Yukon

Aquifer mapping report

Village of Carmacks

July 2021

Aquifer mapping
Village of Carmacks, Yukon

Government of Yukon
Water Resources Branch

Authors
Golder Associates Ltd.

Background

The purpose of the project was to identify, delineate, and classify aquifers underlying the boundary of the Village of Carmacks and build a foundation for future hydrogeological work in the area. This report presents the geological setting and relevant background information for the study area, methods used to process and interpret the subsurface hydrogeological data, and resultant aquifer delineations and classification according to the British Columbia aquifer classification system.

Reviewers and contributors:

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- Department of Energy, Mines and Resources, Yukon Geological Survey

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Citation:
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Study limitations

This document has been prepared for the purposes of identifying and mapping aquifers in the vicinity of Carmacks and is provided for the exclusive use of the Yukon Government Water Resource Branch (WRB).

The scope of work for this study was intended to provide a regional scale overview only and did not include such items as detailed subsurface investigations or site-specific hydrogeological assessments. In preparing this document, Golder Associates Ltd. (Golder) has relied in good faith on information provided by sources noted in this document. We accept no responsibility for any deficiency, misstatements or inaccuracy contained in this document as a result of omissions, misstatements, or fraudulent acts of others.

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Executive summary

The purpose of the project was to identify, delineate, and classify aquifers within the boundary of the Village of Carmacks (Carmacks) and build a foundation for the development of a conceptual hydrogeological model for the area. This report presents the geological setting and relevant background information for the study area, methods used to process and interpret the subsurface hydrogeological data and resultant aquifer delineations and classification according to the British Columbia aquifer classification system (Bernardinucci and Ronneseth, 2002).

This report refers to places using Northern Tutchone, wherever possible. Northern Tutchone is the language of the Tagé Cho Hudän, the people of Little Salmon Carmacks First Nation (LSCFN). Agnes Charlie and Alma Wrixon, Uts'ęnjí nay hats'edän (Life Long Learning) LSCFN, generously and graciously supported this project by translating existing place names to Northern Tutchone and by conferring names to newly mapped aquifers in Northern Tutchone.

The Village of Carmacks, known as Tsâwnjik Dechäk to the Tagé Cho Hudän, is located in the central Yukon Territory, approximately 180 km north of Whitehorse and has approximately 600 residents. Tsâwnjik Dechäk means "Nordenskiold confluence," an apt name given that Carmacks is situated at the confluence of Tsâwnjik Tagé (the Nordenskiold River) with Tagé Cho (the Yukon River). The Carmacks area has been subject to many periods of glaciation during the Quaternary (last 2.65 million years). The earliest glaciations occurred prior to 200,000 years ago and were more extensive than later glaciations. Surficial materials related to these glaciations are largely eroded, and modern surficial sediments are associated with the penultimate Reid Glaciation (~140,000 years ago) and the most recent McConnell Glaciation that occurred during the global Last Glacial Maximum (LGM) ~20,000 years ago. Exposure of unconsolidated Quaternary deposits in the vicinity of Carmacks are primarily associated with glaciation during the LGM. Generally, unconsolidated deposits are thickest in the main valleys associated with Tagé Cho and Tsâwnjik Tagé. The valley deposits are described in detail by Cronmiller *et al*. (2020):

"During the McConnell glaciation, ice sculpted the hills around Carmacks and deposited a mantle of till over the landscape. As ice receded, meltwater cut through valley walls and ridges along the margins of the ice. In front of the ice sheet, large glaciofluvial outwash plains formed. These were subsequently incised as the ice withdrew, leaving behind large terraces that fill much of the Yukon River valley. Stagnant ice filled much of the Nordenskiöld and Yukon River valleys, leaving behind topography ranging from terraces with small kettle depressions to large, chaotic, hummocky ice stagnation complexes. During deglaciation large volumes of fine sediment were mobilized by strong katabatic winds from the ice sheet and deposited across much of the map area in thin veneers, rarely forming dune ridges. The present landscape is dominantly modified by fluvial processes, anthropogenic activities including mining and road building, and rare landsliding, particularly where permafrost is present or fluvial undercutting occurs."

The topography of the local bedrock valleys drops off steeply at the valley edges and, based on extrapolation of the side slopes, the lowest elevation for the top of bedrock is inferred to be approximately 426 metres above sea level (masl) in the vicinity of the LSCFN Category B settlement parcel LSC C-1B/D, which hosts their government office.

Two proven aquifers and one inferred aquifer were identified within the study area as part of project.

1. The Chu Íntthi Aquifer is an unconfined sand and gravel aquifer that is comprised of Holocene-aged fluvial and overbank deposits associated with Tagé Cho and Tsâwnjik Tagé.

2. The Łots'an Aquifer is an unconfined aquifer comprised of a thick sequence of sand which represents extensive fluvial, eolian or glaciolacustrine materials likely deposited in a paraglacial or post-glacial environment.
3. The inferred Deep Carmacks Aquifer consists of confined pre-glacial coarse sand and gravel directly overlying the bedrock. The deep sand and gravel were intersected by the YWON-2006D and inferred to have likely been intersected by a deep well at LSCFN C-1B/D (no lithology information was available). Insufficient data is available at this time to delineate these deposits as an aquifer although it is suspected that the inferred aquifer may exist throughout the valley.

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Contents

Place names and acronyms

Northern Tutchone Place Names

Tagé Cho	Yukon River
Tsâwnjik Tagé	Nordenskiold River
Tsâwnjik Dechäk	Village of Carmacks

Acronyms

CDEM	Canadian Digital Elevation Model
GIN	Groundwater Information Network
GW	Groundwater
ID	Identifier or Identification number
LSCFN	Little Salmon Carmacks First Nation
masl	Metres above sea level
mbgs	Metres below ground surface
WRB	Water Resources Branch
YOWN	Yukon Observation Well Network
YWWR	Yukon Water Well Registry

Study area location

The Village of Carmacks (Carmacks) is located in Central Yukon, approximately 180 km north of Whitehorse. Carmacks has a population of approximately 600 residents and is home to the Tagé Cho Hudän, the people of Little Salmon Carmacks First Nation (LSCFN), who traditionally speak Northern Tutchone. Carmacks in situated at the confluence of Tsâwnjik Tagé (the Nordenskiold River) with Tagé Cho (the Yukon River). The Northern Tutchone name for the place called "Carmacks" is Tsâwnjik Dechäk, which means "Nordenskiold confluence." For the purposes of aquifer mapping, the Study Area was constrained to the 43 km^2 contained within the municipal boundary, including LSCFN's settlement lands shown below in Figure 1.

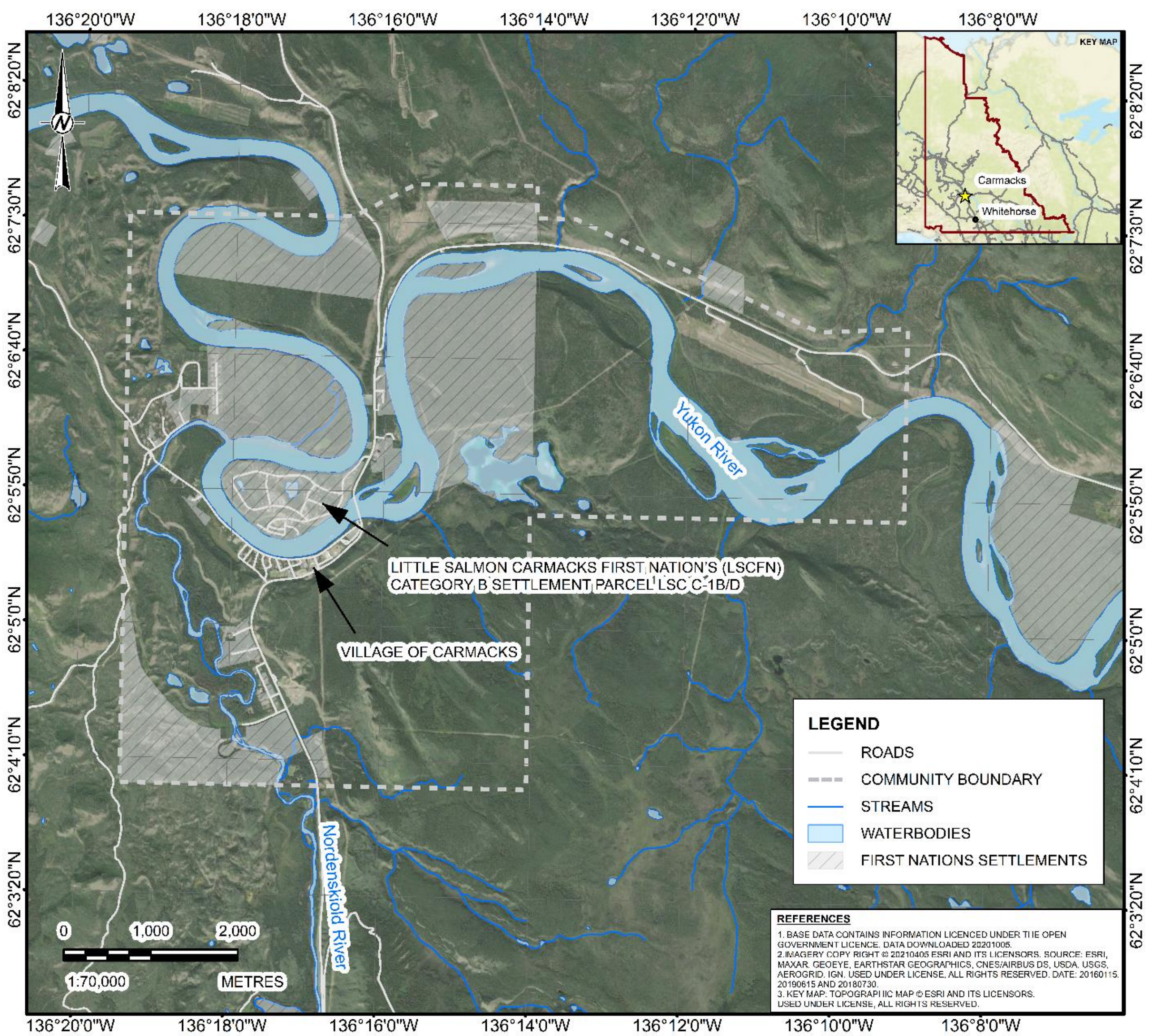

Fig. 1. Study area

Methods

Subsurface geological and hydrogeological data was compiled, preprocessed, standardized, and imported into Leapfrog Works (v 4.0.4), a commercially available 3D subsurface modelling software package, for interpretation and aquifer delineation. The data sources and workflows for the preprocessing, lithological standardization, 3D visualization and interpretation are described in the subsections below.

Data Sources

Golder conducted a data gathering exercise to obtain Quaternary geologic and hydrogeologic information for the Study Area by means of correspondence with the Yukon Government Department of Environment, Water Resources Branch (WRB) and on-line searches of publicly available information sources including the Yukon Water Well Registry (YWWR). The WRB coordinated the gathering of information from wells associated with the LSCFN as well as available geological and subsurface data from other government agencies and consultants. Table 1 provides a summary of the data that was compiled.

Table 1: Summary of Data Sources

Source	Data Type	Data Coverage
Yukon Water Well Registry (YWWR)	Well locations and water well records for public and private water supply wells, environmental monitoring wells and industrial, commercial, and institutional wells	104 wells total, 72 wells with lithology available
Yukon Highways and Public Works	Geotechnical borehole logs	189 boreholes/test pits
Groundwater Information Network (GIN)	Well locations and well logs	One additional borehole log not found in YWWR.
Little Salmon Carmacks First Nation	Well locations and well logs	45 well locations, 28 wells with lithology information
1 m resolution bare earth LiDAR data from Geomatics Yukon (2019)	Digital elevation data to support accurate positioning of boreholes	Community Boundary of the Village of Carmacks and LSCFN's settlement land within the Community Boundary
Canadian Digital Elevation Model (CDEM)	Digital elevation data to support accurate positioning of boreholes	Data downloaded with a buffer of ~10 km around the Village of Carmacks

Source	Data Type	Data Coverage
Surficial Geology Map (Geological Survey of Canada Map 1879A) & Quaternary Geology Map Area Report (Jackson, 2000)	Description and mapped distribution of surficial geological units	Regional coverage of the Tantalus Butte area
Surficial Geology Map, Scale 1:15 000 (Cronmiller et al., 2020).	Finer scale mapped distribution of surficial geological units and descriptions	Coverage of the Carmacks area.
Yukon Observation Well Network (YOWN) Subsurface Investigation	Stratigraphic borehole and two nested monitoring wells	One location in the Village of Carmacks

The primary source of subsurface information for the project was the YWWR database. The YWWR contained a total of 104 well records, 72 of which had lithological information, and over 400 unique lithological intervals for the Study Area at the time of download in September 2020. Additional subsurface information related to geotechnical drilling and test pits were obtained from the Yukon Department of Highways and Public Works and included 189 predominantly shallow boreholes and test pits with over 700 unique lithological intervals. Additional well logs were provided by LSCFN for wells that are not currently in the YWWR.

Groundwater wells in the area are used as private domestic wells, public drinking water supply wells, environmental monitoring wells and as a water supply for commercial or industrial processes. The groundwater wells in the Study Area range in depth from approximately 3 m to 116 m (geometric mean of 15 m), with only 18 locations drilled to a depth of greater than 30 m. Installation depths for well screens range from 3 m to 66 m, with an average installation depth of between 10 and 15 metres below ground surface (mbgs) and an average screened interval length of 1.5 m. Lithology descriptions provided on water well records generally include grain-size descriptions such as silt, silty-sand, sand, sand and gravel and gravel. These lithology descriptions are dependent on the driller’s observations and log from the time of drilling and are highly variable with respect to the amount of detail and degree of quality. There is only limited information regarding the degree of saturation, cohesion, plasticity, compaction, and other geotechnical descriptors. The locations of water well records are clustered around populated areas.

Subsurface information from geotechnical investigations is more spatially distributed throughout the Carmacks area. Geotechnical logs provide more detailed lithological descriptions including descriptive modifiers related to degree of saturation, cohesion, plasticity and compaction; however, the depth of investigation is typically shallow, averaging approximately 4 m in depth, with only four locations extending to a depth greater than 10 m.

Following a review of the available data in the Study Area and a summary of the data gaps for aquifer mapping (Golder, 2020), the WRB advanced a deep stratigraphic borehole in Carmacks to obtain additional deep data, increase the confidence in the stratigraphic correlations, and to further the understanding of the depositional environment. This borehole was subsequently completed with two nested monitoring wells for the YOWN-2006S/D and represents an important control point for the geological and hydrostratigraphic interpretation (Section 3.1).

High resolution topographic information in the form of 1 m resolution bare earth LiDAR data from 2019 was provided by Geomatics Yukon for the full extent of the Study Area. Outside of the municipal boundary, lower resolution topographic data from the 20 m resolution CDEM was utilized for the extrapolation of bedrock depth from valley side slopes. Information on the depth to bedrock within the main valleys is limited, with only the newly drilled YOWN-2006S/D borehole definitively intersecting bedrock.

Limited information exists on the depth and morphology of the bedrock surface within the valleys. The bedrock surface below the thick valley sediments was estimated using a series of 2D planes placed coincident to bedrock side slopes from the topographic data and extended to depth below the valley. Points placed on these surfaces were used as control points together with the bedrock depth from the YOWN-2006S/D borehole to generate the top of bedrock as an offset surface from topography generally assuming a U-shaped valley. In the highlands the bedrock surface is assumed to mimic topography where unconsolidated sediments are relatively thin (generally < 5 m). Generating a bedrock surface using an offset surface from topography and assuming a U-shaped valley is a standard method for estimating the bedrock surface in a valley in an area where limited information is available. Due to the limited information of definitive bedrock contacts (one borehole), this assumed bedrock surface should be considered conceptual only with a high degree of uncertainty. Small scale morphological features in the assumed bedrock surface are an artifact of the method used to generate the surface and may not be indicative of actual conditions.

Data Standardization

Well information and lithological descriptors are variable in terms of documentation and overall data quality, with substantial variation depending on the age of the well record and drilling company. Common types of preprocessing that was conducted as part of this study include:

- Conversion from imperial units to metric
- Manual entry of lithological information from the YWWR and LSCFN well records
- Standardization of lithological descriptors

Given the variability of the raw lithology descriptors, standardization of the lithological dataset was required for effective interpretation of subsurface stratigraphy and conditions. The method of standardization primarily consisted of keyword scripts to extract relevant data descriptors from the lithology field. Once the relevant lithological data were extracted, they were classified on the basis of sediment texture into groups that were expected to behave in a hydraulically similar manner. These sediment textural groupings were implemented in the 3D subsurface model and were used to facilitate the geological and hydrostatigraphic interpretations described in Sections 3.0 and 4.0, respectively. Table 2, below, presents the main lithological descriptors and their associated sediment textural grouping.

Table 2: Lithological Descriptor Standardization

Lithological Descriptor	Sediment Textural Grouping
Silt Sand and Gravel	Sand and Gravel
Gravelly Sand	
Sand (Fine / Medium / Coarse / Clean)	Sand
Silty Sand	Silt / Sand
Sandy Silt	

Lithological Descriptor	Sediment Textural Grouping
Silt	Silt
Clay	Till/Clay
Silty Clay	
Till	
Bedrock	Bedrock

It should be noted that these groupings and classifications are methods used only to facilitate visualization of the data in 3D for the interpreter; the full raw lithologies were still queried by the interpreter during the aquifer mapping and delineation process to ensure that professional judgement was applied throughout the process as opposed to being strictly an automated process.

3-Dimensional Visualization and Hydrostratigraphic Interpretation

To conduct the 3D hydrostratigraphic visualization and interpretation, standardized datasets for lithology, degree of saturation, and groundwater levels / depths to water were imported into Leapfrog Works (v4.0.4) for 3D rendering. Well collar elevations were frequently unavailable or, where available, were typically low accuracy. In order to vertically reference well or borehole collars, collars were assigned elevations by projecting them onto the topographic surface in the 3D model, which was defined by the high-resolution LiDAR mapping. This allowed for vertical referencing of all associated wells and lithological data within the 3D space of the subsurface model; however, it also meant that vertical elevation errors could be introduced where the associated well record has low horizontal accuracy in an area of high topographic relief.

Aquifers and hydrostratigraphy were interpreted by visualizing the associated datasets in 3D, cutting cross-sections, manipulating the model, and then by manually selecting and assigning various intervals to hydrostratigraphic units and aquifers. This method allowed the interpreter to assess and visualize the different types of hydrogeological data quickly and the ability to easily and continuously cut cross-sections to investigate areas of interest. Subsurface data, existing geological mapping, groundwater levels, and landform morphology were all considered when delineating the aquifer boundaries. Assumptions and notes regarding the delineation of the aquifers are documented in the associated aquifer description worksheets in Appendix 1.

Overview of geology

The primary references that define the framework for the geological setting and background for the Quaternary geology in the Carmacks area are the Geological Survey of Canada's Bulletin 539, Quaternary Geology of the Carmacks Map Area, Yukon Territory (Jackson, 2002), Yukon Geological Survey's "Carmacks surficial geology and community hazard susceptibility mapping" (Cronmiller et al., 2020) and the bedrock geology is defined in "Northern Cordilleran terranes and their interactions through time" (Colpron et al., 2007). Bedrock and surficial geology maps are provided in Appendix 2.

Limited information on depth to bedrock in the valley bottoms is available; however, the morphology of the bedrock valleys is assumed to be U-shaped as a result of the glacial history. Three bedrock units underlie the study area (Yukon Geological Survey, 2020; see Appendix 2)):

- **Upper Cretaceous Carmacks Group Volcanics of the Little Ridge/Casino Formation** located on the western side of the study area and consists of augite-olivine basalt and breccia.
- **Middle Jurassic to Lower Cretaceous Tantalus Formation Sedimentary Bedrock** located in the centre portion of the study area and consists of chert pebble conglomerate and gritty quartz-chert-feldspar sandstone.
- **Lower Jurassic to Middle Jurassic Laberge Group Sedimentary Bedrock of the Tanglefoot Formation** located on the western portion of the study area and consists of arkosic sandstone and minor shale, pebble and boulder conglomerate.

The depth to bedrock has been observed or inferred at two locations. In the YOWN-2006S/D stratigraphic borehole, the top of bedrock was intersected at 68.3 m below ground surface (457.5 masl). The Little Salmon Carmacks First Nation Well #3 (Lot C1B/D 1047), was drilled to 116.7 m (elev. ~426 masl) which is approximately 30 m below the elevation in which bedrock was intersected at in the YOWN-2006S/D stratigraphic borehole. Lithological information was unavailable for this well, however it was assumed that this hole was likely advanced into bedrock and subsequently the well was installed in the overlying unconsolidated materials.

The Carmacks area has been subject to many periods of glaciation during the Quaternary (last 2.65 million years). The earliest glaciations occurred prior to 200,000 years ago, and were more extensive than later glaciations (Jackson, 2002). Surficial materials related to these glaciations are largely eroded, and modern surficial sediments are associated with the penultimate Reid Glaciation (~140,000 years ago) and the most recent McConnell Glaciation that occurred during the global Last Glacial Maximum (LGM) ~20,000 years ago. Exposure of unconsolidated Quaternary deposits in the vicinity of Carmacks are primarily associated with glaciation during the LGM. Generally, unconsolidated deposits are thickest in the main valleys associated with Tagé Cho and Tsâwnjik Tagé.

In 2020, surficial geological mapping and hazard susceptibility mapping near Carmacks was undertaken by Cronmiller *et al.* (2020; see Appendix 2) for the purpose of future land development. The valley deposits are described in detail by Cronmiller *et al*. (2020):

"During the McConnell glaciation, ice sculpted the hills around Carmacks and deposited a mantle of till over the landscape. As ice receded, meltwater cut through valley walls and ridges along the margins of the ice. In front of the ice sheet, large glaciofluvial outwash plains formed. These were subsequently incised as the ice withdrew, leaving behind large terraces that fill much of the Yukon River valley. Stagnant ice filled much of the Nordenskiöld and Yukon River valleys, leaving behind topography ranging from terraces with small kettle depressions to large, chaotic, hummocky ice stagnation complexes.

During deglaciation large volumes of fine sediment were mobilized by strong katabatic winds from the ice sheet and deposited across much of the map area in thin veneers, rarely forming dune ridges. The present landscape is dominantly modified by fluvial processes, anthropogenic activities including mining and road building, and rare landsliding, particularly where permafrost is present or fluvial undercutting occurs."

YOWN-2006S/D Stratigraphic Borehole

Following a review of the available data in the Study Area and a summary of the data gaps for aquifer mapping (Golder, 2020), the WRB advanced a deep stratigraphic borehole in November 2020 in order to provide an additional deep data point, increase the confidence in the stratigraphic correlations, and to further the understanding of the depositional environment. This borehole, located in the Carmacks Riverside Park, was subsequently completed with two nested monitoring wells for the YOWN-2006S/D and represents an important control point for the geological and hydrostratigraphic interpretation. The core from the stratigraphic borehole was logged by staff from the Yukon Geological Survey (YGS) and Golder. A simplified version of the borehole log, including the inferred depositional environment and hydraulic behavior is summarized in Table 3, below.

Table 3: Simplified YOWN Borehole Log

Start Depth (m)	***End Depth (m)***	***Material***	***Texture / Structure***	***Inferred Age and Depositional Setting***	***Inferred Hydraulic Behavior***
0	*1.8*	*Surface overbank*	*Clayey silt and sand*	*Holocene overbank*	*Low Permeability*
1.8	*3.9*	*Sand*	*Silty fine sand coarsening up to fine sand*	*Holocene overbank and terrace deposits*	*Permeable*
3.9	*11*	*Matrix-supported sandy pebble gravel*	*Gravel (60-70%) subrounded pebble (avg 2-4 cm; range 1-10 cm); medium sand (30%) with some muddier intervals*	*Holocene age fluvial deposits associated with Tagé Cho*	*Permeable*
11	*32*	*Fine sand*	*Uniform, clean fine sand with <10% silt*	*Fluvial, glaciolacustrine and/or eolian*	*Permeable*
32	*36.5*	*Medium sand*	*Uniform, clean medium sand*	*Fluvial, glaciolacustrine and/or eolian*	*Permeable*
36.5	*47.8*	*Fine sand*	*Uniform, clean fine sand with <10% silt*	*Fluvial, glaciolacustrine and/or eolian*	*Permeable*
47.8	*52.4*	*Silt*	*Silt, with < 20% fine sand*	*Glaciolacustrine and/or eolian*	*Low Permeability*
52.4	*61.5*	*Silty sand and gravel*	*Predominantly medium sand with interbeds of silty sand and silty sandy gravel*	*Glaciofluvial and/or eolian*	*Variable Permeability*
61.5	*62.5*	*Diamict*	*Compact silty sand matrix; coarse sand to pebble clasts*	*Glacial*	*Low Permeability*
62.5	*64.3*	*Coarse sand and gravel*	*Fining upwards from pebble gravel to coarse sand*	*Pre-glacial or interglacial fluvial*	*Permeable*
64.3	*68.3*	*Interbedded sand and gravel*	*Pebble gravel and coarse sand*	*Pre-glacial or interglacial fluvial*	*Permeable*
68.3	*68.5*	*Bedrock*	*Basalt*	***Age:*** *Upper Cretaceous* ***Formation:*** *Little Ridge/Casino* ***Group:*** *Carmacks*	*Low Permeability*

The geological interpretation of the YOWN-2006S/D stratigraphic borehole provides important insight into depositional processes and geological controls on groundwater movement. The bedrock valleys are expected to be low permeability and to control the distribution and thickness of unconsolidated materials within the study area but the depth to bedrock had not been previously confirmed in any well records or drilling in the area. Intersecting bedrock relatively close to the centerline of the Tagé Cho valley represents an important constraint for modelling the bedrock valley.

Directly overlying bedrock in the YOWN-2006S/D stratigraphic borehole is approximately 6 m of sand and gravel. Based on sorting and grading in this unit, it is interpreted to be a remnant of pre-LGM or older non-glacial fluvial deposition. This unit is inferred to have been deposited throughout the valley however the extent of the unit is unknown and the unit may have been partially eroded by subsequent processes.

The diamict observed at 62 mbgs above the lowest sand and gravel unit in the YOWN-2006S/D borehole is thin (1 m thick) and interpreted to be till based on the presence of striated clasts. Directly overlying the glacial diamict is an approximately 50 meter thick package of sediment including a 9 m sequence of highly variable interbedded silt, sand, and gravel which fines upwards into a 4.5 m interval of silt, followed by approximately 35 meters of clean, uniform sands. The interbedded silt, sand, and gravel at the base of the package is interpreted to reflect glacial or glaciofluvial deposition during glacial retreat. The overlying silt interval is suspected to be of glaciolacustrine, eolian or fluvial origin. The depositional process for the sand is uncertain and may have been associated with enhanced eolian deposition after deglaciation when the landscape remained vegetation free, glaciolacustrine deposition in lakes formed from ice or debris dams in the valley, and/or fluvial deposition. Based on the inferred depositional environment, this entire package is likely continuous across the entire valley and likely contains a finer horizon near the base throughout that is potentially low permeability.

To confirm the composition of the low permeability silt layer from 47.8 – 52.4 mbgs, two samples were submitted to Golder's laboratory for grain size and hydrometer testing. A summary of the grain size analysis results is presented in Table 4 below, confirming the presence of a sizable low permeability layer. Full grain size analysis results are provided in Appendix 3.

Table 4: Summary of Grain Size Analysis

Grain Size	**Percentage Retained of Sample**	
	Sample Depth 49.3 m	**Sample Depth 50.9 m**
Gravel	2.1 %	0%
Sand	11.9%	16.3%
Silt (<0.075 mm)	79.1%	78.4%
Clay (<0.002 mm)	6.9%	5.3%

The upper 11 m of the YOWN-2006S/D stratigraphic borehole represents Holocene-aged fluvial and overbank deposits associated with Tagé Cho.

Hydrogeology

The hydrostratigraphy of an area is a simplified representation of the geology where the various geological units are grouped and classified according to the hydraulic characteristics and expected hydrogeological behaviour (i.e., aquifer or aquitard). Classification of hydrostratigraphic units as aquifers or aquitards is completed on the basis of their relative hydraulic conductivity to other units and ability of the hydrostratigraphic unit to provide a useable source of groundwater. Table 5 presents a summary of the hydrostratigraphic units for the Study Area with detailed descriptions provided in Sections 4.1 through 4.7 below.

Table 5: Inferred Hydrostratigraphic Units and Classifications

Hydrostratigraphic Unit	Thickness (m)	Elevation Range (masl)	Age	Interpreted Depositional Environment	Hydrostratigraphic Classification
Chu íntthi Aquifer	< 15	505 - 520	Holocene	Fluvial	Unconfined Aquifer
Łots'an Aquifer	Up to 40	475 - 600	Post-glacial or paraglacial	Fluvial, glaciolacustrine, and/or eolian	Unconfined Aquifer
Carmacks Aquitard	15	460 - 475	Unknown	Glaciofluvial, glaciolacustrine, and/or eolian	Aquitard
McConnell Ice Stagnation Complex	70	450 - 620	LGM or older	Ice-marginal or subglacial	Local Aquifer / Aquitard
Glacial Till	10	560 - 900	Glacial	Glacial	Local Aquifer / Aquitard
Inferred Aquifer - Deep Carmacks Sand and Gravel	6	430 - 460	Pre-LGM or older	Fluvial	Inferred Confined Aquifer
Bedrock	-	425 - 900	Variable-	N/A	Aquitard

Two aquifers were identified and delineated as part of the hydrostratigraphic interpretation, namely, the Łots'an and Chu Ínthi Aquifers. A third, inferred aquifer, preliminarily identified in this report as the Deep Carmacks Sand and Gravel, was identified from the YOWN-2006S/D stratigraphic borehole but, as this deposit was intersected only in one borehole, insufficient evidence is available to definitively map this unit as an aquifer. These aquifers are described in the subsections below with aquifer description sheets provided in Appendix 1. Hydrostratigraphic cross-sections showing the locations of the hydrostratigraphic units relative to one another are provided in Appendix 4 and an Aquifer Summary Table in the format of the BC Aquifer Mapping and Classification System (Bernardinucci and Ronneseth, 2002) is provided in Appendix 5. Aquifer shapefiles are provided in Appendix 6, aquifer-well correlations are provided in Appendix 7, and a table of the interpreted hydrostratigraphic picks by well record is provided in Appendix 8.

Bedrock

The bedrock valleys are the main controls on the distribution and extent of the unconsolidated deposits in the study area. As the majority of the population in the study area reside in the valleys, where the depth to bedrock is relatively large and the unconsolidated deposits are thicker, no water wells have been completed in bedrock and the hydrogeological understanding of the bedrock is low. As described in the Section 3, there are three bedrock units (Yukon Geological Survey, 2020) that underlie the study area which include:

- **Upper Cretaceous Carmacks Group Volcanics of the Little Ridge/Casino Formation** consisting of augite-olivine basalt and breccia.
- **Middle Jurassic to Lower Cretaceous Tantalus Formation Sedimentary Bedrock** consisting of chert pebble conglomerate and gritty quartz-chert-feldspar sandstone.
- **Lower Jurassic to Middle Jurassic Laberge Group Sedimentary Bedrock of the Tanglefoot Formation** consisting of arkosic sandstone and minor shale, pebble and boulder conglomerate.

In general, as the hydraulic conductivity of the bedrock is expected to be low in comparison to the unconsolidated sediments and is classified as an aquitard. Where appreciable groundwater flow within the bedrock occurs, it is expected to be controlled primarily by faults and fractures. More permeable locations or horizons within the bedrock units have not been identified. Despite the classification as an aquitard, low hydraulic conductivity shallow bedrock is often exploited for small scale domestic water supply purposes. It is expected that the bedrock hydrostratigraphic unit would often be capable of providing a private domestic water supply, however the potential groundwater quality is unknown.

Inferred Aquifer - Deep Carmacks Sand and Gravel

The Deep Carmacks Sand and Gravel is a confined unit directly overlying bedrock in the deepest portions of the bedrock valleys in the study area and has been identified as an inferred aquifer. In the stratigraphy of the YOWN-2006S/D borehole, the Deep Carmacks Sand and Gravel unit is represented by sand and gravel that underlies a glacial diamict observed at approximately 62 mbgs. As a result, the inferred aquifer is interpreted to have been deposited prior to the LGM, and potentially prior to the initiation of Quaternary glaciations. The uniform, well-sorted, medium to fine gravel deposits that comprise the inferred aquifer may be widely deposited throughout the valley and constrained by the bedrock valley walls, however, there is also potential that subsequent glacial and fluvial processes may have eroded much of this unit. The YOWN-2006D monitoring well was installed in the Deep Carmacks Sand and Gravel unit with a screened interval of approximately 63.7 – 66.8 mbgs. A weak upward vertical hydraulic gradient in groundwater hydraulic head was observed between the YOWN-2006D monitoring well and the YOWN-2006S monitoring well screened from 9.1 – 10.7 mbgs at the same location. Other than the YOWN-2006D monitoring well, only one LSCFN well is inferred (lithology not available on well record) to have been installed in the Deep Carmacks Sand and Gravel.

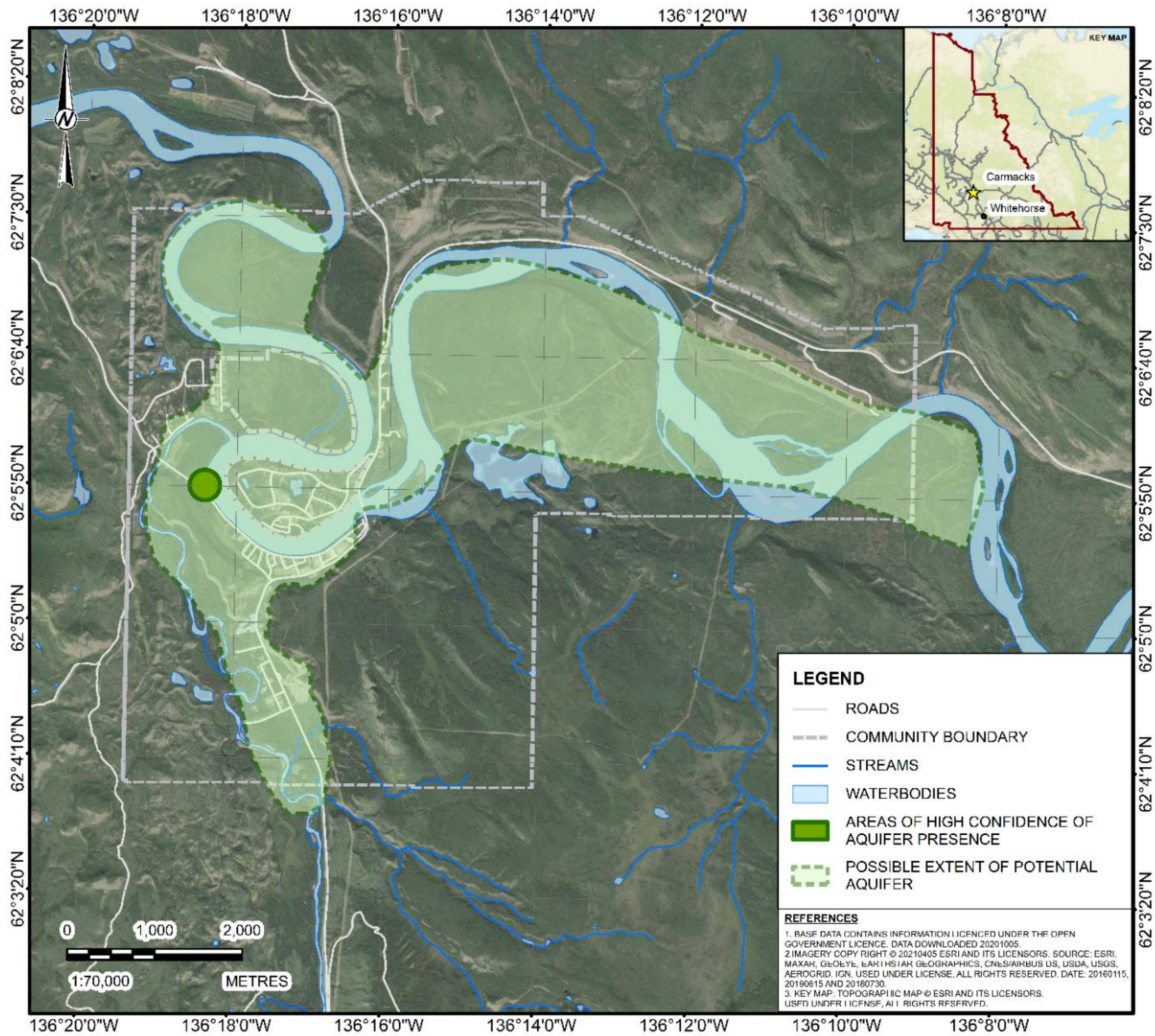

Figure 2: Possible extent of the inferred Deep Carmacks Aquifer and Areas of High Confidence in Aquifer Mapping

McConnell Ice Stagnation Complex

The McConnell Ice Stagnation Complex hydrostratigraphic unit comprise the large north-south trending ice stagnation complex and end moraine deposits observed to the west of Carmacks as well as other localized ice stagnation complex deposits observed in the uplands southeast of Carmacks and elsewhere throughout the Study Area (see Appendix 2). The McConnell Ice Stagnation Complex is frequently deformed, slumped and kettled, with the deposit west of Carmacks representing the glacial terminus of the McConnell Glaciation. Where the McConnell Ice Stagnation Complex deposits have been drilled, mostly by geotechnical boreholes, the lithology is often variable, with permeable coarse-grained deposits as well as finer less permeable material, often interbedded and folded. Due to the variability and unpredictability of this hydrostratigraphic unit, the McConnell Ice Stagnation Complex have been classified as a Local Aquifer / Local Aquitard and has not been carried forward as a mappable aquifer. It is possible that groundwater can be found in sizable amounts within the McConnell Ice Stagnation Complex, but the variability is high and the hydrostratigraphic unit may be expected to behave as an aquifer or aquitard depending on the local area. Further investigation in the future may refine this interpretation.

Glacial Till

The Glacial Till hydrostratigraphic unit within the study area is associated with the McConnell Glaciation and is generally observed as a thin deposit that directly overlies the bedrock at higher elevations. In the surficial geology mapping completed by Cronmiller et al. (2020), glacial till was inferred to be exposed at surface for 7% of the study area; however it was noted that the glacial till distribution is likely larger but has been subsequently covered by the extensive loess and colluvium deposits in the area. Groundwater wells in the area are primarily localized to the valley bottom and information about the till deposits is limited. Similar to the McConnell Ice Stagnation Complex, the Glacial Till may have localized areas that may be behave as an aquifer of aquitard.

Carmacks Aquitard

The Carmacks Aquitard hydrostratigraphic unit directly overlies the Deep Carmacks Sand and Gravel in the bedrock valleys or, where the inferred aquifer is not present, the aquitard directly overlies the bedrock. The aquitard is interpreted to be comprised of a sequence of diamict or glacial till and the overlying interbedded and fine-grained deposits f that are expected to have low or variable hydraulic conductivity in relation to the overlying and underlying hydrostratigraphic units. The aquitard is assumed to be distributed contiguously across the bedrock valley, confining the Deep Carmacks Sand and Gravel unit throughout where it is present. In the YOWN-2006S/D borehole log, the thickness of the Carmacks Aquitard hydrostratigraphic unit was observed to be approximately 15 m.

Łots'an Aquifer

The Łots'an Aquifer is a large, unconfined sand aquifer located in the valleys of the study area. The aquifer was named by Agnes Charlie with LSCFN's Uts'ęnjí nay hats'edän (Life Long Learning) Department. "Łots'an" is a Northern Tutchone word meaning, roughly, "low hills." In the YOWN-2006S/D borehole, the sands of the Łots'an Aquifer were observed to be over 35 m thick and were often noted to be clean, uniform, and massive. The Łots'an Aquifer overlies the Carmacks Aquitard in the bedrock valleys and is hydraulically connected with the overlying Holocene fluvial sands of the Chu Íntthi Aquifer where they are present in the valley bottom. The Łots'an Aquifer is assumed to be comprised of both the 35 m sequence of uniform sands observed in the YOWN-2006S/D borehole as well as the incised glaciofluvial outwash terraces documented in the surficial geology mapping (Cronmiller et al., 2020). While the depositional environment for the sequence of sands from YOWN-2006S/D is uncertain (see Section 3.1), it is assumed that they are hydraulically connected to the outwash sands of the glacial terraces. Based on the expectation of similar hydraulic properties, both of these have been included in the Łots'an Aquifer. The Łots'an Aquifer has been intersected by numerous wells in Carmacks and near the Carmacks Airport and is assumed to be present through the Tagé Cho and Tsâwnjik Tagévalleys.

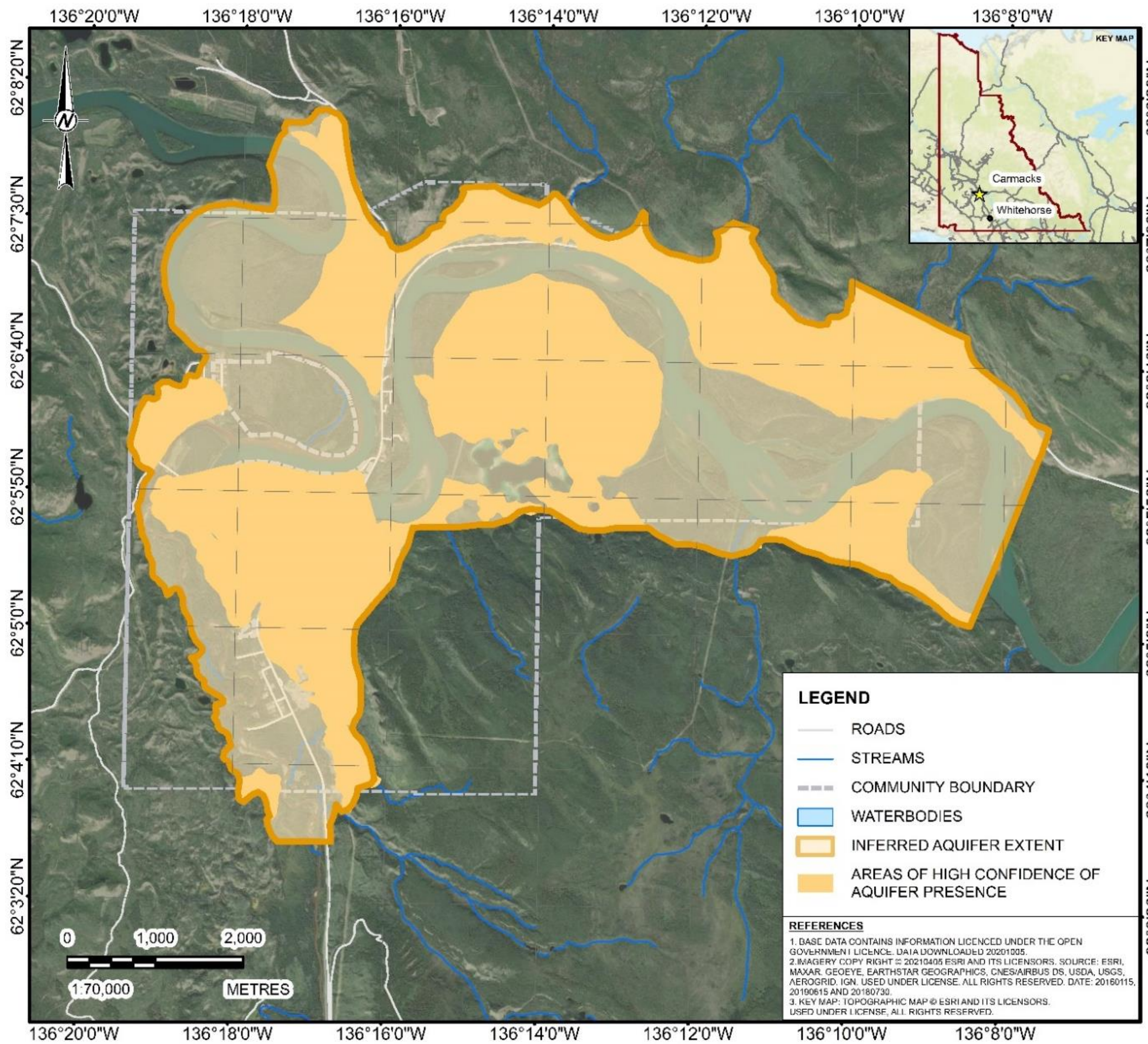

Figure 3: Inferred Extent of Łots'an Aquifer and Areas of High Confidence in Aquifer Mapping

Chu Íntthi Aquifer

The Chu Íntthi Aquifer is an unconfined sand and gravel aquifer associated with fluvial deposition from Tagé Cho and Tsâwnjik Tagé. Due to the variability of fluvial deposition, the composition of the Chu Íntthi Aquifer is variable and is also assumed to include modern overbank deposits. The aquifer was named by Agnes Charlie with LSCFN’s Uts'ęnjí nay hats'edän (Life Long Learning) Department. “Chu Íntthi” is a Northern Tutchone phrase meaning, roughly, “floodplain.” The extent of the aquifer is generally based on the distribution of the fluvial deposits as mapped by Cronmiller et al. (2020). The aquifer directly overlies and is in hydraulic communication with the underlying glacial outwash and glaciofluvial deposits of the Łots'an Aquifer with the distinction between the Chu Íntthi and Łots'anAquifers made on the basis of depositional process and expected hydraulic behaviour. The Chu Íntthi Aquifer is used as a groundwater supply by numerous wells in the Study Area.

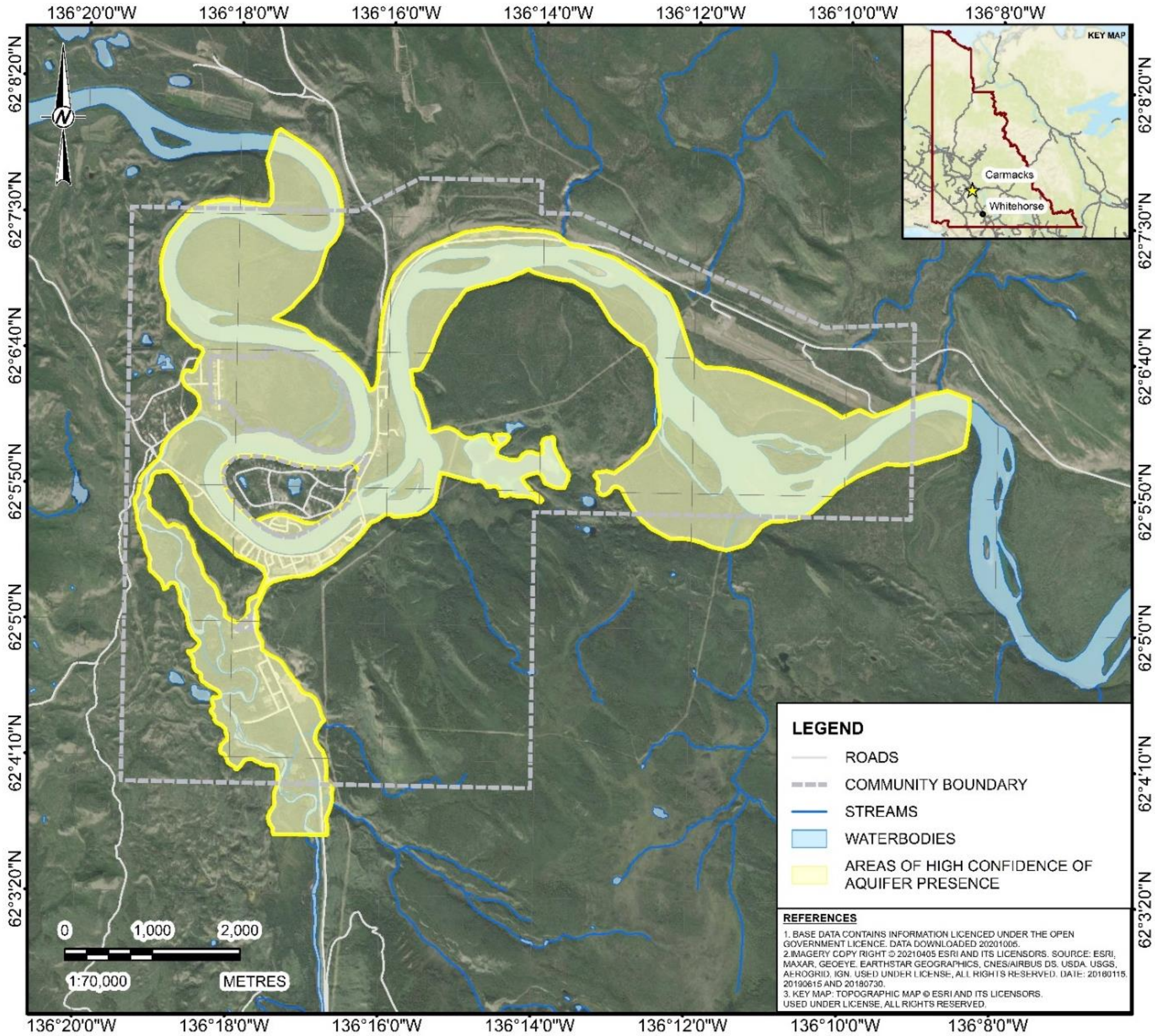

Figure 4: Inferred Extent of Chu Íntthi Aquifer

Data gaps and uncertainty

As part of a data gap assessment for the project, Golder reviewed available data for the Study Area and prepared a Technical Memorandum on Data Coverage and Gap Analysis for Carmacks Aquifer Mapping Area (Golder, 2020) for the YGWRB. The primary data gaps identified during this assessment included:

- A limited number of deep boreholes (> 50 m)
- Uncertainty associated with the lithological descriptions included in the deeper boreholes from the Yukon Water Well Registry (descriptions are from well drillers and not geologists)
- Lack of spatial distribution of deep boreholes which would allow for stratigraphic correlation of potential deeper aquifers or confining units at depth (primarily below ~475 masl)
- Limited or inconsistent description/presence of possible confining units or aquitards (till, clay, silt) at depth
- Limited information outside of the populated area to delineate lateral extent of aquifers
- No information from borehole logs on the bedrock or depth of bedrock contacts in the valley

Based on the results of this data gap assessment, the YGWRB drilled the YOWN-2006S/D stratigraphic borehole to address some of the data gaps and uncertainties that were identified. The YOWN-2006S/D stratigraphic borehole was extremely beneficial to the project as it provided the following:

- A deep borehole in a strategically important area that reached the top of bedrock
- High quality sediment descriptions, logged and reviewed with local experts at the YGS, that could be used to correlate lithology descriptions from other water well records and boreholes
- Information on the geological history and depositional environment, which allowed greater confidence in extrapolating aquifer boundaries in areas of uncertainty and limited information
- Monitoring wells that provide the opportunity for ongoing groundwater monitoring at these locations

Outstanding data gaps include the following:

- Other than the YOWN-2006S/D stratigraphic borehole, limited information on the deeper hydrostratigraphic units (i.e. Inferred Deep Carmacks Sand and Gravel Aquifer and Carmacks Aquitard) exists to confirm lateral continuity of the units and the hydrostratigraphic interpretation

Limited subsurface information outside of populated areas and areas of major projects (i.e. landfill, airport, highways).

Conclusions and recommendations

Two proven, unconfined aquifers and one inferred, confined aquifer have been delineated in the Carmacks area. The Łots'an Aquifer is an unconfined aquifer comprised of thick, clean, and uniform sands constrained within the Tagé Cho and Tsâwnjik Tagé valleys. The Chu Íntthi Aquifer is an unconfined Holocene age sand and gravel aquifer primarily associated with fluvial processes related to the Tagé Choand Tsâwnjik Tagé. The majority of the wells in the Study Area are screened in the Chu Íntthi or Łots'an aquifers. The Deep Carmacks Sand and Gravel is a confined sand and gravel deposit identified in the YOWN-2006S/D stratigraphic borehole which has the potential to be a third aquifer, but needs to be confirmed during future investigations.

Recommendations for continuing study include:

- Digitization of YWWR well records into a database format would facilitate future mapping efforts or modifications as additional data become available.
- Survey of newly installed YOWN-2006S/D monitoring wells and establishment of a groundwater hydraulic head and groundwater quality monitoring program at those wells.
- While high resolution LiDAR significantly reduces vertical uncertainty in comparison to the Canadian Digital Elevation Model (CDEM), further reduction in spatial uncertainty and errors associated with the well records could be accomplished with a well survey. Well survey data of important stratigraphic wells would increase accuracy in the horizontal (XY) dimension as well as the vertical (Z) dimension, providing additional confidence and stratigraphic control on the interpretation.
- Areas with limited subsurface information are candidate locations where surficial geophysical methods (electric resistivity imaging, electromagnetic methods, or seismic surveys) could be employed to better understand stratigraphy. Ideally, to interpret the geophysical data, the data should be calibrated to the stratigraphy logged from a test borehole or at the very least a competent water well log. Areas of particular interest may include locations proposed for future development or locations outside of Carmacks where limited deep well records and/or subsurface information exists.
- Uncertainties with respect to items such lateral extents of aquifer borders, spatial uncertainty and interconnectivity of permeable units are highlighted both in this report and in the aquifer classification worksheets. Subsurface data continues to be generated that can address gaps in the current conceptual understanding. Consideration should be given to mechanisms whereby the newly generated data that has the potential to improve the current interpretation of the subsurface is integrated and disseminated to the public in a timely manner.
- Assumptions concerning the extrapolation of aquifer boundaries using geological rationale to areas where there is limited to no subsurface lithological data are outlined on the aquifer description sheets. The implications of these assumptions should be considered within the context of territorial aquifer mapping and water allocation strategies. For example, is it more desirable to have a situation where an aquifer is intersected where no aquifer is mapped as a result of conservative delineation or to have a situation where an aquifer is not intersected in an area where it is anticipated to be as a result of hydrostratigraphic extrapolation?
- Additional deep boreholes or wells located away from the YOWN-2006S/D stratigraphic borehole would be useful to confirm the bedrock topography and the presence and lateral

continuity of the Łots'an Aquifer, Carmacks Aquitard, and the inferred Deep Carmacks Sand and Gravel Aquifer as well as to reduce uncertainty in the hydrostratigraphic interpretation. Potential areas for future drilling are presented in Figure 6, below. These areas were selected on the basis that they are all current or future areas for development which are located away from the YOWN-2006S/D borehole for the purposes of stratigraphic correlation.

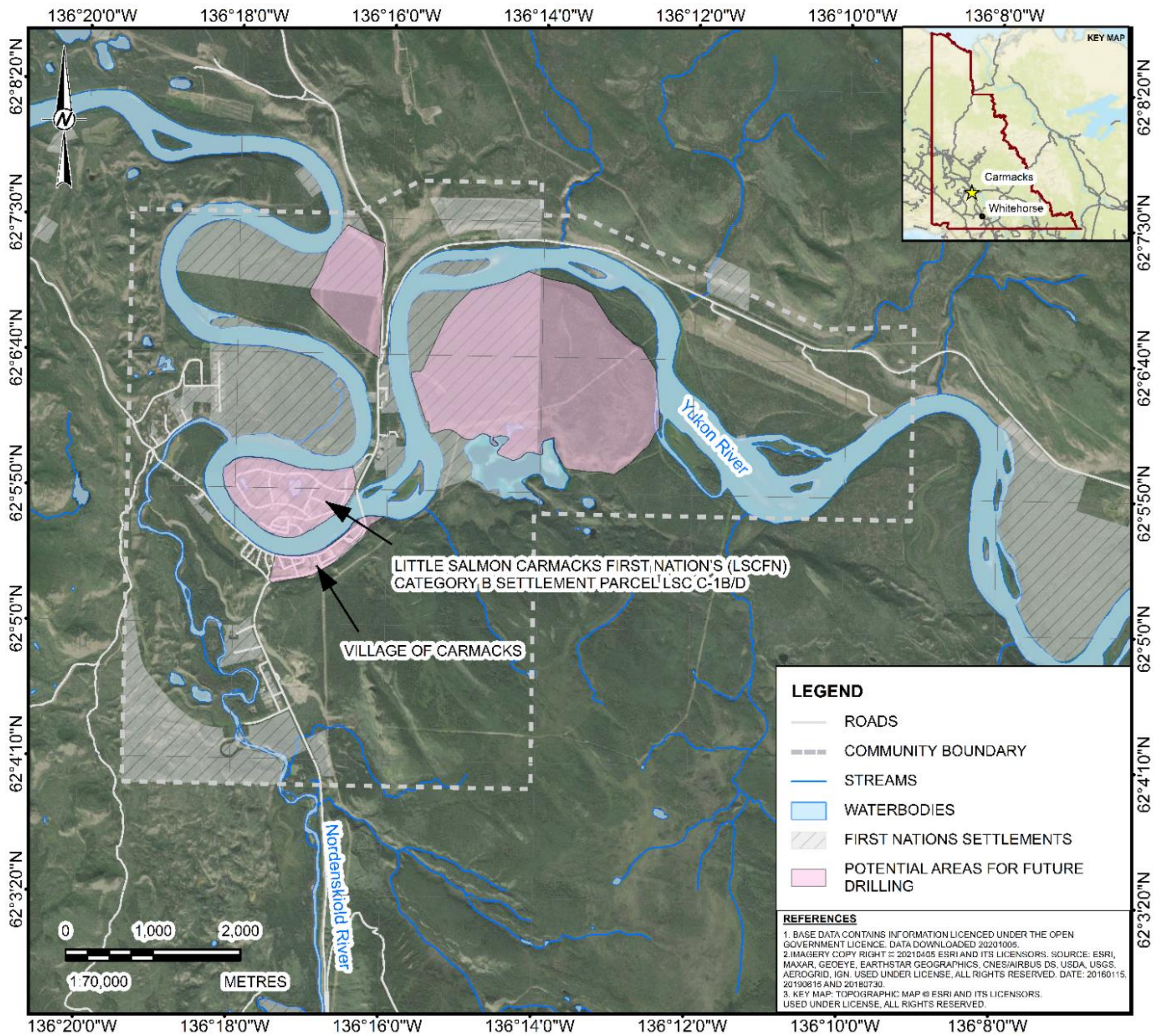

Figure 5: Potential Locations for Future Drilling

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Appendices

Appendix 1. Aquifer Description Sheets

Aquifer Description for Chu Íntthi Aquifer (Aquifer 1)

1. Conceptual Understanding of Hydrostratigraphy

Aquifer Extents

The Chu Íntthi Aquifer is an unconfined sand and gravel aquifer generally located along Tagé Cho (the Yukon River) and Tsâwnjik Tagé (the Nordenskiold River) and associated floodplains throughout the valleys. The aquifer is located in the areas where the rivers have meandered and down cut through the glacial outwash and glaciofluvial materials, leaving glacial terraces. The aquifer extent is generally based on the distribution of the fluvial deposits as delineated in Quaternary mapping by Cronmiller et al. (2020). Outside of the Study Area, the aquifer likely extents upstream and downstream in the valleys based on the geomorphology of the region.

Geologic Formation (Overlying Materials)

The aquifer is generally unconfined and exposed at surface. Some areas may have lower permeability overbank deposits overlying the more permeable fluvial sand and gravel deposits, but the distribution of these finer, lower permeability deposits has not been delineated and is expected to be variable and discontinuous.

Geologic Formation (Aquifer)

The aquifer consists of Holocene aged fluvial sands and gravels and associated overbank deposits. Overbank deposits are assumed to be variably and discontinuously distributed in the valley and have been included in the Chu Íntthi Aquifer.

Vulnerability

High – the aquifer is unconfined, at surface, and hydraulically connected to Tagé Cho. The water levels observed in wells screen in this aquifer are shallow (< 10 m below surface) and the groundwater levels are typically located at similar elevations to the water levels observed in Tagé Cho.

2. Conceptual Understanding of Flow Dynamics

Groundwater Levels and Flow Direction

The depth to water is shallow (< 10 m below surface), ranging from 4 m to 8 m with a geometric mean of 5.2 m. Water levels associated with the Chu Íntthi aquifer are located at a similar elevation to the water level observed in Tagé Cho.

Recharge

Recharge occurs from precipitation and via infiltration from Tagé Cho and Tsâwnjik Tagé.

Potential for Hydraulic Connection

The aquifer is hydraulically connected to the underlying Łots'an Aquifer as well as to Tagé Cho and Tsâwnjik Tagé.

3. Water Management

Additional Information on Water Use and Management

A significant number of the wells in the Carmacks area are inferred to be screened in the Chu Íntthi aquifer, including private wells, small water supply wells and environmental monitoring wells. Well yields range from 45 to 95 L/min (12 to 25 USGPM) with a geomean of 83 L/min (22 USGPM) estimated at time of development. Water quality data was not available for wells screened in this aquifer at the time of the report.

Additional Assessments or Management Actions

A hydrogeological assessment of the Carmacks Solid Waste Facility was conducted in 2003 (EBA, 2003) and additional environmental monitoring wells have been installed at the Facility since the initial assessment (EBA, 2015; EBA, 2004). The majority of the environmental monitoring wells at the Facility are inferred to be screened in the Chu Íntthi aquifer.

4. Aquifer references

Berardinucci, J. and Ronneseth, K., 2002. Guide to Using the BC Aquifer Classification Maps for the Protection and Management of Groundwater. BC Ministry of Water, Land and Air Protection, Water Air and Climate Change Branch, Water Protection Section.

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5. Revision history

Date	Version	Revision Class	Comments	Author
20210319	001	Major	Initial mapping of aquifer	Golder

Aquifer Description for Łots'an Aquifer (Aquifer 2)

1. Conceptual Understanding of Hydrostratigraphy

Aquifer Extents

The Łots'an Aquifer is an unconfined sand aquifer comprised of thick sand deposits located throughout the bedrock valleys in the vicinity of Carmacks. The aquifer is exposed in the glacial terraces lining much of the valley sides in the region and is assumed to extend laterally across the valleys of the Study Area, likely extending upstream and downstream in the valley outside of the Study Area.

Geologic Formation (Overlying Materials)

Where the aquifer is overlain by the Chu Íntthi Aquifer in the valley, the Łots'an Aquifer is overlain by Holocene and modern age fluvial deposits associated with Tagé Cho and Tsâwnjik Tagéand their floodplains. Elsewhere, the aquifer often observed at or near surface, often with a thin layer of overlying eolian deposits.

Geologic Formation (Aquifer)

The aquifer consists of a thick package of clean sands of possible post-glacial eolian, fluvial, or glaciolacustrine origin together with terraced glacial outwash deposits. The YOWN-2006 stratigraphic borehole completed by the YG WRB suggests that the unit in the valley is massive with no apparent structures. The heights of the glaciofluvial terraces, suggest that a one point in time the deposit was upwards of 100 m thick and subsequently eroded and incised by fluvial processes. In the valley bottom, where the aquifer has been overlain by Holocene deposits, the sands are up to 40 m thick.

Vulnerability

High – the aquifer is unconfined, and the water table is typically shallow (< 10 m below surface). The aquifer is near surface or hydraulically connected to the overlying unconfined Chu Íntthi Aquifer and indirectly to Tagé Cho. Some areas of the overlying Chu Íntthi Aquifer are comprised of finer-grained overbank deposits. These lower permeability sediments are variable and discontinuous but may provide some degree of confinement in some locations.

2. Conceptual Understanding of Flow Dynamics

Groundwater levels and flow direction

Groundwater wells are relatively limited in the area, however the groundwater levels for wells inferred to be screened in the aquifer unit are between 4 m and 20 m below ground with an average depth of 10 mbgs. The depth to water is generally greater at well locations that are situated on the terrace deposits, i.e. well collar is at a greater elevation. Regional groundwater flow directions are expected to be towards the valley from the surrounding highlands but may be locally influenced by the stage of Tagé Cho.

Recharge

Recharge occurs from the surrounding highlands and via precipitation in the areas where the aquifer is present at higher elevations and near surface. Locally, infiltration from the overlying Chu Íntthi Aquifer and Tagé Cho to the Łots'an Aquifer may occur depending on the stage of Tagé Cho.

Potential for hydraulic connection

The aquifer is assumed to be hydraulically connected to the overlying Chu Íntthi Aquifer and indirectly to Tagé Cho.

3. Water Management

Additional information on water use and management

Wells screened in Łots'an aquifer are used for private domestic purposes and water supply purposes. Well yield estimates for this aquifer obtained from airlifting during development range from 19 to 150 L/min (5 to 39 USGPM) with a geomean of 75 L/min (20 USGPM) excluding Borehole ID 109010043 which has an estimated yield of 485 L/min (128 USGPM). Water supply well PW05-01 and backup well TW17-01 are inferred to be screened in the Łots'an aquifer. In the Source Water Protection Plan (Morrison Hershfield, 2020), these wells were inferred to be screened in a suspected deep confined aquifer. However, a wider interpretation of other local well records in the area do not show strong evidence of the continuity of the potential confining unit. It is interpreted that the confining unit may represent local variability in the Łots'an Aquifer and that the confining deposit is not contiguous. Water quality testing completed at PW05-1 indicated water quality exceeded the Canadian Drinking Water Quality Guideline for dissolved magnesium with concentrations of 0.17 to 0.22 mg/L.

Additional Assessments or Management Actions

LSCFN's truck fill water supply system is served by Water supply well PW05-01 and backup well TW17-01, which are inferred to be screened in the Łots'an aquifer. This water supply system was included in the Overarching Yukon Source Water Supply and Protection Study – Summary Report (Tetra Tech, 2017). The borehole log and estimated water well capture zone for PW05-01 are on the YWWR. A source water protection plan has been completed for LSCFN's water treatment plant (Morrison Hershfield, 2020).

A supplemental Phase II and Phase III Environmental Site Assessment has been completed for the Carmacks Highway Maintenance Camp (Core 6 Environmental, 2020). The Assessment involved the installation of environmental monitoring wells inferred to be screened in the Łots'an aquifer.

A hydrogeological assessment of the Carmacks Solid Waste Facility was conducted in 2003 (EBA, 2003) and additional environmental monitoring wells have been installed at the Facility since the initial assessment (EBA, 2015; EBA, 2004). Some of the environmental monitoring wells at the Facility are inferred to be screened in the Łots'an aquifer.

4. Aquifer references

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5. Revision history

Date	Version	Revision Class	Comments	Author
20210319	001	Major	Initial mapping of aquifer	Golder

Note: The inferred Deep Carmacks Aquifer has not been definitively mapped due to limited information on its presence and distribution (one borehole). This aquifer description sheet is provided as an interim, working starting point for the potential aquifer if it is confirmed by future drilling investigations.

Inferred Deep Carmacks Aquifer

1. Conceptual Understanding of Hydrostratigraphy

Aquifer Extents

The Deep Carmacks Aquifer is confined sand and gravel aquifer located directly above the bedrock surface in the deeper portions of the bedrock valleys near Carmacks. Although only the YOWN-2006D is known to intersect the sand and gravel deposits associated with the permeable deposits, based on the inferred pre-glacial fluvial deposition, the unit may extend relatively contiguously throughout the valley and constrained by the bedrock valley sidewalls. The extent of the permeable inferred aquifer upstream and downstream of Carmacks and upstream into the Tsâwnjik TagéValley is uncertain as no deep subsurface information is available outside of the Village of Carmacks.

Geologic Formation (Overlying Materials)

The aquifer is directly overlain by the Carmacks Aquitard, a sequence of lower permeability deposits including a layer of dimictic, interbedded silts and sands, and silt that act as an aquitard between the overlying Łots'an Aquifer. The Carmacks Aquitard was observed to be 15 m thick in the YOWN-2006 stratigraphic borehole.

Geologic Formation (Aquifer)

The aquifer is inferred to be comprised of pre-LGM sand and gravel deposits directly overlying the bedrock surface. The aquifer deposits are inferred to be on the order of 10 to 25 m thick with the thickest deposits located in the deepest portion of the valley near Little Salmon Carmacks First Nation's Category B settlement parcel LSC C-1B/D.

Vulnerability

Low – the aquifer is deep (> 50 mbgs) and is confined by an aquitard up to 15 m in thickness.

2. Conceptual Understanding of Flow Dynamics

Groundwater Levels and Flow Direction

Limited data is available for the depth to water for this aquifer. The depth to water at the YOWN-2006D well, installed in the inferred Deep Carmacks Aquifer, was 4.013 m below top of casing in November 2020. A small upward vertical gradient of 0.005 was noted between the YOWN-2006D well and the YOWN-2006S, installed in the Chu Íntthi Aquifer. The valley is assumed to be a groundwater discharge zone, with local groundwater flow directions towards the center of the valley from the surrounding highlands.

Recharge

Recharge is assumed to be predominantly via recharge from the surrounding highlands.

Potential for hydraulic connection

The aquifer is not inferred to be hydraulically connected to a surface body of water or the overlying Middle or Chu Íntthi aquifers.

3. Water Management

Additional information on water use and management

At the time of this report, available water well records do not indicate any water supply wells screened in this aquifer. The YOWN-2006D monitoring well is installed in this aquifer.

Additional Assessments or Management Actions

Additional assessments of this aquifer had not been completed at the time of publication of this report.

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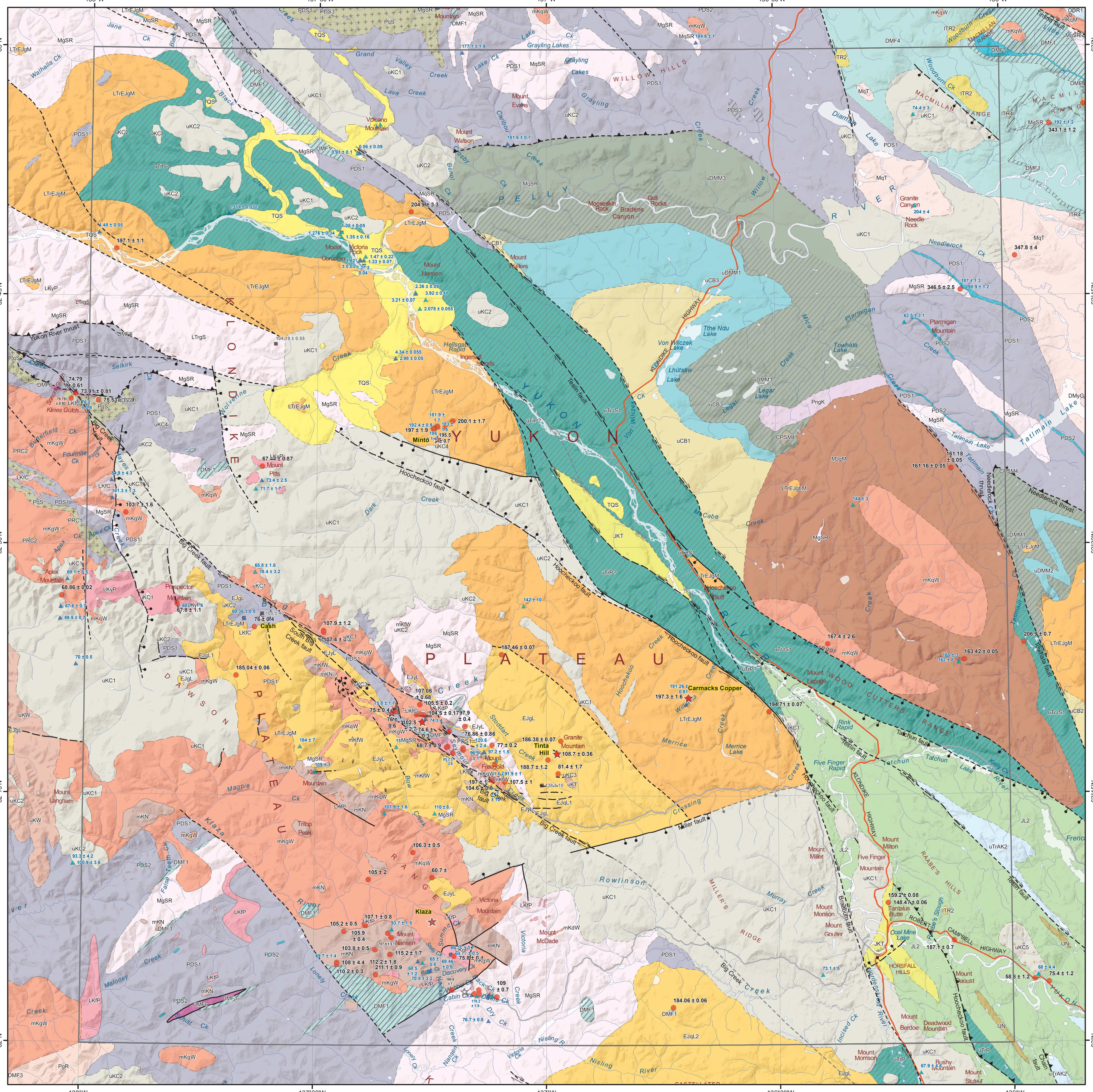
5. Revision history

Date	Version	Revision Class	Comments	Author
20210319	001	Major	Initial identification	Golder

Appendix 2. Geological Mapping

Yukon Geological Survey

Yukon



Note: legend contains geological information for the NTS map sheet and not the surrounding area.

TERTIARY(?) AND

TQS: SELKIRK: columnar jointed, vesicular to massive basalt flows

PALEOCENE TO LOWER EOCENE

PRC1: RHYOLITE CREEK: light grey, green, maroon, purple and black rhyolite and dacite

LOWER TERTIARY, MOSTLY(?) EOCENE

lTR2: ROSS: rhyolite flows, tuff, ash-flow tuff and breccia

LATE CRETACEOUS TO TERTIARY

LKdP: PROSPECTOR MOUNTAIN SUITE: coarsely crystalline gabbro and diorite

LKgP: PROSPECTOR MOUNTAIN SUITE: Hbl-Bt granodiorite, Hbl diorite, quartz diorite

LKyP: PROSPECTOR MOUNTAIN SUITE: syenite

LKfP: PROSPECTOR MOUNTAIN SUITE: quartz-feldspar porphyry

LKqC: CASINO SUITE: quartz monzonite, Bt quartz-rich granite

LKfC: CASINO SUITE: quartz-feldspar porphyry

MID-CRETACEOUS

mKfW: WHITEHORSE SUITE: quartz-feldspar porphyry; feldspar-hornblende porphyry

mKdW: WHITEHORSE SUITE: Hbl diorite, Bt-Hbl quartz diorite

mKgW: WHITEHORSE SUITE: Bt-Hbl granodiorite, Hbl quartz diorite and Hbl diorite

mKqW: WHITEHORSE SUITE: Bt quartz monzonite, Bt granite and leucogranite

mKN: MOUNT NANSEN: massive aphyric or feldspar-phyric andesite to dacite flows

UPPER CRETACEOUS

uKC1: CARMACKS: augite-olivine basalt and breccia

uKC2: CARMACKS: andesite, porphyry

uKC3: CARMACKS: acid vitric crystal tuff, lapilli tuff and welded tuff

uKC4: CARMACKS: sandstone, pebble conglomerate, shale, tuff, and coal

uKC5: CARMACKS: gabbro and monzonite bodies

uKT: TLANSANLIN: basalt, basaltic andesite, Pl and Hbl-phyric andesite, dacite, lapiili tuff

UPPER JURASSIC AND LOWER

JKT: TANTALUS: chert pebble conglomerate and gritty quartz-chert-feldspar sandstone

MID-JURASSIC

MJgM: MCGREGOR SUITE: Hbl-Bt (± Ep) granodiorite and quartz monzodiorite

LOWER AND MIDDLE JURASSIC, HETTANGIAN TO BAJOCIAN

JL2: TANGLEFOOT: arkosic sandstone and minor shale, pebble and boulder conglomerate

LOWER JURASSIC, PLEINSBACHIAN TO TOARCIAN

lJN: NORDENSKIOLD: khaki-green dacite crystal tuff and volcaniclastic sandstone

EARLY JURASSIC

EJgL: LONG LAKE SUITE: massive to weakly foliated Bt-Hbl granodiorite

EJqL2: LONG LAKE SUITE: Bt, Bt-Ms and Bt-Hbl quartz monzonite to granite

EJqL1: LONG LAKE SUITE: Bt, Bt-Ms and Bt-Hbl quartz monzonite to granite

EJyL: LONG LAKE SUITE: coarse to very coarse grained and porphyritic, mesocratic Hbl syenite

LATE TRIASSIC TO EARLY JURASSIC

LTrEJgM: MINTO SUITE: foliated Bt-Hbl granodiorite; Bt-rich screens and gneissic schlieren

LTrEJgbM: MINTO SUITE: Hbl gabbro

LATE TRIASSIC

LTrgS: STIKINE SUITE: coarse-grained, foliated, gabbroic Hbl orthogneiss

UPPER TRIASSIC, CARNIAN TO NORIAN

uTrAK2: HANCOCK: massive to thick-bedded limestone

UPPER TRIASSIC, CARNIAN AND OLDER

uTrP: POVOAS: augite or feldspar-phyric andesitic basalt flows, breccia, tuff, sandstone, argillite

uTrP?: POVOAS: augite or feldspar-phyric andesitic basalt flows, breccia, tuff, sandstone, argillite

UPPER TRIASSIC TO LOWER JURASSIC

uTrJS1: SEMENOF: augite-phyric basalt flow and agglomerate, andesite

MIDDLE TO LATE PERMIAN

PqS: SULPHUR CREEK SUITE: variably foliated, K-feldspar augen granite, metaporphyry

UPPER CARBONIFEROUS, LOWER AND MIDDLE PENNSYLVANIAN

uCB1: BOSWELL: siliceous argillite, siltstone, sandstone, chert conglomerate, volcanic breccia

uCB3: BOSWELL: micritic limestone, bioclastic limestone, marble

PngK: KELLY SUITE: strongly foliated Hbl ± Bt tonalite, Hbl diorite to granodiorite

CARBONIFEROUS TO PERMIAN

CPSM4: SLIDE MOUNTAIN: brown weathering, variably serpentinized ultramafic rocks

MISSISSIPPIAN

MqT: TATLMAIN SUITE: variably foliated to unfolitated, coarse-grained granite

MqSR: SIMPSON RANGE SUITE: foliated metagranite, quartz monzonite and granodiorite; augen granite

MgSR: SIMPSON RANGE SUITE: Hbl-bearing metagranodiorite, metadiorite and metatonalite

DEVONIAN, MISSISSIPPIAN AND(?)

uDMM1: MOOSE: massive and pillow basalt, amphibolite and greenstone

uDMM3: MOOSE: intermediate metavolcanic and metavolcaniclastic rocks

DMF1: FINLAYSON: intermediate to mafic volcanic and volcaniclastic rocks

DMF4: FINLAYSON: light green to grey, fine-grained siliciclastic and metavolcaniclastic rocks

DMF5: FINLAYSON: light grey to white marble, locally crinoidal

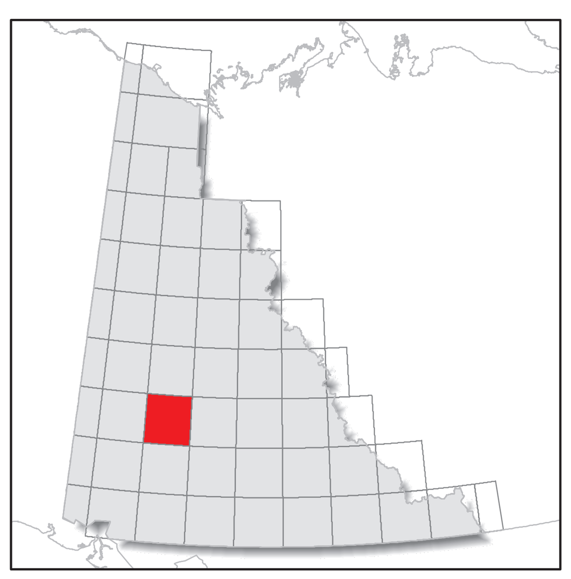
DMF6: FINLAYSON: ultramafic rocks, serpentinite; metagabbro

NEOPROTEROZOIC AND

PDS1: SNOWCAP: quartzite, psammite, pelite and marble; minor greenstone and amphibolite

PDS2: SNOWCAP: light grey to buff weathering marble

PDS3: SNOWCAP: amphibolite, commonly garnet-bearing; greenstone



1:250 000-scale base data produced by CENTRE FOR TOPOGRAPHIC INFORMATION, NATURAL RESOURCES CANADA

30 metre shaded relief from Geomatics Yukon www.geomaticsyukon.ca

BEDROCK GEOLOGY
CARMACKS (115I)
YUKON

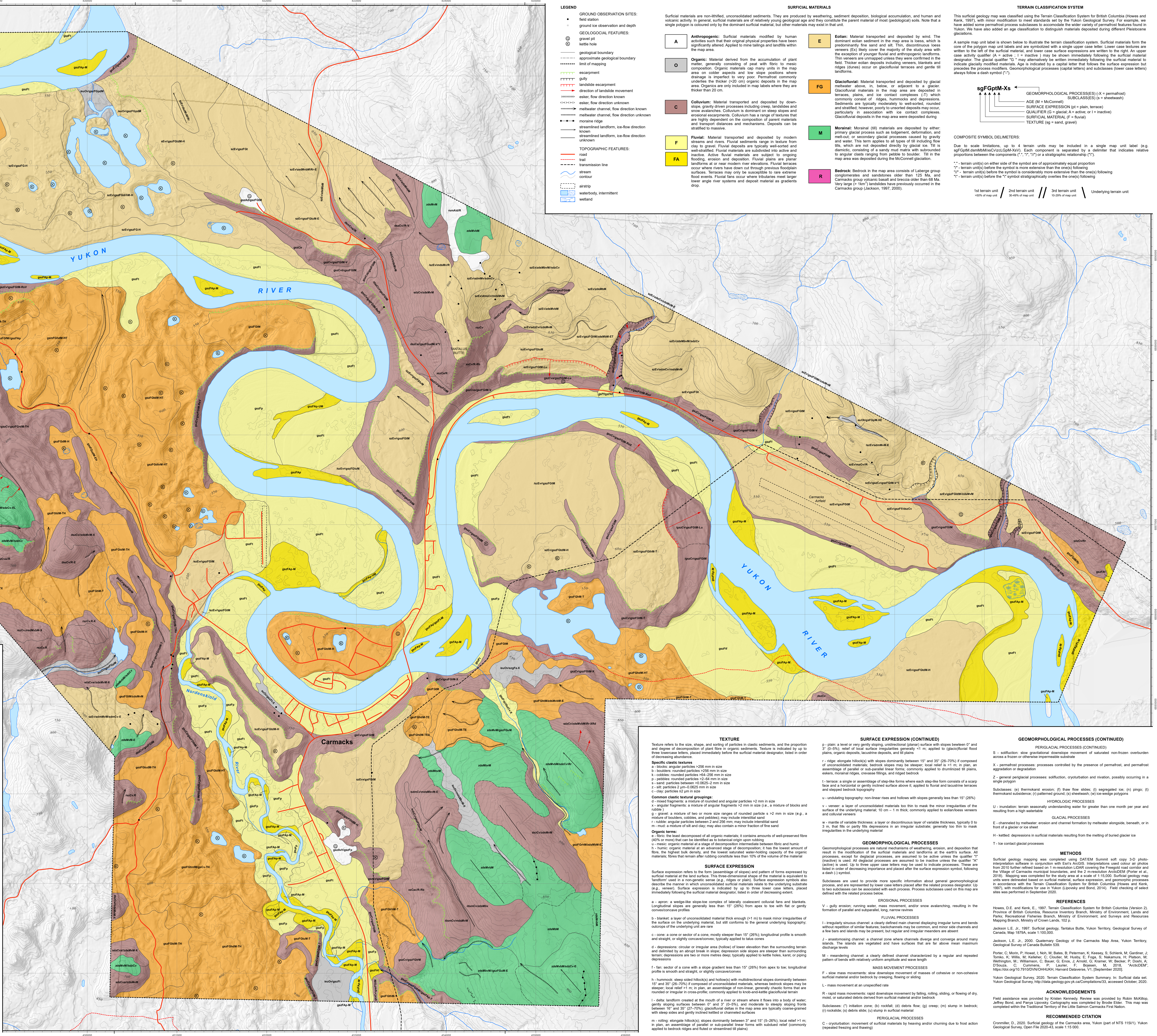
0 5 10 15 20 25
kilometres

These maps contain the most current bedrock geology information in Yukon. All geological data are from the Yukon Geological Survey and available free of charge. Data are from recent mapping, regional compilations and thesis work.

The geological data used to create these maps can be downloaded at http://data.geology.gov.yk.ca/Compilation/3.

These maps are subject to periodic updates. This map was last updated in May 2018.

The Yukon Geological Survey welcomes any revisions or new geological information. Any questions or comments can be directed to geology@gov.yk.ca.



LEGEND

GROUND OBSERVATION SITES:
- field station
- ground ice observation and depth

GEOLOGOCIAL FEATURES:
- gravel pit
- kettle hole
- geological boundary
- approximate geological boundary
- limit of mapping
- escarpment
- gully
- landslide escarpment
- direction of landslide movement
- esker, flow direction known
- esker, flow direction unknown
- meltwater channel, flow direction known
- meltwater channel, flow direction unknown
- moraine ridge
- streamlined landform, ice-flow direction known
- streamlined landform, ice-flow direction unknown

TOPOGRAPHIC FEATURES:
- road
- trail
- transmission line
- stream
- contour
- airstrip
- waterbody, intermittent
- wetland

SURFICIAL MATERIALS

Surficial materials are non-lithified, unconsolidated sediments. They are produced by weathering, sediment deposition, biological accumulation, and human and volcanic activity. In general, surficial materials are of relatively young geological age and they constitute the parent material of most (pedological) soils. Note that a single polygon is coloured only by the dominant surficial material, but other materials may exist in that unit.

A — **Anthropogenic:** Surficial materials modified by human activities such that their original physical properties have been significantly altered. Applied to mine tailings and landfills within the map area.

O — **Organic:** Material derived from the accumulation of plant matter, generally consisting of peat with fibric to mesic composition. Organic materials cap many units in the map area on colder aspects and low slope positions where drainage is imperfect to very poor. Permafrost commonly underlies the thicker (>20 cm) organic deposits in the map area. Organics are only included in map labels where they are thicker than 20 cm.

C — **Colluvium:** Material transported and deposited by down-slope, gravity driven processes including creep, landslides and snow avalanches. Colluvium is dominant on steep slopes and erosional escarpments. Colluvium has a range of textures that are highly dependent on the composition of parent materials and transport distances and mechanisms. Deposits can be stratified to massive.

F / FA — **Fluvial:** Material transported and deposited by modern streams and rivers. Fluvial sediments range in texture from clay to gravel. Fluvial deposits are typically well-sorted and well-stratified. Fluvial materials are subdivided into active and inactive. Active fluvial materials are subject to ongoing flooding, erosion and deposition. Fluvial plains are planar landforms at or near modern river elevations. Fluvial terraces occur where rivers have down cut through previous floodplain surfaces. Terraces may only be susceptible to rare extreme flood events. Fluvial fans occur where tributaries meet larger lower angle river systems and deposit material as gradients drop.

E — **Eolian:** Material transported and deposited by wind. The dominant eolian sediment in the map area is loess, which is predominantly fine sand and silt. Thin, discontinuous loess veneers (Ex) likely cover the majority of the study area with the exception of younger fluvial and anthropogenic landforms. Thin veneers are unmapped unless they were confirmed in the field. Thicker eolian deposits including veneers, blankets and ridges (dunes) occur on glaciofluvial terraces and gentle till landforms.

FG — **Glaciofluvial:** Material transported and deposited by glacial meltwater above, in, below, or adjacent to a glacier. Glaciofluvial materials in the map area are deposited in terraces, plains, and ice contact complexes (-T) which commonly consist of ridges, hummocks and depressions. Sediments are typically moderately to well-sorted, rounded and stratified; however, poorly to unsorted deposits may occur, particularly in association with ice contact complexes. Glaciofluvial deposits in the map area were deposited during

M — **Morainal:** Morainal (till) materials are deposited by either: primary glacial process such as lodgement, deformation, and melt-out; or secondary glacial processes caused by gravity and water. This term applies to all types of till including flow tills, which are not deposited directly by glacial ice. Till is diamictic, consisting of a sandy mud matrix with subrounded to angular clasts ranging from pebble to boulder. Till in the map area was deposited during the McConnell glaciation.

R — **Bedrock:** Bedrock in the map area consists of Laberge group conglomerates and sandstones older than 125 Ma, and Carmacks group volcanic basalt and breccia older than 68 Ma. Very large (> 1km^2) landslides have previously occurred in the Carmacks group (Jackson, 1997, 2000).

TERRAIN CLASSIFICATION SYSTEM

This surficial geology map was classified using the Terrain Classification System for British Columbia (Howes and Kenk, 1997), with minor modification to meet standards set by the Yukon Geological Survey. For example, we have added some permafrost process subclasses to accomodate the wider variety of permafrost features found in Yukon. We have also added an age classification to distinguish materials deposited during different Pleistocene glaciations.

A sample map unit label is shown below to illustrate the terrain classification system. Surficial materials form the core of the polygon map unit labels and are symbolized with a single upper case letter. Lower case textures are written to the left of the surficial material, and lower case surface expressions are written to the right. An upper case activity qualifier (A = active ; I = inactive) may be shown immediately following the surficial material designator. The glacial qualifier "G " may alternatively be written immediately following the surficial material to indicate glacially modified materials. Age is indicated by a capital letter that follows the surface expression but precedes the process modifiers. Geomorphological processes (capital letters) and subclasses (lower case letters) always follow a dash symbol ("-").

sgFGptM-Xs
- GEOMORPHOLOGICAL PROCESS(ES) (-X = permafrost)
- SUBCLASS(ES) (s = sheetwash)
- AGE (M = McConnell)
- SURFACE EXPRESSION (pt = plain, terrace)
- QUALIFIER (G = glacial; A = active; or I = inactive)
- SURFICIAL MATERIAL (F = fluvial)
- TEXTURE (sg = sand, gravel)

COMPOSITE SYMBOL DELIMETERS:

Due to scale limitations, up to 4 terrain units may be included in a single map unit label (e.g. sgFGptM.dsmMbM/xsCv\zcLGpM-XsV). Each component is separated by a delimiter that indicates relative proportions between the components (".", "/", "//") or a stratigraphic relationship ("\").

"." - terrain unit(s) on either side of the symbol are of approximately equal proportion
"/" - terrain unit(s) before the symbol is more extensive than the one(s) following
"//" - terrain unit(s) before the symbol is considerably more extensive than the one(s) following
"\" - terrain unit(s) before the "\" symbol stratigraphically overlies the one(s) following

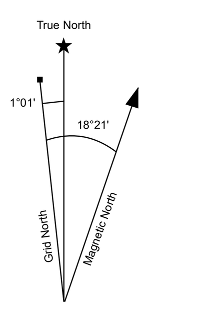
1st terrain unit >50% of map unit	/	2nd terrain unit 30-49% of map unit	//	3rd terrain unit 10-29% of map unit	\	Underlying terrain unit

Open File 2020-43

Surficial Geology, Carmacks area, Yukon
Parts of NTS 115I/1
1:15 000 scale

by
D.C. Cronmiller

0 0.5 1 1.5 2
kilometres

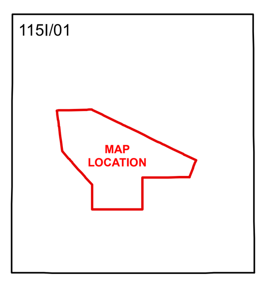


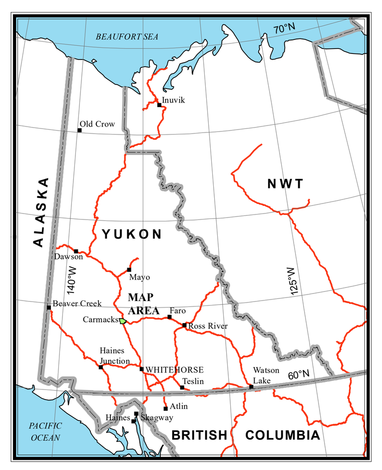
Use diagram only to obtain numerical values
APPROXIMATE MEAN DECLINATION NOVEMBER 2020
FOR CENTRE OF MAP

ONE THOUSAND METRE GRID
Universal Transverse Mercator Projection
North American Datum 1983
Zone 8

CONTOUR INTERVAL 10 METRES
Elevations in metres above Mean Sea Level

November 2020





Any revisions or additional geological information known to the user would be welcomed by the Yukon Geological Survey.

Paper copies of this map may be obtained from Yukon Geological Survey, Room 102 - 300 Main St., Whitehorse, Yukon, Y1A 2B5. E-mail: geology@gov.yk.ca.

A digital PDF (Portable Document Format) file of this map may be downloaded free of charge from the Yukon Geological Survey website: http://data.geology.gov.yk.ca

Yukon
Palmer™

TEXTURE

Texture refers to the size, shape, and sorting of particles in clastic sediments, and the proportion and degree of decomposition of plant fibre in organic sediments. Texture is indicated by up to three lowercase letters, placed immediately before the surficial material designator, listed in order of decreasing abundance.

Specific clastic textures
a - blocks: angular particles >256 mm in size
b - boulders: rounded particles >256 mm in size
k - cobbles: rounded particles >64–256 mm in size
p - pebbles: rounded particles >2–64 mm in size
s - sand: particles between >0.0625–2 mm in size
z - silt: particles 2 µm–0.0625 mm in size
c - clay: particles ≤2 µm in size

Common clastic textural groupings:
d - mixed fragments: a mixture of rounded and angular particles >2 mm in size
x - angular fragments: a mixture of angular fragments >2 mm in size (*i.e.*, a mixture of blocks and rubble)
g - gravel: a mixture of two or more size ranges of rounded particle s >2 mm in size (*e.g.*, a mixture of boulders, cobbles, and pebbles); may include interstitial sand
r - rubble: angular particles between 2 and 256 mm; may include interstitial sand
m - mud: a mixture of silt and clay; may also contain a minor fraction of fine sand

Organic terms:
e - fibric: the least decomposed of all organic materials; it contains amounts of well-preserved fibre (40% or more) that can be identified as to botanical origin upon rubbing
u - mesic: organic material at a stage of decomposition intermediate between fibric and humic
h - humic: organic material at an advanced stage of decomposition; it has the lowest amount of fibre, the highest bulk density, and the lowest saturated water-holding capacity of the organic materials; fibres that remain after rubbing constitute less than 10% of the volume of the material

SURFACE EXPRESSION

Surface expression refers to the form (assemblage of slopes) and pattern of forms expressed by surficial material at the land surface. This three-dimensional shape of the material is equivalent to 'landform' used in a non-genetic sense (*e.g.*, ridges or plain). Surface expression symbols also describe the manner in which unconsolidated surficial materials relate to the underlying substrate (*e.g.*, veneer). Surface expression is indicated by up to three lower case letters, placed immediately following the surficial material designator, listed in order of decreasing extent.

a - apron: a wedge-like slope-toe complex of laterally coalescent colluvial fans and blankets. Longitudinal slopes are generally less than 15° (26%) from apex to toe with flat or gently convex/concave profiles

b - blanket: a layer of unconsolidated material thick enough (>1 m) to mask minor irregularities of the surface on the underlying material, but still conforms to the general underlying topography; outcrops of the underlying unit are rare

c - cone: a cone or sector of a cone, mostly steeper than 15° (26%); longitudinal profile is smooth and straight, or slightly concave/convex; typically applied to talus cones

d - depressions: circular or irregular area (hollow) of lower elevation than the surrounding terrain and delimited by an abrupt break in slope; depression side slopes are steeper than surrounding terrain; depressions are two or more metres deep; typically applied to kettle holes, karst, or piping depressions

f - fan: sector of a cone with a slope gradient less than 15° (26%) from apex to toe; longitudinal profile is smooth and straight, or slightly concave/convex

h - hummock: steep sided hillock(s) and hollow(s) with multidirectional slopes dominantly between 15° and 35° (26–70%) if composed of unconsolidated materials, whereas bedrock slopes may be steeper; local relief >1 m; in plan, an assemblage of non-linear, generally chaotic forms that are rounded or irregular in cross-profile; commonly applied to knob-and-kettle glaciofluvial terrain

l - delta: landform created at the mouth of a river or stream where it flows into a body of water; gently sloping surfaces between 0° and 3° (0–5%), and moderate to steeply sloping fronts between 16° and 35° (27–70%); glaciofluvial deltas in the map area are typically coarse-grained with steep sides and gently inclined kettled or channeled surfaces

m - rolling: elongate hillock(s); slopes dominantly between 3° and 15° (5–26%); local relief >1 m; in plan, an assemblage of parallel or sub-parallel linear forms with subdued relief (commonly applied to bedrock ridges and fluted or streamlined till plains)

SURFACE EXPRESSION (CONTINUED)

p - plain: a level or very gently sloping, unidirectional (planar) surface with slopes bewteen 0° and 3° (0–5%); relief of local surface irregularities generally <1 m; applied to (glacio)fluvial flood plains, organic deposits, lacustrine deposits, and till plains

r - ridge: elongate hillock(s) with slopes dominantly between 15° and 35° (26–70%) if composed of unconsolidated materials; bedrock slopes may be steeper; local relief is >1 m; in plan, an assemblage of parallel or sub-parallel linear forms; commonly applied to drumlinized till plains, eskers, morainal ridges, crevasse fillings, and ridged bedrock

t - terrace: a single or assemblage of step-like forms where each step-like form consists of a scarp face and a horizontal or gently inclined surface above it; applied to fluvial and lacustrine terraces and stepped bedrock topography

u - undulating topography: non-linear rises and hollows with slopes generally less than 15° (26%)

v - veneer: a layer of unconsolidated materials too thin to mask the minor irregularities of the surface of the underlying material; 10 cm – 1 m thick; commonly applied to eolian/loess veneers and colluvial veneers

w - mantle of variable thickness: a layer or discontinuous layer of variable thickness, typically 0 to 3 m, that fills or partly fills depressions in an irregular substrate; generally too thin to mask irregularities in the underlying material

GEOMORPHOLOGICAL PROCESSES

Geomorphological processes are natural mechanisms of weathering, erosion, and deposition that result in the modification of the surficial materials and landforms at the earth's surface. All processes, except for deglacial processes, are assumed to be active unless the qualifier "I" (inactive) is used. All deglacial processes are assumed to be inactive unless the qualifier "A" (active) is used. Up to three upper case letters may be used to indicate processes. These are listed in order of decreasing importance and placed after the surface expression symbol, following a dash (-) symbol.

Subclasses are used to provide more specific information about general geomorphological process, and are represented by lower case letters placed after the related process designator. Up to two subclasses can be associated with each process. Process subclasses used on this map are defined with the related process below.

EROSIONAL PROCESSES

V - gully erosion; running water, mass movement, and/or snow avalanching, resulting in the formation of parallel and subparallel, long, narrow ravines

FLUVIAL PROCESSES

I - irregularly sinuous channel: a clearly defined main channel displaying irregular turns and bends without repetition of similar features; backchannels may be common, and minor side channels and a few bars and islands may be present, but regular and irregular meanders are absent

J - anastomosing channel: a channel zone where channels diverge and converge around many islands. The islands are vegetated and have surfaces that are far above mean maximum discharge levels

M - meandering channel: a clearly defined channel characterized by a regular and repeated pattern of bends with relatively uniform amplitude and wave length

MASS MOVEMENT PROCESSES

F - slow mass movements: slow downslope movement of masses of cohesive or non-cohesive surficial material and/or bedrock by creeping, flowing or sliding

L - mass movement at an unspecified rate

R - rapid mass movements: rapid downslope movement by falling, rolling, sliding, or flowing of dry, moist, or saturated debris derived from surficial material and/or bedrock

Subclasses: (") initiation zone; (b) rockfall; (d) debris flow; (g) creep; (m) slump in bedrock; (r) rockslide; (s) debris slide; (u) slump in surficial material

PERIGLACIAL PROCESSES

C - cryoturbation: movement of surficial materials by heaving and/or churning due to frost action (repeated freezing and thawing)

GEOMORPHOLOGICAL PROCESSES (CONTINUED)

PERIGLACIAL PROCESSES (CONTINUED)

S - solifluction: slow gravitational downslope movement of saturated non-frozen overburden across a frozen or otherwise impermeable substrate

X - permafrost processes: processes controlled by the presence of permafrost, and permafrost aggradation or degradation

Z - general periglacial processes: solifluction, cryoturbation and nivation, possibly occurring in a single polygon

Subclasses: (e) thermokarst erosion; (f) thaw flow slides; (l) segregated ice; (n) pingo; (t) thermokarst subsidence; (r) patterned ground; (s) sheetwash; (w) ice-wedge polygons

HYDROLOGIC PROCESSES

U - inundation: terrain seasonally understanding water for greater than one month per year and resulting from a high watertable

GLACIAL PROCESSES

E - channeled by meltwater: erosion and channel formation by meltwater alongside, beneath, or in front of a glacier or ice sheet

H - kettled: depressions in surficial materials resulting from the melting of buried glacier ice

T - Ice contact glacial processes

METHODS

Surficial geology mapping was completed using DAT/EM Summit soft copy 3-D photo-interpretation software in conjunction with Esri's ArcGIS. Interpretations used colour air photos from 2010 further refined based on 1 m-resolution LiDAR covering the Freegold road corridor and the Village of Carmacks municipal boundaries, and the 2 m-resolution ArcticDEM (Porter et al., 2018). Mapping was completed for the study area at a scale of 1:15,000. Surficial geology map units were delineated based on surficial material, surface expression, and geomorphic processes in accordance with the Terrain Classification System for British Columbia (Howes and Kenk, 1997), with modifications for use in Yukon (Lipovsky and Bond, 2014). Field checking of select sites was performed in September 2020.

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ACKNOWLEDGEMENTS

Field assistance was provided by Kristen Kennedy. Review was provided by Robin McKillop, Jeffrey Bond, and Panya Lipovsky. Cartography was completed by Brodie Elder. This map was completed within the Traditional Territory of the Little Salmon Carmacks First Nation.

RECOMMENDED CITATION

Cronmiller, D., 2020. Surficial geology of the Carmacks area, Yukon (part of NTS 115I/1). Yukon Geological Survey, Open File 2020-43, scale 1:15 000.

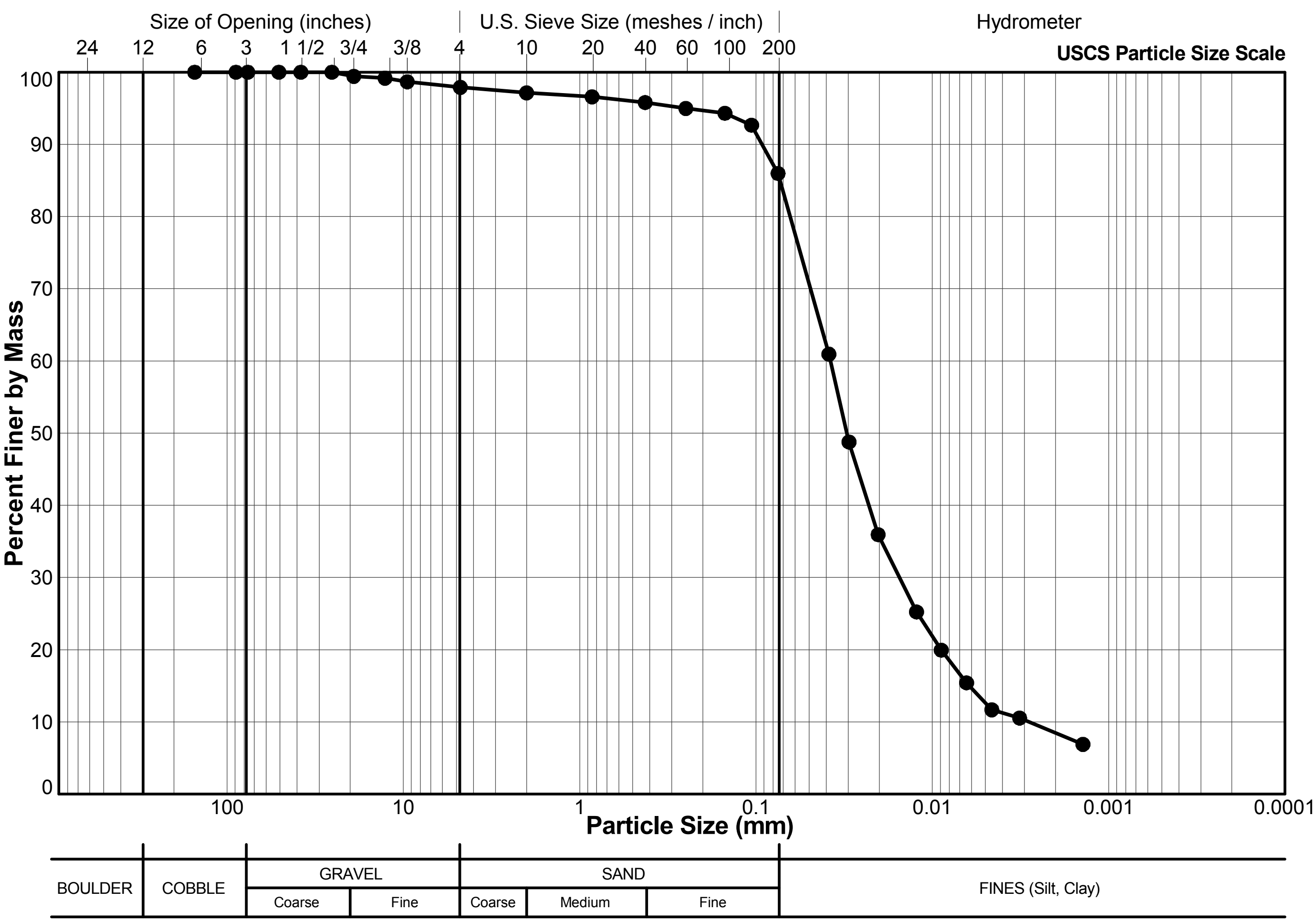
Appendix 3. Grainsize Analyses

SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Government of Yukon, Water Resources Branch
Project: Carmacks Aquifer Mapping
Location: Carmacks, Yukon
Project No.: 20148488 **Phase:** 3000

Sample Location: YOWN Carmacks
Sample No.: 15568-02
Depth (m): 162.00
Lab Schedule No.: B21-046



Legend

Sieve Size (USS)	Sieve Size (mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
2"	50.8		100.0
1 1/2"	38.1		100.0
1"	25.4		100.0
3/4"	19.1		99.4
1/2"	12.7		99.2
3/8"	9.5		98.7
#4 US MESH	4.75		97.9
#10 US MESH	2		97.1
#20 US MESH	0.85		96.6
#40 US MESH	0.425		95.8
#60 US MESH	0.25		95.0
#100 US MESH	0.15		94.3
#140 US MESH	0.106		92.7
#200 US MESH	0.075		86.0
		0.0386	60.9
		0.0297	48.8
		0.0203	35.9
		0.0123	25.2
		0.0089	19.9
		0.0064	15.4
		0.0046	11.7
		0.0032	10.5
		0.0014	6.9

KS/PE	2/11/2021	SJ	2/19/2021
Tech	Date	Checked	Date

National IM Server:GINT_GAL_NATIONALIM Unique Project ID:2704 Output Form:_LAB_PARTICLE SIZE (W/ GRADATIONS) 2018 SJohn 19/2/21

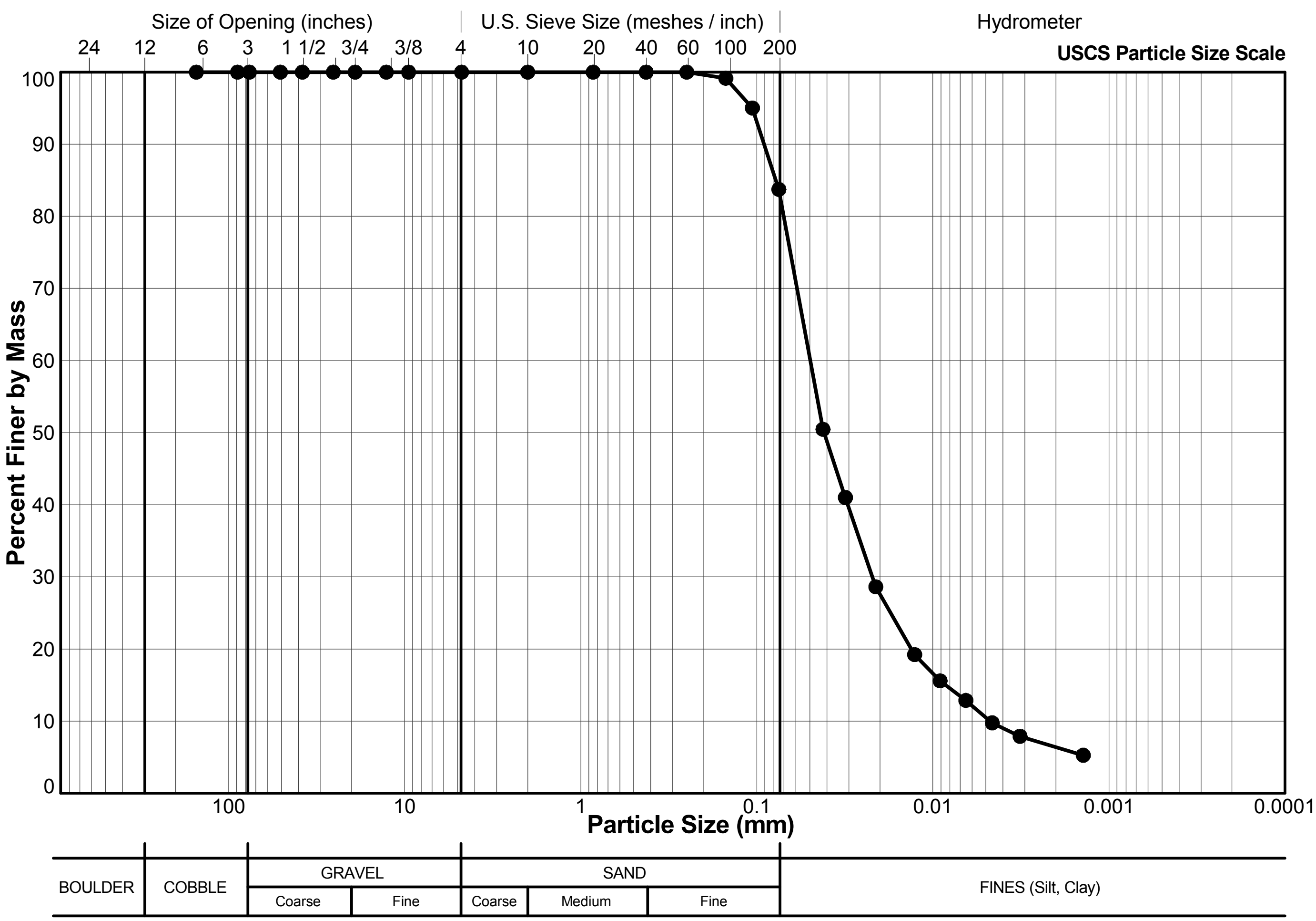
Golder Associates Ltd.
300 - 3811 North Fraser Way, Burnaby, BC V5J 5J2 CANADA
Tel: +1 (604) 412 6899 Fax: +1 (604) 412 6816 www.golder.com

SUMMARY OF PARTICLE SIZE DISTRIBUTION

ASTM D 422

Client: Government of Yukon, Water Resources Branch
Project: Carmacks Aquifer Mapping
Location: Carmacks, Yukon
Project No.: 20148488 **Phase:** 3000

Sample Location: YOWN Carmacks
Sample No.: 15568-01
Depth (m): 167.00
Lab Schedule No.: B21-046



Legend

Sieve Size (USS)	Sieve Size (mm)	Particle Size (mm)	Percent Passing
6"	152.4		100.0
3.5"	88.9		100.0
3"	76.2		100.0
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3/8"	9.5		100.0
#4 US MESH	4.75		100.0
#10 US MESH	2		100.0
#20 US MESH	0.85		100.0
#40 US MESH	0.425		100.0
#60 US MESH	0.25		100.0
#100 US MESH	0.15		99.1
#140 US MESH	0.106		95.0
#200 US MESH	0.075		83.7
		0.0421	50.5
		0.0314	41.0
		0.0211	28.6
		0.0127	19.2
		0.0091	15.6
		0.0065	12.9
		0.0046	9.8
		0.0032	7.9
		0.0014	5.3

KS/PE	2/11/2021	SJ	2/19/2021
Tech	Date	Checked	Date

National IM Server:GINT_GAL_NATIONALIM Unique Project ID:2704 Output Form:_LAB_PARTICLE SIZE (W/ GRADATIONS) 2018 SJohn 19/2/21

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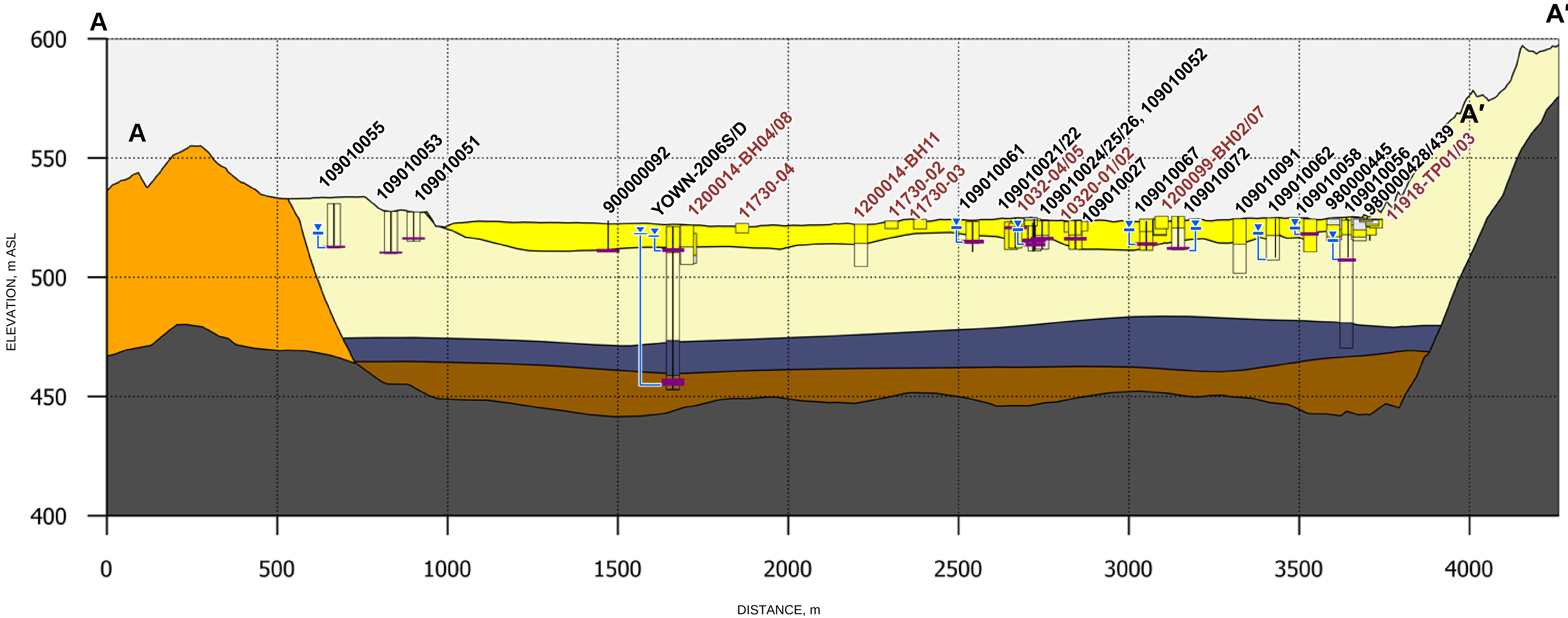
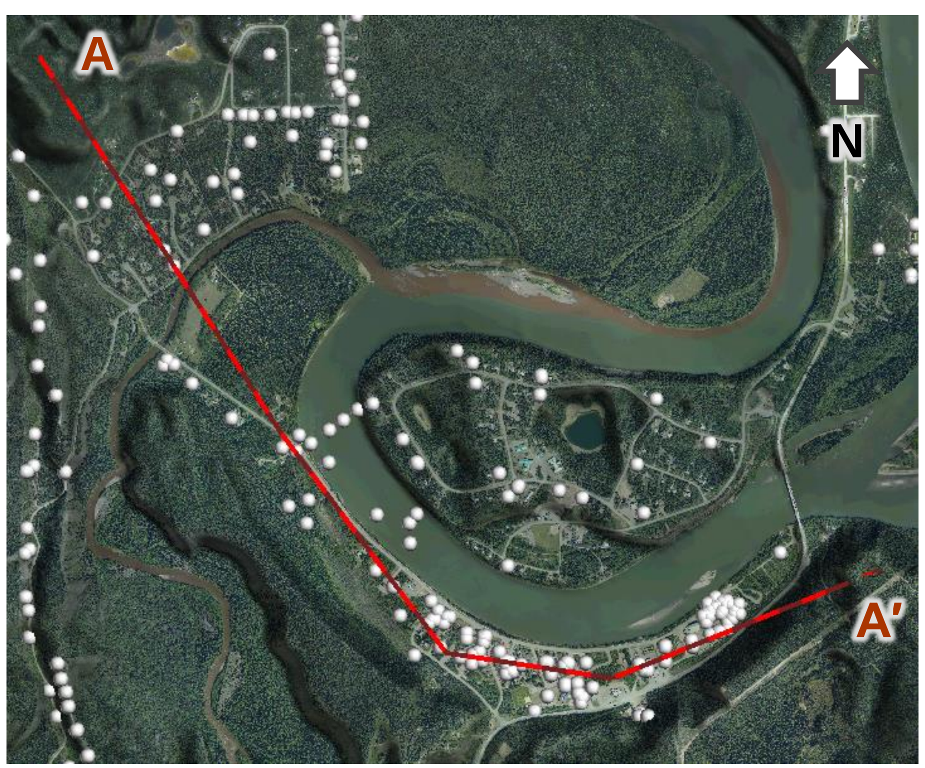
Appendix 4. Hydrostratigraphic Cross Sections





LEGEND

- BEDROCK
- CARMACKS AQUITARD
- ŁOTS'AN AQUIFER
- McCONNELL ICE STAGNATION COMPLEX
- CHU ÍNTTHI AQUIFER
- INFERRED DEEP CARMACKS SAND AND GRAVEL AQUIFER
- ANTHROPOGENIC MATERIALS
- SCREENED INTERVAL
- GROUNDWATER HEAD (AT TIME OF DRILLING)
- 1200-BH01 BOREHOLE/TEST PIT LOCATION
- 10901000 WATER WELL LOCATION

NOTE(S)
VERTICAL EXAGGERATION 5:1

REFERENCE
WELL COMPLETION DATA, AND WATER LEVELS OBTAINED FROM YUKON WELL REGISTRY
BOREHOLE LOGS OBTAINED FROM YUKON HIGHWAYS AND CIVIL WORKS

CLIENT
YUKON GOVERNMENT
WATER RESOURCE BRANCH

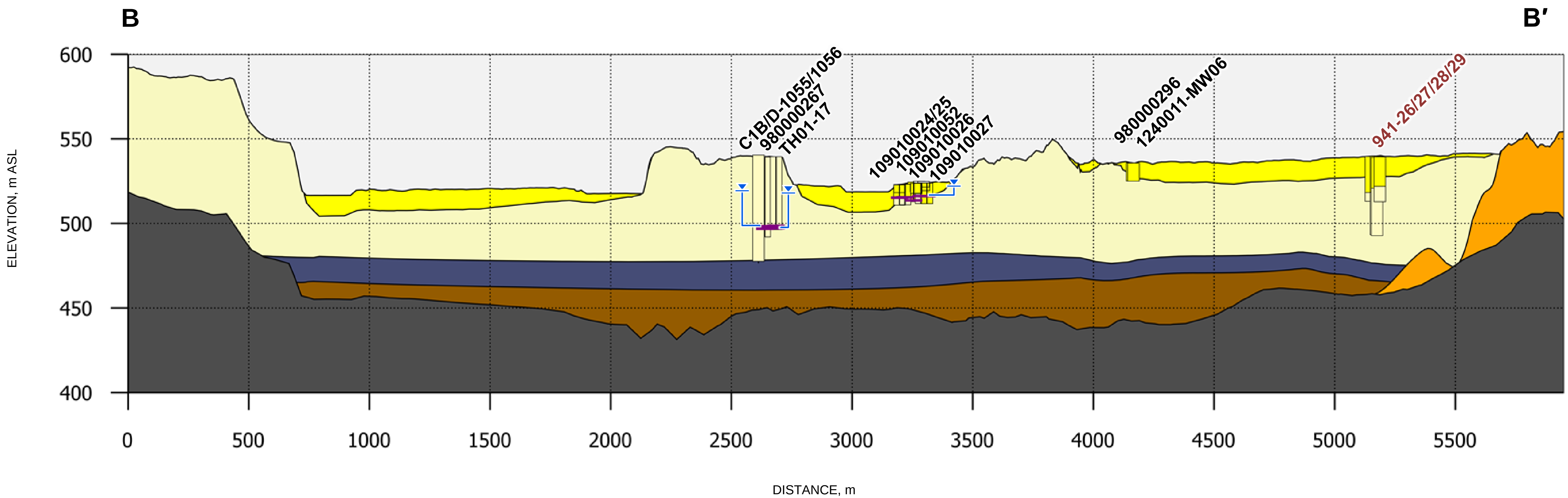
CONSULTANT

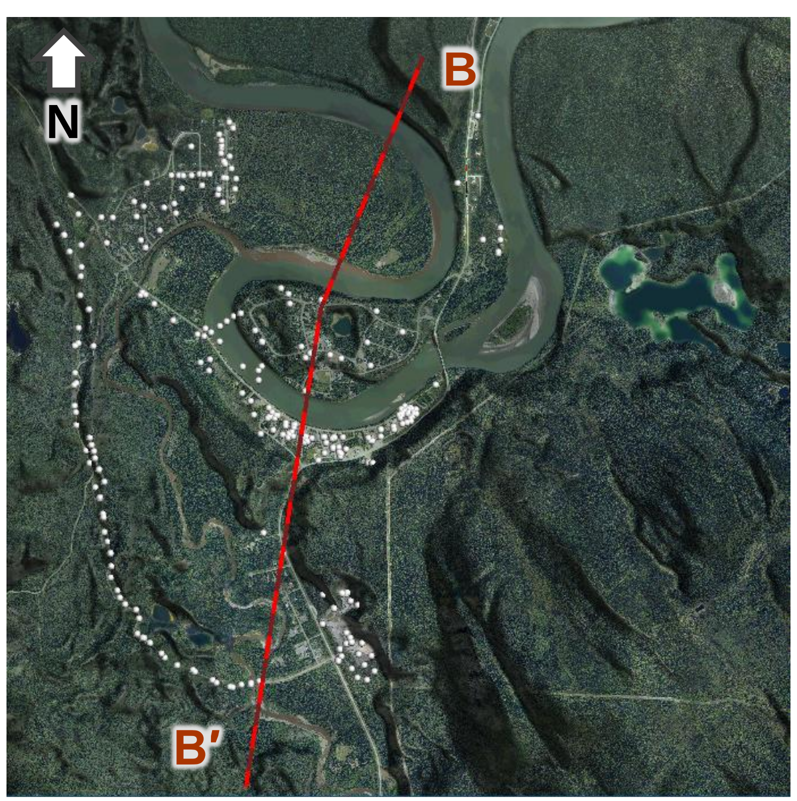
YYYY-MM-DD	2021-07-26
PREPARED	RKS
DESIGN	RKS
REVIEW	NGG
APPROVED	TR

PROJECT
CARMACKS AQUIFER MAPPING

TITLE
HYDROSTRATIGRAPHIC CROSS-SECTION A-A' LOOKING NORTH

PROJECT No.	PHASE	Rev.	FIGURE
20148488	2000	1	4-1





LEGEND

BEDROCK	INFERRED DEEP CARMACKS SAND AND GRAVEL AQUIFER
CARMACKS AQUITARD	ANTHROPOGENIC MATERIALS
ŁOTS'AN AQUIFER	SCREENED INTERVAL
McCONNELL ICE STAGNATION COMPLEX	GROUNDWATER HEAD (AT TIME OF DRILLING)
CHU ÍNTTHI AQUIFER	1200-BH01 BOREHOLE/TEST PIT LOCATION
	10901000 WATER WELL LOCATION

NOTE(S)
VERTICAL EXAGGERATION 5:1

REFERENCE
WELL COMPLETION DATA, AND WATER LEVELS OBTAINED FROM YUKON WELL REGISTRY
BOREHOLE LOGS OBTAINED FROM YUKON HIGHWAYS AND CIVIL WORKS

CLIENT
YUKON GOVERNMENT
WATER RESOURCE BRANCH

CONSULTANT

YYYY-MM-DD	2021-07-26
PREPARED	RKS
DESIGN	RKS
REVIEW	NGG
APPROVED	TR

PROJECT
CARMACKS AQUIFER MAPPING

TITLE
HYDROSTRATIGRAPHIC CROSS-SECTION B-B' LOOKING EAST

PROJECT No.	PHASE	Rev.	FIGURE
20148488	2000	1	4-2

Appendix 5. Aquifer Summary

Aquifer Summary Table

#	Name	Lithostratigraphic Unit	Descriptive Location	Vulnerability	Subtype	Material	Quality Concerns	Size (km^2)	Productivity	Demand	Artesian Conditions Noted	Observation Wells
1	Chu Íntthi Aquifer	Holocene silty sand and gravels	Tagé Cho (Yukon River) and Tsâwnjik Tagé Valleys in the vicinity of the Village of Carmacks	High	1a	Sand and gravel	None	21.0	Moderate	Low	None documented	YOWN-2006S
2	Łots'an Aquifer	Post and paraglacial fluvial, glaciolacustrine and/or eolian; glacial outwash	Tagé Cho and Tsâwnjik Tagé Valleys in the vicinity of the Village of Carmacks	High	4a	Sand, Sand and Gravel	None	39.6	Moderate/ High	Low	None documented	YOWN-1925

The aquifer classifications in the above table are based on the BC aquifer classification system is outlined in the Guide to Using the BC Aquifer Classification Maps for the Protection and Management of Groundwater, issued by the BC Ministry of Water Land and Air Protection, June 2002 (Bernardinucci and Ronneseth, 2002).

Aquifer subtypes are described in Wei, M., D. Allen, A. Kohut, S. Grasby, K. Ronneseth and B. Turner, 2009. Understanding the Types of Aquifers in the Canadian Cordillera Hydrogeological Region to Better Manage and Protect Groundwater. Streamline Watershed Management Bulletin Vol. 13, No.1, Fall 2009.

- 4a: Unconfined glacio-fluvial outwash or ice contact sand and gravel aquifers generally formed near or at the end of the last period of glaciation.
- 1a: Predominantly unconfined fluvial or glacio-fluvial sand and gravel Aquifers found along major rivers of higher stream order with the potential to be hydraulically influenced by the river.

Appendix 6. Aquifer Shapefiles

Shapefiles for the Chu Íntthi Aquifer, Łots'an Aquifer and Inferred Deep Carmacks Aquifers are provided digitally in an attached folder.

Appendix 7. Aquifer Well-Correlation

For Aquifer-Well correlation sheet of the Carmacks area, reference the attached csv file entitled "Aquifer_Well_Correlation_Carmacks_10June2021.csv".

Appendix 8. Interpreted Hydrostratigraphy

For a summary of the hydrostratigraphic contacts for each well, reference the attached csv file entitled “Interpreted_Hydrostratigraphic_Units_Carmacks_10June2021.csv”.