



Peel River Basin Transboundary Surficial Aquifer Assessment

Government of Northwest Territories and Government of Yukon

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Executive Summary

The protection and management of transboundary groundwater resources within the Peel River basin and Western Mackenzie Delta requires an understanding of the types, distribution, and characteristics of surficial aquifers within this region, yet little groundwater-related information is available. This report, completed by SLR in association with Aurora Geosciences on behalf of the Government of the Northwest Territories in collaboration with the Government of Yukon, presents the results of a desktop-based transboundary assessment of potential surficial aquifers and their vulnerability to existing land use activities within the Yukon and NWT portions of the Peel River basin. Our work broadly aligns with similar assessments completed by Levson et al. (2018) for the portion of the Liard River basin in British Columbia, by Palmer (2020) for the portion of the Liard River basin in the Yukon and NWT, and by SLR (2025) for the Stewart River watershed in the Yukon.

Systematic compilation and review of available mapping of bedrock and surficial geology, permafrost, topography, land cover, land use activities, and limited site-specific subsurface information (e.g., water wells, seismic shotholes, and geotechnical boreholes) revealed incomplete regional-scale data coverage and key knowledge gaps that constrain basin-wide characterization. Areas of surficial aquifer potential were delineated primarily using available 1:10,000- to 1:250,000-scale surficial geology mapping and classified according to Wei et al. (2009), with targeted Topographic Position Index analysis applied to improve representation of potential fluvial surficial aquifers where mapping coverage was limited to coarse national-scale products. Basin-wide results indicate that potential surficial aquifer areas are dominated by Type 1 (fluvial valley-bottom; 17% of the study area) surficial aquifers, with smaller contributions from Type 3 (fan; 1%) and Type 4a (glaciofluvial; 2%) surficial aquifers, while most of the study area is characterized as low surficial aquifer potential.

A preliminary basin-wide water budget was completed by partitioning precipitation surplus into runoff and infiltration using a GIS-based model that integrates surficial materials, land cover, slope, and permafrost reduction factors (75% reduction in continuous permafrost and 60% in discontinuous permafrost) to better understand the relative distribution of groundwater recharge across the landscape. The median basin-wide precipitation and evapotranspiration values used in the water balance (415 mm/yr and 193 mm/yr, respectively) imply a median annual surplus of approximately 213 mm/yr available for runoff and recharge. Modelled recharge was evaluated against baseflow estimates derived from nine Water Survey of Canada hydrometric stations using winter-flow and recursive-filter approaches. The resulting water-budget outputs are useful for screening-level identification of recharge and discharge patterns at the basin scale while recognizing uncertainty associated with permafrost controls and a lack of field verification.

An assessment of the vulnerability of groundwater to land use activities was completed through an adaptation of the approach used by Levson et al. (2018) and refined by Palmer (2020) and SLR (2025). The vulnerability of groundwater quality was assessed for each of the three subbasins in the study area through spatial association of the distribution of land use activities, categorized and weighted according to three levels of disturbance, with areas of surficial aquifer potential and average recharge potential. The vulnerability of groundwater quantity within each subbasin was assessed simply based on its well density. Normalized indices used to rank each subbasin identified the Lower Peel and Western Mackenzie Delta as the most vulnerable to surface disturbance subbasin-wide. Whereas the Upper Peel subbasin is most vulnerable to surface disturbance in areas of surficial aquifer potential and recharge.

Recommendations for future groundwater-related research are provided based on the basin-wide results of this assessment, the implications of data gaps and modelling uncertainty



(including permafrost controls), and the value of incorporating traditional knowledge and climate-change considerations to better inform long-term management of transboundary groundwater resources.



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- Appendix B List of Compiled Land Use Activity Mapping and Associated Disturbance Footprints**
- Appendix C Principal Spatial Data Sources**
- Appendix D Processed Spatial Dataset**



Acronyms and Abbreviations

bgs	below ground surface
BFI	baseflow index
CDEM	Canadian Digital Elevation Model
DEM	digital elevation model
ET	evapotranspiration
GIN	Groundwater Information Network
GIS	geographic information system
GNWT	Government of the Northwest Territories
GSC	Geological Survey of Canada
km	kilometres
km ²	square kilometres
OROGO	Office of the Regulator of Oil and Gas Operations
MAD	mean annual discharge
MAP	mean annual precipitation
m	metres
m ²	square metres
m ³ /yr	cubic metres per year
m asl	metres above sea level
mm/yr	millimetres pre year
MOE	Ontario Ministry of the Environment
MOEE	Ontario Ministry of the Environment and Energy
MRDEM	medium resolution digital elevation model
MRBB	Mackenzie River Basin Board
NRCan	Natural Resources Canada
NTGS	Northwest Territories Geological Survey
NWT	Northwest Territories
P	precipitation
R	rainfall
RO	runoff
TPI	Topographic Position Index
WSC	Water Survey of Canada
YG	Government of Yukon
YGS	Yukon Geological Survey



YOWN	Yukon Well Observation Network
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1.0 Introduction

SLR Consulting (Canada) Ltd. (SLR), in association with Aurora Geosciences Limited, is pleased to provide the Government of the Northwest Territories (GNWT) in collaboration with the Government of Yukon (YG) the results of our transboundary surficial aquifer assessment of the Yukon and Northwest Territories (NWT) portions of the Peel River basin. This project follows from, and broadly aligns with, similar assessments completed by Levson et al. (2018) for the portion of the Liard River basin in British Columbia, by Palmer (2020) for the portion of the Liard River basin in the Yukon and NWT, and by SLR (2025) for the Stewart River watershed in the Yukon. We present the results of our desktop-based assessment of potential surficial aquifers and their vulnerabilities to different land use activities within the Peel River basin based on compilation, synthesis and analysis of existing geological, topographic, permafrost and limited hydrogeological information. Our key findings will ultimately help inform decision-making pertaining to the protection and management of transboundary groundwater resources by the GNWT and YG.

Following provision of important introductory background information (Section 1.0), we outline the methods followed through all key phases of the project (Section 2.0). Results of the data compilation, review, analysis and interpretation are provided in Section 3.0. Key findings and recommendations for follow-up research are discussed in Section 4.0. Section 5.0 highlights overarching conclusions. Appendix A includes a 3-page plain language information summary and Appendix B presents a list of compiled land-use activity mapping. A complete set of digital spatial data (GIS) files generated as part of this project has been provided separately via web-link.

1.1 Objectives

Through initial discussions with the GNWT and YG, three principal objectives of the project within the Peel River basin were identified:

1. Infer and delineate potential surficial aquifer areas;
2. Characterize surficial aquifer conditions, groundwater recharge and discharge areas, and surface water-groundwater interactions, where possible; and
3. Identify knowledge gaps as a basis for prioritizing future surficial aquifer mapping and research.

Additionally, SLR developed a preliminary water budget for the Peel River basin to better understand water movement and help quantify groundwater recharge potential using a simplified water partitioning methodology. The results of this analysis help quantify groundwater recharge in areas that may support groundwater-influenced natural features or have water supply potential.

1.2 Basic Premises and Limitations

This surficial aquifer assessment is premised on the understanding that the general distribution and characterization of potential surficial aquifers can be meaningfully inferred based on compilation and interpretation of available geological, topographic, permafrost and limited hydrogeological information. A comprehensive literature search and review completed following project commencement revealed incomplete regional-scale surficial geology mapping coverage and limited availability of subsurface and hydrogeological information. Basin-wide mapping of permafrost is modelled and largely unverified through field investigations. As such, the accuracy



and precision of analyses and associated interpretations must be considered in the context of the limitations of the source information. Where more than one spatial dataset of a particular type is available, preference was given to the higher-resolution (more detailed, larger scale) source. This avoided unnecessary information loss that would otherwise have occurred if a more spatially consistent product was produced through a simplification process. Characterization of potential surficial aquifers was necessarily based on extrapolation and inference from limited borehole data without any record of groundwater level.

The project focuses on baseline characterization of potential surficial aquifer areas and the potential vulnerability of groundwater to surface land use activities. Only brief mention is made of deep bedrock aquifers, for context, as their limited interaction with surface (especially where beneath continuous permafrost) and inherent water quality (e.g. saline) give them a comparably low likelihood for impacts from surface activities. Surficial aquifers utilized for potable water and that predominantly support stream baseflow and natural features are generally shallow and reflective of surficial geological conditions. No consideration is given to uncertain or speculative land use projections; the most up-to-date readily available information on current land use activities (e.g. road networks) was used.

The relevance of traditional knowledge to managing and protecting groundwater resources is well appreciated. Although beyond the scope of this study, incorporating traditional knowledge would valuably inform understanding of surficial aquifer potential, traditional water uses, and surface water and groundwater resources in particular need of protection.

1.3 Study Area

The study area encompasses the Peel River basin, which drains into the Mackenzie River and ultimately into the Beaufort Sea, and the Western Mackenzie Delta spanning approximately 90,000 km² (Figure 1-1). The Peel River basin extends from its headwaters in the Ogilvie and Selwyn Mountains of the Yukon to its confluence with the Mackenzie River near Fort McPherson, NWT. The Western Mackenzie Delta stretches roughly 200 km north-south and 50-80 km east-west, forming a vast alluvial plain punctuated by lakes, wetlands, and sinuous channels (Burn 2010).

The study area is split into three major subbasins, the Upper Peel, Central Peel and Lower Peel and Western Mackenzie Delta, and spans portions of the Taiga Cordillera and Taiga Plains ecozones (Meikle & Waterreus 2008). Elevations range from 0 m above sea level (asl) at the mouth of the delta to 2,682 m asl in the Bonnet Plume Range in the Central Peel subbasin. The mountainous regions are dominated by boreal forest and alpine tundra, while the delta and plateau regions feature extensive wetlands, sedge meadows, and shrub tundra (Marshall et al. 1999, Meikle & Waterreus 2008). The physiography includes rugged terrain, braided rivers, and permafrost-related landforms such as pingos, ice-wedge polygons, and retrogressive thaw slumps, particularly in the delta and adjacent uplands (Kokelj et al. 2009, Burn 2010).

The climate is subarctic to low Arctic, characterized by long, cold winters and short, cool summers (Marshall et al. 1999, Meikle & Waterreus 2008). The mean monthly air temperature in the Fort McPherson region of the Peel River basin ranges from approximately -27°C in January to 15°C in July, with a mean annual temperature of approximately -7°C (Environment and Climate Change Canada 2025). The average annual precipitation is approximately 294 mm, of which approximately 155 mm falls as rain, with the remainder coming from snowfall (Environment and Climate Change Canada 2025). The region is underlain by extensive discontinuous to continuous permafrost (Heginbottom et al. 1995) with ground ice content ranging from negligible to very high (O'Neill et al. 2022), impacting permeability and thaw



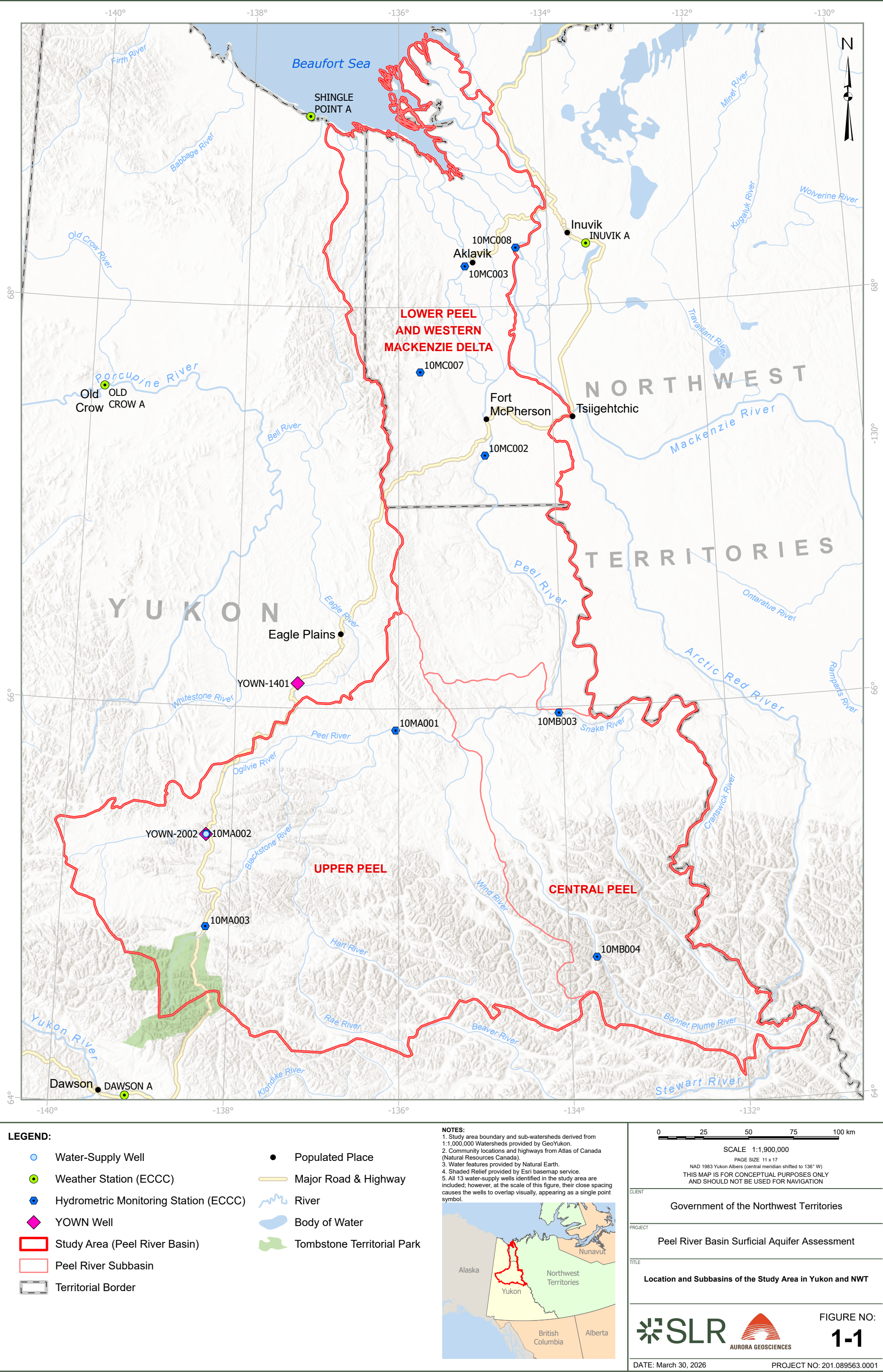
sensitivity of the permafrost. Climate change has led to permafrost thaw, increased streamflow variability, and warmer water temperatures, with implications for hydrology and ecosystem health (Mackenzie River Basin Board (MRBB) 2021).

Human settlement is sparse, with Aklavik and Fort McPherson being the only permanent communities in the Peel River basin and Western Mackenzie Delta. The region overlaps with the traditional territories of several Indigenous groups, including the Tetlit Gwich'in, Na-Cho Nyak Dun, Tr'ondëk Hwëch'in, and Vuntut Gwitch'in, whose cultural and subsistence practices are closely tied to the land and water systems (Parlee et al. 2020).

Table 1-1. Basic Characteristics of the Three Subbasins in the Study Area

Subbasin	Area (km²)	Lowest Elevation (m asl)	Highest Elevation (m asl)
Upper Peel	37,523	201	2,387
Central Peel	21,198	90	2,682
Lower Peel and Western Mackenzie Delta	31,691	0	1,689





2.0 Methods

SLR achieved the objectives stated above (Section 1.1) through the completion of five main phases of desktop-based work, each of which is described in the following subsections. The project was approached in a way that broadly aligns with similar assessments by Levson et al. (2018) for the portion of the Liard River basin in British Columbia, by Palmer (2020) for the portion of the Liard River basin in the Yukon and NWT, and by SLR (2025) for the Stewart River watershed in the Yukon.

2.1 Data Compilation and Review

A systematic and comprehensive search for information pertinent to understanding the distribution, types and characteristics of surficial aquifers in the study area was completed following project commencement. Publications containing groundwater-related information, such as bedrock and surficial geology mapping, biophysical maps, seismic shot hole drill logs, water well records, and information on current groundwater uses, were compiled and reviewed. Representatives from the GNWT and YG reviewed the initial data compilation and shared additional information of direct or indirect relevance. Recent mapping of ground ice (O'Neill et al. 2022) was compared with nationwide mapping of permafrost zones by Heginbottom et al. (1995) and Brown et al. (2002).

Key information on land use activities, such as agricultural, mining and forestry activities (e.g. cut lines, wells, drillholes, facilities); transportation facilities and networks (e.g. roads, highways, airstrips); and community infrastructure (e.g. townsites, transmission lines), was compiled in a geographic information system (GIS) format. Systematic interpretation of aerial photography or satellite imagery as a means of identifying any additional activities not already represented by existing spatial data layers or specific sites highlighted by the GNWT or YG was beyond the scope of this study.

2.2 Mapping of Surficial Aquifer Potential

2.2.1 Delineation

Areas with potential surficial aquifers were delineated based primarily on the pre-existing compilations of 1:50,000- to 1:250,000-scale surficial geology mapping available within each territory (NWT: Côté et al. 2013, Yukon: Yukon Geological Survey (YGS) 2023) and 1:10,000- to 1:30,000-scale surficial geology mapping of Aklavik (Palmer 2023a) and Fort McPherson (Palmer 2023b) in the NWT¹. The compilation for each territory and the NWT community mapping was combined into a single dataset (geodatabase) for analysis purposes. Each of the numerous, unique surficial geology map units (polygons) in the Yukon and NWT datasets, which are at least attributed according to surficial material (e.g. fluvial) and surface expression (e.g. plain), was classified either with “Low Surficial Aquifer Potential” to represent a poor aquifer (or an aquitard) or according to one of the six main types of aquifers defined for the Canadian Cordillera Hydrogeologic Region by Wei et al. (2009) (Table 2-1; Figure 2-1). Classification of surficial aquifer potential was primarily based on the type (e.g. glaciofluvial, till), relative thickness (surface expression) and texture (as defined, calibrated through review of subsurface

¹ The community-scale surficial geology mapping by Palmer (2023a,b) has not yet been updated based on recent field checks by the NTGS, but a preliminary review of observations suggests refinements will have little effect on overall outcomes of this regional-scale study.



logs, or inferred based on an understanding of material geneses) of surficial material. Thickness was not calculated numerically; instead, relative thickness was inferred from mapped surface-expression terms (e.g., veneer vs blanket vs terrace/raised deposits) using standard surficial/terrain mapping conventions (Howes and Kenk 1997, Deblonde et al. 2024) and applied qualitatively to distinguish thin units from thicker valley-fill or terrace deposits. Only secondary consideration was given to the potential depth to the groundwater table (below which material is saturated), potential thickness and lateral extent of the water-bearing material, and ease with which groundwater could be withdrawn.

Table 2-1. Summary of Aquifer Classification from Wei et al. (2009)

Type	Hydrologic Connections with Surface Water
1. Unconfined aquifers of fluvial^a origin along river valley bottoms	
a. Aquifers along higher-order rivers	Common
b. Aquifers along moderate-order rivers	Common
c. Aquifers along lower-order rivers	-
2. Unconfined deltaic aquifers	
	Common
3. Unconfined fluvial, colluvial fan aquifers	
	Common in aquifers adjacent to surface water
4. Aquifers of glacial or pre-glacial origin	
a. Unconfined glaciofluvial aquifers	Common in aquifers adjacent to surface water
b. Confined glacial or pre-glacial aquifers	-
c. Confined glaciomarine aquifers	Limited
5. Sedimentary rock aquifers	
a. Fractured sedimentary rock aquifers	Limited
b. Karstic aquifers ^b	Unknown, but possible
6. Crystalline rock aquifers	
a. Flat-lying volcanic flow aquifers	Limited
b. Fractured igneous intrusive, metamorphic, volcanic or metavolcanics aquifers	Limited

^a Type 1 (modern fluvial floodplains & terraces) aquifers excluded landforms of glaciofluvial origin, otherwise included by Wei et al. (2009), due to overlap with Type 4a (unconfined glaciofluvial) aquifers at the scale of this study.

^b The hydrologic connection of karstic aquifers in permafrost is generally unknown or presumed.

High-permeability surficial materials comprising sand or coarser-grained sediment, such as fluvial² plains and glaciofluvial landforms, were assumed to have high surficial aquifer potential. This may overestimate surficial aquifer potential in some glaciofluvial landforms that form topographic highs (e.g. eskers), which are well-drained and may be unsaturated beyond their base, and in areas of alluvium in continuous permafrost (as acknowledged further at the end of this subsection). Glaciolacustrine deposits were interpreted as having low surficial aquifer

² The term “fluvial,” as opposed to “alluvial,” is used throughout this report for simplicity and consistency with most mapping.



potential, at least in comparison to glaciofluvial deposits, considering their generalized descriptions of available surficial geology mapping (e.g. YGS 2023). Tills in the region have relatively low permeabilities and are generally considered to be aquitards. Areas mapped as organic material were assumed to have low surficial aquifer potential, despite having relatively high near-surface permeability based on their composition, for three main reasons: (i) organics are commonly underlain by low-permeability sediments (even if unmapped); (ii) organics are more likely to contain permafrost, making them an aquitard, even in the zone of discontinuous permafrost; and (iii) organics were universally assumed by Levson et al. (2018) to be permafrost-controlled aquitards even in a more southern (warmer) study area. It is important to acknowledge that even unconsolidated material or bedrock with low surficial aquifer potential can generally accept groundwater recharge and provide a groundwater discharge function. While these units would not be targets for water supply and would have a lower vulnerability to disturbance, they still provide an important function as part of the overall water balance within the study area.

Mapped veneers (i.e. thinner than about 1 or 2 m) were not treated as regionally mappable surficial aquifers because they are commonly discontinuous. At the basin scale they are better represented as modifying near-surface infiltration rather than forming laterally persistent water-supply units. Surficial aquifer-type classification is based on the underlying mapped material to avoid over-representing thin, discontinuous units as aquifers. Surficial aquifer potential in areas of exposed or veneered bedrock was classified based on inference from bedrock formations and lithologies, considering the type and typical properties of bedrock (e.g. Freeze and Cherry 1979) and reference to limited subsurface water records.

For the purposes of this basin-wide study, consideration was only given to primary materials in the cases where the presence of a secondary material (~10-50% areal extent) was noted in the label of a map unit. Where a secondary material is listed in a map-unit label, its spatial distribution and exact proportion within the polygon are not resolved in the existing mapping. Re-interpreting polygons to delineate secondary-material subareas (or estimating their true areal extent) was beyond the scope of this basin-wide study, so the analysis was limited to consideration of only the primary material for consistency and repeatability across the study area. As a result, surficial aquifer potential associated with secondary materials may be underrepresented in map units where the secondary material is the more permeable/aquifer-forming component. This introduces a conservative bias where more permeable material occurs as a secondary component within large polygons.



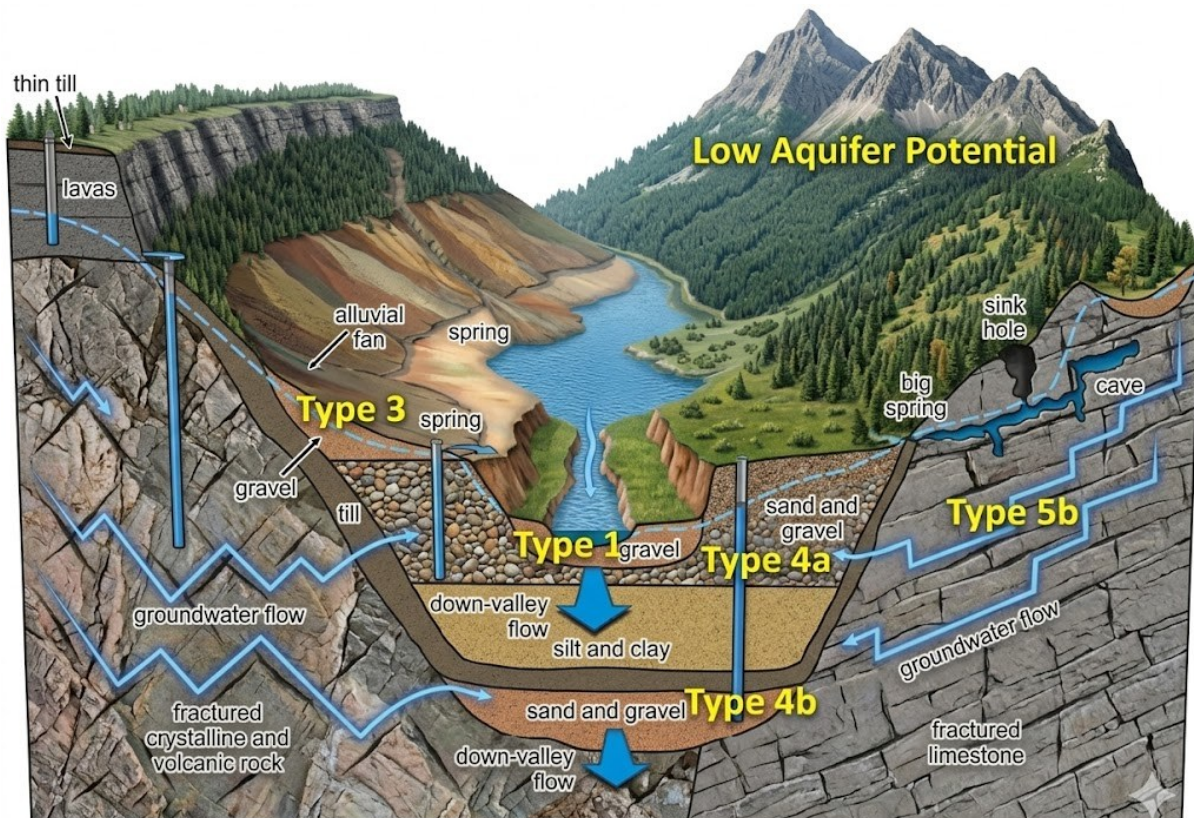


Figure 2-1. Schematic cross-sectional representation of main types of aquifers in valley settings (adapted from Wei et al., 2009; from the GSC). The five types of aquifers with potential occurrences in the study area are identified with yellow text labels, along with an example of steep colluvial and bedrock terrain with low surficial aquifer potential.

Potential surficial aquifer areas could not be reasonably identified based on available 1:5,000,000-scale surficial geology mapping, in the data gap areas encompassing the southern half of the Central Peel subbasin, portions of the west-central and east-central Upper Peel subbasin and a small portion of the west-central Lower Peel and Western Mackenzie Delta subbasin (Figure 1-1), because the national-scale mapping provides no representation of fluvial deposits (apart from the Mackenzie Delta itself) and only very approximate representation of a few glaciofluvial deposits. Therefore, an attempt was made to improve representation of potential surficial aquifer areas through an analysis involving generation of a series of Topographic Position Index (TPI) values (Jenness 2006) using the TPI tool in SAGA GIS. The TPI is a scale-dependent index that compares the elevation of a cell in a digital elevation model (DEM) to the mean elevation of a specified neighbourhood around that cell. It provides a means of classifying areas of a landscape into one of ten topographic landform categories (i.e. streams, midslope drainages, upland drainages, U-shaped valleys, plains, open slopes, upper slopes, local ridges, midslope ridges, high ridges) based on relative relief. Potential fluvial surficial aquifer areas, beyond those identified through association with mapped surficial geology, were inferred from their association with ranges of TPI values and particular landform categories using a 10 m-resolution version of the ArcticDEM (Porter et al. 2023). The inference was calibrated using two 'training areas' of similar topography, Type 1 (2,283 km²) and Type 3



(1,932 km²), situated immediately adjacent to the 18,340 km² TPI-analysis data-gap area. Through comparison to surficial geology mapping in areas of overlap, TPI values within “U-shaped valleys” and “plains” landforms were determined to be the best predictors of Type 1 (modern fluvial floodplains & terraces) surficial aquifers, and values within “midslope drainages” and “upland drainages” landforms³ were determined to be the best predictors of Type 3 (modern fluvial fans and colluvial fans/cones) surficial aquifers. Inference of the potential distribution of Type 4a (glaciofluvial) or Type 4b (confined glaciofluvial) aquifers based on TPI analysis was deemed inappropriate due to complexities in glacial and deglacial histories that correlate poorly with (topographic) landforms alone.

The distribution and extent (continuity) of permafrost affects surficial aquifer potential by locally barring infiltration and groundwater flow. Materials considered to have surficial aquifer potential in permafrost-free regions may function more like aquitards where frozen. An explanation of how permafrost was incorporated into the basin-wide estimation of groundwater recharge is provided in Section 2.3.

2.2.2 Characterization

Limited subsurface information was available in the study area, mainly in association with seismic shotholes in the Lower Peel and Western Mackenzie Delta subbasin and with water wells and geotechnical boreholes in the Upper Peel subbasin along the Dempster Highway. Seismic shothole, water well and geotechnical borehole logs, where available, were used to help characterize the main types of aquifers. Subsurface conditions were also necessarily inferred based on knowledge of Quaternary history and stratigraphy, correlated with available surficial geology mapping, given the sparsity of actual subsurface information.

2.3 Preliminary Water Budget

A meaningful understanding of where current or proposed land use activities are most likely to affect groundwater quantity and quality cannot be gained without consideration of the relative amount and distribution of groundwater recharge contributions across the landscape. Some areas without the properties of an aquifer (e.g. till plains) still provide important groundwater recharge and discharge functions, especially where driven by low-relief and depressed terrain, so they should not be screened out as was done by Levson et al. (2018). As such, a preliminary water budget was developed for the entire study area to improve the representation and quantification of groundwater recharge areas within and beyond areas of mapped surficial aquifer potential (Section 2.2.1).

2.3.1 Water Balance

In its most basic sense, a water budget is used to describe the movement of water in a basin. The total precipitation (P) accounts for the water that falls both as rain and as snow and constitutes the total amount of water available for hydrological processes such as stream flow or groundwater recharge. A water budget also considers the amount of water that is returned to the atmosphere by both evaporation and plant transpiration in the combined process called evapotranspiration (ET). The amount of water held as soil moisture can vary seasonally, especially in areas that undergo freeze-thaw cycles, and should be accounted for in a water

³ The landform terminology used here follows SAGA’s default TPI classification and is intended as a standardized terrain binning approach for regional analysis. These categories do not necessarily correspond one-to-one with geomorphological landforms mapped in the field.



balance calculation. The surface water flow component of the water balance can be represented by the volume of runoff (RO), whereas the groundwater component can be represented by the volume of recharge (R). Over a large area (e.g. basin scale) and a long timescale (sufficient to represent stable conditions in a system), the change in storage components for groundwater, surface water, and soil moisture are considered to be in equilibrium and can be assumed to be zero.

With the above assumptions and limitations in mind, a simplified water budget equation can be expressed as follows:

$$P = RO + R + ET$$

where:

P = Precipitation (mm/yr)

RO = Surface Runoff (mm/yr)

R = Groundwater Recharge (mm/yr)

ET = Evapotranspiration (mm/yr)

Within a large drainage basin, precipitation rates can be spatially and temporally variable. Therefore, it is important to obtain precipitation estimates from multiple points within a basin that have been averaged over a long period of time. Long-term mean annual precipitation (MAP) data from the 1961 – 1990 Canadian climate normals were obtained as a continuous gridded layer (210 x 133 m) from the University of British Columbia ClimateNA_MAP interactive platform (ClimateNA_Map) which provides scale-free climate data through a combination of bilinear interpolation and elevation adjustments (Wang et al, 2016). The median precipitation across the Peel River basin using this continuous layer is 415 mm/yr, noting that average annual precipitation is calculated to range from 1036 mm/yr in the mountainous areas in the south of the basin to just 179 mm/yr in the north of the basin near the Mackenzie River Delta.

The publicly available ClimateNA_MAP 1961–1990 continuous precipitation layer was evaluated against station precipitation statistics at seven Environment Canada climate stations within or near the study area (Table 2-2). The ClimateNA_MAP gridded dataset was queried at each of the seven climate station locations to give the 1961-1991 MAP values presented in Table 2-2. One location, Fort McPherson, also has an MAP value from the Environment Canada climate normal for 1991-2020. These values were compared to MAP calculated for each station using available daily rainfall data.

Table 2-2 indicates the period of record considered at each climate station and indicates the number of years that were considered for the calculation of MAP. The criterion for including a year in the calculation of MAP was having a record for daily rainfall on >320 days of each year.

Considering the differences in the amount of available data and the varying periods of record at the Environment Canada climate stations, the ClimateNA_MAP 1961–1990 gridded dataset for MAP was selected for use in this water budget. ClimateNA_MAP estimates are within 15% of the climate station data in all locations except for Rock River, which has only used four years to calculate MAP.

Evapotranspiration values used in the completion of the preliminary water budget were sourced from the Natural Resources Canada Land Surface Evapotranspiration for Canada's Landmass datasets. These contain land surface evapotranspiration (ET, in mm of water) for Canada's landmass at a spatial resolution of 5 km and temporal intervals of a year over a 24-year period of 2000-2023. ET values in these datasets were derived from the Land Surface Model



Ecological Assimilation of Land and Climate Observations EALCO, developed at Natural Resources Canada. The annual median ET based on these datasets was 193 mm/yr with a minimum of 113 mm/yr and a maximum of 306 mm/yr across the Peel River basin and Western Mackenzie Delta.

The MAP and ET datasets were selected for this water budget as they were the most readily available and spatially continuous, gridded datasets that covered the project area. It is acknowledged that the time periods are not consistent (MAP based on 1961-1990 normals, and ET based on annual analysis from 2000-2023), and future updates to the water budget could consider datasets based on more closely aligned time periods. It was anticipated that the modelling inputs for the Canada1Water project may have been useful for this water budget; they were requested in the early stages of this project, but the inputs were not yet published or available.

2.3.2 Peel River Basin Water Surplus

Assuming that changes in soil moisture storage (ΔS_s) are negligible and that there is no change in groundwater storage (ΔG_s) in the basin, the total water surplus that is available for surface runoff to the surface water system and infiltration as groundwater recharge can be determined. The water surplus (mm/yr) is expressed as follows:

$$\text{Surplus} = P - ET$$

The proportion of the water surplus that infiltrates or runs off depends primarily upon the characteristics of the surficial materials, topography, land use, vegetative cover, and the extent and continuity of permafrost. The premise of this concept is that water will infiltrate more easily through flat-lying, high-permeability soils than it will on steep slopes or through low-permeability soils. Water that infiltrates helps recharge the groundwater table and shallow aquifers. In permafrost terrain or within low permeability materials, infiltration of precipitation may recharge only a perched groundwater table (e.g. within the active layer). Groundwater is expected to flow laterally towards river valleys and contribute to baseflow within the study area, including in winter before complete freeze-back of the active layer (or where shallow taliks have formed). The travel time through the soil may be slow, thus creating a long-time lag (commonly ranging from weeks to years or even decades) between when the water infiltrated and when it is exposed again at surface.

Surface runoff, on the other hand, generally coincides with rainfall and/or snowmelt events. As the surficial soil layers become saturated by rainfall, water may run off to low-lying areas. This process is especially pronounced during the spring snowmelt where the melting snowpack is forced to run off because the upper soil layers and bedrock are still frozen and prevent infiltration. Furthermore, the amount of runoff depends on many factors such as surficial materials, slope gradients, vegetative cover, soil moisture, and the extent and depth of permafrost prior to the rainfall or snowmelt event.

The overall water surplus was determined for the Peel River basin using two gridded datasets: the ClimateNA_tool 1961-1990 climate normals for precipitation (median 415 mm/yr), and the Land Surface Evapotranspiration for Canada's Landmass datasets for evapotranspiration (median 193 mm/yr). The median difference (surplus) between these two datasets gives an annual average surplus of 213 mm/yr with a surplus range of <10 mm/yr to 865 mm/yr that broadly follows trends in mean annual precipitation (i.e. higher in the mountainous areas to the south, and lower near the ocean in the Western Mackenzie Delta).

The median surplus value calculated for the study area (213 mm/yr) is close to the approximately 200 mm/yr estimated for the Peel River basin and Western Mackenzie Delta in



the Hydrological Atlas of Canada (Hartog and Ferguson 1978). In that atlas, precipitation is 200–400 mm/yr and evapotranspiration is 100–300 mm/yr, both of which were used to indicate a Canada-wide water budget.

2.3.3 Partitioning Between Recharge and Runoff

Based on the annual water surplus presented in Section 2.3.1, groundwater recharge and surface water runoff rates were calculated for the study area using a GIS-based analytical model. The model integrates physical characteristics such as slope, elevation, surficial materials, and land cover, and permafrost extent over a 30 x 30 m grid to estimate groundwater recharge rates and runoff volumes for the Peel River basin.

To partition between runoff and recharge, a distribution of weighted runoff/recharge factors was determined for each of the different surficial and exposed/veneered bedrock geological units, vegetative types (land cover) and topographies (slope classes) within the study area, according to the formula:

$$\text{Total IF (1)} = [\text{Slope IF (0.3)} + \text{Surficial Geology IF (0.4)} + \text{Land Cover IF (0.3)}] \\ * \text{Permafrost Reduction Factor}$$

where:

IF = Infiltration Factor

Permafrost Reduction Factor = a value between 0 and 1 predicting how much infiltration/recharge would be reduced by the presence of permafrost, with 1 being no reduction and 0 being total reduction.

It is noted that the weighting value applied to each factor type is the maximum value that can be assigned to a category within that factor type e.g. eolian deposits (surficial geology) have an infiltration factor of 0.4, which means there would be no reduction in the surplus available for groundwater recharge for the surficial geology factor type.

The Medium Resolution Digital Elevation Model (MRDEM) from Natural Resources Canada (NRCAN) (2024) and land cover mapping (used to assign values for slope and vegetative (land) cover) are presented in Sections 3.1.1 and 3.1.5, respectively.



Table 2-2. Precipitation Comparison between Climate_NA 1961-1990 normal and Climate Station Data Sources

Station Name	Station ID	Latitude	Longitude	Elevation (masl ¹)	Mean Annual Precipitation (MAP) (mm)			
					Climate_NA 1961-1990 normal	1991-2020 normal	MAP from available record ²	
							MAP	data availability (years)
Aklavik A	2200105	68°13'24" N	35°00'20" W	6.4	211	-	239	1926 – 2006 (45)
Fort McPherson	2201600	67°26'00" N	134°53'00" W	30.5	273	294.3	316	1892 – 1977 (34)
Fort McPherson A	2201606	67°24'25" N	134°51'35" W	35.4	275	-	287	1981 – 2014 (23)
Eagle Plains	2100468	66°22'10" N	136°43'04" W	620	423	-	394	1979 – 2007 (19)
Klondike	2100679	64°27'14" N	138°12'56" W	962.7	424	-	471	1966 – 2010 (32)
Ogilvie River	2100794	65°21'37" N	138°18'19" W	597.4	328	-	340	1971 – 2007 (26)
Rock River	2100935	66°58'52" N	136°13'05" W	731	492	-	286	2013 – 2025 (4) ³
¹ masl - metres above sea level ² MAP calculated using years when more than 320 days of precipitation data were available. Parentheses denote number of years considered in the average based on the 320-day criteria. ³ Variation between the calculated MAP from daily rainfall data at Rock River and the ClimateNA_MAP 1961-1990 normal is likely due to the limited availability of daily rainfall data from the climate station. - denotes no data were available								



Table 2-3 specifies the infiltration factors assigned on the basis of land cover type, and Table 2-4 lists the infiltration factors assigned on the basis of slope steepness class (Ontario Ministry of Environment and Energy (MOEE) 1995, Ontario Ministry of Environment (MOE) 2003). The surficial geology mapping (Section 3.1.3) was the basis for weighting infiltration values in the model and the ranking of infiltration factors for the various types of surficial material (including landforms) and bedrock (Table 2-5). Once weights were applied to all layers, they were combined within the GIS to create a layer of infiltration distribution. The runoff/recharge factors are based on hydrologic analysis designed for assessing peak runoff curves for stormwater management purposes (e.g. US Department of Agriculture Natural Resources Conservation Service curves) and modified based on the specific conditions within the study area and SLR's experience in the area. This methodology generally provides an overestimate with respect to runoff and is therefore conservative in estimating the amount of groundwater recharge (i.e. groundwater recharge is underestimated).

Permafrost, where present, can also significantly reduce groundwater recharge; however, recharge efficiency also depends on active-layer thickness and its capacity to store water under unsaturated conditions. Even within the active layer, where precipitation can infiltrate during unfrozen (thawed) conditions, the volume of water recharging the groundwater table can be decreased. To account for the groundwater recharge-limiting effects of permafrost, the following reduction factors were applied to the surficial geology and vegetation (land cover) parameters of each raster grid cell: 75% reduction in continuous permafrost and 60% in discontinuous permafrost. These reduction factors were selected in consideration of Brown et al.'s (2002) generalized proportions of ground underlain by permafrost within each zone: 90-100% extent in continuous permafrost and 50-90% extent in extensive discontinuous permafrost. However, the selected reduction factors do not lie within the Brown et al. (2002) proportions in acknowledgment that, at a basin scale, gaps in both continuous and discontinuous permafrost (e.g. taliks) could allow for the infiltration of precipitation and groundwater recharge or discharge. It also acknowledges the potential role of active layer (suprapermfrost) groundwater to be recharged by precipitation and then to discharge in streams, contributing to their baseflow. More complex partitioning of runoff/recharge in association with permafrost would require a more precise understanding of the distribution of permafrost and active layer dynamics than is currently available.

The infiltration distribution, in combination with the distribution of water surpluses and permafrost effects, produced a model of the spatial variability of infiltration of groundwater across the study area, from which the estimated groundwater recharge could be evaluated spatially. The purpose of the recharge potential map is to highlight areas with greater potential for recharge from direct infiltration by rainfall, which may be associated with more productive shallow hydrostratigraphic units and higher, more sustained winter baseflows. This relationship is less direct for confined or deeper aquifers, or aquifers that are not primarily recharged by rainfall, where recharge may occur through localized windows, distant recharge areas or surface water features such as rivers or lakes. The opposite is true for low recharge areas. Areas where there is a greater potential for surface runoff should correspond to areas with lower surficial aquifer potential and proportionally higher peak flows with limited winter baseflows.



Table 2-3. Infiltration Factors for Different Land Cover Types

Land Cover Type	Infiltration Factor
Temperate or sub-polar needleleaf forest	0.2
Sub-polar taiga needleleaf forest	0.2
Temperate or sub-polar broadleaf deciduous forest	0.2
Mixed forest	0.2
Temperate or sub-polar shrubland	0.15
Temperate or sub-polar grassland	0.15
Sub-polar or polar shrubland-lichen-moss	0.1
Sub-polar or polar grassland-lichen-moss	0.1
Wetland	0.25
Barren lands	0.3
Urban	0.05
Water	0
Snow and Ice	0

Note: Maximum possible infiltration factor for land cover type is 0.3.

Table 2-4. Infiltration Factors for Different Slope Steepness Classes

Slope (%)	Infiltration Factor
>10	0
5 – 10	0.05
2.5 – 5	0.1
1 – 2.5	0.15
0.5-1	0.2
0.1-0.5	0.25
0.0-0.1	0.3

Note: Slope steepness infiltration factors developed in consideration of MOEE (1995) and MOE (2003).

Note: Maximum possible infiltration factor for slope steepness is 0.3.



Table 2-5. Infiltration Factors for Different Surficial Geology Types

Surficial Geology	Infiltration Factor
Waterbodies and rock glaciers	0
Lacustrine and glaciolacustrine deposits	0.1
Bedrock (primarily sedimentary)	0.15
Morainal deposits	0.2
Anthropogenic, colluvial, morainal, and undifferentiated material deposits	0.25
Fluvial deposits	0.3
Fluvial fan deposits	0.35
Eolian, glaciofluvial, and organic deposits	0.4

Note: Surficial geology infiltration factors developed in consideration of MOEE (1995) and MOE (2003).

Note: Maximum possible infiltration factor for surficial geology type is 0.4.

2.3.4 Baseflow Hydrograph Separation for Model Calibration

Although several assumptions were necessarily made in the development of the preliminary water balance model, the overall results of the model were tested against established datasets from hydrometric stations within the Peel River basin and Western Mackenzie Delta. At the basin scale, it is reasonable to assume that the vast majority of groundwater recharge eventually discharges to the surface as stream baseflow. Therefore, the baseflow component of the hydrograph provides a good approximation of groundwater recharge such that the assumptions made in the selection of precipitation, ET, infiltration factors, and permafrost reductions can be validated for the whole basin. Assuming that groundwater loss to deep aquifers and across basin boundaries is negligible, the average annual recharge within a basin should be equal to the average annual baseflow of the surface water body draining the basin. Therefore, baseflow separation of the streamflow hydrographs was conducted to provide a comparison with the results of the GIS-derived water budget.

Baseflow was determined for nine Water Survey of Canada (WSC) hydrometric stations (Table 2-6). Data from these nine stations are considered suitable for water balance model calibration as they range in basin area, climatic conditions and surficial geology, and continuity of permafrost extent. Furthermore, their basins are broadly representative of the different physical characteristics within the Peel River basin and Western Mackenzie Delta.



Table 2-6. Hydrometric Stations Used in the Baseflow Separation Analysis

Station Name	Latitude	Longitude	Station No.	Period of Record
Peel River Above Fort McPherson	67°15'32"N	134°53'19"W	10MC002	1969-2025
Mackenzie River (Peel Channel)	68°12'13"N	135°06'53"W	10MC003	1974-1977; 1982-1986; 1991-2025
Rat River Near Fort McPherson	67°40'37"N	135°43'05"W	10MC007	1981-1990; 2016-2025
Mackenzie River (Middle Channel) Below Raymond Channel	68°17'32"N	134°25'47"W	10MC008	1982-1986; 1991-2025
Peel River Above Canyon Creek	65°53'33"N	136°02'16"W	10MA001	1961-1965; 1968-1998; 2005-2025
Ogilvie River at Km 197.9 Dempster Highway	65°21'43"N	138°18'07"W	10MA002	1974-1996; 2016-2025
Blackstone River Near Chapman Lake Airstrip	64°54'05"N	138°16'33"W	10MA003	1984-1994; 2005-2025
Snake River Near the Mouth	65°58'13"N	134°02'17"W	10MB003	1975-1995; 2021-2025
Bonnet Plume River Above Gillespie Creek	64°44'54"N	133°40'48"W	10MB004	1981-1994; 2016-2025

Note: Station locations shown on Figure 1-1.

Streamflow data for each of the three basins were accessed using the 'tidyhydat' R package (Albers 2017). To be consistent with the evaluation of meteorological data, the baseflow analysis was conducted on streamflow data across the fullest extent of the record for each station. The baseflow separation was then conducted using the following two approaches:

1. **Winter Flow Method** – In northern basins, mid-winter streamflow is assumed to be completely sustained by groundwater inputs. During the winter period, contributions to streamflow from surficial inputs (runoff and thaw events) are generally considered to be negligible (St. Jacques and Sauchyn 2009). Therefore, one approach to determine the baseflow component of the hydrograph was to assume that the total average streamflow from January 1 to March 31 is a reasonable approximation of the baseflow contributions over an annual cycle. This approach has been applied throughout northern Canada in previous investigations of baseflow (e.g. St. Jacques and Sauchyn 2009); however, this approach likely underestimates the total annual baseflow contributions, which likely are higher during summer months because of the effect of summer precipitation and thaw events on the groundwater table in the shallow, active zone and subsequent groundwater fluxes (St. Jacques and Sauchyn 2009). In previous studies involving the use of this method to estimate baseflow in watersheds in the NWT, the percentage of long-term mean annual discharge (MAD) attributed to baseflow ranged from 1.2 – 86.6%, with most watersheds with annual baseflow in the range of 30 – 60% of MAD (St. Jacques and Sauchyn 2009).

Groundwater dynamics are also known to be influenced by the presence of permafrost and permafrost thaw, which is not possible to quantify through this method, adding additional uncertainty. The water budget assumes that recharge to, and discharge from,



deep aquifers is negligible; however, this may overlook or underestimate discharge from deeper groundwater systems through taliks, which could contribute to baseflow estimated using the winter flow method. Future studies that characterize hydraulic connectivity through taliks for specific watercourses or regions would help understand how this limitation should be considered when interpreting water budget results.

2. **Recursive Filtering** – A common approach to separate the baseflow component of a hydrograph is through the application of a recursive filter, commonly referred to as an ‘Eckhardt filter’ (Gonzales et al. 2009, Eckhardt 2012). Recursive filtering for baseflow separation is a digital signal processing method that separates streamflow into slow (baseflow) and fast (surface runoff) components by applying mathematical filters to a streamflow hydrograph, effectively removing high-frequency surface runoff to reveal the underlying baseflow. However, when baseflow is defined purely as groundwater contribution, it may be overestimated through this method due to the inclusion of slow-moving runoff in the baseflow signal, depending on the filter parameters and watershed characteristics. The recursive filtering approach requires the specification of two input parameters: (1) a recession constant (a) and (2) a baseflow index (BFI) to be modelled by the algorithm (for further information regarding this technique, refer to Eckhardt [2012]). The application of the Eckhardt filter to the streamflow data was conducted using the ‘FlowScreen’ R package (Dierauer and Whitfield 2019). A recession constant (a) of 0.85 and the maximum value of long-term ratio of baseflow to total streamflow (BFI_{max}) of 0.7 was utilized for the recursive filtering equation based on guidance in Eckhardt (2012), the inspection of long-term hydrographs, and comparison to typical baseflow/MAD ratios of the region (St. Jacques and Sauchyn 2009).
3. **Blended Approach** – Initial evaluations of the baseflow separation using the recursive filtering method produced an unrealistically low baseflow component during winter months, when virtually all streamflow is sustained by baseflow contributions. Therefore, the Eckhardt filter was only applied to warm-season flows (April 16 – October 31) and it was assumed that total cold-season streamflow (November 1 – April 15) could be completely attributed to baseflow. The November 1 and April 15 boundaries between the ‘cold’ and ‘warm’ seasons were determined through visual interpretation of the inflection point in the long-term daily average hydrographs (Figure 2-3).

Long-term average annual baseflow rates, developed through the winter baseflow, recursive filtering method, and blended approach are summarized in Table 2-7. The winter flow method provides baseflow estimates ranging from 0.1– 47% of MAD. As suggested by St. Jacques and Sauchyn (2009), these winter-flow estimates likely underrepresent actual baseflow conditions; therefore, they should only be used to project minimum potential baseflow values. In contrast, results using the recursive filter and the blended approach suggested that baseflow comprised 69 – 70% of MAD and 70 – 76% of MAD, respectively. Average baseflow derived from the blended approach for each site, compared to average daily observed streamflow is displayed in Figure 2-3.



Table 2-7. Mean Annual Baseflow for Selected WSC Gauges in the Peel River Basin and Western Mackenzie Delta

Station Number	Station Name	Basin Area	Mean Annual Discharge (MAD)		Baseflow Contributions					
					Winter Baseflow Method		Recursive Filter**		Blended Approach***	
		km ²	m ³ /s	mm/yr*	m ³ /s	% MAD	m ³ /s	% MAD	m ³ /s	% MAD
10MC002	Peel River Above Fort McPherson	70,600	682	305	95.9	14	477	70	492	72
10MC003	Mackenzie River (Peel Channel)	-	474	-	131	28	331	69	351	74
10MC007	Rat River Near Fort McPherson	1260	8	205	0.009	0	5.6	70	5.7	70
10MC008	Mackenzie River (Middle Channel) Below Raymond Channel	-	7907	-	3702	47	5536	70	6039	76
10MA001	Peel River Above Canyon Creek	25,500	202	250	25.0	12	140.8	70	145	72
10MA002	Ogilvie River at Km 197.9 Dempster Highway	5,410	33	194	1.5	4	22.9	70	23.2	70
10MA003	Blackstone River Near Chapman Lake Airstrip	1,180	10	273	0.2	2	7.1	70	7.1	71
10MB003	Snake River Near the Mouth	8,910	100	353	9.3	7	69.1	69	70.9	71
10MB004	Bonnet Plume River Above Gillespie Creek	3,760	52	439	6.5	12	36.5	70	37.7	72

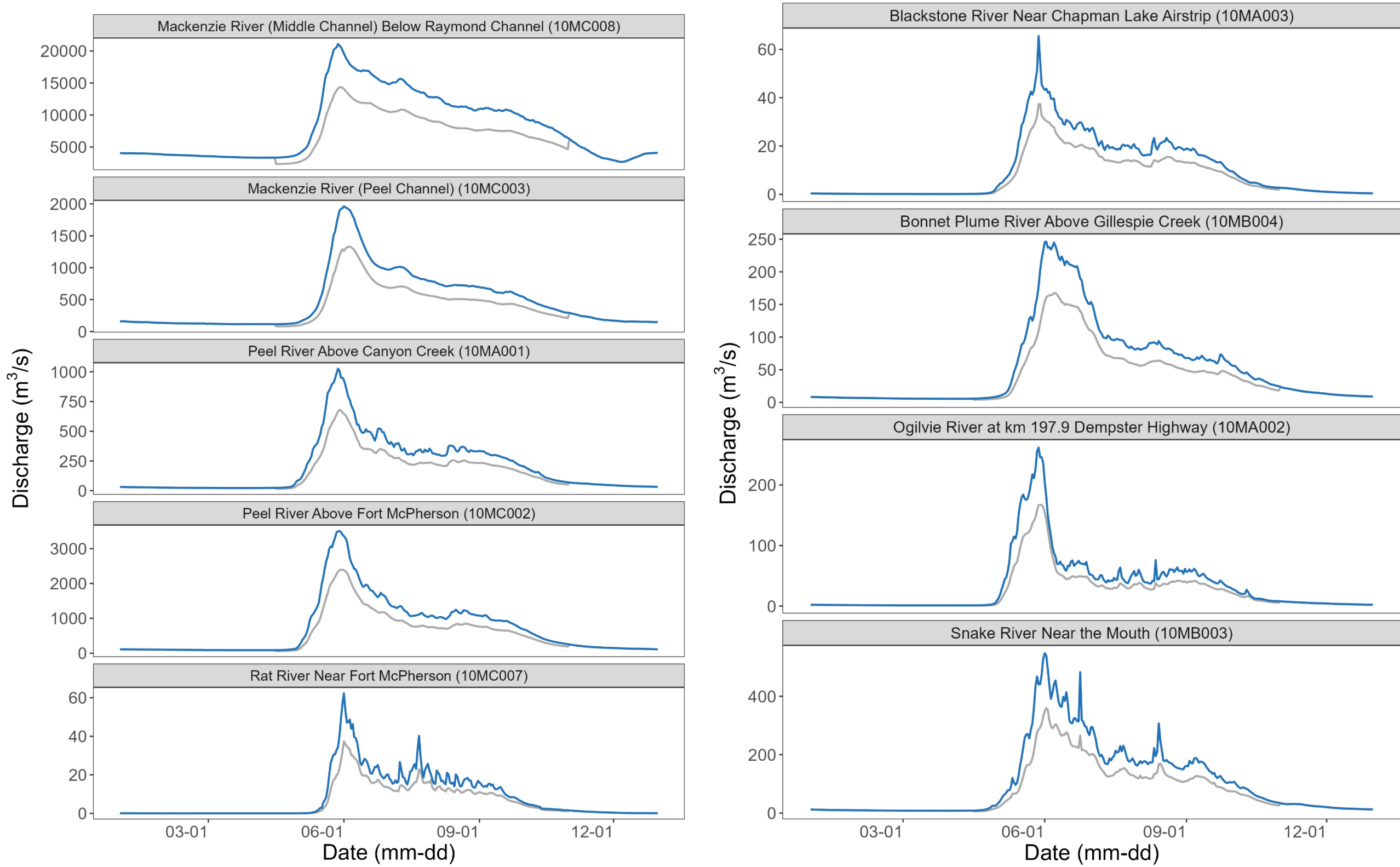
*Spatial calculation of mean annual discharge in mm/yr completed where basin area is defined.

**Results from use of Eckhardt recursive filter is used for the whole year.

***The blended approach is a combination of Eckhardt recursive filtering for warm season flows (April 16 – October 31) and the winter baseflow method for cold season flow (November 1 – April 15).



Figure 2-2. Average daily hydrographs of daily streamflow (blue) and the estimated baseflow component (grey) for the entire period of record (see Table 2-6) at each site



2.4 Assessment of Potential Groundwater Vulnerability

Various land use activities have the potential to affect groundwater quality and/or quantity, especially where coincident with surficial (unconfined) aquifers or important recharge areas. An adaptation of Levson et al.'s (2018) approach for drawing attention to subbasins most susceptible to contamination or unsustainable groundwater withdrawal was followed, as described in the following subsections.

Mapping of all major land use activities⁴ in the study area was compiled based on the highest resolution, most up-to-date information available. All land use activities were evaluated and assigned to one of three broad categories based on their potential effect on groundwater quality and quantity in the study area (based on Levson et al. 2018) (Table 2-8). The relative degree of surface disturbance and potential for groundwater impact increases from Category 1 to Category 3. The highest disturbance category was used in areas where two or more disturbances overlapped.

**Table 2-8. Categories of Disturbance Associated with Different Land Use Activities
(Based on Levson et al. 2018)**

Category	General Characterization	Example of land use activities
1	Land use activities involving minimal surface disturbance primarily to vegetation, with no or limited/short-term exposure of mineral soil, with relatively low potential for contamination of groundwater.	Cut-lines, trails, seismic lines, seismic shotholes*
2	Land use activities involving moderate surface disturbance, with removal of most or all vegetation and long-term exposure of mineral soils, with a low to moderate potential for contamination of groundwater.	Water wells/drill holes**
3	Land use activities involving major surface disturbance, with removal of all vegetation, long-term exposure of mineral soils and reclamation unexpected, with the highest potential for contamination of groundwater.	Aggregate pits/quarries, residential areas, camps, fuel storage, roads, runways, mining areas, waste facilities

*Seismic shotholes are generally small-diameter, short-duration, temporary boreholes that are drilled, loaded, and then plugged/backfilled, typically with limited, localized soil exposure at the collar.

**Water wells/drill holes commonly require a larger working area and longer on-site duration for drilling, therefore representing moderate disturbance and higher potential for groundwater contamination.

Areas (m²) associated with each land use activity were adopted directly from polygon shapefiles of areal disturbances (e.g. aggregate pits/quarries, mining areas). For land use activities represented in available mapping as lines (e.g. pipelines, roads) and points (e.g. oil & gas wells, seismic shot holes), standardized buffers were applied to approximate the corresponding areal

⁴ Only anthropogenic activities were included. Wildfires, which were included by Levson et al. (2018), were excluded due to their natural occurrence in northern Boreal and subarctic environments.



footprints (m²) of disturbance. For example, a 5 m buffer was applied to cut-lines based on the average of modern and historical disturbance footprints. A 5 m-buffer disturbance footprint was assumed for seismic shot holes in accordance with permitted and typical footprints. A complete list of compiled land use activity mapping data and assumed areal footprints (buffers) is included in Appendix B.

2.4.1 Groundwater Quality

Land use activities can affect groundwater quality in surficial aquifers by introducing potential contaminants at rates and/or with concentrations that may trigger an exceedance of regulatory standards in the groundwater. Assessment of the potential impact of land use activities on groundwater quality within each of the three subbasins was completed based on the distribution and nature of land disturbances (Categories 1, 2 or 3) subbasin-wide, within areas of surficial aquifer potential (i.e. later referenced as Figure 3-11) and in association with potential recharge. Drilling waste sump locations were not included in the disturbance classification because consistent, georeferenced, basin-wide sump geospatial data were not identified among the public spatial datasets; incorporation of such inventories (where available) is recommended for future updates. Consideration of the coincidence of land use activities with the areas of greatest contributions to groundwater recharge draws attention to locations where groundwater may be vulnerable to impact beyond the limits of surficial aquifers. Additionally, some areas of surficial aquifer potential could be indirectly affected if they receive groundwater from sources outside their limits.

Three indices of groundwater quality disturbance potential were established for each of the three subbasins. A stepwise overview of the calculation of each index, following its definition, is provided below:

Normalized Index of Proportion of Subbasin Disturbed – a combined representation of the proportional areal extent and severity of disturbance within the entire subbasin.

1. The total area of disturbance was calculated within each subbasin [A].
2. All disturbed areas were categorized according to one of three levels (Category 1 (Cat1), Category 2 (Cat2), Category 3 (Cat3)).
3. Each disturbance level was assigned a weighting factor, corresponding to the associated severity of the disturbance (Category 1 – 1, Category 2 – 3, Category 3 – 9). The departure from Levson et al.'s (2018) weights of 1, 1.5 and 2 was deemed necessary to better represent and contrast the increasing severity of potential disturbances across the three categories. For example, the weights of Levson et al. (2018) imply that groundwater is only twice as vulnerable to impact below mining areas as it is below survey cut-lines. The adjusted weighting better draws attention to areas of greatest concern best satisfies the objective of establishing relative ranks within the study area and is consistent with the approach applied by Palmer (2020) and SLR (2025).
4. Disturbance area values were multiplied by their corresponding weighting factors for each subbasin, then divided by the *total area of the subbasin*, to give a proportional weighted disturbance area within each subbasin:

$$\text{Subbasin-Wide Disturbance Index} = [(A_{\text{Cat1}} \times 1) + (A_{\text{Cat2}} \times 3) + (A_{\text{Cat3}} \times 9)] / \text{Total area of subbasin}$$

5. The index was then normalized to values ranging from 0 to 100 by dividing it by the highest index value for the population, multiplied by 100.



Normalized Index of the Proportion of Surficial Aquifers Disturbed – a combined representation of the proportional areal extent and severity of disturbance in areas of surficial aquifer potential.

1. The total area of disturbance in areas of surficial aquifer potential was calculated within each subbasin [A].
2. Each area of disturbance was characterized both by category (severity) of disturbance and aquifer type (Wei et al., 2009).
3. Weighting factors were assigned to each category of disturbance, as in the previous index, as well as to each surficial aquifer type presented/identified (Section 3.2) (Type 1 (modern fluvial floodplains & terraces), 3 = 2 and Type 4a (unconfined glaciofluvial) = 1), as a reflection of its general sensitivity.
4. Disturbance area values were multiplied by both corresponding weighting factors for each subbasin, then divided by the *total area of surficial aquifers within the subbasin* (all types), to give a proportional weighted disturbance area of all surficial aquifers in each subbasin:

$$\text{Surficial Aquifer Area Disturbance Index} = \{2 \times [(A'_{\text{Cat1}} \times 1) + (A'_{\text{Cat2}} \times 3) + (A'_{\text{Cat3}} \times 9)] + 1 \times [(A''_{\text{Cat1}} \times 1) + (A''_{\text{Cat2}} \times 3) + (A''_{\text{Cat3}} \times 9)]\} / \text{Total area of surficial aquifer potential in subbasin}$$

where A' = Area of Type 1 (modern fluvial floodplains & terraces) and Type 3 (modern fluvial fans and colluvial fans/cones) surficial aquifers, and

A'' = Area of Type 4a (unconfined glaciofluvial) surficial aquifers

5. The index was then normalized to values ranging from 0 to 100 by dividing it by the highest index value for the population, multiplied by 100.

Normalized Index of Proportional Disturbance of Potential Recharge – a combined representation of the proportional areal extent and severity of disturbance within areas of potential recharge.

1. The total area of disturbance was calculated within each subbasin [A].
2. All disturbed areas were categorized according to one of three levels (Category 1 (Cat1), Category 2 (Cat2), Category 3 (Cat3)).
3. Each disturbance category was assigned a weighting factor, corresponding to the associated severity of the disturbance (Category 1 – 1, Category 2 – 3, Category 3 – 9).
4. The average potential recharge value was calculated over the area of disturbance for each disturbance category, then multiplied by its respective weighting factor. The sum of these products for each basin was then divided by the total subbasin area, to give a proportional weighted disturbance area for the potential recharge in each subbasin:

$$\text{Recharge Disturbance Index} = \{[(R_{\text{Cat1}} \times A_{\text{Cat1}}) \times 1] + [(R_{\text{Cat2}} \times A_{\text{Cat2}}) \times 3] + [(R_{\text{Cat3}} \times A_{\text{Cat3}}) \times 9]\} / \text{Total area of subbasin}$$

where R = average recharge over the corresponding disturbance area.

5. The index was then normalized to values ranging from 0 to 100 by dividing it by the highest index value for the population, multiplied by 100.

2.4.2 Groundwater Quantity

Land use activities can affect groundwater quantity by withdrawing water at a rate that exceeds the aquifer recharge capacity or at a rate that interferes with other water users or the natural



environment. Levson et al.'s (2018) straightforward approach for evaluating potential effects of land use activities on groundwater quantity was applied to establish a Normalized Index of Water Supply Well Density. The index was based simply on the water well density for each subbasin, calculated as its total number of wells divided by the subbasin area. For ease of comparison, the index was normalized to a value between 0 and 100 by dividing it by the highest index value for the population, multiplied by 100.

Limited data on water withdrawal rates precluded application of a more robust approach for evaluating 'groundwater stress', for example, through a comparison of total annual withdrawals from a surficial aquifer with total recharge potential to the surficial aquifer (as described further in the recommendations in Section 4.3). Even the establishment of the Normalized Index of Water Supply Well Density as a meaningful ranking tool was challenged by the limited availability of water well data at the time of reporting. Consequently, the resulting index is not considered especially robust or meaningful for this study area, and any comparison among sub-basins should be interpreted cautiously, as it reflects the distribution of available data rather than a rigorous measure of actual water quantity disturbance potential.

2.5 Prioritization of Future Surficial Aquifer Mapping and Characterization

Assessment of the potential effects of land use activities on a combination of both groundwater quality and quantity, in accordance with Levson et al. (2018), culminated in the identification of priority areas for future work. A composite rank of disturbance potential was calculated simply by assigning weighting factors to each of the indices of normalized groundwater disturbance potential. For consistency with Levson et al. (2018), weightings of 1.0 and 0.1 were used for disturbances of land surfaces related to water quality and the effects of well density on groundwater quantity, respectively. A total Index of Groundwater Disturbance Potential was calculated for each of the three combined representations of groundwater disturbance potential using the following formulae:

- **Index of Groundwater Disturbance Potential (Subbasin)** = $1.0 \times \text{Normalized Index of the Proportion of Subbasin Disturbed} + 0.1 \times \text{Normalized Index of Water Well Density}$
- **Index of Groundwater Disturbance Potential (Surficial Aquifers)** = $1.0 \times \text{Normalized Index of the Proportion of Surficial Aquifers Disturbed} + 0.1 \times \text{Normalized Index of Water Well Density}$
- **Index of Groundwater Disturbance Potential (Recharge)** = $1.0 \times \text{Normalized Index of Proportional Disturbance of Potential Recharge} + 0.1 \times \text{Normalized Index of Water Well Density}$

Normalization of this total index was not required; the calculated values were simply ranked from highest (1) to lowest (3) for the three subbasins. Lower-ranked (i.e. smaller rank number) basins were considered lower priority for future work.

3.0 Results

3.1 Summary of Data Coverage and Gaps

Principal spatial data sources were compiled based on a systematic review of available information pertinent to the assessment of surficial aquifers in the Peel River basin and Western Mackenzie Delta in the Yukon and NWT (Appendix C). Basic topographic and land cover data are widely available. However, geological and subsurface datasets are incomplete and less



detailed in comparison to what is available in other jurisdictions such as British Columbia (Levson et al. 2018). There is a relative sparseness of groundwater-related information and an unavailability of any hydrogeological mapping within the study area.

The following subsections reference and summarize the mapping, as well as associated gaps, of several compilation datasets: topography, bedrock geology, surficial geology, permafrost, land cover, site-specific subsurface data and land use activity. Topography Compilation

Approximately 30 m-resolution MRDEM coverage is continuous throughout the study area (NRCan 2024); it provided an appropriate resolution for the topographic analyses in this basin-wide study (Figure 3-1). A 10 m-resolution version of the ArcticDEM (Porter et al. 2023), which provides continuous coverage across the study area, was only consulted to support TPI-based surficial aquifer potential interpretations and help calibrate understanding of areas of particular interest. In a broad sense, average elevations decrease in a northward and eastward direction throughout the study area. The Richardson Mountains predominate along the northwestern margin of the study area. Between these uplands, the Peel Plateau and Plain, including the Eagle Plains, occupy much of the central basin. The southern and eastern headwaters are within the Wernecke and Selwyn Mountains. At its northeastern edge, the Western Mackenzie Delta forms a low-lying, alluvial plain punctuated by numerous small lakes.

3.1.1 Topography Compilation

Approximately 30 m-resolution MRDEM coverage is continuous throughout the study area (NRCan 2024); it provided an appropriate resolution for the topographic analyses in this basin-wide study (Figure 3-1). A 10 m-resolution version of the ArcticDEM (Porter et al. 2023), which provides continuous coverage across the study area, was only consulted to support TPI-based surficial aquifer potential interpretations and help calibrate understanding of areas of particular interest. In a broad sense, average elevations decrease in a northward and eastward direction throughout the study area. The Richardson Mountains predominate along the northwestern margin of the study area. Between these uplands, the Peel Plateau and Plain, including the Eagle Plains, occupy much of the central basin. The southern and eastern headwaters are within the Wernecke and Selwyn Mountains. At its northeastern edge, the Western Mackenzie Delta forms a low-lying, alluvial plain punctuated by numerous small lakes.

3.1.2 Bedrock Geology Compilation

The territory-wide compilations of bedrock geology by the Yukon Geological Survey (YGS) and the Northwest Territories Geological Survey (NTGS) provide seamless, cross-border coverage of bedrock formations and associated lithologies, both exposed and beneath unconsolidated deposits, across the Peel River basin and into the Western Mackenzie Delta (Figure 3-2). The YGS digital bedrock compilation serves as the principal source for Yukon, while the NTGS synthesis covers the NWT portion of the study area, allowing consistent mapping across the study area (Okulitch and Irwin 2017, YGS 2025).

The bedrock geology in the study area is complex and is most readily described by its major terranes (Figure 3-3). In the Peel River basin—spanning the Richardson Mountains, Peel Plateau, and nearby uplands—the dominant substrate comprises North America–basinal strata (Selwyn Basin equivalents) and North America–platformal strata (YGS 2020). The basinal succession (Neoproterozoic to Triassic) consists primarily of fine-grained siliciclastic rocks, chert, and shale deposited on the continental slope and in deep-basin settings, with local volcanic intercalations, whereas the platformal strata record shallow-marine siliciclastic and carbonate packages of broadly similar age (YGS 2020). Northward and eastward into the Western Mackenzie Delta, bedrock is largely concealed beneath thick Quaternary deltaic



sediments covering the North America–craton terrane. Mapping documents extensive Mesozoic–Cenozoic clastic successions underlying the Quaternary cover (Okulitch and Irwin 2017)

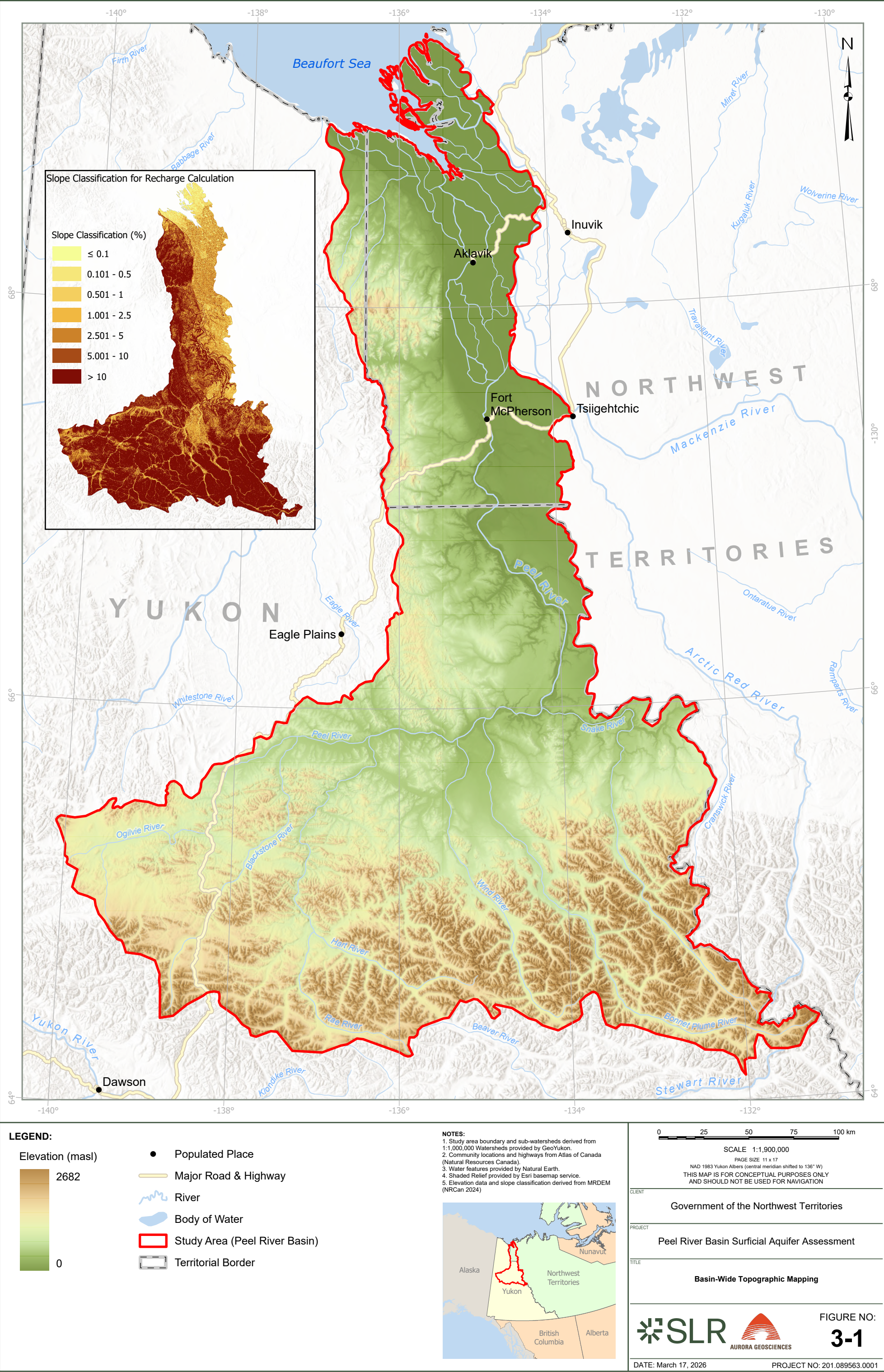
3.1.3 Surficial Geology Compilation

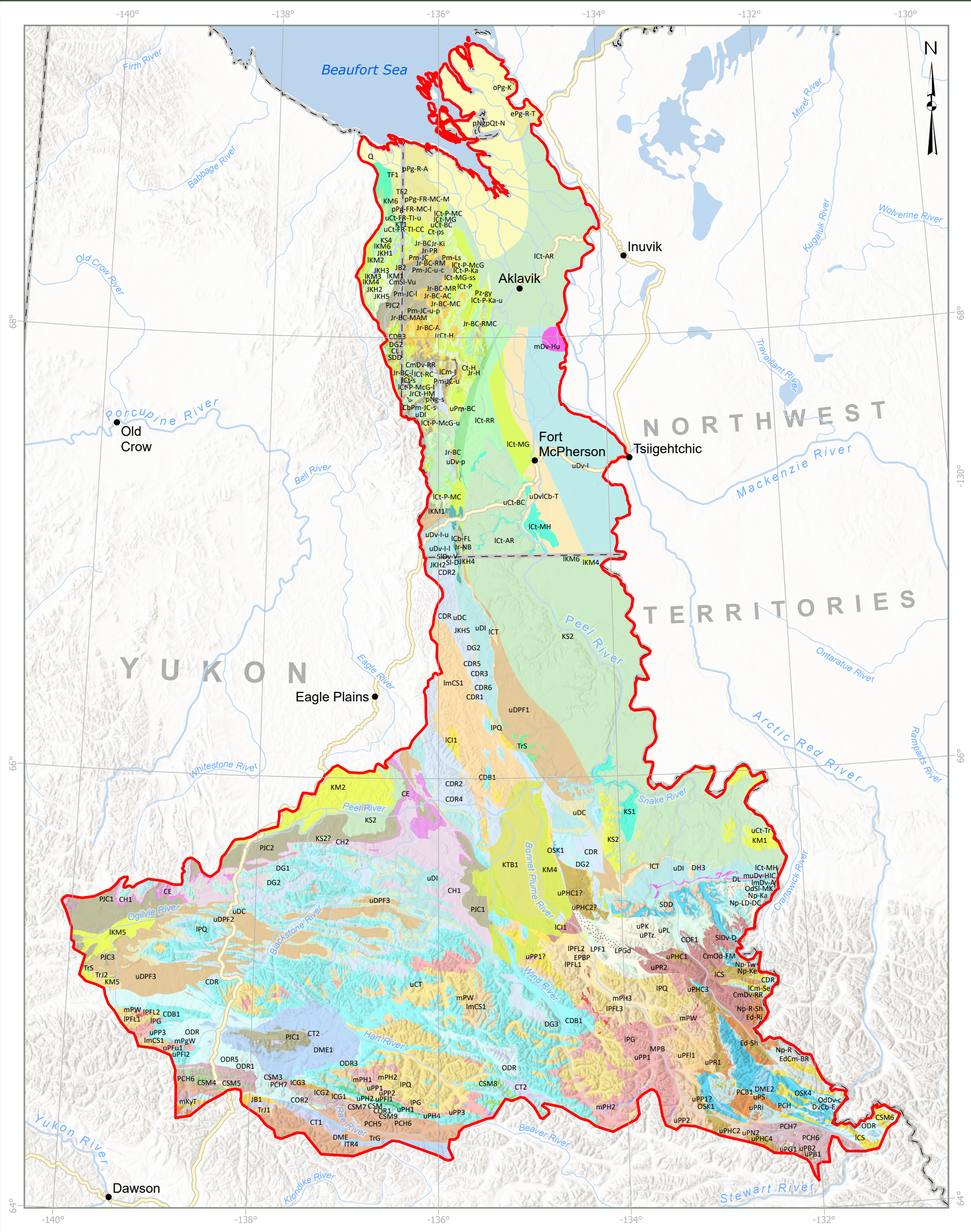
Figure 3-4 presents an index of the basin-wide compilation of pre-existing surficial geology mapping together with new gap-infill of surficial aquifer potential derived from TPIs. The underlying source map scales range from 1:10,000 for community mapping to 1:5,000,000 as part of national mapping. The compilation draws on YGS' territory-wide digital surficial dataset (YGS 2023); the Geological Survey of Canada's digital compilation for the Mackenzie Valley corridor, Yukon Coastal Plain and Tuktoyaktuk Peninsula (Côté et al. 2013); national-scale surficial materials mapping (Fulton 1995); and community-scale surficial geology for Aklavik and Fort McPherson (Palmer 2023a,b). Of greatest significance are the regional-scale (<1:250,000) coverage gaps, which remain substantial in parts of the Peel River basin. These gaps are explicitly illustrated on the index map and were targeted by the project's TPI-based infill classification to provide more consistent (albeit approximate) representation of basin-wide surficial aquifer potential. Figure 3-5 shows the compiled mapping symbolized by dominant surficial material. As in any multi-source compilation, straight-edged boundaries between adjacent surficial units occur along map-sheet joins; these reflect differences in original map scale and interpreter approaches, and reconciliation of poor edge-matches was beyond the scope of this project.

The surficial geology across the Peel River basin and the Western Mackenzie Delta reflects topographic and bedrock controls and the legacy of repeated late Pleistocene glaciations. The surficial mapping compilation reveals widespread colluvium and exposed bedrock at higher elevations and till cover at lower elevations and on plateaus (Figure 3-5). Much of this till and colluvium is characterized as a veneer (<1-2 m thick) and is of little consequence to surficial aquifer potential (as noted in Section 2.2.1, surficial veneers were disregarded when considering aquifer type and infiltration potential). Glaciofluvial outwash and terraces occur locally along major valleys and meltwater corridors and are most concentrated along major tributaries in the Peel plateau portions of the Upper and Central Peel subbasins. Glaciolacustrine sediments are present in isolated basins formed where drainage was ponded during deglaciation, but such units are commonly generalized at small map scales (e.g., 1:5,000,000) and thus appear less prominently than in larger-scale maps. Fluvial sediments follow modern creek and river corridors (including deltaic plains) and include active floodplains, fans and terrace sequences. The expansive area of fluvial deposits in the northeastern corner of the study area corresponds to the Western Mackenzie Delta. Lacustrine sediments occur locally, typically thin and commonly overlain by organics in the delta reaches but are typically too small to map at the regional scale. Organic veneers are commonly thin (<2 m) and may be under-represented by mappers focusing on underlying materials.

In the Yukon portions of the basin, the YGS digital compilation supplies extensive 1:100,000–1:250,000 coverage. In the NWT portions, the Mackenzie corridor compilation (Côté et al. 2013) and existing surficial maps (e.g., Martin House/Arctic Red River sheets) provide key regional context used in our synthesis. Additional legacy mapping in adjacent Yukon areas (e.g., Ricker 1974) was referenced where appropriate to ensure consistent interpretation of glacial and post-glacial deposits and landforms. Finally, the NWT Surficial Maps Compilation index (NTGS 2017) was used to track coverage and identify gaps that our TPI-based infill addressed.







LEGEND:

- Study Area (Peel River Basin)
- Peel River Subbasin
- Territorial Border
- Populated Place
- Major Road & Highway
- River
- Body of Water

For full bedrock geology legend, refer to Yukon Bedrock Geology compilation OF2022-1 and NWT Open File 2016-09:

Yukon Geological Survey, 2022. Yukon digital bedrock geology. Yukon Geological Survey, <https://data.geology.gov.yk.ca/Compilation/3>

Okulitch, A. V., and Irwin, D. 2017. Geological Compilation of the Western Mainland and Arctic Islands of the Northwest Territories; Northwest Geological Survey, NWT Open File 2016-09. ESRI® digital files and PDF files.

- NOTES:
1. Study area boundary and sub-watersheds derived from 1:1,000,000 Watersheds provided by GeoYukon.
 2. Community locations and highways from Atlas of Canada (Natural Resources Canada).
 3. Water features provided by Natural Earth.
 4. Shaded Relief provided by Esri basemap service.



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km

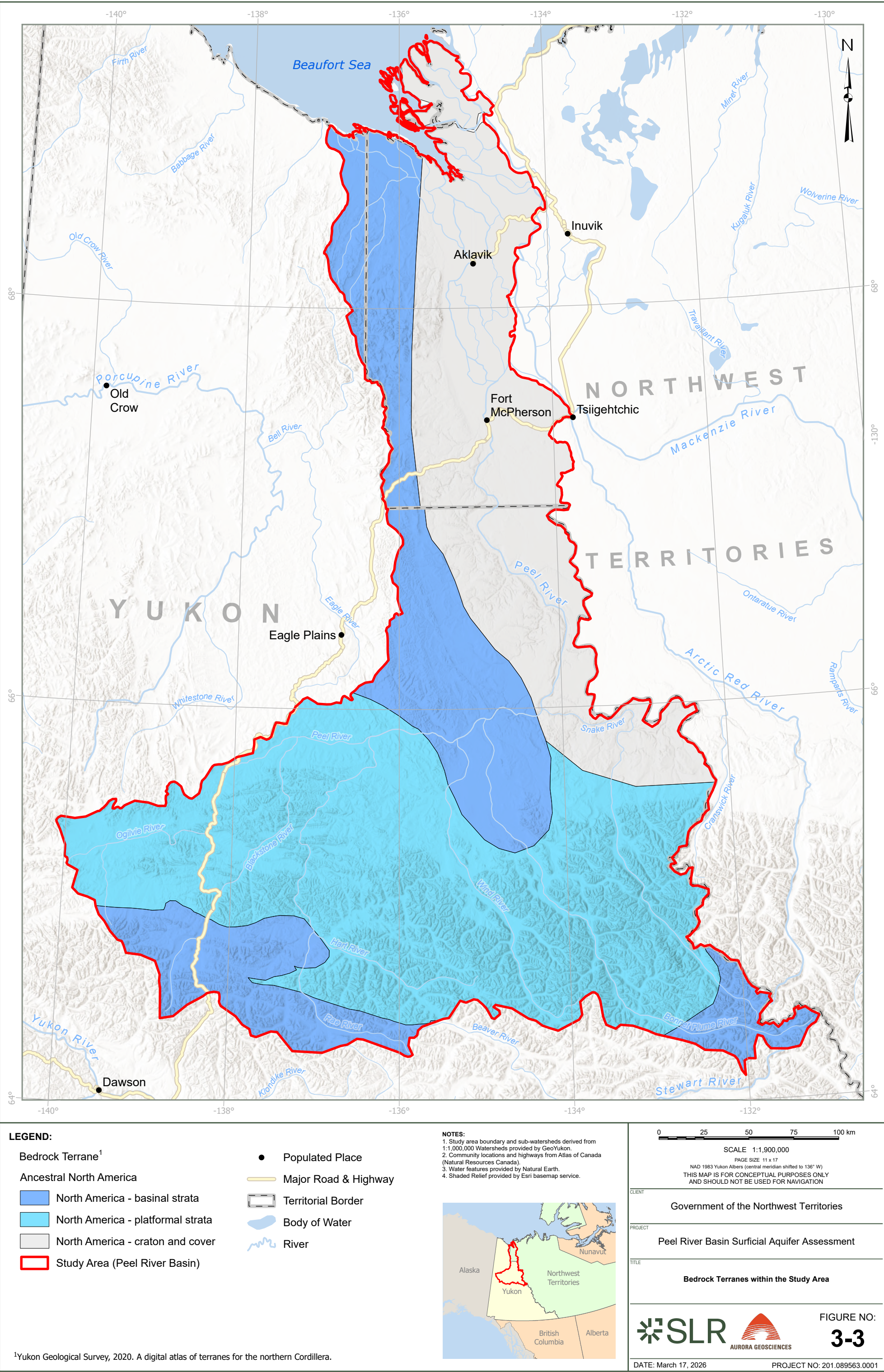
SCALE 1:1,900,000

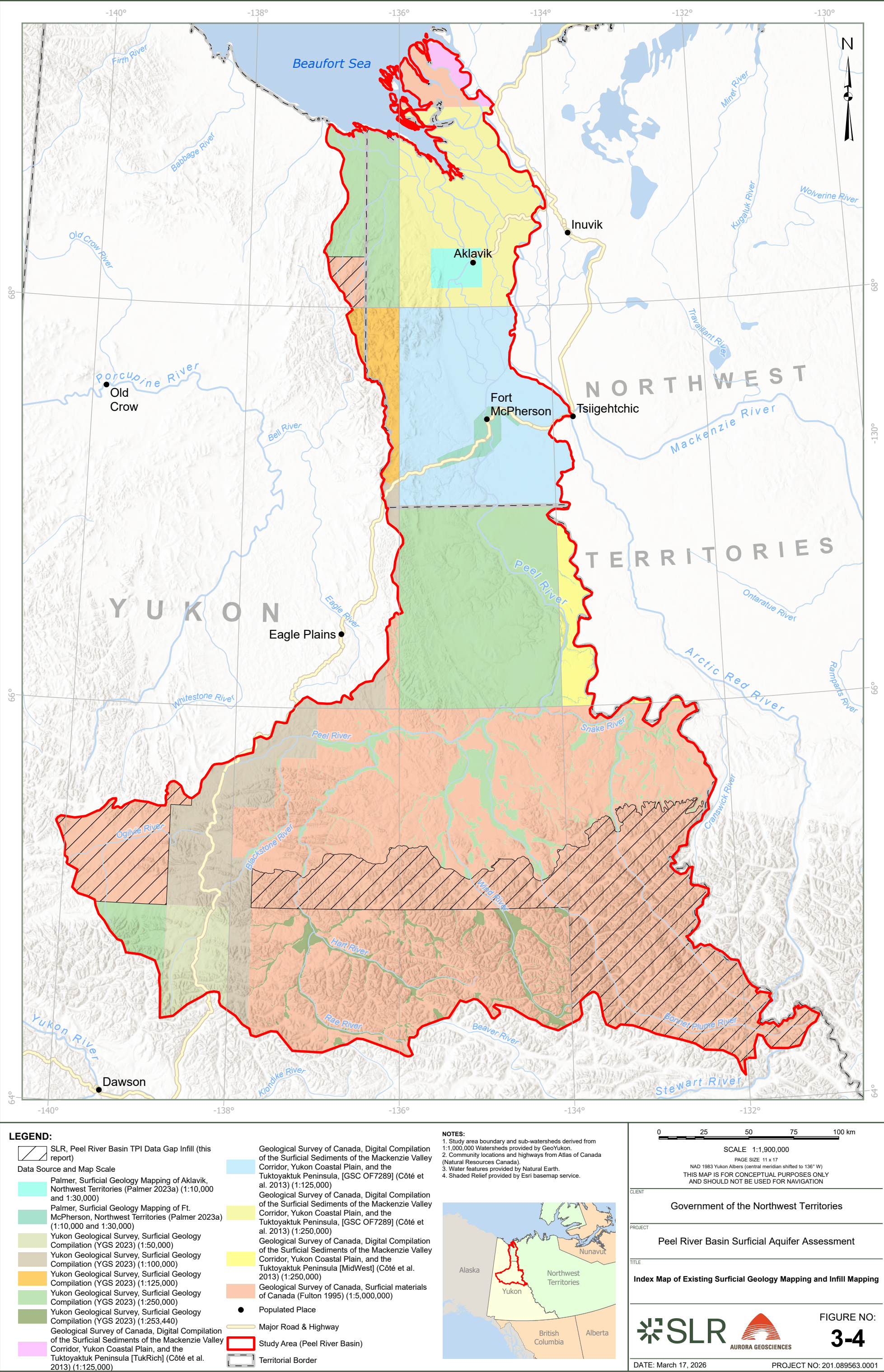
PAGE SIZE 11 x 17

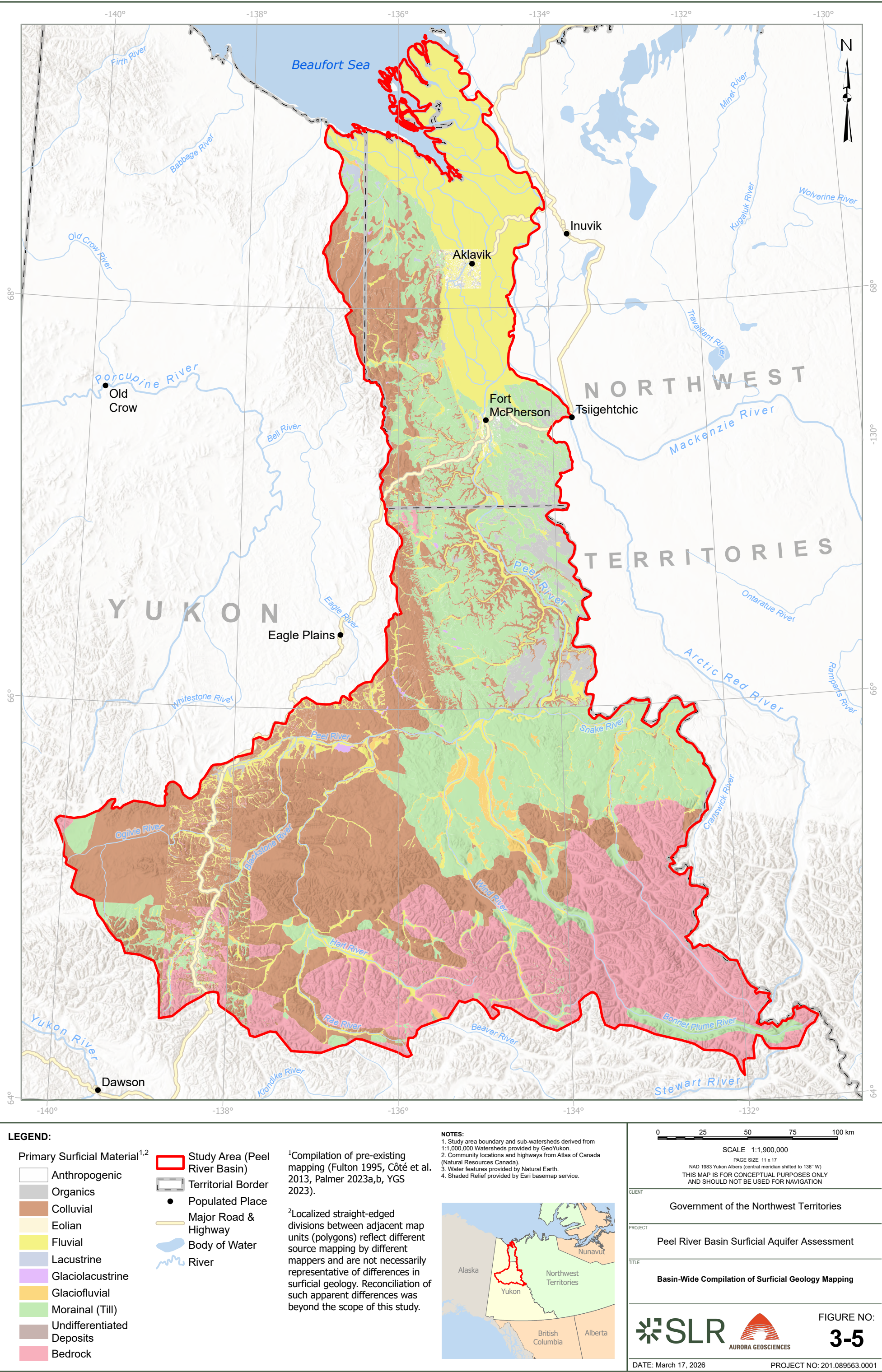
NAD 1983 Yukon Albers (central meridian shifted to 136° W)

THIS MAP IS FOR CONCEPTUAL PURPOSES ONLY AND SHOULD NOT BE USED FOR NAVIGATION

CLIENT	Government of the Northwest Territories
PROJECT	Peel River Basin Surficial Aquifer Assessment
TITLE	Basin-Wide Compilation of Bedrock Geology Mapping
SLR AURORA GEOSCIENCES FIGURE NO: 3-2	
DATE: March 17, 2026	PROJECT NO: 201.089563.0001







3.1.4 Permafrost Compilation

Figure 3-6 presents the permafrost distribution within the Peel River basin and the Western Mackenzie Delta in the Yukon and NWT. Within the study area, discontinuous permafrost (i.e. underlies 50–90% of the area) occurs in the Western Mackenzie Delta and along the southern margins of the upper and central Peel sub-basins (Brown et al. 2002). The remainder of the basin is characterized by continuous permafrost (i.e. underlies 90–100% of the area) (Brown et al. 2002). Localized areas of unfrozen or thawed ground within areas of permafrost, known as taliks, can be found beneath or adjacent to deep water bodies in the Western Mackenzie Delta and even within the zone of generally continuous permafrost characterizing the majority of the study area (Brown et al. 2002, Burn and Kokelj 2009). Paleogeographic modelling for Canada indicates abundant relict ice preserved in thick glaciogenic sediments of the western Arctic, widespread segregated ice in fine-grained lacustrine and marine deposits, and high wedge-ice abundance in tundra terrains long exposed since deglaciation—conditions that collectively raise ground-ice potential across the Lower Peel and Western Mackenzie Delta subbasin (O’Neill et al. 2022).

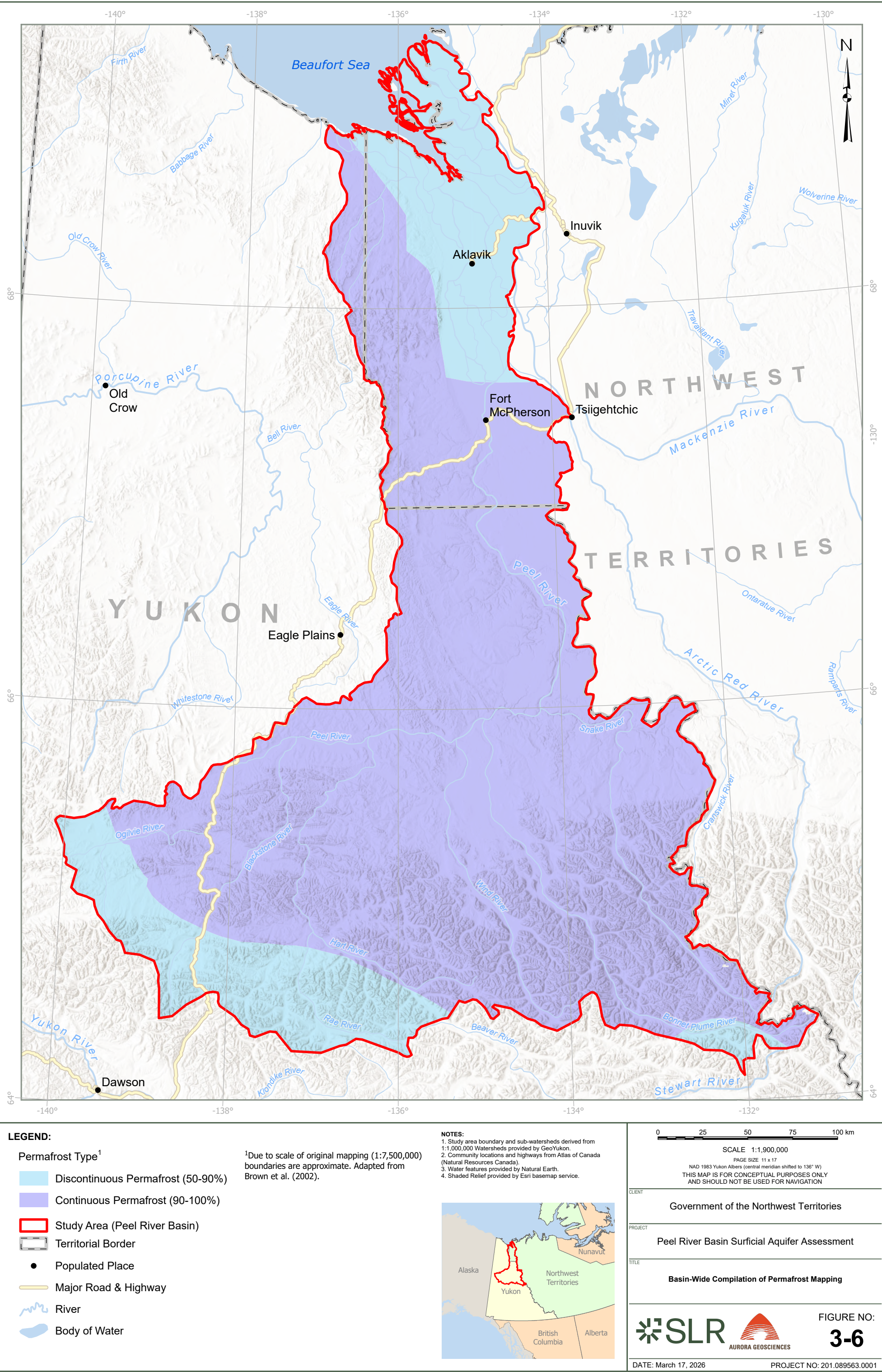
3.1.5 Land Cover Compilation

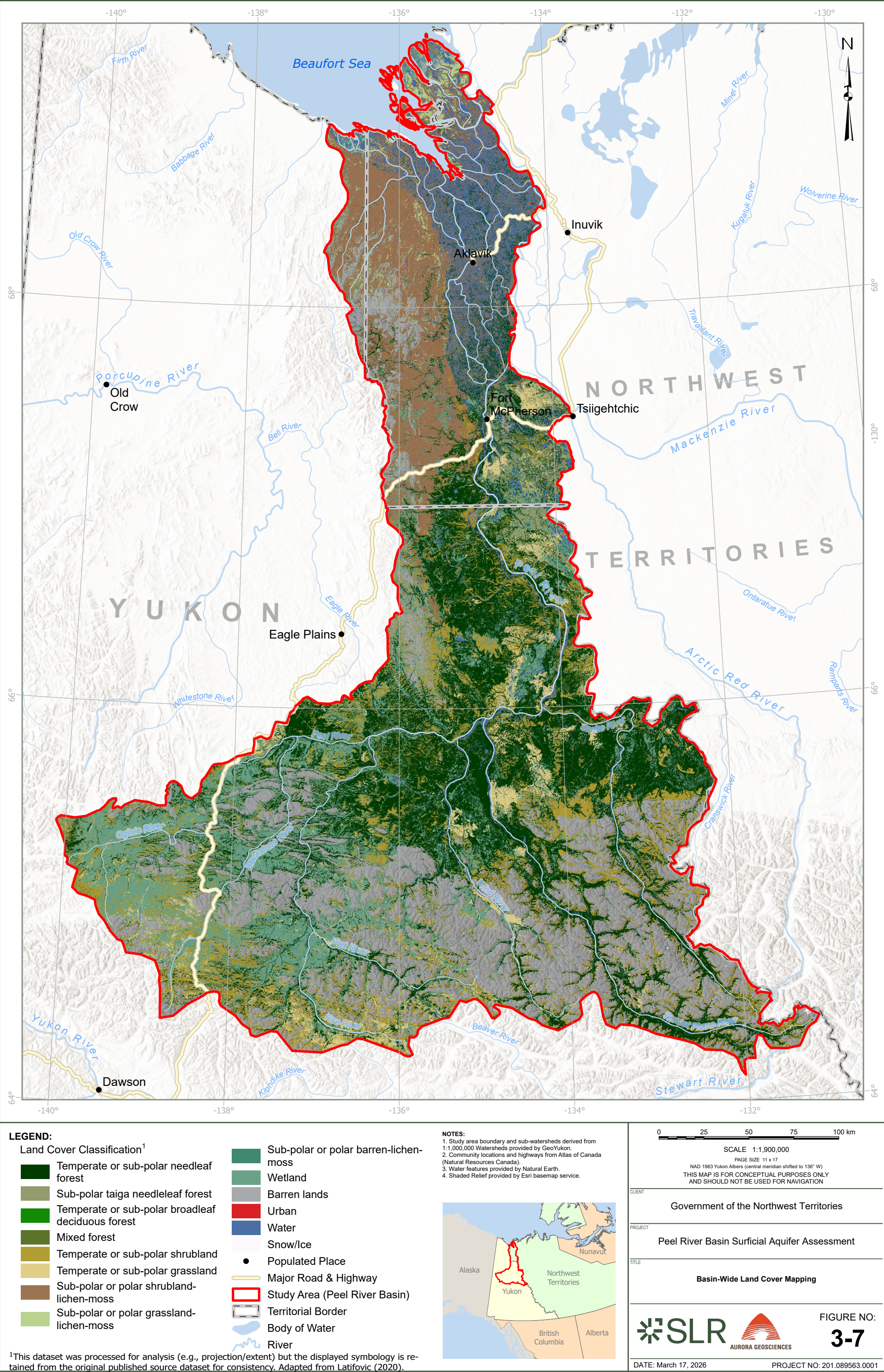
Continuous mapping of land cover data covering Canada at a resolution of 30 m (Latifovic 2020) was available from Natural Resources Canada (Figure 3-7). It distinguishes land cover according to major types of forests, shrubland, grassland, tundra, wetland and other unvegetated characteristics.

In the Peel River basin, the highest elevations of the Mackenzie, Wernecke, Richardson, and adjacent mountain ranges are predominantly barren and sparsely vegetated, with localized patches of permanent snow and ice. Middle to upper elevations transition to tundra environments, expressed mainly as sub-polar shrubland and herbaceous (graminoid/grassland) cover. Moderate and low elevations in the southern and central portions of the basin are largely occupied by temperate or sub-polar needleleaf (coniferous) forests, with pockets of broadleaf (deciduous) and mixed forests occurring along riparian corridors and in areas of recent disturbance. Wetlands are widespread in low-lying terrain—particularly in valley bottoms and on gently rolling uplands—with notable concentrations across the ice-rich Peel Plateau and along major tributary floodplains (Latifovic 2020).

In the Lower Peel and Western Mackenzie Delta subbasin, land cover is dominated by a mosaic of open water, wetlands, and tundra vegetation. Extensive marshes, sedge/graminoid meadows, and willow-dominated shrublands occupy intertributary areas and lake margins, while unvegetated or sparsely vegetated bars and levees occur along active channels. Forest cover is limited and largely confined to the southern delta margin and elevated levee/riparian sites where conditions permit, with the broader delta plain characterized by wetland and tundra classes (Latifovic 2020).







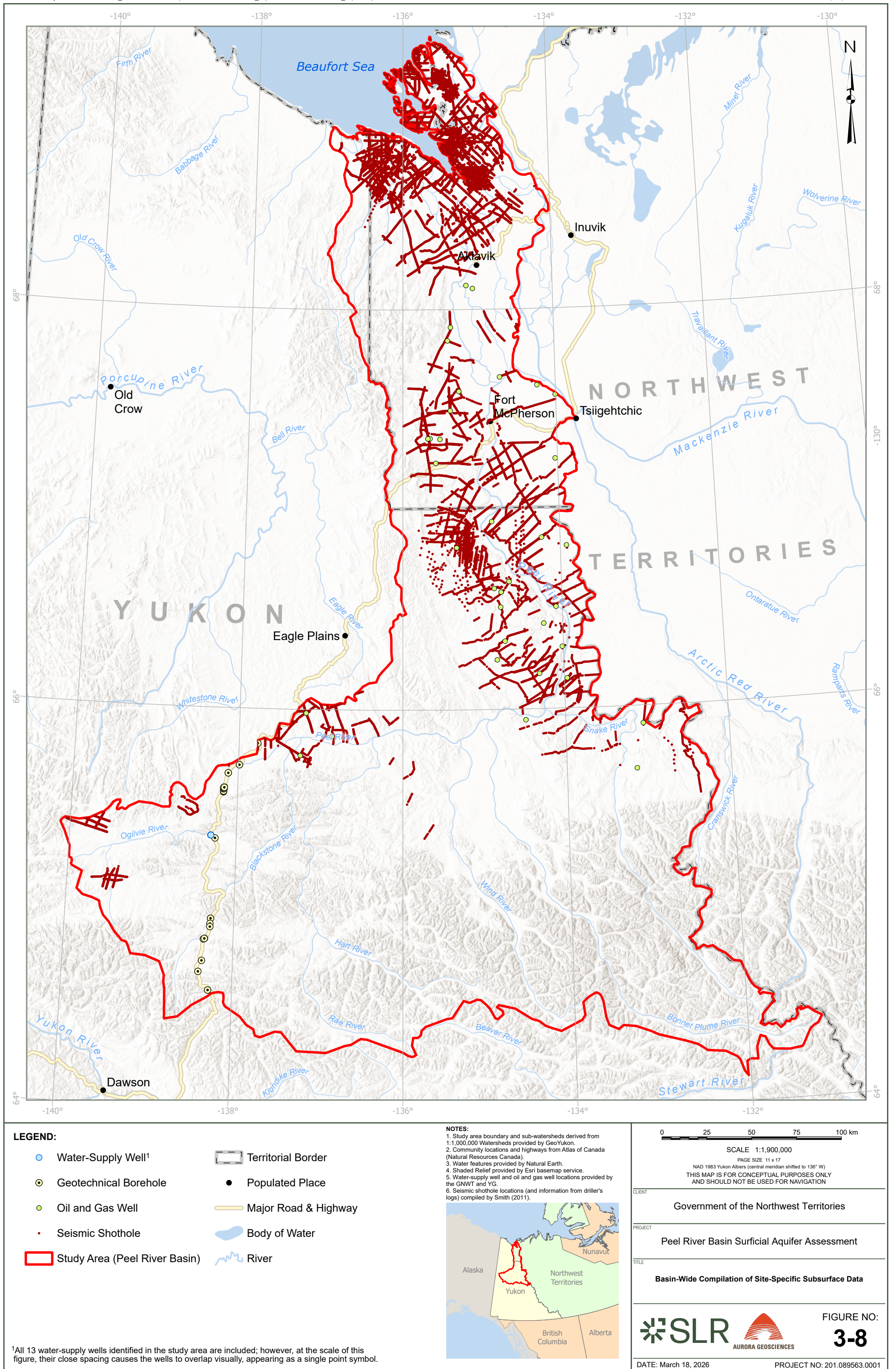
3.1.6 Site-specific Subsurface Data Compilation

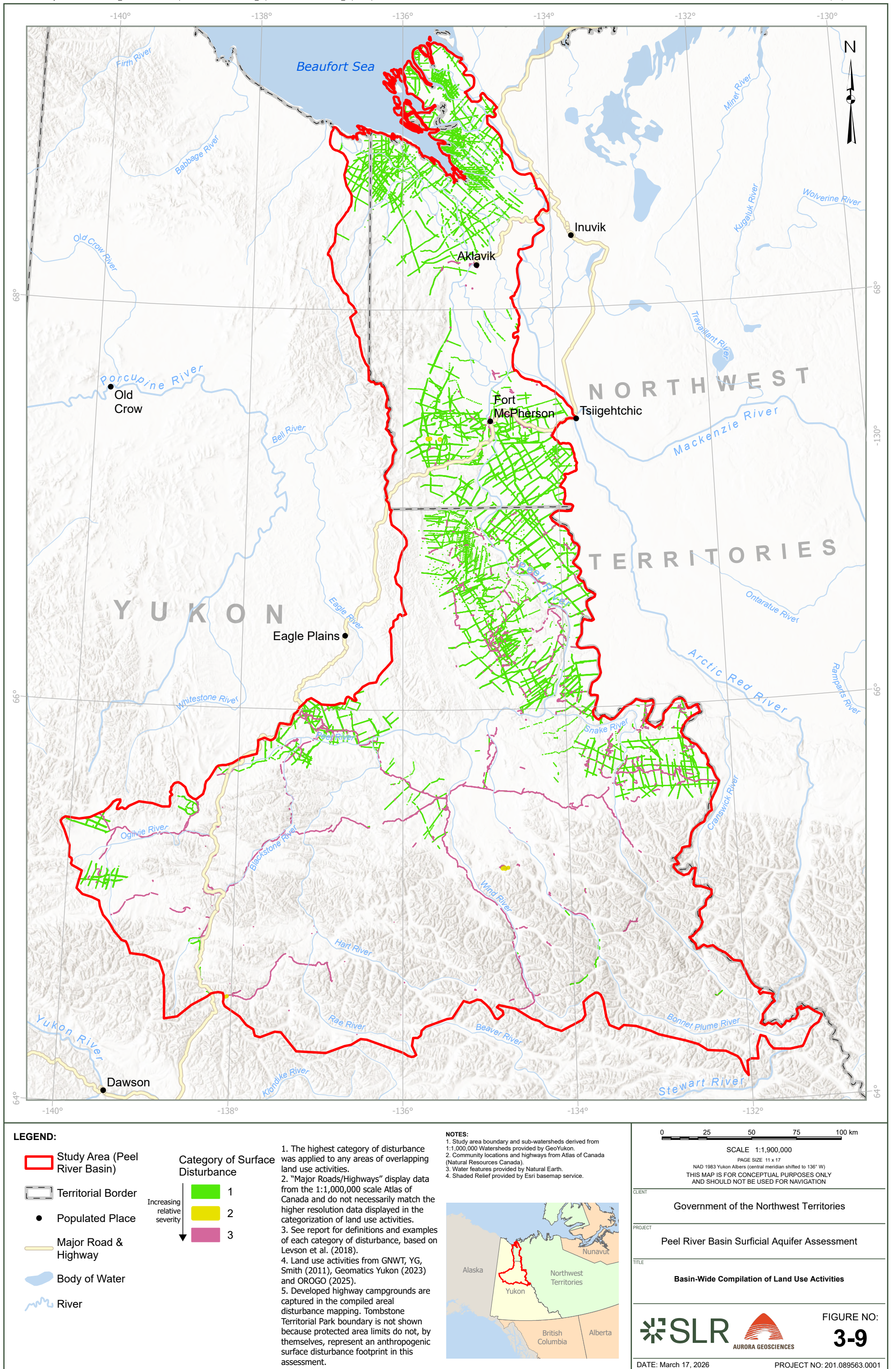
Subsurface data coverage (Figure 3-8) is variable and primarily concentrated in areas of historical hydrocarbon exploration and extraction activity within the Mackenzie Delta, the Peel Plateau, and the Eagle Plains (Smith 2011, OROGO 2025). Beyond the 37 oil and gas wells, a significant archive of near-surface lithostratigraphic data is provided by 37,308 seismic shotholes, which offer extensive coverage across northern Yukon and the NWT (Smith 2011). Unlike the extensive infrastructure in the energy sector, geotechnical boreholes and groundwater well infrastructure is limited. Although standardized water well (13 wells) and geotechnical borehole (44 boreholes) databases are publicly available for the Yukon portion of the study area (GIN 2013, YG 2025b), a comparable centralized public database for water well records is currently not available for the NWT. Consequently, near-surface geological data for the NWT portion of the basin is largely limited to the aforementioned seismic shothole logs (Smith 2011).

3.1.7 Land Use Activity Compilation

A basin-wide compilation of available mapping of land use activities, categorized according to one of three levels of disturbance (based on Levson et al. 2018), indicates most land use activities occur in association with resource activity and road networks in the northern half of the study area (Figure 3-9). The greatest concentration of surface disturbance is in the northeastern portion of the study area, mostly in the lowlands of the Central Peel and Lower Peel and Western Mackenzie Delta subbasins, where oil and gas exploration is most widespread. The most conspicuous disturbance pattern in the Peel River basin represents seismic cut-line grids, which pose minimal direct risk to groundwater. Over time, however, seismic cut-lines have the potential to impact uppermost permafrost and, in turn, shallow groundwater. A variety of overlapping land use activities occur in association with most communities, such as Aklavik and Fort McPherson, and constitute a risk to groundwater where underlain by surficial aquifers.







3.2 Surficial Aquifer Potential

3.2.1 Overview

As noted in Section 2.2.1, a TPI-based analysis was used to approximate the occurrence of potential Type 1 (modern fluvial floodplains & terraces) and Type 3 (modern fluvial fans and colluvial fans/cones) surficial aquifers in the large data gap in the southeastern portion of the study area and smaller gaps in the northwestern and southwestern portions of the study area. The areas of surficial aquifer potential from the raster-based (TPI) analysis contrast in appearance with areas of potential surficial aquifers based on manually delineated (interpreted) surficial geology. The TPI-based Type 1 (modern fluvial floodplains & terraces) and Type 3 (modern fluvial fans and colluvial fans/cones) surficial aquifers inherently have greater granularity and more scattered distribution than those delineated manually. The TPI-based areas of surficial aquifer potential were calibrated with the training area classifications (Figure 3-10) to predict roughly the same proportion of classified Type 1 (modern fluvial floodplains & terraces) surficial aquifers, and balance as best as possible the amount of over-classified and under-classified areas. Therefore, the areal proportion of Type 1 (modern fluvial floodplains & terraces) surficial aquifers classified in the TPI analysis area can be considered roughly representative of the areal proportion of the mapped surficial geology areas. Type 3 (modern fluvial fans and colluvial fans/cones) surficial aquifers were more difficult to predict based purely on TPI-based landscape metrics, as fans have a wider range of TPI values than the lower-lying valley bottom deposits corresponding to Type 1 (modern fluvial floodplains & terraces) surficial aquifers. Training data for Type 3 (modern fluvial fans and colluvial fans/cones) surficial aquifers were also mapped less consistently than units corresponding to Type 1 (modern fluvial floodplains & terraces) surficial aquifers and should therefore be considered less reliable.

Despite the limitations of the attempted delineation of areas of surficial aquifer potential based on the TPI analysis, the general valley-bottom distributions are appropriate and ensure such sensitive environments are not completely overlooked in the assessment of surficial aquifer vulnerability. Areas of Type 4a (unconfined glaciofluvial) and Type 4b (confined glaciofluvial) surficial aquifer potential are not represented in the data gap area (outlined on Figure 3-4), for reasons discussed above in Section 2.2.1, but the relative ruggedness and locally unglaciated history of most of this gap area likely moderate possible under-representation.

Figure 3-11 presents the compilation mapping of areas with surficial aquifer potential, based primarily on the type, characteristics and distribution of surficial geology units, with consideration of limited subsurface and/or aquifer information available in seismic shothole drill logs, sparse well records and groundwater-related publications. Shallow groundwater flow systems are controlled by local topography and relative permeability of the surficial and/or upper bedrock materials (including consideration of permafrost). Groundwater flow is expected to mimic topography and generally flow from areas of higher elevation to areas of lower elevation.

Potential surficial aquifers within the Peel River basin represent three primary types from the classification by Wei et al. (2009) (Table 3-1 and Table 3-2). Figure 2-1 provides a schematic cross-sectional representation of the main surficial aquifer types interpreted to occur within the study area. Illustrative cross-sections representing actual subsurface stratigraphy and inferred aquifer/aquitard units, based on extrapolation from limited subsurface data, have been prepared for the Aklavik and Fort McPherson areas (Sections 3.2.2 and 3.2.5).



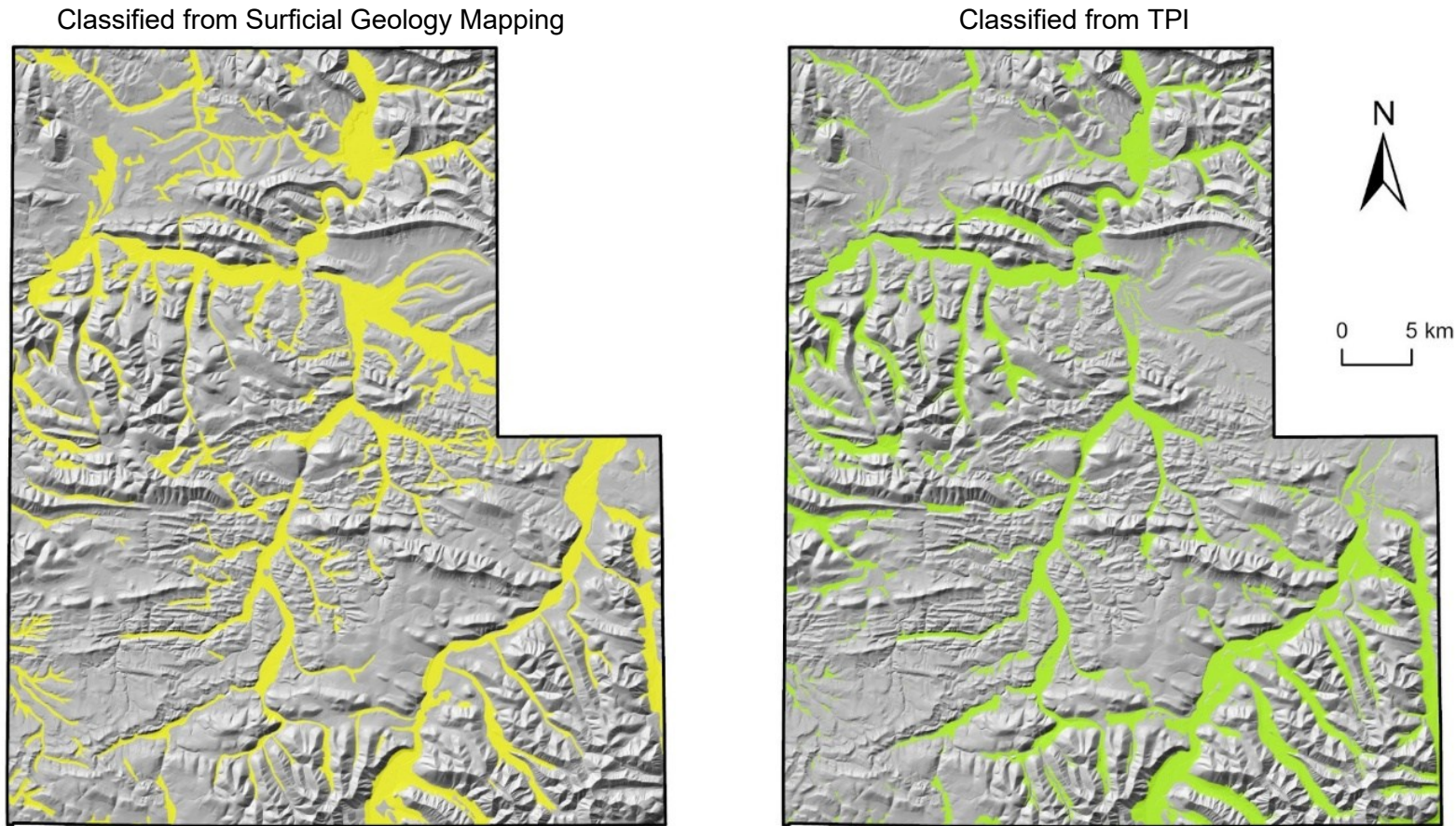


Figure 3-10. Example comparison of the training area of Type 1 (modern fluvial floodplains & terraces) surficial aquifers delineated from existing surficial geology mapping (left; yellow) versus Type 1 (modern fluvial floodplains & terraces) surficial aquifer potential inferred using the TPI method (right; green).



Table 3-1 summarizes the proportional distribution of each potential surficial aquifer type. Areas with potential Type 1 (modern fluvial floodplains & terraces) surficial aquifers are common and geographically widespread; they are predominantly concentrated along the bottoms of river and creek valleys, including the Peel River and its major tributaries (e.g., Ogilvie, Blackstone, Hart, Wind, Snake, and Bonnet Plume), and along distributary corridors in the Western Mackenzie Delta (Aklavik–Inuvik area). Areas with potential Type 3 (modern fluvial fans and colluvial fans/cones) surficial aquifers typically occur at slope-toe positions in mountainous and foothills terrain, especially along the margins of the Richardson and Ogilvie mountains and adjacent valley flanks. Areas with potential Type 4a (unconfined glaciofluvial) surficial aquifers are most widespread in broad-valley settings, including the lower Peel River corridor, Eagle Plains, and Peel Plateau, where meltwater and outwash accumulated during regional deglaciation.

Table 3-1. Areal Proportion of Surficial Aquifer Classes (Based on Wei et al. 2009)

Surficial Aquifer Type	Area (km ²)	Basin-wide Proportional Area (%)
Type 1 - modern fluvial floodplains and terraces	15,151	17
Type 3 - modern fluvial fans and colluvial fans/cones	811	1
Type 4a - unconfined glaciofluvial sediments	1,395	2
Low Surficial Aquifer Potential (poor aquifers & aquitards)	73,055	80
Total	90,412	100

The Western Mackenzie Delta should strictly be classified as a Type 2 (unconfined deltaic) surficial aquifer, according to Wei et al.'s (2009) nomenclature, but for the purposes of this study, it was instead classified as a Type 1 (modern fluvial floodplains & terraces) surficial aquifer. Classification as a Type 1 (modern fluvial floodplains & terraces) surficial aquifer remains consistent with its characterization as an "alluvial plain" in available surficial geology mapping and the similar mapping-based classifications for other landforms. Other areas with potential unconfined deltaic aquifers (Type 2 (unconfined deltaic), Table 2-1) likely occur within the study area, in association with deposition of sediments from meltwater draining valleys and entering regressing glacial lakes, but such landforms are not definitively identifiable in the compilation surficial geology mapping on which this assessment was largely based (Côté et al. 2013, YGS 2023). Localized occurrence of Type 2 (unconfined deltaic) surficial aquifers may have been included in a Type 4a (unconfined glaciofluvial) surficial aquifer classification (e.g. raised deltas mapped as glaciofluvial terraces) or inadvertently as an area of low surficial aquifer potential (e.g. raised deltas mapped as glaciolacustrine terraces). An opportunity to improve recognition and inclusion of such Type 2 (unconfined deltaic) surficial aquifers is explored below in Section 4.3.

Although Type 4b (confined glaciofluvial) surficial aquifers may exist within the study area, they were also not definitively identifiable in the regional-scale surficial geology mapping. Although their distribution and extent are unknown in the study area, future work could aid our understanding of their distribution within the Peel River basin and Western Mackenzie Delta (as described further in Section 4.3). Finally, areas with potential Type 5b (karstic) surficial aquifers were not identified in the study area, despite knowledge of some carbonate bedrock in the



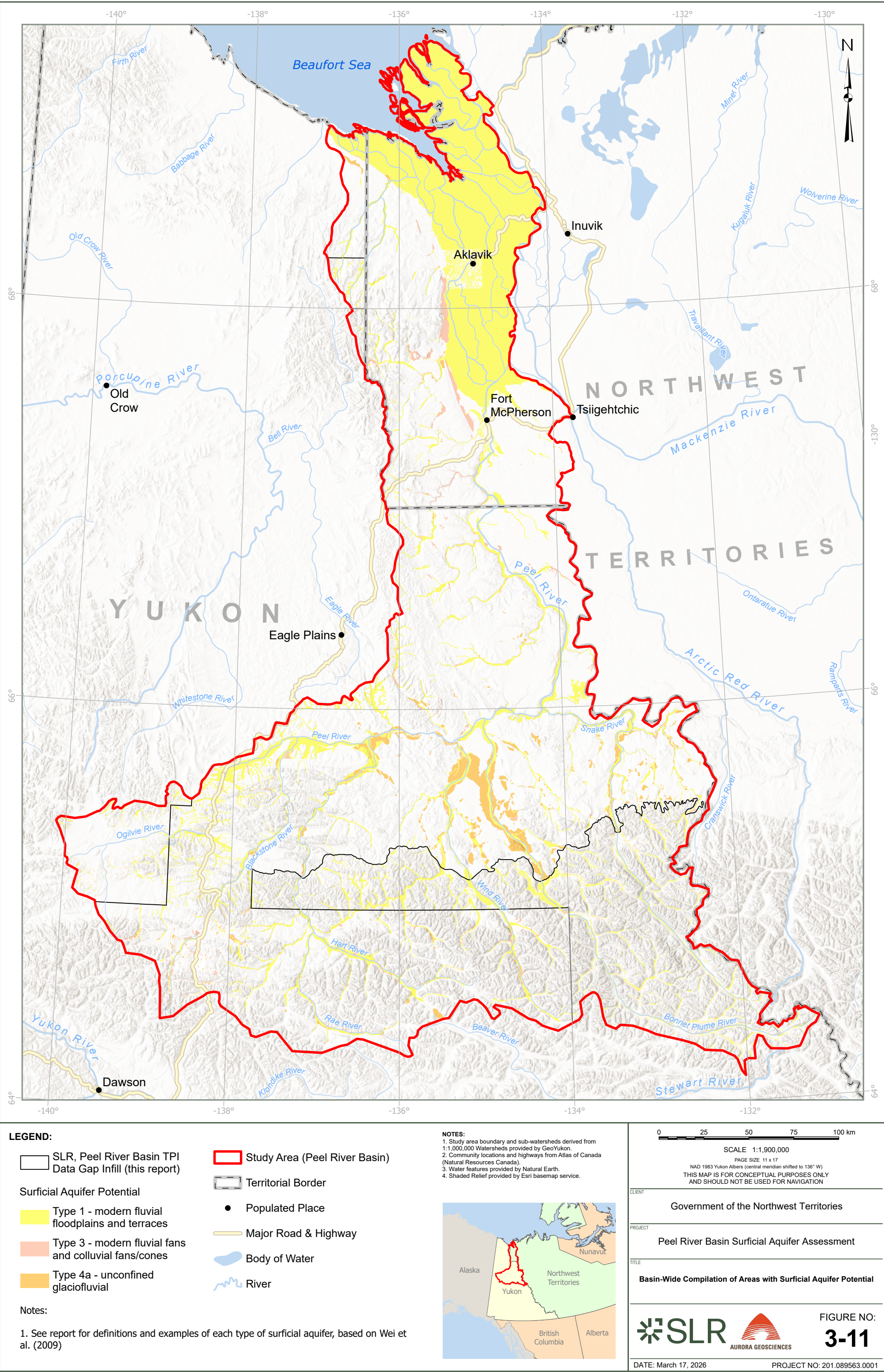
northwestern portion of the study area, due to a lack of karst mapping available for the Peel River basin and Western Mackenzie Delta.

Table 3-2. Summary of Surficial Aquifer Distribution, by Subbasin

Subbasin	Area of subbasin (km ²)	Type 1 (modern fluvial floodplains & terraces) Surficial Aquifer Potential		Type 3 (modern fluvial fans and colluvial fans/cones) Surficial Aquifer Potential		Type 4a (unconfined glaciofluvial) Surficial Aquifer Potential		Total Surficial Aquifer Potential	
		Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%
Upper Peel	37,523	3,288	9	324	1	691	2	4,302	12
Central Peel	21,198	1,556	7	132	1	633	3	2,320	11
Lower Peel and Western Mackenzie Delta	31,691	10,308	33	356	1	72	<1	10,735	34

Table 3-2 summarizes the proportional distribution of surficial aquifer types across the three subbasins. The Lower Peel and Western Mackenzie Delta subbasin exhibits the highest proportional surficial aquifer potential (34%). The surficial aquifer potential in this subbasin is primarily attributable to the extensive fluvial (Type 1 (modern fluvial floodplains & terraces)) deposits (33% of the subbasin; approximately 96% of the surficial aquifer area), whereas fluvial/colluvial fan (Type 3 (modern fluvial fans and colluvial fans/cones)) deposits are limited (1%) and glaciofluvial (Type 4a (unconfined glaciofluvial)) deposits are negligible (<1%). The Upper Peel subbasin, the largest of the three, shows a total surficial aquifer potential of 12%, dominated by Type 1 (modern fluvial floodplains & terraces) (9% of the subbasin; ~75% of the surficial aquifer area), with Type 4a (unconfined glaciofluvial) contributing 2% and Type 3 (modern fluvial fans and colluvial fans/cones) comprising only 1% of the subbasin. The Central Peel subbasin, the smallest of the three, exhibits a total surficial aquifer potential of 11%, primarily associated with fluvial (Type 1 (modern fluvial floodplains & terraces)) deposits (7% of the subbasin; ~64% of the surficial aquifer area), with lesser contributions from Type 4a (unconfined glaciofluvial) (3%) and Type 3 (modern fluvial fans and colluvial fans/cones) (1%) deposits. Overall, surficial aquifer potential across these subbasins ranges from 11% to 34%, with fluvial deposits consistently proving the most widespread in each, providing the principal potential surficial aquifer resource. Across all three subbasins, the combined extent of Type 3 (modern fluvial fans and colluvial fans/cones) and Type 4a (unconfined glaciofluvial) surficial aquifers constitutes less than half of the total surficial aquifer potential, approximately 25% in the Upper Peel, 36% in the Central Peel, and only 3% in the Lower Peel and Western Mackenzie Delta, underscoring the predominance of Type 1 (modern fluvial floodplains & terraces) surficial aquifers.





3.2.2 Type 1 (modern fluvial floodplains & terraces)

Type 1 (modern fluvial floodplains & terraces) surficial aquifers are mostly represented by modern (Holocene-age) fluvial floodplains and terraces along the bottoms of river and creek valleys. They represent approximately 17% of the study area (Figure 3-11 and Table 3-1). Most are inferred to be, or have the potential to be, hydrologically connected with modern watercourses due to their spatial association and low relief (Figure 2-1). Figure 3-12 presents a typical Type 1 (modern fluvial floodplains & terraces) surficial aquifer setting in the Western Mackenzie Delta near Aklavik, NWT. Type 1 (modern fluvial floodplains & terraces) surficial aquifers, originating from deposition of sediments within flowing water, most commonly comprise well-sorted sand and gravel (active channel deposits) overlain by silt and fine to coarse sand (floodplain deposits). Coarser- and finer-grained deposits may be interbedded, a reflection of spatio-temporal changes in the energies of depositional settings, in thicker fluvial valley fills. Thin layers of organic material, representing relatively stable periods, may be buried and/or at surface.

Permafrost may occur in landforms with Type 1 (modern fluvial floodplains & terraces) surficial aquifer potential, especially within stable terraces capped by silty flood deposits and insulated by organic cover, but it is generally discontinuous due to at least localized talik zones that are maintained by year-round surface and hyporheic flow along associated watercourses. Areas prone to flooding also tend to maintain at least shallow, if not open, taliks. Even if frozen (permafrost) at depth, suprapermafrost groundwater is commonly able to flow through the active layer (when not seasonally frozen) of Type 1 (modern fluvial floodplains & terraces) surficial aquifers into watercourses.

Type 1 (modern fluvial floodplains & terraces) surficial aquifers, especially where they represent buried valley surficial aquifers (in some cases in association with Type 4a (unconfined glaciofluvial) surficial aquifer complexes), are important for their groundwater resource potential. All water wells identified during this assessment appear to be screened within Type 1 (modern fluvial floodplains & terraces) surficial aquifers (13 wells), indicating they are a reliable and productive source of groundwater. However, a lack of publicly available water well data for the NWT portion of the study area and no communities located within the Yukon portions of the study area remain a gap in this analysis.

Figure 3-13 illustrates the hydrostratigraphy across the Peel Channel within the Western Mackenzie Delta near Aklavik, NWT. The cross-section depicts a Type 1 unconfined fluvial surficial aquifer occupying the valley-bottom plain and hydraulically connected to the river, at least while not frozen seasonally. Across the transect, the fluvial silty sand surficial aquifer is laterally continuous beneath the active channel. The water table intersects the Peel Channel and lies generally a few to ~10 m below ground surface (bgs) along the transect (although it may be locally perched on permafrost), indicating strong hydraulic connectivity and stage-responsive behaviour via bank storage and hyporheic exchange, a hallmark of unconfined surficial aquifers in riverine terrain (Tonina and Buffington, 2009).

3.2.3 Type 3 (modern fluvial fans and colluvial fans/cones)

Type 3 (modern fluvial fans and colluvial fans/cones) surficial aquifers are mainly represented by modern (Holocene-age) fluvial fans, but also include colluvial fans and cones, due to their morphological similarity and commonly shared geneses. They represent approximately 1% of the study area (Figure 3-11 and Table 3-1). These landforms typically occur at prominent, concave breaks in slope and/or widenings of valleys or gullies. They form fan-like or coalescent wedges of sediment. Sediments comprising mapped fluvial fan (Type 3 (modern fluvial fans and colluvial fans/cones)) surficial aquifers are commonly coarser-grained than adjacent fluvial plain



(Type 1) surficial aquifers due to their deposition along higher-gradient channels. Sand and gravel, up to boulder-sized, typically predominate fluvial fans at the base of steep mountain channels. Such landforms may transition with colluvial fans, which are formed mainly by colluvial (landslide) processes.

Rainfall and snowmelt readily infiltrate Type 3 (modern fluvial fans and colluvial fans/cones) surficial aquifers, but their sediments may not be saturated until considerable depth due to their anomalous thickness in their upper reaches (e.g. fan apex). Groundwater within fans is commonly deepest just downstream of the apex, where water from upslope first encounters thick, permeable substrates, and gradually becomes shallower toward the toe until the fan surface (or incised channel) intercepts the groundwater table itself. Groundwater discharge is common along channels incised into the lower reaches of fluvial fans.

Permafrost is generally less common and/or generally at greater depth in landforms with Type 3 (modern fluvial fans and colluvial fans/cones) surficial aquifer potential than in those with Type 1 (modern fluvial floodplains & terraces) surficial aquifer potential. Landforms with Type 3 (modern fluvial fans and colluvial fans/cones) surficial aquifers tend to have coarser-grained, better-drained sediments that readily allow heat penetration into the ground during snow-free months. They also typically exhibit an overall convex surface expression, which improves drainage and helps resist accumulation of thick, insulating organic cover at surface. Some particularly low-gradient, inactive fans capped by fine-grained sediments may be an exception and may exhibit shallower permafrost.

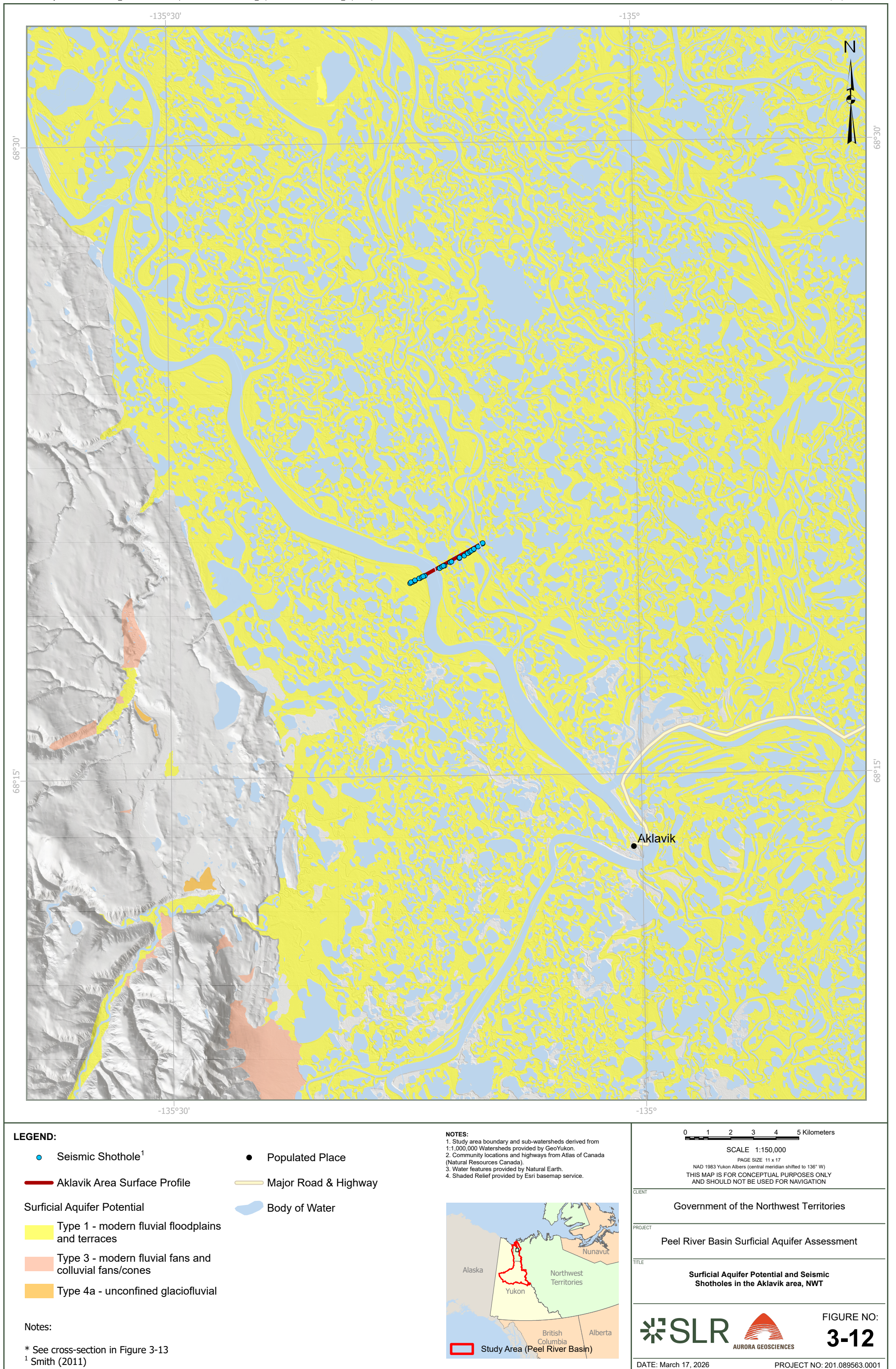
3.2.4 Type 4a (unconfined glaciofluvial)

Type 4a (unconfined glaciofluvial) surficial aquifers are unconfined and associated with surficial glaciofluvial sediments, deposited in proglacial or ice-contact environments. They represent approximately 2% of the study area (Figure 3-11 and Table 3-1). Most Type 4a (unconfined glaciofluvial) surficial aquifers in the study area are represented by outwash deposited in front of, or alongside, retreating glaciers. Ice-contact deposits in the form of eskers, kames, and kame terraces are also represented. Sediments comprising glaciofluvial landforms are typically mixtures of sand and gravel, with the proportion of each reflecting the energy of the depositional environment in which they formed. Eskers tend to have the coarsest-grained sediments (commonly up to boulder in size), owing to their common subglacial (high-energy) origin, followed by kame terraces and outwash.

Glaciofluvial landforms typically offer maximum opportunity for infiltration of precipitation and snowmelt but are commonly unsaturated for considerable depth. Groundwater tables in small and/or high-relief glaciofluvial landforms may be near, or even below, the base of the landform, given how freely water is able to drain away. Perched water table conditions caused by poor drainage through underlying aquitard materials are also expected to be common. As such, the basin-wide surficial aquifer potential within glaciofluvial landforms may be overestimated, although these sediments do have an important recharge function.

These unconfined, highly permeable surficial aquifers are particularly vulnerable to contamination from surface activities due to the lack of a protective confining layer (Wei et al. 2009, ARKTIS Solutions Inc. 2016). Despite their commonly localized and discontinuous nature, these deposits are hydrogeologically significant because they can act as local storage units that discharge groundwater into adjacent streams and lakes, thereby supporting essential baseflow, especially during the low-flow winter months (ARKTIS Solutions Inc. 2016, Levson et al. 2018).





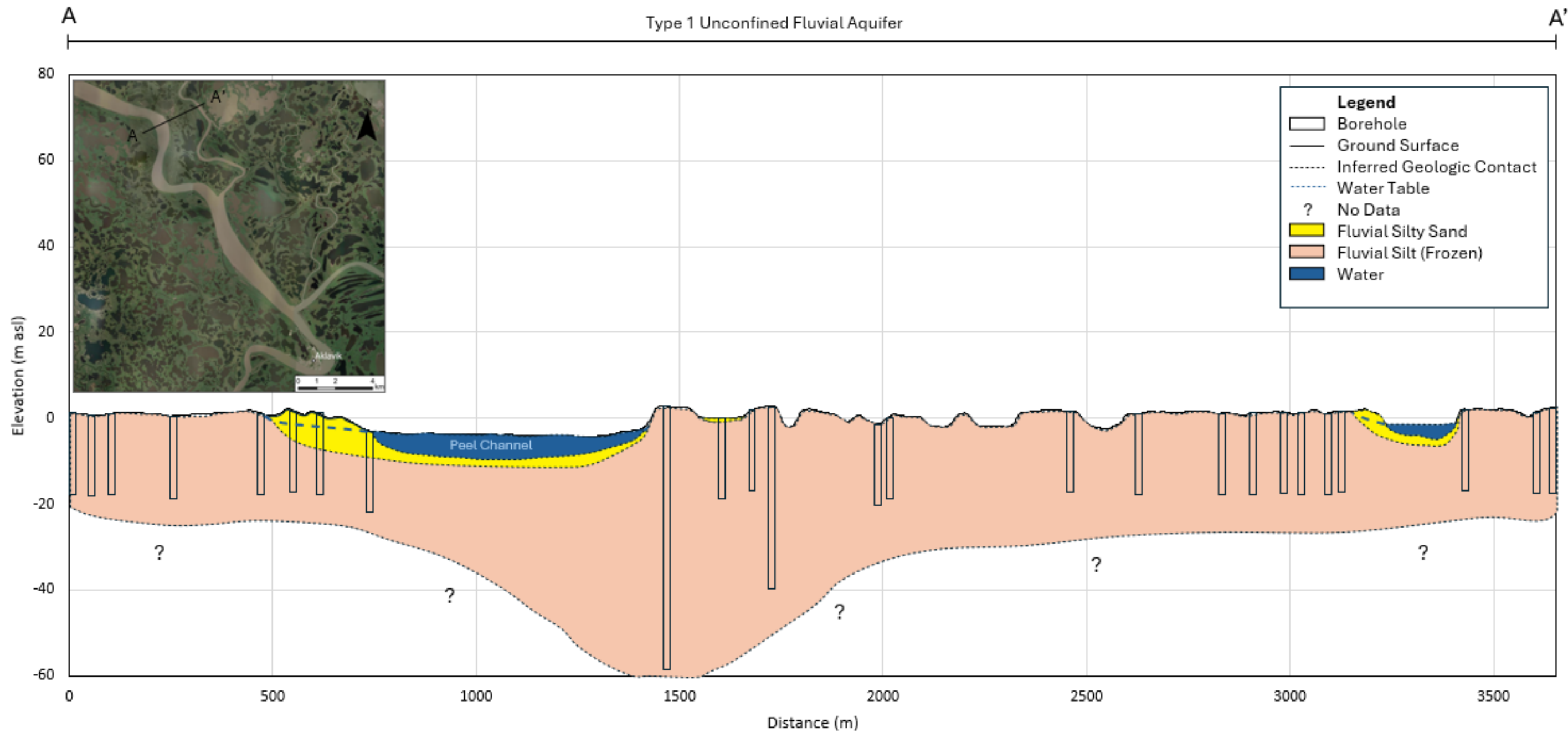


Figure 3-13. Illustrative geological cross-section, informed by seismic shothole drill logs and surficial aquifer classification in the Aklavik area. Permafrost is understood to be continuous across this section except beneath large waterbodies (e.g. Peel Channel) and within recent alluvial deposits. Unfrozen fluvial silty sand is the primary Type 1 (modern fluvial floodplains & terraces) aquifer, while the frozen fluvial silt is an aquitard; however, it is beyond the scope of this study to differentiate surficial aquifer potential beyond the surficial material classifications in the existing surficial geology mapping on which this is based.



3.2.5 Areas with Low Surficial Aquifer Potential

Areas of low surficial aquifer potential, whether poor aquifers or actual aquitards, represent approximately 80% of the study area (Figure 3-11 and Table 3-1). Unconsolidated materials generally interpreted to have low surficial aquifer potential in the study area include most tills, lacustrine and glaciolacustrine deposits, organic material and colluvial blankets inferred to comprise predominantly fine-grained sediments, based on knowledge of depositional settings and representative seismic shothole drill logs assembled by Smith (2011). Precipitation and snowmelt predominantly run off the surface of such materials rather than infiltrating, and the small amount of water that does eventually recharge the groundwater table is not readily accessible due to low permeability of the materials. Exceptions exist, such as glaciolacustrine littoral deposits and subglacial melt-out till locally comprising sandier material and higher relief, but they are of limited extent and not well represented by regional-scale mapping, so they have not been explicitly included as potential surficial aquifers. Runoff from wetland areas may actually be moderated by localized storage in organic soils, especially in closed depressions where water level can rise, but considering the implications of such complexities is beyond the scope of this project. Bedrock formations were also assumed to have relatively low surficial aquifer potential in the absence of information on shallow fracturing, porosity or water quality trends.

Figure 3-14 presents a cross-section profile approximately 50 km west of Fort McPherson. The section shows a valley cut into glaciogenic uplands with till mantling sedimentary bedrock. Although the valley-bottom sand and gravel unit is technically a Type 1 (modern fluvial floodplains & terraces) surficial aquifer, hydraulically connected to its source creek, it is of limited lateral extent or at least poorly represented by available regional-scale surficial geology mapping. The more expansive till-mantled valley walls have low surficial aquifer potential and are likely frozen (permafrost) within a metre or two of surface.

Although not the focus of this study, it is important to recognize the presence of deep saline aquifers within the bedrock underlying any surficial aquifers or aquitards (ARKTIS Solutions Inc. 2016). While these aquifers may have limited interaction with surface water features and are not expected to be suitable for potable water supply (due to brackish or saline nature), they can be an important resource for oil and gas development as water supply for hydrofracking and for water disposal. Investigating the potential linkages between surficial aquifers and those at depth in bedrock is beyond the scope of this assignment yet highlighted for future research in Section 4.3.



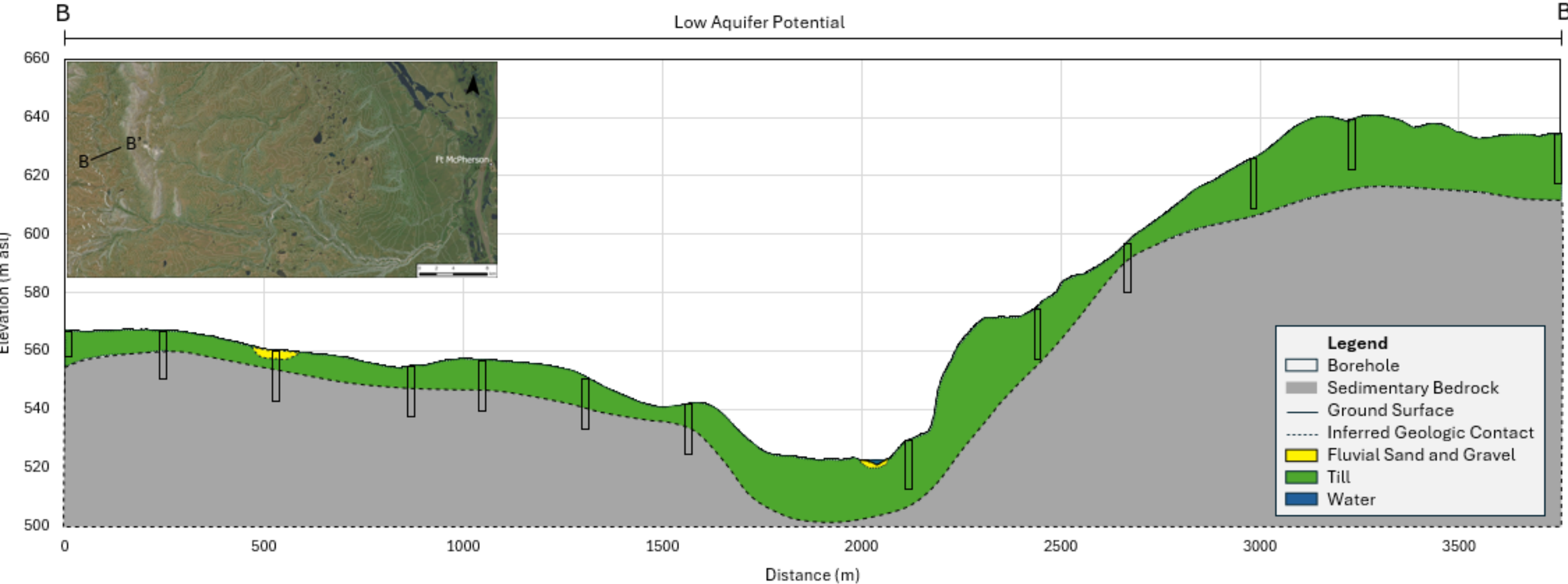


Figure 3-14. Illustrative geological cross-section, informed by seismic shothole drill logs and classification of deposits with and without surficial aquifer potential in the Fort McPherson region, NWT. Permafrost is understood to be continuous along this cross-section, although slightly depressed beneath active stream channels that do not freeze to their beds in winter. Although till is considered an aquitard, the limited occurrences of fluvial sand and gravel along the transect may provide localized Type 1 (modern fluvial floodplains & terraces) aquifer potential. However, differentiating surficial aquifer potential beyond the surficial-material classes in the existing surficial geology mapping used for this assessment was outside the study scope. Accordingly, Low Aquifer Potential is shown continuously across the section. The limited distribution of surficial aquifers along this transect west of Fort McPherson is typical of many of the till-covered regions in the study area.



3.3 Groundwater Recharge and Discharge

Surficial hydrogeology mapping (Figure 3-15) represents the ranking of both unconsolidated and bedrock hydrostratigraphic units to which infiltration factors were assigned as a basis for spatial calculation of potential recharge. Application of the water budget methodology outlined in Section 2.3 indicates potential recharge within the Peel River basin, on average, is about 88 mm/yr (Figure 3-16). The total estimated potential annual discharge (recharge + runoff) in the study area is 247 mm/yr. Therefore, on average, recharge accounts for approximately 12.4% of the estimated water surplus within the study area.

These values are reflective of the variation in the estimated water surplus across the Peel River basin (Section 2.3.2—higher surplus in the mountainous areas to the south, and lower near the ocean in the Western Mackenzie Delta), the distribution of lower permeability surficial materials such as bedrock or till, as well as the distribution of continuous and discontinuous permafrost (i.e. higher recharge in the southwest where permafrost is mapped as discontinuous).

The preliminary water budget indicates the spatial distribution of the water surplus in the study area is the most important factor influencing groundwater recharge rates due to significant regional differences in precipitation from south to north. Second to this is the delineation between areas of continuous (lower recharge) and discontinuous permafrost (higher recharge) (Figure 3-16). Practically, however, only higher permeability materials with at least discontinuities in permafrost (for subpermafrost systems) or sufficient thickness (for suprapermafrost systems) can transmit enough recharge to support a groundwater resource or provide significant contributions to stream baseflows. In the Peel River basin, groundwater recharge varies seasonally, with recharge only occurring during unfrozen (thawed) conditions. A review of groundwater level graphs from the Yukon Observation Well Network (YOWN) indicates that groundwater recharge can occur seasonally in both overburden (YOWN-2002) and bedrock (YOWN-1401) groundwater systems, even in areas that are within mapped continuous permafrost.

It is important to consider that permafrost generally limits groundwater recharge, but it does not significantly affect the distribution of groundwater discharge (Michel 1986). Major discharge areas such as larger watercourses are likely connected to subpermafrost groundwater systems through taliks (Diak et al, 2023). It is also noted that, depending on thickness and composition, the active layer may contain sufficient suprapermafrost groundwater to meaningfully contribute to stream baseflow in the melt season. Groundwater in both suprapermafrost and subpermafrost systems may also discharge at discrete features such as coldwater springs or seeps along breaks in slope.

As discussed in Section 2.3.3, recharge and discharge mechanisms in both suprapermafrost and subpermafrost systems were considered in the development of the water budget to account for the recharge-limiting effects of permafrost. It is acknowledged that these recharge limiting effects are primarily relevant to subpermafrost groundwater. More complex partitioning of runoff/recharge in association with permafrost would require a more precise understanding of the distribution of permafrost and active layer dynamics, and the current approach is considered appropriate for a basin-scale water budget.

Glaciofluvial sands and gravels (Type 4a (unconfined glaciofluvial) surficial aquifers) and fluvial deposits (Type 1 (modern fluvial floodplains & terraces) surficial aquifers) (Figure 3-11) have the highest groundwater recharge potential and have the highest potential for groundwater resource development, although actual recharge across the Peel River basin may vary based on the available surplus.



There is not a direct connection between the areas of higher potential recharge (Figure 3-16) and the surficial geological units with high surficial aquifer potential (Figure 3-15 and Figure 3-11). However, the areas of higher surficial aquifer potential are generally concentrated within valley bottoms or broad, low-lying deltaic areas. The glaciofluvial and fluvial materials present in these potential surficial aquifers are likely to be within the groundwater discharge zones of upgradient mountainous areas where recharge from precipitation is concentrated or connected to drainages that may provide direct recharge from surface water flow or runoff.

Recharge to deep bedrock aquifers is generally considered to be very low, with the vast majority of recharge to surficial aquifers eventually discharging to watercourses as baseflow. Water balance methods that model stream flow based on monthly and annual precipitation, runoff and ET can accurately predict stream flows (Moore et al. 2011). It is expected that the percentage of groundwater recharge that reaches deep geological units is low, and the majority of groundwater flows within the upper, weathered portions of the bedrock.

Traditional knowledge would provide valuable insights into areas of groundwater recharge and discharge, an important recommended follow-up given the limited availability of aquifer mapping and stream flow gauging data (as described further in Section 4.3). Important areas of groundwater discharge can be identified as river systems or areas with limited winter ice cover or springs, for example, and important recharge areas can be identified in association with 'sinking' or 'losing' streams.

3.3.1 Model Calibration to Baseflow

To validate the groundwater recharge values estimated from the GIS-based preliminary water budget analysis, a comparison was made with established streamflow values. At the basin scale, as previously described in Section 2.3.1, it is generally reasonable to assume that groundwater recharge eventually discharges to surface as stream baseflow. Assuming that groundwater loss to deep aquifers and across basin boundaries is negligible, the average annual recharge within a basin should be equal to the average annual baseflow value of the surface water body draining the basin.

A comparison between groundwater recharge and baseflow was completed for the whole Peel River basin as well as for the Upper Peel, Central Peel and Lower Peel and Western Mackenzie Delta subbasins (Table 3-3). A range of stream baseflow estimates at hydrometric stations within each of these subbasins has been provided for comparison using recursive filtering for the Winter Flow method and the blended approach for baseflow separation (Table 3-3).

Baseflow estimated from groundwater recharge compared well with the baseflow estimated using the Winter Flow method from the long-term hydrometric data. Baseflow estimates from the preliminary water budget are approximately 12.5% of the calculated mean annual discharge (MAD) from the whole Peel River basin and each of the contributing subbasins. Winter Flow estimates were developed on streams that vary greatly in basin size and MAD. Winter Flow estimates as a percentage of MAD range from 0% at Rat River with a MAD of 8.2 m³/s (likely due to the river almost completely freezing in winter), to 47% on the Mackenzie River with a MAD of 7907 m³/s (Table 3-3). However, the average Winter Flow estimate from the nine hydrometric stations considered in this assessment is 14% (an unweighted average calculated from the % MAD estimates from each hydrometric station), which indicates a reasonable match between the basin-scale water budget model and the Winter Flow estimates from hydrometric station observations.

The recursive filtering and blended methods for baseflow separation provide higher estimates of baseflow as a component of mean annual discharge (an unweighted average of 70% and 72%



of MAD, respectively, calculated from the % MAD estimates from each hydrometric station) at Peel River and the other reviewed subbasins compared to the Winter Flow method and the outputs from the preliminary water budget.

Baseflow calculations using the recursive filtering method for baseflow separation could be further refined in the future with a more detailed understanding of basin characteristics, noting that this would also influence baseflow estimates using the blended approach.

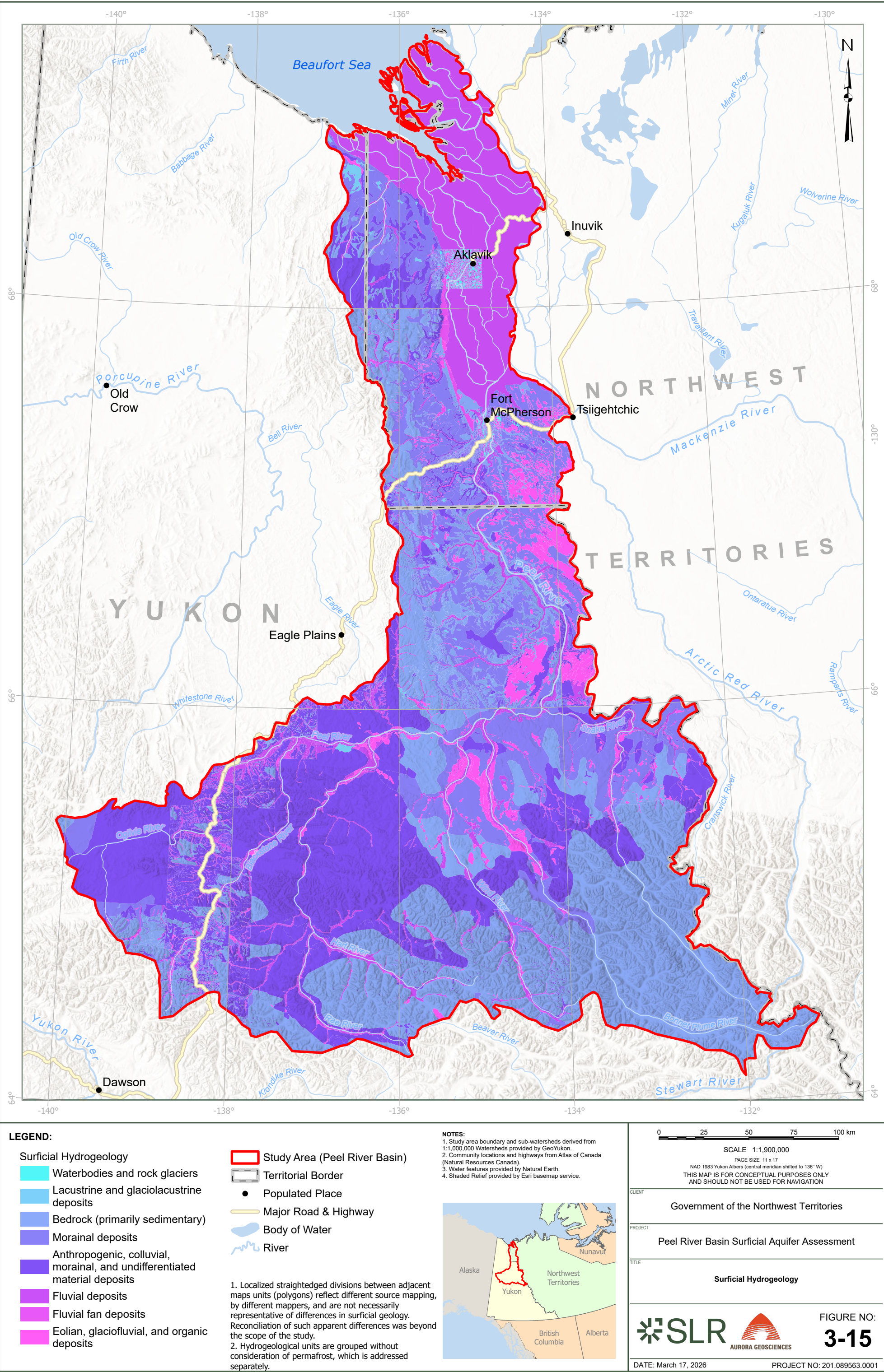
Although the preliminary water budget shows a good match to baseflow derived using the Winter Flow method, it is acknowledged that this approach likely underestimates the total annual baseflow contributions, which likely are higher during summer months due to the effect of the seasonal thawing of the supra-permafrost active layer, which would allow for the transmission of recharge from snowmelt and summer precipitation events to the groundwater table and subsequent discharge as baseflow (St. Jacques and Sauchyn 2009). If the Winter Flow Method is underestimating baseflow, then it is also likely that the preliminary water budget model is underestimating baseflow.

The precipitation, ET, infiltration factors and permafrost reduction factors are reasonable within the preliminary water budget to estimate groundwater recharge and discharge values within the overall Peel River basin and its subbasins. We have confidence that the spatial representation of recharge across the Peel River basin developed using the GIS-based water budget model provides a meaningful indication of where areas of enhanced or lower groundwater recharge are likely.

Refinement of groundwater recharge and discharge values could be achieved in a number of ways (as described further in Section 4.3):

- Updates to surficial geology mapping at a more consistent scale across the Peel River basin.
- Review of additional publicly available groundwater level and pumping data to provide preliminary estimates of surficial aquifer parameters that could help validate model results.
- Completion of pumping tests and groundwater level observations in existing or new groundwater monitoring wells within a variety of representative surficial aquifer materials across the basin.
- Subbasin-specific permafrost studies to better understand the distribution and continuity of permafrost and how it may influence groundwater recharge and runoff.





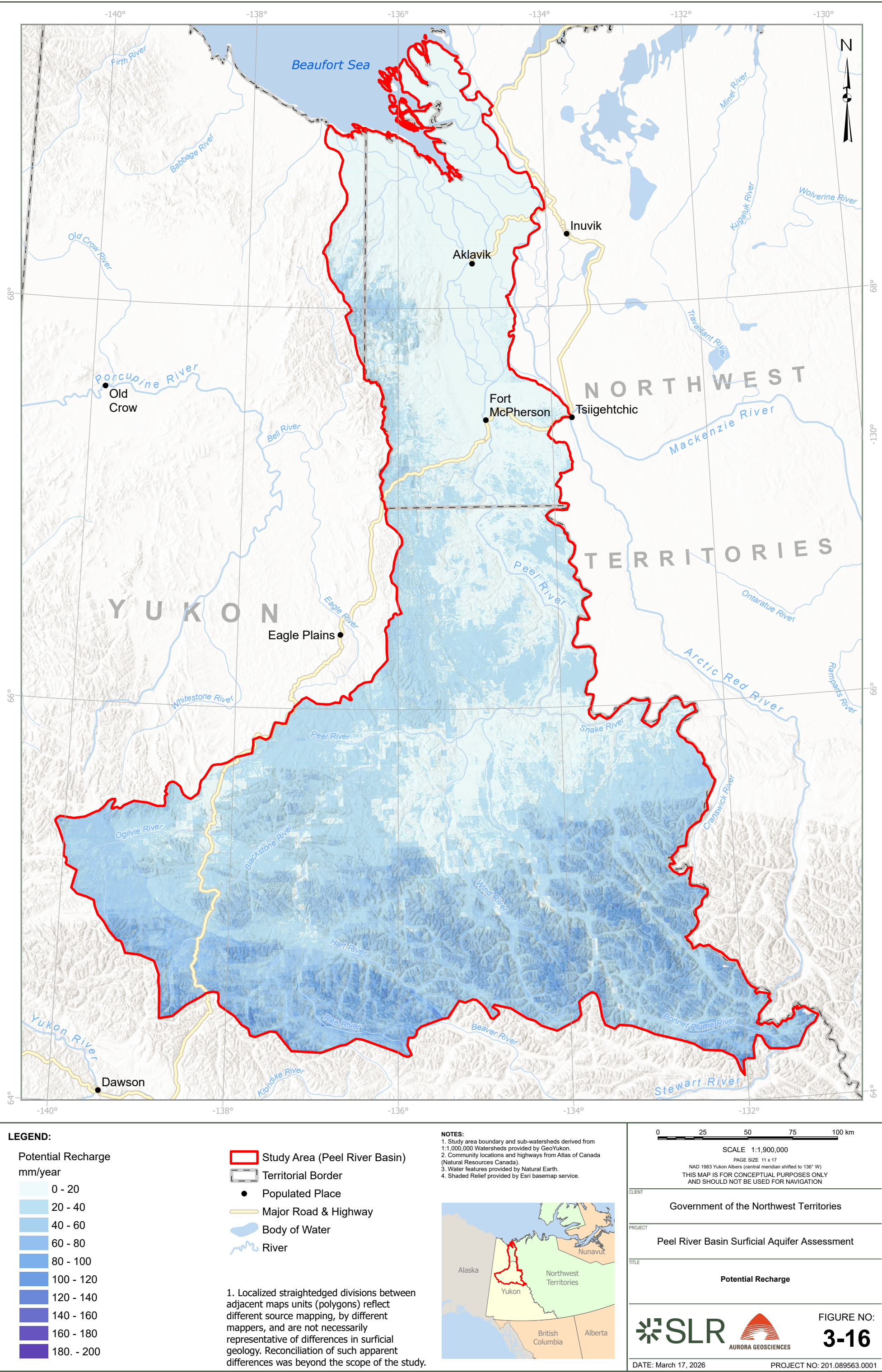


Table 3-3. Comparison of Baseflow from Water Budget and Hydrometric Stations

Water Budget Model						Hydrometric Station Data			Mean Annual Discharge and Winter Contribution*				Baseflow Contribution (from Table 2-7)					
WATERSHED	Basin Area	Mean Annual Discharge (MAD)		Recharge		Station Number	Station Name	Basin Area	MAD	MAD		Winter Baseflow	Winter Baseflow		Recursive Filter		Blended Approach	
	km²	mm/yr	m³/s	m³/s	%			km²	m³/s	mm/yr	mm/yr	% MAD	m³/s	% MAD	m³/s	% MAD	m³/s	% MAD
Upper Peel	37,523	290	345	47	13.5%	10MA001	Peel River Above Canyon Creek	25,500	25,500	202	250	237	14.1%	25	12%	140.8	70%	145
						10MA002	Ogilvie River at Km 197.9 Dempster Highway	5,410	5,410	33.33	194	179	5.1%	1.45	4%	22.9	70%	23.2
						10MA003	Blackstone River Near Chapman Lake Airstrip	1,180	1,180	10.2	273	265	2.3%	0.2	2%	7.1	70%	7.1
Central Peel	21,198	350	235	26	11.0%	10MB003	Snake River Near the Mouth	8,910	8,910	99.7	353	-	-	9.27	7%	69.1	69%	70.9
						10MB004	Bonnet Plume River Above Gillespie Creek	3,760	3,760	52.25	439	442	13.6%	6.51	12%	36.5	70%	37.7
Lower Peel and Western Mackenzie Delta	31,691	127	127	16	12.2%	10MC002	Peel River Above Fort McPherson	70,600	70,600	682	305	-	-	95.9	14%	477	70%	492
						10MC003	Mackenzie River (Peel Channel)	-	-	474	-	-	-	131	28%	331	69%	351
						10MC007	Rat River Near Fort McPherson	1,260	1,260	8.2	205	210	0.6%	0.009	0%	5.6	70%	5.7
						10MC008	Mackenzie River (Middle Channel) Below Raymond Channel	-	-	7,907	-	-	-	3,702	47%	5,536	70%	6,039
Peel River Basin Total	90,412	247	707	88	12.4%													

* From Crites et al. (2020)



3.4 Assessment of Potential Groundwater Vulnerability

Mapping of a variety of land use activities, each classified according to one of three disturbance categories, was combined into a comprehensive, single dataset. This section synthesizes land-disturbance, surficial aquifer occurrence, recharge potential, and water-use indicators to highlight where groundwater in the Peel River basin and Western Mackenzie Delta appears most vulnerable to impacts from current surface activities and water withdrawals. The same index framework used in prior basin-scale surficial aquifer assessments, calculating three groundwater quality disturbance indices (sub-basin, surficial aquifer areas, and potential recharge) and a groundwater quantity index (well density), was applied and then combined to produce comparative rankings by sub-basin. The approach, weighting, and normalization mirror the methods described in the Stewart River watershed (SLR 2025) and Liard basin assessments (Levson et al. 2018, Palmer 2020).

Application of the findings of the inventory and categorization of land use activities to the assessment of groundwater vulnerability are described in the following sections of groundwater quality (Section 3.4.1) and groundwater quantity (Section 3.4.2). It is imperative to note these indices are intended as screening-level, relative indicators to guide prioritization for field verification, monitoring, and protection planning; they do not replace site-specific risk evaluations.

3.4.1 Groundwater Quality

An assessment of potential vulnerability of groundwater quality to land-use activity within each subbasin is presented as indices for subbasin-level disturbance, disturbance within surficial aquifer areas, and potential recharge disturbance (Table 3-4). We applied category weights for increasing disturbance severity, surficial aquifer-sensitivity weighting and normalization to enable direct comparison. The Lower Peel and Western Mackenzie Delta are most vulnerable when weighted by subbasin-level disturbance and potential recharge disturbance, and the Upper Peel subbasin is the most vulnerable when weighted by disturbance within surficial aquifer areas. In contrast, Central Peel is consistently identified as the least vulnerable across all three indices, a result that reflects its comparatively undisturbed condition, more rugged terrain, and a smaller relative extent of unconsolidated deposits with surficial aquifer potential.

3.4.2 Groundwater Quantity

The number of documented wells located in each type of surficial aquifer are tallied for each subbasin in Table 3-5. Across the study area, only one active water-supply wells was documented and is located in the Yukon in the Upper Peel subbasin and is associated with Type 1 (fluvial) surficial aquifers. No water-supply wells are documented in the Central Peel or Lower Peel and Western Mackenzie Delta subbasins in the compiled dataset. This may indicate either a true absence of water-supply wells or a lack of publicly available water-supply well records, particularly in the NWT portion of the study area. Given the continuity of permafrost across much of the region, it is reasonable to assume that there are indeed relatively few water-supply wells in the region, even in areas of human settlement or use.

The results of the assessment of the potential vulnerability of groundwater quantity to land use activity, within each subbasin, are provided based on the density of water-supply wells within each subbasin area (Table 3-6). Groundwater quantity appears to be most vulnerable to impact from land use activities in the Upper Peel subbasin; however, this is likely a result of gaps in publicly available water-supply well data and/or a lack of water-supply wells within other subbasins.



Table 3-4. Indices of Groundwater Quality Disturbance Potential, by Subbasin

Subbasin	Subbasin Level Disturbance			Disturbance within Surficial Aquifer Areas			Potential Recharge Disturbance		
	Subbasin Wide Disturbance Index	Normalized Index of the Proportion of Subbasin Disturbed	Rank*	Surficial Aquifer Area Disturbance Index	Normalized Index of the Proportion of Surficial Aquifers Disturbed	Rank*	Recharge Disturbance Index	Normalized Index of Proportional Disturbance of Potential Recharge	Rank*
Upper Peel	0.0102	55	2	0.0095	100	1	0.288	97	2
Central Peel	0.0076	41	3	0.0018	19	3	0.211	71	3
Lower Peel and Western Mackenzie Delta	0.0187	100	1	0.0090	95	2	0.298	100	1

Note: An explanation of how each index was calculated is provided in Section 2.4.1.

* Highest disturbance potential (rank) = 1; lowest disturbance potential (rank) = 3.



Table 3-5. Summary of Water-Supply Well Counts within Each Surficial Aquifer Potential Area, by Subbasin

Subbasin	Type 1 (modern fluvial floodplains & terraces)	Type 3 (modern fluvial fans and colluvial fans/cones)	Type 4a (unconfined glaciofluvial)	Low Potential	Total
Upper Peel	1	0	0	0	1
Central Peel	0	0	0	0	0
Lower Peel and Western Mackenzie Delta	0	0	0	0	0
Total	1	0	0	0	1

Note: Cells with a value of zero either do not have water-supply wells located within that subbasin/surficial aquifer type or there is a lack of publicly available water-supply well data (e.g. in the NWT)

The results of the assessment of the potential vulnerability of groundwater quantity to land use activity, within each subbasin, are provided based on the density of water-supply wells within each subbasin area (Table 3-6). Groundwater quantity appears to be most vulnerable to impact from land use activities in the Upper Peel subbasin; however, this is likely a result of gaps in publicly available water-supply well data and/or a lack of water-supply wells within other subbasins.

It is important to recognize that using water-supply well density as a basis for evaluating potential vulnerability to groundwater quantity, given the limited availability of groundwater use data, overlooks actual 'groundwater stress' based on a quantitative comparison between permitted (or practiced) water withdrawal rates and the rate of groundwater recharge within the basin. Because the relatively few water-supply well records available commonly lack information on pumping rates or specific yields, a comparison between groundwater withdrawals (in m³/yr) with groundwater recharge volumes within a basin (also in m³/yr) cannot be directly made. Future comparison of groundwater use with predicted groundwater recharge rate would strengthen the groundwater quantity vulnerability assessment (as described further in Section 4.3).

Table 3-6. Index of Groundwater Quantity Disturbance Potential, by Subbasin

Subbasin	Water-supply well density (per 1,000 km ²)	Normalized index of water-supply well density
Upper Peel	0.03	100
Central Peel	0	0
Lower Peel and Western Mackenzie Delta	0	0

Note: Cells with a value of zero either do not have water-supply wells located within that subbasin/surficial aquifer type or there is a lack of publicly available water well data (e.g. in the NWT)

However, this index has limited applicability in the Peel River Basin because the available well data are not representative of meaningful basin-scale water supply use. Of the 13 wells identified, only one is an operational water supply well and the remainder are monitoring wells



and a decommissioned water supply well. Additionally, all 13 wells are located at a single Yukon highway maintenance compound. Consequently, the resulting index is not considered especially robust or meaningful for this study area, and any comparison among sub-basins should be interpreted cautiously, as it reflects the distribution of available data rather than a rigorous measure of actual water quantity disturbance potential.

3.4.3 Overall Ranking by Subbasin

The indices of combined groundwater quality and quantity disturbance potential have been tabulated for each of the three subbasins (Table 3-7) and visually depicted in Figure 3-17. The Lower Peel and Western Mackenzie Delta are ranked highest according to the subbasin composite index, reflecting its larger areal footprint of mapped disturbance and extensive fluvial (Type 1) surficial aquifer occurrences. By comparison, the Upper Peel emerges highest for the surficial aquifer and recharge composite indices, owing to greater coincidence of disturbance with mapped surficial aquifers and, in particular, its higher well-density. The Central Peel is consistently the lowest-ranked of the three subbasins, a result that corresponds to its comparatively undisturbed condition, rugged terrain and subsequently high runoff coupled with its limited extent of unconsolidated deposits with surficial aquifer potential.

Table 3-7. Indices of Combined Groundwater Quality and Quantity Disturbance Potential, by Subbasin

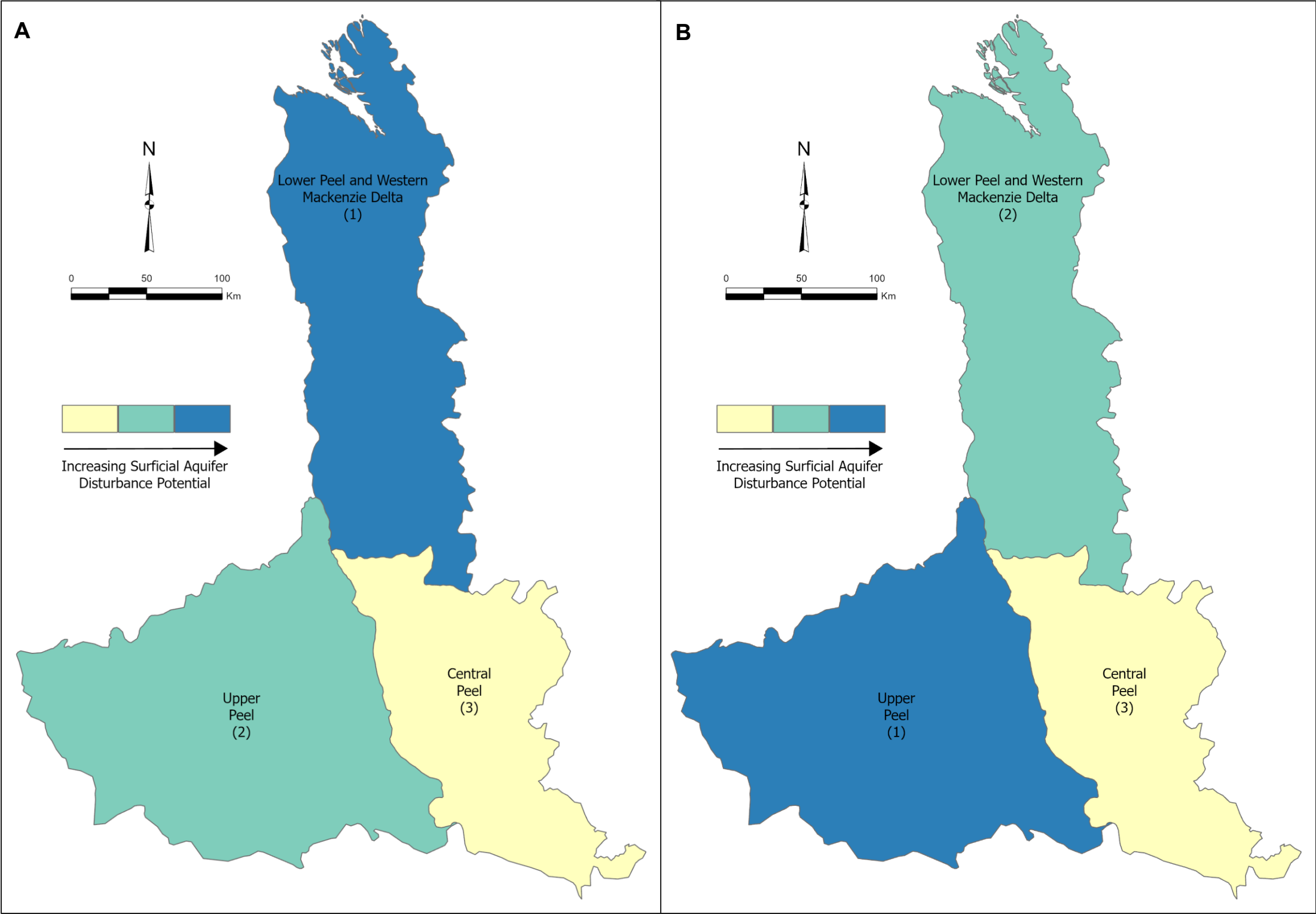
Subbasin	Index of Groundwater Disturbance Potential (Subbasin)	Rank*	Index of Groundwater Disturbance Potential (Surficial Aquifers)	Rank*	Index of Groundwater Disturbance Potential (Recharge)	Rank*
Upper Peel	65	2	110	1	107	1
Central Peel	41	3	19	3	71	3
Lower Peel and Western Mackenzie Delta	100	1	95	2	100	2

Note: An explanation of how each index was calculated is provided in Sections 2.4.1 and 2.5.

* Highest disturbance potential (rank) = 1; lowest disturbance potential (rank) = 3.



Figure 3-17. Subbasin scale disturbance potential. A) Subbasins weighted (coloured) by subbasin disturbance potential. B) Subbasins weighted (coloured) by surficial aquifer and recharge disturbance potential (same subbasin rankings). The rank out of the three subbasins is provided in parentheses and symbolized by colour gradient, from darkest (navy blue, highest rank: 1) to lightest (tan, lowest rank: 3).



4.0 Discussion

4.1 Summary of Key Findings

Several key findings and implications of this project warrant highlighting:

- **Significant data gaps** – The compilation of available groundwater-related information completed following project commencement revealed significant gaps in the coverage and resolution of datasets on which surficial aquifer delineation and characterization were to be at least partly based. More than 20% of the study area is covered by only 1:5,000,000-scale surficial geology mapping (Figure 3-4), with a resolution incomparable to the 1:10,000 to 1:250,000-scale coverage available elsewhere. An attempt was made to refine the interpretation of areas of surficial aquifer potential within the main data gap area through semi-automated topographic modelling, which yielded improvements albeit with limitations that still need to be considered in the context of how they were derived.
- **Dominant types, distribution and characteristics of surficial aquifers** – Three main types of surficial aquifers occur within the study area. Areas with Type 1 (modern fluvial floodplains and terraces) surficial aquifer potential are most widespread (17% of the study area), generally associated with the floodplains and terraces of creeks and rivers. Areas with Type 3 (modern fluvial fans and colluvial fans/cones; 1%) and Type 4a (unconfined glaciofluvial; 2%) surficial aquifer potential are more localized. The only active water-supply well documented appears to be screened in Type 1 fluvial surficial aquifers, which tend to be productive. Glaciofluvial deposits are also strong contributors to groundwater recharge due to their permeable material and level to gently sloping surfaces.
- **Preliminary water budget** – A basin-wide spatial partitioning of surplus precipitation to runoff and infiltration was completed based on available climate data and mapping of surficial material, permafrost, topography and land cover, in order to better understand contributions to groundwater recharge within and beyond the delineated limits of potential surficial aquifers. Most recharge appears to occur in the mountainous regions in the southern and, to a lesser degree, western portions of the study area. Relatively little is known about the exact distribution of groundwater discharge, which typically occurs within localized lowland areas or along creeks and rivers throughout most of the study area. Known indicators of perennial groundwater discharge, such as aufeis (icings), have been mapped regionally in eastern Yukon and adjacent NWT; however, these data were not compiled as a spatial layer for this study but could be considered as a water budget validation tool in future studies. Knowledge of exactly how to account for permafrost (including shallow and deep groundwater connectivity) in this regional-scale analysis remains a key limitation, although the calibration of initial results against measured river baseflows partly addresses this uncertainty.
- **Groundwater vulnerability to land use activities** – A variety of indices were adapted from Levson et al. (2018) to facilitate comparison of the vulnerability of groundwater to land use activities within each of the three subbasins comprising the study area. The Lower Peel and Western Mackenzie Delta subbasin ranks highest in disturbance potential for the subbasin-scale index. In contrast, the Upper Peel ranks highest for the surficial aquifer and recharge composites, owing to greater overlap of disturbance with mapped surficial aquifers, the study area's only documented concentration of water wells (Table 3-6), and comparatively higher modelled recharge. The Central Peel has the



lowest vulnerability, consistent with its comparatively undisturbed condition, rugged, runoff-dominated terrain.

- **Implications of climate change** – The entire Peel River basin is within the zone of discontinuous or continuous permafrost (Heginbottom et al. 1995, Brown et al. 2002). Permafrost temperatures across this region differ with latitude, elevation and terrain characteristics, but they are commonly relatively warm. A compilation of temperatures by Burn et al. (2015) indicates annual mean ground temperatures along the section of the Dempster Highway that crosses the Peel Plateau range from -1.8°C to -2.6°C; a temperature of -2.5°C is reported for Fort McPherson. With projected continuation and potential acceleration of climate warming, the permafrost underlying much of the study area is likely to warm and eventually may thaw and disappear. Progression of the degradation of permafrost will not be consistent in space or time across the study area given the various factors on which it depends; even elevated ground ice contents, such as locally present in the Peel Plateau, may slow thaw due to the latent heat required to induce the phase change. Over the coming decades to centuries, the thickening of the active layer and the ultimate loss of permafrost will undoubtedly affect patterns of groundwater recharge, flow and discharge (Section 4.2). Climate warming is also expected to drive vegetation change across the basin (e.g., increased shrub cover and stature, and potential treeline advance), which can alter snow trapping and surface energy balance and increase evapotranspiration (Loranty and Goetz 2012, Cameron and Lantz 2016). Increased canopy development and longer growing seasons are likely to increase total evapotranspiration, modifying the basin water budget and potentially offsetting some increases in infiltration/recharge associated with permafrost thaw (Helbig et al. 2020, Nicholls et al. 2023). Opportunities for groundwater recharge will be enhanced, particularly within areas of gentler terrain (where more infiltration is possible). Potential recharge will likely increase in the middle to northern portions of the Peel River basin, where it is currently limited by continuous permafrost. Higher recharge may translate into higher baseflows and slightly lower flood peaks, reflecting an overall more muted response, although possible changes in precipitation patterns may offset some of this response.

4.2 Priorities for Future Groundwater-related Research

The ranking of each of the three subbasins within the study area according to their groundwater disturbance potential, whether considered at the subbasin level, solely within areas of surficial aquifer potential, or in association with groundwater recharge potential, provides one basis for prioritizing areas for groundwater-related research. The highest-ranked subbasins intuitively warrant greater and sooner attention than the lowest-ranked subbasins.

Another perspective for prioritizing groundwater-related research is to consider the availability of spatial and site-specific data on which to base an understanding of groundwater vulnerability. Consideration could be given to the geographic distribution of existing data, which could justify effort being spent on filling critical spatial gaps, or to the type or quality of available information. A key priority, based on the methods through which this study was conducted, should be the preparation of regional-scale (>1:250,000) surficial geology mapping within the large data gap in the southeastern and smaller gaps in the northwestern and southwestern portions of the study area. Mapping would be best based on traditional expert interpretation of aerial photography, satellite imagery and high-resolution DEMs, although semi-automated predictive methods are also an option. Results of the TPI-based, gap-filling analysis used in this study were reasonable but could undoubtedly be improved through a more rigorous analysis such as those used by the



GSC as part of its “remote predictive mapping” of surficial geology (e.g. Schetselaar et al. 2007).

Cold climate hydrogeology, more specifically hydrogeology in regions of permafrost, is increasingly becoming a focus for researchers interested in water movement in ground underlain by discontinuous to continuous permafrost (e.g. Morse (compiler) 2017). The presence and distribution of permafrost impart an additional factor affecting the flow of groundwater above (suprapermafrost groundwater), within (intrapermafrost groundwater), and below (subpermafrost groundwater) permafrost. As described in this study, permafrost has a fundamental influence on infiltration that lacks understanding for application to regional studies. A principal catalyst for heightened interest in permafrost hydrogeology is better understanding the hydrological response of northern environments to climate change and, more specifically, permafrost degradation. Figure 4-1 provides a schematic representation of forecasted changes in permafrost in response to climatic warming (Walvoord and Kurylyk 2016). Suprapermafrost groundwater that has been restricted to the active layer until now may become connected with subpermafrost groundwater through open taliks. Groundwater recharge and discharge are also likely to be enhanced through active-layer thickening, as more volume of ground becomes available for storage and less surplus is lost to runoff. Permafrost degradation may also drive hydrogeochemical changes by mobilizing metals and contributing to acidification. Skierszkan et al. (2024) identify thawing permafrost as an emergent risk to water resources because it can alter the processes governing metal mobility, with implications for water quality. Improving the estimation of groundwater recharge and mapping of surficial aquifers in northern environments relies on a fundamental understanding of surface water and groundwater interactions, even without the added complexity introduced by climate change.

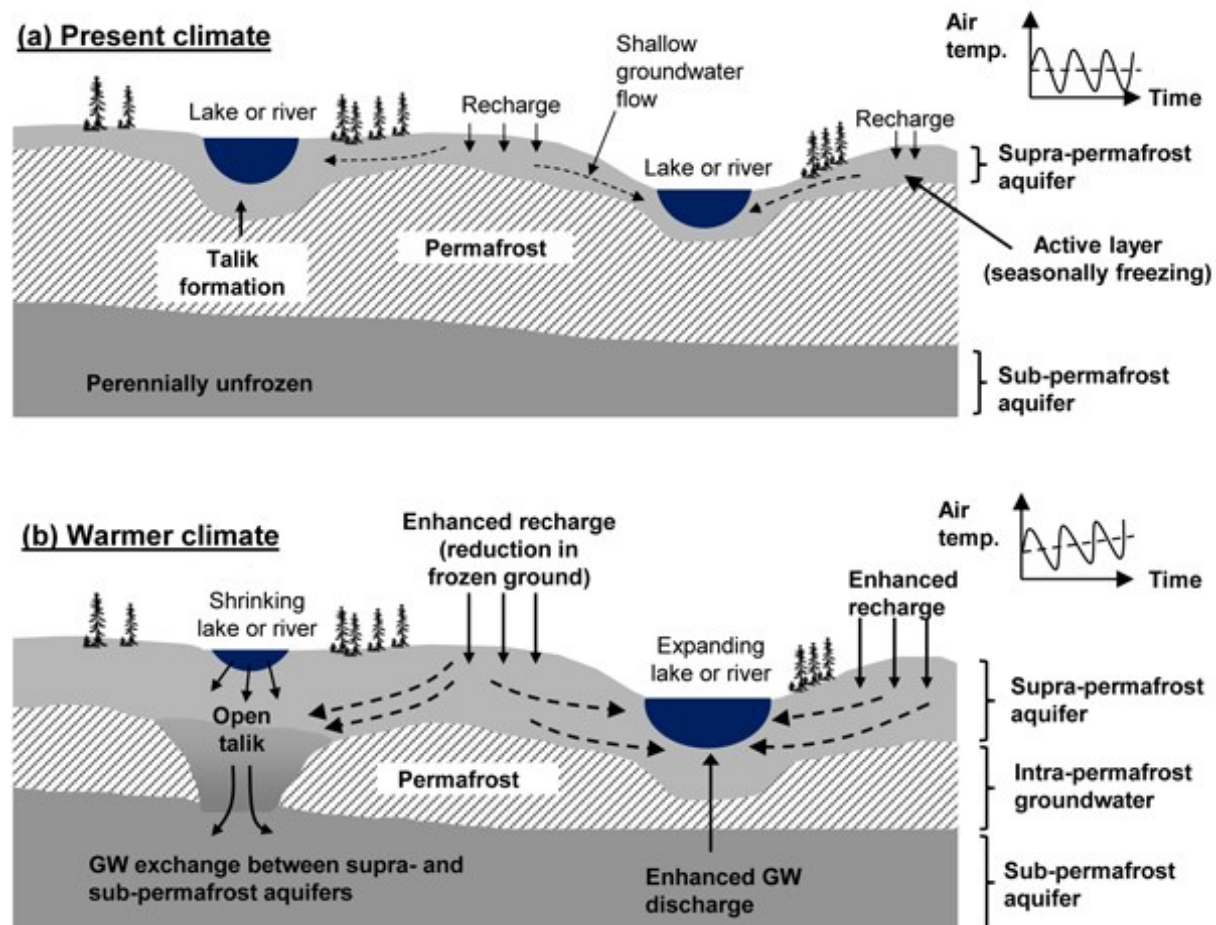
4.3 Recommended Follow-up Opportunities

This project has culminated in a number of specific recommendations for follow-up research in the Peel River basin and Western Mackenzie Delta, consistent with one or more of the overarching priorities identified above in Section 4.2:

- **Preparation of better-resolution surficial geology mapping** – Regional-scale (>1:250,000) surficial geology mapping should be undertaken to fill the main data gap areas in the southeastern and northwestern portions of the study area (e.g. Figure 3-4). Such mapping has applications well beyond hydrogeological research, but it has also been shown to serve as a foundation for delineating and characterizing surficial aquifer potential in regions with limited to no subsurface information. In addition to improving the resolution of surficial geology information, new mapping could also be better tailored to surficial aquifer research by more consistently representing stratigraphic relationships that can be inferred based on an understanding of depositional environments and the glacial and deglacial history of a region. Furthermore, completing new higher-resolution regional mapping for the entire study area would remove artifacts in the processed data that arise from using mapping completed at different scales and by different mappers. As noted in Section 3.2.5, Type 4b (confined glaciofluvial) surficial aquifers are likely present in the study area, but their location and extent are unknown due to poor identification of permeable strata blanketed by an aquitard material.



Figure 4-1. Schematic representation of possible changes in groundwater-surface water interaction driven by thawing permafrost in response to climatic warming (from Walvoord and Kurylyk, 2016).



- Improved storage of, and accessibility to, water-supply well data** – Additional water-supply well data would obviously benefit research on surficial (and deep) aquifers. More simply, existing water-supply well databases in the Yukon and the NWT should be more comprehensive and maintained in such a way that individual borehole logs and any associated well yield data are readily accessible. Hyperlinks accessing logs from individual borehole records were at times invalid when checked during searches in this project. More user-friendly access to borehole logs represents a critical first step toward better protection and management of groundwater resources. GNWT has indicated a public groundwater data portal is forthcoming. When launched, the portal is expected to provide standardized information for GNWT-owned/co-owned monitoring wells (e.g., locations, well depths, groundwater elevations/water levels, and links to borehole logs/lithology where available), which would strengthen future Peel River basin groundwater baseline and conceptual model updates. However, at the time of reporting, this dataset was not publicly accessible.
- Improvement and updates to land use activity/disturbance mapping** – Recent advancements in spatial data analysis tools are improving automated mapping of anthropogenic disturbances (e.g. Pickell et al. 2014). The Yukon now maintains a



standardized Anthropogenic Surface Disturbance Database with layers for linear (roads, seismic lines, pipelines, etc.) and areal (pads, camps, quarries, etc.) footprints (Geomatics Yukon 2023). Further refinement to the Yukon database and a similar initiative for surface disturbance in the NWT would benefit groundwater-related research, especially if the prioritization of the types and areas of mapped disturbances was established in the context of groundwater vulnerability. Further refinement could include addition of groundwater-relevant attributes, specifically: (i) disturbance intensity (cleared vs stripped/graded vs excavated/borrow vs fill/embankment), (ii) flow-modification indicators (ditch/berm, ponding evidence, and whether linear features form continuous preferential corridors or intersect wetlands/streams), and (iii) site status (active vs reclaimed). Additionally, future disturbance datasets would be strengthened by adding an up-to-date, georeferenced inventory of drilling waste sumps, as these features can represent localized, persistent risks to water quality where permafrost degradation compromises containment.

- **Groundwater stress analysis** – At least in select areas where reliable information on water withdrawal rates is available, a more refined representation of groundwater quantity vulnerability could be determined than is possible solely based on consideration of water well density, particularly in areas of sparse water well records. A comparison should be made between the actual, or permitted, groundwater withdrawals from a given well and the estimated groundwater recharge in the associated catchment. The resultant ‘groundwater stress’ would draw attention to areas where continued withdrawal may not be sustainable.
- **Refinement of water budget** – The GIS-based preliminary water budget for the Peel River basin and Western Mackenzie Delta inevitably relied on simplifying assumptions. More rigorous analysis of appropriate spatial partitioning of climate data could help improve the overall water budget. In addition, the baseflow estimates used to validate the water budget are based on published techniques with uncertainties that can only be resolved through field data collection. Validation of baseflow remains the key limiter: combining vetted digital filters with environmental tracers (e.g., electrical conductivity, stable isotopes) improves separation and reduces bias (Gonzales et al., 2009; Mei et al., 2024). This would improve precision of baseflow within different subbasins and, in turn, the basin-wide water budget. Further refinement of the model input parameters tested against site-specific groundwater recharge/discharge studies could improve the model results for small watersheds, especially where permafrost is discontinuous. Finally, site-specific recharge/discharge tests should be interpreted with tracer-aided models that consider permafrost and have already been demonstrated in Yukon catchments, and with recognition that thaw-related disturbances can alter pathways in discontinuous permafrost (Piovano et al. 2019).
- **Incorporation of traditional knowledge into groundwater studies** – As noted above in Section 3.3, incorporating traditional knowledge into this surficial aquifer assessment was beyond the scope of this study. However, traditional knowledge should be explored and used to improve understanding of the distribution of groundwater recharge and discharge areas based on generations of repeated, seasonal observations. The locations of groundwater springs, sourced shallowly or deeply (e.g. thermal springs), may be part of traditional knowledge. Understanding where and how water has been used traditionally is also fundamental to evaluating proposed project applications with the potential to compromise traditional water uses. It provides another means of helping to prioritize subbasins, or portions of subbasins, for groundwater-related research.



- **Projected changes in water budget** – The preliminary water budget developed for the Peel River basin could be re-run with simulations for different climate change scenarios, at different times in the future. Such an analysis would help highlight where the ground and, in turn, infiltration and groundwater recharge are most sensitive to projected changes in air temperature and precipitation. The results of this modelling could also inform prioritization of areas for further research and for assessment and mitigation of more local-scale risks to groundwater.
- **Temporal alignment of climate inputs for the water budget** – Future refinement of the Peel River basin water budget should, where feasible, use MAP and ET datasets from more closely aligned time periods (or matched multi-year climates) to reduce bias associated with mixing 1961–1990 normals with 2000–2023 ET estimates. The datasets used in this study were selected because they were the most spatially continuous, publicly available data for the project area. Future updates could re-run the budget with temporally consistent inputs once newer nationally consistent gridded historical data are publicly available. Additionally, while beyond the scope of this project, a more robust permafrost correction could be achieved by varying the permafrost factor based on typical material properties of surficial map units rather than the bulk difference between continuous and discontinuous permafrost zones.

5.0 Conclusion

A desktop-based assessment of the potential occurrence and vulnerabilities of surficial aquifers in the Peel River basin and Western Mackenzie Delta in the Yukon and NWT has been completed based on the best available spatial datasets and limited subsurface information. Areas of potential surficial aquifers classified as Type 1 (modern fluvial floodplains and terraces; 17%), Type 3 (modern fluvial fans and colluvial fans/cones; 1%) and Type 4a (unconfined glaciofluvial; 2%) (Wei et al., 2009) were delineated in approximately 17,357 km² (20%) of the study area, despite the absence of regional-scale (>1:250,000) surficial geology mapping in the southeastern and northwestern portions of the study area. Preliminary mapping indicates that the main groundwater-recharge zones occur in the mountainous regions of the Upper Peel and Central Peel subbasins to the south and to a lesser extent along the western margin of the Lower Peel and Western Mackenzie subbasin. This reflects a relatively higher surplus in these areas, as well as the extent of permeable deposits in areas of locally discontinuous permafrost. Groundwater quality and quantity are most vulnerable in valley-bottom and community/transportation corridors along the Peel River basin and the Western Mackenzie Delta, where land-use activities commonly overlie fluvial (Type 1) and glaciofluvial (Type 4a) surficial aquifers. The Central Peel subbasin is consistently ranked lowest according to its groundwater vulnerability due to its nearly pristine (undisturbed) condition. Future groundwater-related research should focus on the most at-risk subbasins and aim to resolve critical gaps in spatial data coverage and knowledge of permafrost hydrogeology, especially in response to climate change.



6.0 Closure

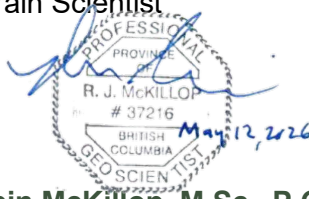
SLR Consulting (Canada) Ltd. appreciates the opportunity to support the GNWT in collaboration with YG in this preliminary assessment of surficial aquifers in the Peel River basin. Should you have any questions, please do not hesitate to contact Robin McKillop at 604-355-8788 or robin.mckillop@slrconsulting.com.

Regards,

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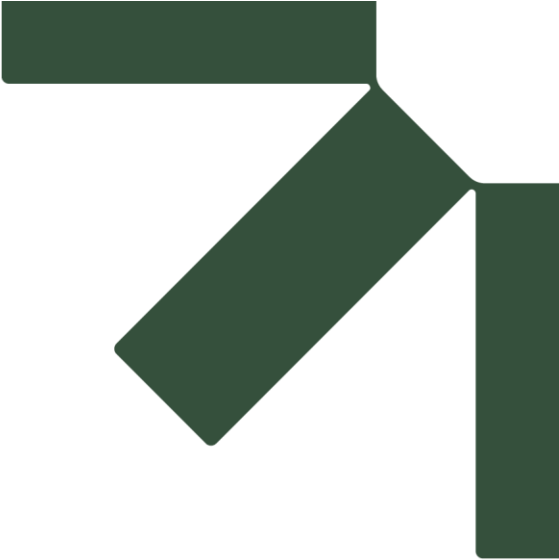
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Appendix A Plain Language Summary

Peel River Basin Transboundary Surficial Aquifer Assessment

Government of Northwest Territories and Government of Yukon

SLR Project No.: 201.089563.00001

May 12, 2026

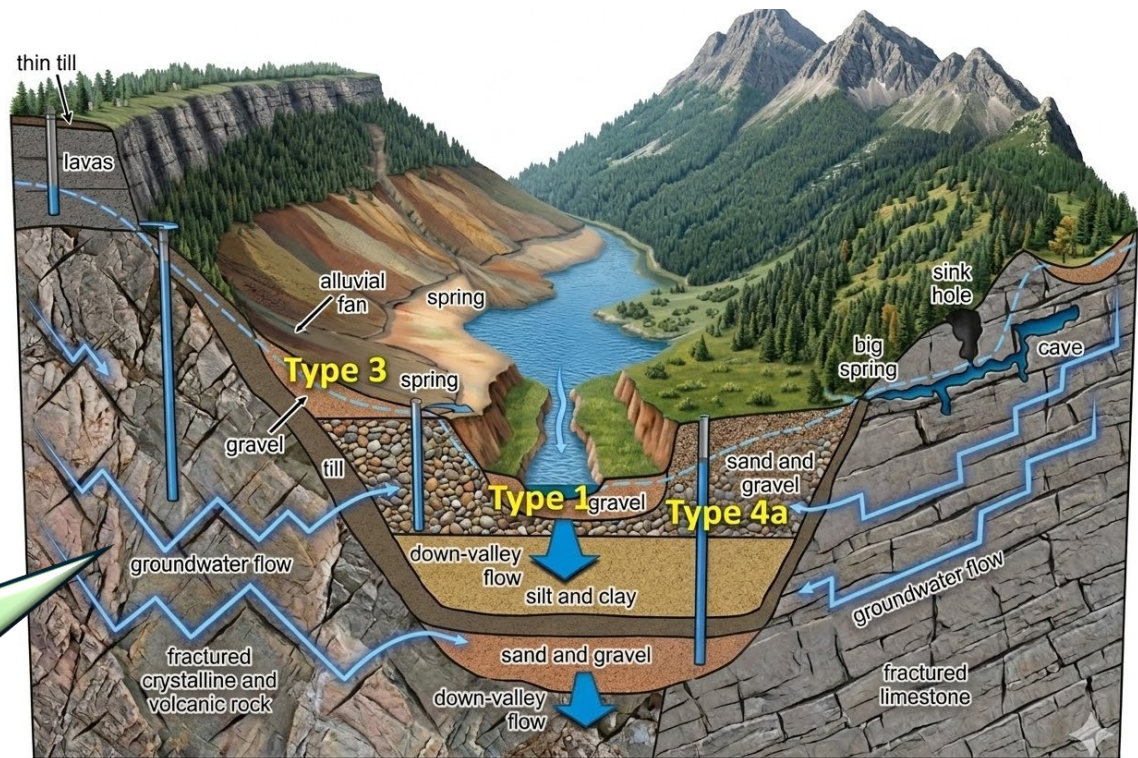
Shallow groundwater in the Peel River basin: Where is it and where might it be at risk?

Groundwater is a key part of the water cycle. It is also an important natural resource for humans, plants and animals. Rainfall and snowmelt that soak into the ground flow as groundwater through soil and rock. The groundwater is naturally stored underground in "aquifers" before eventually making its way to springs or larger waterbodies such as lakes or rivers.

The Government of the Northwest Territories and the Government of Yukon want to ensure groundwater in the Peel River basin and Western Mackenzie Delta is understood and managed properly. Groundwater helps keep streams and rivers flowing during the long winter months when surface water is frozen. Many animals and their habitats depend on this water and how it interacts with the land.

A slice through the ground helps show where the three main types of shallow surficial aquifers are in valleys like those of the Peel River basin. Modified from Wei et al. (2009).

Shallow surficial aquifers are particularly important because they are right below the ground surface. Many community members rely on groundwater for drinking, cooking and bathing, as well as for commercial and industrial uses. Sometimes, the groundwater in shallow surficial aquifers can be too short in supply for use or can become unsafe if it becomes contaminated by dirty material from leaks or spills at the surface.

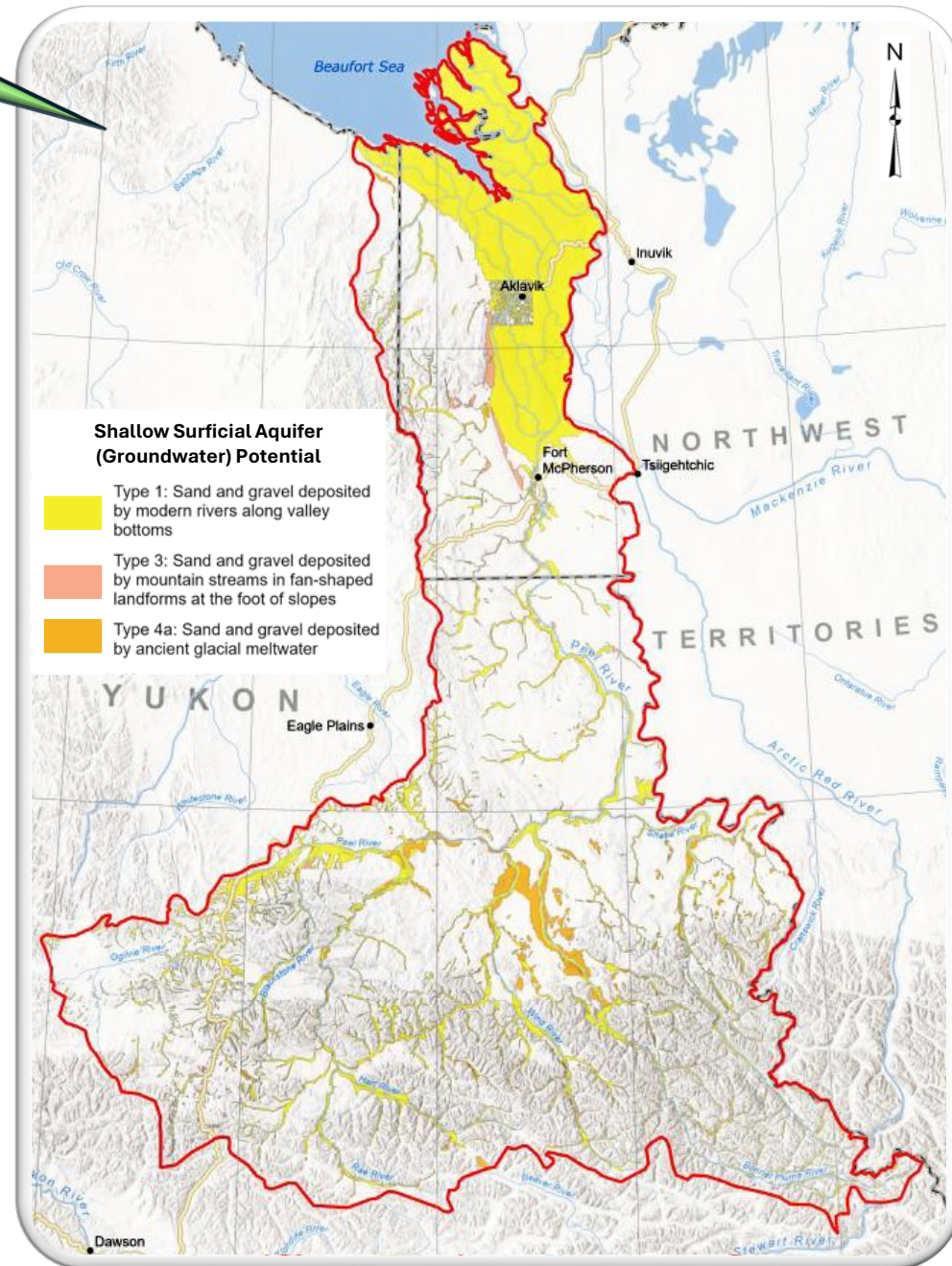


Shallow groundwater is most likely to be found in one of three main types of surficial aquifer along the valleys of the Peel River basin.

The study of shallow surficial aquifers was mostly based on information and maps about landforms, different types of soil and rock, vegetation, and frozen ground called "permafrost." This information provides valuable clues about where water can move underground. Permafrost is widespread in the Peel River basin. It stops rainfall and snowmelt from soaking deeply into the ground and, instead, forces slow seepage of shallow groundwater toward waterbodies.

Information from water wells is very limited in this remote region. To fill in the gaps, the study used records from oil and gas exploration (seismic shotholes) and looked at river flow records to estimate how much water is coming from underground.

The study determined that rainfall and snowmelt soak into the ground mostly in the mountainous regions to the south (the Upper and Central Peel areas). Although the flat plains of the Western Mackenzie Delta have soil that can hold water, less water actually soaks in there because there is less rainfall and snowmelt overall compared to in the mountains. On average, only about 88 millimetres of water (less than the height of a coffee mug) soaks into the ground each year to replenish aquifers within the Peel River basin. However, this groundwater is vital, providing roughly 12% to 14% of the water that flows through the basin's rivers.

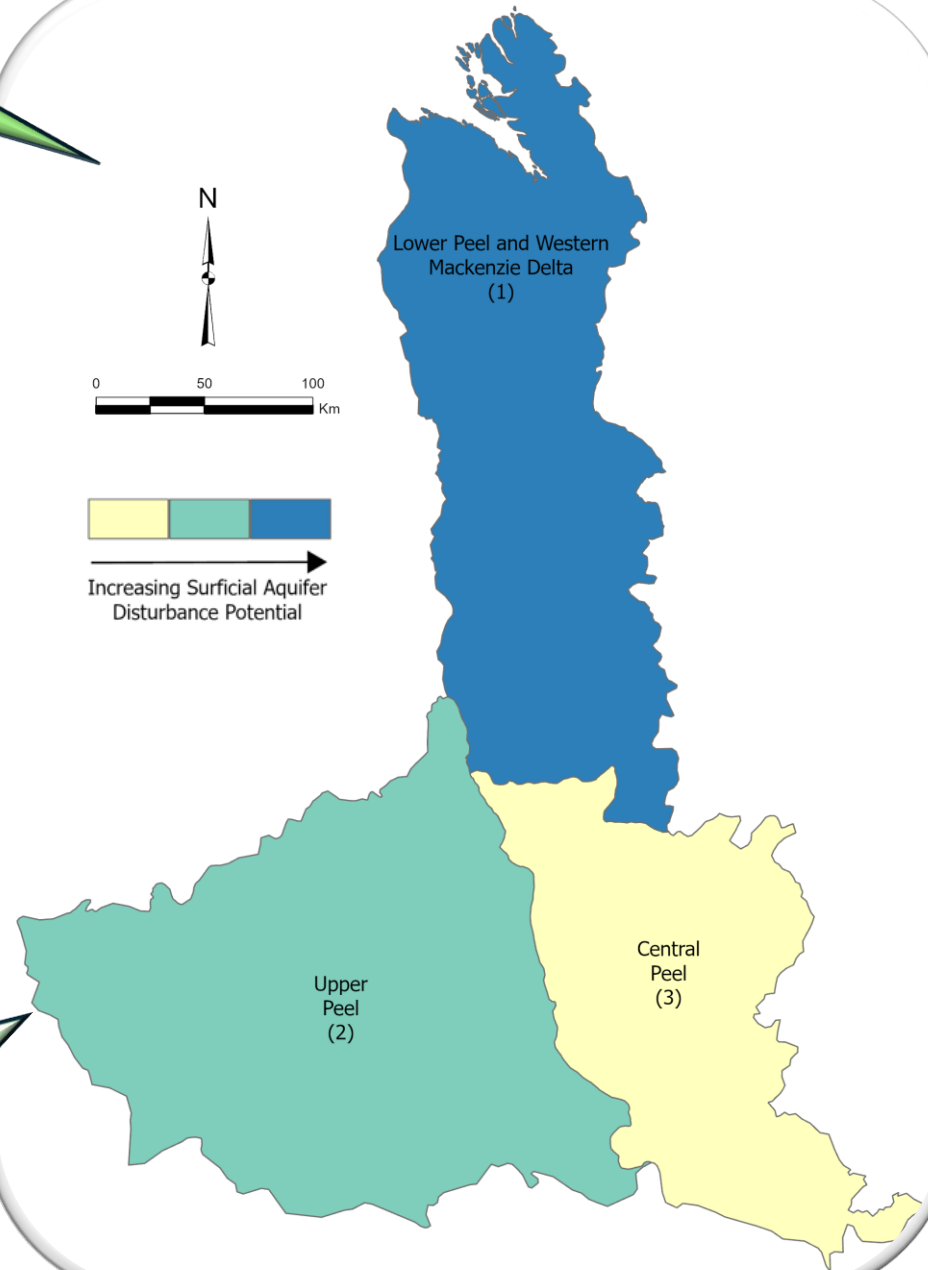


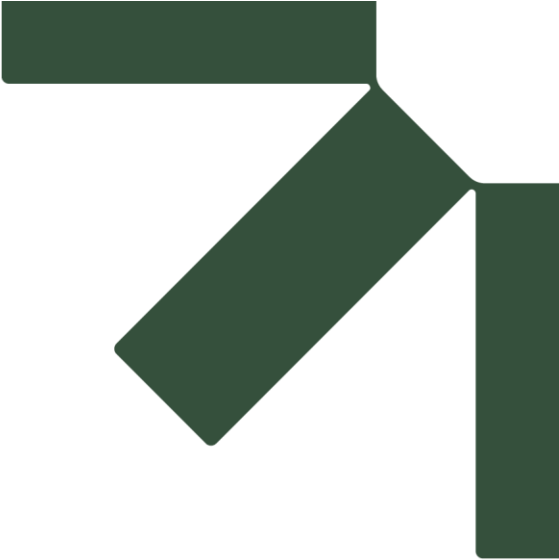
The mountains and valleys of the Peel River basin were divided into three subbasins for the purposes of studying shallow groundwater.

The study also found that groundwater in the Lower Peel and Western Mackenzie Delta is most vulnerable to surface disturbance because there is more human activity there. The Upper Peel area is most vulnerable in specific places where surficial aquifers and recharge areas overlap with what few water-supply wells exist. Groundwater is least at risk in the Central Peel area, which is rugged and has very little human disturbance.

One thing that became clear through this study is that additional research and Traditional Knowledge are needed to better understand these surficial aquifers. As the climate warms and permafrost thaws, the way water moves underground will change. Better information will allow the governments and communities to protect water resources for the future.

By considering where human activities overlap with areas of shallow surficial aquifers, it is possible to rank the three subbasins of the Peel River basin from lowest (light yellow) to highest (dark blue) groundwater disturbance potential.





Appendix B List of Compiled Land Use Activity Mapping and Associated Disturbance Footprints

Peel River Basin Transboundary Surficial Aquifer Assessment

Government of Northwest Territories and Government of Yukon

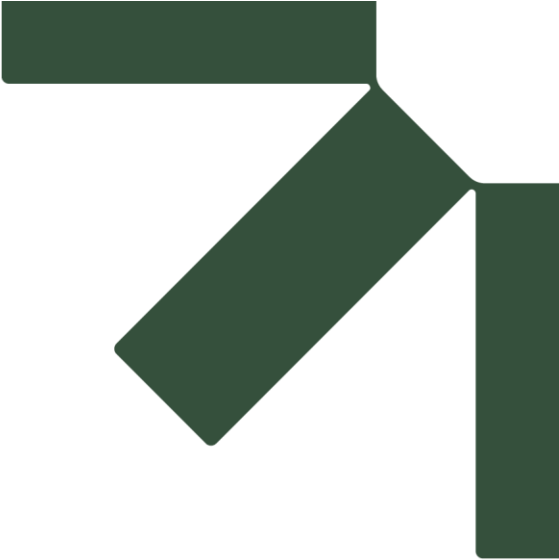
SLR Project No.: 201.089563.00001

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Appendix B. List of Compiled Land Use Activity Mapping and Associated Disturbance Footprints

Feature	Layer Name	Category of Disturbance	Buffer (m)	Buffer Comment
Oil and gas seismic lines (YT)	Oil_and_Gas_Seismic_Lines_YT	1	5	Estimate from imagery
Cut lines (NT)	Canvec250k_cut_line_NT	1	5	Average between modern day cutlines and historical
Trails (NT)	Canvec50k_trail_NT	1	5	Estimate
Seismic shotholes (YT and NT)	SeismicShot_Point	1	5	Permitted size
Seismic lines (YT and NT)	BorealDisturbance_Linear_EnvironmentCan_YT_NT	1	5	For "Seismic" features in the "Class" field. Estimate from imagery
Pipelines (YT and NT)	BorealDisturbance_Linear_EnvironmentCan_YT_NT	2	30	For "Pipeline" features in the "Class" field. Right of way
Water wells (YT)	Water_Wells_YT	2	5	Estimate
Drill holes (YT)	Drillhole_Location_YT	2	5	Typical size
Oil and gas wells (YT)	Oil_and_Gas_Wells_50k_YT	3	250	Estimate from imagery
Oil and gas wells (NT)	OROGO_OilWells_FromGovNT	3	250	Estimate from imagery
Buildings (NT)	Canvec50k_building_NT	3	30	Average shape area, calculated radius
Roads (NT)	Canvec50k_road_segment_NT	3	60	Most legal descriptions of NWT highways say 60m
Human development footprint (NT)	Human_Development_Footprint_Area_NT	3	n/a	Actual areal extent
Runway (NT)	Canvec50k_runway_NT	3	n/a	Actual areal extent
Residential area (NT)	Canvec50k_residential_area_NT	3	n/a	Actual areal extent
Buildings (NT)	Canvec50k_building_poly_NT	3	n/a	Actual areal extent
Roads (YT and NT)	w_roads_SeismicShotDatabase_YT_NT	3	60	Most legal descriptions of NWT highways say 60m
Roads (YT and NT)	r_roads_SeismicShotDatabase_YT_NT	3	60	Most legal descriptions of NWT highways say 60m
Roads (YT and NT)	BorealDisturbance_Linear_EnvironmentCan_YT_NT	3	60	For "Road" features in the "Class" field. Most legal descriptions of NWT highways say 60m
Airstrip (YT and NT)	BorealDisturbance_Linear_EnvironmentCan_YT_NT	3	150	For "Airstrip" features in the "Class" field. Average shape width calculated from imagery
Boreal disturbance polygons (YT and NT)	BorealDisturbance_Poly_EnvironmentCan_YT_NT	Various	n/a	Actual areal extent
Surface disturbance - linear features (YT)	SurfaceDisturbance_LinearFeatures_YT	Various	Various	Width of feature stated in database
Surface disturbance - areal features (YT)	SurfaceDisturbance_ArealFeatures_YT	Various	n/a	Actual areal extent





Appendix C Principal Spatial Data Sources

Peel River Basin Transboundary Surficial Aquifer Assessment

Government of Northwest Territories and Government of Yukon

SLR Project No.: 201.089563.00001

May 12, 2026

Appendix C. Principal Spatial Data Sources Compiled for the Peel River Basin Surficial Aquifer Assessment.

Theme	Dataset	Source/Publisher	Scale/ Resolution ¹	Relevance	Reference
Bedrock Geology	Yukon Digital Bedrock Geology	Yukon Geological Survey (YGS)	1:250,000	Surficial aquifer potential and water budget input	YGS 2025
	Geological Compilation of the Western Mainland and Arctic Islands of the Northwest Territories	Northwest Territories Geological Survey	1:250,000	Surficial aquifer potential and water budget input	Okulitch, A. V., and Irwin, D. 2017
	A Digital Atlas of Terranes for the Northern Cordillera	Yukon Geological Survey	1:5,000,000	Background and geological context	YGS 2020
Surficial Geology	Surficial Geology Mapping of Aklavik and Fort McPherson, Northwest Territories	Palmer	1:10,000 and 1:30,000	Surficial aquifer potential and water budget input	Palmer, 2023
	Yukon Surficial Geology Compilation	Yukon Geological Survey	1:50,000 – 1:250,000	Surficial aquifer potential and water budget input	YGS 2023
	Digital compilation of the surficial sediments of the Mackenzie Valley corridor, Yukon Coastal Plain, and the Tuktoyaktuk Peninsula	Geological Survey of Canada (GSC)	1:125,000 – 1:250,000	Surficial aquifer potential and water budget input	Côté et al. 2013
	Surficial Geology of Canada		1:5,000,000	Surficial aquifer potential and water budget input; superseded where possible by higher resolution data	GSC 2014
Permafrost	Ground Ice Maps for Canada	Geological Survey of Canada	~1:5,000,000	Surficial aquifer potential and water budget input	O'Neill et al. 2022
	Permafrost Map of Canada	Natural Resources Canada	1:7,500,000	Surficial aquifer potential and water budget input	Heginbottom et al. 1995
	Circum-Arctic Map of Permafrost and Ground-Ice Conditions	National Snow and Ice Data Center	1:10,000,000	Surficial aquifer potential and water budget input	Brown et al. 2002
Elevation ²	ArcticDEM	Polar Geospatial Center	10 m	Regional context and site-specific interpretation of representative areas	Porter et al. 2023
Land Cover and Use	Land Cover of Canada	Natural Resources Canada	30 m	Surficial aquifer potential and water budget input; superseded where possible by higher resolution data	Latifovic 2020
	Land Use Activities (Disturbances)	Various	Various	Assessment of potential vulnerability of groundwater to surface disturbances	
Site-specific Groundwater and Subsurface Information	GIN Water Wells	Groundwater Information Network (GIN)	N/A	Representative hydrostratigraphic and hydrogeological properties of surficial aquifers	GIN 2013
	Yukon YOWN Waterwells	Yukon Well Observation Network (YOWN)	N/A	Representative hydrostratigraphic and hydrogeological properties of surficial aquifers	YG 2025a
	Water Well Records	Yukon Water Registry	N/A	Representative hydrostratigraphic and hydrogeological properties of surficial aquifers	YG 2025b
	Geotechnical Boreholes	Geomatics Yukon	N/A	Characterization of subsurface materials	Geomatics Yukon 2022
	Seismic Shothole Log Database	Geological Survey of Canada	N/A	Characterization of near-surface materials and ground ice	Smith 2011
	OROGO Well Data	Office of the Regulator of Oil and Gas Operations (OROGO)	N/A	Characterization of subsurface materials	OROGO 2025
Climate – Mean Annual Precipitation	ClimateNA_MAP 1961-1990 normals	University of British Columbia	2.5 x 2.5 arc minutes	Gridded dataset for mean annual precipitation used in the water budget.	Wang et al. 2016
Climate – Evapotranspiration	Land Surface Evapotranspiration for Canada's Landmass	Canada Centre for Mapping and Earth Observation (CCMEO)	5km	Gridded dataset for evapotranspiration used in the water budget	CCMEO 2013

Notes:

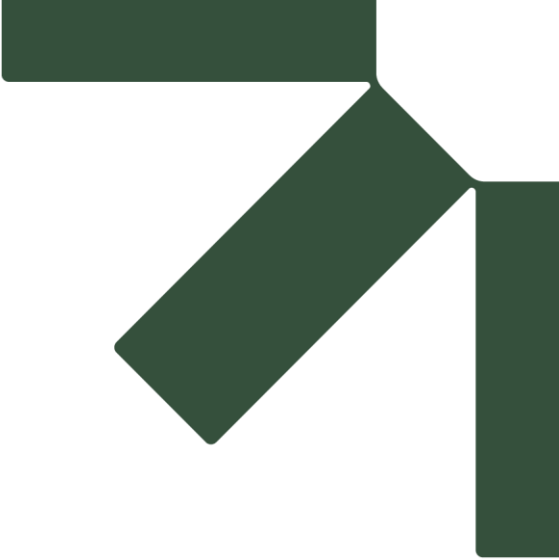
1.

Resolution is quantitative and does not necessarily reflect utility of data.

2.

High-resolution LiDAR data for the small communities within the study exists, but its coverage is too limited for applicability in this regional-scale project.





Appendix D Processed Spatial Dataset

Peel River Basin Transboundary Surficial Aquifer Assessment

Government of Northwest Territories and Government of Yukon

SLR Project No.: 201.089563.00001

May 12, 2026

Appendix D. Processed Spatial Dataset

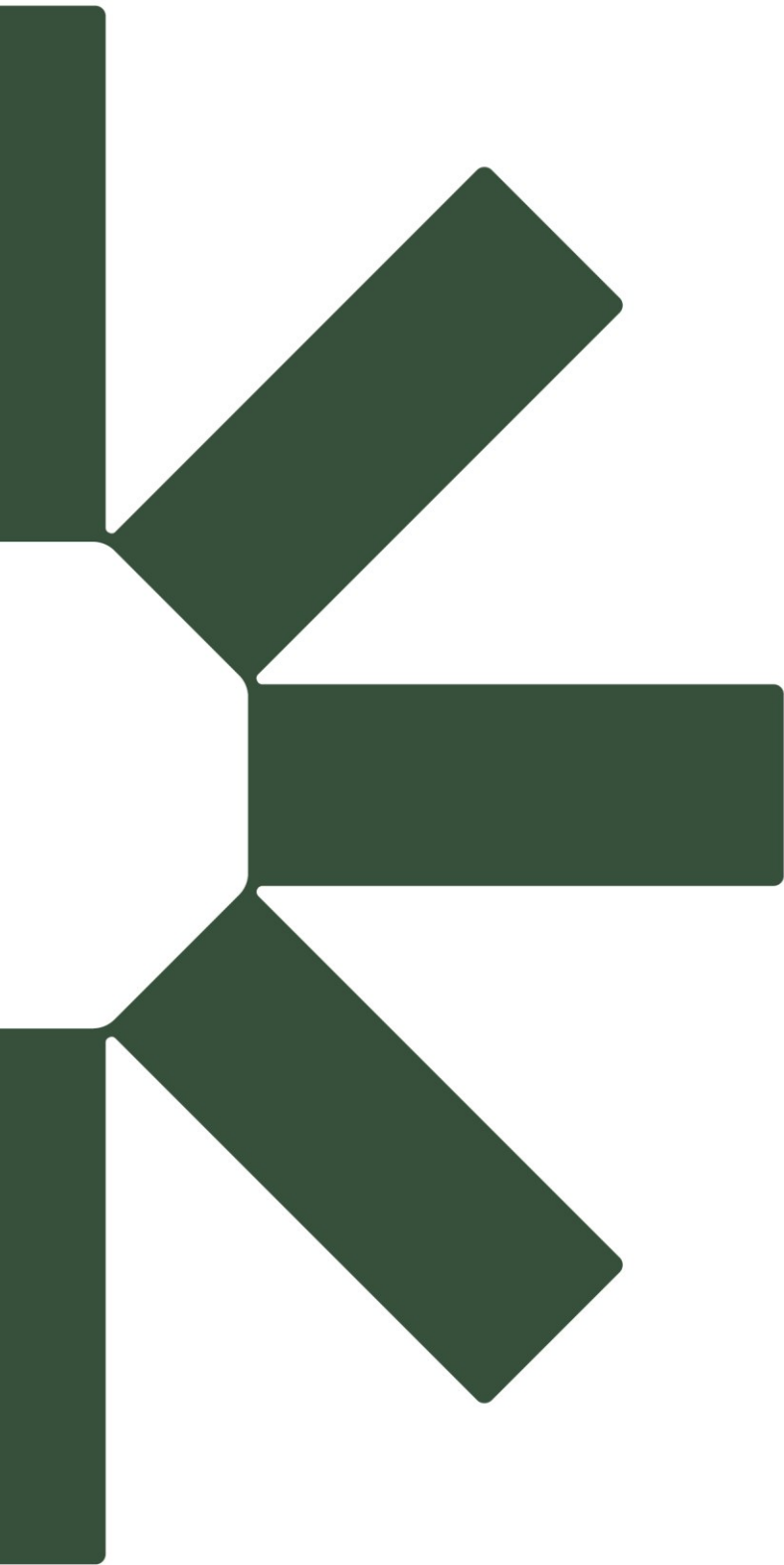
Provided separately as a zipped folder containing an ArcGIS geodatabase, raster files and a statement of limitations. **These files are to be viewed in a Geographic Information System (GIS) and an understanding of GIS programs and file types is required to fully utilize this dataset.**

Processed spatial dataset folder hierarchy and file names:

SLR_Peel River Basin_Processed Data_12May2026.zip

- **SLR_Peel_River_Basin_Aquifer_Assessment_Data_Deliverable_12May2026.gdb**
 - o SLR_Peel_Surficial_Aquifer_TPI_Infill_Area
 - o SLR_Peel_Surficial_Aquifer_Surficial_Geology_Compilation
 - o SLR_Peel_Surficial_Aquifer_Surface_Disturbance
 - o SLR_Peel_Surficial_Aquifer_Subbasins
 - o SLR_Peel_Surficial_Aquifer_Study_Area
 - o SLR_Peel_Surficial_Aquifer_Permafrost_Zones
 - o SLR_Peel_Surficial_Aquifer_Classification_TPI_Results
 - o SLR_Peel_Surficial_Aquifer_Classification'
 - o SLR_Peel_Surficial_Aquifer_Bedrock_Geology_Compilation
- **Raster**
 - o SLR_Peel_AnnualWaterSurplus_mm.tif
 - o SLR_Peel_ArcticDEM_TPI_Area1_10m.tif
 - o SLR_Peel_ArcticDEM_TPI_Area2_10m.tif
 - o SLR_Peel_Landcover_30m_alb.tif
 - o SLR_Peel_MRDEM_30m.tif
 - o SLR_Peel_MRDEM_Slope_30m.tif
 - o SLR_Peel_Potential_Recharge.tif
 - o SLR_Peel_Potential_Runoff.tif





Making Sustainability Happen