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Wolf Creek 2019 Hydrologic Assessment

Arviat, Nunavut

PECG Project #
14003401

Prepared For
Associated Engineering

March 4, 2020

Palmer™

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March 4, 2020

Paul Hague
Associated Engineering (B.C.) Ltd.
Suite 703, Northwest Tower
5201-50th Avenue
Yellowknife, NT X1A 3S9

Dear Paul Hague

Re: Wolf Creek 2019 Hydrologic Assessment
Project #: 14003401

Palmer Environmental Consulting Group Inc. is pleased to present our Wolf Creek 2019 Hydrologic Assessment.

This report presents a summary of the hydrologic data collected at the Wolf Creek monitoring station for the Hamlet of Arviat. These data, in addition to regional climate and hydrometric data, provide the basis for hydrologic assessment of options to increase water availability for replenishing the Hamlet's reservoir.

If there are any questions or comments on this report, please contact Rick Palmer at 604-629-9075 or rick.palmer@pecg.ca. Thank you for the opportunity to work with you on this project.

Yours truly,
Palmer™

R. Palmer

Rick Palmer, M.Sc., R.P.Bio.
President and CEO

Executive Summary

This report presents a summary of the hydrologic data collected at the Wolf Creek monitoring station for the Hamlet of Arviat, which, in combination with Environment Canada streamflow and climate data, provides the basis for a hydrologic assessment of Wolf Creek to determine water availability for replenishing the Hamlet's reservoirs. A streamflow monitoring station was installed early spring of 2019 on Wolf Creek, adjacent to the pump house which supplies the water to the town's reservoirs. To ensure that the station would capture the entirety of freshet, it was installed while conditions were still frozen. Stage-discharge measurements were collected throughout the open water season by Palmer staff and a locally trained technician.

The key findings within this report pertain to the timing of runoff, magnitude of runoff, long-term average runoff estimates and year-to-year variability in runoff, including future climate conditions. Runoff in Southern Nunavut (Kivalliq Region) and Wolf Creek is characterised as follows:

- Streamflow typically commences in early to mid-June as temperatures climb above 0°C and ends in late October. Larger rivers may flow year-round, but smaller watersheds (like Wolf Creek) freeze and cease to flow through the winter.
- The annual hydrograph for long-term streamflow stations in the region is dominated by a nival (snowmelt) freshet, which occurs predominantly between late June and the end of July, followed by a period of moderate flows driven lake and wetland dewatering and rainfall. Base flows are punctuated by precipitation events through July to early October.
- The 2019 measured streamflow record at Wolf Creek is likely higher than long-term average conditions and comparison of 2019 data to long-term data at regional hydrology and climate stations indicate:
    - Winter (Oct-May) streamflow and precipitation appear to be lower than average in 2019
    - Freshet (Jun-July) streamflow and precipitation appear to be close to average in 2019
    - Summer/Fall (Aug-Oct) streamflow and precipitation appear to be above average in 2019. Of note, precipitation at all three climate stations is much higher than average in August 2019
- The 2019 measured record was adjusted based on scaling factors determined from Arviat climate station and the estimated long-term mean annual discharge for Wolf Creek at the gauging station (and pumphouse) is 3.4 m^3/s (107,128,416 m^3/year), which equates to a unit runoff of 178 mm/year.

Climate change is predicted to result in substantial changes in temperature and precipitation in Southern Nunavut. The projected changes tend to suggest that surface water availability in Wolf Creek will increase in the future, but the magnitude of change and runoff response cannot be predicted with certainty. Variability may increase, resulting in increases in average conditions, but a wider range of conditions between years.

Given the limited streamflow record on Wolf Creek, paucity of regional datasets and uncertainty in potential future conditions, continuing data collection at the Wolf Creek gauging station would reduce uncertainty in the predicted streamflow conditions. Water supply options should provide appropriate resilience for potential future conditions, including potential changes in annual, seasonal and extreme flow events. However, the water treatment facility storage capacity of approximately 232,965 m^3 appears to be much less than water availability in Wolf Creek (approximately 0.2% of the average annual runoff).

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1. Introduction

Palmer has been retained by Associated Engineering (AE) to complete a hydrological assessment of Wolf Creek. The Community of Arviat (ᐊᕐᕕᐊᑦ) is located within the Kivalliq Region of Nunavut, on the western coast of Hudson Bay. The Community obtains its water supply from Wolf Creek approximately 8 km southwest of town. The intake is located in a pool in the creek and water is pumped via a pumphouse and pipeline to reservoirs located in Arviat. With the completion of a new reservoir cell, the water treatment facility has a storage capacity of approximately 232,965 m^3. Due to several system constraints, there is concern about whether Wolf Creek can provide future water demands. The Government of Nunavut (GN) Department of Community and Government Services (CGS) has requested a hydrological assessment of Wolf Creek and to assess options to increase water availability for replenishing the Hamlet’s reservoir.

A streamflow gauging station was established on Wolf Creek on May 9, 2019 and has been operated through the 2019 open water season. These data, in addition to regional and climate data, provide the basis for a hydrologic assessment of Wolf Creek to determine water availability for replenishing the Hamlet’s reservoirs.

The following sections discuss regional hydrologic characteristics before summarizing the data collected in 2019. An analysis to estimate long-term flow conditions is then presented. Finally, discussions of climate change at Wolf Creek are presented before the final section provides the conclusions and recommendations of the report.

2. Regional Streamflow and Climate Characterization

2.1 Climate

The Hamlet of Arviat is located on the western coastline of Hudson Bay in the Maguse River upland ecoregion (Campbell et. al., 2012). Mean annual temperature within this ecoregion ranges from approximately -8°C in the south to -11°C in the north and mean summer and winter temperatures are approximately 6°C and -24°C, respectively. Mean annual temperature tends to increase to the south, due to decreasing latitude and to the west due to the coastal influence of Hudson Bay. The mean annual precipitation ranges 250 mm in the northwest of the Ecoregion to over 400 mm occurring south of Arviat (Figure 1). Similar to temperature, annual precipitation tends to increase to the south, due to increasing temperature and to the west due to the coastal influence of Hudson Bay. Damp, foggy weather is common near the open waters of Hudson Bay during the late summer and early fall, prior to freeze-up.

Three Environment and Climate Change Canada (ECCC) climate stations were reviewed to characterize the climate in the region around the Wolf Creek Project area. The locations of these regional climate stations are shown in Figure 2. Arviat temperature and precipitation data are also summarized in Table 1and Table 2, while average monthly precipitation and temperature for Rankin Inlet, Arviat and Churchill are shown in Figure 3 and Figure 4, respectively. All values are based on 1981 to 2010 Climate Normal data reported by ECCC.

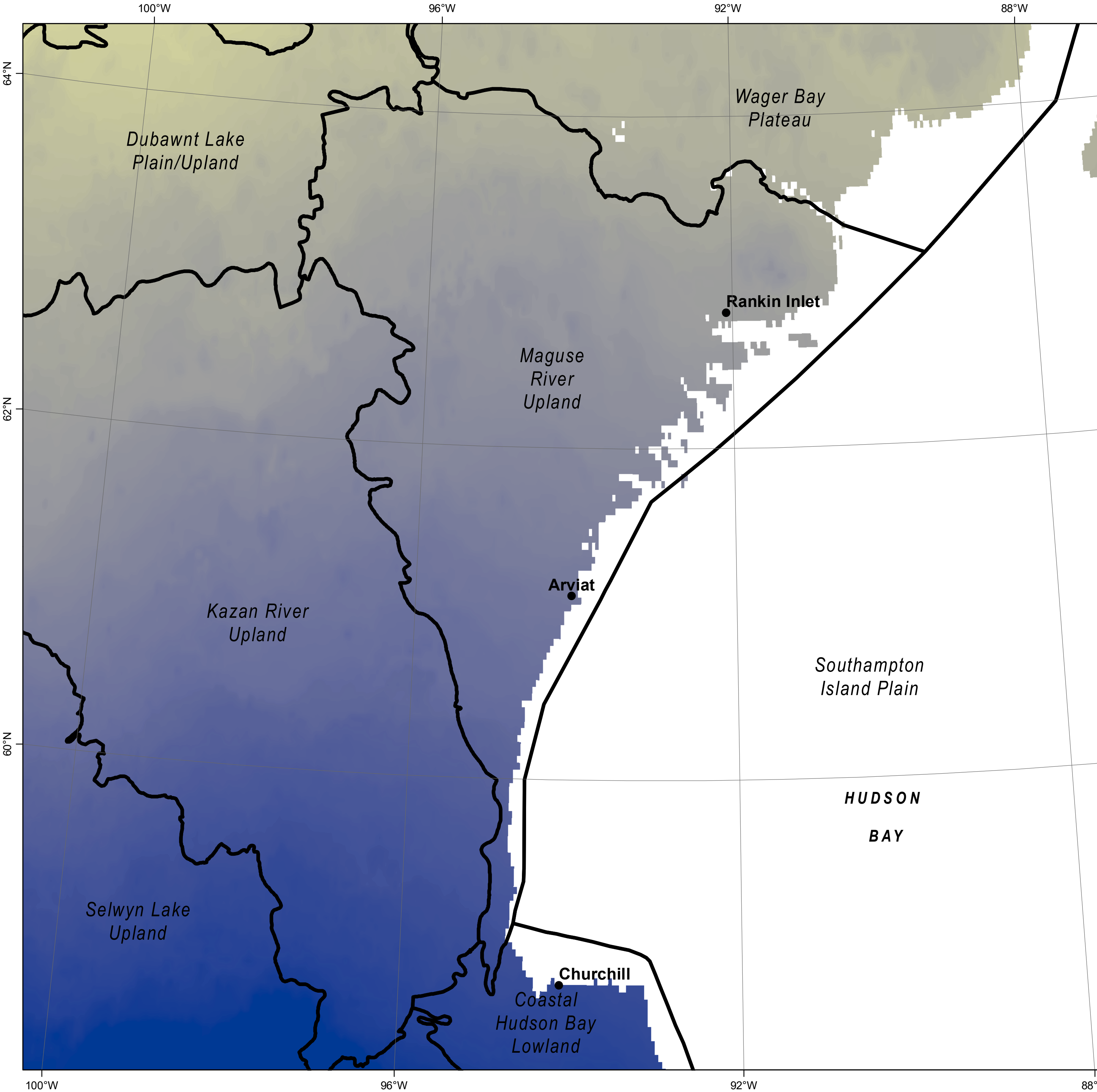
Table 1. Arviat Temperature Summary (1981-2010 Climate Normal)

Month	Daily Average ± SD (°C)	Extreme Maximum (°C)	Extreme Minimum (°C)
January	-29.3 ± 3.5	-1.5	-48.3
February	-28.3 ± 3.1	-1.5	-47
March	-22.8 ± 2.8	3.5	-41.5
April	-14 ± 2.7	4	-36.7
May	-4.3 ± 2.3	14.5	-26.7
June	4.4 ± 2	25.5	-11
July	11.1 ± 1.7	33.9	-4
August	10.8 ± 1	30	-0.6
September	4.8 ± 1.5	23	-8.3
October	-3.6 ± 2.2	13	-26
November	-16.1 ± 3.2	1.5	-34
December	-24.1 ± 3.7	-1.5	-42.5

Notes: SD = Standard Deviation

Table 2. Arviat Precipitation Summary (1981-2010 Climate Normal)

Month	Rainfall (mm)	Snowfall (cm)	Precipitation (mm)	Extreme Daily Rainfall (mm)
January	0	10.1	10.1	0
February	0	6.6	6.6	0
March	0	11.4	11.4	0
April	0.5	12.1	12.5	6.8
May	6.1	12.1	18.2	26.2
June	26.3	3.2	29.6	25
July	36.7	0	36.7	33.8
August	56	0	56	37.6
September	41.2	2.8	44	30.8
October	7.6	16.9	24.5	13.5
November	0	18.8	18.6	0
December	0	18.3	18.3	0
Yearly	174.4	112.4	286.5	NA



LEGEND:

Ecoregion Boundary

1961-1990 Average Annual Precipitation

450 mm

200 mm

Precipitation data provided by ClimateNA_MAP (http://www.climatewna.com/) Copyright(2019) University of British Columbia

Disclaimer: Predictions of historical and future climates are based on the methodologies described in Wang et al. 2016. Authors do not bear any liability for financial or other losses due the use of this program.

Ecoregion data provided by National Ecological Framework for Canada (Agriculture and Agri-Food Canada).

0 50 100 150
kilometres

N

PROJECT NO.	1400340	REVISION:	1
DATE:	Dec 11, 2019	SCALE:	1:3500000
DRAWN:	BE	DATUM:	NAD 1983
CHECKED:	CG	PROJECTION:	Lambert Conf. Conic

CLIENT: Associated Engineering

PREPARED BY: Palmer™

PROJECT: Arviat Hydrology Assessment

TITLE: **Precipitation in the Maguse River Upland Ecoregion**

FIGURE 1

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LEGEND:

- Hydrology Station
- Weather Station

Imagery provided by Esri basemap service.

0 50 100 150
kilometres

N

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DATE: Dec 10, 2019	SCALE: 1:4000000
DRAWN: BE	DATUM: NAD 1983
CHECKED: CG	PROJECTION: Lambert Conf. Conic

CLIENT: Associated Engineering

PREPARED BY: Palmer™

PROJECT: Arviat Hydrology Assessment

TITLE:

Regional Climate and Hydrology Stations

FIGURE 2

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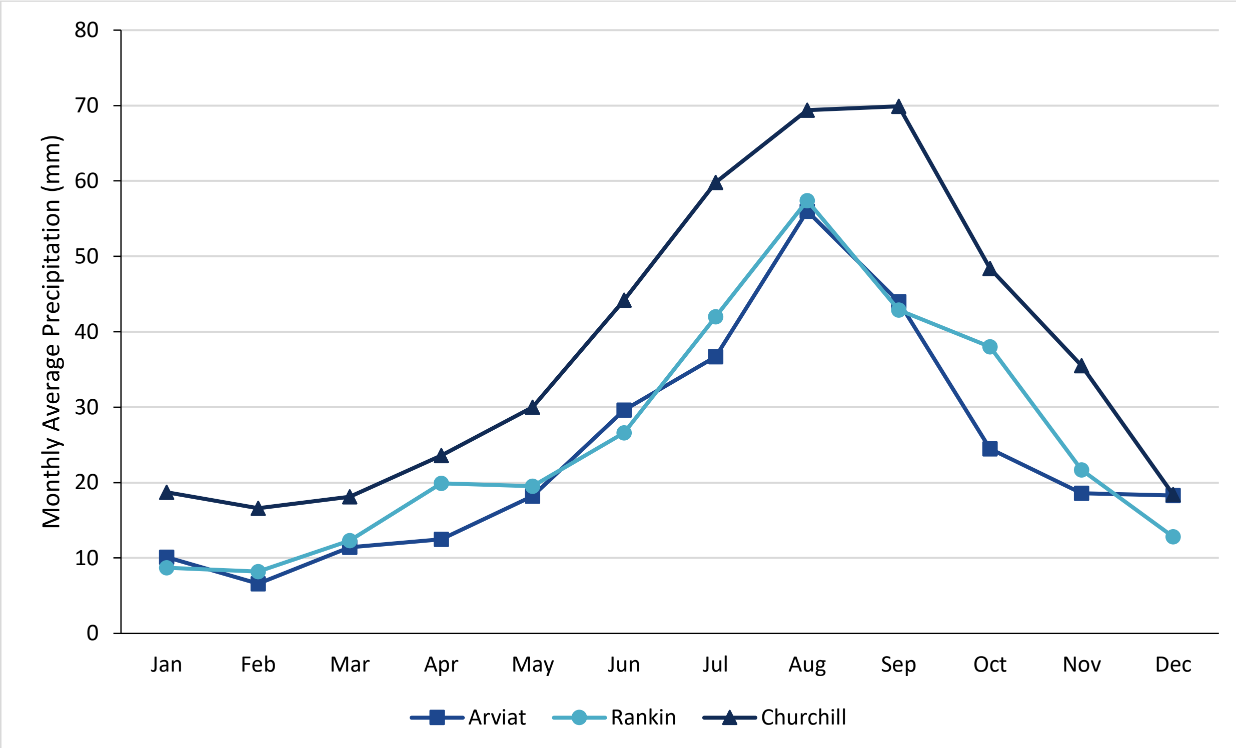


Figure 3. Regional Climate Station Average Monthly Precipitation (1981-2010 Climate Normals).

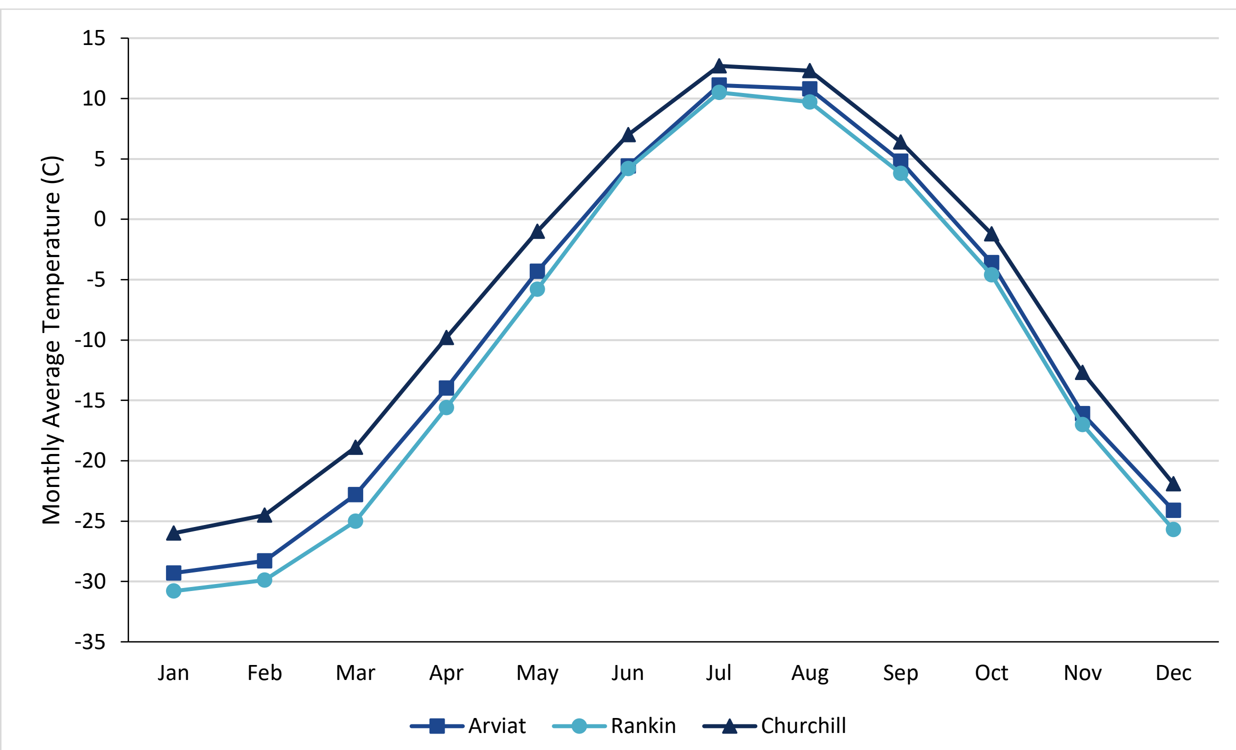


Figure 4. Regional Climate Station Average Monthly Temperature (1981-2010 Climate Normals).

2.2 Streamflow

Streamflow regimes in the Arctic are influenced by many factors, including climatic conditions such as precipitation and temperature, and watershed characteristics such as elevation, aspect, permafrost, glaciation, lakes and ground conditions. Throughout the winter months the temperatures are bitterly cold, combined with permafrost ground conditions, which results in most smaller streams and rivers either drying up or freezing solid and ceasing to flow. As temperatures rise above 0 ºC, snow and ice melt, and streamflow resumes until freeze-up occurs during the following winter. Considerable differences in the timing and volume of runoff can occur between systems depending on climatic and watershed characteristics. Elevation, aspect, and glacial cover are not expected to contribute significantly to hydrologic variability in the region surrounding Wolf Creek watershed. Rather, differences in lake and ground cover are expected to be dominant.

Lake content and wetlands within a watershed act to attenuate the effects of melt and rainfall storm events. Watersheds with a greater proportion of lakes, ponds and wetlands tend to have a smoothed hydrograph and a muted (attenuated) response to rainfall events compared to other watersheds. Lakes also provide a source of water to river systems later in the year, due to attenuation of inflows, when precipitation is falling as snow, permafrost melt has ceased, and other systems are no longer receiving input of water and are therefore drying up and/or freezing over. As a result, systems that include significant lake components tend to continue to flow later into the winter than watersheds with little or no lake volume. Wetlands make up 25-50% of the land area in the Maguse River ecoregion and lakes are generally extensive in the Southern Arctic region, having been formed by the melting glaciers of the last glaciation (Campbell et. al., 2012).

The long length of the sub-zero degree temperatures in this ecoregion results in a very short runoff period that typically occurs from June through September but may extend to late October or even early November in systems where large lakes are present.

Five regional hydrologic stations operated by Water Survey of Canada (WSC) were reviewed to characterize the hydrology in the region around the Wolf Creek Project area. Due to the sparse hydrologic network in the Canadian Arctic, these systems are a significant distance from the Project and have records with missing years. Runoff characteristics for these stations are listed in Table 3 and the gauge location is shown in Figure 2. Mean daily unit runoff for the available period of record at the five stations is shown in Figure 5. Smaller systems (Diana River and Siraqu Creek) begin to flow in late May to mid-June, with the larger watersheds reporting flow year-round, albeit low between November and May. The majority of annual runoff therefore typically occurs during the nival freshet in late June through July, with runoff decreasing through the late summer before freezing up again at the onset of winter. The watershed areas are significantly different between the five stations but the mean annual unit runoff (MAUR) is quite similar between them, ranging from 5.1 l/s/km^2 (161 mm/year) to 7.5 l/s/km^2 (237 mm/year) as shown in Table 3. All stations show the muted response of lake attenuation, except Siraqu Creek which appears to have a flashier response.

Table 3. Regional Streamflow Monitoring Stations.

Station Name	Period of Record	# of years complete	Catchment Area (km^2)	Active WSC Station	Mean Annual Discharge (m^3/s)	Average annual Unit Runoff	
						l/s/km^2	mm/yr
HANBURY RIVER ABOVE HOARE LAKE (06JB001)	1971-2017	22	5,770	Yes	29.4	5.1	161
KAZAN RIVER ABOVE KAZAN FALLS (06LC001)	1965-2016	47	70,000	Yes	452.6	6.5	204
DIANA RIVER NEAR RANKIN INLET (06NC001)	1985 - 2001	7	1460	No	9.1	6.2	196
SIURAQ CREEK NEAR OUTLET TO KAZAN RIVER (06LC003)	1979 - 1994	8	1480	No	7.6	5.2	162
KOGNAK RIVER BELOW MOUNTAIN LAKE (06HD001)	1975 - 1996	14	6900	No	51.8	7.5	237

Notes: See Figure 2 for station locations

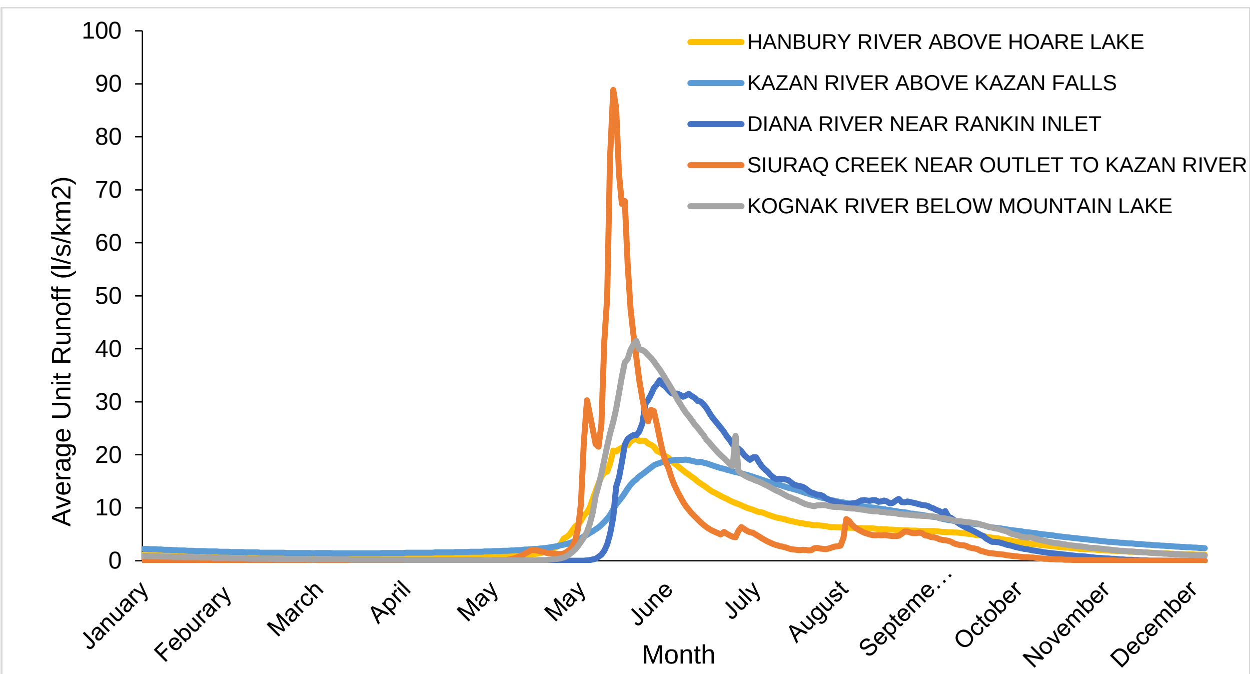


Figure 5. Mean Daily Unit Runoff for Regional Monitoring Stations.

3. Hydrometric Monitoring and Analysis Procedures

3.1 Station Installation and Removal

The Wolf Creek monitoring station was installed May 9, 2019 and has operated through the 2019 open water season. The sensor was installed in the small pond adjacent to the pump house because it provided good hydraulic conditions for streamflow gauging. These criteria include:

1. A stable hydraulic control,
2. Suitable installation conditions,
3. A site with minimal turbulence and water surface fluctuations,
4. A site where the pressure transducer will remain submerged at low flows, and
5. Suitable conditions for accurate discharge measurement at a wide range of flow conditions.

Installation during frozen conditions is challenging, but it was considered important to record data during freshet, to determine volumes and timing. The station was comprised of a Stevens Smart SDI-12/RS-485 ceramic pressure and temperature transducer housed in a 1.8 m PVC tube that was secured to in-situ boulders using rock bolts and pipe clamps. The sensor was vented to correct for changes in atmospheric pressure. A Neon data logger, stored inside a weatherproof case, was installed to record data at 15 min intervals. Approximately 20 m of PVC coated aluminum conduit was used to connect the hydrology sensor and data logger. The data logger was protected in a metal bear-bin that was secured with a pad lock.

A secondary absolute pressure (atmospheric pressure + gauge pressure) and temperature sensor (Solinst Levelogger Edge) was installed on July 19, 2019. A barometric compensation sensor (Solinst Barologger) was installed in the metal bear-bin to correct for atmospheric pressure. The Solinist sensors were programmed to record water level measurements at 15-minute intervals throughout the season.

Three benchmarks were installed to confirm that the water level loggers remained stationary and functioned correctly during the monitoring season. They also allow for the stage record from successive years to be corrected to a common datum. A staff gauge was also installed and surveyed. The gauging station location is presented in Figure 6. Photos of the site and surrounding terrain are provided in Appendix A.

During the October 16, 2019 site visit, the Solinist water level sensor and the barometric compensation sensor were removed for the winter. The Stevens level sensor and Neon logger are specified by the manufacturer to withstand winter conditions and following approval by AE, the logger battery was replaced and the equipment was left in-place to allow data collection in 2020. Overall, this instrumentation appears to be in good condition as of the October 2019 site visit, but inspection should be conducted prior to freshet (May/June 2020) if data collection is to continue.

Site visits completed during 2019 are summarized in Table 4.

LEGEND:

→ Flow Direction

Imagery (2017, DigitalGlobe) provided by Google Earth.

0 20 40 60 80
metres

PROJECT NO. 1400340		REVISION: 1	
DATE: Dec 09, 2019		SCALE: 1:2000	
DRAWN: BE		DATUM: NAD 1983	
CHECKED: CG		PROJECTION: UTM zone 15	

CLIENT: Associated Engineering

PREPARED BY: Palmer™

PROJECT:
Arviat Hydrology Assessment

TITLE:
Water Intake

FIGURE 5

Table 4. Summary Table of Wolf Creek Site Visits by Palmer Field Crews, 2019.

Date	Field Crew	Summary
May 9, 2019	Cris Gomez	• Station Installation (Neon Micrologger with Stevens SDI-12 ceramic pressure and temperature transducer, 4 m range)
July 19, 2019	Cris Gomez & Hallauk Karetak	• Back-up level and temperature sensor installed (Solinist Levelogger Edge and Solinist Barologger Edge) • Staff gauge installed • Stage-discharge measured
July 20, 2019	Cris Gomez & Hallauk Karetak	• Stage-discharge measured • Benchmark survey
August 26, 2019	Cris Gomez & Hallauk Karetak	• Stage-discharge measured
September 3, 2019	Hallauk Karetak	• Stage-discharge measured
September 9, 2019	Hallauk Karetak	• Stage-discharge measured
September 16, 2019	Hallauk Karetak	• Stage-discharge measured
September 23, 2019	Hallauk Karetak	• Stage-discharge measured
October 2, 2019	Hallauk Karetak	• Stage-discharge measured
October 8, 2019	Hallauk Karetak	• Stage-discharge measured
October 16, 2019	Cris Gomez & Hallauk Karetak	• Station winterization (back-up sensor removed) • Benchmark survey • Creek flowing, but could not be measured due to ice conditions

3.2 Stage and Discharge Measurements

Discharge measurements were recorded using a velocity meter (Marsh Mcbirney Flo-Mate 2000) and the velocity-area technique. Approximately 20 distance-depth-velocity measurements were recorded in each pass across the creek and two passes were measured to check measurement precision. Flows were too high to allow for safe wading through much of August and September. During these visits, depth and velocity measurements were recorded as far across the channel as could safely be waded. The same measurement section was used for all measurements and when the channel could not be crossed the unmeasured portion was estimated from the ratio of measured to unmeasured flow during complete streamflow measurements.

Measurement uncertainty for the velocity-area measurements was quantified by assessing the precision between concurrent discharge measurements, the distribution of cross-sectional discharge within depth-velocity measurement cells (ideally each cell contains less than 5% of the total discharge) and a qualitative assessment of the measurement transect quality. Typical measurement uncertainty ranged from +/- 5% to 20% of measured discharge.

Stage, which is water level corrected to the gauge datum, was recorded during each site visit either by surveying the water level relative to the station benchmarks or by reading the staff gauge. These measurements allow for confirmation that the water level logger data are reliable and correction of the water level logger data to gauge datum. Benchmark 1 (BM1) was assigned an elevation of 5 m and all stage data were corrected to this datum.

Stage and discharge measurements collected during 2019 are summarized in Table 5.

Table 5. Stage-Discharge Measurement Summary, Wolf Creek, 2019.

Date	Gauge Height (m)	Discharge (m^3/s)	Discharge Accuracy (%)
09-May-19	-	0.0	-
19-Jul-19	2.638	8.7	5%
20-Jul-19	2.635	8.0	5%
26-Aug-19	2.909	21.7	20%
03-Sep-19	2.983	34.4	20%
16-Sep-19	2.831	25.5	20%
23-Sep-19	2.779	13.6	10%
02-Oct-19	2.745	13.0	10%
08-Oct-19	2.686	8.9	10%

Notes: Discharge accuracy is an estimate, based on the precision between concurrent discharge measurements and a qualitative assessment of the measurement transect quality.

3.3 Rating Curve Development

Eight stage-discharge calibration measurements were successfully collected at the monitoring station between July 19, 2019 to October 8, 2019 (Table 5). The stage-discharge data were plotted and a rating curve was derived by minimizing the error between the measured stage-discharge calibration points collected at the station while considering the estimated uncertainty associated with each point. The form of the rating curve equation is also based on general hydraulic theory pertaining to open channel flow, which predicts that stage and discharge will be related by a power function with values of the coefficient and exponent being dependent on the hydraulic characteristics of the control section at the gauge (Maidment, 1993). The empirical rating curve equation can be compared against the expected theoretical values of the exponent and coefficient, which serves as a useful check on its reliability and accuracy when extrapolated to predict high flows.

The rating curve prepared for the Wolf Creek gauge is presented in Figure 7. The rating curve is considered to be of good quality over the range of measured conditions (approximately 8 to 35 m^3/s), although there is greater uncertainty in flows above approximately 20 m^3/s due to the lower accuracy of these measurements and below approximately 5 m^3/s (50% of the lowest measured flow).

3.4 Wolf Creek Measured Streamflow Record

All water level data were adjusted by a logger offset of 1.973 m to correct the data to gauge datum. The rating curve was applied to the adjusted logger record to develop the Wolf Creek streamflow record. The 15-minute data were averaged to generate a daily streamflow record, which is presented in Figure 8. Daily precipitation recorded at the Arviat climate station (Station ID 2300427) is also presented. The streamflow record is summarized as monthly mean and annual mean discharge in Table 6. The Wolf Creek watershed area is 603 km^2, as shown in Figure 9, and unit discharge (discharge divided by watershed area) is also presented in Table 6. Characteristics of the Wolf Creek streamflow record include the following:

- Streamflow began in early June, but the hydraulic control was ice affected until mid-June;
- The maximum daily mean discharge was 49.4 m^3/s recorded on August 30, 2019;
- The minimum daily mean discharge was 2.5 m^3/s recorded on October 16, 2019 just prior to station removal; and,
- Monthly mean discharge ranged from a low of 8.56 m^3/s during July to a high of 22.26 m^3/s during September 2019.

Table 6. Wolf Creek Streamflow Record Summary, 2019.

Month	Monthly Mean Discharge (m^3/s)	Unit Discharge ($l/s/km^2$)
June	10.0	16.7
July	8.6	14.2
August	16.5	27.6
September	22.4	36.9
October	10.2	16.8
Annual Average (2019)	5.6	9.4

Notes: The rating curve cannot be applied when the hydraulic control at the gauge is ice affected. Therefore, flows in early June and late October are not accounted.

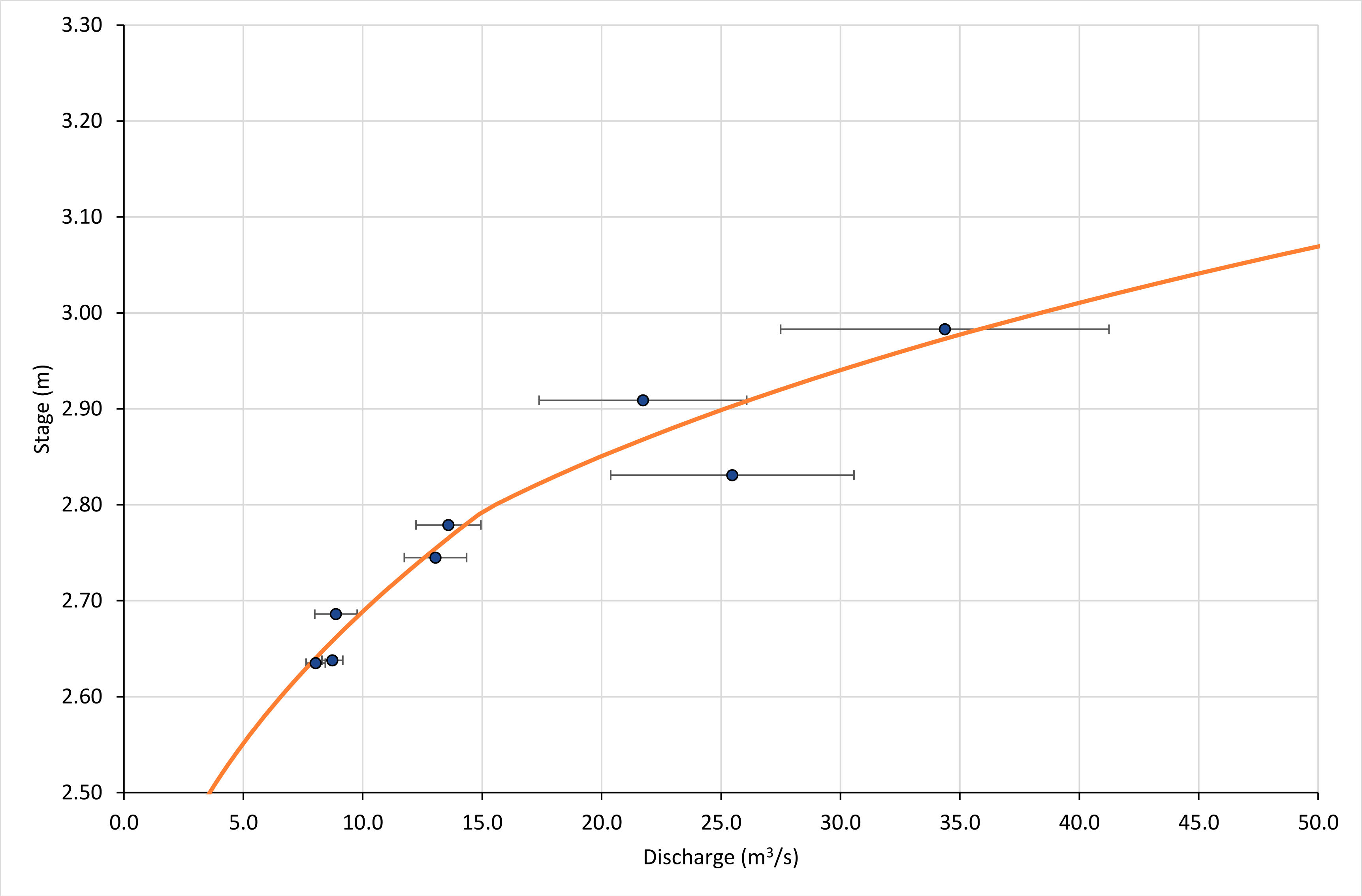


Figure 7. Wolf Creek Rating Curve, 2019.

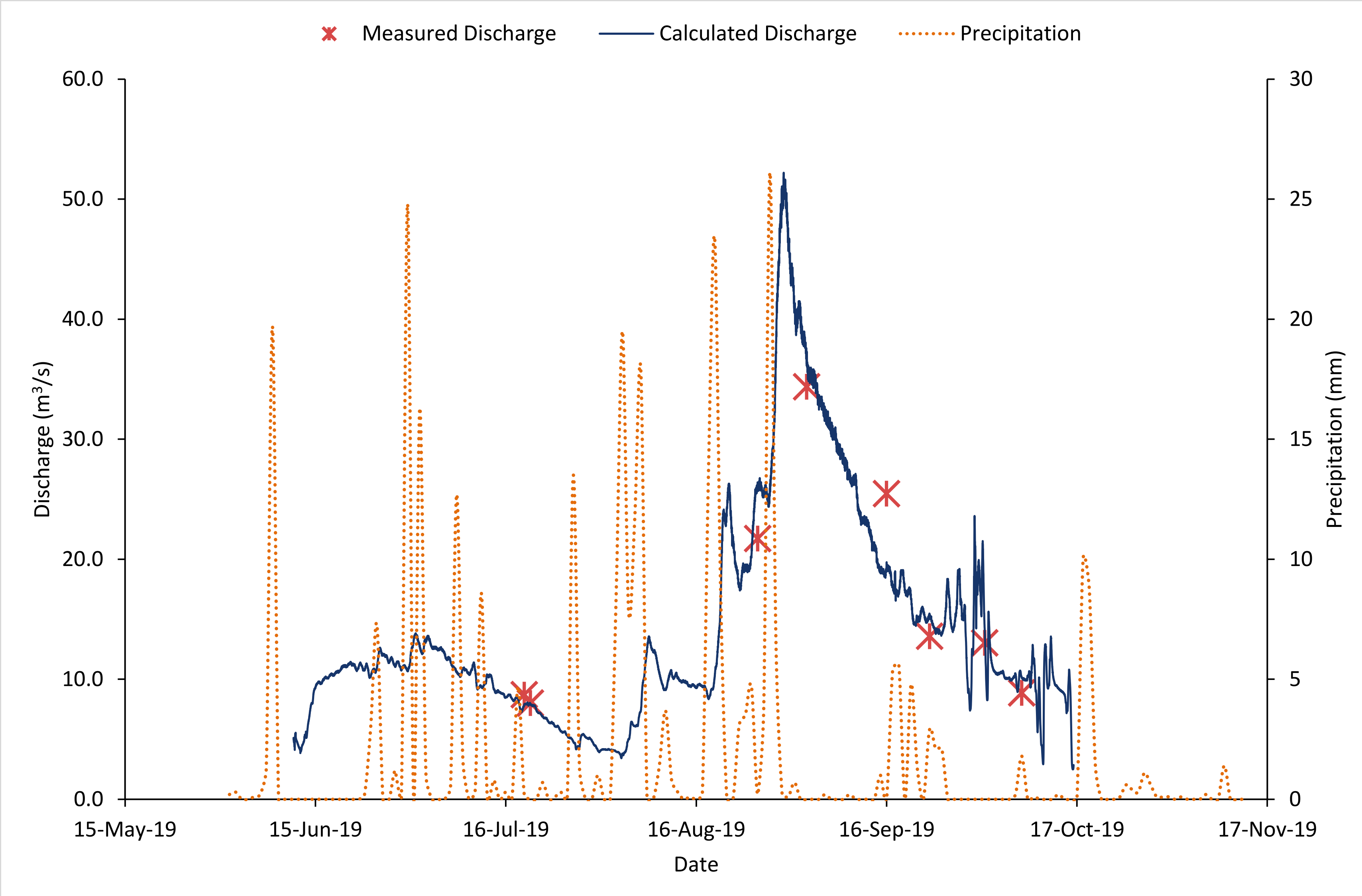
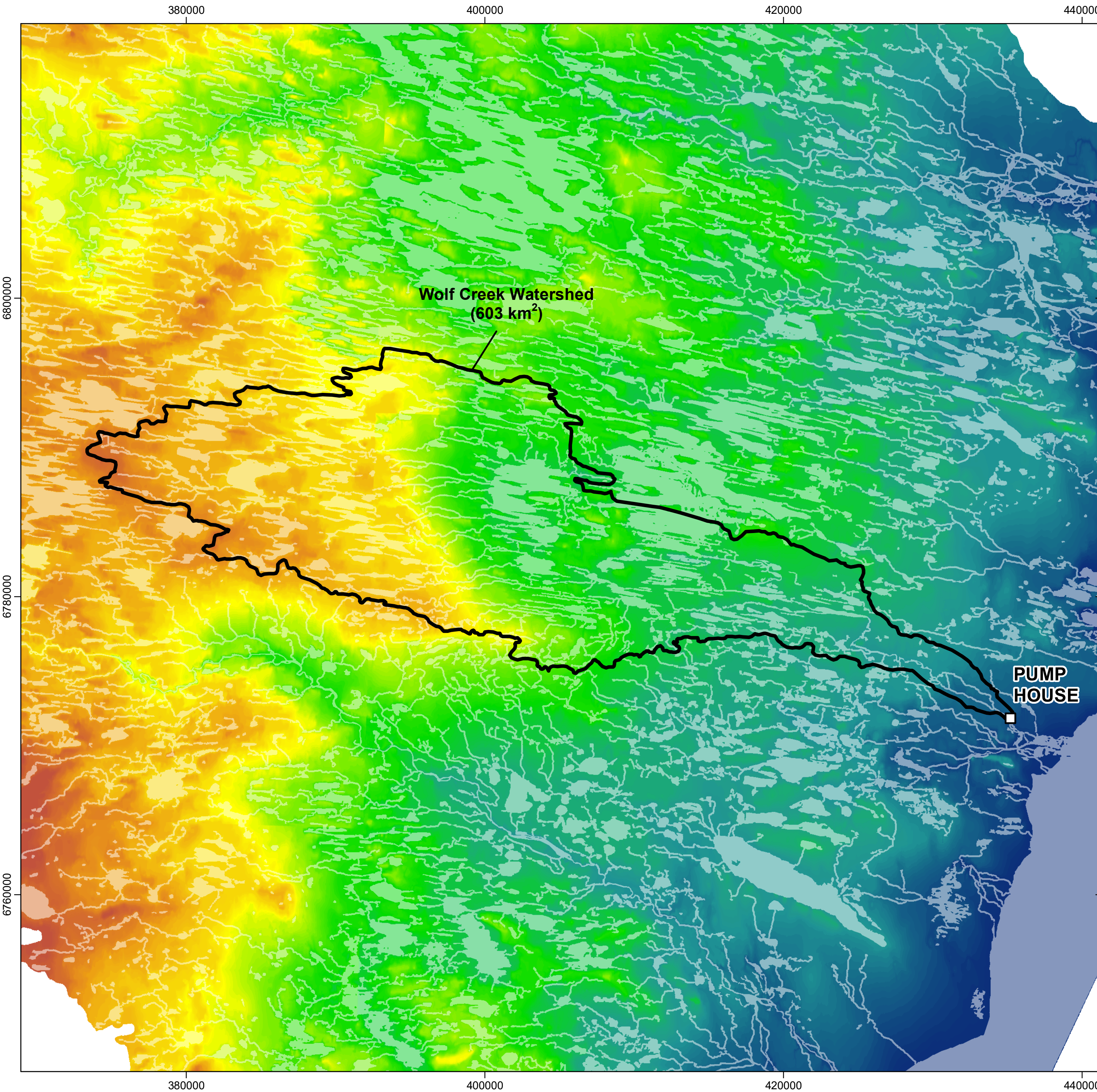


Figure 8. Wolf Creek Measured Streamflow Hydrograph and Daily Precipitation, 2019.



LEGEND:

Wolf Creek Watershed (603 km^2)

*Water features displayed as transparency

Elevation (masl)

120

0

Digital Elevation Model (CDEM) and water features (NHN, CanVec) provided by Natural Resources Canada.

0 5 10 15

kilometres

PROJECT NO.	1400340	REVISION:	1
DATE:	Dec 11, 2019	SCALE:	1:350000
DRAWN:	BE	DATUM:	NAD 1983
CHECKED:	CG	PROJECTION:	UTM zone 15

CLIENT: Associated Engineering

PREPARED BY: Palmer™

PROJECT: Arviat Hydrology Assessment

TITLE:

Wolf Creek Watershed

FIGURE 9

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4. Long-Term Streamflow Estimates

One year of hydrometric data are now available for the Wolf Creek gauging station. However, to support water supply planning, an understanding of the long-term average conditions and low flow conditions are required. Regional precipitation and streamflow data were reviewed.

Precipitation data for the 2018/2019 hydrologic year were compared to long-term average conditions at Arviat, Churchill and Rankin Inlet climate stations, as shown in Table 7, to assess whether 2018/2019 was wetter or dryer than average. The hydrologic year begins in October 2018, when snowfall typically begins. This snow accumulates and contributes to the 2019 freshet. Similarly, provisional 2019 streamflow data at two WSC gauging stations that report real-time data were compared to long-term average values, as shown in Table 8. There is considerable variability in the wetter/dryer trends, due to spatial variability of climatic conditions and differences in watershed characteristics. However, as a board summary, the following observations are noted, when compared to long-term average conditions:

1. Winter (Oct-May) streamflow and precipitation appear to be lower than average in 2019
2. Freshet (Jun-July) streamflow and precipitation appear to be close to average in 2019
3. Summer/Fall (Aug-Oct) streamflow and precipitation appear to be above average in 2019. Of note, precipitation at all three climate stations is well above average in August 2019

Table 7. Regional Climate Stations Precipitation.

Month	Arviat			Churchill			Rankin Inlet		
	1981-2010	2018-2019	% Diff	1981-2010	2018-2019	% Diff	1981-2010	2018-2019	% Diff
Oct.	25	M	-	48	12	-75%	38	25	-35%
Nov.	19	M	-	36	10	-73%	22	19	-11%
Dec.	18	M	-	18	16	-13%	13	8	-34%
Jan.	10	17	67%	19	11	-40%	9	19	114%
Feb.	7	3	-55%	17	4	-74%	8	2	-71%
Mar.	11	32	176%	18	3	-83%	12	21	69%
Apr.	13	20	59%	24	15	-35%	20	18	-9%
May.	18	9	-50%	30	8	-74%	20	37	92%
Jun.	30	58	97%	44	53	21%	27	27	2%
Jul.	37	64	74%	60	30	-50%	42	113	169%
Aug.	56	166	196%	69	153	120%	57	113	97%
Sept.	44	26	-40%	70	27	-62%	43	79	85%
Hydrologic Year	287	395*	38%	453	343	-24%	310	482	56%

Notes: all values reported as (mm) precipitation, values for 1981-2010 are mean monthly precipitation,
M = missing data, * = value based on an incomplete year.

Table 8. Regional Streamflow Trends.

Month	Kazan River			Hanbury River		
	1965-2016	2019	% Diff	1971-2017	2019	% Diff
Jan.	136.5	91.2	-33%	6.1	3.1	-48%
Feb.	107.5	61.1	-43%	5.0	5.7	15%
Mar.	100.5	56.7	-44%	4.6	6.4	40%
Apr.	112.7	75.2	-33%	4.8	6.3	33%
May.	175.7	81.8	-53%	13.8	4.5	-68%
Jun.	871.7	351.6	-60%	109.7	78.4	-29%
Jul.	1236.1	1077.0	-13%	76.3	94.2	23%
Aug.	902.0	1028.2	14%	41.7	43.9	5%
Sept.	659.1	696.5	6%	33.9	26.6	-22%
Oct.	**466.7**	629.5	35%	26.4	18.9	-29%
Nov.	305.1	-	-	14.1	14.2	0%
Dec.	202.4	-	-	8.4	11.7	40%
Annual	476.8	414.9	-13%	28.7	26.2	-9%

Notes: all values reported as m^3/s; 2019 data are Provisional and subject to revision

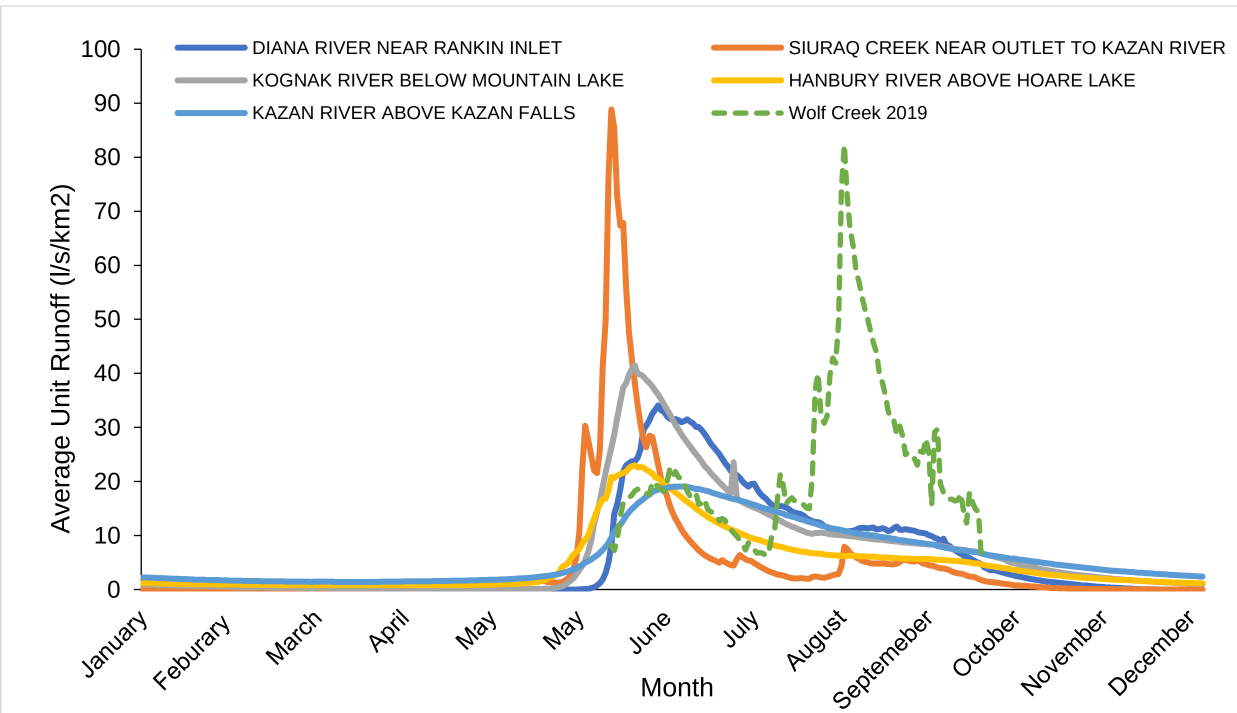

Figure 10. Long-term unit discharge at WSC Stations compared to 2019 Wolf Creek unit runoff.

Paucity of regional long-term hydrometeorological data that are concurrent with the measured site record, spatial variability of climatic conditions and differences in watershed characteristics make prediction of long-term streamflow conditions in Wold Creek difficult. Long-term average streamflow conditions were estimated by scaling the streamflow data, based on available hydroclimate data. Given the proximity of the Arviat climate station to the Wolf Creek watershed, it was selected as the basis for scaling. June and July flows were scaled based on the ratio of November to July precipitation (the period of snow accumulation plus rainfall in June and July) and August to October flows were scaled by the precipitation ratio for this period. Scaling factors are shown in Table 9 and the resulting estimated long-term average streamflow is summarized in Table 10.

Table 9. Long-Term streamflow Scaling Factors.

Period	1981-2010	2018-2019	% Diff
Freshet (Nov-July)	162	240	48%
Rain (Aug-Oct)	125	216	74%
Annual Average	287	456	59%

Notes: Average precipitation was assumed for the period of missing data (Oct-Nov)

Monthly low flow conditions with a 1-in-10 year return period were then calculated based on streamflow variability at Kognak River (06HD001). Kognak River was considered the most suitable surrogate given its proximity, length of complete record and comparable watershed area, relative to the available alternatives. The coefficient of variability (CV) which is the ratio of mean (µ) flow and standard deviation (σ), $CV=\sigma/\mu$, was calculated for each month based on the 14 years of record. Low flow conditions were then calculated for Wolf Creek assuming a normal distribution and are presented in Table 10.

Table 10. Estimated Long-Term Streamflow Conditions.

	Jan-May	Jun	Jul	Aug	Sep	Oct	Nov-Dec	Annual		
	Discharge (m^3/s)								Unit runoff (mm/yr)	Volume (m^3/yr)
Measured record (2019)	-	10.0	8.6	16.5	22.4	10.2	-	5.6	295	177,633,000
Mean Monthly Discharge	-	6.8	5.8	9.5	12.9	5.9	-	3.4	178	107,128,000
10-Year Low Monthly Mean	-	4.6	3.8	4.4	2.9	3.0	-	2.5	132	79,370,000

5. Climate Change

In the International Panel on Climate Change (IPCC) Climate Change 2014 Synthesis Report, it is noted that “In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate”. When making decisions about resource use and availability, it is clear that future climate conditions may be different to current conditions or those of the recent past.

The scenario often used to assess future climate change is Representative Concentration Pathways (RCP) scenario 8.5, which assumes minimal additional efforts to constrain emissions (’baseline scenarios’) (IPCC, 2014). It has been described by some as a “worst case” scenario, while others have suggested it may underestimate future conditions. For the Hamlet of Arviat, the ensemble means of three General Circulation Models (GCMs) for RCP8.5 and 2055 time horizon were reviewed from the Climate NA model (Wang et. al. 2016). Although there is clearly a spread in the predicted conditions, the climate models indicate increases in both temperature and precipitation by 2055 compared to the 1981-2010 mean values as presented in Figure 11 and Figure 12. The mean annual temperature is predicted by the three models to increase by approximately 4ºC to 6ºC by 2055. The mean December, January and February (DJF) temperatures rising by 3ºC to 8ºC and mean June, July and August (JJA) temperatures increasing by approximately 3ºC to 6ºC. An increase in mean annual precipitation was also predicted for the Arviat region by 2055, the average of which predicts an increase of 25% over 1981-2010 levels. The ensemble mean DJF precipitation is expected to increase approximately 10-17%, while the mean JJA precipitation is expected to increase by 6-20%.

The effects of the predicted increases in temperature and precipitation on the hydrology of Wolf Creek are not easy to determine. For instance, increases in precipitation may not necessarily lead to increases in runoff as they may be offset by higher evaporation rates driven by warmer temperatures. Along similar lines, a shorter winter season resulting from warmer temperatures may not lead to smaller spring freshet flows because higher winter precipitation may be enough to offset the shorter snow-accumulation period. Additionally, changes in permafrost conditions may change the timing and magnitude of runoff. However, the projected changes in temperature and precipitation tend to suggest that surface water availability in Wolf Creek will increase in the future, the magnitude of change and runoff response cannot be predicted with certainty.

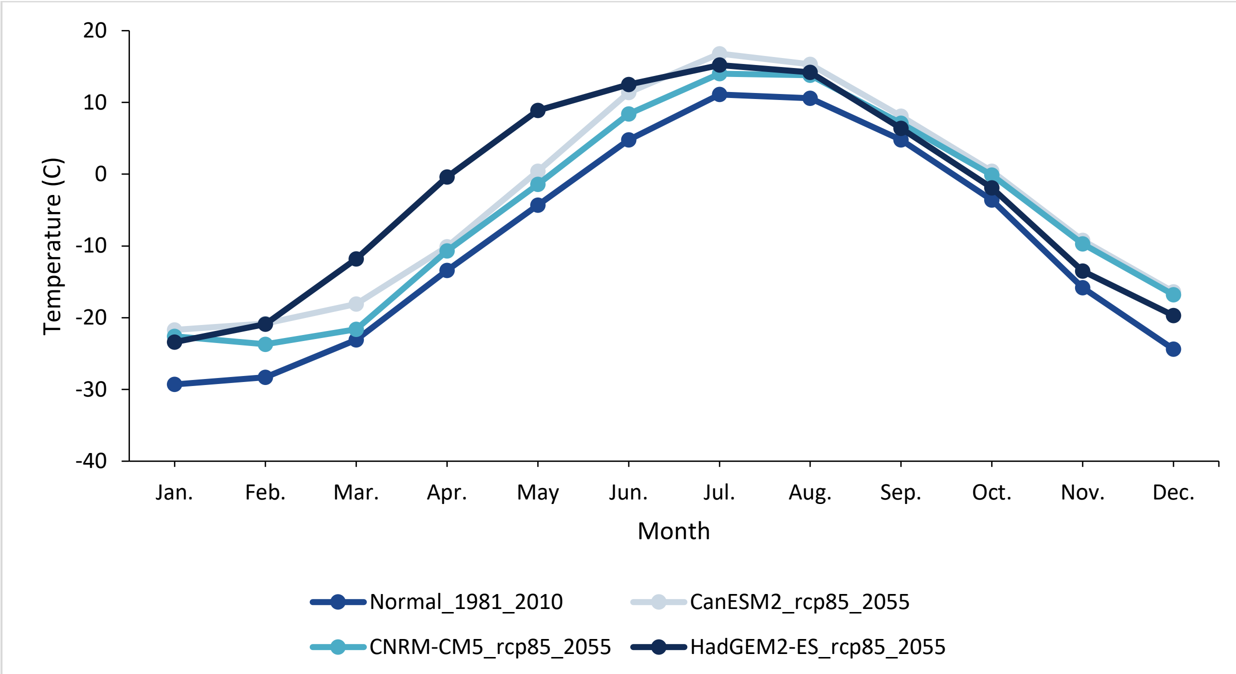

Figure 11. Mean Monthly Temperature Climate Normals and Predictions for Arviat.

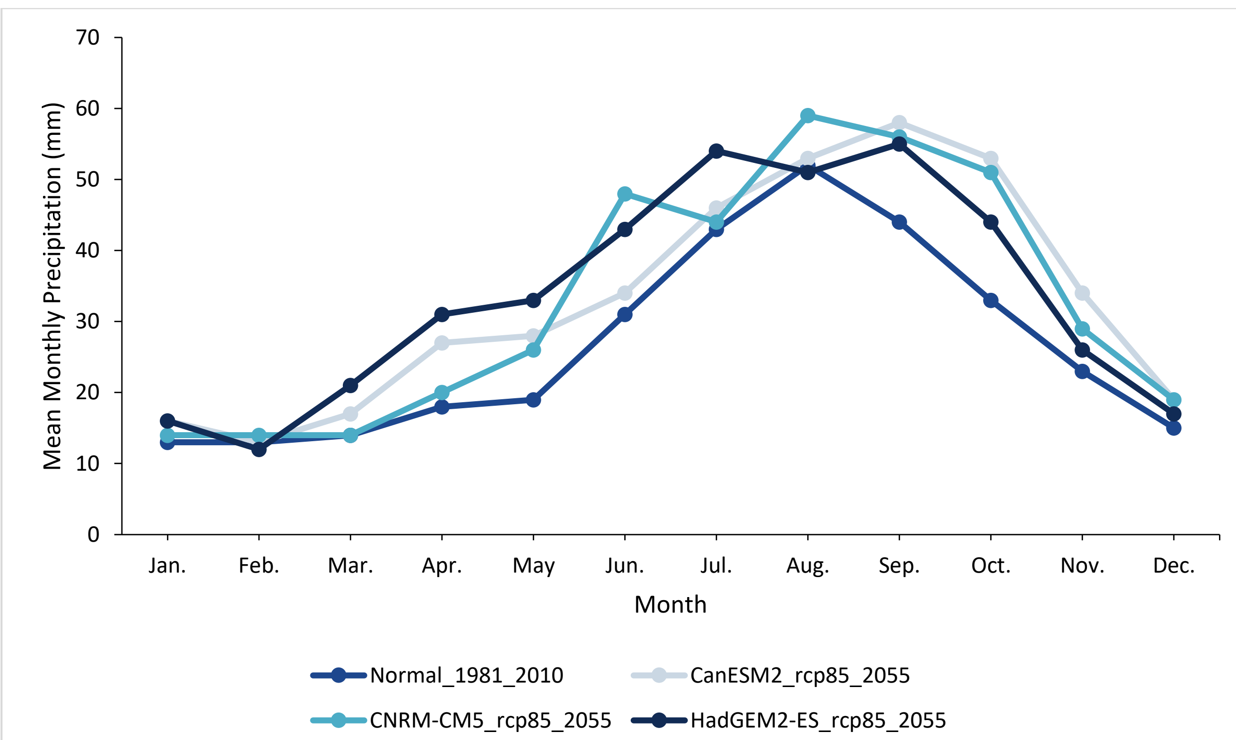

Figure 12. Mean Monthly Precipitation Climate Normals and Predictions for Arviat.

6. Discussion

The Hamlet of Arviat obtains its water supply from Wolf Creek approximately 8 km southwest of town. With the completion of a new reservoir cell, the water treatment facility has a storage capacity of approximately 232,965 m^3. In order to assess the suitability of Wolf Creek to provide the communities current and future water demands, a streamflow gauging station was established on Wolf Creek on May 9, 2019 and has operated through the 2019 open water season.

The measured 2019 flow has a unit runoff of 295 mm/year which is above the long-term average values determined for the available WSC stations (Table 3). The 2019 measured record was adjusted, based on the ratio of 2019 precipitation to long-term precipitation at the Arviat climate station. Ratios were calculated for two seasons; Freshet (November to July precipitation that contributes to runoff in June and July) and Rain (August to October precipitation that falls as rain and contributes to runoff in August to October). The estimated long-term unit runoff for Wolf Creek at the gauging station is 178 mm/year (107,128,416 m^3) which sits near the middle of the values presented in Section 2.2. However, it is noted that the predicted annual distribution of runoff is different to the available regional datasets, with the Wolf Creek hydrograph showing a relatively small freshet and high runoff during August and September. Continuation of the streamflow monitoring program is the best way to increase accuracy of the predicted conditions.

Climate change is predicted to result in substantial changes in temperature and precipitation. The projected changes tend to suggest that surface water availability in Wolf Creek will increase in the future, but the magnitude of change and runoff response cannot be predicted with certainty. Variability may increase, resulting in increases in average conditions, but with a wider range of conditions between years.

Palmer is not aware of the pumping scenarios that are being considered, but to provide context it has been assumed that 232,965 m^3 is diverted from Wolf Creek in one calendar month. The percentage of instream flow diverted is shown in Table 11.

Table 11. Water Diversion Volumes Compared to Average Water Availability.

	Jan-May	Jun	Jul	Aug	Sep	Oct	Nov-Dec	Annual
Mean Discharge (m^3/s)	-	6.8	5.8	9.5	12.9	5.9	-	3.4
Mean Volume (m^3 x10^6)	-	17.6	15.6	25.4	33.3	15.2		107.1
Volume Diverted (m^3 x10^6)		0.23	0.23	0.23	0.23	0.23		0.23
Percent Diverted		1.3%	1.5%	0.9%	0.7%	1.5%		0.2%

Given the limited streamflow record on Wolf Creek, paucity of regional datasets and uncertainty in potential future conditions, continuing data collection at the Wolf Creek gauging station would reduce uncertainty in the predicted streamflow conditions. Water supply options should provide appropriate resilience for potential future conditions, including potential changes in annual, seasonal and extreme flow events. However, the water treatment facility storage capacity of approximately 232,965 m^3 appears to be much less than water availability in Wolf Creek.

7. Certification

This report was prepared, reviewed and approved by the undersigned:

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President and CEO

8. References

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Wang T, Hamann A, Spittlehouse D, Carroll C (2016) Locally Downscaled and Spatially Customizable Climate Data for Historical and Future Periods for North America. PLoS ONE 11(6): e0156720. https://doi.org/10.1371/journal.pone.0156720

Appendix A

Photo Log

Project Name:	Project No.	Site Location:
Wolf Creek 2019 Hydrometric Monitoring Summary	14003401	Arviat, Nunavut

Photo #:	Date.
1	5/10/2019
Direction Photo Taken	

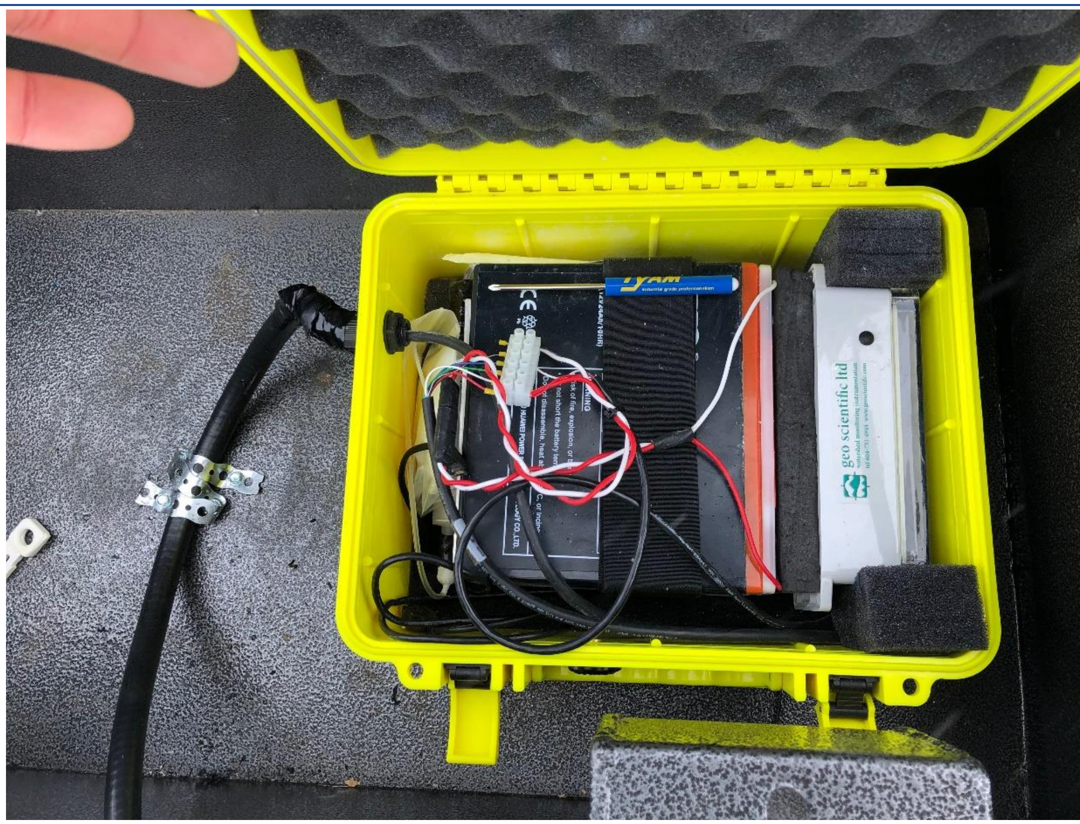
Description

Trench for installation of pressure sensor.

Photo #:	Date.
2	5/10/2019
Direction Photo Taken	

Description

Neon Data Logger secured in weatherproof casing, secured in metal bear bin.



Project Name:	Project No.	Site Location:
Wolf Creek 2019 Hydrometric Monitoring Summary	14003401	Arviat, Nunavut

Photo #:	Date.
3	7/19/2019
Direction Photo Taken	

Description

Wolf Creek pumping station staff gauge.

Photo #:	Date.
4	7/20/2019
Direction Photo Taken	

Description

Discharge measurement on transect site. Local technician Hallauk Karetak.

Photograph Log

Project Name:	Project No.	Site Location:
Wolf Creek 2019 Hydrometric Monitoring Summary	14003401	Arviat, Nunavut

Photo #:	Date.
5	7/20/2019
Direction Photo Taken	EWNS

Description

Wolf Creek pumping station staff gauge.

Photo #:	Date.
6	7/20/2019
Direction Photo Taken	EWNS

Description

Pressure transducer data logger bear bin.

Photograph Log

Project Name:	Project No.	Site Location:
Wolf Creek 2019 Hydrometric Monitoring Summary	14003401	Arviat, Nunavut

Photo #:	Date.
7	7/20/2019
Direction Photo Taken	

Description

Transect site location relative to pumphouse.