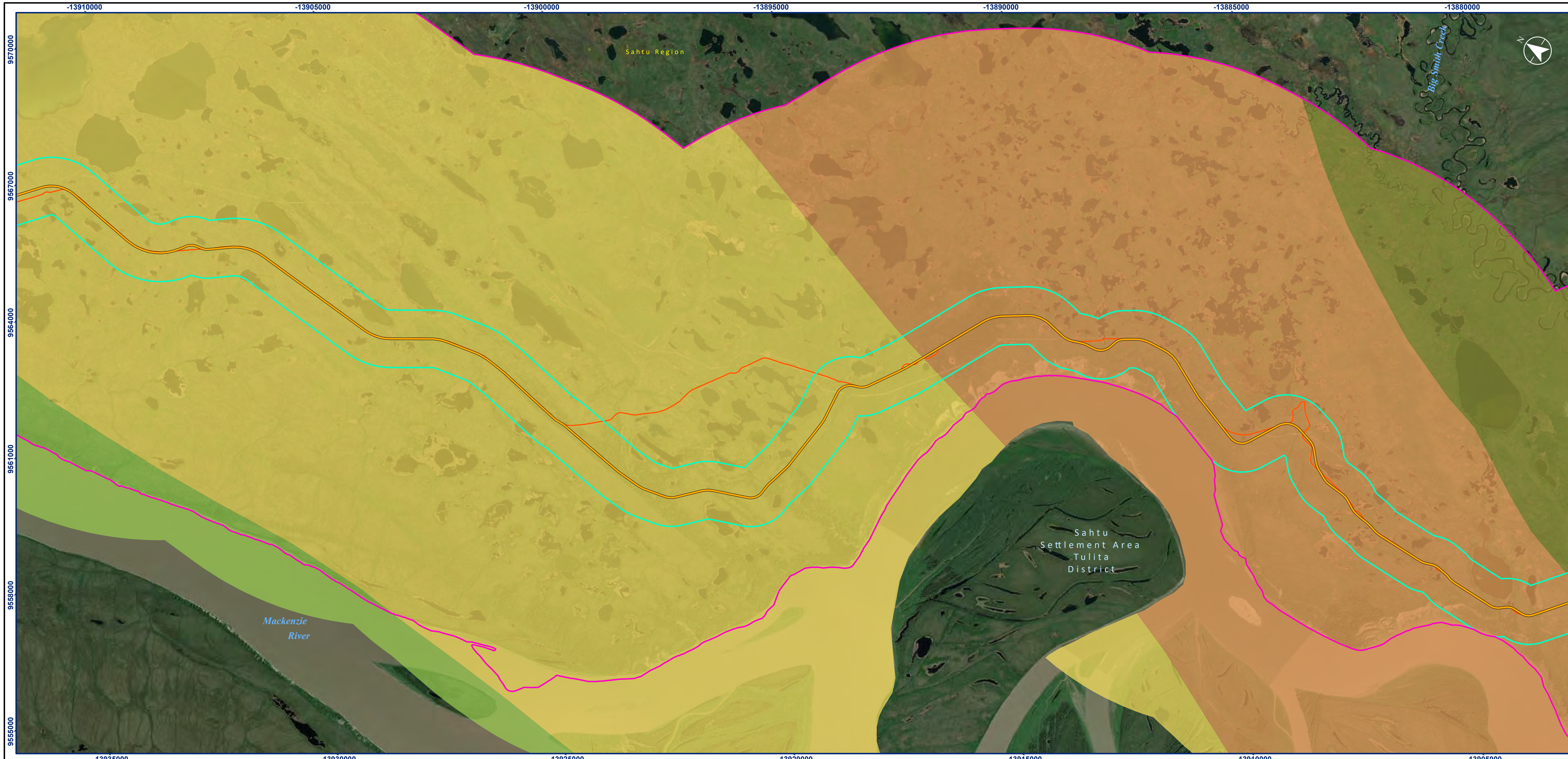
Prepared by AT on 2023-03-07
TR by AJ on 2023-03-07

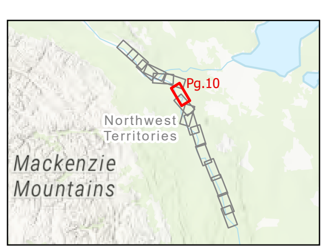
Client/Project
144903025-0072 REVB

Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
C.9

Title
RSA Geologic Formations with Aquifers Noted





Aquifer[4]

Geologic Formation

- Summit Creek
- East Fork
- Little Bear
- Slater River
- Arctic Red
- Fort Simpson
- Unnamed
- Imperial
- Canol
- Ramparts
- Hare Indian
- Hume
- Nahanni
- Headless
- Landry (Bear Rock Group)
- Arnica (Bear Rock Group)
- Fort Norman (Bear Rock Group)
- Mount Kindle
- Franklin Mountain
- Saline River
- Mount Cap

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

0 1 2 Kilometres

1:70,000 (at original document size of 11x17)

Kálo-Stantec

Project Location

Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-07
TR by AJ on 2023-03-07

Client/Project

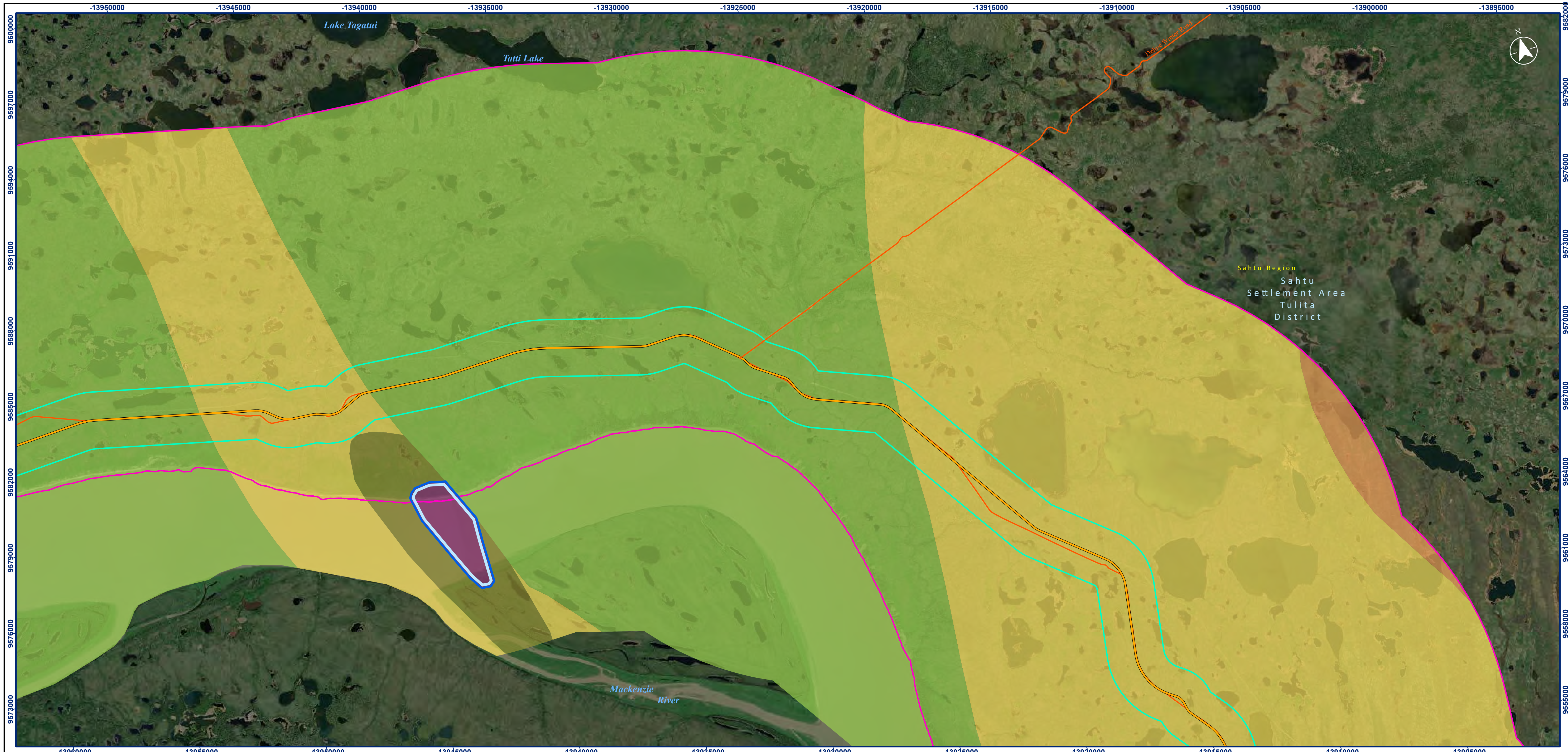
144903025-0072 REVB

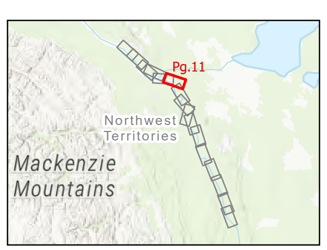
Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
C.10

Title
RSA Geologic Formations with Aquifers Noted

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Bedrock formations Stantec infers are important aquifer hydrostratigraphic units relative to the Project LSA and RSA include the Saline River, Franklin Mountain, and Mount Kindle Formations and the Fort Norman, Arnica, and Landry Formations that constitute the Bear Rock Group.





Aquifer[4]

Geologic Formation

- Summit Creek
- East Fork
- Little Bear
- Slater River
- Arctic Red
- Fort Simpson
- Unnamed
- Imperial
- Canol
- Ramparts
- Hare Indian
- Hume
- Nahanni
- Headless
- Landry (Bear Rock Group)
- Arnica (Bear Rock Group)
- Fort Norman (Bear Rock Group)
- Mount Kindle
- Franklin Mountain
- Saline River
- Mount Cap

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Bedrock formations Stantec infers are important aquifer hydrostratigraphic units relative to the Project LSA and RSA include the Saline River, Franklin Mountain, and Mount Kindle Formations and the Fort Norman, Arnica, and Landry Formations that constitute the Bear Rock Group.

0 1 2 Kilometres
1:70,000 (at original document size of 11x17)

Kalo-Stantec

Project Location
Wrigley to Norman Wells, NWT

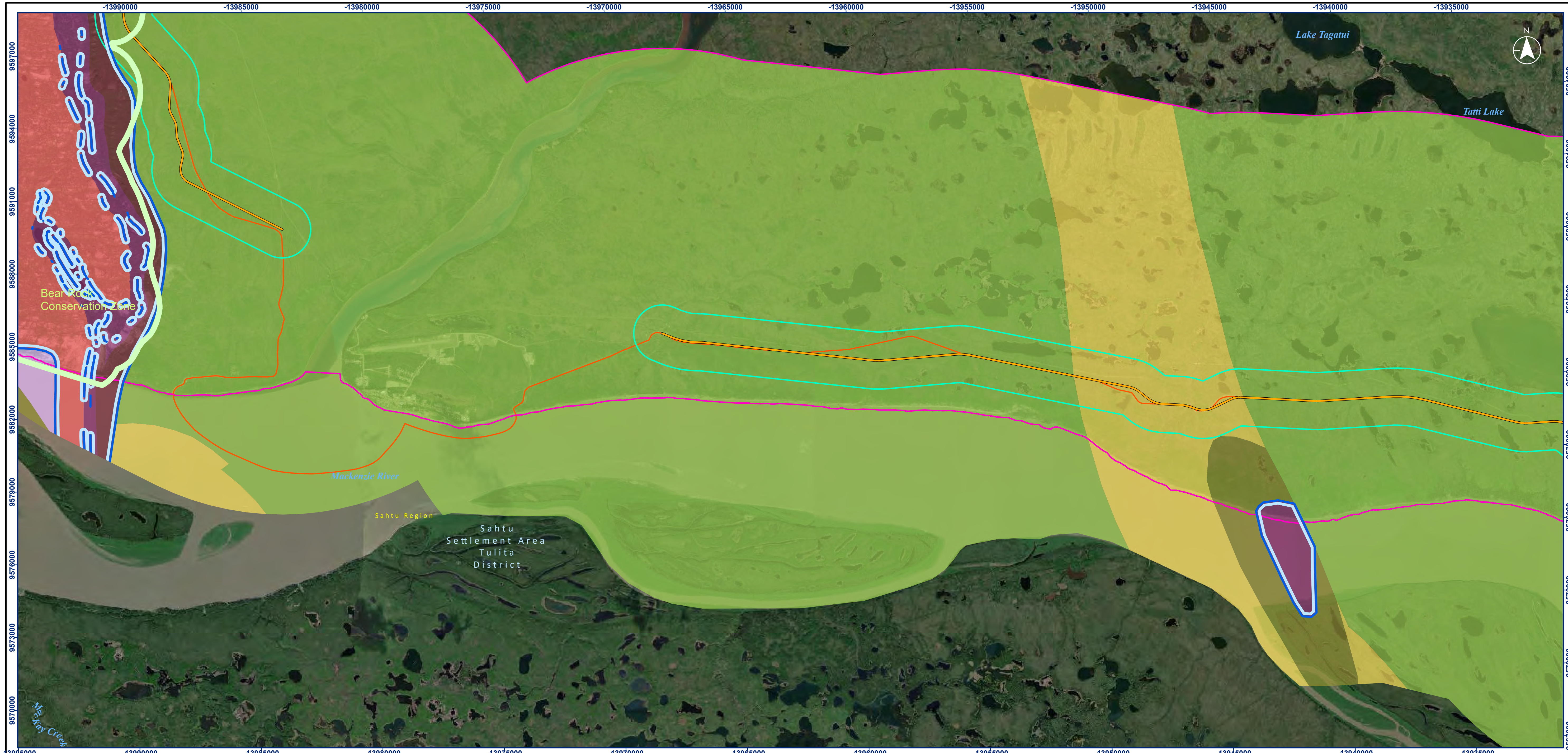
Prepared by AT on 2023-03-07
TR by AJ on 2023-03-07

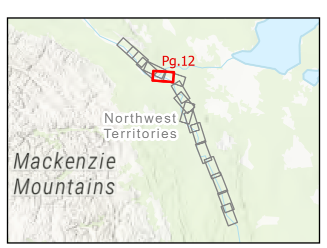
Client/Project
144903025-0072 REVB

Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
C.11

Title
RSA Geologic Formations with Aquifers Noted





Aquifer[4]

Geologic Formation

- Summit Creek
- East Fork
- Little Bear
- Slater River
- Arctic Red
- Fort Simpson
- Unnamed
- Imperial
- Canol
- Ramparts
- Hare Indian
- Hume
- Nahanni
- Headless
- Landry (Bear Rock Group)
- Arnica (Bear Rock Group)
- Fort Norman (Bear Rock Group)
- Mount Kindle
- Franklin Mountain
- Saline River
- Mount Cap

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Bedrock formations Stantec infers are important aquifer hydrostratigraphic units relative to the Project LSA and RSA include the Saline River, Franklin Mountain, and Mount Kindle Formations and the Fort Norman, Arnica, and Landry Formations that constitute the Bear Rock Group.

0 1 2 Kilometres
1:70,000 (at original document size of 11x17)

K'alo-Stantec

Project Location
Wrigley to Norman Wells, NWT

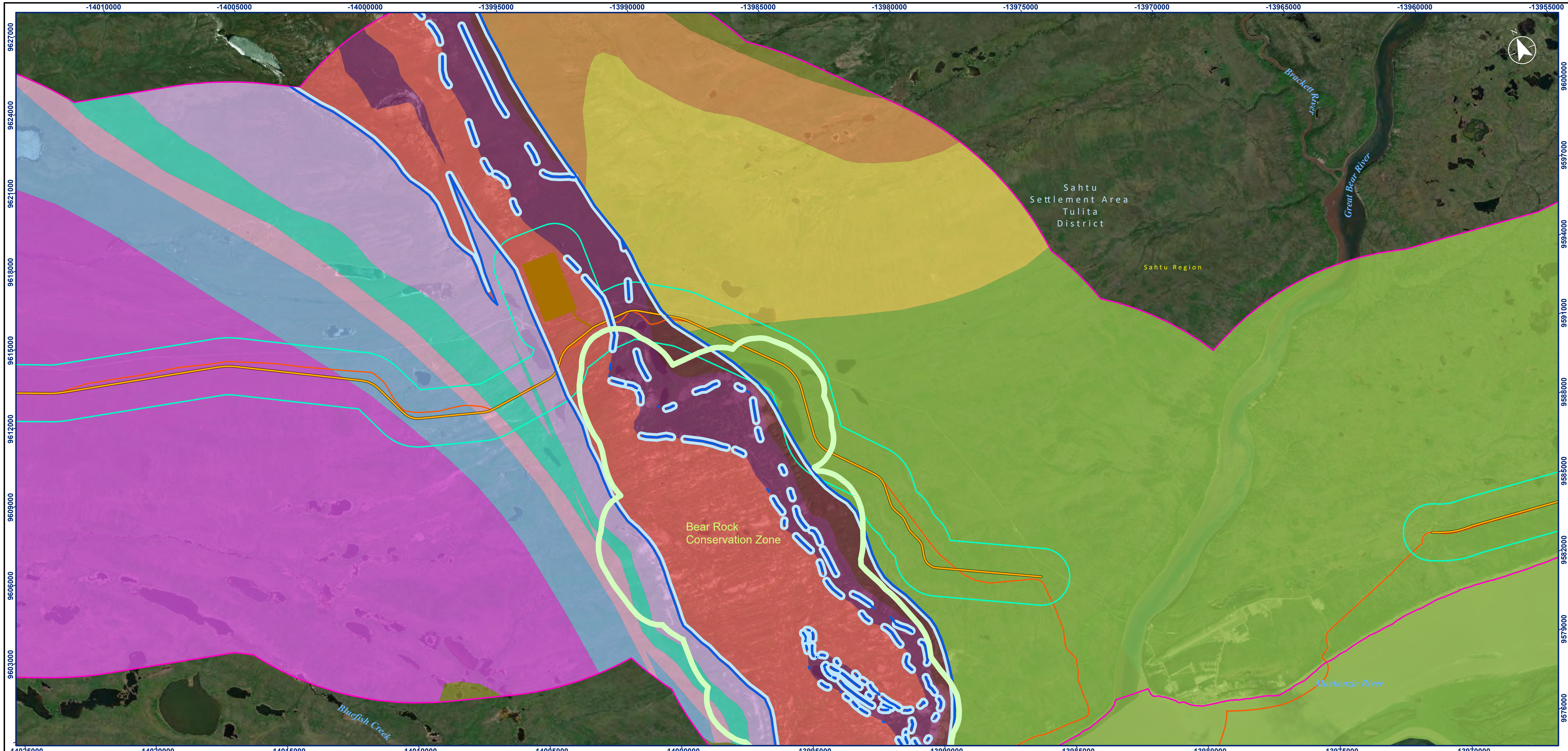
Prepared by AT on 2023-03-07
TR by AJ on 2023-03-07

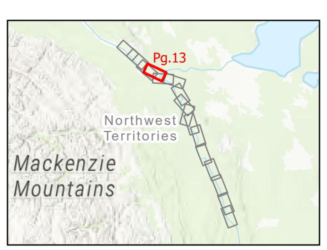
Client/Project
144903025-0072 REVB

Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
C.12

Title
RSA Geologic Formations with Aquifers Noted





Aquifer[4]

Geologic Formation

- Summit Creek
- East Fork
- Little Bear
- Slater River
- Arctic Red
- Fort Simpson
- Unnamed
- Imperial
- Canol
- Ramparts
- Hare Indian
- Hume
- Nahanni
- Headless
- Landry (Bear Rock Group)
- Arnica (Bear Rock Group)
- Fort Norman (Bear Rock Group)
- Mount Kindle
- Franklin Mountain
- Saline River
- Mount Cap

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Bedrock formations Stantec infers are important aquifer hydrostratigraphic units relative to the Project LSA and RSA include the Saline River, Franklin Mountain, and Mount Kindle Formations and the Fort Norman, Arnica, and Landry Formations that constitute the Bear Rock Group.

0 1 2 Kilometres

1:70,000 (at original document size of 11x17)

Project Location

Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-07
TR by AJ on 2023-03-07

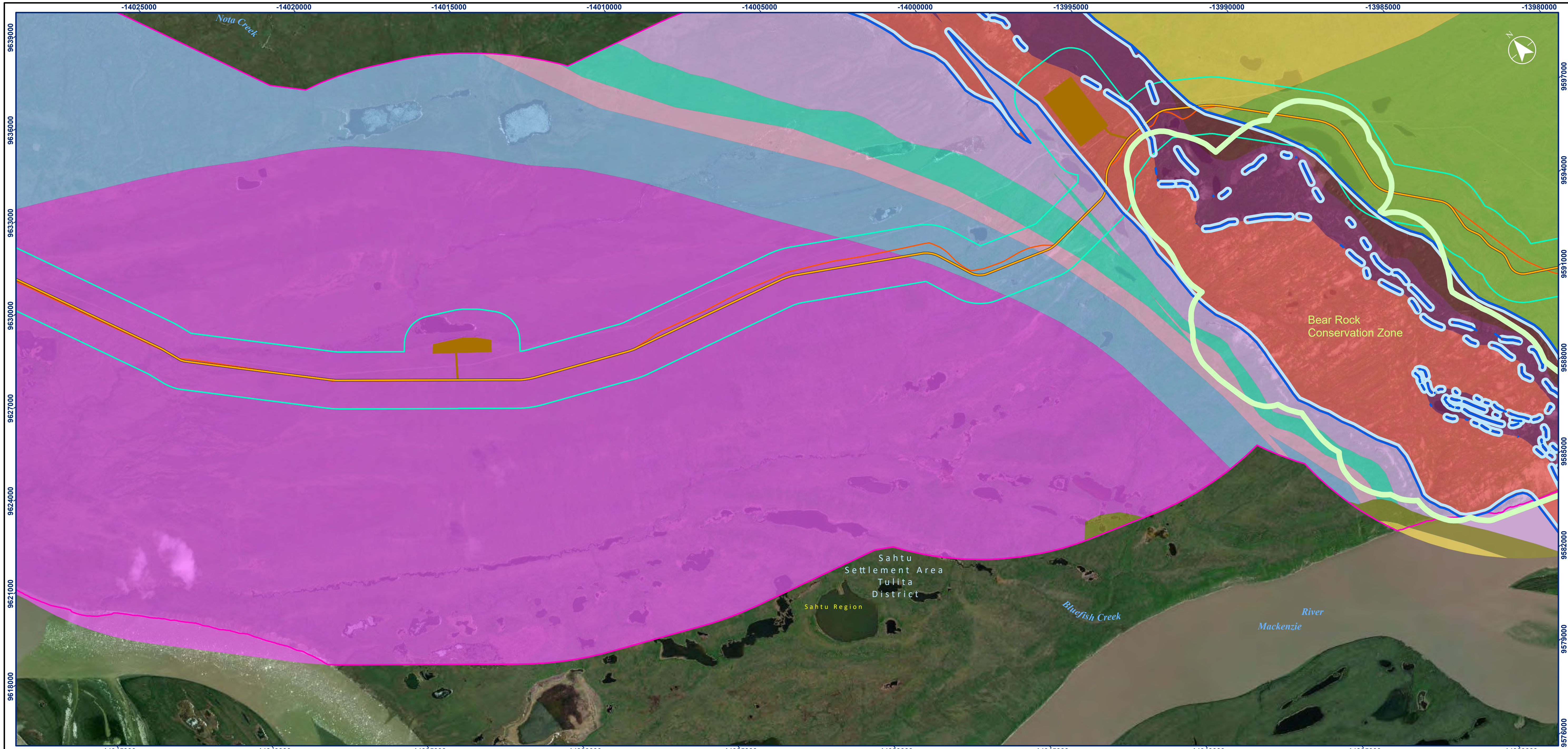
Client/Project

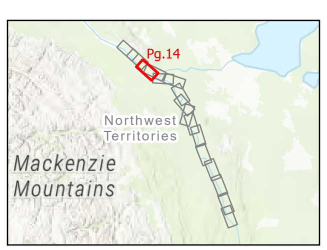
144903025-0072 REVB

Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
C.13

Title
RSA Geologic Formations with Aquifers Noted





Aquifer[4]

Geologic Formation

- Summit Creek
- East Fork
- Little Bear
- Slater River
- Arctic Red
- Fort Simpson
- Unnamed
- Imperial
- Canol
- Ramparts
- Hare Indian
- Hume
- Nahanni
- Headless
- Landry (Bear Rock Group)
- Arnica (Bear Rock Group)
- Fort Norman (Bear Rock Group)
- Mount Kindle
- Franklin Mountain
- Saline River
- Mount Cap

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Notes

1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Bedrock formations Stantec infers are important aquifer hydrostratigraphic units relative to the Project LSA and RSA include the Saline River, Franklin Mountain, and Mount Kindle Formations and the Fort Norman, Arnica, and Landry Formations that constitute the Bear Rock Group.

0 1 2 Kilometres
1:70,000 (at original document size of 11x17)

K'alo-Stantec

Project Location
Wrigley to Norman Wells, NWT

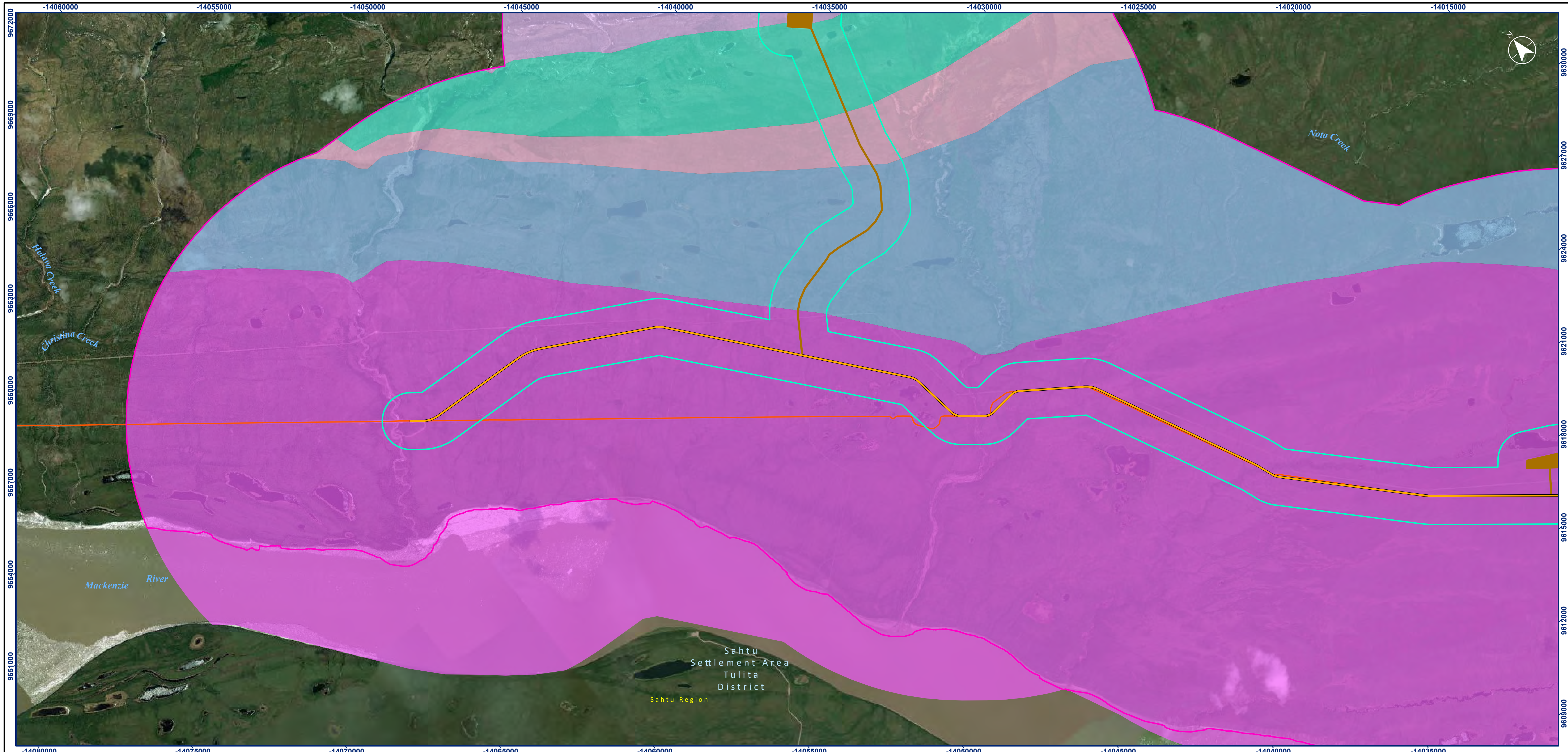
Prepared by AT on 2023-03-07
TR by AJ on 2023-03-07

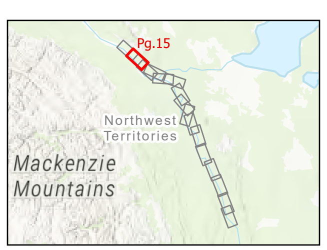
Client/Project
144903025-0072 REVB

Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
C.14

Title
RSA Geologic Formations with Aquifers Noted





Aquifer[4]

Geologic Formation

- Summit Creek
- East Fork
- Little Bear
- Slater River
- Arctic Red
- Fort Simpson
- Unnamed
- Imperial
- Canol
- Ramparts
- Hare Indian
- Hume
- Nahanni
- Headless
- Landry (Bear Rock Group)
- Arnica (Bear Rock Group)
- Fort Norman (Bear Rock Group)
- Mount Kindle
- Franklin Mountain
- Saline River
- Mount Cap

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Bedrock formations Stantec infers are important aquifer hydrostratigraphic units relative to the Project LSA and RSA include the Saline River, Franklin Mountain, and Mount Kindle Formations and the Fort Norman, Arnica, and Landry Formations that constitute the Bear Rock Group.

0 1 2 Kilometres

1:70,000 (at original document size of 11x17)

Kalo-Stantec

Project Location: Wrigley to Norman Wells, NWT

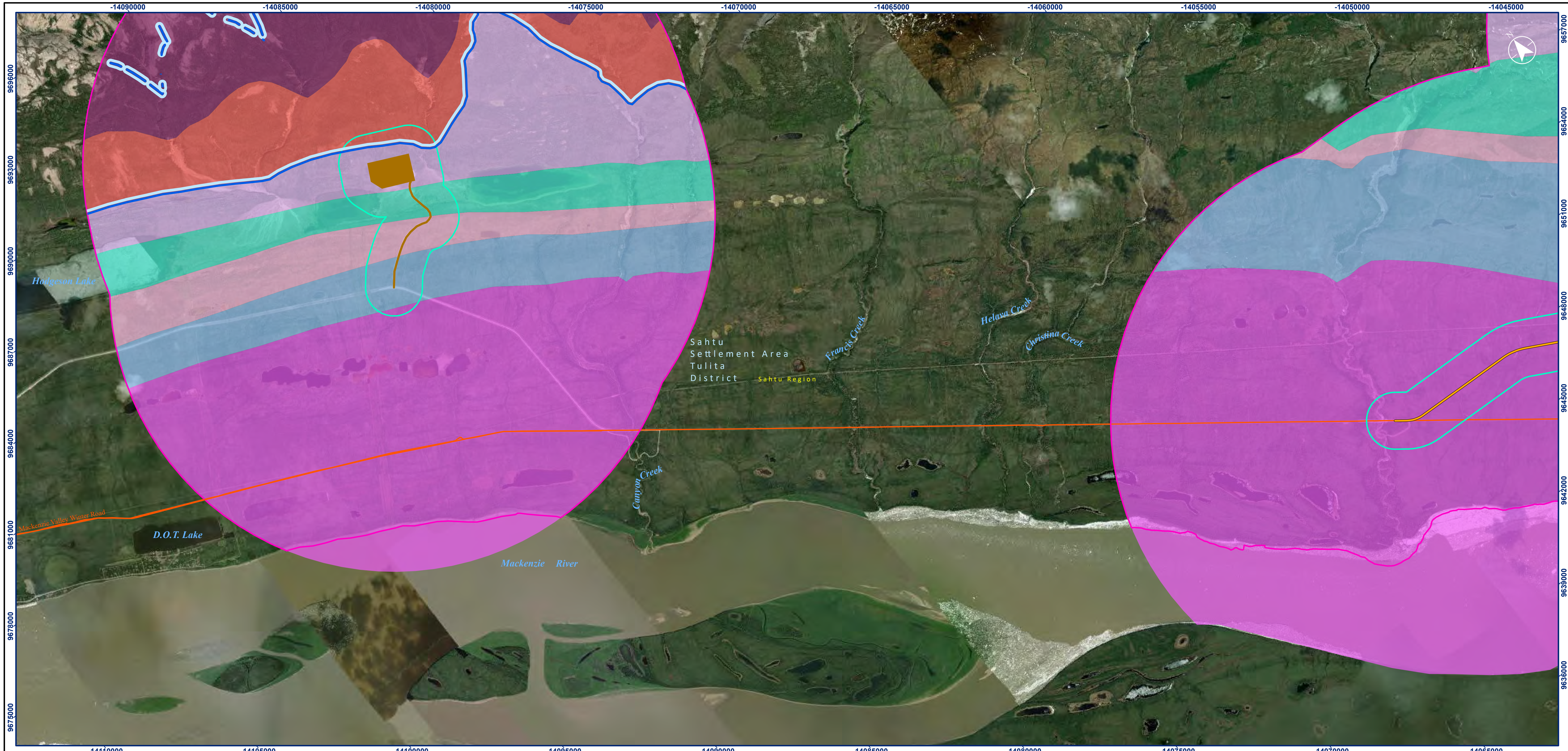
Prepared by AT on 2023-03-07
TR by AJ on 2023-03-07

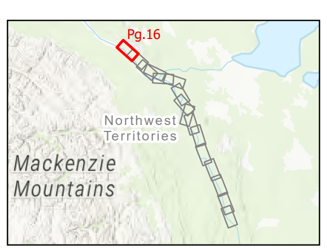
Client/Project: 144903025-0072 REVB

Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
C.15

Title
RSA Geologic Formations with Aquifers Noted





Aquifer[4]

Geologic Formation

- Summit Creek
- East Fork
- Little Bear
- Slater River
- Arctic Red
- Fort Simpson
- Unnamed
- Imperial
- Canol
- Ramparts
- Hare Indian
- Hume
- Nahanni
- Headless
- Landry (Bear Rock Group)
- Arnica (Bear Rock Group)
- Fort Norman (Bear Rock Group)
- Mount Kindle
- Franklin Mountain
- Saline River
- Mount Cap

- Proposed Mackenzie Valley Highway Alignment - Issued for EA 2022
- Granular Borrow / Rock Quarry Site and Access
- Local Study Area
- Regional Study Area
- All-Season Road
- Winter Road
- Conservation Zone
- District Boundary
- Region Boundary
- Settlement Area Boundary

0 1 2 Kilometres

1:70,000 (at original document size of 11x17)

Kʼalo-Stantec

Project Location

Wrigley to Norman Wells, NWT

Prepared by AT on 2023-03-07
TR by AJ on 2023-03-07

Client/Project

144903025-0072 REVB

Government of Northwest Territories
Mackenzie Valley Highway Project

Figure No.
C.16

Title
RSA Geologic Formations with Aquifers Noted

Notes
1. Coordinate System: NAD 1983 UTM Zone 10N
2. Data Sources: Government of Canada
3. Background: World Topographic Map: Northwest Territories, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NRCan, Parks Canada
World Imagery: Earthstar Geographics
World Hillshade: Esri, USGS
4. Bedrock formations Stantec infers are important aquifer hydrostratigraphic units relative to the Project LSA and RSA include the Saline River, Franklin Mountain, and Mount Kindle Formations and the Fort Norman, Arnica, and Landry Formations that constitute the Bear Rock Group.

Appendix D Groundwater Quality Data

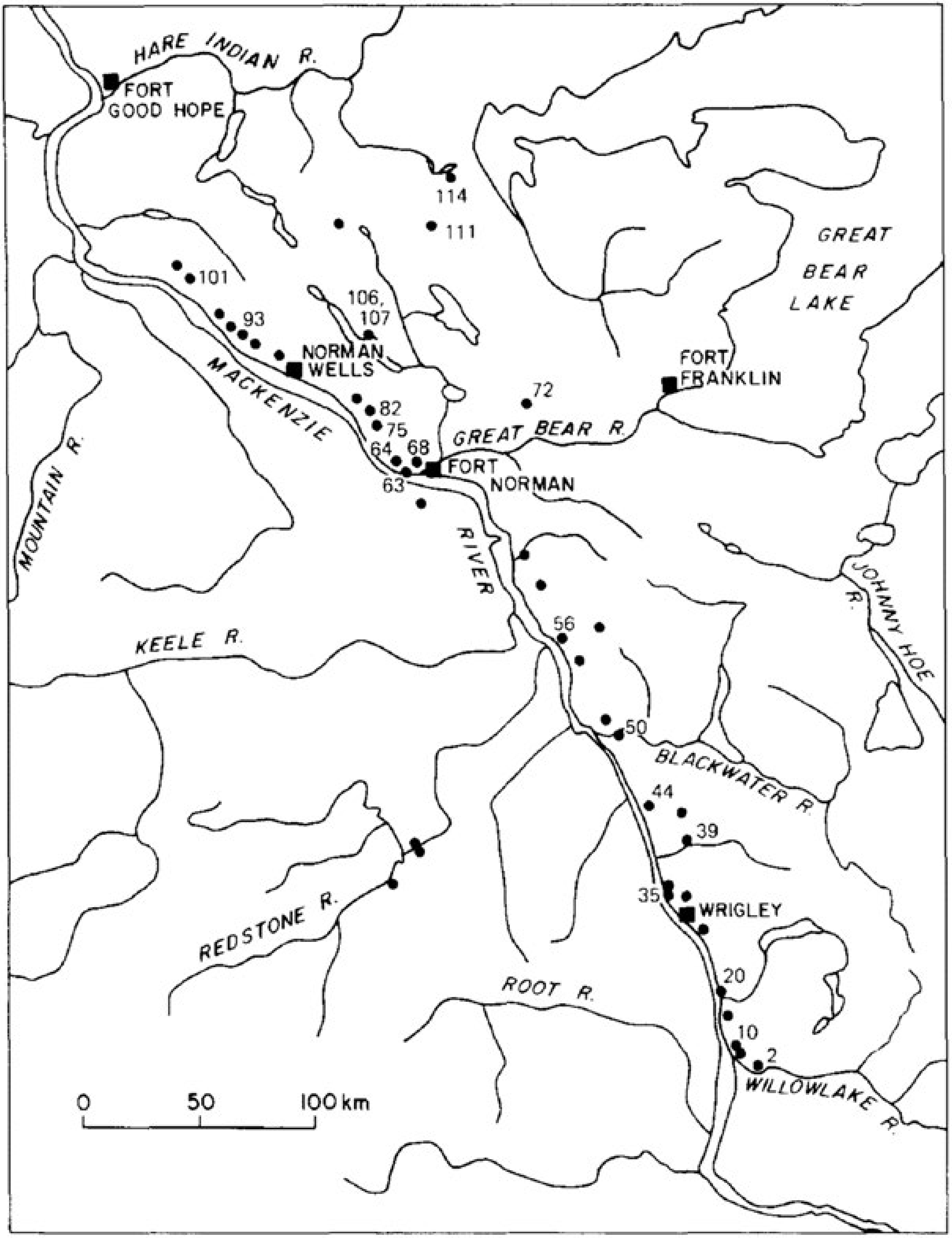
D1 Michel (1986) Seep Information and Sample Location Map

Table D1.1 Chemistry of Seeps Sampled by Michel (1977) between Wrigley and Norman Wells as Reported *in* Michel (1986)

Site ID	Site	T (°C)	pH	Cond. (µS/cm)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Fe (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	δO^{18} (‰ SMOW)	δH^{2} (‰ SMOW)
35	Roche-Qui- Trempe-AL'eau, South	31.3	7.6	17,800	900	149	3,240	49	0.21	177	2,920	5,210	-23.2	-182
39	Ochre River Spring	5.8	7.6	9,000	429	115	1,130	10.3	0.21	283	1,325	1,730	-22.3	-174
44	Rainbow Creek Spring	3.6	7.9	3,900	297	88	561	5.5	<0.04	257	930	831	-22.8	-
50	Blackwater River Spring Field	1.5	-	2,500	341	72	231	2.8	0.04	266	870	342	-	-
56	Saline River Spring	0	8.4	3,160	112	36	480	1.2	<0.04	317	185	705	-	-
63	Bear Rock South Sulphur Spring	6.9	7.1	3,500	380	119	480	4.1	0.22	318	1,195	700	-23.5	--
64	Bear Rock West Sulphur Spring	4.2	7.2	2,650	297	78	31	2.5	0.04	272	830	38	-23.3	--
68	Bear Rock S.E. Springs	2.8	7.5	1,880	528	34	3	1.5	0.16	295	1,090	2.2	-23.2	-179
75	Nota Creek Spring	0.5	7.4	8,000	39	23	1,910	6.0	0.24	2,856	35	1,320	-	-
82	Vermilion Creek Sulphur	8.0	7.4	1,550	484	79	50	2.9	0.06	268	1,250	56	-	-
106	Kelly Lake Iron	3.3	7.4	7,710	192	109	1,450	7.5	1.0	266	800	2,250	-23.7	-
107	Kelly Lake Spring	4.3	7.9	2,800	65	111	475	35.0	0.04	270	400	710	-23.7	-

Notes:

1. Spring locations provided on map from Michel (1986) in Appendix D1, page D1-4.
2. "T" is temperature; "Cond." Is conductivity; "Ca" is calcium; "Mg" is magnesium; "Na" is sodium; "K" is potassium; "Fe" is iron; "HCO_3" is bicarbonate; "SO_4" is sulfate; "Cl" is chloride; "δO^{18}" is the oxygen-18, oxygen-16 fractionation ratio relative to standard mean ocean water (SMOW); "δH^{2}" is the deuterium, hydrogen fractionation ratio relative to standard mean ocean water (SMOW).


HARE INDIAN R.
FORT GOOD HOPE
114
111
GREAT BEAR LAKE
101
93
106, 107
NORMAN WELLS
MACKENZIE
FORT FRANKLIN
72
82
75
GREAT BEAR R.
64
68
FORT NORMAN
63
MOUNTAIN R.
RIVER
56
KEELE R.
JOHNNY HOE R.
50
BLACKWATER R.
44
39
REDSTONE R.
35
WRIGLEY
20
ROOT R.
10
2
WILLOWLAKE R.
0
50
100 km

D2 Michel (1986) Oxygen-18 Profiles and Borehole Location Map

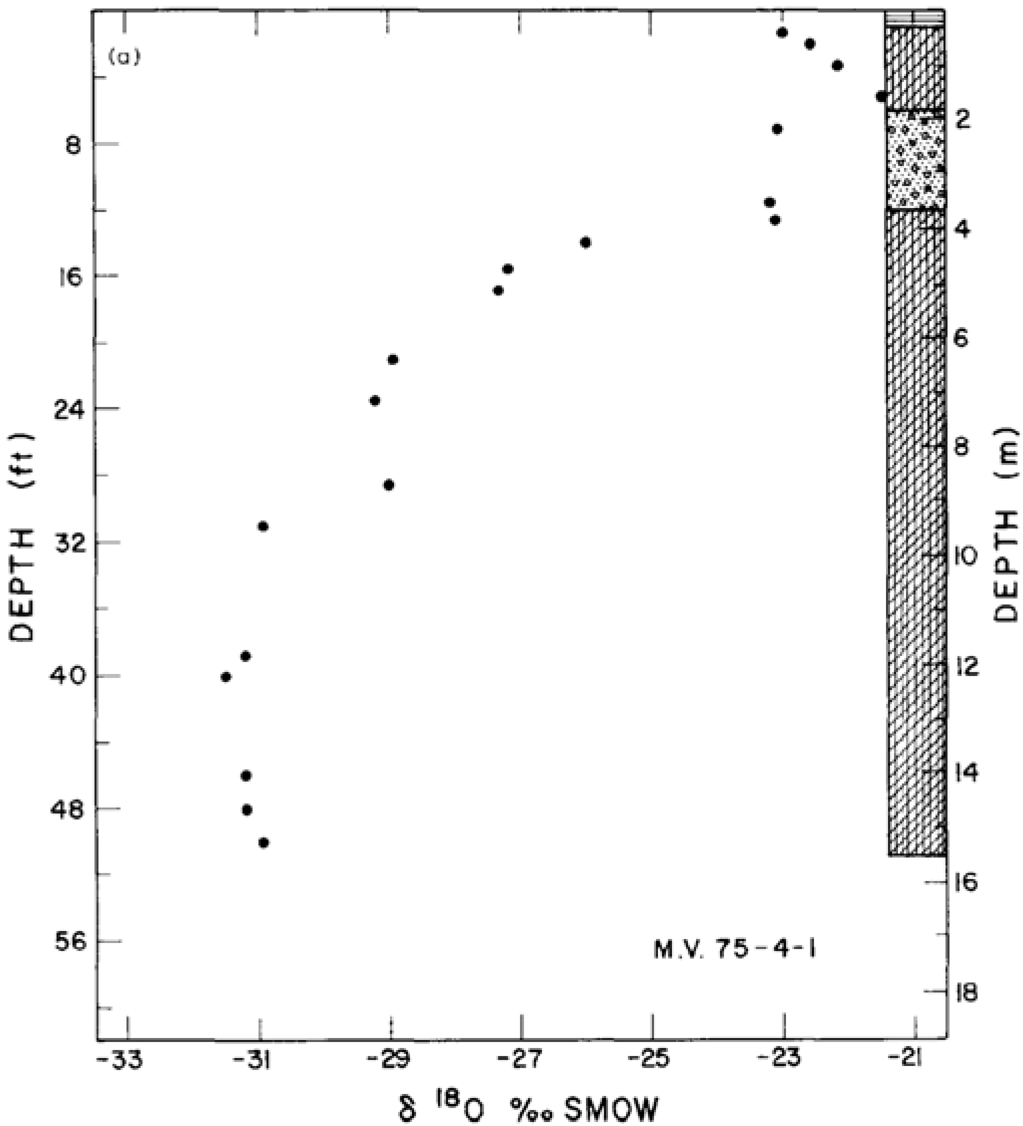


Fig. 5. Variation in ^{18}O content with depth for cores 75-4-1 (a), 75-8-2 (b), 75-13-2 (c), and 75-19-3 (d). (Horizontal bars = peat; solid dots = sand; vertical bars = silt; cross-hatched = clay; and open circles = stony material.)

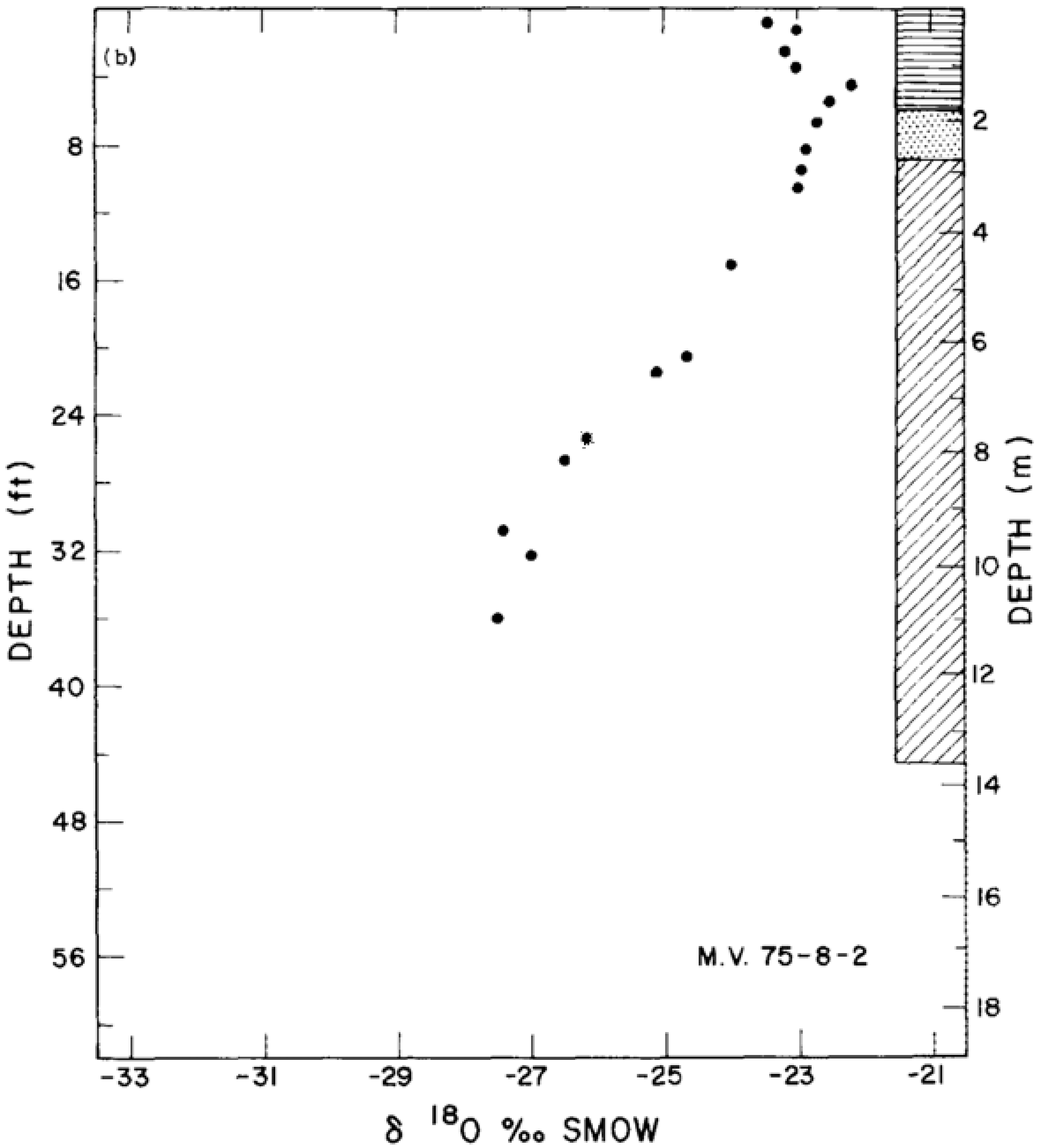


Fig. 5b (see p. 389 for caption)

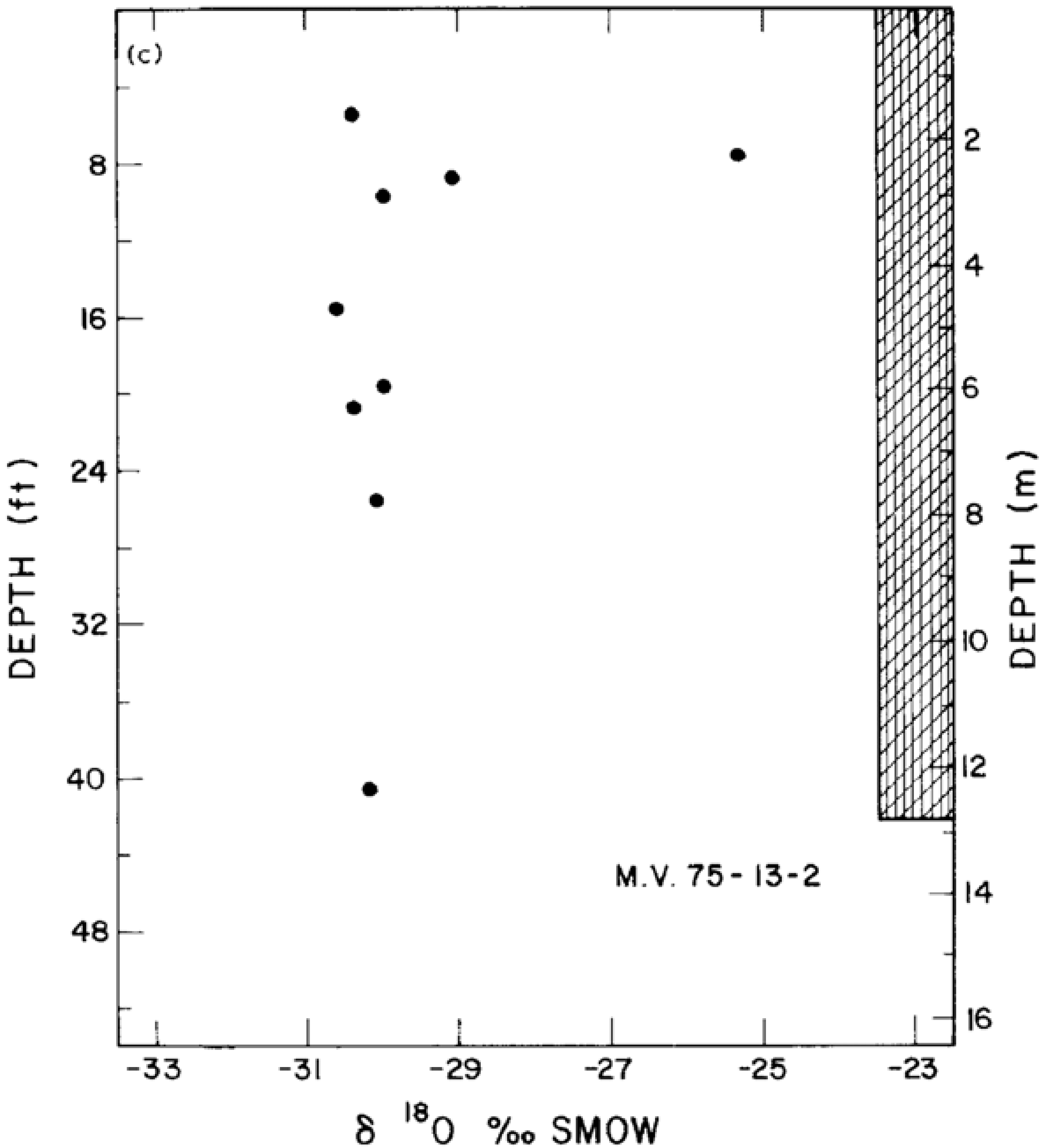


Fig. 5c (see p. 389 for caption)

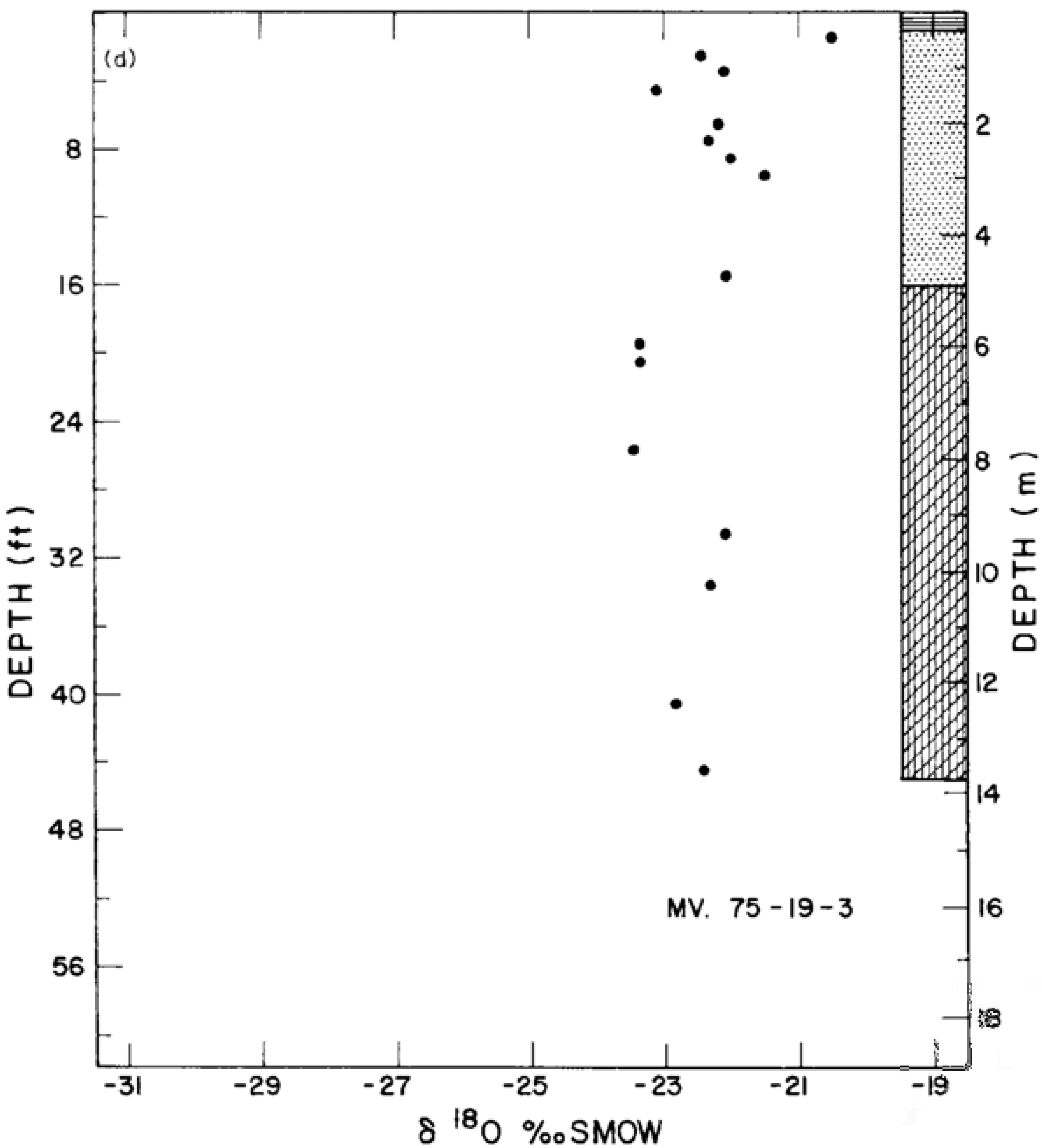
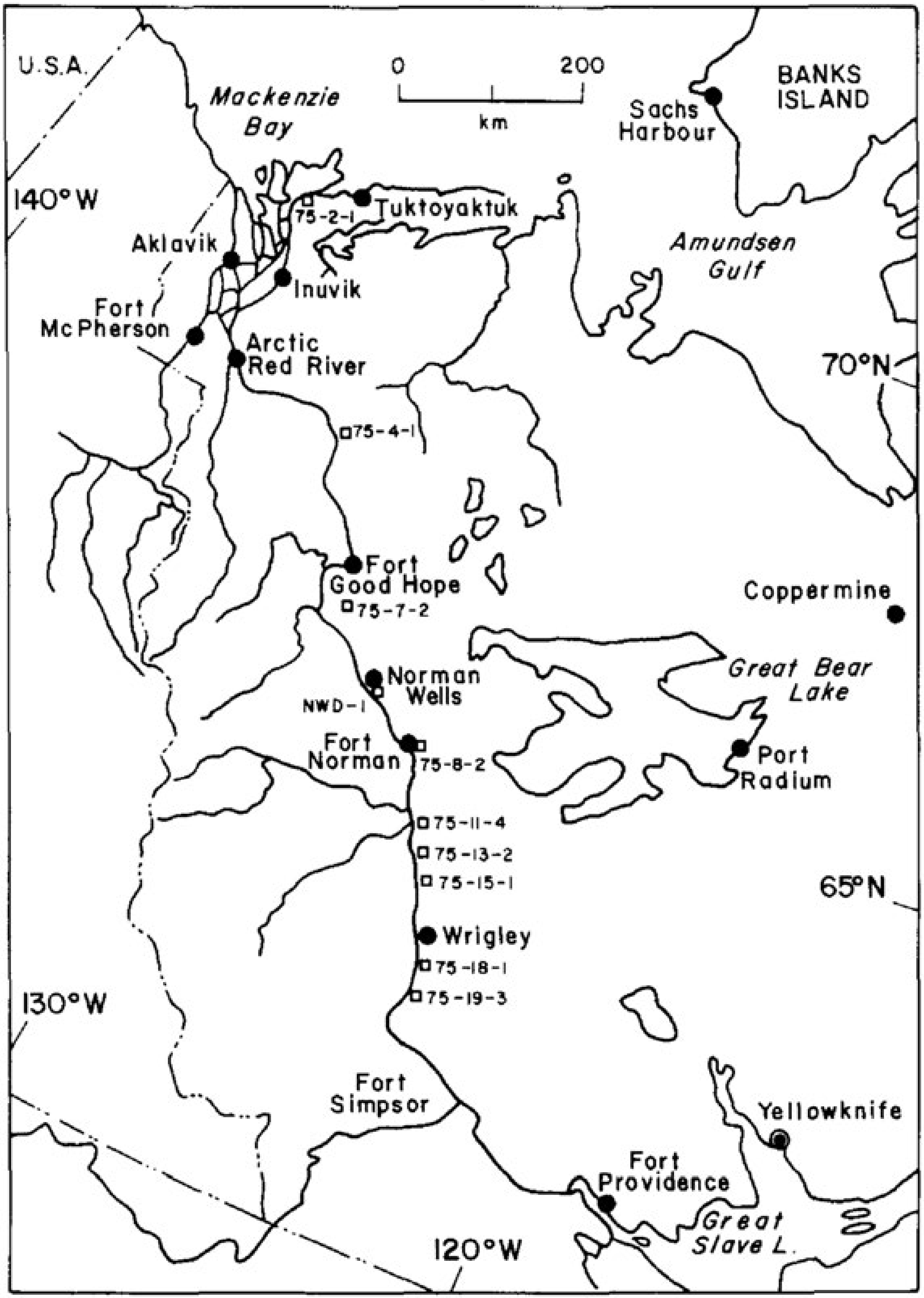


Fig. 5d (see p. 389 for caption)


U.S.A.
Mackenzie Bay
0
200
km
Sachs Harbour
BANKS ISLAND
140° W
75-2-1
Tuktoyaktuk
Aklavik
Inuvik
Amundsen Gulf
Fort McPherson
Arctic Red River
70°N
75-4-1
Fort Good Hope
75-7-2
Coppermine
Norman Wells
NWD-1
Great Bear Lake
Fort Norman
75-8-2
Port Radium
75-11-4
75-13-2
75-15-1
65°N
Wrigley
75-18-1
75-19-3
130°W
Fort Simpsor
Yellowknife
Fort Providence
Great Slave L.
120°W

D3 IORVL (2004) Seep Information and Sample Location Maps

Table D3.1 Characteristics of Seep Discharge Described in IORVL (2004)

Associated Stream	Spring ID	IORVL, 2004 Comment	Discharge Rate (L/s)[1]	TDS (mg/L)[1]
Hodgson Creek	A02-55, 56, 57, 58	calcium-bicarbonate water type	-[3]	Moderately low
Hodgson Creek	M31	M series spring samples collected by Michel (1977)	3	320
Ochre River	n/a[2]	No springs identified from the air during the survey		-
White Sand Creek	n/a	No springs identified from the air during the survey	-	-
Blackwater River	A52	Sodium-chloride, sodium-sulfate water type	100	Twice A51 TDS
Blackwater River	A51	Calcium-magnesium bicarbonate water type	100	-
Steep Creek	A24, A24b, A24c	Larger perennial springs near creek-level; calcium-carbonate water type	-	452 to 472
Little Smith Creek Tributary	n/a	Spring appeared representative of other discharge along the bank; possible flow from active layer	0.25	276
Little Smith Creek	M57	M series spring samples collected by Michel (1977)	93	365 to 476
Vermilion Creek North	A27 and A27b	Calcium-sulfate water type; higher than normal water temperature	180 (combined)	2,324
Helava Creek	Helava Creek Spring	Calcium-carbonate water type	-	315
Christina Creek	Christina Creek Spring	Calcium-carbonate water type	-	292
Prohibition Creek	A28	Calcium-sulfate water type	2.2	1,712
Bosworth Creek	A22b	Higher mineralization than Bosworth Creek	-	-
Bosworth Creek	A22	Higher mineralization than Bosworth Creek	-	-

Notes:

1. “L/s” is litres per second; “mg/L” is milligrams per litre.
2. “n/a” is not available.
3. “-“ is not provided by IORVL, 2004.
4. Spring locations provided on figures from IORVL (2004) in Appendix D3, pages D3-3 to D3-13.

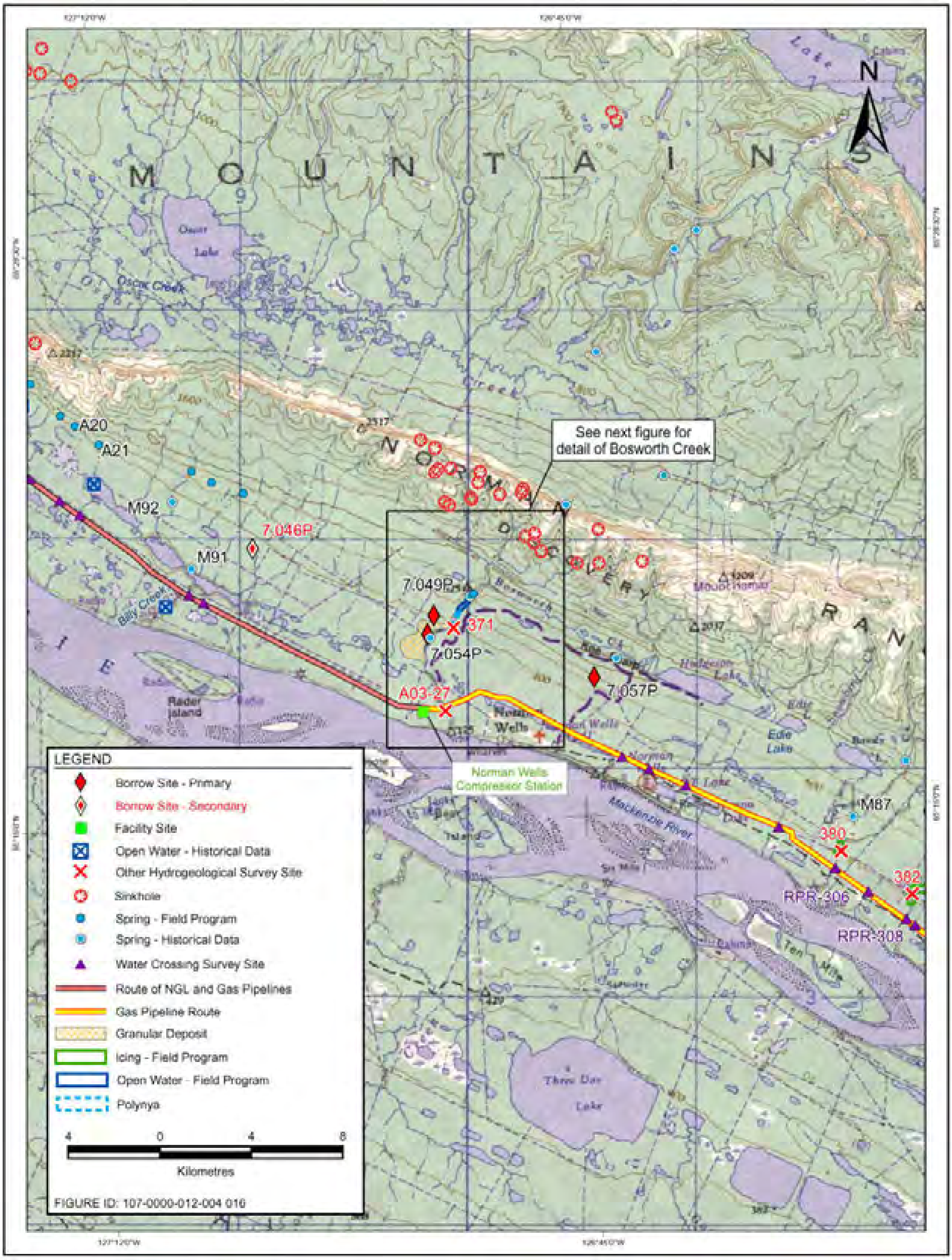


Figure 4-33: Hydrogeological Features – Oscar Creek to Edie Lake

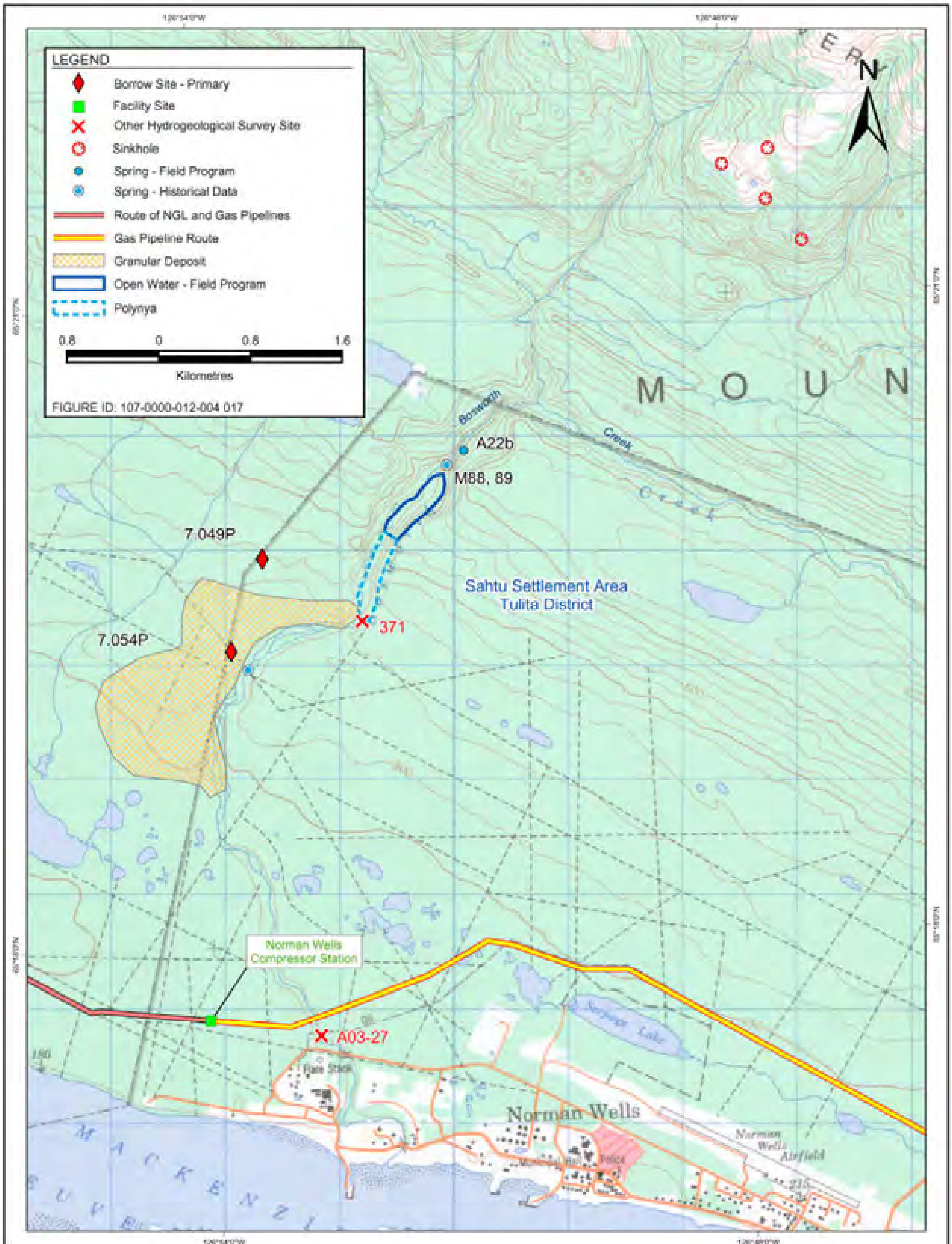


Figure 4-34: Hydrogeological Features – Bosworth Creek – Site 371

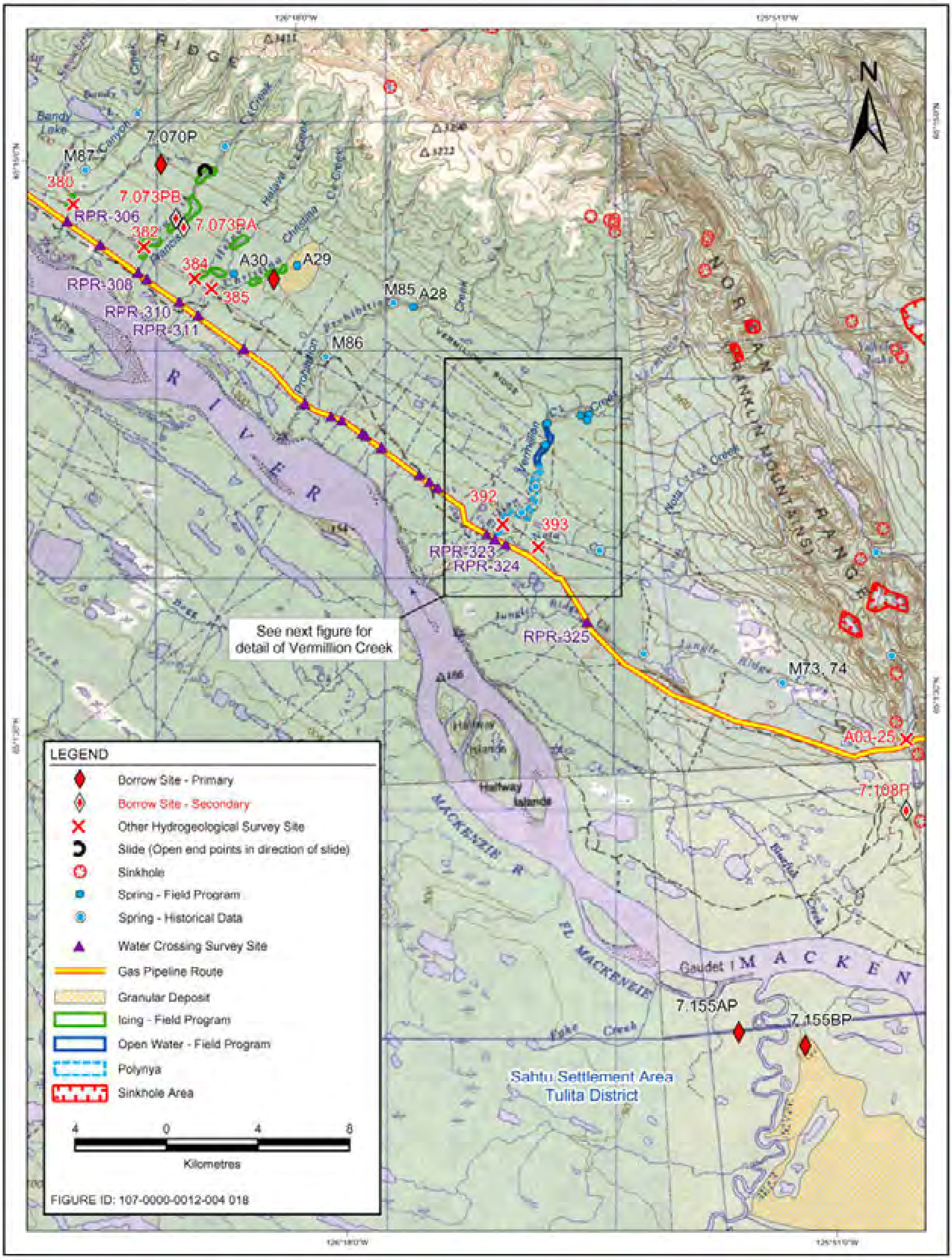


Figure 4-35: Hydrogeological Features – Bandy Lake to Bluefish Creek

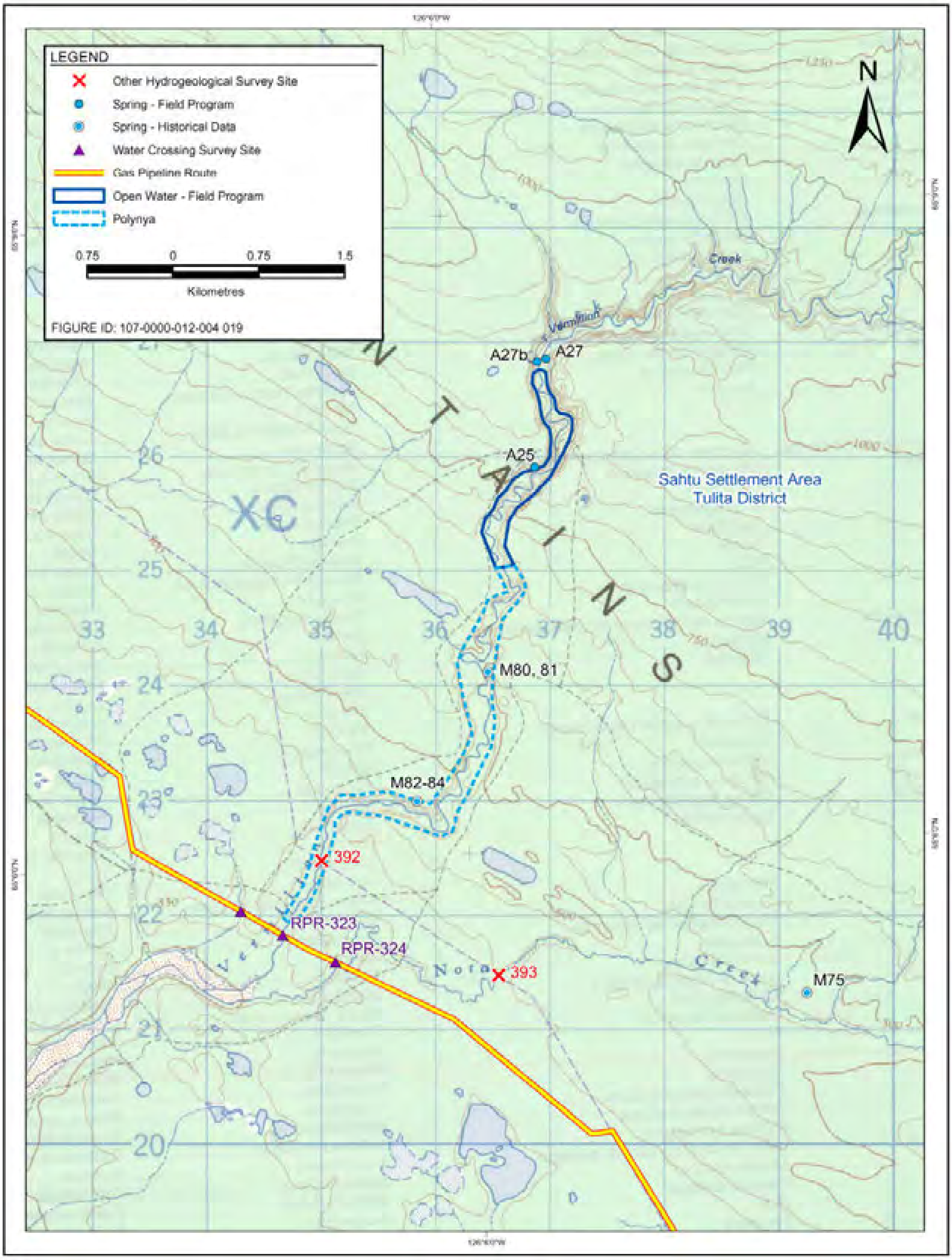


Figure 4-36: Hydrogeological Features – Vermilion Creek – Site 392

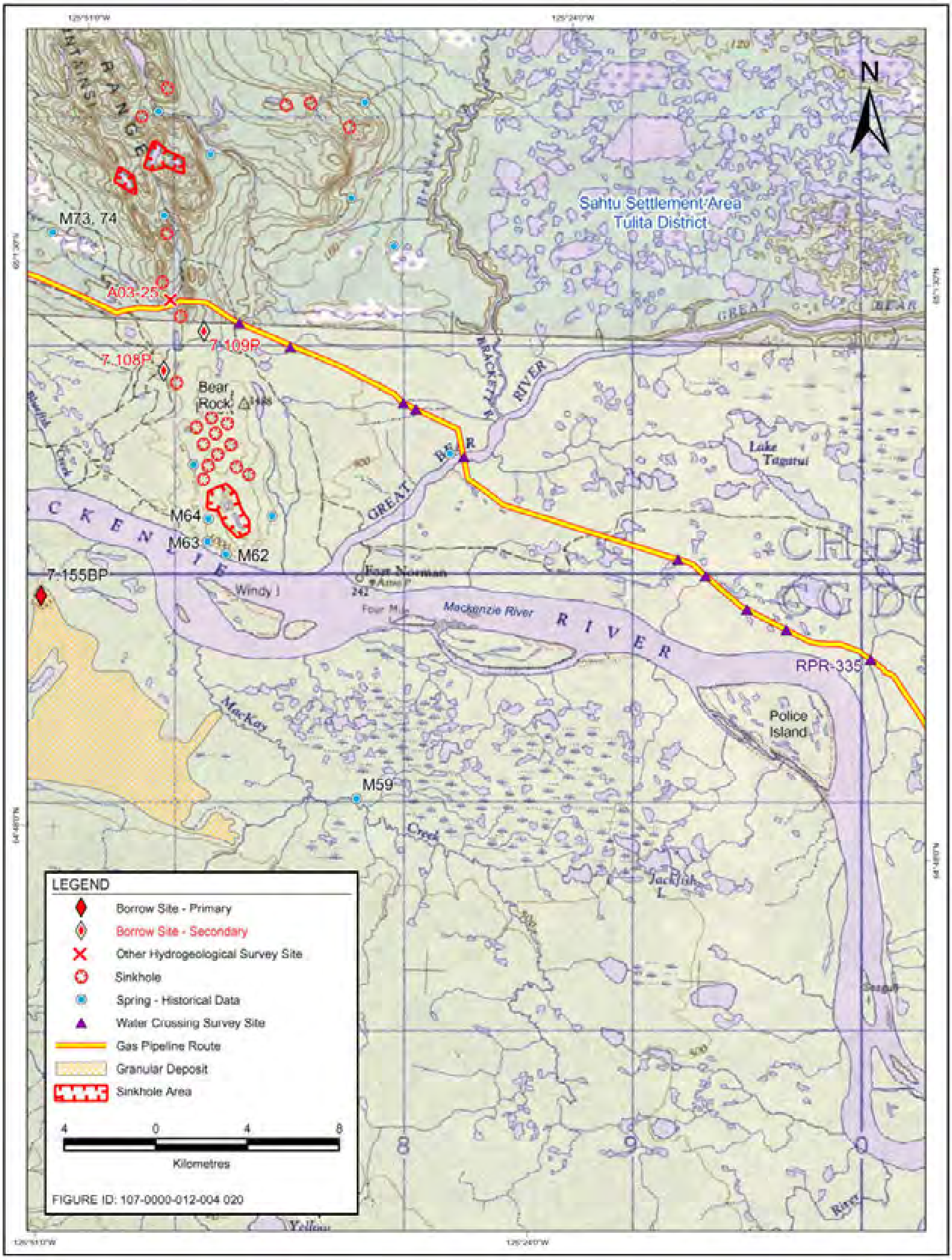


Figure 4-37: Hydrogeological Features – Bear Rock to Police Island

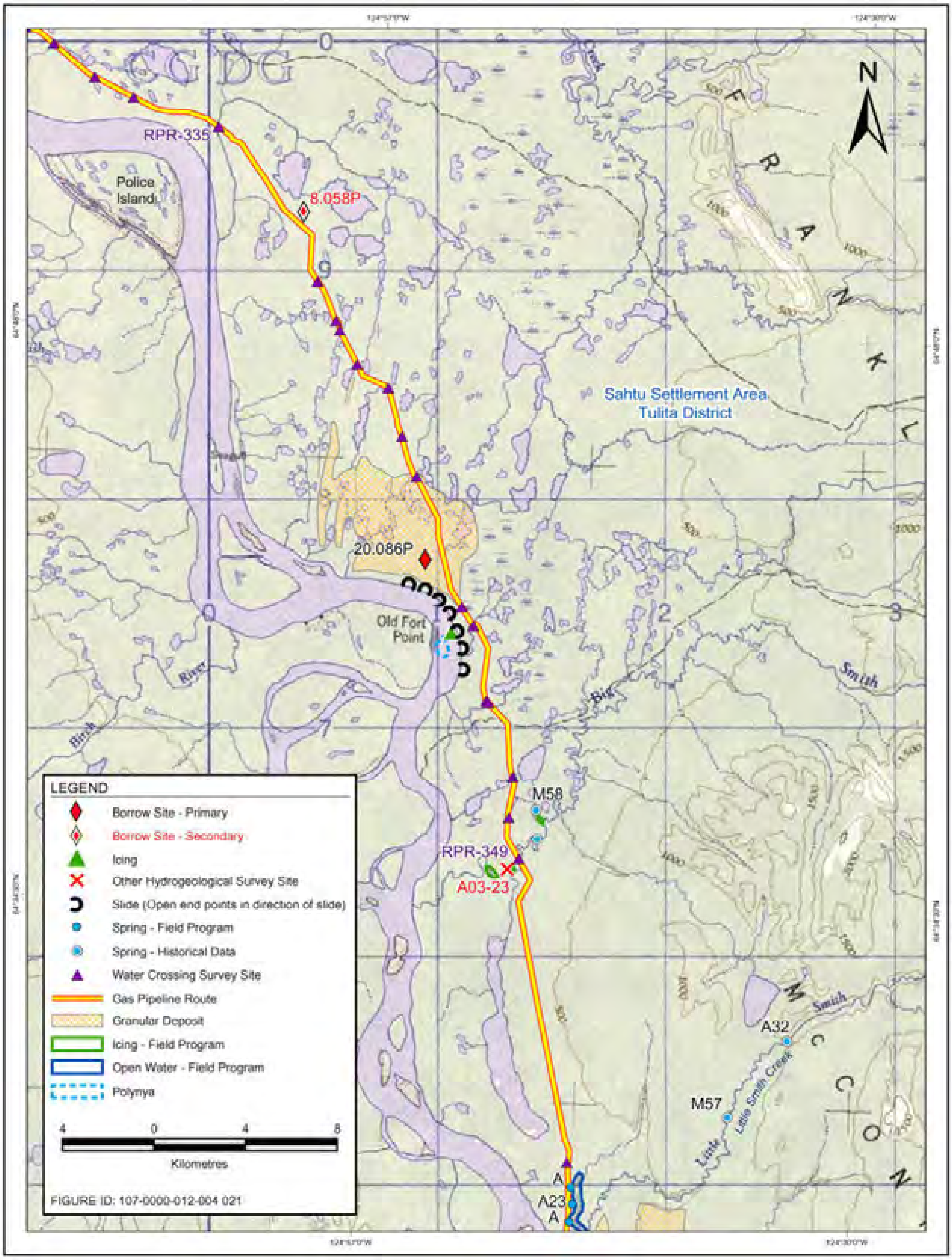


Figure 4-38: Hydrogeological Features – Police Island to Little Smith Creek

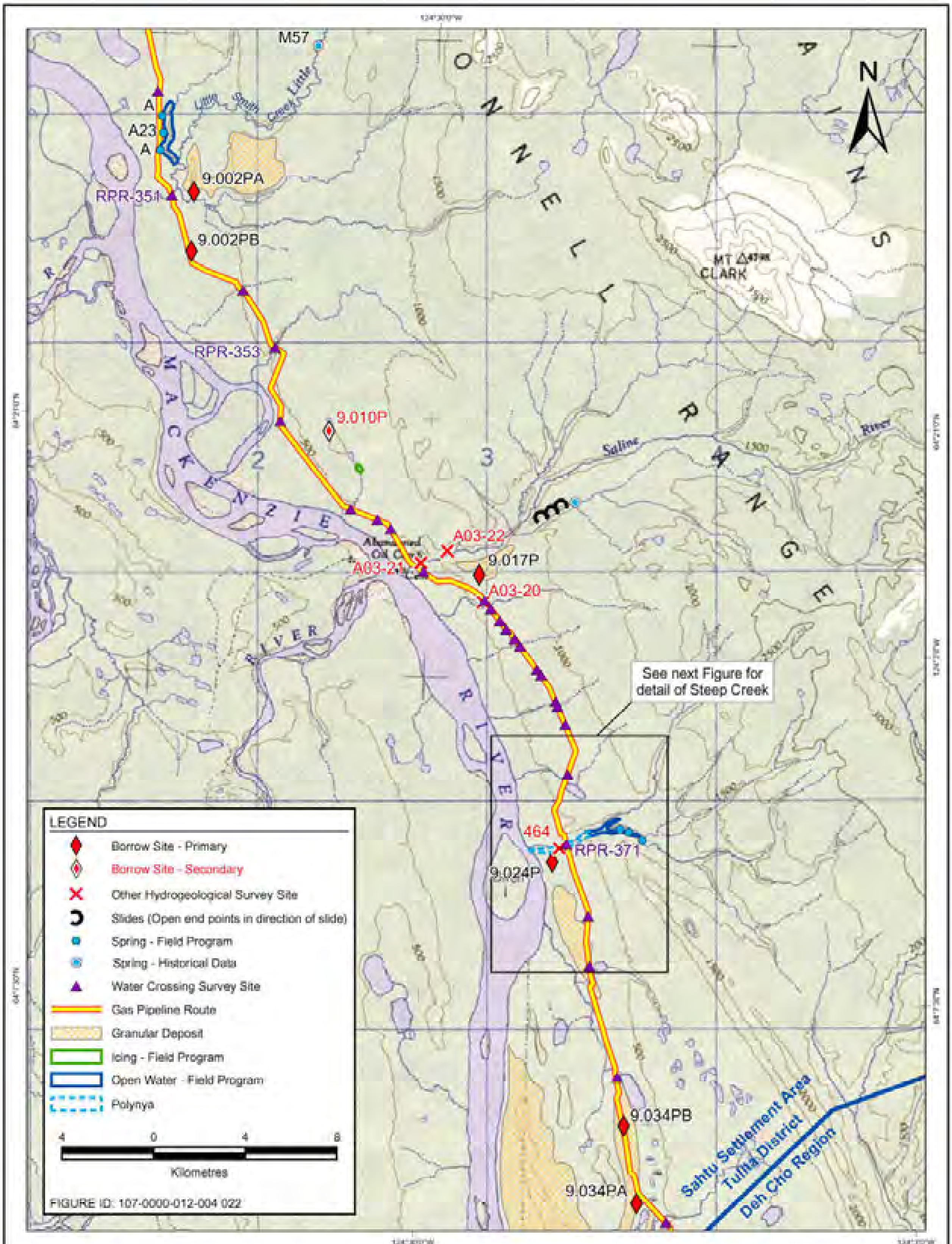


Figure 4-39: Hydrogeological Features – Little Smith Creek to the Sahtu–Deh Cho Boundary

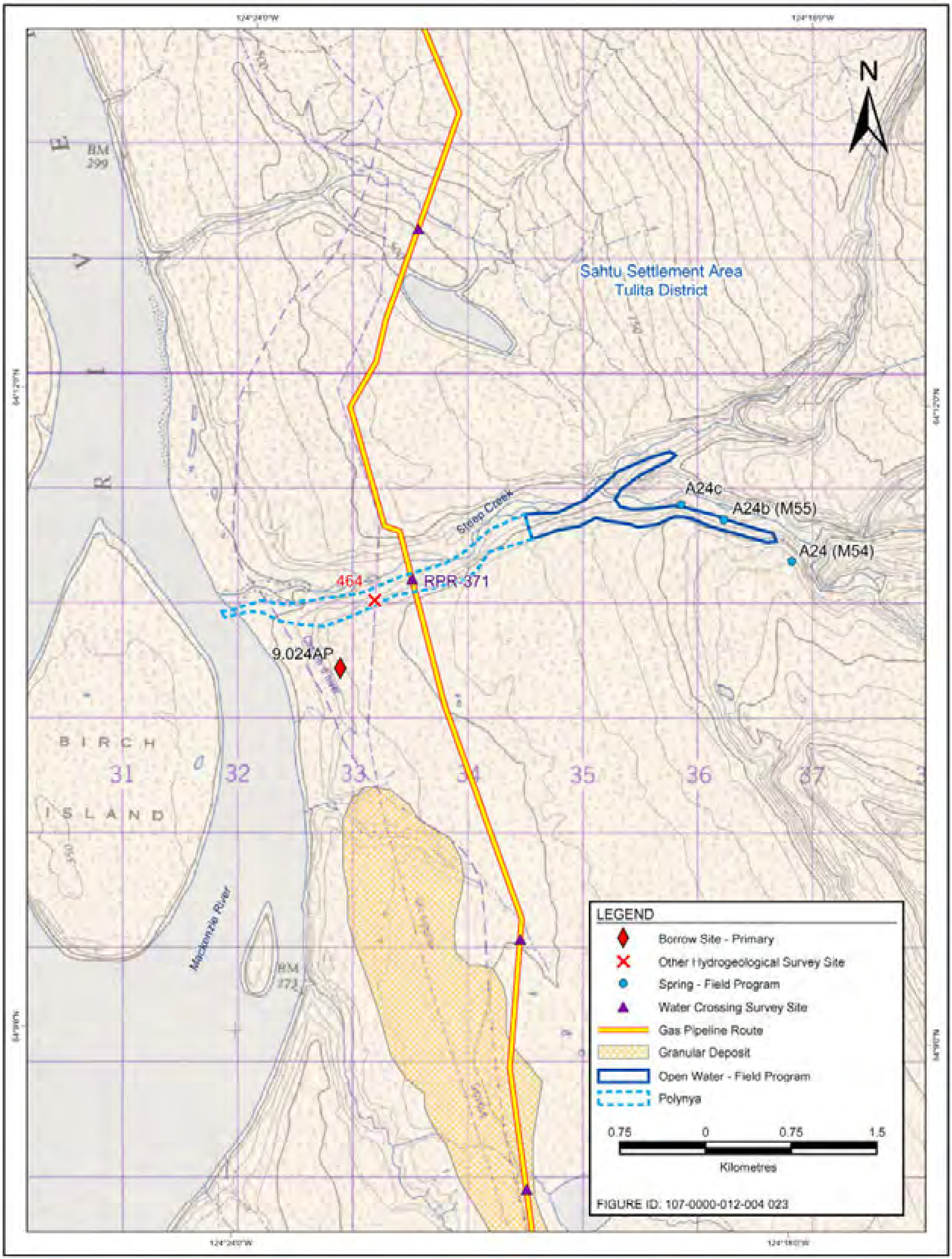


Figure 4-40: Hydrogeological Features – Steep Creek – Site 464

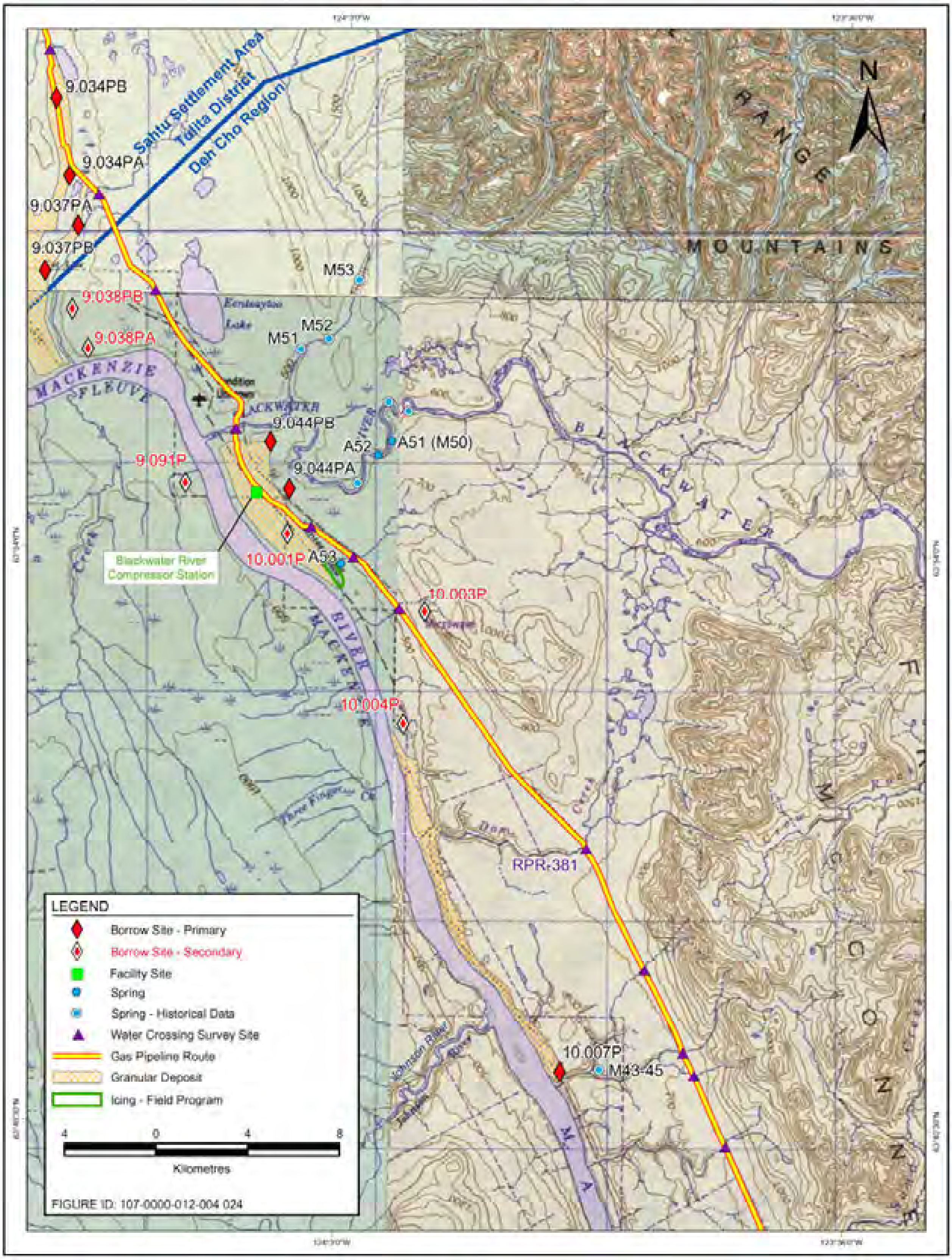


Figure 4-41: Hydrogeological Features – Sahtu-Deh Cho Boundary to Johnson River

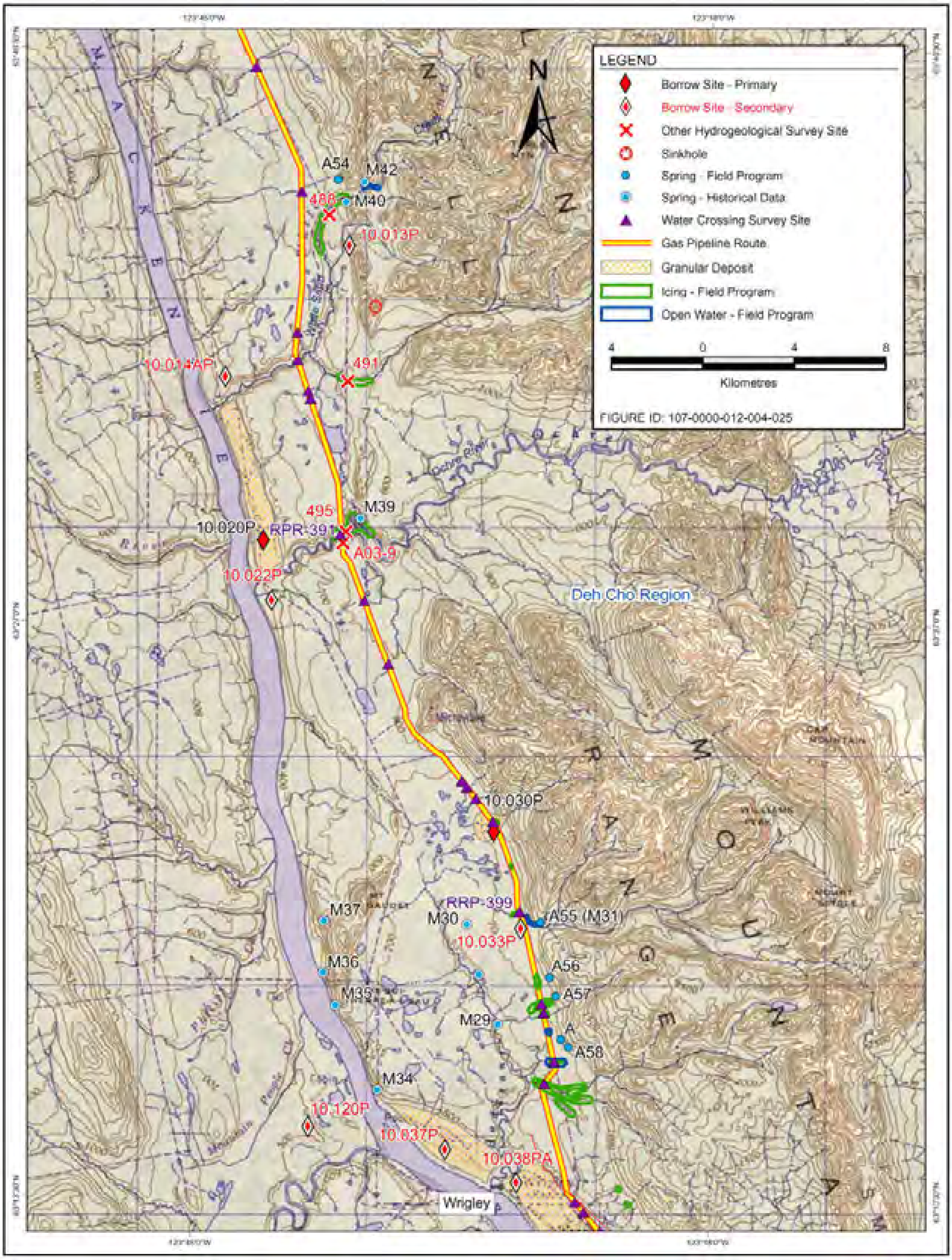


Figure 4-42: Hydrogeological Features – White Sand Creek to Wrigley

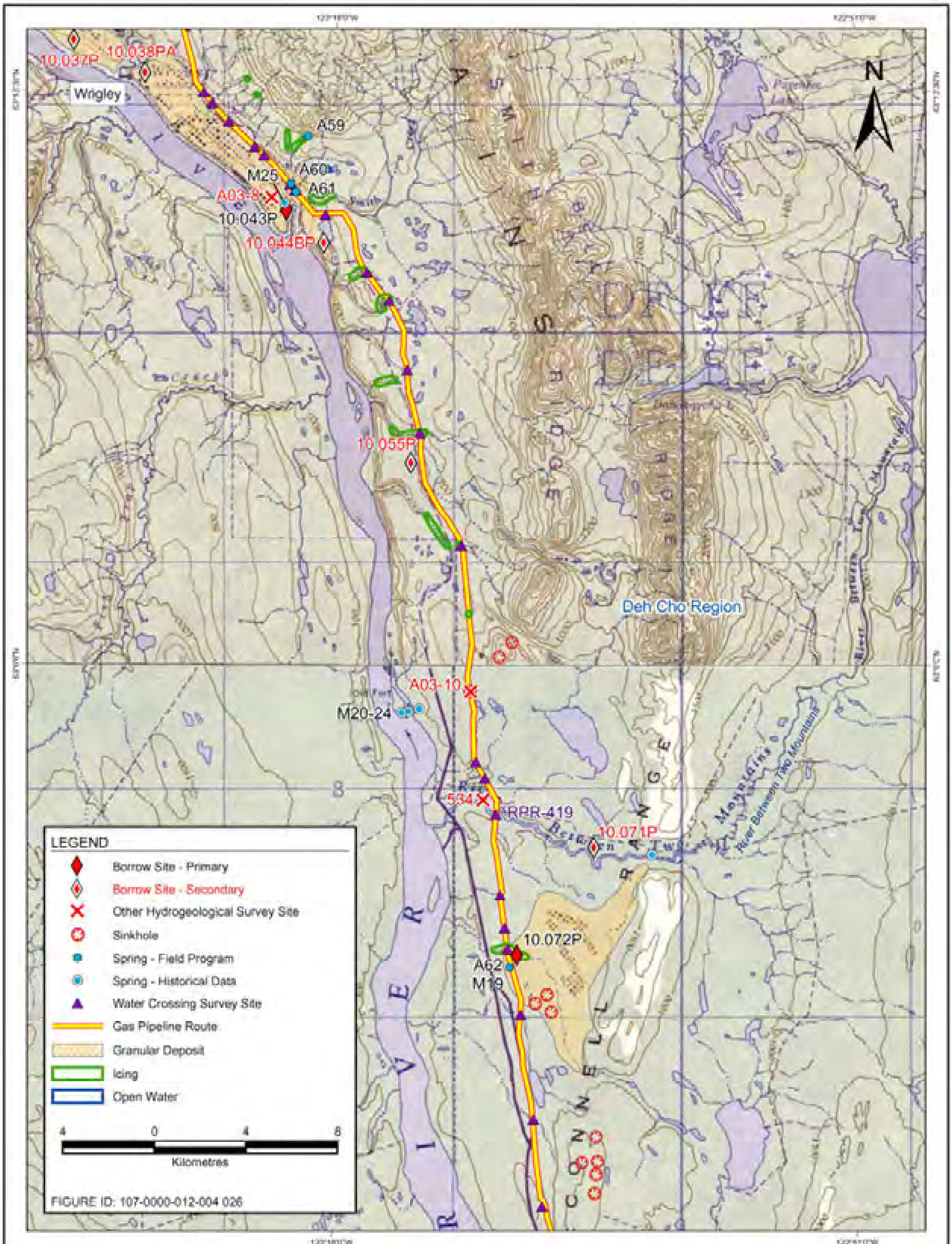


Figure 4-43: Hydrogeological Features – Wrigley to South of River Between Two Mountains

D4 AMEC (2014) Groundwater Sample Chemistry

Table D4.1 Groundwater Results Analytical Summary from AMEC (2014)

Parameter	Units	CCME-PAL	GW001		GW002		GW003		
			22-Jan-13	8-Mar-13	22-Jan-13	7-Mar-13	22-Jan-13	2-Feb-13	8-Mar-13
Physical Tests									
Total Suspended Solids	mg/L		19	2	70	200	14	-	<2
Turbidity	NTU		34.6	7.46	79.3	50.1	14.8	-	23.9
Anions and Nutrients									
p-Alkalinity (as $CaCO_3$)	mg/L		26	29	25	25	8	-	28
Alkalinity, Total (as $CaCO_3$)	mg/L		282	290	312	295	290	283	296
Bicarbonate (HCO_3)	mg/L		280	284	320	300	336	310	293
Carbonate (CO_3)	mg/L		31	34	30	30	9	17.2	34
Chloride (Cl)	mg/L	120	6	2	2	1	3	0.91	1
Conductivity (EC)	µS/cm		574	572	589	576	648	578	579
Fluoride	mg/L	0.12	**0.31**	**0.23**	**0.21**	**0.18**	**0.21**	**-**	**0.27**
Hardness (as $CaCO_3$)	mg/L	-	10	5	8	5	12	6.5	5
Hydroxide (OH)	mg/L		<5	<5	<5	<5	<5	<5	<5
Nitrate and Nitrate (as N)	mg/L	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrate (as N)	mg/L	13	<0.113	<0.113	<0.113	<0.113	<0.113	<0.050	<0.113
Nitrite (as N)	mg/L	0.197	<0.015	<0.015	<0.015	<0.015	<0.015	<0.050	<0.015
Total Kjeldahl Nitrogen	mg/L	-	0.21	0.10	0.24	0.24	0.22	-	<0.05
pH	pH	6.5-9	**9.23**	**9.25**	**9.14**	**9.23**	8.94	8.82	**9.24**
TDS	mg/L	-	360	345	355	370	320	360	330
TDS (Calculated)	mg/L	-	348	340	357	338	342	331	339
Sulphate (SO4)	mg/L	-	36	26	23	24	25	19.6	22
Nitrite	mg.L	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

Parameter	Units	CCME-PAL	GW001		GW002		GW003		
			22-Jan-13	8-Mar-13	22-Jan-13	7-Mar-13	22-Jan-13	2-Feb-13	8-Mar-13
Dissolved Metals									
Aluminum (Al)- Dissolved	mg/L	0.1	**0.208**	0.011	**0.581**	0.016	0.021	<0.0050	0.033
Antimony (Sb) – Dissolved	mg/L	-	0.002	0.001	0.001	<0.001	0.002	<0.00040	<0.001
Arsenic (As) – Dissolved	mg/L	0.005	**0.005**	0.004	0.004	0.002	**0.006**	<0.00040	<0.001
Barium (Ba) -Dissolved	mg/L	-	<0.05	<0.05	<0.05	<0.05	<0.05	0.0084	<0.05
Boron (B)	mg/L	-	0.03	0.07	0.07	0.07	0.07	0.056	0.07
Cadmium (Cd) – Dissolved	mg/L	0.00001	**0.000074**	**0.000025**	**0.000018**	<0.000016	**0.000026**	<0.00010	<0.000016
Calcium (Ca) – Dissolved	mg/L	-	3.4	2.2	2.8	2.1	4	2.38	2.1
Chromium (Cr) – Dissolved	mg/L	0.0089	0.002	0.002	0.002	0.001	<0.001	<0.0050	0.003
Copper (Cu) – Dissolved	mg/L	0.002	**0.018**	<0.002	**0.003**	<0.002	**0.002**	<0.00010	<0.002
Iron (Fe) – Dissolved	mg/L	0.3	**0.3**	<0.1	**0.3**	<0.1	<0.1	<0.010	<0.1
Lead (Pb) – Dissolved	mg/L	-	0.002	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.001
Magnesium (Mg) – Dissolved	mg/L	-	0.4	<0.2	0.3	<0.2	0.5	0.13	<0.2
Manganese (Mn) – Dissolved	mg/L	-	0.014	0.005	0.015	<0.005	0.006	0.0038	<0.005
Mercury (Hg) – Dissolved	mg/L	0.000026	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025
Molybdenum (Mo) – dissolved	mg/L	0.073	0.004	0.005	0.004	0.004	0.006	-	0.003
Nickel (Ni) – Dissolved	mg/L	0.025	<0.01	<0.01	<0.01	<0.01	<0.01	<0.0020	<0.01
Potassium (K) -Dissolved	mg/L	-	<0.6	<0.6	<0.6	<0.6	0.6	0.2	<0.6
Selenium (Se) – Dissolved	mg/L	-	<0.001	<0.001	<0.001	<0.001	<0.001	<0.00040	<0.001
Silver (Ag) – Dissolved	mg/L	0.001	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
Sodium (Na) – Dissolved	mg/L	-	133	136	141	134	135	138	136
Strontium (Sr) - Dissolved	mg/L	-	-	0.016	-	-	-	-	0.014
Thallium (Tl) – Dissolved	mg/L	0.0008	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	-	<0.0005

Parameter	Units	CCME-PAL	GW001		GW002		GW003		
			22-Jan-13	8-Mar-13	22-Jan-13	7-Mar-13	22-Jan-13	2-Feb-13	8-Mar-13
Uranium (U) – Dissolved	mg/L	0.015	<0.001	<0.001	<0.001	<0.001	<0.001	<0.00010	<0.001
Zinc (Zn) – Dissolved	mg/L	0.03	**0.038**	0.003	0.005	0.001	0.002	<0.0030	0.004
Speciated Metals									
Hexavalent Chromium	mg/L	0.001	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	-	<0.0010
Methyl Mercury – Dissolved	µg/L		<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	-	<0.000050
Methyl Mercury – Total	µg/L		<0.0000025	<0.0000025	<0.0000025	<0.0000025	<0.0000025	-	<0.0000025
Volatile Organic Compounds									
Benzene	mg/L	0.37	0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Ethylbenzene	mg/L	0.09	0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Toluene	mg/L	-	0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Xylenes	mg/L	-	0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
F1 (>C10-16)	mg/L	-	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
F1-BTEX	mg/L	-	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Hydrocarbons									
F2 (>C10-C16)	mg/L	-	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
F3 (C16-C34)	mg/L	-	0.1	0.2	<0.1	<0.1	0.2	<0.1	<0.1
F4 (C34-C50)	mg/L	-	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Polycyclic Aromatic Hydrocarbons									
Acenaphthylene	mg/L	0.0058	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001
Acenaphthylene	mg/L	-	0.00003	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001
Acridine	mg/L	0.0044	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001
Benzo(a)anthracene	mg/L	0.000018	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001
Benzo(a)pyrene	mg/L	0.000015	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001
Benzo(b&j)fluoranthene	mg/L	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001
Benzo(g,h,i)perylene	mg/L	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001

Parameter	Units	CCME-PAL	GW001		GW002		GW003		
			22-Jan-13	8-Mar-13	22-Jan-13	7-Mar-13	22-Jan-13	2-Feb-13	8-Mar-13
Benzofluoranthene	mg/L	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001
Chrysene	mg/L	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001
Dibenzo(a,h)anthracene	mg/L	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001
Fluorene	mg/L	0.003	0.00009	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001
Indeno(1,2,3-cd_pyrene	mg/L	-	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	-	<0.00001

Notes:

Table adapted from AMEC (2014)

CCME-PAL is Canadian Council for Ministers of the Environment and Water Quality Guidelines for Protection of Aquatic Life

Red bold indicates the results exceed the CCME guidelines

The groundwater from GW001 and GW002 was tested in January and March of 2013 and GW003 was tested in January, February, and March of 2013 and provide a sample of groundwater within the Summit Formation. The results are summarized in Table D4.1. The results were compared to the Canadian Council for Ministers of the Environment Water Quality Guidelines for Protection- " of Aquatic Life (CCME, 2012). Some dissolved metals were found to be in exceedance of the guidelines in GW001 – GW003 including aluminum, arsenic, cadmium, copper, iron and zinc. These are possibly from natural sources such as the bedrock. There was also exceedances in the pH and fluoride in these wells (AMEC, 2014). These are thought to be from natural sources as well. Inorganic fluoride is often found in the bedrock in fluoride containing minerals that are leached by groundwater (CCME, 2002).