Mackenzie Valley Highway: Desktop-based Assessment of Water Availability

Prepared for:

Department of Infrastructure, Government of the Northwest Territories
Yellowknife, NT

Prepared by:

K'alo-Stantec Limited
P.O. Box 176
Tulita, NT

December 13, 2022

Project No.: 144903284

Executive Summary

Water volumes available for withdrawal have been assessed for 22 watercourses and 24 waterbodies along the proposed Mackenzie Valley Highway (MVH) alignment, spanning roughly from Wrigley, Northwest Territories (NT) to Norman Wells.

For the purposes of this document, a watercourse is defined as surface water that flows in a natural defined channel (e.g., creeks, streams, and rivers), and a waterbody is "*any water-filled basin that is potential fish habitat. A waterbody is defined by the ordinary high water mark of the basin, and excludes connecting watercourses*" (DFO 2010).

Water will be used for construction-related activities, compaction, and dust control in winter and non-winter periods. The amount and timing of water withdrawals are not yet known; however, the majority is anticipated to be needed in early winter (November-December) for winter road construction.

General findings are summarized in the summary figure and summary tables below.

For watercourses, water available for withdrawal was calculated as 10% of monthly flow in months where discharge is greater than 30% of mean annual discharge (MAD) (DFO 2013) Monthly flows were sourced using regional analysis (n=16), monitored flows (n=5), or reproduced from previously published reports (n=1; Great Bear River near the Mackenzie River).

For watercourses:

- water is likely typically available for withdrawal from approximately from April to October, and not available for withdrawal over winter due to low flows in winter (Summary Table 1).
- the main exception is Great Bear River near the Mackenzie River, where extremely large volumes of water are available year-round due to winter outflow from Great Bear Lake.
- volumes available for withdrawal are likely to be large compared to waterbodies (Summary Figure).
- not all the annual volume available for withdrawal may be useful. Much of this water is available in May when there may be limited water demand and accessibility (Summary Table 1).
- potential sources are relatively spatially extensive. For example, the largest gap between watercourses is about 41 km (Gotcha to Big Smith creeks; Summary Table 1).
- water availability generally scales with upstream watershed area and varies by orders of magnitude.

For waterbodies, water available for withdrawal in ice covered periods (‘winter’) was evaluated using criteria intended to protect oxygen levels under ice for fish (DFO 2010) and littoral habitat (MVLWB 2021a; MVLWB 2021b). Conservative potential withdrawals in ice covered periods are calculated for lakes with maximum depths greater than 3.0 m as the *lesser of* (1) 10% of the under ice water volume (DFO 2010) and (2) the volume equivalent of 0.1 m of drawdown based on the lake surface area (MVLWB 2021a; MVLWB 2021b). The MVLWB protocol is considered here because it provides guidance for preservation of littoral habitat and because it is regionally applicable; however, its intended use is for small projects.

Water withdrawals in the open water period (‘non-winter’) are evaluated here using the MVLWB method, since it is intended to preserve littoral zone habitat. The DFO (2010) method is not applied in the open water period since lakes typically experience wind-generated mixing and seasonal overturn which oxygenates the water column.

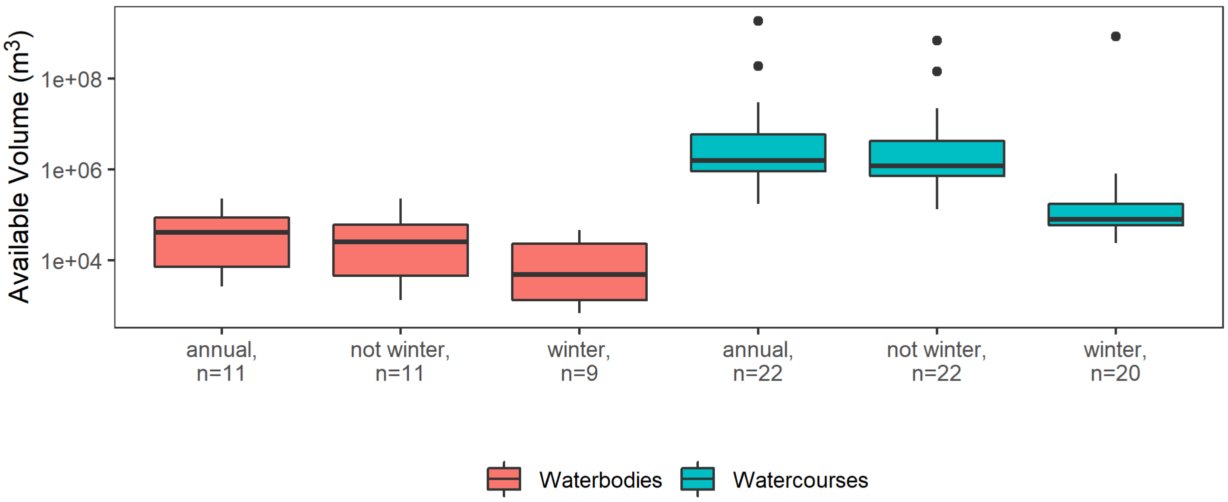
For waterbodies:

- in the ice-covered period there are nine lakes where data are available that meet criteria for winter withdrawals. In the open water period, there are eleven lakes (Summary Table 2).
- volumes available for withdrawal from waterbodies are small compared to watercourses (Summary Figure).
- there are long distances between lakes that meet assessment criteria and where data are available (Summary Table 2).
- additional lakes have been identified as candidates for future bathymetric surveys based on their surface area and depth (where known). However, even if the bathymetry of these lakes is surveyed and the lakes are found to meet withdrawal criteria, large gaps between lakes will remain along the proposed MVH alignment.

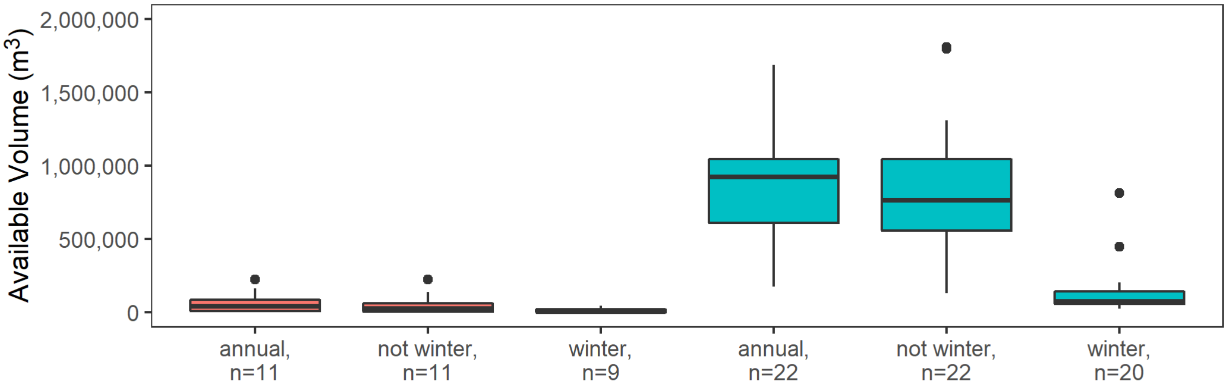
The provided volumes are estimates based on desktop studies. Additional data on a site-specific basis may be required by regulators in support of authorizations. Additional limitations are described in Section 2.

Summary Figure: Summary of Available Water for Withdrawal for Waterbodies and Watercourses

(a) all waterbodies and watercourses ($\log_{10}$ y-axis)



(b) waterbodies and watercourses, excluding the largest ten watercourses (linear y-axis)



NOTES:

- Boxplots summarize distributions of available water volumes for all waterbodies or watercourses annually and by season. They show the median (heavy line inside box) and interquartile range (IQR; spanning from 25th to 75th percentiles). The upper whisker extends from the top of the box to the largest value no further than 1.5 * IQR from the lower and upper edges of the box (the 'hinge'). The lower whisker extends from the bottom of the box to the smallest value at most 1.5 * IQR of the hinge. Data beyond the end of the whiskers are outliers and are plotted individually where present (Wickham 2016).
- 'Winter' as used here is November through April and 'not winter' is May through October, which aligns with approximate freeze up and breakup dates for waterbodies in the region.
- Positive outliers in panel A are the Great Bear and Blackwater rivers.
- n = sample size.
- A total of 24 waterbodies were assessed. Results shown here are for those waterbodies where sufficient data were available to calculate water availability or where waterbodies passed withdrawal criteria.
- Except for Great Bear River, watercourses do not have water available for withdrawal over most of the winter (Summary Table 1). However, most smaller watercourses have some water availability in April. One watercourse other than Great Bear River has availability in November (Hodgson Creek).

Summary Table 1: Calculated Water Availability at Assessed Watercourses Along the Proposed Mackenzie Valley Alignment

Watercourse Location	MVH Alignment (km)	Watershed Area (km^2)	Monthly Water Availability (m^3)												Annual Water Availability (m^3)
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Hodgson Creek Bridge	695.6	358	0	0	0	253,860	2,561,344	745,800	781,913	700,817	576,570	386,663	193,710	0	6,200,677
Ochre River Bridge	725.7	1,207	0	0	0	813,120	13,287,561	3,524,820	3,443,046	3,780,326	3,758,520	1,439,857	0	0	30,047,250
Whitesand Creek Bridge	733.8	346	0	0	0	179,340	2,346,545	788,370	524,396	490,668	426,300	313,658	0	0	5,069,277
Big Strawberry Creek Culvert	748.5	59	0	0	0	67,140	511,097	98,280	67,146	73,005	63,240	59,458	0	0	939,366
Small Strawberry Creek Culvert	748.6	49	0	0	0	60,570	435,705	79,050	54,157	59,799	51,780	49,941	0	0	791,002
Vermillion Creek South Bridge	752.3	68	0	0	0	72,630	577,592	116,160	79,174	85,064	73,710	67,952	0	0	1,072,282
Bob's Canyon Creek Culvert	755.3	9	0	0	0	23,880	102,765	10,980	7,719	9,827	8,490	10,323	0	0	173,984
Dam Creek Bridge	764.8	110	0	0	0	94,890	874,200	204,630	138,477	142,786	123,840	106,795	0	0	1,685,618
Blackwater Bridge	785.3	10,716	0	0	0	0	57,512,502	59,656,980	31,846,269	15,246,389	13,791,420	10,055,470	0	0	188,109,030
Steep Creek Bridge	816.5	154	0	0	0	114,390	1,168,204	304,050	204,724	205,158	178,020	146,537	0	0	2,321,083
Devil's Canyon Bridge	828.4	21	0	0	0	37,800	209,870	29,130	20,212	23,994	20,760	22,506	0	0	364,272
Saline River Bridge	831.9	317	0	0	0	170,850	2,176,076	711,180	473,680	446,524	387,900	288,858	0	0	4,655,068
Seagrams Creek Bridge	844.3	57	0	0	0	65,850	496,124	94,380	64,511	70,339	60,930	57,567	0	0	909,701
Little Smith Creek Bridge	852.3	439	0	0	0	204,720	2,880,799	1,043,340	691,486	634,105	551,130	392,336	0	0	6,397,916
Big Smith Creek Bridge	872.1	1,076	0	0	0	0	9,012,816	4,527,960	1,438,524	1,730,141	1,973,850	827,545	0	0	19,510,836
Gotcha Creek Bridge	912.7	155	0	0	0	114,810	1,174,745	306,360	206,274	206,615	179,280	147,436	0	0	2,335,520
Twelve Mile Creek Bridge	922.0	42	0	0	0	55,830	384,028	66,510	45,663	51,057	44,220	43,524	0	0	690,832
Four Mile Creek Culvert	931.5	17	0	0	0	33,630	174,933	22,710	15,810	19,096	16,530	18,445	0	0	301,154
Great Bear River Bridge	937.2	158,400	141,955,200	126,524,160	139,276,800	132,710,400	182,666,880	169,257,600	168,739,200	169,810,560	162,000,000	160,704,000	144,892,800	145,972,800	1,844,510,400
Jungle Ridge Creek Bridge	967.8	60	0	0	0	39,960	550,219	168,660	60,419	78,864	88,890	48,701	0	0	1,035,713
Notta Creek Bridge	971.5	65	0	0	0	70,830	555,582	110,160	75,144	81,034	70,200	65,131	0	0	1,028,081
Vermillion Creek North Bridge	973.4	92	0	0	0	85,920	749,456	165,810	112,530	117,800	102,120	90,272	0	0	1,423,908

NOTES:

Watercourses are sorted from south to north along the proposed MVH alignment.

Zero water availability indicates that discharge in that month is less than 30% of mean annual discharge (DFO 2013).

Summary Table 2: Calculated Water Availability at Waterbodies Along the Proposed MVH Alignment

Waterbody	Alignment (km)	Surface Area (m^2)	Available Volume (m^3) Winter	Available Volume (m^3) Not winter	Available Volume (m^3) Annual
WR2	702.2	364,955	4,277	36,496	40,773
WR6	804.0	796,473	682	79,647	80,330
WR8	820.0	251,743	25,174	25,174	50,349
WR10	835.0	13,160	1,316	1,316	2,632
WR16	882.5	56,631	4,899	5,663	10,562
WR18	892.0	1,385,441	22,937	138,544	161,481
WR19	903.0	35,950	1,181	3,595	4,776
WR22	916.0	2,254,359	0	225,436	225,436
WR21	921.3	30,606	0	3,061	3,061
WR25	944.6	461,128	46,113	46,113	92,226
WR28	950.4	204,493	20,449	20,449	40,899

NOTES:

- A total of 24 waterbodies were assessed. Results shown here are for those waterbodies where sufficient data were available to calculate water availability or where waterbodies passed withdrawal criteria.
- ‘Winter’ as used here is November through April and ‘not winter’ is May through October, which aligns with approximate freeze up and breakup dates for waterbodies in the region.
- There is zero reported water availability for WR21 and WR22 in winter because volume data are not available for these waterbodies.

Table of Contents

1 INTRODUCTION 1

2 LIMITATIONS 6

3 REGIONAL HYDROCLIMATIC CONTEXT 7

4 METHODS 9
4.1 Watercourses 9
  4.1.1 Criteria for Assessment of Environmental Flow Needs in Watercourses 9
  4.1.2 Calculation of Volumes Available for Withdrawal in Watercourses 9
4.2 Waterbodies 19
  4.2.1 Criteria for Assessment of Environmental Flow Needs in Waterbodies 19
  4.2.2 Calculation of Volumes Available for Withdrawal in Waterbodies 21

5 RESULTS 24
5.1 Watercourses 24
  5.1.1 Flows Estimation and Water Availability for Gauged Basins: WSC Scaling 24
  5.1.2 Flows and Water Availability at Ungauged Basins Derived Using Regional Analyses 26
  5.1.3 Flows and Water Availability at the Great Bear River near the Mackenzie River 31
  5.1.4 Summary of Flow Predictions and Water Availability at all Studied Locations 33
5.2 Waterbodies 36
  5.2.1 Withdrawals During Periods of Ice-Cover 36
  5.2.2 Withdrawals During Periods of Open-Water 39
  5.2.3 Summary of Water Availability from Waterbodies in the Ice-Covered and Ice-Free Periods 42

6 DISCUSSION 43
6.1 Licensing Considerations 43
6.2 Assessment of Methods for Determination of Streamflow In Ungauged Catchments 43
  6.2.1 Comparison Results from Regional Analysis and 'WSC Scaling' Methods 43
  6.2.2 Comparison of Flows Predicted Using Differing Regression Equations 46
6.3 Approaches for Assessment of Withdrawals from Waterbodies Appropriate for Preserving Downstream Environmental Flow Needs 48

7 CONCLUSIONS AND RECOMMENDATIONS 50

8 LITERATURE CITED 52
8.1 Personal Communications 55

9 CLOSURE 56

List of Tables

Table 3.1 Summary Climate Data from Norman Wells and Wrigley, NT 7
Table 4.1 Mackenzie Valley Highway Watercourse Crossings where Water Availability was Assessed 10
Table 4.2 Gauged Watercourses along the Proposed Mackenzie Valley Highway Alignment 12
Table 4.3 Regional Water Survey of Canada Stations Used for Flow Predictions in the Study Area along the Proposed Mackenzie Valley Highway Alignment 15
Table 4.4 Fisheries and Oceans Canada (DFO) Winter Water Withdrawal Guidance for Ice-Covered Waterbodies, Applicable to Lakes Located South of the Tree Line but North of Fort Simpson, Northwest Territories 20
Table 4.5 Waterbodies Considered for Withdrawals Near the Proposed Mackenzie Valley Highway 23
Table 5.1 Regional Analysis Regression Coefficients and Statistics 26
Table 5.2 Great Bear River Near the Mackenzie River: Average Flow Predictions and Statistics 32
Table 5.3 Flow Summary Statistics for Flow and Water Availability at Potential Water Withdrawal Locations Along the Proposed Mackenzie Valley Highway Alignment 34
Table 5.4 Potential Withdrawal Limits for Waterbodies Along the Proposed Mackenzie Valley Highway Alignment during Periods of Ice Cover 37
Table 5.5 Potential Withdrawal Limits for Waterbodies Along the Proposed Mackenzie Valley Highway Alignment during Periods of Open Water 41
Table 5.6 Open Water Withdrawal Categories based on Maximum Open Water Depth 42
Table 6.1 Comparison of Annual Water Availability per DFO Criteria Predicted Using the ‘WSC Scaling’ Technique and the Regional Analysis (MVH) Technique 45
Table 6.2 Comparison of Annual Water Availability Predicted Using Differing Sets of Regional Stations 48

List of Figures

Figure 1.1 Mackenzie Valley Highway Proposed Alignment: Regional Map and Selected Water Survey of Canada Stations 2
Figure 1.2 Potential Watercourse Water Sources along the Mackenzie Valley Highway Proposed Alignment 3
Figure 1.3 Potential Waterbody Water Sources near the Mackenzie Valley Highway Proposed Alignment 4
Figure 4.1 Histograms for Selected Water Survey of Canada Stations, Showing the Number of Observations in Each Month for the Period of Record 17
Figure 5.1 Monthly Average Discharge at Potential Water Withdrawal Locations Along the Proposed Mackenzie Valley Highway Alignment, Derived Directly from Water Survey of Canada Stations (WSC Scaling Approach) 25
Figure 5.2 Relationships Between Watershed Area and Mean Monthly Discharge at Selected Regional Water Survey of Canada Stations 28
Figure 5.3 Monthly Average Discharge at Potential Water Withdrawal Locations Along the Proposed Mackenzie Valley Highway Alignment, Predicted by Regression 30
Figure 5.4 Area Charts of Monthly Water Availability from Studied Watercourses 35
Figure 6.1 Comparison of Monthly Flows Predicted using the ‘WSC Scaling’ Technique and the Regional Analysis Technique 44
Figure 6.2 Comparison of Monthly Flows Predicted Using Differing Sets of Regional Stations 47

Abbreviations

A.	watershed area
b.	regression line intercept
BCOGC.	British Columbia Oil and Gas Commission
e.g.	example
DFO	Fisheries and Oceans Canada
EFN	Environmental Flow Needs
ENV	Ministry of Environment and Climate Change Strategy
FLNRORD	Ministry of Forests, Lands, Natural Resource Operations and Rural Development
GBR	Great Bear River
i.e.	that is to say
IQR	Inter Quartile Range
m	regression line slope
MAD	Mean Annual Discharge
masl	Metres Above Sea Level
MVH	Mackenzie Valley Highway
MVLWB	Mackenzie Valley Land and Water Board
MVWR	Mackenzie Valley Winter Road
n	sample size
NHC	Northwest Hydraulic Consultants
NT	Northwest Territories
PCAR	Prohibition Creek Access Road
Q	Discharge
QAQC	Quality Assurance/Quality Control
TOR	Terms of Reference
WSC	Water Survey of Canada

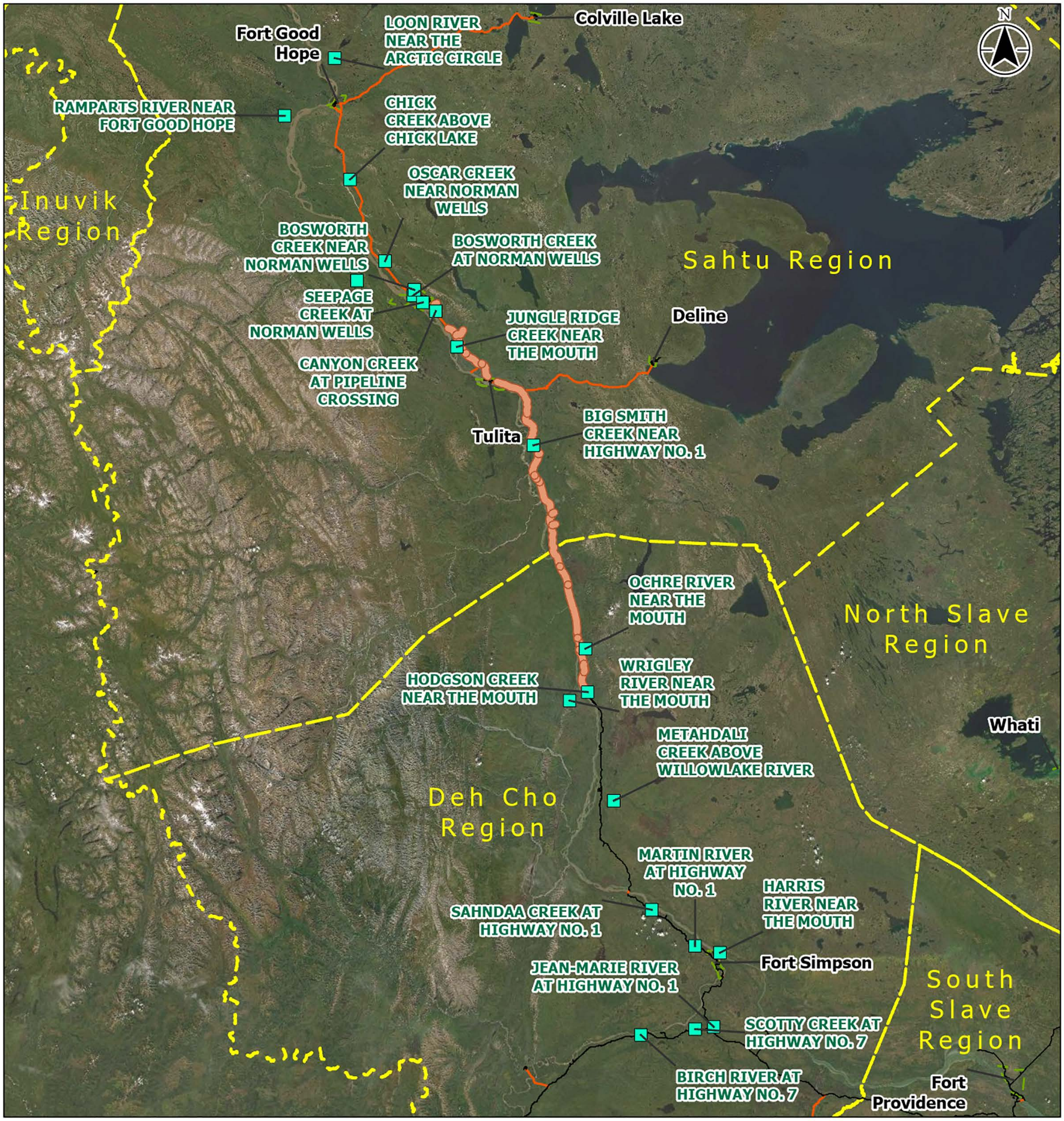
1 Introduction

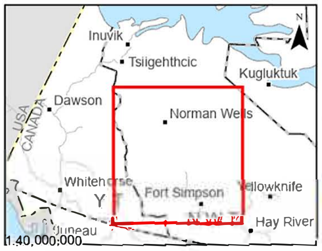
This document provides flow and water withdrawal volume estimates for watercourses and waterbodies near the proposed Mackenzie Valley Highway alignment (MVH; Figure 1.1) identified for assessment as potential water sources for construction and operations of the MVH. The assessed area spans roughly from Wrigley, Northwest Territories (NT) in the south to Prohibition Creek, 18 kilometres (km) south of Norman Wells, NT in the north (an approximately 260 km straight line distance). The proposed MVH alignment distance between the southernmost and northernmost assessed sites is about 275 km (the 'Study Area'). The proposed alignment typically parallels the east bank of the Mackenzie River, mostly along the alignment of the Mackenzie Valley Winter Road (MVWR). Watercourse crossings and water availability between Prohibition Creek and Norman Wells are published elsewhere (K'alo-Stantec 2022a). Twenty-two watercourses and twenty-four waterbodies were evaluated for potential future water withdrawals within approximately 500 m of the proposed MVH alignment between Wrigley and Prohibition Creek (Figure 1.2, Figure 1.3). These sources were identified based on their size and proximity to the alignment. Larger waterbodies and all watercourses with existing bridge crossings were included in the study.

The objectives and scope of the study are to:

- Review potential water withdrawal sources along the proposed MVH alignment.
- Review existing available data to identify sources that are likely to support water withdrawal (based on watershed, flow data, hydrographs, etc.) during certain times of the year.
- Identify monthly and/or seasonal withdrawal magnitudes that are likely to meet environmental flow needs (EFN); i.e., the volume and timing of water flow required for proper functioning of the aquatic ecosystem. EFN criteria were assessed and applied from the Mackenzie Valley Land and Water Board (MVLWB), Fisheries and Oceans Canada (DFO), Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD), and the Ministry of Environment and Climate Change Strategy (ENV) (FLNRORD and ENV 2022; DFO 2013; DFO 2010).
- Identify additional studies required to verify the findings of this desktop study (Section 7) and to support environmental assessment and licensing of water withdrawal.

During construction and operation of the MVH, water will be used for winter road construction, compaction, and dust control. The amount and timing of water withdrawals are not yet known. This document aims to research potential water withdrawal sources that could support withdrawals throughout the year while meeting EFN, and therefore could be supported by regulators for purpose of licensing. It is understood that the majority of water for winter road construction is needed in early winter (November–December); whereas water is used for compaction and dust control from June to September (Stevens, pers. comm., 2022).





🟩 Water Survey of Canada Hydrometric Station

Winter Road

All Weather Road

Project Alignment

Region Boundary

Community Boundary

0 40 80 120 160 km

1:3,847,888 (at original document size of 8.5x11)

Notes

1. Coordinate System: NAD83 Northwest Territories Lambert
2. Data Sources: Government of Northwest Territories, Open Data Canada, Government of Canada, ESRI Base Layers

Stantec

Project Location:

Northwest Territories, Canada

Project Number: <144903284>

Prepared by EHERTZMAN on 20220908

Requested by TLEWIS on 20220908

Client/Project/Report

Mackenzie Valley Highway

Mackenzie Valley Highway: Desktop Based Assessment of Water Availability

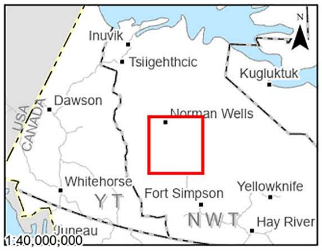
Figure No.

1.1

Title

Mackenzie Valley Highway Proposed Alignment: Regional Map and Selected Water Survey of Canada Stations

\\Cd0183-cbanf01\workgroup\1233\projects\144903284\figures\reports\144903284_MVH_Analysis_Maps\144903284_MVH_Analysis_Maps.aprx Revised: 2022-09-14 By: ehertzman



Notes
1. Coordinate System: NAD83 Northwest Territories Lambert
2. Data Sources: Government of Northwest Territories, Open Data Canada, Government of Canada, ESRI Base Layers

Prediction Type
- ● Regional Analysis (MVH)
- ⊗ Regional Analysis (PCAR)
- ● WSC Scaling
- ● NHC
- — Winter Road
- — All Weather Road
- ═ Project Alignment
- ⬚ Region Boundary
- ⬚ Community Boundary

0 10 20 30 40 km
1:1,600,000 (at original document size of 8.5x11)

Project Location:
Northwest Territories, Canada

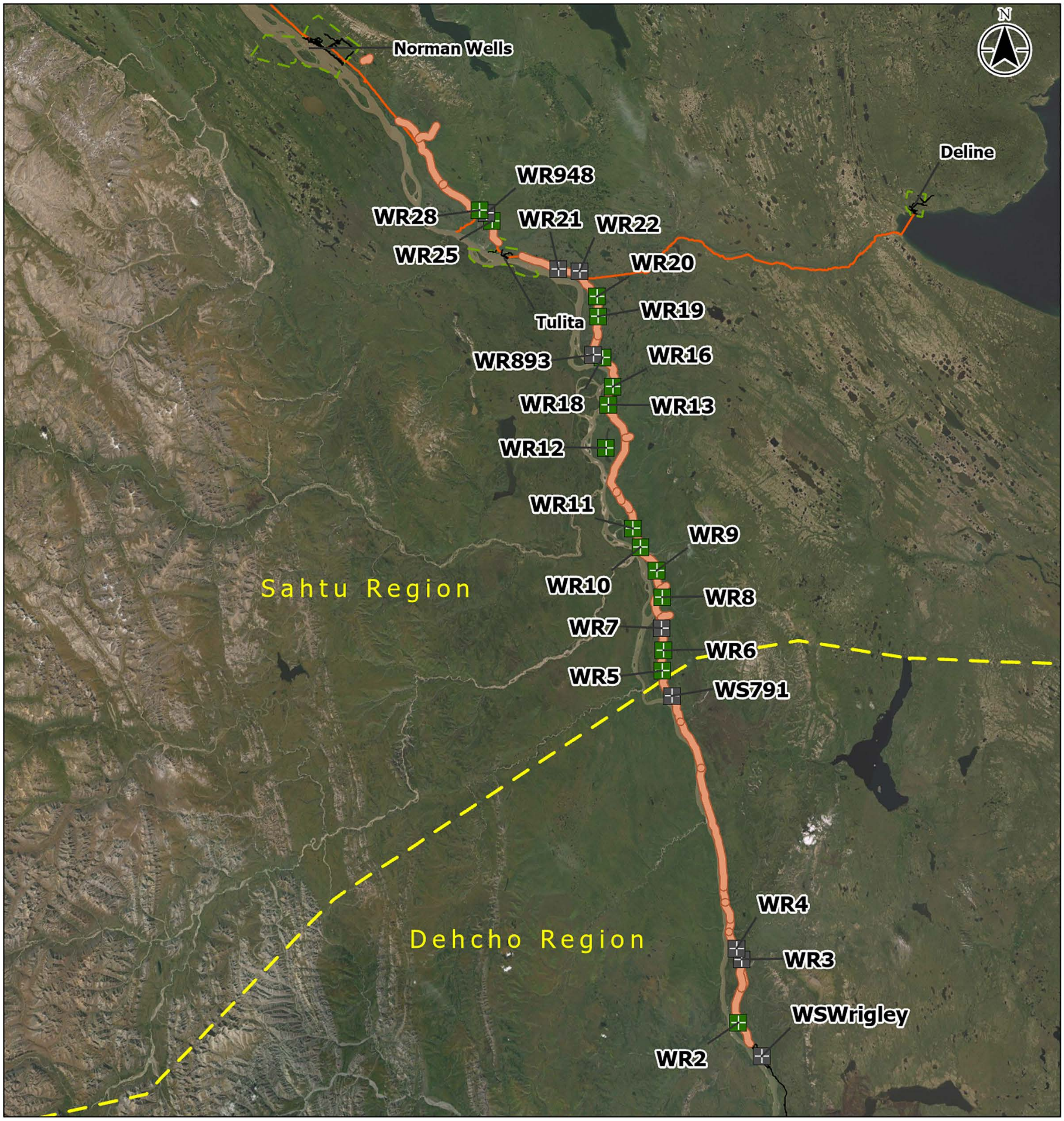
Project Number: <144903284>
Prepared by EHERTZMAN on 20220908
Requested by TLEWIS on 20220908

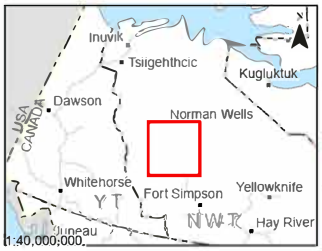
Client/Project/Report
Mackenzie Valley Highway
Mackenzie Valley Highway: Desktop Based Assessment of Water Availability

Figure No.
1.2

Title
Potential Watercourse Water Sources along the Mackenzie Valley Highway Proposed Alignment

\\Ca0183-pbad01\workgroup\1232\projects\144903284\figures\reports\144903284 MVH Analysis Maps\144903284 MVH Analysis Maps.aprx Revised: 2022-09-22 By: ehertzman





Potential Waterbody Water Sources

🟩	Bathymetry Data Available
⬛	No Bathymetry Data Available
—	Winter Road
—	All Weather Road
▬	Project Alignment
⬚	Region Boundary
⬚	Community Boundary

0 10 20 30 40 km

1:1,525,000 (at original document size of 8.5x11)

Notes

1. Coordinate System: NAD83 Northwest Territories Lambert
2. Data Sources: Government of Northwest Territories, Open Data Canada, Government of Canada, ESRI Base Layers

Stantec

Project Location: Northwest Territories, Canada

Project Number: <144903284>

Prepared by EHERTZMAN on 20220908

Requested by TLEWIS on 20220908

Client/Project/Report

Mackenzie Valley Highway
Mackenzie Valley Highway: Desktop Based Assessment of Water Availability

Figure No.

1.3

Title

Potential Waterbody Water Sources near the Mackenzie Valley Highway Proposed Alignment

For watercourses, this document provides average monthly and annual volumes available for withdrawal designed to meet EFN and Fisheries and Oceans Canada (DFO) protocols (DFO 2013). This requires flows to be known. Of the 22 studied watercourses:

- Five are gauged by the WSC and these gauged data are appropriate for deriving flows at ungauged MVH crossings.
- One is gauged by the WSC, but the gauge is far upstream of the proposed bridge crossing, and several large tributaries contribute to flows between the gauge and the crossing. This site is the proposed bridge over the Great Bear River (GBR) near Tulita and the Mackenzie River. Flow data at this crossing were obtained from previous studies (NHC 2006; NHC 2018).
- Flows at the remaining 16 proposed MVH crossings were calculated using a regional analysis approach based on the principle that streamflow from ungauged basins can be reasonably estimated from gauged basins of similar physiographic, geologic, or climatic factors (MOE 1991). Regional flow analysis was conducted by compiling flow data from 21 regional WSC stations and relating monthly flows to watershed size. Regression equations were then used to predict flows using the watershed area of each ungauged catchment.

For waterbodies, this document provides estimates of water volumes that will protect littoral habitat and oxygenated water for fish in winter, and follows protocols developed by DFO (DFO 2010) and the Mackenzie Valley Land and Water Board (MVLWB; called the ‘MVLWB method’ here) (MVLWB 2021a; MVLWB 2021b). Recommendations are made for withdrawal protocols from waterbodies that could protect flows in downstream watercourses (Section 6.3, Section 7).

2 Limitations

Flows, water volumes, and water withdrawals provided here are estimates. Most studied withdrawal sources are ungauged, and bathymetric surveys have not yet been conducted at many waterbodies. Results are approximations and are intended to focus efforts on watercourses, waterbodies, and seasons where withdrawals will have the least ecological impacts. Limitations include:

- Flows and water volumes provided here are not precise assessments of water availability in a given year. Flow predictions are reflective of average conditions in the years regional data were collected.
- Flows during floods and changes in flow due to climate change have been evaluated elsewhere (Tetra Tech 2021; Tetra Tech 2022; Tetra Tech 2020; K’alo-Stantec 2021).
- Results presented here should not be used for purposes other than those stated. For example, data presented here do not provide engineering design parameters. Engineering design and analysis of crossings (e.g., conveyance capacity and channel stability) would require a separate study tailored for such purposes.
- Analysis and recommendations are based on data available at the time of the report and rely on data provided by others which we assume to be correct but were not verified as part of this study.
- Cumulative withdrawals are not accounted for here.
- Results provided here do not consider potential effects on specific species of interest, cultural values, or on downstream flows (Section 6.3 and Section 7).
- Further site-specific study or evaluation may be required to support regulatory approval for water withdrawal.
- Changes in flows and water availability due to backwatering have not been considered. Backwatering causes river levels to rise independently from discharge, often in response to a downstream obstruction (e.g., ice, beaver dams), or a downstream waterbody or watercourse.

Recommendations for refining estimates provided here are presented in Section 6.3 and Section 7.

3 Regional Hydroclimatic Context

The watercourses and waterbodies evaluated in this study are located between approximately Wrigley, NT in the south to Prohibition Creek in the north (Figure 1.1) and are within about 500 m of the proposed MVH alignment. Climate at the northern and southern ends of the alignment is summarized in Table 3.1. Overall, climatic normal conditions (1991-2020) are similar at the southern and northern ends of the Study Area (Table 3.1). Air temperatures cool slightly from south to north. Annual total precipitation decreases slightly, i.e., by about 2%. Potential evapotranspiration (ET) increases by about 3%. These north-south differences are negligible from a hydrologic perspective. At both locations. ET exceeds precipitation (Wang 2022; Wang et al. 2012; K’alo-Stantec 2022a); i.e., there is a potential annual moisture deficit in the region.

Table 3.1 Summary Climate Data from Norman Wells and Wrigley, NT

Community	Elevation (masl)	Air Temperature (°C)			Annual Total Precipitation (MAP, mm)	Annual Total Potential Evapotranspiration (ET, mm)	MAP-ET (mm)
		Mean Annual	Maximum	Minimum			
Norman Wells	72	-4.5	16.4	-24.3	323	389	-66
Wrigley	150	-3.6	17.1	-25.4	316	401	-85
Difference (Wrigley-Norman Wells)	**78**	**0.9**	**0.7**	**-1.1**	**-7**	**12**	**-19**
Difference (%; Wrigley-Norman Wells)	**n/a**	**n/a**	**n/a**	**n/a**	**-2**	**3**	**n/a**

NOTES:
Elevations in metres above sea level (masl) are at the airstrip in both communities.
Climate data are interpolated 1991 to 2020 climate normals from ClimateNA (Wang 2022).
Evapotranspiration (ET) is Hargreaves reference potential ET.
Maximum and minimum air temperatures are monthly averages for the warmest and coolest months.
n/a = not applicable.

Climate normal data used here are from ClimateNA, which uses peer-reviewed gridded climate data (Wang 2022; Wang et al. 2012). This data source was selected over station data (ECCC 2022a) because (a) climate normal data are available from Wrigley which allowed assessment of north-south climate trends along the proposed alignment, and (b) because it provides evapotranspiration data from land surfaces, while climate normal data from stations do not. There are therefore slight differences between climate normal data presented here from gridded datasets, and climate normal data presented elsewhere based on station data (K’alo-Stantec 2022b).

The Study Area is within the ‘extensive discontinuous’ (50-90%) permafrost zone (GNWT 2022a). Most of the Study Area falls within the ‘Taiga Plains, Norman Range LS Ecoregion’; vegetation is a “*complex of mixed-wood forests on westerly slopes and lacustrine deposits, mixed spruce stands on the interior plateau and slopes, and extensively burned areas*” (GNWT 2009). The entirety of the Study Area is south of the tree line (GNWT 2022b).

Elevations in the Study Area decrease generally from south to north (Table 3.1), and close to the Mackenzie River. Watercourses generally drain westward from highlands to the east towards the Mackenzie River.

The Study Area is part of the Dehcho and Sahtu regions. Runoff patterns in both regions are similar and are classified as nival, i.e., a “*large portion of the annual precipitation is stored for several months in the form of snow and therefore snowmelt runoff in spring is a dominant feature of regional stream hydrographs*” (Kokelj 2001). The period of snowmelt runoff in spring is called freshet, and typically starts in May. Flows decline after freshet, with occasional increases in response to rainfall, then decline through winter (October to April). The ability of a watercourse in the region to sustain flows over winter depends watershed area as well as “*watershed-specific factors including precipitation, channel slope, upland storage and particularly the presence of springs*” (Golder Associates 2006). Watersheds larger than 50-100 km^2 may be perennial (MGP 2004; K’alo-Stantec 2021).

Annual runoff changes outside of the Study Area. For example, runoff increases to the west of the Mackenzie River in the Mackenzie Mountains, decreases to the east towards Great Bear Lake, and north towards the Arctic Ocean (Cole 2013).

Precipitation and ET are similar at the northern and southern ends of the Study Area (Table 3.1). This helps explain the north-south similarity of runoff noted above.

Gauged runoff in the Sahtu region spans from 60 to about 330 mm/year, not including stations in the Mackenzie Mountains (Kokelj 2001). In the Dehcho region, the Study Area falls within the ‘Interior plains’ regime, where annual runoff at gauging stations spans from 55 to almost 200 mm (Faria 2002). Mean annual runoff in the Study Area was found to range between 151 and 220 mm (K’alo-Stantec 2021). Differences among published ranges may be more reflective of local site conditions and the relatively sparse gauging network than general spatial hydroclimatic trends (e.g., storage in muskeg and lakes that locally affects the timing and magnitude of flows).

4 Methods

Methods are described below for watercourses and waterbodies. Each section begins by presenting regionally applicable criteria for water withdrawals, then provides the methodologies used to assess these criteria at candidate withdrawal sites.

The MVH alignment used here is the IFAE21 alignment, and KPs cited here are relative to this. Data were collected, filtered, analyzed, and plotted using R (R Core Team 2022).

4.1 Watercourses

For the purposes of water availability calculations, all watercourses are conservatively considered to be potential fish habitat.

4.1.1 Criteria for Assessment of Environmental Flow Needs in Watercourses

For watercourses, DFO guidance (DFO 2013) is:

- "*cumulative flow alterations of less than +/- 10% of the magnitude of actual (instantaneous) flow in the river relative to a "natural flow regime" have a low probability of detectable negative impacts to ecosystems*"; and
- "*cumulative flow alterations that result in instantaneous flows less than 30% of the Mean Annual Discharge (MAD) have a heightened risk of impacts to ecosystems that support fisheries*". Periods below 30% MAD were identified as 'highest risk'.

Mean monthly flows are predicted here in place of instantaneous flows as a desktop-based means of estimating monthly and annual low risk withdrawals. MAD is calculated from mean monthly flows to identify the months with the 'highest risk'. This approach allows for: (a) an assessment of which months are likely candidates for low-risk water withdrawal; and (b) an estimation of water available for withdrawal during low-risk conditions.

Flow data are required to apply these criteria and calculate water availability. Flow and water availability methodologies are described below.

4.1.2 Calculation of Volumes Available for Withdrawal in Watercourses

Volumes of water potentially available for withdrawal were calculated using criteria described above (DFO 2013). Application of these criteria require flow data. Methodologies for compiling and calculating flow data are described below.

Table 4.1 Mackenzie Valley Highway Watercourse Crossings where Water Availability was Assessed

Watercourse Location	MVH Alignment (km)	UTM			Region	Watershed Area (km^2)	Watershed Area Source	Prediction Type
		Easting (m)	Northing (m)	Zone				
Hodgson Creek Bridge	695.6	475,755	7,011,710	10	Dehcho	358	(K'alo-Stantec 2021)	WSC Scaling
Ochre River Bridge	725.7	465,971	7,038,047	10	Dehcho	1,207	(K'alo-Stantec 2021)	WSC Scaling
Whitesand Creek Bridge	733.8	463,508	7,045,441	10	Dehcho	346	(K'alo-Stantec 2021)	Regional Analysis
Big Strawberry Creek Culvert	748.5	459,694	7,059,416	10	Dehcho	59	(K'alo-Stantec 2021)	Regional Analysis
Small Strawberry Creek Culvert	748.6	459,640	7,059,510	10	Dehcho	49	herein	Regional Analysis
Vermillion Creek South Bridge	752.3	457,967	7,062,906	10	Dehcho	68	(K'alo-Stantec 2021)	Regional Analysis
Bob's Canyon Creek Culvert	755.3	456,550	7,065,460	10	Dehcho	9	(Tetra Tech 2020)	Regional Analysis
Dam Creek Bridge	764.8	452,501	7,074,004	10	Dehcho	110	(K'alo-Stantec 2021)	Regional Analysis
Blackwater Bridge	785.3	443,181	7,091,526	10	Dehcho	10,716	(K'alo-Stantec 2021)	WSC Scaling
Steep Creek Bridge	816.5	432,421	7,118,214	10	Sahtu	154	(K'alo-Stantec 2021)	Regional Analysis
Devil's Canyon Bridge	828.4	430,299	7,128,819	10	Sahtu	21	(K'alo-Stantec 2021)	Regional Analysis
Saline River Bridge	831.9	427,270	7,130,500	10	Sahtu	317	(K'alo-Stantec 2021)	Regional Analysis
Seagrams Creek Bridge	844.3	421,623	7,141,075	10	Sahtu	57	(K'alo-Stantec 2021)	Regional Analysis
Little Smith Creek Bridge	852.3	416,273	7,146,420	10	Sahtu	439	(K'alo-Stantec 2021)	Regional Analysis
Big Smith Creek Bridge	872.1	413,214	7,163,972	10	Sahtu	1,076	(K'alo-Stantec 2021)	WSC Scaling
Gotcha Creek Bridge	912.7	400,354	7,196,273	10	Sahtu	155	(K'alo-Stantec 2021)	Regional Analysis
Twelve Mile Creek Bridge	922.0	392,054	7,198,761	10	Sahtu	42	herein	Regional Analysis
Four Mile Creek Culvert	931.5	382,829	7,200,812	10	Sahtu	17	(K'alo-Stantec 2021)	Regional Analysis
Great Bear River	937.2	377,381	7,201,412	10	Sahtu	158,400	(NHC 2006; NHC 2018)	NHC
Jungle Ridge Creek Bridge	967.8	638,257	7,218,483	9	Sahtu	60	(K'alo-Stantec 2021)	WSC Scaling
Notta Creek Bridge	971.5	636,476	7,221,655	9	Sahtu	65	(K'alo-Stantec 2021)	Regional Analysis
Vermillion Creek North Bridge	973.4	634,748	7,222,289	9	Sahtu	92	(K'alo-Stantec 2021)	Regional Analysis

NOTES:

UTM coordinates use the WGS84 datum and are approximate.

Watercourses are sorted from south to north.

Watershed delineation methodologies for this document are described in Section 4.1.2.2. 'Watershed Area Sources' noted as 'herein' were calculated as part of this study.

'Prediction types' are described in the text.

4.1.2.1 Flow Estimation for Gauged Basins: WSC Scaling

Five candidate watercourses are gauged by the WSC (Table 4.2), not including Great Bear River (Section 4.1.2.3). Where gauged data are available, they were used to assess water availability, rather than deriving them using regional analyses.

WSC stations and studied withdrawal locations are often not at the same location. Scaling factors were produced that relate the watershed area at each WSC station to the watershed area at each bridge crossing (Table 4.2). Monthly average flows from WSC stations were modified by multiplying by scaling factors.

Table 4.2 Gauged Watercourses along the Proposed Mackenzie Valley Highway Alignment

Water Survey of Canada				Existing Bridge Crossing			
Station Name	Station Number	Watershed Area (km²)	Delineation Source	Crossing Name	Watershed Area (km²)	Delineation Source	Scaling Factor
HODGSON CREEK NEAR THE MOUTH	10HC007	303	K'alo-Stantec (this document)	Hodgson Creek Bridge	358	K'alo-Stantec (2022)	1.18
OCHRE RIVER NEAR THE MOUTH	10HC008	1,031	K'alo-Stantec (this document)	Ochre River Bridge	1,207	K'alo-Stantec (2022)	1.17
BLACKWATER RIVER AT OUTLET OF BLACKWATER LAKE	10HC006	7,850	ECCC (2022b)	Blackwater Bridge	10,716	K'alo-Stantec (2021)	1.37
BIG SMITH CREEK NEAR HIGHWAY NO. 1	10HC003	980	ECCC (2022b)	Big Smith Creek Bridge	1,076	K'alo-Stantec (2021)	1.10
JUNGLE RIDGE CREEK NEAR THE MOUTH	10KA006	60	ECCC (2022b)	Jungle Ridge Creek Bridge	47	BP-TEC (2002)	0.78

NOTES:

Stations are sorted from south to north.

'Scaling factor' is the watershed area at each crossing divided by watershed area at each WSC station.

Coordinates for each site are provided in Table 4.1 and Table 4.3.

4.1.2.2 *Flow Estimation at Ungauged Basins: Regional Analysis*

Monthly average flows and water availability were calculated using linear regressions between monthly average flow and watershed area using flow data from regional WSC stations. Regression equations were then used to calculate monthly flows at proposed crossing locations using the upstream watershed areas for these locations.

Daily flow data from WSC stations were compiled with the R library ‘Tidyhydat’ (Goetz, Albers and Pike 2018). Tidyhydat uses the WSC database ‘Hydat’ (ECCC 2022b). The Hydat version used here was published on 2022-04-18 and is the most recent database at the time of writing. The most recent finalized data for regional stations is from 2020. Provisional real-time data that have not yet undergone full quality assurance/quality control (QA/QC) were not used here.

Station Selection Methodologies

To develop an applicable dataset for regional analyses and flow predictions of watercourses in the Study Area, a set of selection criteria were developed and applied to regional WSC stations. Hydrometric data were compiled for all WSC stations in the NT, then filtered to include only:

- Stations falling within a 300 km buffer of the proposed MVH alignment. The start and end points of the buffer are Norman Wells in the north and Wrigley in the south.
- Stations with watershed areas up to 7,400 km^2 (set to include WSC stations 10KB001 and 10KD004; Table 4.3). This is larger than the threshold used in a recent water availability study for the Prohibition Creek Access Road (PCAR), where a ~1,000 km^2 upper limit was applied (K’alo-Stantec 2022a). The larger threshold was applied to: (a) provide more applicable predictions for MVH watercourses with larger watersheds (up to about 440 km^2; Table 4.1) compared to PCAR crossings (up to about 86 km^2), and (b) increase the number of regional WSC stations used in analyses in this data-sparse region. Effects of increasing this threshold are assessed in Section 6.2.1. For reference, proposed PCAR crossings are mapped in Figure 1.2.
- Stations with watersheds that do not drain the Mackenzie Mountains, due to the different hydrologic regime there (Golder Associates 2015) (Section 3).
- Stations where discharge is unlikely to be affected by drainage of large upstream lakes or muskeg, potentially causing delays between snowmelt and rainfall, and runoff (Section 3).
- Months (regardless of the year) with greater than or equal to 92 daily observations (i.e., greater than about three years of data per month; Figure 4.1). The statistical validity of using relatively small sample sizes was explored in the PCAR water availability study (K’alo-Stantec 2022a) and is discussed below for the MVH.

WSC stations remaining after applying the filtering process are summarized in Table 4.3, mapped in Figure 1.1, and monthly data availability at each station is presented in Figure 4.1.

Annual runoff is generally relatively uniform in the Study Area (Section 3). However, regional WSC stations that remain following the filtering process described above extend north and south of the Study Area (Figure 1.1). The relatively invariant north-south trends in runoff described in Section 3 also generally apply to these spatial limits. In the south, runoff decreases eastwards along the Mackenzie River between Fort Simpson and Great Slave Lake. In the north, runoff decreases north of Tsiigehtchic (Figure 1.1) (Cole 2013).

Data from three WSC stations[1] were frequently anomalous when flagged as backwatered and were removed from analyses.

.

---

[1] 10KA005 (SEEPAGE CREEK AT NORMAN WELLS), 10LA004 (WELDON CREEK NEAR THE MOUTH), and 10GB005 (METAHDALI CREEK ABOVE WILLOWLAKE RIVER).

Table 4.3 Regional Water Survey of Canada Stations Used for Flow Predictions in the Study Area along the Proposed Mackenzie Valley Highway Alignment

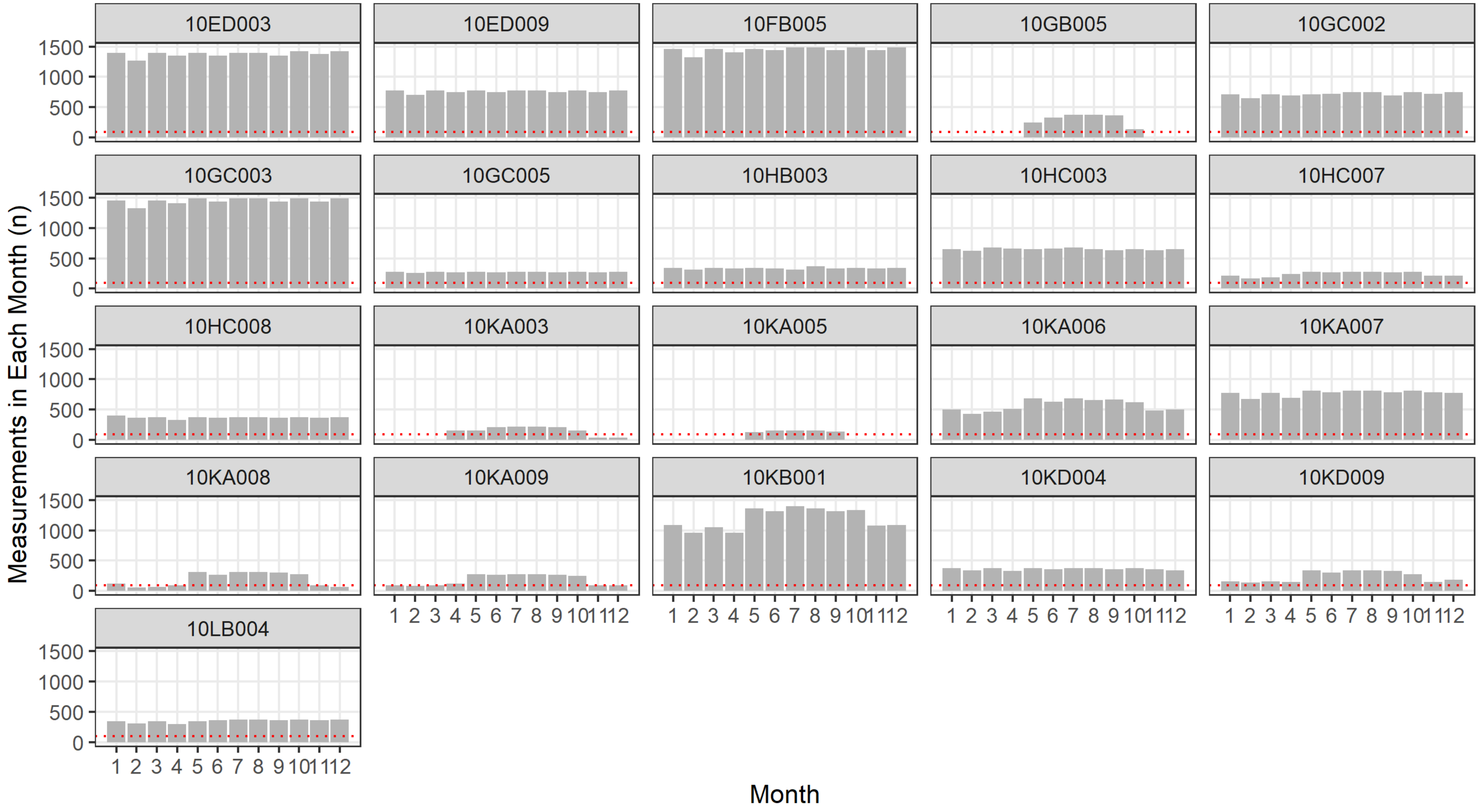
Station Number	Station Name	UTM			Drainage Area (km^2)	Location[a]		Monitoring Period		Data Points (n)[c]
		Easting (m)	Northing (m)	Zone		Dist. (km)	Bearing (deg)[b]	Begins	Ends	
10ED003	BIRCH RIVER AT HIGHWAY NO. 7	548,472	6,800,280	10	542	434	155	1974	2019	16,528
10ED009	SCOTTY CREEK AT HIGHWAY NO. 7	582,393	6,810,134	10	202	440	150	1995	2019	9,131
10FB005	JEAN-MARIE RIVER AT HIGHWAY NO. 1	593,943	6,813,683	10	1,310	442	148	1972	2019	17,380
10GB005	METAHDALI CREEK ABOVE WILLOWLAKE RIVER	504,798	6,946,566	10	344	283	151	1976	1987	4,201
10GC002	HARRIS RIVER NEAR THE MOUTH	589,613	6,861,617	10	701	399	146	1972	1995	8,584
10GC003	MARTIN RIVER AT HIGHWAY NO. 1	572,957	6,863,145	10	2,050	389	148	1972	2019	17,411
10GC005	SAHNDAA CREEK AT HIGHWAY NO. 1	541,293	6,881,332	10	251	358	151	1982	1990	3,287
10HB003	WRIGLEY RIVER NEAR THE MOUTH	465,247	7,005,398	10	1,230	213	154	1977	1988	4,018
10HC003	BIG SMITH CREEK NEAR HIGHWAY NO. 1	413,224	7,164,281	10	980	50	133	1973	1994	7,820
10HC007	HODGSON CREEK NEAR THE MOUTH	475,833	7,012,887	10	**303**	211	150	2006	2014	2,896
10HC008	OCHRE RIVER NEAR THE MOUTH	469,488	7,040,295	10	**1,031**	184	148	2006	2019	4,412
10KA003	BOSWORTH CREEK AT NORMAN WELLS	599,129	7,242,508	9	122	75	-54	1973	1979	1,375
10KA005	SEEPAGE CREEK AT NORMAN WELLS	606,333	7,239,786	9	31	68	-53	1974	1978	1,614
10KA006	JUNGLE RIDGE CREEK NEAR THE MOUTH	635,408	7,217,955	9	60	31	-56	1980	2018	6,796
10KA007	BOSWORTH CREEK NEAR NORMAN WELLS	598,863	7,246,213	9	125	77	-52	1980	2018	9,256
10KA008	OSCAR CREEK NEAR NORMAN WELLS	575,639	7,259,095	9	638	104	-53	2009	2018	2,264
10KA009	CANYON CREEK AT PIPELINE CROSSING	615,995	7,236,583	9	*68*	58	-50	2009	2018	2,199
10KB001	CARCAJOU RIVER BELOW IMPERIAL RIVER	561,399	7,242,010	9	7,400	108	-65	1976	2020	14,321

Table 4.3 Regional Water Survey of Canada Stations Used for Flow Predictions in the Study Area along the Proposed Mackenzie Valley Highway Alignment

Station Number	Station Name	UTM Easting (m)	UTM Northing (m)	UTM Zone	Drainage Area (km^2)	Location[a] Dist. (km)	Location[a] Bearing (deg)[b]	Monitoring Period Begins	Monitoring Period Ends	Data Points (n)[c]
10KD004	RAMPARTS RIVER NEAR FORT GOOD HOPE	487,561	7,332,446	9	7,300	218	-50	1985	1996	4,322
10KD009	CHICK CREEK ABOVE CHICK LAKE	539,521	7,304,005	9	**16**	160	-47	2008	2018	2,870
10LB004	LOON RIVER NEAR THE ARCTIC CIRCLE	508,817	7,377,239	9	2,745	233	-38	2009	2020	4,202

NOTES:
Stations are sorted by station number.
[a] Relative to Tulita, NT.
[b] Bearing is degrees clockwise (+) or counterclockwise (-) from Tulita, NT to the WSC station.
[c] Number of daily observations of flow.
Bolded watershed areas were calculated herein by K'alo-Stantec (see text for methods). The watershed area for Canyon Creek was obtained from hydrotechnical assessment and design documents (Tetra Tech 2021; Tetra Tech 2022).
Coordinates use the WGS84 datum.

Figure 4.1 **Histograms for Selected Water Survey of Canada Stations, Showing the Number of Observations in Each Month for the Period of Record**



NOTES:

(1) the red horizontal line is at n=92. Months where n<92 at each station were excluded from regression modelling.

(2) Month=1 represents January; Month=12 represents December

Watershed Delineation Methodologies

The regional flow analysis method requires watershed areas for regional WSC stations and for target watercourses. For WSC stations, most watershed areas are available from HYDAT (ECCC 2022b) (Table 4.3). For target crossings, most watershed areas have been published in previous studies (Table 4.1).

Where watershed areas were missing, they were calculated by K'alo-Stantec in ArcGIS. The watershed areas for these stations were calculated using ArcGIS software. National Hydrographic Network basins (Natural Resources Canada 2022) were segmented along topographic ridgelines and flow patterns.

Flow and Water Availability Calculation

Flows were calculated using linear regressions between watershed area and mean monthly discharge for selected regional WSC stations (Table 4.3; Figure 1.2). Discharge and watershed area were log-transformed and regressions were conducted for each month. Watershed area is the predictor and mean monthly flow is the predictand.

Flow data were grouped by station and month, and average flows were retained if at least 92 daily data points remained in each group (Figure 4.1; horizontal red lines). This represents about three years of monitoring in each month if monitoring was continuous. This small sample size threshold may not capture the full range of hydroclimatic variability. Effects of sample size on flow statistics were assessed in the PCAR water availably report; stations with small monthly sample sizes were found to have similar variability as stations with larger samples sizes (K'alo-Stantec 2022a). An assessment of the relationships between sample size and flow variability was also conducted for WSC stations selected here (Table 4.3); variability was also found to be more controlled by site-specific factors than by sample size.

4.1.2.3 Flow Estimation at the Great Bear River near the Mackenzie River: 'NHC' Method

The proposed MVH alignment crosses the GBR near Tulita and the Mackenzie River (Figure 1.2). A WSC gauging station is located on the GBR about 100 km^2 upstream of the proposed crossing, near the outlet of Great Bear Lake (GREAT BEAR RIVER AT OUTLET OF GREAT BEAR LAKE, station number 10JC003). The WSC Scaling approach was not used at this crossing because several large tributaries enter the GBR between the WSC gauge and Tulita, potentially altering the timing and magnitude of flows (NHC 2006; NHC 2018).

The upstream watershed area at the outlet of Great Bear Lake is 145,400 km^2 (ECCC 2022b), and downstream tributaries contribute an additional 12,000 km^2 (NHC 2006; NHC 2018), so the total watershed area at the proposed crossing is about 158,400 km^2. The regional analysis approach used here is also not appropriate for estimating GBR flows because of the extremely large watershed area of both the lake and downstream tributaries.

Monthly flow statistics for the GBR at Tulita have been published (NHC 2006; NHC 2018). These were calculated by combining gauged flows at the WSC station with flows from downstream tributaries estimated using a regional analysis deemed to be appropriate for the scale of the downstream tributaries.

The 50th percentile (median) monthly flow data from this analysis are used here (NHC 2018). Other methodologies used here present monthly mean rather than median flow statistics. Water available from the GBR is likely more constrained by pump capacity than by river flow rates; therefore, this decision is not expected to impact water availability for the Project.

It should also be noted that the Mackenzie River seasonally backwaters into the GBR near the proposed crossing (NHC 2006; NHC 2018). When backwatering occurs, water availability would not be directly related to flows in the GBR. Water availability would increase at these times due to contributions from the Mackenzie River

4.2 Waterbodies

4.2.1 Criteria for Assessment of Environmental Flow Needs in Waterbodies

For the purposes of water availability calculations, all waterbodies with open water maximum depths greater than 1.5 m (the maximum ice depth in the region; DFO, 2010) are potential fish habitat. Lakes shallower than this would freeze to ground in winter.

Criteria for withdrawals vary depending on when lakes are ice covered or ice-free. The ice-covered period for lakes in the region spans from approximately November to April (Bigras 1990), though this period has been shortening (Duguay et al. 2006), and larger lakes would be expected to freeze and break up later than smaller lakes due to their larger thermal inertia. Methods for ice-covered periods are applied for November to April, and methods for open water periods are applied for May through October, with the caveat that these should be adjusted where site-specific information is available.

4.2.1.1 Criteria During Periods of Ice-Cover

DFO (2010) Criteria

The proposed alignment is located south of the tree line, but north of Fort Simpson, NT. Maximum ice thickness is expected to be about 1.5 m (DFO 2010). Given this expected maximum thickness, DFO winter withdrawal guidance is summarized in Table 4.4. To apply these criteria, maximum lake depth and lake volume are needed.

Table 4.4 Fisheries and Oceans Canada (DFO) Winter Water Withdrawal Guidance for Ice-Covered Waterbodies, Applicable to Lakes Located South of the Tree Line but North of Fort Simpson, Northwest Territories

Maximum Open Water Depth	DFO Protocol Guidance (applies to ice-covered waterbodies)
Shallower than 1.5 m	"*exempt from 10% maximum withdrawal limit*". Interpreted as withdrawals cannot occur when ice is at its maximum thickness, and may occur based on site-specific conditions when ice thickness is less than its annual maximum.
Deeper than 1.5 m, and shallower than 3.0 m	waterbodies are "*particularly vulnerable to the effects of water withdrawal*" Interpreted as withdrawals should not occur.
Deeper than 3.0 m	"*total water withdrawal… is not to exceed 10% of the available water volume*"

NOTE:
Guidance is from DFO 2010.

Importantly, these criteria are not applicable if less than 100 m^3 is to be withdrawn over the course of one ice-covered period, or if the waterbody is not potential fish habitat (DFO 2010).

Mackenzie Valley Land and Water Boards Method

The above (DFO) criteria were developed for winter water withdrawals as a means of preserving oxygenated water for overwintering fish (Cott et al. 2008); however, protocols for withdrawal from waterbodies often also include consideration of littoral habitat (BCOGC 2022; Hatfield Consultants 2016).

The Land and Water Boards of the Mackenzie Valley (MVLWB) developed a simple methodology for determining winter water use capacity for small-scale projects in the NT that explicitly considers changes to littoral habitat (MVLWB 2021b; MVLWB 2021a) (called 'MVLWB method' here). The MVLWB method may not be directly applicable to the MVH due to the large size of the MVH project and potential multi-year use of water sources; however, it is considered here because it provides guidance for preservation of littoral habitat and because it is regionally applicable.

Where waterbodies have under-ice water depth of at least 1.5 m and a minimum total (open water) depth of at least 3 m, the MVLWB method defines total available water in winter as (MVLWB 2021b; MVLWB 2021a):

$$\text{Total Available Water Use Capacity } (m^3) = \text{Total Surface Area } (m^2) * 0.10 \text{ m}$$

The MVLWB method has the advantage of not requiring detailed bathymetric surveys to determine water availability, unlike the DFO (2010) protocol.

Where this method is used, seasonal field verification of water depth is recommended, with at least three depth measurements >20 m from shore and approximately 20 m apart recommended (MVLWB 2021b; MVLWB 2021a).

4.2.1.2 Criteria During Periods of Open-Water

Criteria for open water withdrawals from lakes have not been published for the NT. The DFO (2010) method is not directly pertinent since lakes typically experience wind-generated mixing and seasonal overturn which oxygenates the water column (Wetzel 2001). The MVLWB criterion (volume equivalent of 0.1 m of drawdown) is ecologically relevant during periods of open water from the perspective of preserving littoral habitat. This is also a criterion adopted by the British Columbia Oil and Gas Commission (BCOGC)(BCOGC 2022). Therefore, the MVLWB method is applied here for periods of open water.

Lakes with maximum open water depths of less than 1.5 m would freeze to bottom in winter. These are not considered waterbodies by the definition in DFO (2010) and would not be expected to support fish. Therefore, it is proposed that these lakes may be considered for withdrawal in periods of open water. This is supported by discussions with MVLWB. However, MVLWB also noted that these lakes may contain environmental values other than fish; therefore, for these instances MVLWB encourage submission of information demonstrating how impacts would be minimized (Potten, pers. comm., 2022).

Withdrawals from lakes with maximum open water depths between 1.5 and 3.0 m are not allowed during periods of ice cover and were identified as "*particularly vulnerable to the effects of water withdrawal*" (DFO 2010)(Table 4.4). This vulnerability is considered here to extend into the open water period, given that residence time could be low in some lakes and in some months where throughflow is low. This is a conservative assumption that could be refined on a site-specific basis and/or with additional study (Section 6.3).

The criterion used here during periods of open water only requires surface area, not volume from bathymetric surveys. Therefore, a larger set of lakes are available for open water withdrawal calculations (Section 4.2.2).

The criterion applied here for open water withdrawals is intended for the preservation of littoral habitat only. Volumes provided here are coarse estimates for environmental assessment. For the purposes of licensing, other environmental values may need to be considered, for example EFN in watercourses downstream of where withdrawals occur. A potential water balance methodology based on methodologies in British Columbia and Alberta is described in Section 6.3.

4.2.2 Calculation of Volumes Available for Withdrawal in Waterbodies

Waterbodies for consideration for withdrawal were selected based on their previous use by the GNWT for winter road construction and/or proximity to the MVH alignment and are summarized in Table 4.5. Bathymetry, volume, surface area, lake depth, and long axis length for these waterbodies were compiled from previous studies (Golder Associates 2008; Golder Associates 2006; AAR 2003; K'alo-Stantec 2021). Where surface area and long axis length were not available, they were calculated by K'alo Stantec using remotely sensed imagery.

To summarize the criteria for calculating withdrawals from waterbodies used here:

- In periods of ice-cover (November to April), the *minimum* of the DFO (10% of under ice volume) and MVLWB methods (volume equivalent of a 0.1 m drawdown).
- In periods of open-water (May to October), the MVLWB method only (volume equivalent of a 0.1 m drawdown).

For evaluation of DFO criteria, volumes available for withdrawal were calculated at 10% of winter lake volume where available (DFO 2010). For evaluation using MVLWB methods, lake surface areas (units = m^2) were multiplied by 0.1 m (units = m^3) to approximate available under-ice volume (MVLWB 2021b; MVLWB 2021a).

Table 4.5 Waterbodies Considered for Withdrawals Near the Proposed Mackenzie Valley Highway

Waterbody Name		MVH Alignment (km)[a]	UTM[b]				Long Axis Length (m)	Surface Area (m^2)	Depth (m)			Volume (m^3)		Data Sources			
Used Here	Other		Easting (m)	Northing (m)	Zone	Region			Max.	Max. (coarse)[d]	Mean	Non-Winter	Winter[c]	Long Axis	Area	Depth	Bathymetry and Volume
WSWrigley	Lake 686.5	686.5	479,403	7,008,904	10	Dehcho	2,700	902,073						herein	herein		
WR2	DCN3	702.2	472,036	7,016,389	10	Dehcho	800	364,955	5.1		1.1	296,193	42,770	(Golder Associates 2006)	(Golder Associates 2006)	(Golder Associates 2006)	(AAR 2003)
WR3		718.8	470,063	7,032,542	10	Dehcho	1,235	533,832		2.9				herein	herein	(Golder Associates 2006)	
WR4		721.8	468,228	7,035,063	10	Dehcho	290	36,400		2.9				herein	herein	(Golder Associates 2006)	
WS791		791.0	440,446	7,096,280	10	Dehcho	215	36,388						herein	herein		
WR5	ST24	798.8	436,935	7,102,044	10	Dehcho	1,100	200,168	2.1		0.8	107,350	729	herein	(Golder Associates 2006)	(Golder Associates 2006)	(AAR 2003)
WR6	ST23	804	436,369	7,107,258	10	Sahtu	1,780	796,473	3.4		0.9	743,539	6,823	herein	herein	(Golder Associates 2006)	(AAR 2003)
WR7		810.1	434,895	7,112,780	10	Sahtu	498	207,259		1.5				herein	herein	(Golder Associates 2006)	
WR8		820.0	433,668	7,120,640	10	Sahtu	1,005	251,743	15.2		6.2	1,604,238	1,265,534	(Golder Associates 2008)	(Golder Associates 2008)	(Golder Associates 2008)	(Golder Associates 2008)
WR9	ST21	826.6	431,087	7,127,153	10	Sahtu	195	19,617	2.2		1.1	14,646	1,159	(Golder Associates 2006)	(Golder Associates 2006)	(Golder Associates 2006)	(Golder Associates 2006)
WR10		835.0	425,896	7,132,328	10	Sahtu	200	13,160	15.1		3.3	44,488	30,844	(Golder Associates 2008)	(Golder Associates 2008)	(Golder Associates 2008)	(Golder Associates 2008)
WR11	ST20	839.5	423,158	7,136,740	10	Sahtu	450	43,646	1.9		1.0	29,979	1,492	(Golder Associates 2006)	(Golder Associates 2006)	(Golder Associates 2006)	(Golder Associates 2006)
WR12	Mio Lake	863	412,714	7,155,905	10	Sahtu	8,931	7,432,430	2.3			9,144,746	987,269	herein	herein	(Golder Associates 2006)	(Golder Associates 2008)
WR13	ST18	876.3	411,369	7,166,920	10	Sahtu	1,100	714,769	1.7		0.9	464,479	6,061	(Golder Associates 2006)	(Golder Associates 2006)	(Golder Associates 2006)	(Golder Associates 2006)
WR16		882.5	411,677	7,171,746	10	Sahtu	300	56,631	4.9		2.1	120,505	48,991	(Golder Associates 2008)	(Golder Associates 2008)	(Golder Associates 2008)	(Golder Associates 2008)
WR18		892.0	407,963	7,179,438	10	Sahtu	1,010	1,385,441	9.3		2.8	400,864	229,369	(Golder Associates 2008)	(Golder Associates 2008)	(Golder Associates 2008)	(Golder Associates 2008)
WR893		893	405,318	7,178,932	10	Sahtu	823	190,086						herein	herein		
WR19		903.0	404,789	7,188,754	10	Sahtu	870	35,950	3.8		1.4	51,306	11,811	(Golder Associates 2008)	(Golder Associates 2008)	(Golder Associates 2008)	(Golder Associates 2008)
WR20	ST14	908.9	403,623	7,193,829	10	Sahtu	1,780	3,595,971	2.6		1.1	2,400,015	114,579	(Golder Associates 2006)	(Golder Associates 2006)	(Golder Associates 2006)	(Golder Associates 2006)
WR22		916	398,118	7,199,490	10	Sahtu	2,455	2,254,359		3.4				herein	herein	(Golder Associates 2006)	
WR21		921.3	392,634	7,199,056	10	Sahtu	262	30,606		5.2				herein	herein	(Golder Associates 2006)	
WR948		948.4	371,930	7,210,050	10	Sahtu	163	16,463						herein	herein		
WR25	ST12x	944.6	373,663	7,208,213	10	Sahtu	1,700	461,128	21.7		8.2	3,804,074	3,163,813	(Golder Associates 2008)	(Golder Associates 2008)	(Golder Associates 2008)	(Golder Associates 2008)
WR28	ST11	950.4	370,015	7,210,416	10	Sahtu	800	204,493	14.8		6.6	941,140	746,860	(Golder Associates 2006)	(Golder Associates 2006)	(Golder Associates 2006)	(Golder Associates 2006)

NOTES:

Waterbodies are sorted from south to north.

[a] 'Alignment (km)' is the approximate mid-point of each lake along the proposed MVH alignment.

[b] UTM coordinates use the WGS84 datum.

[c] the liquid water volume is calculated assuming 1.5 m thick ice.

[d] From Table 8.1 in Golder (2006). These are lakes where full bathymetric surveys have not been conducted and may not represent the true maximum lake depth.

Data are not available when cells are blank.

Lake metric sources noted as 'herein' were calculated as part of this study.

5 Results

5.1 Watercourses

5.1.1 Flows Estimation and Water Availability for Gauged Basins: WSC Scaling

Results are provided here for each of the watercourses (at the noted location) analyzed for potential water withdrawals as calculated directly from WSC stations (Figure 1.2, Appendix A). This includes Big Smith Creek, Blackwater River, Hodgson Creek, Jungle Ridge Creek, and Ochre River (Table 4.2). Flows from these sites were obtained from WSC stations, then adjusted according to 'scaling factors': the watershed area at each crossing divided by the watershed area at each WSC station (Section 4.1.2.1).

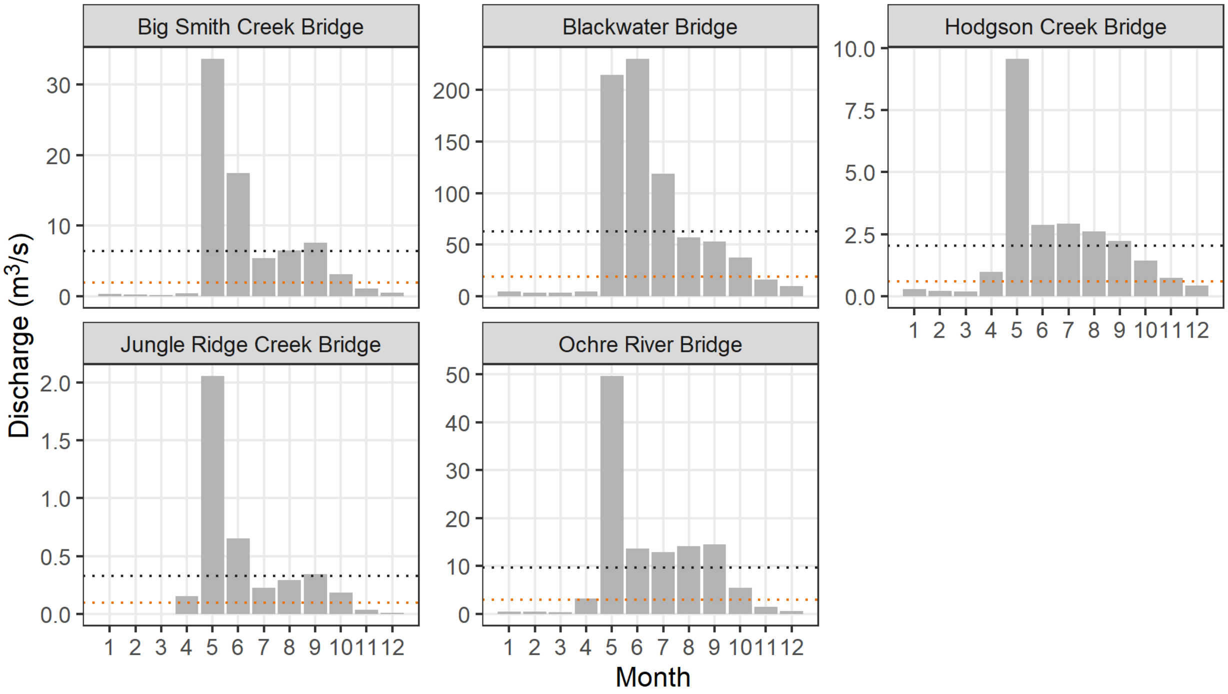
Where WSC stations exist on the same watercourse, scaling factors are typically within ±20% (Table 4.2) indicating that watershed areas are relatively similar.

The exception is Blackwater River (Figure 1.1, Table 4.2). The WSC station 10HC006 (BLACKWATER RIVER AT OUTLET OF BLACKWATER LAKE) is about 55 km upstream of the Blackwater River bridge. In addition, 10HC006 is located at the outlet of Blackwater Lake. Between these two sites, the Blackwater River watershed area increases from 7,850 km^2 to 10,716 km^2 (Table 4.2). Flows from 10HC006 would be expected to be highly influenced by the upstream lake. For example, all other sites analyzed here experience peak flow in May, while peak flow at Blackwater River occurs in June. This delay is likely a result of slow release of water from Blackwater Lake (Faria 2002). Flows at Blackwater River bridge are also likely influenced from the almost 3,000 km^2 of land area downstream of 10HC006.

Flows at Blackwater River bridge were calculated using the 'scaling factor' approach rather than the regression-based approach because of the large watershed size at Blackwater River. The largest target watershed area used in the regression approach was about 440 km^2: about 24 times smaller than the Blackwater River watershed area at the bridge (Table 4.1). Given the large size of the Blackwater River, flows there may have very different timing and magnitudes compared to smaller watersheds; therefore. regional analysis was not used at this site. However, this site was used to evaluate differences between the regional analysis and WSC scaling approaches; results are presented in Section 6.2.1.

Notably, a WSC station briefly operated on the Blackwater River, much closer to the bridge crossing: 10HC005: BLACKWATER RIVER NEAR THE MOUTH. However, this station only operated from 1983 to 1985. Its period of operation did not overlap with 10HC006, preventing comparison of flows at both sites.

Figure 5.1 Monthly Average Discharge at Potential Water Withdrawal Locations Along the Proposed Mackenzie Valley Highway Alignment, Derived Directly from Water Survey of Canada Stations (WSC Scaling Approach)



NOTES:

The upper dark horizontal lines are MAD at each location calculated using the 'scaling factor'. The lower orange lines are 30% of MAD. Month=1 represents January; Month=12 represents December.

5.1.2 Flows and Water Availability at Ungauged Basins Derived Using Regional Analyses

Regressions developed for ungauged watercourses along the proposed MVH alignment are presented in Figure 5.2 and statistics are provided in Table 5.1.

Table 5.1 Regional Analysis Regression Coefficients and Statistics

Month	Slope (m)	Intercept (b)	r^2	p-value	n
Jan	1.352	-4.651	0.60	<0.001	16
Feb	1.918	-6.603	0.68	<0.001	15
Mar	1.439	-5.155	0.59	0.001	14
Apr	0.556	-1.571	0.65	<0.001	16
May	0.862	-1.245	0.91	<0.001	21
Jun	1.177	-2.505	0.96	<0.001	21
Jul	1.162	-2.658	0.92	<0.001	21
Aug	1.077	-2.472	0.90	<0.001	21
Sep	1.079	-2.523	0.85	<0.001	21
Oct	0.940	-2.319	0.93	<0.001	19
Nov	1.104	-3.282	0.90	<0.001	16
Dec	1.101	-3.607	0.74	<0.001	17

NOTES:

Regressions equations are solved using $\log_{10}$-transformed drainage area (see text below). r^2 is a measure of the regression's overall 'goodness of fit' and a p-value >0.05 indicates that a regression is not statistically significant. n = sample size, i.e., the number of flow-area pairs in each regression.

Monthly average discharge (Q) is calculated as follows:

$$\log_{10}Q = m*\log_{10}A + b$$

where '$\log_{10}Q$' is $\log_{10}$ transformed monthly average discharge, 'm' and 'b' are regression coefficient slopes and intercepts (Table 5.1), and '$\log_{10}A$' is the $\log_{10}$ transformed watershed area (A, km^2) for the location of interest.

Q in metres cubed per second (m^3/s) is calculated as:

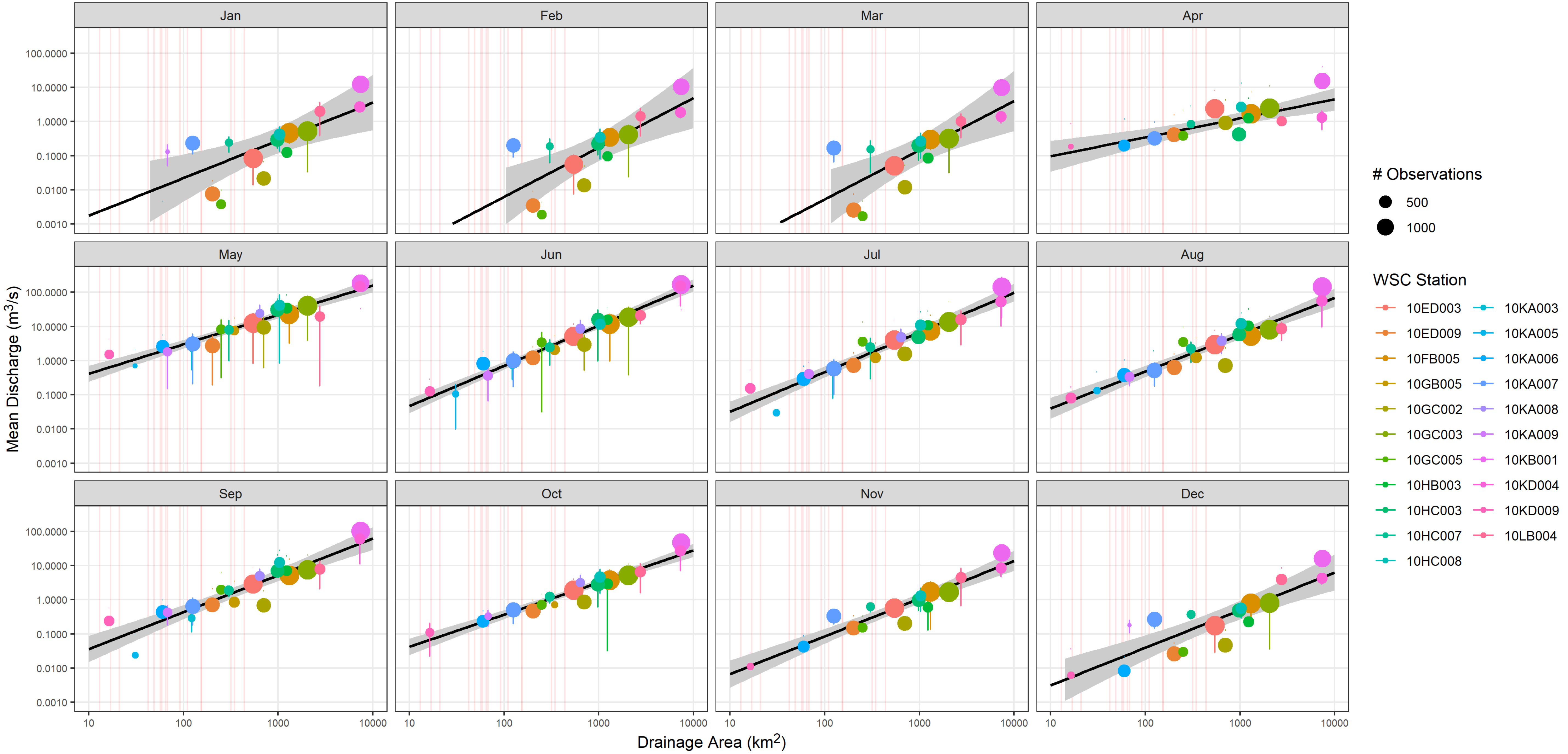
$$Q = 10^{\log_{10}Q}$$

All monthly regressions are statistically significant (p-value less than or equal to 0.05; Figure 5.2; Table 5.1). Correlation coefficients are high (>0.85) from May to November, and lower (but >0.59) from December through April. Correlation coefficients are highest from spring through to early fall when snowmelt and rainfall feed watercourses and flow magnitudes scale with the land area over which water collects (watershed area). This is the period when flows are highest and most of the annual runoff occurs.

In winter months, regressions remain statistically significant (p-value >0.05), but correlation coefficients are lower (Figure 5.2; Table 5.1), meaning that discharge is less directly related to watershed area compared to other months. Discharge is low in these months and is a small fraction of MAD. Discharge in winter is likely mainly fed by site-specific occurrence of groundwater seeps (Section 3). Seasonal operation of regional WSC stations also leads to smaller sample sizes for regressions in these winter months, which likely negatively affects regression results in these months (Figure 4.1).

Watersheds where regional analyses were applied span a large range of areas (9 to 440 km^2; Table 4.1). From April to December, regional WSC data exist from stations with watershed areas in the range of those of target watersheds (Table 4.3; vertical lines on Figure 5.2). From January through March, there are fewer data from WSC stations with small watersheds, which contributes to uncertainty in flow predictions in these months.

Figure 5.2 Relationships Between Watershed Area and Mean Monthly Discharge at Selected Regional Water Survey of Canada Stations

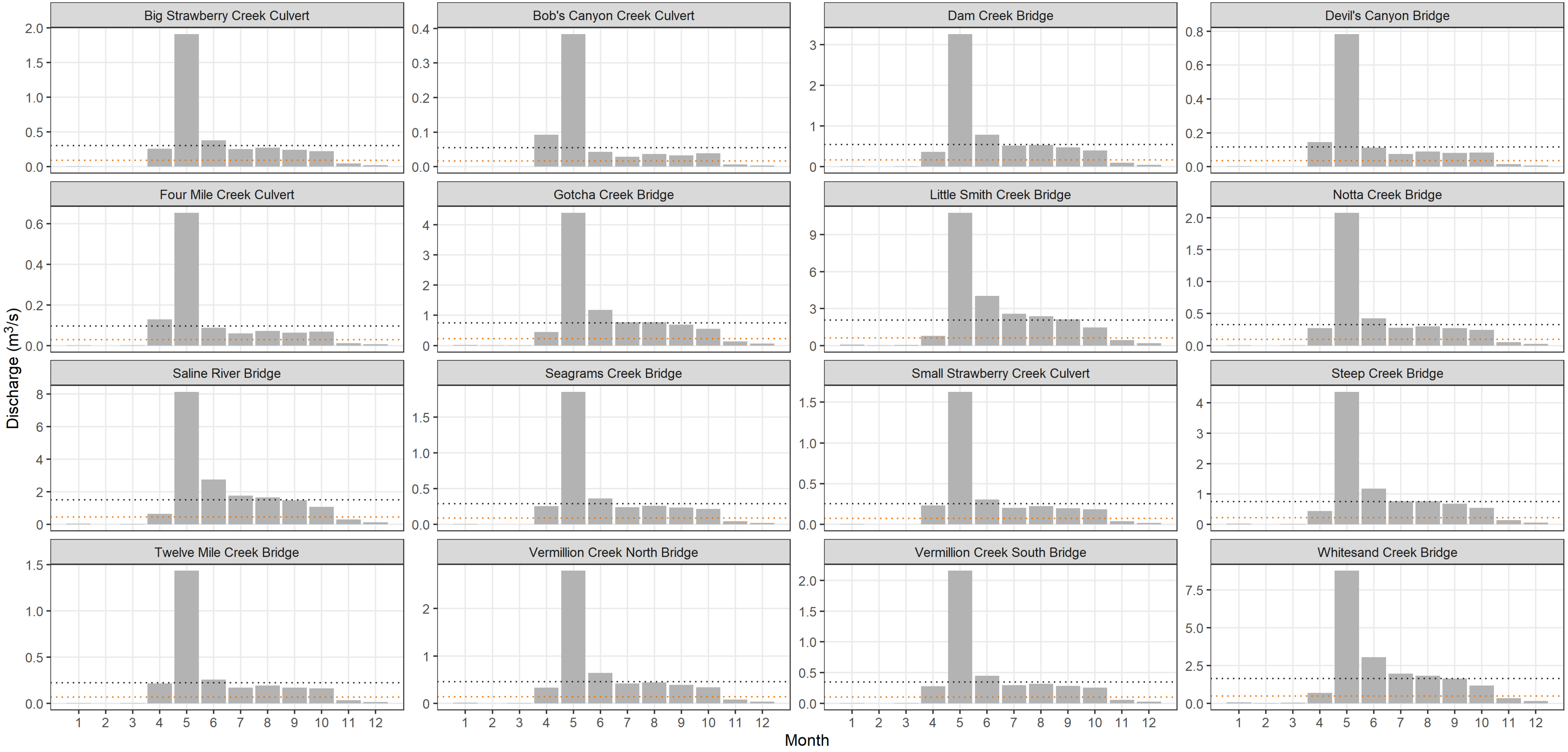


NOTES:

Vertical red lines are the watershed areas of potential withdrawal sites (not including sites where WSC stations exist and the 'WSC scaling' flow prediction approach was used). Black lines are best-fit linear regressions and grey envelopes represent 95% confidence intervals. Confidence intervals are outside y-axis limits for small watersheds in January, February, and March. Vertical error bars on points are +/- one standard deviation and the size of each point is scaled to the number of daily observations. Regression statistics are provided in Table 5.1.

Results are provided for each of the watercourses analyzed for potential water withdrawals predicted with regression-based techniques in Figure 5.3 and Appendix B. Predicted flows follow the nival hydrologic regime of the region, i.e., typically a snowmelt dominated freshet in May, declining flows from June through to early fall, and a small increase in flows due to rainfall runoff in October (Section 3).

Figure 5.3 Monthly Average Discharge at Potential Water Withdrawal Locations Along the Proposed Mackenzie Valley Highway Alignment, Predicted by Regression



NOTES:
The upper dark horizontal lines are MAD at each crossing. The lower orange lines are 30% of MAD. Month=1 represents January; Month=12 represents December. Watercourses are sorted alphabetically.

5.1.3 Flows and Water Availability at the Great Bear River near the Mackenzie River

Flows and water availability at the GBR near the Mackenzie River are summarized in Table 5.2. Unlike all other rivers analyzed here, the GBR has large amounts of flow over winter (*cf.* Appendices A and B). No months have flows that are less than 30% of MAD. Therefore, according to DFO (2013) criteria, water is available for withdrawal in all months. Due to the large size of the GBR, large volumes are available for withdrawal in all months.

Table 5.2 Great Bear River Near the Mackenzie River: Average Flow Predictions and Statistics

	Discharge			Daily Flows (m^3/d)		Monthly Flows (m^3/m)		
Month	Median (m^3/s)	% of Annual Discharge[a]	10% Median (m^3/s)	Median	10% Median	Median	10% Median	Available[b]
Jan	530	91	53	4.58E+07	4.58E+06	1.42E+09	1.42E+08	1.42E+08
Feb	523	89	52	4.52E+07	4.52E+06	1.27E+09	1.27E+08	1.27E+08
Mar	520	89	52	4.49E+07	4.49E+06	1.39E+09	1.39E+08	1.39E+08
Apr	512	88	51	4.42E+07	4.42E+06	1.33E+09	1.33E+08	1.33E+08
May	682	117	68	5.89E+07	5.89E+06	1.83E+09	1.83E+08	1.83E+08
Jun	653	112	65	5.64E+07	5.64E+06	1.69E+09	1.69E+08	1.69E+08
Jul	630	108	63	5.44E+07	5.44E+06	1.69E+09	1.69E+08	1.69E+08
Aug	634	108	63	5.48E+07	5.48E+06	1.70E+09	1.70E+08	1.70E+08
Sep	625	107	63	5.40E+07	5.40E+06	1.62E+09	1.62E+08	1.62E+08
Oct	600	103	60	5.18E+07	5.18E+06	1.61E+09	1.61E+08	1.61E+08
Nov	559	96	56	4.83E+07	4.83E+06	1.45E+09	1.45E+08	1.45E+08
Dec	545	93	55	4.71E+07	4.71E+06	1.46E+09	1.46E+08	1.46E+08
Annual Mean	**584**	**n/a**	**58**	**5.05E+07**	**5.05E+06**	**n/a**	**n/a**	**n/a**
Annual Sum	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**1.84E+10**	**1.84E+09**	**1.84E+09**

NOTES:

Flow data source is NHC (2018); described in Section 4.1.2.3.

No months have less than 30% of mean annual discharge (175 m^2/s).

[a] Calculated as monthly discharge divided by MAD x100.

[b] 'Available' is the monthly water volume available for withdrawal using DFO's 'desktop-based' criteria (i.e., 10% of monthly flows in months where flow is >30% MAD; DFO 2013).

n/a: not applicable.

5.1.4 Summary of Flow Predictions and Water Availability at all Studied Locations

Detailed month-by-month flow and water availability predictions are provided in Appendices A and B. Key statistics are summarized and visualized in Table 5.3 and Figure 5.4.

In Table 5.3, the '*Annual Available Withdrawal Volume*' is the water volume available for low-risk withdrawal, using criteria from DFO (2013); i.e., 10% of monthly average flow in months where discharge is greater than 30% of MAD. These volumes are useful as a basis for water license applications and will need to be verified by monitoring/measuring flows in the field (Section 7).

Not all the annual volume available for withdrawal may be useful. Much of this water is available in May when there may be limited water demand and accessibility. Please refer to Appendices A and B for monthly water availability data.

The GBR and Blackwater River are much larger than the other studied watercourses, and water availability is correspondingly high.

At the proposed GBR crossing, water is available for withdrawal year-round according to criteria applied here. Volumes available are extremely large compared to other assessed sources. Water available from this source represents 87% of all water availability from all assessed watercourses.

At the Blackwater River bridge, the watershed area of the river is 10,716 km^2, about 24 times larger than the next largest watershed area where regional analysis was conducted. Excluding the GBR, the annual available withdrawal volume there (~1.9 x 10^8 m^3) is more than twice what is available at all other studied locations combined (~8.7 x 10^7 m^3; Table 5.3).

Note that according to DFO protocols (DFO 2013), water is likely to be available for withdrawal from most watercourses from approximately from April to October[2]. Flows in these months are greater than 30% of MAD. In addition, about half of the annual water volume available for low-risk withdrawal occurs in May (Figure 5.4). See Appendices A and B for monthly flow data and volumes.

As described above, the availability of water from watercourses is highly seasonal (Figure 5.4); however, waterbodies provide additional potential water sources in winter. This is assessed in the next section.

---

[2] Exceptions are flows at Blackwater River bridge (allowed from May to October) and Hodgson Creek bridge (allowed from April to November).

Table 5.3 Flow Summary Statistics for Flow and Water Availability at Potential Water Withdrawal Locations Along the Proposed Mackenzie Valley Highway Alignment

Watercourse Location	MVH Alignment (km)	Watershed Area (km^2)	MAD (m^3/s)	30%MAD (m^3/s)	Max Discharge (m^3/s)	Potential Annual Available Withdrawal Volume (m^3)[a]	Flow Prediction Type
Hodgson Creek Bridge	695.6	358	2.04	0.613	9.6	6,200,677	WSC Scaling
Ochre River Bridge	725.7	1,207	9.71	2.91	49.6	30,047,250	WSC Scaling
Whitesand Creek Bridge	733.8	346	1.64	0.492	8.8	5,069,277	Regional Analysis
Big Strawberry Creek Culvert	748.5	59	0.30	0.090	1.9	939,366	Regional Analysis
Small Strawberry Creek Culvert	748.6	49	0.25	0.076	1.6	791,002	Regional Analysis
Vermillion Creek South Bridge	752.3	68	0.34	0.103	2.2	1,072,282	Regional Analysis
Bob's Canyon Creek Culvert	755.3	9	0.06	0.017	0.4	173,984	Regional Analysis
Dam Creek Bridge	764.8	110	0.54	0.163	3.3	1,685,618	Regional Analysis
Blackwater Bridge	785.3	10,716	62.8	18.9	230	188,109,030	WSC Scaling
Steep Creek Bridge	816.5	154	0.75	0.224	4.4	2,321,083	Regional Analysis
Devil's Canyon Bridge	828.4	21	0.12	0.035	0.8	364,272	Regional Analysis
Saline River Bridge	831.9	317	1.51	0.452	8.1	4,655,068	Regional Analysis
Seagrams Creek Bridge	844.3	57	0.29	0.087	1.9	909,701	Regional Analysis
Little Smith Creek Bridge	852.3	439	2.08	0.623	10.8	6,397,916	Regional Analysis
Big Smith Creek Bridge	872.1	1,076	6.38	1.91	33.7	19,510,836	WSC Scaling
Gotcha Creek Bridge	912.7	155	0.75	0.226	4.4	2,335,520	Regional Analysis
Twelve Mile Creek Bridge	922.0	42	0.22	0.066	1.4	690,832	Regional Analysis
Four Mile Creek Culvert	931.5	17	0.10	0.029	0.7	301,154	Regional Analysis
Great Bear River Bridge	937.2	158,400	584	175	682	1,844,510,400	NHC[b]
Jungle Ridge Creek Bridge	967.8	60	0.33	0.099	2.1	1,035,713	WSC Scaling
Notta Creek Bridge	971.5	65	0.33	0.099	2.1	1,028,081	Regional Analysis
Vermillion Creek North Bridge	973.4	92	0.46	0.137	2.8	1,423,908	Regional Analysis

NOTES:

Watercourse crossings are sorted from south to north.

'Max Discharge' is the maximum monthly average flow, which typically occurs in May (the exception is Blackwater River, where maximum annual discharge occurs in June).

Flow prediction types are described in Section 4.1.

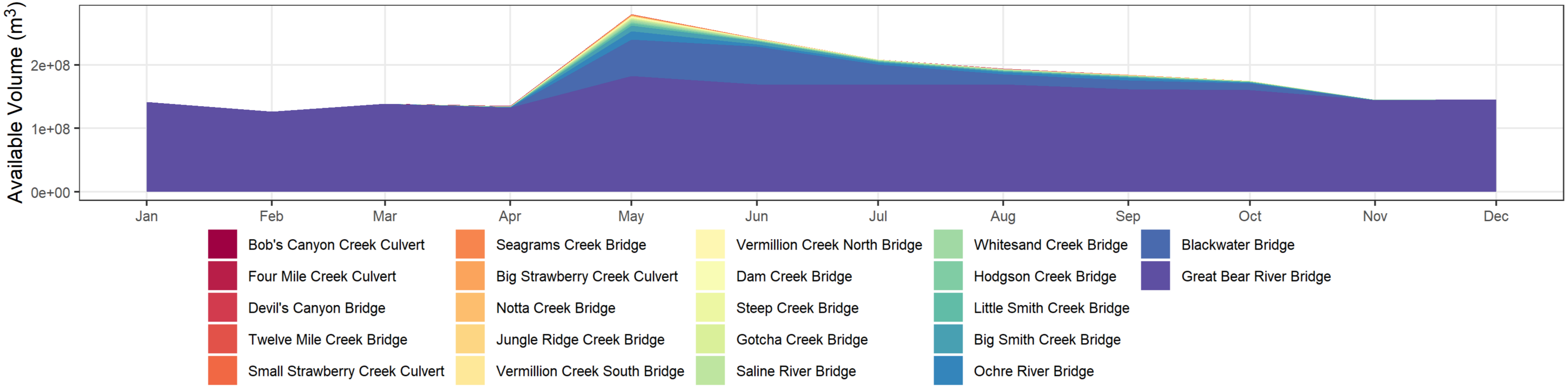
Please refer to Appendices A and B for the full monthly set of flow and water availability statistics.

[a] calculated as 10% of volumetric flow in months where discharge is more than 30%MAD (DFO 2013).

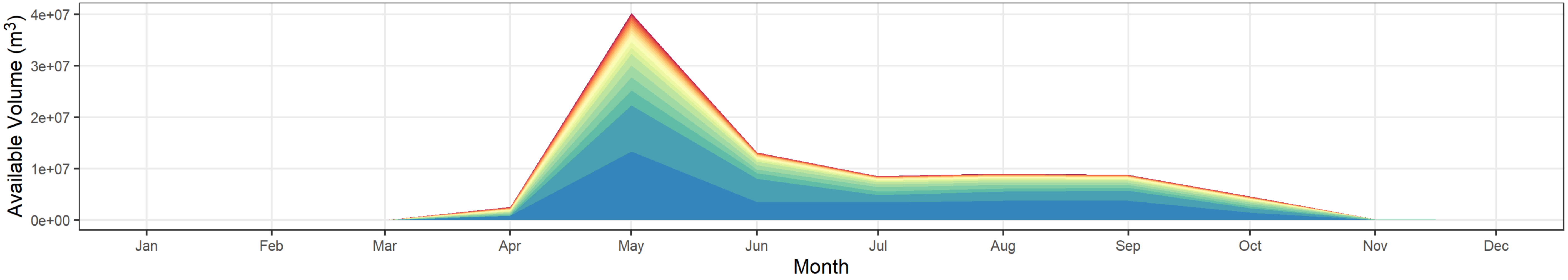
[b] Flows for the GBR near the Mackenzie River are from the hydrotechnical design document for the proposed GBR bridge (NHC 2018).

Figure 5.4 Area Charts of Monthly Water Availability from Studied Watercourses

(a) All Assessed Watercourses



(b) Great Bear River and Blackwater River Removed



NOTE:
Watercourses are sorted in order of increasing annual water availability. Plots are stacked, i.e., the uppermost line represents cumulative monthly total withdrawal volumes from considered watercourses.

5.2 Waterbodies

Potential withdrawal volumes for studied lakes along the proposed MVH alignment are presented in Table 5.5 using criteria presented in Section 4.2.1.1.

5.2.1 Withdrawals During Periods of Ice-Cover

Waterbodies that are too shallow (DFO 2010) for winter withdrawals are first removed from analyses; i.e., lakes with open water maximum depths between 1.5 and 3.0 m. None of the considered lakes have maximum open water depths of less than 1.5 m. A total of 11 lakes are likely sufficiently deep (Table 5.5; '*Max Depth (m)*' columns).

DFO (2010) criteria require lake volume to be known. Volumes are unknown in two of the eleven remaining lakes because bathymetric survey data are not available (WR21 and WR22), leaving nine lakes for consideration (Table 5.5; '*Volume (DFO 2010)*' columns).

Volumes potentially available for winter withdrawal using DFO (2010) criteria were calculated as 10% of the under-ice water volume, assuming a 1.5 m thick ice cover. To assess these volumes relative to MVLWB criteria, depth equivalents were calculated by dividing by lake surface area (Table 5.5, column '*Depth Equivalent of Winter Volume (m)*'). Where this depth equivalent is greater than 0.1 m, the withdrawal volume exceeds that recommended by MVLWB (MVLWB 2021b; MVLWB 2021a). These are flagged as 'littoral zone loss' (Table 5.5; column '*Winter Volume Comments*').

Next, the MVLWB method was applied using lake surface area (i.e., the volume of the lake surface area multiplied by 0.1 m)(MVLWB 2021b; MVLWB 2021a). Lake surface area is available from all considered lakes, so MVLWB method can be applied for all lakes. These volume estimates are cross-checked against volumes calculated using DFO (2010) criteria (Table 5.5, column '*Volume (%)*'). In five out of nine lakes where this is possible to assess, the volume of under ice water lost by solely applying the MVLWB method would exceed 10% (Table 5.5, column '*Surface Area Notes*', flagged as 'Volume Loss').

From the perspective of preserving environmental values, DFO (2010) criteria are explicitly intended to preserve oxygen under ice, while MVLWB method is explicitly intended to preserve littoral habitat. Neither set of protocols are consistently limiting for lakes along the proposed MVH alignment. It is therefore not considered appropriate to only apply one set of criteria. Choosing the *minimum* volume predicted by both sets of criteria is intended to preserve both littoral habitat and under ice oxygen (Table 5.5, column '*Conservative Withdrawal* (m^3)').

Application of both protocols limits assessments to lakes where bathymetric surveys have been conducted (this would also be true if only DFO (2010) criteria were applied). After filtering lakes that are too shallow to support withdrawals, this leaves nine lakes where conservative withdrawal volumes can be provided (Table 5.5, column '*Conservative Withdrawal* (m^3)').

Again, 'conservative' potential winter withdrawal volumes are provided here (Table 5.5) that consider the environmental values of littoral zone habitat and overwinter oxygen levels. Results provided here do not consider other potential environmental values, such as potential effects on specific species of interest, cultural values, or on downstream flows (Section 6.3 and Section 7).

Table 5.4 Potential Withdrawal Limits for Waterbodies Along the Proposed Mackenzie Valley Highway Alignment during Periods of Ice Cover

		Max Depth (m)			Under Ice Volume (DFO 2010)[c]			Surface Area (MVLWB 2021)				Recommended Withdrawals			Candidate for Future Bathymetric Surveys?	
Name	MVH Alignment (km)[a]	Surveyed	Coarse[b]	Too Shallow?	10% of Under Ice Volume (m^3)	Depth Equivalent of Volume (m)	Volume Comments	Surface Area (m^2)	Volume from Surface Area (m^3)[d]	Volume (%)	Surface Area Notes	Conservative Withdrawal (m^3)	Limiting Criterion	Notes	Assessment	Comment
WSWrigley	686.5			UNKNOWN			Volume unknown	902,073	90,207		Volume unknown			Volume unknown	Yes	
WR2	702.2	5.1		NO	4,277	0.01	PASSES CRITERIA	364,955	36,496	85	Volume loss	4,277	DFO (2013)	Conservative volume available	n/a	n/a survey already conducted
WR3	718.8		2.9	YES (Potentially)			Volume unknown	533,832	53,383		Volume unknown			Volume unknown	Yes	If max. depth >3.0 m
WR4	721.8		2.9	YES (Potentially)			Volume unknown	36,400	3,640		Volume unknown			Volume unknown	Yes	If max. depth >3.0 m
WS791	791			UNKNOWN			Volume unknown	36,388	3,639		Volume unknown			Volume unknown	Maybe	Given small surface area, may be shallow
WR5	798.8	2.1		YES			Too shallow to withdraw	200,168	20,017		Too shallow to withdraw			Too shallow to withdraw	No	Too shallow
WR6	804	3.4		NO	682	0.00	PASSES CRITERIA	796,473	79,647	1167	Volume loss	682	DFO (2013)	Conservative volume available. volume anomalously low?	n/a	n/a survey already conducted
WR7	810.1		1.5	YES (Potentially)			Volume unknown	207,259	20,726		Volume unknown			Too shallow to withdraw (based on coarse max depth)	No	Too shallow to withdraw
WR8	820	15.2		NO	126,553	0.50	Littoral zone loss	251,743	25,174	2	PASSES CRITERIA	25,174	MVLWB (2021)	Conservative volume available	n/a	n/a survey already conducted
WR9	826.6	2.2		YES			Too shallow to withdraw	19,617	1,962		Too shallow to withdraw			Too shallow to withdraw	No	Too shallow
WR10	835	15.1		NO	3,084	0.23	Littoral zone loss	13,160	1,316	4	PASSES CRITERIA	1,316	MVLWB (2021)	Conservative volume available	n/a	n/a survey already conducted
WR11	839.5	1.9		YES			Too shallow to withdraw	43,646	4,365		Too shallow to withdraw			Too shallow to withdraw	No	Too shallow
WR12	863	2.3		YES			Too shallow to withdraw	7,432,430	743,243		Too shallow to withdraw			Too shallow to withdraw	No	Too shallow to withdraw (based on coarse max depth)
WR13	876.3	1.7		YES			Too shallow to withdraw	714,769	71,477		Too shallow to withdraw			Too shallow to withdraw	No	Too shallow
WR16	882.5	4.9		NO	4,899	0.09	PASSES CRITERIA	56,631	5,663	12	Volume loss	4,899	DFO (2013)	Conservative volume available	n/a	n/a survey already conducted
WR18	892	9.3		NO	22,937	0.02	PASSES CRITERIA	1,385,441	138,544	60	Volume loss	22,937	DFO (2013)	Conservative volume available	n/a	n/a survey already conducted
WR893	893			UNKNOWN			Volume unknown	190,086	19,009		Volume unknown			Volume unknown	Yes	
WR19	903	3.8		NO	1,181	0.03	PASSES CRITERIA	35,950	3,595	30	Volume loss	1,181	DFO (2013)	Conservative volume available	n/a	n/a survey already conducted
WR20	908.9	2.6		YES			Too shallow to withdraw	3,595,971	359,597		Too shallow to withdraw			Too shallow to withdraw	No	Too shallow

Table 5.4 Potential Withdrawal Limits for Waterbodies Along the Proposed Mackenzie Valley Highway Alignment during Periods of Ice Cover

		Max Depth (m)			Under Ice Volume (DFO 2010)[c]			Surface Area (MVLWB 2021)				Recommended Withdrawals			Candidate for Future Bathymetric Surveys?	
Name	MVH Alignment (km)[a]	Surveyed	Coarse[b]	Too Shallow?	10% of Under Ice Volume (m^3)	Depth Equivalent of Volume (m)	Volume Comments	Surface Area (m^2)	Volume from Surface Area (m^3)[d]	Volume (%)	Surface Area Notes	Conservative Withdrawal (m^3)	Limiting Criterion	Notes	Assessment	Comment
WR22	916		3.4	NO			Volume unknown	2,254,359	225,436		Volume unknown			Volume unknown	Yes	
WR21	921.3		5.2	NO			Volume unknown	30,606	3,061		Volume unknown			Volume unknown	Yes	
WR948	948.4			UNKNOWN			Volume unknown	16,463	1,646		Volume unknown			Volume unknown	Maybe	Given small surface area, may be shallow
WR25	944.6	21.7		NO	316,381	0.69	Littoral zone loss	461,128	46,113	1	PASSES CRITERIA	46,113	MVLWB (2021)	Conservative volume available	n/a	n/a survey already conducted
WR28	950.4	14.8		NO	74,686	0.37	Littoral zone loss	204,493	20,449	3	PASSES CRITERIA	20,449	MVLWB (2021)	Conservative volume available	n/a	n/a survey already conducted

NOTES:

Waterbodies are sorted from south to north.

[a] 'Alignment (km)' is the approximate mid-point of each lake along the proposed MVH alignment.

[b] From Table 8.1 in Golder (2006). These are lakes where full bathymetric surveys have not been conducted and may not represent the true maximum lake depth.

[c] under ice water volume is calculated assuming 1.5 m thick ice.

[d] Waterbody surface area (units = m^2) multiplied by 0.1 m.

Data are not available when cells are blank.

Please refer to Table 4.5 for waterbody metadata.

Candidate Lakes for Future Bathymetric Surveys

The number of lakes assessed for withdrawals during periods of ice cover could be increased by conducting additional bathymetric surveys (Section 7). Bathymetry has not been conducted at nine lakes. The ‘Candidate for Future Bathymetric Surveys’ columns (Table 5.5) identify:

- six lakes (WSWrigley, WR3, WR4, WR893, WR21, WR22) where bathymetric surveys have not been conducted and are potentially deeper than 3.0 m and may support withdrawals. These are primary candidates for future bathymetric surveys. Note that if surveys determined maximum depth to be between 1.5 and 3.0 m, then DFO (2010) criteria would not be met.
- two lakes (WS791, WR948) where bathymetric surveys have not been conducted; however, these lakes have small surface areas and/or long axis lengths. If maximum open water depth were less than 1.5 m or greater than 3.0, then withdrawals may be allowed. These are secondary candidates for future bathymetric surveys.
- one lake (WR7) that has a (coarsely determined) maximum depths of 1.5 m. This lake is not recommended for future bathymetric surveys.

Lakes with larger surface areas and long axes would have a greater chance of being sufficiently deep to support withdrawals, and more water would be available for withdrawal from more voluminous lakes. For (e.g., WSWrigley and WR893). The above assessments could be refined by statistically relating surface area, long axis length, and other morphology indicators to maximum depth and lake volume using regional datasets of lakes where bathymetry is known (AEP 2019; Islam et al. 2018).

5.2.2 Withdrawals During Periods of Open-Water

Volumes of water potentially available for withdrawal using the MVLWB criterion are presented in Table 5.5. Lakes with open water maximum depths less than 1.5 m might be considered for licensing (Section 4.2.1.2), but no candidate lakes have been identified as being this shallow (Table 5.5). Lakes with maximum open water depths between 1.5 and 3.0 m are excluded given their potential sensitivity to withdrawal.

Lakes were categorized based on available maximum depth data (Table 5.6). Lakes that are either known to be too shallow to support open water withdrawals, or where maximum depth is not confidently known, were not carried forward. Eleven lakes remained (Table 5.5; Table 5.6).

In Section 5.2.1, candidate lakes were identified for additional bathymetric surveys to assess winter withdrawal volumes. This would also be beneficial for lakes identified in Table 5.6. However, note that MVLWB may allow maximum depth to be coarsely determined by measuring lake depth “*prior to each season of use, avoiding freshet. This must be measured in at least three locations >20 m from shore and approximately 20 m apart.*” (MVLWB 2021a). This is applicable only in the open water period because under ice volume is required in the ice-covered period.

Neither the DFO nor MVLWB methods are explicitly intended to preserve downstream flows for EFN. Impacts to downstream flows caused by withdrawals in upstream lakes are important to assess both in summer and potentially in winter, given that some of the larger watercourses in the Study Area flow in winter (Section 5.1.1) (K’alo-Stantec 2022a). Please refer to Section 6.3 for potential methods to estimate EFN in watercourses downstream of waterbodies.

Table 5.5 Potential Withdrawal Limits for Waterbodies Along the Proposed Mackenzie Valley Highway Alignment during Periods of Open Water

		Max Depth (m)			Surface Area (MVLWB 2021)		
Name	MVH Alignment (km)[a]	Surveyed	Coarse[b]	Too Shallow?	Surface Area (m^2)	Volume from Surface Area (m^3)[c]	Surface Area Notes
WSWrigley	686.5			UNKNOWN	902,073		Unknown if too shallow to withdraw
WR2	702.2	5.1		NO	364,955	36,496	Sufficiently deep
WR3	718.8		2.9	YES (Potentially)	533,832		Potentially too shallow to withdraw
WR4	721.8		2.9	YES (Potentially)	36,400		Potentially too shallow to withdraw
WS791	791			UNKNOWN	36,388		Unknown if too shallow to withdraw
WR5	798.8	2.1		YES	200,168		Too shallow to withdraw
WR6	804	3.4		NO	796,473	79,647	Sufficiently deep
WR7	810.1		1.5	YES (Potentially)	207,259		Potentially too shallow to withdraw
WR8	820	15.2		NO	251,743	25,174	Sufficiently deep
WR9	826.6	2.2		YES	19,617		Too shallow to withdraw
WR10	835	15.1		NO	13,160	1,316	Sufficiently deep
WR11	839.5	1.9		YES	43,646		Too shallow to withdraw
WR12	863	2.3		YES	7,432,430		Too shallow to withdraw
WR13	876.3	1.7		YES	714,769		Too shallow to withdraw
WR16	882.5	4.9		NO	56,631	5,663	Sufficiently deep
WR18	892	9.3		NO	1,385,441	138,544	Sufficiently deep
WR893	893			UNKNOWN	190,086		Unknown if too shallow to withdraw
WR19	903	3.8		NO	35,950	3,595	Sufficiently deep
WR20	908.9	2.6		YES	3,595,971		Too shallow to withdraw
WR22	916		3.4	NO	2,254,359	225,436	Sufficiently deep
WR21	921.3		5.2	NO	30,606	3,061	Sufficiently deep
WR948	948.4			UNKNOWN	16,463		Unknown if too shallow to withdraw
WR25	944.6	21.7		NO	461,128	46,113	Sufficiently deep
WR28	950.4	14.8		NO	204,493	20,449	Sufficiently deep

NOTES:
Waterbodies are sorted from south to north.
[a] ‘Alignment (km)’ is the approximate mid-point of each lake along the proposed MVH alignment.
[b] From Table 8.1 in Golder (2006). These are lakes where full bathymetric surveys have not been conducted and may not represent the true maximum lake depth.
[d] Waterbody surface area (units = m^2) multiplied by 0.1 m.
Data are not available when cells are blank.
Please refer to Table 4.5 for waterbody metadata.

.

Table 5.6 Open Water Withdrawal Categories based on Maximum Open Water Depth

Category	Category Description	Applies to	Action	Recommendation
Sufficiently deep	Either bathymetric surveys or coarse measurements of depth indicate that open water maximum depth is greater than 3.0 m	WR2, WR6, WR8, WR10, WR16, WR18, WR19, WR21, WR22, WR25, WR28	Calculate open water withdrawal volumes	None
Unknown if too shallow to withdraw	No bathymetric surveys have been conducted and no coarse measurements of maximum depth are available	WSWrigley, WS791, WR893, WR948	Exclude from open water withdrawal volume calculations	Conduct additional measurements* where morphology suggests lakes may be sufficiently deep.
Potentially too shallow to withdraw	No bathymetric surveys have been conducted. However, limited depth measurements indicate that the open water maximum depth may be between 1.5 and 3.0 m, and hence withdrawals may not be permissible.	WR3, WR4, WR7	Exclude from open water withdrawal volume calculations	These are lower priority for additional measurements* surveys given preliminary indications of their maximum depth.
Too shallow to withdraw	Either bathymetric surveys or coarse measurements of depth indicate that open water maximum depth is shallower than 3.0 m and not shallower than 1.5 m	WR5, WR9, WR11, WR12, WR13, WR20	Exclude from open water withdrawal volume calculations	None

NOTE:
*Bathymetry or coarse measurements of depth, see text.

5.2.3 Summary of Water Availability from Waterbodies in the Ice-Covered and Ice-Free Periods

Please refer to Summary Table 2 in the executive summary for a compilation of water availability from watercourses in open-water periods, ice-covered periods, and annually.

6 Discussion

6.1 Licensing Considerations

For ‘miscellaneous’ projects, the *Northwest Territories Waters Act* and Regulations permit water to be withdrawn from watercourses[3] without a licence for uses less than 100 m^3 *per day* (GNWT 2014; Schedule H). This equates to 36,400 m^3 annually, or about 18,000 m^3 in both the ice covered and open water periods. This implies that:

- if required water volumes from watercourses and waterbodies are less than identified maximums in Table 5.3, Table 5.4, and Table 5.5, then water licenses may not be required.
- if regulators only consider the *Waters Act* criterion, then more water may be available for waterbodies than identified in Table 5.4 and Table 5.5.

In contrast to the *Waters Act*, the MVLWB method and DFO protocols both stipulate non-application below 100 m^3 withdrawal *in a single ice-covered season.* The application of these protocols is preferred for environmental assessment despite being more limiting and more conservative. The *Waters Act* criterion is discussed here only because of its implications for when licensing is —and is not— required.

Note that if desired withdrawals do not meet limits calculated using protocols (e.g., DFO 2010, DFO 2013), a Request for Review could be submitted to DFO.

6.2 Assessment of Methods for Determination of Streamflow In Ungauged Catchments

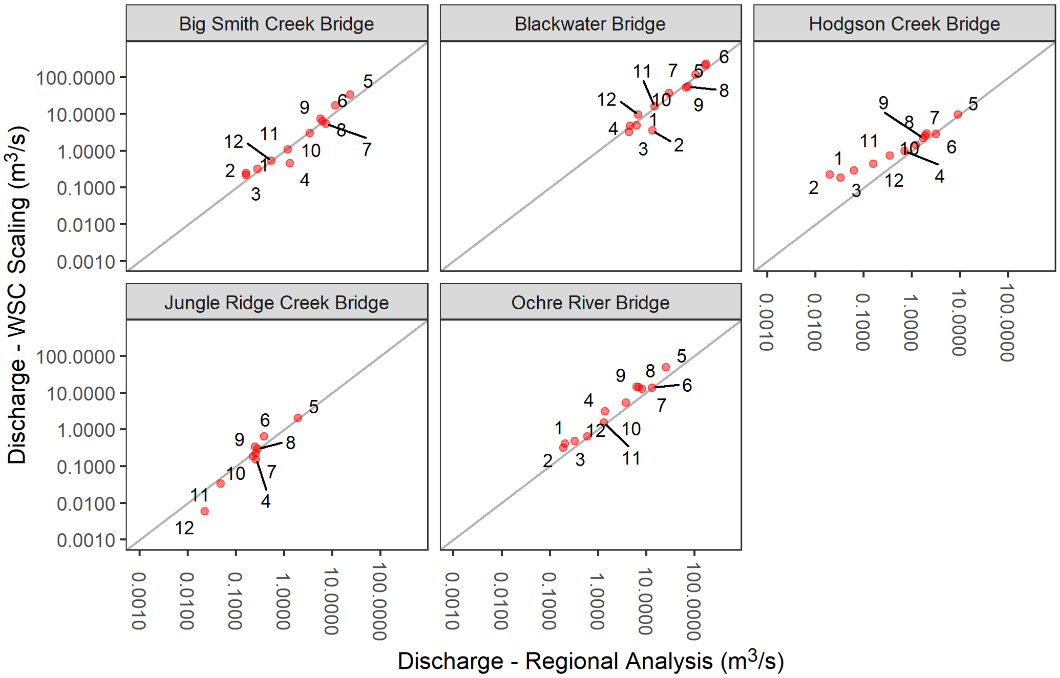
6.2.1 Comparison Results from Regional Analysis and ‘WSC Scaling’ Methods

Figure 6.1 compares monthly average flows calculated using the WSC scaling approach and the regional regression approach. Results appear similar for both approaches except for Hodson Creek Bridge, where the WSC scaling approach suggests higher flows in winter. Hodgson Creek is the southernmost studied watercourse, and its watershed area is relatively large (Figure 1.1; Table 4.1); winter flows may be higher here than suggested by regional analyses. Monitored flows from Hodson Creek are relatively recent and the period of record is relatively short (2006 to 2014; Table 4.3). Available flow data from this site may not be representative of the full range of hydroclimatic variability, or winter flows may be affected by recent climate change.

---

[3] The definition of ‘watercourse’ differs here compared to the Waters Act. The Waters Act defines a watercourse as “a natural watercourse, body of water or water supply, whether usually containing water or not, and includes groundwater, springs, swamps and gulches.”, i.e., it includes waterbodies.

Figure 6.1 Comparison of Monthly Flows Predicted using the 'WSC Scaling' Technique and the Regional Analysis Technique



NOTES:

Labeled numbers are months (1=January, 12=December).

Grey lines are 1:1 lines (i.e., have slopes of one and intercepts of zero). Monthly predictions (red dots) falling exactly on the 1:1 line are identical.

Flows from the regional analysis method were predicted using regression equations provided in Table 5.1.

'WSC scaling' flows were scaled directly from WSC stations on the same watercourse as the proposed crossing.

Table 6.1 compares annual water availability per DFO criteria calculated using the WSC scaling approach and the MVH regional regression approach. Except for the Ochre River, water availability calculated from both approaches is within about 22%. For all five gauged crossings, the MVH regression approach is conservative, as it predicts that less water is available for withdrawal than the WSC scaling approach.

Table 6.1 Comparison of Annual Water Availability per DFO Criteria Predicted Using the 'WSC Scaling' Technique and the Regional Analysis (MVH) Technique

Watercourse	Crossing Watershed Area (km^2)	Availability (m^3/yr)[a]		Difference	
		WSC Scaling	Regional Analysis	m^3	%
Big Smith Creek	1,076	19,510,836	15,220,279	4,290,557	22
Blackwater River	10,716	188,109,030	163,361,027	24,748,003	13
Hodgson Creek	358	6,200,677	5,240,689	959,988	15
Jungle Ridge Creek	60	1,035,713	954,213	81,500	8
Ochre River	1,207	30,047,250	17,097,693	12,949,557	43

NOTE:
[a] calculated as 10% of volumetric flow in months where discharge is more than 30%MAD (DFO 2013).

For the Ochre River, the difference between approaches in annual water availability is 43% (Table 6.1). This is not apparent in the comparison of monthly discharge (Figure 6.1), partly because of the use of log-log axes. The WSC scaling approach predicts about 1.3 x 10^7 m^3 of water available for withdrawal in May, while the regional analysis approach predicts about half this volume: 6.9 x10^6 m^3. This is a large difference in the month with peak annual flows. In addition, the WSC scaling approach suggests that withdrawals are likely permissible in April, while the MVH approach suggests that no water is available for withdrawal in this month due to flows being <30%MAD (DFO 2013). Similar to Hodgson Creek, Ochre River is located far south along the proposed MVH alignment and has a relatively large watershed area (Figure 1.1; Table 4.1), which could affect the accuracy of regional regression-based flow predictions. Also similar to Hodson Creek, the Ochre River monitoring period is relatively short and recent (2006 to 2019). Available flow data from this site may not be representative of the full range of hydroclimatic variability, or winter flows may be affected by recent climate change.

At Blackwater River, flows and water availability calculated using both approaches are relatively similar. This is surprising given the large size of the Blackwater River watershed area and given that its flows are likely influenced by discharge from Blackwater Lake (Faria 2002) (Section 4.1.2.1).

Overall, the regional analysis approach appears to provide conservative estimates of water availability. The WSC scaling approach uses site-specific data where available. These data are preferable over regionally based flow predictions, but results can be susceptible to influences from short records and potentially, climate change.

6.2.2 Comparison of Flows Predicted Using Differing Regression Equations

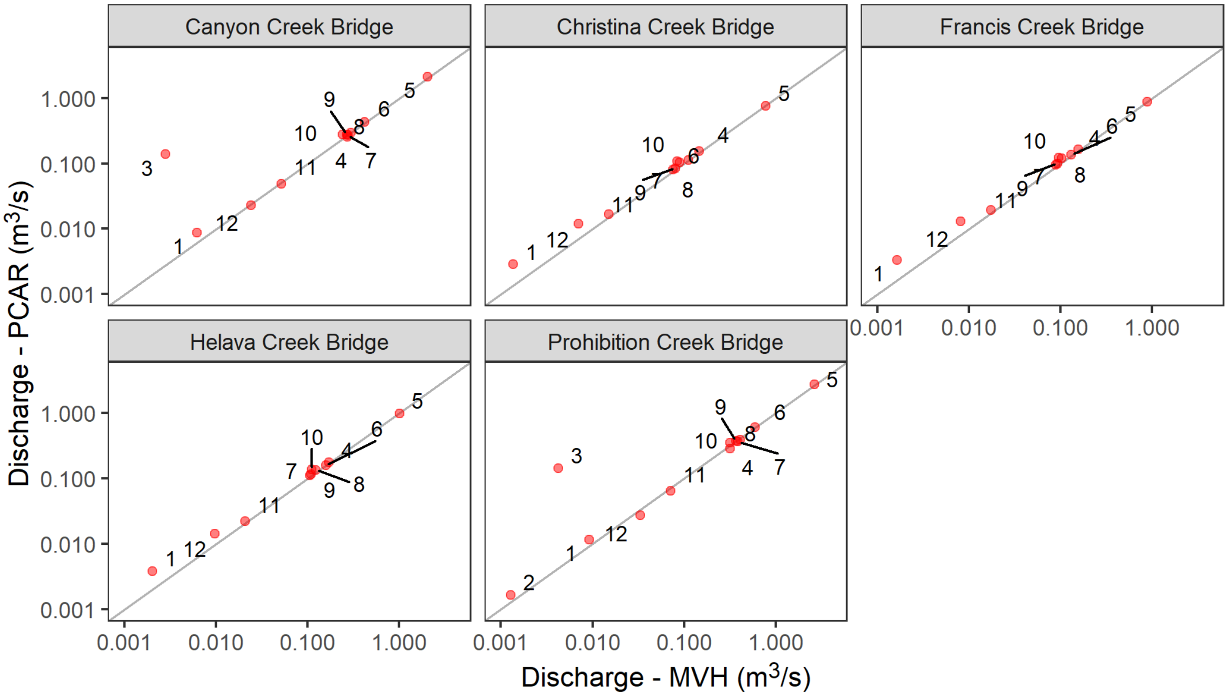
Flow estimates and water availability were recently assessed for five watercourses along the proposed Prohibition Creek Access Road (PCAR) alignment (K'alo-Stantec 2022a) (Figure 1.2). A similar regional analysis methodology was used for flow predictions for both MVH and PCAR. However, regional station selection criteria were tailored to crossings along each alignment. Differences include:

- WSC stations were selected based on a point for the PCAR study rather than a buffered linear feature used here (Section 4.1.2.2). The difference occurs because the proposed PCAR alignment spans only about 14 km while watercourse crossings along the proposed MVH alignment span about 275 km.
- The maximum considered watershed area for regional WSC stations in the PCAR study was about 1,000 km^2, compared to about 7,400 km^2 for the MVH study. WSC stations were chosen to best represent the range of target watershed areas for each study. For example, target watersheds for the PCAR study spanned from 21 to 86 km^2 but reach about 440 km^2 for this study.

Differing station selection criteria produced differing regression coefficients and flow predictions. The PCAR alignment immediately north of the proposed MVH alignment, and the watershed areas of some MVH crossings are smaller than those of PCAR crossings (as small as about 9 km^2; Table 4.1). Therefore, it could be argued that the same regional station selection criteria should be applied to both MVH and PCAR crossings.

To evaluate the effects of differing regional station selection criteria on flow predictions and water availability, flows were predicted for the five previously studied PCAR watercourses using regression coefficients derived in this study and in the PCAR study, and results are compared in Figure 6.2. Flows are similar for both approaches in most months. The exception is March. Regionally, flows are variable in March: flows begin to increase at some sites, while flow is delayed at other sites. March regression equations were not statistically significant in the PCAR study.

Figure 6.2 Comparison of Monthly Flows Predicted Using Differing Sets of Regional Stations



NOTES:
Labeled numbers are months (1=January, 12=December).
Grey lines are 1:1 lines (i.e., have slopes of one and intercepts of zero). Monthly predictions (red dots) falling exactly on the 1:1 line are identical.
MVH flows were predicted using regression equations provided in Table 5.1.
PCAR flows were predicted using regression equations provided in the PCAR water availability study (K'alo-Stantec 2022a) and Appendix B.
Flow predictions from March for Christina, Francis, and Helava creeks are lower than axes limits.

The PCAR water availability study found that withdrawals may be permitted in March, since predicted flows were >30%MAD. However, it was noted that uncertainty was high in spring. This study finds that withdrawals may be permissible at some MVH crossings in March, but uncertainty is high, and site-specific field investigations would be required to assess this possibility.

On an annual basis, the impact of differing methodologies on predicted water availability is small, i.e., less than 11% at PCAR crossings (Table 6.2). Differences are larger for smaller watersheds, reflecting greater uncertainty in predictions from smaller watersheds (Figure 5.2).

Table 6.2 Comparison of Annual Water Availability Predicted Using Differing Sets of Regional Stations

Creek	Watershed Area (km^2)	Availability (m^3/yr)[a] PCAR	MVH	Difference m^3	%
Canyon	64	1,079,056	1,013,325	65,731	6
Christina	21	402,695	364,272	38,423	10
Francis	24	460,297	411,145	49,152	11
Helava	28	518,448	472,932	45,516	9
Prohibition	86	1,408,600	1,336,324	72,276	5

NOTE:
[a] calculated as 10% of volumetric flow in months where discharge is more than 30%MAD (DFO 2013).

6.3 Approaches for Assessment of Withdrawals from Waterbodies Appropriate for Preserving Downstream Environmental Flow Needs

Withdrawal volumes provided here for waterbodies follow guidelines intended to preserve littoral habitat and under-ice oxygen for aquatic life (MVLWB 2021b; MVLWB 2021a; DFO 2010). However, these guidelines do not explicitly consider impacts to downstream flows from upstream waterbody withdrawals. If this environmental value were to be considered, then appropriate withdrawal volumes in non-winter periods could be assessed as best practice. This may also be important to assess in winter at sites with large upstream lakes or with large watersheds, where flow continues over winter. It is possible in some cases, and at some times, that this environmental value may not be limiting. For example, at lakes with short residence times and during periods of high throughflow, i.e., when and where inflow is much greater than proposed withdrawals.

Impacts to downstream EFN from upstream lake withdrawals are explicitly considered in protocols from neighbouring jurisdictions. For short-term water withdrawals from lakes in the open water period, the British Columbia Oil and Gas Commission (BCOGC) guidance is:

> *"the water availability as calculated by NEWT, NWWT or OWT*[4]*, and limited to the 10 centimetre maximum drawdown limit from the HWL [High Water Level] mark. An estimate of the available water must be provided for the lake based on a 10 centimetre drawdown, and other authorizations"* (BCOGC 2022)

---

[4] Online water tools that produce discharge and water availability estimates for watercourses for regions in British Columbia.

Similar online water tools do not exist in NT. In Alberta, allocation criteria for lakes also consider downstream flows, but do not rely on data from online water tools. Instead, allocation limits in the open water period are calculated using a site-specific water balance approach. In particular:

- "The cumulative annual allocation limit is ≤12% of the mean annual outflow"; and
- To protect downstream EFN over shorter periods of time "*Mean annual outflow divided equally across April to October. Monthly cumulative limit ≤ 15% of monthly apportioned outflow*".

Withdrawals from Alberta Lakes in winter follow a similar approach, but also consider volumetric equivalents of lake surface area, modified from DFO (2010).

Application of a similar water balance approach to preserving flows downstream of waterbodies in NT would be possible using publicly available data sources or can be readily calculated. Required data include lake area, watershed area, average annual evaporation and precipitation, average annual runoff, and groundwater flux (where relevant). Lake area has been provided here, watershed area can be readily calculated, site-specific precipitation is readily available (Wang et al. 2012; Wang 2022), and runoff can be calculated with the regional analysis approach presented here (Section 4.1). Site-specific evaporation from lakes requires calculation (McMahon et al. 2013), but may be negligible relative to other water balance components in lakes with small surface areas and/or high throughflow.

The water balance approach described above may help satisfy the MVH environmental assessment Terms of Reference (TOR) request to "*describe the recharge ability of lakes that will be used for winter road watering or ice mining*" (MVEIRB 2015).

7 Conclusions and Recommendations

Water volumes available for withdrawal have been assessed for 22 watercourses and 24 waterbodies along the proposed Mackenzie Valley Highway (MVH) alignment, spanning roughly from Wrigley to Norman Wells, NT.

Conclusions for watercourses include:

- For all watercourses except the GBR, water is typically available for withdrawal from approximately April to October, and not available for withdrawal over winter. Over winter, withdrawals are unlikely to be classified as ‘low-risk’ because flows are likely to be less than 30% of mean annual discharge (DFO 2013). Large volumes of water are expected to be available for withdrawal from the GBR year-round.
- On an annual basis, volumes available for withdrawal are likely to be large compared to waterbodies.
- There are numerous (22) potential watercourse water sources.
- No long gaps exist between candidate watercourses along the proposed MVH alignment (‘long’ relative to gaps between waterbodies).

Conclusions for waterbodies include:

- Conservative, low-risk, regionally appropriate potential withdrawal volumes have been provided here in ice covered and ice-free periods.
  - In ice covered periods, volumes provided here are the *minimum* of criteria designed to protect littoral habitat (MVLWB 2021a; MVLWB 2021b) and oxygen levels under ice (DFO 2010).
  - In ice-free periods, volumes provided here align with criteria designed to protect littoral habitat (MVLWB 2021a; MVLWB 2021b).
- Volumes available for withdrawal from waterbodies are likely to be small compared to watercourses.
- In ice covered periods, there are nine waterbodies with sufficient data to assess relative to withdrawal criteria. In ice-free periods there are eleven waterbodies.
- There are long distances between lakes that meet assessment criteria and where data are available.

Recommendations related to watercourses include:

- Withdrawal from a watercourse —whether under licence or not— should include a requirement for measurements of instantaneous flow at the time of withdrawal. These flow measurements should be compared to mean annual discharge for each creek to ensure flows are >30%MAD at the time of withdrawal and that withdrawals are <10% of instantaneous flow.
- If water is required in spring and to a lesser extent autumn, then additional site-specific flow measurements would be beneficial, given (a) uncertainties in flow predictions in spring, (b) the months where discharge is greater than 30% of MAD varies regionally, (c) monthly averages have been provided here, and flows will vary within each month and year, and (d) months in spring and autumn where flows pass DFO criteria sometimes vary between the WSC scaling approach and the regional analysis approach.
- Flow measurements over winter would help define the timing and magnitudes of flows. This is recommended since the MVH TOR request a description of watercourses that have year-round flow (MVEIRB 2015), and in the event that over winter withdrawals from watercourses are sought.
- Pertinent supplemental information for winter MVH withdrawals would be defined by DFO and/or MVLWB. Where not already available, this could take the form of a fish periodicity table, baseline hydrological data, detailed fish habitat modelling, reconnaissance-level fish and fish habitat impact assessment, withdrawal rate limits, limited licence terms, and/or requirements to monitor water use (FLNRORD and ENV 2022).

Recommendations related to waterbodies include:

- Candidate lakes where bathymetric data are not available but may have maximum depths greater than 3.0 m were selected based on their surface areas and long axis lengths. The list could be refined by statistically relating surface area, maximum length, and other morphology indicators to maximum depth and lake volume using regional datasets of lakes where bathymetry is known (AEP 2019; Islam et al. 2018).
- Given the absence of published regional protocols for withdrawals from the open water period, discussions should occur with decision makers to identify data requirements for the Project. A potential water balance approach that aligns with EFN methodologies in neighbouring jurisdictions has been described in Section 6.3. This approach could be applied to watercourses and waterbodies in the non-winter period and may also be applicable in the winter period at watercourses that are downstream of large waterbodies and continue to flow through winter. This approach could be combined with targeted flow measurements in the winter and non-winter periods.

8 Literature Cited

AAR. 2003. Applied Aquatic Research Ltd. Bathymetric survey of potential water bodies to supply the 2004 winter geotechnical program. Mackenzie Gas Project.

AEP. 2019. Alberta Environment and Parks, Government of Alberta. Surface water allocation directive.

BCOGC. 2022. British Columbia Oil and Gass Commission. Oil and Gas Activity Application Manual Chapter 4.7, ‘Short Term Water Use Activity Details’.

Bigras, Steven C. 1990. Hydrological Regime of Lakes in the Mackenzie Delta, Northwest Territories, Canada. *Arctic and Alpine Research* 22, Nr. 2 (May): 163. doi:10.2307/1551301, .

Cole, Anna. 2013. Annual unit runoff in Canada. *Agriculture and Agri-Food Canada*.

Cott, Peter A., Paul K. Sibley, Andrew M. Gordon, R.A. (Drew) Bodaly, Kenneth H. Mills, W. Murray Somers and Gerald A. Fillatre. 2008. Effects of Water Withdrawal From Ice-Covered Lakes on Oxygen, Temperature, and Fish 1. *JAWRA Journal of the American Water Resources Association* 44, Nr. 2 (April): 328–342. doi:10.1111/j.1752-1688.2007.00165.x, .

DFO. 2010. Fisheries and Oceans Canada. DFO Protocol for Winter Water Withdrawal from Ice-covered Waterbodies in the Northwest Territories and Nunavut.

DFO. 2013. Fisheries and Oceans Canada. Framework for Assessing the Ecological Flow Requirements to Support Fisheries in Canada. Canadian Science Advisory Secretariat Science Advisory Report 2013/017.

Duguay, Claude R, Terry D Prowse, Barrie R Bonsal, Ross D Brown, Martin P Lacroix and Patrick Ménard. 2006. Recent trends in Canadian lake ice cover. *Hydrological Processes* 20, Nr. 4: 781–801.

ECCC. 2022a. Environment and Climate Change Canada. Canadian Climate Normals. http://climate.weather.gc.ca/climate_normals/index_e.html.

ECCC. 2022b. Environment and Climate Change Canada. Environment Canada Data Explorer. HYDAT Database (April 2022 database).

Faria, Derek A. 2002. Overview of the hydrology in the Deh Cho Region - NWT. Water Resources Division Indian and Northern Affairs Canada Yellowknife, Northwest Territories Canada.

FLNRORD and ENV. 2022. Ministry of Forests, Lands, Natural Resource Operations and Rural Development Ministry of Environment and Climate Change Strategy. Environmental Flow Needs Policy. Amendment No: 3 (2022).

GNWT. 2009. Government of Northwest Territories. Ecological Regions of the Northwest Territories–Taiga Plains. Ecosystem Classification Group. Department of Environment and Natural Resources.

GNWT. 2014. Government of Northwest Territories. Waters Act. Waters Regulations. R-019-2014. In force April 1, 2014.

GNWT. 2022a. Government of Northwest Territories. NWT State of the Environment Report. https://www.enr.gov.nt.ca/en/services/nwt-state-environment-report/13-state-permafrost.

GNWT. 2022b. Government of Northwest Territories. Position of treeline. https://www.enr.gov.nt.ca/en/state-environment/142-position-treeline.

Goetz, Jon, Sam Albers and Robin Pike. 2018. Creating reproducible approaches for streamflow data analysis using the ‘tidyhydat’ and ‘fasstr’ R packages. In: *The 71st CWRA National Conference*. 71st Canadian Water Resources Association National Conference.

Golder Associates. 2006. Assessment of winter conditions at potentail water extraction sources along the Mackenzie Valley Winter Road. Sahtu Region, NWT. Submitted to Department of Transportation, GNWT.

Golder Associates. 2008. Final Report. Bathymetric Surveys of Potential Water Extraction Sources.

Golder Associates. 2015. Central Mackenzie surface water and groundwater baseline assessment.

Hatfield Consultants. 2016. Screening tool to identify low risk withdrawals from lakes in Alberta and Northeast British Columbia.

Islam, Z, M Seneka, E Kerkhoven and L Makowecki. 2018. Canadian Society for Civil Engineering Annual General Conference. Estimating Water Availability and Under Ice Volume of Alberta Lakes using Minimal Data. Fredericton, NB.

K’alo-Stantec. 2021. Draft. Mackenzie Valley Highway Extension Project. Technical Data Report - Surface Water Quantity.

K’alo-Stantec. 2022a. Prohibition Creek Access Road: Desktop based Assessment of Water Availability.

K’alo-Stantec. 2022b. Mackenzie Valley Highway Project. Technical Data Report—Air Quality, Greenhouse Gas Emissions and Climate Baseline.

Kokelj, S V. 2001. Hydrologic overview of the Gwich’in and Sahtu Settlement Areas. Water Resources Division Indian and Northern Affairs Canada. Yellowknife, Northwest Territories. Canada.

McMahon, T A, M C Peel, L Lowe, R Srikanthan and T R McVicar. 2013. Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis. *Hydrology and Earth System Sciences* 17, Nr. 4: 1331.

MGP. 2004. Mackenzie Gas Project. Environmental Impact Statement for the Mackenzie Gas Project. Volume 3: Biophysical Baseline. Section 7: Fish and Fish Habitat. Prepared by Mackenzie Project Environmental Group for Imperial Oil Resources Ventures Limited.

MOE. 1991. Ministry of Environment, Water Management Division, Hydrology Section. Manual of Operational Hydrology in British Columbia. Second Edition. Edited by C.H. Coulson.

MVEIRB. 2015. Mackenzie Valley Environmental Impact Review Board. Terms of Reference - Mackenzie Valley Highway.

MVLWB. 2021a. Land and Water Boards of the Mackenzie Valley. Method for Determining Available Winter Water Use Capacity for Small-Scale Projects April 7,.

MVLWB. 2021b. Land and Water Boards of the Mackenzie Valley. Technical Reference Document for the Method for Determining Available Winter Water Volumes for Small-Scale Projects.

Natural Resources Canada. 2022. National Hydro Network - NHN - GeoBase Series. https://open.canada.ca/data/en/dataset/a4b190fe-e090-4e6d-881e-b87956c07977.

NHC. 2006. Northwest Hydraulic Consultants. Hydrotechnical design input for proposed bridge over Great Bear River at Tulita.

NHC. 2018. Northwest Hydraulic Consultants. Great Bear River Bridge at Tulita Hydrotechnical Deign Update.

R Core Team. 2022. A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Tetra Tech. 2020. Mount Gaudet Access Road Hydrotechnical Assessments. Presented to Government of the Northwest Territories, Department of Infrastructure, Issued for Review, Nov 10, 2020.

Tetra Tech. 2021. Mackenzie Valley Highway Prohibition Creek Access Road Hydrotechnical Assessments.

Tetra Tech. 2022. Mackenzie Valley Highway Prohibition Creek Access Road Hydrotechnical Design GNWT Service Contract SC-5078.

Wang, Tongli. 2022. climateNA. https://climatena.ca/ (accessed: 5. September 2022).

Wang, Tongli, Andreas Hamann, David L Spittlehouse and Trevor Q Murdock. 2012. ClimateWNA—high-resolution spatial climate data for western North America. *Journal of Applied Meteorology and Climatology* 51, Nr. 1: 16–29.

Wetzel, Robert G. 2001. *Limnology: lake and river ecosystems*. gulf professional publishing.

Wickham, Hadley. 2016. *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag New York. https://ggplot2.tidyverse.org.

8.1 Personal Communications

Stevens. 2022. Teleconference meeting GNWT-INF and K'alo-Stantec January 21, 2022.

Potten. 2022. Email correspondence between E.Bonhomme (K'alo Stantec) and MVLWB. September 23, 2022.

9 Closure

If you have any questions, please do not hesitate to contact the undersigned.

Respectfully Submitted,

K'ALO-STANTEC LIMITED

Original signed by

Lewis, Ted

Digitally signed by Lewis, Ted
Date: 2023.01.26 12:18:38 -08'00'

Ted Lewis, Ph.D., P.Ag.
Senior Hydrologist
Tel: 604-356-7596
Ted.Lewis@stantec.com

Appendix A Average Flows and Statistics for Gauged Crossings (‘WSC Scaling’ Method)

This Appendix provides flow and water availability statistics at proposed MVH crossings that were compiled from WSC stations on the same watercourse. Monitored flows have been scaled to flows at each crossing using scaling factors that scale crossing watershed area to the watershed area at each crossing (Section 4.1.2.1)

Predicted monthly average discharge is provided (units = m^3/s), along with mean daily and monthly flows (units = m^3/d, m^3/m).

Ten percent of these discharge and flow estimates are provided to indicate the maximum of cumulative withdrawals for a "low probability of detectable impacts to ecosystems" (DFO 2013).
Water availability is set to zero in months where flow is <30% of MAD. Although DFO guidelines are for instantaneous rather than monthly average flows, monthly average flows are useful for initial assessment of typical flow magnitudes and water availability.

Table A.1 Big Smith Creek Bridge: Average Flow Predictions and Statistics

Table A.2 Blackwater Bridge: Average Flow Predictions and Statistics

Table A.3 Hodgson Creek Bridge: Average Flow Predictions and Statistics

Table A.4 Jungle Ridge Creek Bridge: Average Flow Predictions and Statistics

Table A.5 Ochre River Bridge: Average Flow Predictions and Statistics

Appendix B Average Flows and Statistics for Ungauged Crossings Derived Using Regional Analyses

This Appendix provides flow and water availability statistics at proposed MVH crossings that were predicted with regression-based techniques.

Predicted monthly average discharge is provided (units = m^3/s), along with mean daily and monthly flows (units = m^3/d, m^3/m).

Ten percent of these discharge and flow estimates are provided to indicate the maximum of cumulative withdrawals for a “low probability of detectable impacts to ecosystems” (DFO 2013).
Water availability is set to zero in months where flow is <30% of MAD. Although DFO guidelines are for instantaneous rather than monthly average flows, monthly average flows are useful for initial assessment of typical flow magnitudes and water availability.

Table B.1 Big Strawberry Creek Culvert: Average Flow Predictions and Statistics

Table B.2 Bob's Canyon Creek Culvert: Average Flow Predictions and Statistics

Table B.3 Dam Creek Bridge: Average Flow Predictions and Statistics

Table B.4 Devil's Canyon Bridge: Average Flow Predictions and Statistics

Table B.5 Four Mile Creek Culvert: Average Flow Predictions and Statistics

Table B.6 Gotcha Creek Bridge: Average Flow Predictions and Statistics

Table B.7 Little Smith Creek Bridge: Average Flow Predictions and Statistics

Table B.8 Notta Creek Bridge: Average Flow Predictions and Statistics

Table B.9 Saline River Bridge: Average Flow Predictions and Statistics

Table B.10 Seagrams Creek Bridge: Average Flow Predictions and Statistics

Table B.11 Small Strawberry Creek Culvert: Average Flow Predictions and Statistics

Table B.12 Steep Creek Bridge: Average Flow Predictions and Statistics

Table B.13 Twelve Mile Creek Bridge: Average Flow Predictions and Statistics

Table B.14 Vermillion Creek North Bridge: Average Flow Predictions and Statistics

Table B.15 Vermillion Creek South Bridge: Average Flow Predictions and Statistics

Table B.16 Whitesand Creek Bridge: Average Flow Predictions and Statistics