Hamlet of Pangnirtung – Hydrological Desktop Study

Hamlet of Pangnirtung

Type of Document:
Hydrological and Water Balance Desktop Study Report – Hamlet of Pangnirtung

Project Name:
Hydrological Desktop Study – Hamlet of Pangnirtung

EXP Project Number:
FRE-22019494-A0

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Date Submitted:
2022-09-21

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1 Introduction

1.1 Overview

EXP was retained by the Hamlet of Pangnirtung to complete a coarse-resolution hydrological and water-balance desktop study for the Hamlet of Pangnirtung to determine if the existing water source (Duval River) and watershed is sustainable to provide enough water each year to meet the current and future needs for the community over a 30-year horizon.

It is anticipated that this initial desktop study will be used to develop a more comprehensive field program to further investigate the flow characteristics and regime of the Duval River.

1.2 Objectives

Arctic community water supply systems have several components that are vulnerable to changing conditions such as capacity of the existing water infrastructure (water storage, distribution, treatment) and variability in streamflow. The main objective of this study is to complete a hydrological and water balance study to assess the suitability of the community's current source watershed and its ability to provide enough water to meet the current and future needs of the community over a 30-year horizon to the year 2054. The specific tasks of this study include:

- Review of existing background information.
- Climate characterization and potential impacts on water supply from climate change.
- Summary of the hydrologic regime of the system.
- Water balance study considering the ecologic characteristics of the source. This includes defining any regulatory requirements that may impact water use volumes.
  - Watershed characterization and coarse resolution analysis to characterize annual watershed yield versus expected water use of the community and accounts for annual municipal water supply usage, population growth and potential impacts of climate change.
- Review of existing discharge and stream flow data for the Duval River water source.
- Recommendations on if the current water source will be sustainable for the community for a 30-year horizon.
- Note that this desktop study does not include any field investigations.

Based on the Hamlet's current Type A Water Licence (# 3AM-PAN1828), EXP understands that a future study is required to ultimately detail discharge volume/velocity, drawdown rates, erosion, sedimentation, water quality, and variability of discharge into the Duval River. It is anticipated that this initial desktop study will be used to develop a more comprehensive field program to further investigate the flow characteristics and regime of the Duval River (e.g. flow rates, installation of flow gauges, timing dates of flow/melt period, topographic survey, water quality analyzes).

2 Previous Hydrological Investigations

2.1 Hydrological Analysis of Municipal Source Water Availability in the Canadian Arctic Territory of Nunavut (Hayward, J., Johnston, L., Jackson, A. and Jamieson, R., 2020)

A desktop study in 2020 provides a screening level vulnerability assessment of municipal drinking water supplies for the communities in Nunavut with consideration to climate change, population growth, and infrastructure changes. Water balance models were used to predict the annual water yield for each watershed using historical and projected climate data. The study only focuses on the ability of the source watershed to supply annual water volumes and did not include an analysis of storage infrastructure or seasonal water availability. Findings from the study include:

- Overall increasing trends in evapotranspiration (22 out of 24 communities)
- Statistical precipitation trends for Pangnirtung were inconclusive due to limited data availability
- Based on the worst-case scenario of 50-year return period minimum precipitation and maximum evapotranspiration (ET), the following vulnerability threat levels were identified for historical, 2016-2040 and 2041-2070 timelines:
  - Pangnirtung
    - Water shortage vulnerability for the current water source (Duval River) was considered low for all three timeline scenarios (historical, 2016-2040 and 2041-2070)
    - Duval River watershed area was estimated as 9,270 ha (92,700,000 m^2)
- Most influential factor regarding water supply vulnerability threat levels appears to be the size of the source watershed

2.2 Water Resources Development for High Arctic Communities (Suk, 1975)

A Master's thesis from McMaster University in 1975 titled "Water Resources Development for High Arctic Communities" included a field campaign that measured the flow rates and discharge of the Duval River in Pangnirtung over the 1974 season. Findings from this document will be discussed in Section 5 of the report.

2.3 Water Survey of Canada – Duval River, Pangnirtung (1973 to 1983)

Between 1973 and 1983, the Water Survey of Canada monitored and recorded daily discharge for the Duval River near Pangnirtung (Station 10UF001 – 66° 04' 03" N, 65° 41' 10" W). This information has been reviewed and will be discussed in Section 5 of the report.

3 Background

3.1 Community and Existing Water Supply System

3.1.1 Pangnirtung

The Hamlet of Pangnirtung is located at 66°08′ N latitude and 65°41′ W longitude on the eastern side of Baffin Island in Nunavut. The core community lies on the western side of Cumberland Peninsula and on the southeast side of Pangnirtung Fiord. The municipal boundary covers an area of approximately 7.5 km^2 and is within Northern Arctic and Arctic Cordillera terrestrial ecozones (Figure 3-1).

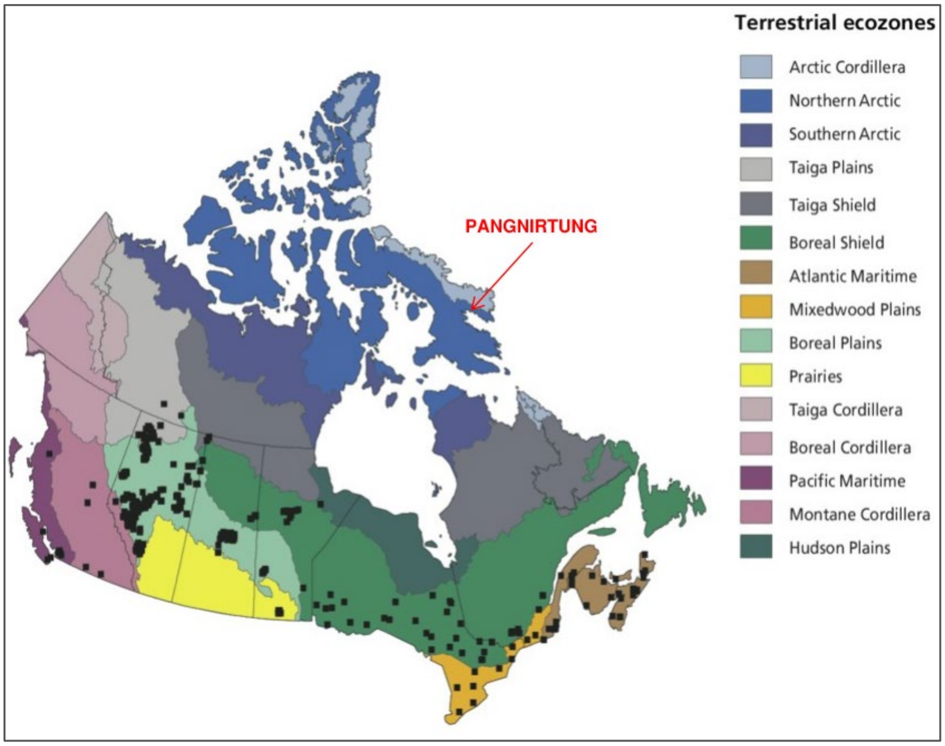

Figure 3-1: Pangnirtung and Terrestrial Ecozones of Canada

The Duval River is the main drinking water source for the Hamlet of Pangnirtung which runs through the community (Figure 3-2). The river is typically frozen from October to June each year.

A water storage reservoir originally constructed in the mid 1980's is located approximately 100 m east of the Duval River and is used for the Hamlet's annual storage. The reservoir has a nominal capacity of 120,000 m^3; current annual water use is in the order of approximately 50,000 to 60,000 m^3. The reservoir is 40 m X 140 m along the bottom and 125 m X 225 m along the top. The 10 m depth includes an ice allowance of 1.8 m which reduces the effective storage to about 71,000 m^3 for the eight- to ten-month period of ice cover (over-winter storage) (EXP, 2018).

The reservoir is filled at the beginning of each summer when the Duval River is flowing. The current Water Licence (#3AM-PAN1828) limits withdrawal of water from the Duval River to the months of July and August. Water is drawn from the Duval River via a wheel-mounted pump and a 200 mm diameter high density polyethylene (HDPE) fill pipe. The pump and pump-suction intake are only in place during the duration of the reservoir filling. Following the filling operation, the pump and pump suction are then drained, winterized and returned to storage.

The existing water treatment plant is located just to the east of the reservoir. Following treatment, a fleet of water delivery vehicles brings water from the water treatment plant and distributes it to residents.

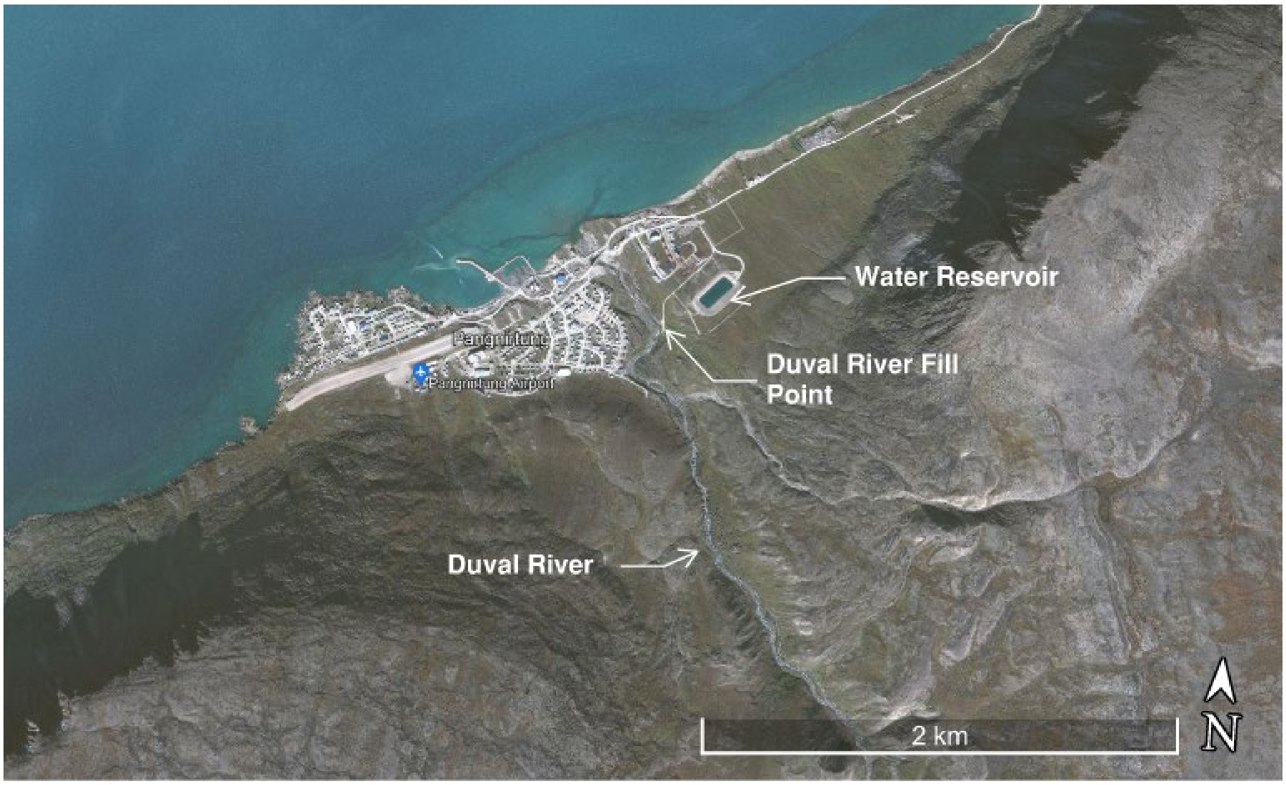

Figure 3-2: Map of Pangnirtung and Duval River

3.2 Methodology

3.2.1 Catchment and Basin Physiography

This study focuses on a coarse-resolution analysis to characterize annual watershed yield versus expected water use of the community and accounts for annual municipal water supply usage, population growth and potential impacts of climate change.

3.2.2 Watershed Delineation

- High Resolution Digital Elevation Models (HRDEM – CanElevation Series) were downloaded from the Natural Resources Canada website and were used to delineate the various watersheds. Digital Surface Model (DSM) datasets were provided at 2 m resolution using the Polar Stereographic North coordinate system referenced to WGS84 horizontal datum or UTM NAD83 (UTM Zone 20N)
- Watersheds were delineated using ERSI ArcGIS Pro. Spatial Analyst Tool (Hydrology Tools) within the ArcGIS Pro software were used to preprocess the DEMs/DSMs prior to analysis. The flow direction, flow accumulation and watershed delineation tools were used to delineate each watershed for a specific extraction point (i.e., extraction point for the water source)

3.2.3 Water Supply Modelling

3.2.3.1 ***Water Balance Formulation***

Water budgets (as volumes) were computed on an annual basis assuming steady conditions with respect to storage within the watershed. Water volumes are removed (losses) from the watershed through community water usage and evapotranspiration (ET). Water volumes are recharged (inputs) into the watershed through annual precipitation.

The change in annual storage volume equation (water balance) within a watershed is given as:

$$\Delta S = \frac{(P - ET)}{1000} \times Area_w - U$$

Where:

- ΔS = change in annual storage volume (m^3/year)
- P = annual total precipitation as rain or snow (mm/year)
- ET = annual evapotranspiration rate (mm/year)
- $Area_w$ = catchment area of the watershed (m^2)
- U = annual water usage of the community (m^3/year)

If $\Delta S > 0$, precipitation (input) exceeds ET and water use (losses) in the watershed and the annual net balance is positive.

If $\Delta S < 0$, precipitation does not exceed ET and water use in the watershed and the annual net balance is negative.

This approach assumes no cross-boundary sub-surface water flow and treats one drainage basin. Each drainage basin is a single unit and recognizes no ET spatial distribution within the basin.

Percolation due to groundwater is assumed to be negligible due to underlain permafrost. The equation above assumes that the entirety of the precipitation entering the watershed experiences evapotranspiration.

Underestimation of precipitation due to snow undercatch and water losses due to sublimation were not accounted for in the calculation. Actual basin snow amounts are usually larger than measured values (at weather stations) which suffer from gauge undercatch and thus the use of snow gauge data was deemed as a conservative approach for this study. Estimates for snow undercatch can range from 10% to 75% depending on gauge type and wind conditions. Sublimation losses have not been characterized. Characterization of these processes requires detailed meteorological data.

3.2.3.2 ***Population Projections, Daily Water Consumption and Annual Water Use Rates***

Population projections for the Hamlet of Pangnirtung up to 2035 have been provided by the Nunavut Bureau of Statistics (2014). The average population growth rate of 1.21% from 2014 to 2035 was used to project populations to the design horizon year of 2054.

The 2020 Nunavut Draft Guideline Document “Water Treatment Plant Design” and Standardized Treatment Train (SWTT) guideline states a minimum per capita average day water consumption rate of 120 litres per capita per day (lpcd) for water treatment plant design for truck fill communities.

Annual historical water use records were reviewed between 2002-2018 to determine the actual recorded average daily consumption. Note that records were missing for the years 2004, 2005, 2007, 2008 and 2009. For the Hamlet of Pangnirtung between 2008-2020, average daily consumption was recorded as 76 lpcd. The maximum recorded average daily demand occurred in 2003 and was 98 lpcd. Historical recorded daily demands for the Hamlet are typically lower than the design value of 120 lpcd. Thus, the design value of 120 lpcd has been used as a conservative value to estimate the annual water use rates for the water balance calculations. Population projections and projected annual water use rates for Pangnirtung to 2054 are provided in Table 3-1.

Table 3-1: Pangnirtung Population Projections and Projected Annual Water Use Rates

Year	Population	Projected Water Use (m^3/year) *		Year	Population	Projected Water Use (m^3/year) *
2021	1,789	78,358		2038	2,151	94,224
2022	1,810	79,278		2039	2,177	95,364
2023	1,829	80,110		*2040*	2,204	96,518
2024	1,847	80,899		2041	2,230	97,686
2025	1,866	81,731		2042	2,257	98,868
2026	1,885	82,563		2043	2,285	100,064
2027	1,906	83,483		2044	2,312	101,275
2028	1,934	84,709		2045	2,340	102,501
2029	1,953	85,541		2046	2,369	103,741
2030	1,973	86,417		2047	2,397	104,996
2031	1,992	87,250		2048	2,426	106,267
2032	2,012	88,126		2049	2,456	107,552
2033	2,034	89,089		2050	2,485	108,854
2034	2,055	90,009		2051	2,515	110,171
2035	2,075	90,885		2052	2,546	111,504
2036	2,100	91,985		2053	2,577	112,853
2037	2,126	93,098		**2054**	**2,608**	**114,219**

** Water use based on design value of 120 lpcd*

3.2.3.3 *Meteorology / Precipitation Data*

- Historical data was downloaded from the Environment and Climate Change Canada website to calculate annual total precipitation at a given weather station
  - Total precipitation includes the input of snowfall and rainfall
  - 28 years of climate data was used for Pangnirtung during the periods of 1931-1939 and between 1996-2021 and have been summarized in Table 3-2 and attached in Appendix B.

- Minimum, maximum, median, average, 3-year low, 5-year low, 10-year low and 3-year high values (mm/year) were calculated for each complete precipitation dataset.
  - At many of the weather stations near to Pangnirtung, there are significant gaps in the collected data and concerns about the accuracy of measurements. If a yearly dataset had three or more months of missing data, this dataset was omitted.

Table 3-2: Summary of Estimated Total Annual Precipitation (Snow + Rain) for Pangnirtung

	Annual Total Precipitation (mm/year)
Minimum (mm/year)	212
Maximum (mm/year)	585
Median (mm/year)	352
Mean (mm/year)	341
3-year low average	219
5-year low average	226
10-year low average	258
3-year high average	515
5-year high average	469

LeBlanc et al. (2010) noted that annual precipitation for the Hamlet for the period of 1925 to 1950 was 336 mm. From the 1950's to the early 1990's, the average annual precipitation was 395 mm. This is comparable and consistent with the annual precipitation values calculated above.

30-year Climate Normal Datasets (1981-2010) are available on the Environment and Climate Change Canada website for select communities in Nunavut and have been provided to compare average annual precipitation values and trends. Iqaluit (300 km away from Pangnirtung) has more available and continuous weather records compared to the Pangnirtung weather stations and provides a snapshot of the precipitation values and trends that are experienced in similar North Arctic environments. Average monthly precipitation data using the 30-year Climate Normal datasets for Iqaluit are summarized in Table 3-3.

Table 3-3: Climate Normals Precipitation between 1981-2010 for Iqaluit, Nunavut

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Rainfall (mm)	0.0	0.0	0.0	0.2	3.1	23.8	51.9	68.6	42.2	6.8	0.6	0.0	197
Snowfall (mm)	21.7	21.0	21.6	31.5	27.6	9.3	0.0	0.9	13.2	29.4	29.7	23.4	229
Precipitation (mm)	19.7	18.7	18.7	27.5	29.2	33.0	51.9	69.5	55.2	33.3	27.2	19.9	404

3.2.3.4 ***Precipitation Projections for Water Balance Calculations***

Snow and rainfall contribute to the precipitation inputs for the water balance calculations. However, as raw water extraction only occurs up until the end of August, rainfall that occurs from September onwards is not available to the watershed and must be omitted from the available inputs.

LeBlanc et al. (2010) also noted that during the period between the 1950s and 1990s, 44% of the annual precipitation occurred as rain typically between June and September. Between 1996 and 2007, the portion of precipitation occurring as rainfall showed increasing trends. During this period, the Hamlet received an average of 200 mm of precipitation (rainfall) during the summer months which equated to approximately 54% of the annual total precipitation.

Based on best available climate information, the following assumptions have been used to estimate the available total precipitation for the water balance studies:

- 40% of the total annual precipitation occurs as snowfall. It is assumed that the entire portion of snowfall is available and provides positive inputs into the watershed as snowmelt
- The remaining 60% of the total annual precipitation occurs as rainfall between June and September
- Based on the 30-year Climate Normals datasets for Iqaluit, it is assumed that for Pangnirtung, approximately 70% of the rainfall occurs before September (i.e. months of June, July and August).

The precipitation available to the Duval River watershed has been estimated based on these assumptions and is summarized in Table 3-4 below.

Table 3-4: Summary of Estimated Available Precipitation for Duval River Water Balance Studies

	Annual Total Precipitation (mm/year)	Annual Snowfall (mm/year) *	Annual Rainfall (mm/year) **	Available Rainfall for Extraction (mm/year) ***	Total Inputs for Calculations (mm/year) ****
Minimum (mm/year)	212	85	127	89	**174**
Maximum (mm/year)	585	234	351	246	**480**
Median (mm/year)	352	141	211	148	**289**
Mean (mm/year)	341	137	205	143	**280**
3-year low average	219	88	131	92	**179**
5-year low average	226	90	136	95	**185**
10-year low average	258	103	155	108	**212**
3-year high average	515	206	309	216	**422**
5-year high average	469	188	281	197	**385**

* 40% of total precipitation

** 60% of total precipitation

*** rainfall occurring before September = 70% of annual rainfall

**** Total Inputs = Annual Snowfall + Available Rainfall for Extraction

3.2.3.5 ***Evapotranspiration***

Evapotranspiration (ET) is the primary mechanism for water loss from a watershed underlain by permafrost. However, sparse data is available regarding actual ET rates for the study community of Pangnirtung and for the Arctic geography as a whole.

For this assignment, a literature review was completed using past research that investigated annual ET in geographies above 60°N latitude and specifically for the terrestrial ecozones of the Arctic Cordillera and the Northern Arctic. This information includes ET data for intermittent river and ephemeral stream systems. These values have been listed in Table 3-5 below.

Table 3-5: Reported Annual ET Rates (mm/year) in Arctic Environments

Location	Lat (°N)	Long (°W)	Year	Reported Annual ET Rate (mm/year)	Reference Paper
Cape Dorset, NU	64.2	76.5	2016	63	1
Naujaat, NU	66.5	86.2	2016	65	2
Resolute, NU	74.7	95.0	1978 (July 1 - Aug 31)	61	3
			1979 (July 1 - Aug 26)	52	
			1976 (May - Sept)	39	
			1978 (May - Sept)	46	
Axel Heiberg Island, NU	79.8	91.3	1969 (June 20 - Aug 31)	85	5
			1970 (June 1 - Aug 14)	86	
			1972 (June 28 - Aug 22)	82	
McMaster River Basin, Cornwallis Island, NU	75.1	95.1	1976-1981	30-51	3
Ellesmere Island, NU	80.8	72.7	1975 (July 6 - Aug 17)	27	3
Heather Creek, Ellesmere Island, NU	80.0	84.5	1990-1991	86	4
Hot Weather Creek, Ellesmere Island, NU	80.0	84.5	1997	56	5
Devon Island, NU	76.0	85.0	1972-1974	81	4
Bathurst Island, NU	75.7	98.7	2008-2010, 2012	103	4
Melville Island, NU	74.9	109.5	2007-2009	81	4
Ross Point, Melville Island, NU	74.0	107.0	1986	43	4

[1] Centre for Water Resource Studies (2017). Wetland Treatment Area Study in Cape Dorset, Nunavut. Dalhousie University, Halifax, NS, January 2017.
[2] Centre for Water Resource Studies (2017). Wetland Treatment Area Study in Naujaat, Nunavut. Dalhousie University, Halifax, NS, January 2017.
[3] Kane, D.L., Gieck, R.E., & Hinzman, L.D. (1990). Evapotranspiration from a Small Alaskan Arctic Watershed. *Nordic Hydrology, 21, 253-272.*
[4] Young, K.L., Lafrenière, M.J.m Lamoureux, S.F., Abnizova, A. & Miller, E.A. (2015). Recent multi-year streamflow regimes and water budgets of hillslope catchments in the Canadian High Arctic: evaluation and comparison to other small Arctic watershed studies. *Hydrology Research, 46(4), 533-550.*
[5] Young, K.L. & Woo, M.K. (2004). Queen Elizabeth Islands: water balance investigations. *Northern Research Basins Water Balance, 290, 152-163.*

Minimum, maximum, median, average and 3-year high annual ET values for the water balance study have been calculated using these literature values and have been presented in Table 3-6, below.

Table 3-6: Calculated ET Values Used for Water Balance Calculations

ET Parameter	ET (mm/year)
Minimum ET	27
Maximum ET	103
Median ET	63
Average ET	65
3-year high ET	86

As a comparison, in a study completed by Wang et al. (2013), mean annual ET values were modeled for the 15 ecozones in Canada over the period of 1979-2008. In both the Arctic Cordillera and northern Arctic ecozones, mean annual ET values were noted to be less than 100 mm/year.

ET rates greatly decrease with increasing latitude because of the decrease of solar irradiance and air temperature. The annual surface irradiance in the Northern Arctic is approximately 2500 MJ•$m^{-2}yr^{-1}$ which is almost 60% less than communities in the south (Wang et al., 2015). Typically, communities further south (below 60°N latitude) experience higher ET values, which illustrates that the chosen ET values for the Northern Arctic communities are appropriate for the conservative approach applied for the purposes of this screening study.

3.2.3.6 *Water Balance Scenarios*

For the water balance calculations, fifteen (15) scenarios were analyzed. Taking a conservative approach, the fifteen analyzed scenarios use below average values for precipitation (inputs) and above average values for evapotranspiration (losses). The worst-case would be represented as Scenario 1, with minimum precipitation and maximum ET.

Table 3-7: Scenarios for Water Balance Calculations

Scenario No.	Precipitation Scenario	ET Scenario
1	minimum	maximum
2	minimum	3-year high
3	minimum	average
4	3-year low	maximum
5	3-year low	3-year high
6	3-year low	average
7	5-year low	maximum
8	5-year low	3-year high

9	5-year low	average
10	10-year low	maximum
11	10-year low	3-year high
12	10-year low	average
13	median	maximum
14	median	3-year high
15	median	average

4 Results

4.1 Pangnirtung – Duval River

4.1.1 Watershed Delineation

The catchment/watershed area for Duval River is shown in Figure 4-1 below (Appendix A). Table 4-1 presents the delineated watershed area for the Duval River.

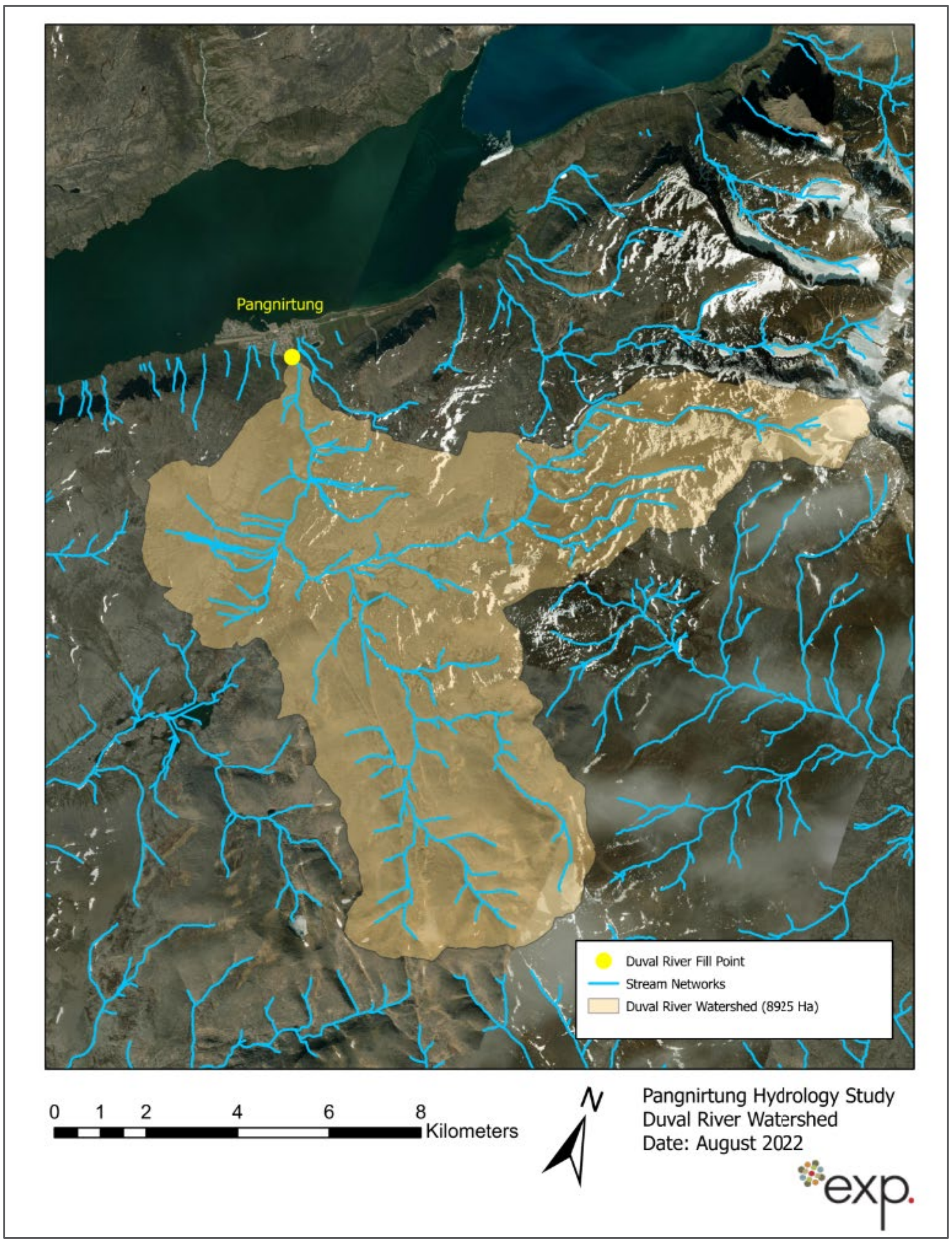

Figure 4-1: Pangnirtung - Duval River Watershed

Table 4-1: Duval River Delineated Watershed Areas

Water Source	Watershed Area (m^2)	Watershed Area (km^2)	Watershed Area (ha)
Duval River	89,250,000	89.25	8,925

4.1.2 Water Balance and Water Source Assessment

The results showing the amount of potential annual runoff for the Hamlet of Pangnirtung are presented in Table 4-2.

Table 4-2: Pangnirtung - Duval River Potential Runoff Analysis

Scenario No.	Precipitation Scenario	ET Scenario	Precipitation (mm/year)	Estimated ET (mm/year)	Potential Runoff (mm/year)
1	minimum	maximum	174	103	71
2	minimum	3-year high	174	86	88
3	minimum	average	174	65	109
4	3-year low	maximum	179	103	76
5	3-year low	3-year high	179	86	93
6	3-year low	average	179	65	114
7	5-year low	maximum	185	103	82
8	5-year low	3-year high	185	86	99
9	5-year low	average	185	65	120
10	10-year low	maximum	212	103	109
11	10-year low	3-year high	212	86	126
12	10-year low	average	212	65	146
13	Median	maximum	289	103	186
14	Median	3-year high	289	86	203
15	Median	average	289	65	223

The results of the water balance analysis for the Duval River watershed are presented in Table 4-3.

If the annual precipitation volume is greater than or equal to the annual losses (annual ET plus community water use), the water supply sufficiently meets the needs of the community. Based on the assessment, in all scenarios, the annual precipitation experienced over the Duval River watershed sufficiently meets the community current and future water supply needs.

Table 4-3: Pangnirtung - Duval River Water Balance Analysis

PANGNIRTUNG		DUVAL RIVER	
Scenario No.	2054 Water Use (m^3/year)	Runoff Volume (m^3/year)	ΔS > 0
1	114,219	6,315,152	YES
2	114,219	7,832,402	YES
3	114,219	9,696,152	YES
4	114,219	6,822,568	YES
5	114,219	8,339,818	YES
6	114,219	10,203,568	YES
7	114,219	7,335,350	YES
8	114,219	8,852,600	YES
9	114,219	10,716,350	YES
10	114,219	9,683,857	YES
11	114,219	11,201,107	YES
12	114,219	13,064,857	YES
13	114,219	16,561,052	YES
14	114,219	18,078,302	YES
15	114,219	19,942,052	YES

5 Discussion

5.1 Hydrologic Regime

The Duval River watershed is associated with snowfall and snowmelt-generated runoff, which characterizes an Arctic nival regime streamflow. The Duval River catchment was calculated at approximately 89,250,000 m^2 (89.25 km^2 or 8,925 ha). The river begins at an elevation of approximately el. 1200 m in mountainous ice fields. From the ice fields, the water flows into a large plain that contains tundra vegetation – the last section of the river that flows through the community and out into Pangnirtung Fiord is comprised of steep and channelized banks (Suk, 1975).

These nival regimes are characterized by very low or negligible winter flows (typically from October to early May). Snowmelt represents the major source of runoff with additional inputs from rainfall during the summer months. Evapotranspiration is the main hydrological loss and is apparent for a couple of months after snowmelt until soil moisture declines. Evapotranspiration is greatest following the snowmelt (typically around late June/early July) and decreases substantially throughout the summer except for lesser events caused by precipitation.

Runoff ratio, the ratio between runoff and precipitation, are typically high for polar deserts, oases and glacierized basins (Young and Woo, 2004). In the late spring/summer, high solar radiation causes rapid snowmelt where a large portion of the annual runoff flow occurs within a few weeks period (can typically be in the order of greater than 80%). It is expected that flows (and peak flow) will lag the initial snowmelt event as integrated channel networks are established by collecting runoff from upstream hillslopes and valleys. Year-to-year variability in peak flow can be substantial and timing and duration of the melt season depends on the rainfall events (intensity and duration), weather and end-of-winter snow conditions. After snowmelt, flow generally declines. The presence of permafrost at shallow depths prevents infiltration and limits storage capacity.

Limited field data is available for the Duval River. However, the Water Survey of Canada investigated flow and discharge rates for the river over a ten-year period between 1973-1983. This information has been reviewed and is discussed in Section 5.2.5 below.

5.2 Pangnirtung

5.2.1 Water Balance Scenarios and Outcomes

Based on the water balance assessment, under all fifteen scenarios, the Duval River water source and watershed provides sufficient water quantities to meet the community's current and future water supply needs. The catchment area of the Duval River watershed is relatively large at approximately 89,250,000 m^2 (89.25 km^2 or 8,925 ha) and any net-positive annual runoff for the Duval River watershed will provide sufficient water supply to meet the community's needs.

In a study investigating vulnerability levels of municipal drinking water supplies for the communities in Nunavut, Hayward et al. (2020), it was stated that the most influential factor regarding water supply vulnerability threat levels appears to be the size of the source watershed. The same study noted a low-level water supply vulnerability threat for Pangnirtung based on the worst-case scenario assessment (minimum precipitation and maximum ET scenario) which is consistent with the results from this assessment.

As discussed previously, the maximum ET rate used in the water balance assessment is likely overestimated (conservative) as seasonal recharge caused by snow melt occurs over a short period in the summer and is substantial enough to produce a flowing stream – this short duration of flow reduces the amount of time that the runoff is exposed to evapotranspiration and is represented by the high runoff ratio (ratio between runoff and precipitation) that is seen in polar deserts. During the cold season, precipitation storage is in the form of snow and ice and undergoes negligible evapotranspiration.

5.2.2 Climate Change Considerations

It is well documented that anticipated climate change impacts include a general warming of ambient air temperature and increases in precipitation volumes over most of the Arctic region. Changing patterns also include increasing precipitation percentages occurring as rainfall vs. snow which will subsequently influence runoff patterns and water budgets.

The presence of permafrost is important in Arctic hydrology as it influences infiltration, runoff and groundwater storage and flow. Increases in air temperature results in permafrost degradation and increases the active (thaw) layer – this leads to increased infiltration, larger groundwater storage and flows, and changes to spring runoff and melt timing. Additionally, as the permafrost thaws, different settlement and ponding can occur leading to the introduction of new hydrological pathways and significantly alter drainage networks and distribution of surface/groundwater flows. Ice content that is typically frozen has the potential to increase streamflow by providing additional inputs (Lemmen et al., 2008 & Spence et al., 2020).

The Geological Survey of Canada (Ednie & Smith, 2015) noted that mean annual permafrost temperatures at 15 m depth in Pangnirtung were measured at -5.2°C in 2008 and -4.9°C in 2012. Since 2008, ground temperatures have followed the warming trends observed with increasing air temperatures.

As ambient air temperatures increase, ET rates experienced by watersheds are likely to increase due to larger amounts of radiation input, longer evaporation seasons as the snowmelt will begin earlier and increases in vegetation cover (Young and Woo, 2004).

5.2.3 Flooding Risks

In June 2008, an extreme rain event occurred in Pangnirtung. From June 8-9, 2008, over 40 mm of rainfall was recorded. The combination of heavy rain and rapid snowmelt caused the Duval River to flood rapidly, leading to severe permafrost degradation and erosion of the river's banks. This included severely damaging a key road bridge within the community. Residents noted that the river began to "run underneath the land" causing severe settlement of between 2.5 m to 4.5 m in some areas (Spinney & Pennesi 2012, Leblanc et al. 2010).

Young et al. (2015) noted that for watersheds in the Alaskan Arctic, for basins less than 200 km^2, flooding events are typically caused by rainfall rather than rapid snowmelt and this confirms the importance of undertaking further studies to investigate the impact of summer rainfalls in generating peak flows.

As noted from past events, the Hamlet of Pangnirtung is vulnerable to extreme flooding events. Potential climate change impacts such as warming ambient air temperatures, permafrost degradation and changing precipitation patterns will likely increase the likelihood of these extreme events. Additional studies assessing the potential discharge volumes and erosion potential for the Duval River will be critical in mitigating future flooding risks.

A surface displacement map showing the relative ground surface displacement has been developed for community of Pangnirtung (Short et al., 2012) using radar (InSAR) data correlated with surficial geology and ground ice mapping (Appendix D). This map has been used to identify areas that are stable and suitable for potential development and areas that are potentially vulnerable to severe settlement issues – additional attention should be taken to correlate changing ground conditions and the subsequent impacts on hydrological flows.

5.2.4 Water Licence

The current Type A Water Licence #3AM-PAN1828 for the Hamlet of Pangnirtung was issued on May 4, 2018 and expires on May 3, 2028. The Water Licence states the following:

- The current Water Licence permits a water extraction volume of up to 120,000 m^3.
- Withdrawal from the Duval River shall not exceed 10% of the instantaneous flow and shall cease all water withdrawal when the instantaneous flow in the river is below 30% of the mean annual discharge.
  - Currently, the withdrawal of the Duval River is limited to the months of July and August, unless otherwise recommended by future hydrological studies.
- As part of the current licence, the Hamlet is required to complete additional field hydrological studies that assesses at a minimum, details related to the discharge volume and velocity, erosion, sedimentation, water quality, and variability of discharge into the Duval River.

The Water Survey of Canada has flow and discharge information for the Duval River for the period of record between 1973 – 1983 (see Section 5.2.5 below). However, it is our understanding that no additional related field work has been completed since 1983.

5.2.5 Previous Flow and Discharge Information for Duval River (1973 – 1983)

In the 1970's, McMaster University (Suk, 1974) completed an investigation in collaboration with the Water Survey Branch of Environment Canada that included monitoring streamflows and discharge rates for the Duval River. Following the initial investigation, the water level recorders and station were taken over by the Water Survey of Canada and used to monitor the Duval River over the period between 1973 and 1983.

Hydrological discharge rates for the Duval River were reviewed for this period and are summarized in Table 5-1 and Figure 5-1 below (Appendix C). Total estimated annual river discharge volumes (m^3) were calculated based on the cumulative recorded daily flows during the monitoring years. In most years, early season flows were not recorded and thus, it is expected that the actual discharge volumes are higher than estimated volumes due to gaps in the datasets.

Table 5-1: Historical Duval River Discharge Monitoring (1973-1983)

Year	Start Date	End Date	Mean Daily Discharge (m^3/s)	Maximum Daily Discharge (m^3/s)	Total Estimated Annual River Discharge (m^3)	30% of Mean Daily Discharge (m^3/s) *
1973	18-Jun-1973	6-Aug-1973	8.1	20.4	28,855,008	2.4
1974	7-Jun-1974	24-Aug-1974	5.2	16.8	35,706,528	1.6
1975	25-Jun-1975	30-Sep-1975	3.4	17.0	28,599,782	1.0
1976	28-Jun-1976	31-Aug-1976	4.6	15.8	25,899,091	1.4
1977	1-Jul-1977	30-Sep-1977	3.7	22.3	29,462,227	1.1
1978**						
1979	20-Jul-1979	30-Sep-1979	5.0	19.7	31,496,947	1.5
1980	27-Jun-1980	30-Sep-1980	3.5	11.8	29,304,806	1.1
1981	24-Jun-1981	19-Sep-1981	5.0	20.3	38,256,710	1.5

1982	1-Jun-1982	30-Sep-1982	4.3	21.2	45,528,566	1.3
1983	1-Jun-1983	30-Sep-1983	3.6	13.4	38,298,096	1.1

** Per current Water Licence, water withdrawal to stop when the instantaneous flow in the river is below 30% of the mean annual discharge*

*** data not available/complete for 1978*

The year-to-year variability in the timing and magnitude of the peak flows between 1973-1983 is quite large. In general, measurable flows begin in mid-June and peak sometime in July/early August. Flows tend to decrease starting in the month of September although there are apparent peaks in various years likely due to rainfall events.

As per the current water licence, water withdrawal should stop once the instantaneous flow of the river is below 30% of the mean annual discharge. This average threshold is approx. 1.3 m^3/s between 1973-1983. Based on the limited available information, the current practice of extracting water from the Duval River to refill the reservoir during the months of July and August appears to be appropriate.

The projected water extraction volume in 2054 for the community of Pangnirtung is approximately 115,000 m^3. This equates to only about 0.5% of the total annual discharge of the Duval River (assuming a total annual discharge of 25,000,000 m^3 for the Duval River). From a water quantity perspective, the extraction volume required by the community is negligible compared to the estimated annual discharge of the Duval River and thus, the volume extracted is not expected to be a concern.

It should be noted that these findings have been based on best-available information provided for the Duval River and surrounding watershed. This is a limited dataset that is 40-50 years old. Site conditions have likely changed, and thus, an up-to-date field monitoring program should be established to update discharge rates and streamflows accordingly.

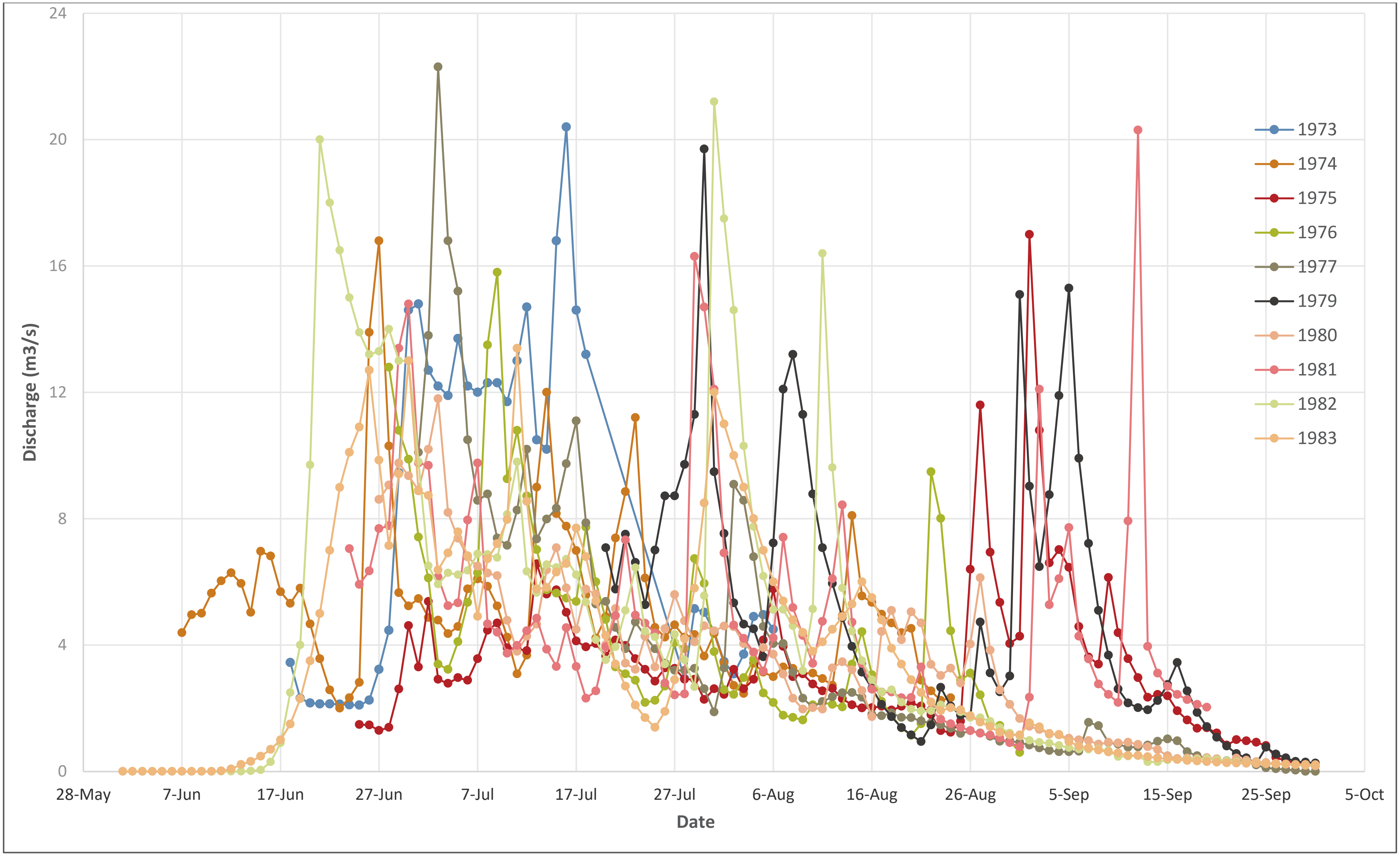

Figure 5-1: Duval River Discharge Rates (1973-1983)

5.2.6 Recommendations for Future Studies

The flow regime for the Duval River requires further investigation. The findings from this report have been based on best-available information provided for the Duval River which is over 40 years old. Based on the Hamlet's current Type A Water Licence (# 3AM-PAN1828), EXP understands that a future study is required to ultimately detail discharge volume/velocity, drawdown rates, erosion, sedimentation, water quality, and variability of discharge into the Duval River. Recommendations for future studies include:

- Installation of flow gauges and levels to monitor the Duval River during flow periods
  - Hydrograph development of the Duval River
    - Timing dates of flow/melt period
    - Impact of rain events in generating peak flows
    - Pattern and duration, magnitude of peak to low flows, shape of hydrograph peak
  - Ongoing monitoring of precipitation and ET rates for the Duval River watershed
- Additional topographic survey of the Duval River water basin
- Additional water quality sampling – recommend weekly sampling during the flow season to understand the temporal water quality fluctuations and sediment transport that occur over the flow period and to confirm optimal dates for raw water collection
- Further investigations related to permafrost monitoring
  - potential impacts on hydrological patterns
  - impacts on flood mitigations

6 Limitations of Water Balance Analysis

Results from this analysis should be considered high-level and coarse resolution. This desktop study provides a screening level assessment of the drinking water supplies for the Hamlet of Pangnirtung with consideration to climate change, population growth, and existing water infrastructure. This study focuses solely on water quantity and does not comment on water quality.

There are a number of limitations based on poor data availability, as well as the questionable quality of the data. If a yearly climate dataset had three or more months of missing data, this climate dataset was omitted from the water balance analysis. Discharge and flow information for Duval River is outdated and over 40 years old.

Evapotranspiration (ET) characteristics of the studied watersheds are also extremely limited – no field data for measured evapotranspiration rates was available at any of the sites. A literature review was completed to estimate ET rates in similar Arctic environments but there is still a high degree of uncertainty in the quality of this historical data. Variations in environmental conditions, plant community composition, soil freeze/thaw and micro-topographical features have a significant influence on ET rates. There is a large spatial and temporal variability in geomorphic and climatic drivers of evapotranspiration which makes it difficult to predict ET rates in the absence of any field data. As precipitation and ET are the main sources of water inputs and losses, any variation or error in these values could significantly alter the results of the water modeling assessments.

Underestimation of precipitation due to snow undercatch and water losses due to sublimation were not accounted for in the calculation. Actual basin snow amounts are usually larger than measured values (at weather stations) which suffer from gauge undercatch and thus the use of snow gauge data was deemed as a conservative approach for this study. Estimates for snow undercatch can range from 10% to 75% depending on gauge type and wind conditions. Sublimation losses have not been characterized. Characterization of these processes requires detailed meteorological data.

In general, there is a lack of field studies detailing the hydrological regime and hydrological features that affect recharge (streams, glaciers, flows through the active layer) at the study sites.

To improve the accuracy of future studies, it is recommended to conduct additional field studies to provide more complete and site-specific climate information, evapotranspiration rates and flow rates and water levels for major streams and channels. Future studies must consider the potential impacts of climate change and also flooding risks for the community of Pangnirtung.

7 Conclusions

Based on the water balance assessment, under all fifteen scenarios, the Duval River water source and watershed provides sufficient water quantities to meet the community's current and future water supply needs to the year 2054 (projected annual water usage for Pangnirtung in 2054 is approximately 115,000 m^3).

The catchment area of the Duval River watershed is relatively large at approximately 89,250,000 m^2 (89.25 km^2 or 8,925 ha) and any net-positive annual runoff for the Duval River watershed will provide sufficient water supply to meet the community's needs.

EXP reviewed the limited dataset that documented the discharge and flow rates of the Duval River between 1973-1983. The year-to-year variability in the timing and magnitude of the peak flows for the Duval River between 1973-1983 is quite large. In general, measurable flows begin in mid-June and peak sometime in July/early August. Flows tend to decrease starting in the month of September although there are apparent peaks in various years likely due to rainfall events.

As per the current water licence, water withdrawal should stop once the instantaneous flow of the river is below 30% of the mean annual discharge. This average threshold is approx. 1.3 m^3/s between 1973-1983. Based on the limited available information, the current practice of extracting water from the Duval River to refill the reservoir during the months of July and August appears to be appropriate.

The projected water extraction volume in 2054 for the community of Pangnirtung is approximately 115,000 m^3. This equates to only about 0.5% of the total annual discharge of the Duval River (assuming a total annual discharge of 25,000,000 m^3 for the Duval River). From a water quantity perspective, the extraction volume required by the community is negligible compared to the estimated annual discharge of the Duval River and thus, the volume extracted is not expected to be a concern.

It should be noted that these findings have been based on best-available information provided for the Duval River and surrounding watershed. This is a limited dataset that is 40-50 years old. Site conditions have likely changed, and thus, future field studies are recommended.

Based on the Hamlet's current Type A Water Licence (# 3AM-PAN1828), EXP understands that a future study is required to ultimately detail discharge volume/velocity, drawdown rates, erosion, sedimentation, water quality, and variability of discharge into the Duval River. It is anticipated that this initial desktop study will be used to develop a more comprehensive field program to further investigate the flow characteristics and regime of the Duval Recommendations for future studies include:

- Installation of flow gauges and levels to monitor the Duval River during flow periods
  - Hydrograph development of the Duval River
    - Timing dates of flow/melt period
    - Impact of rain events in generating peak flows
    - Pattern and duration, magnitude of peak to low flows, shape of hydrograph peak
  - Ongoing monitoring of precipitation and ET rates for the Duval River watershed
- Additional topographic survey of the Duval River water basin
- Additional water quality sampling – recommend weekly sampling during the flow season to understand the temporal water quality fluctuations and sediment transport that occur over the flow period and to confirm optimal dates for raw water collection
- Further investigations related to permafrost monitoring

- potential impacts on hydrological patterns
- impacts on flood mitigations

As noted from past events, the Hamlet of Pangnirtung is vulnerable to extreme flooding events. Potential climate change impacts such as warming ambient air temperatures, permafrost degradation and changing precipitation patterns will likely increase the likelihood of these extreme events. Additional studies assessing the potential discharge volumes and erosion potential for the Duval River will be critical in mitigating future flooding risks.

8 References

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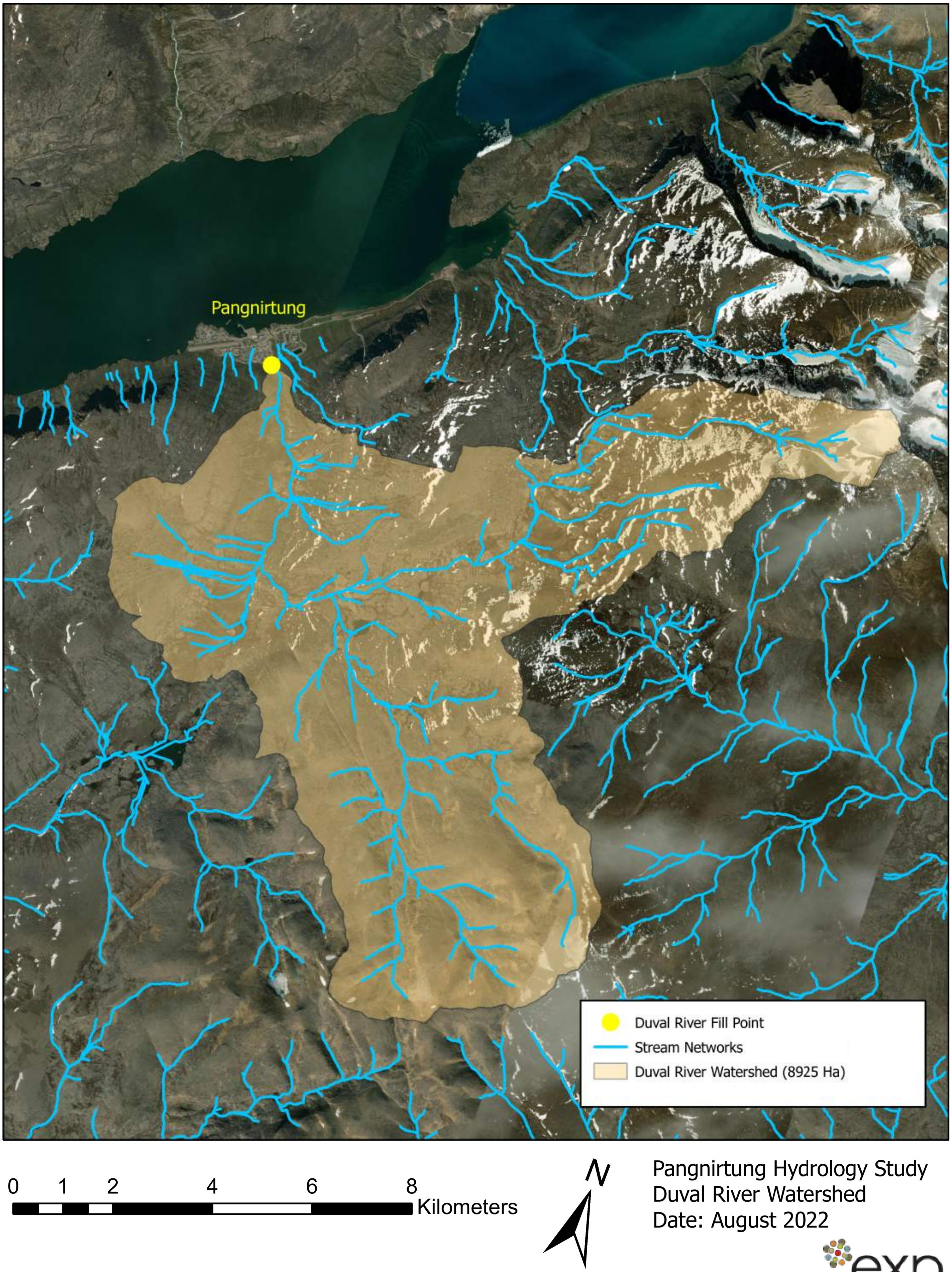
Appendix A – Watershed Delineation Map (Duval River)



Pangnirtung Hydrology Study
Duval River Watershed
Date: August 2022

Appendix B – Water Balance Calculations and Precipitation Data (Pangnirtung)

PANGNIRTUNG - WATER BALANCE AND VOLUME CALCULATIONS

						Duval River- Watershed Area		
			Pangnirtung				89,250,000	*m2*
Scenario No.	Precipitation Scenario	ET Scenario	Precipitation (mm/year)	Estimated ET (mm/year)	Potential Runoff (mm/year)	runoff (m3/year)	2054 Annual Water Use (m3/year)	ΔS > 0
1	minimum	maximum	174	103	71	6,315,152	114,219	YES
2	minimum	3-year high	174	86	88	7,832,402	114,219	YES
3	minimum	average	174	65	109	9,696,152	114,219	YES
4	3-year low	maximum	179	103	76	6,822,568	114,219	YES
5	3-year low	3-year high	179	86	93	8,339,818	114,219	YES
6	3-year low	average	179	65	114	10,203,568	114,219	YES
7	5-year low	maximum	185	103	82	7,335,350	114,219	YES
8	5-year low	3-year high	185	86	99	8,852,600	114,219	YES
9	5-year low	average	185	65	120	10,716,350	114,219	YES
10	10-year low	maximum	212	103	109	9,683,857	114,219	YES
11	10-year low	3-year high	212	86	126	11,201,107	114,219	YES
12	10-year low	average	212	65	146	13,064,857	114,219	YES
13	Median	maximum	289	103	186	16,561,052	114,219	YES
14	Median	3-year high	289	86	203	18,078,302	114,219	YES
15	Median	average	289	65	223	19,942,052	114,219	YES

WATER USE (2054) 114,219

Pangnirtung Historical Precipitation Data

Station Name	Pangnirtung (2010-2021)	Pangnirtung (1925)	Pangnirtung (1995-2007)
Climate ID	2403049	2403050	2403053
WMO ID	71826		
Latitude	66°08'36.300" N	66°08'00.000" N	66°08'42.000" N
Longlitude	65°42'40.500" W	65°44'00.000" W	65°42'49.000" W
Elevation	22.60m	15.20m	24.10m

Year	Annual Precipitation (mm)	Used for Analysis (Y or N)	Comments
1931	383.5	Y	
1932	218.4	Y	
1933	302.1	Y	
1934	303.2	Y	
1935	295.7	Y	
1937	349.4	Y	
1938	360.7	Y	
1939	585.1	Y	
1996	490.8	Y	
1997	399.8	Y	
1998	371.7	Y	
1999	363.6	Y	
2000	362.1	Y	
2001	305.5	Y	
2002	243	Y	
2003	392.2	Y	
2004	400.4	Y	
2005	469.7	Y	
2006	243.6	Y	
2007	356.2	Y	
2008		N	more than 3 months missing
2009		N	more than 3 months missing
2010	211.9	Y	
2011		N	more than 3 months missing
2012	349.2	Y	
2013	229.7	Y	
2014		N	more than 3 months missing
2015		N	more than 3 months missing
2016	308.1	Y	
2017	354.4	Y	
2018	312.3	Y	
2019	226.2	Y	
2020		N	more than 3 months missing
2021	368.7	Y	

		***40% of Total*	***60% of Total*	***70% of Annual Rainfall*	
Annual Precipitation (mm/year)	**Total Precip**	Annual Snowfall	Annual Rainfall	Available Rainfall for Extraction	**Total Inputs to Watershed (mm)**
Minimum (mm/year)	212	85	127	89	**174**
Maximum (mm/year)	585	234	351	246	**480**
Median (mm/year)	352	141	211	148	**289**
Mean (mm/year)	341	137	205	143	**280**
3-year low average	219	88	131	92	**179**
5-year low average	226	90	136	95	**185**
10-year low average	258	103	155	108	**212**
3-year high average	515	206	309	216	**422**
5-year high average	469	188	281	197	**385**

PANGNIRTUNG - PROJECTED WATER CONSUMPTION

WATER DEMAND PROJECTIONS **120 lpcd

Year	Population	Growth Rate (%)	Annual Use (m3/year)
2014	1,613		70,649
2015	1,638	1.55%	71,744
2016	1,664	1.59%	72,883
2017	1,691	1.62%	74,066
2018	1,718	1.60%	75,248
2019	1,744	1.51%	76,387
2020	1,768	1.38%	77,438
2021	1,789	1.19%	78,358
2022	1,810	1.17%	79,278
2023	1,829	1.05%	80,110
2024	1,847	0.98%	80,899
2025	1,866	1.03%	81,731
2026	1,885	1.02%	82,563
2027	1,906	1.11%	83,483
2028	1,934	1.47%	84,709
2029	1,953	0.98%	85,541
2030	1,973	1.02%	86,417
2031	1,992	0.96%	87,250
2032	2,012	1.00%	88,126
2033	2,034	1.09%	89,089
2034	2,055	1.03%	90,009
2035	2,075	0.97%	90,885
2036	2,100		91,985
2037	2,126		93,098
2038	2,151		94,224
2039	2,177		95,364
2040	2,204		96,518
2041	2,230		97,686
2042	2,257		98,868
2043	2,285		100,064
2044	2,312		101,275
2045	2,340		102,501
2046	2,369		103,741
2047	2,397		104,996
2048	2,426		106,267
2049	2,456		107,552
2050	2,485		108,854
2051	2,515		110,171
2052	2,546		111,504
2053	2,577		112,853
2054	2,608		114,219

avg. growth rate 1.21%

HISTORICAL WATER USE

Year	Population	Annual Consumption (L)	Per Capita Consumptio n (lpcd)
1997			
2002	1276	43764.669	94.0
2003	1300	46372	97.7
2006	1325		
2010	1400	48440	94.8
2011	1425	49752	95.7
2012	1500	52204	95.3
2013	1600	51531	88.2
2014	1613	52543	89.2
2015	1638	51218	85.7
2016	1664	47372	78.0
2017	1691	46642	75.6
2018	1718	48419	77.2

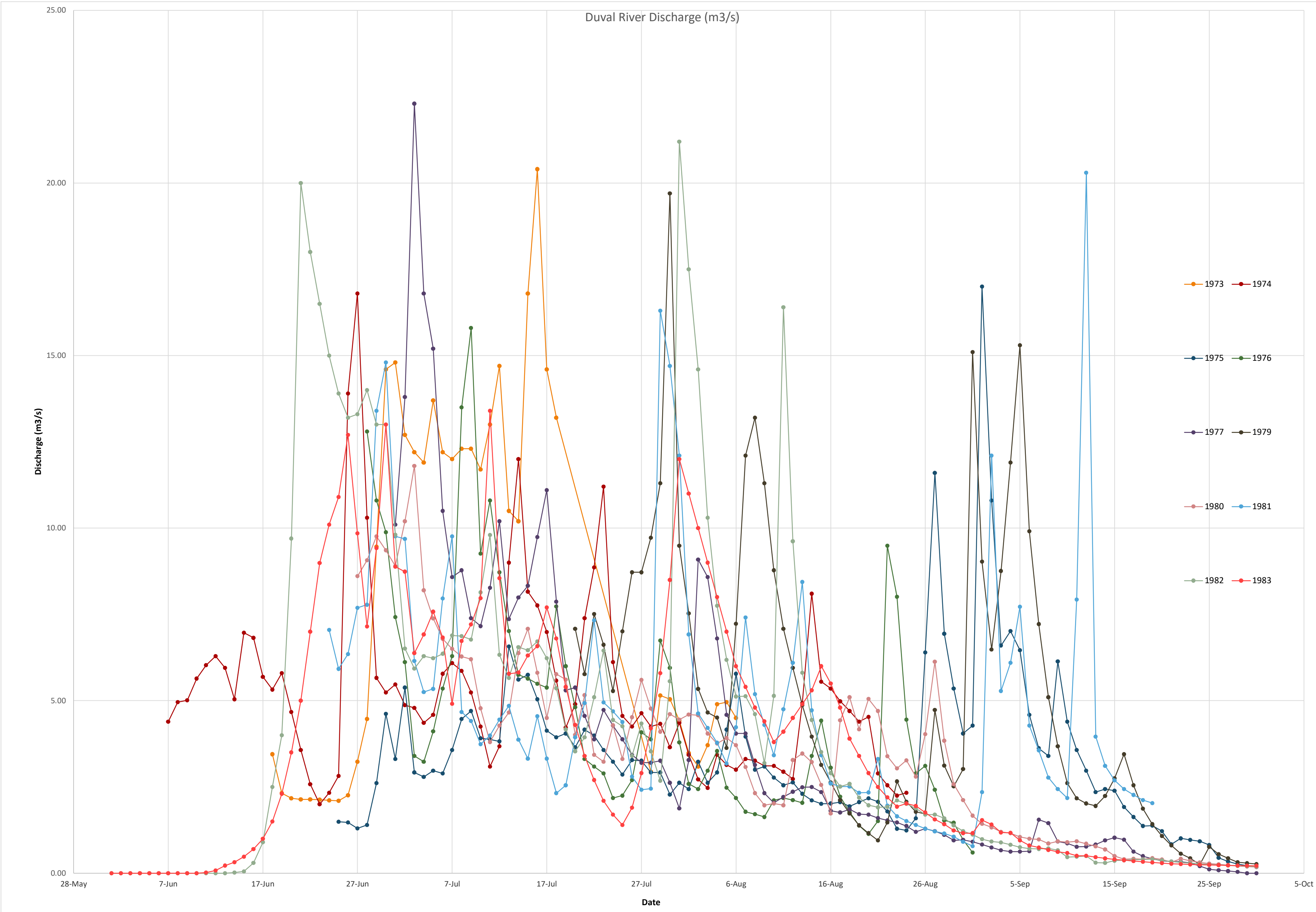
max	97.7
min	75.6
average	88.3

***** 120 lpcd estimate is conservative based on historical usage***

Appendix C – Duval River Discharge and Flow Data (1973-1983)

SUMMARY - PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)

Year	Start Date	End Date	Mean Discharge (m3/s)	Min Discharge (m3/s)	Max Discharge (m3/s)		Total Discharge Volume (m3)	30% of Mean Discharge (m3/s)
1973	18-Jun-1973	6-Aug-1973	8.1	2.1	20.4		28,855,008	2.4
1974	7-Jun-1974	24-Aug-1974	5.2	2.0	16.8		35,706,528	1.6
1975	25-Jun-1975	30-Sep-1975	3.4	0.2	17.0		28,599,782	1.0
1976	28-Jun-1976	31-Aug-1976	4.6	0.6	15.8		25,899,091	1.4
1977	1-Jul-1977	30-Sep-1977	3.7	0.0	22.3		29,462,227	1.1
1978								0.0
1979	20-Jul-1979	30-Sep-1979	5.0	0.3	19.7		31,496,947	1.5
1980	27-Jun-1980	30-Sep-1980	3.5	0.2	11.8		29,304,806	1.1
1981	24-Jun-1981	19-Sep-1981	5.0	0.8	20.3		38,256,710	1.5
1982	1-Jun-1982	30-Sep-1982	4.3	0.0	21.2		45,528,566	1.3
1983	1-Jun-1983	30-Sep-1983	3.6	0.0	13.4		38,298,096	1.1


Duval River Discharge (m3/s)
Discharge (m3/s)
25.00
20.00
15.00
10.00
5.00
0.00
28-May
7-Jun
17-Jun
27-Jun
7-Jul
17-Jul
27-Jul
6-Aug
16-Aug
26-Aug
5-Sep
15-Sep
25-Sep
5-Oct
Date
1973
1974
1975
1976
1977
1979
1980
1981
1982
1983

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	6/18/1973		3.45	298,080
10UF001	6/19/1973		2.32	200,448
10UF001	6/20/1973		2.17	187,488
10UF001	6/21/1973		2.14	184,896
10UF001	6/22/1973		2.14	184,896
10UF001	6/23/1973		2.13	184,032
10UF001	6/24/1973		2.11	182,304
10UF001	6/25/1973		2.10	181,440
10UF001	6/26/1973		2.26	195,264
10UF001	6/27/1973		3.23	279,072
10UF001	6/28/1973		4.47	386,208
10UF001	6/29/1973		9.46	817,344
10UF001	6/30/1973		14.60	1,261,440
10UF001	7/1/1973		14.80	1,278,720
10UF001	7/2/1973		12.70	1,097,280
10UF001	7/3/1973		12.20	1,054,080
10UF001	7/4/1973		11.90	1,028,160
10UF001	7/5/1973		13.70	1,183,680
10UF001	7/6/1973		12.20	1,054,080
10UF001	7/7/1973		12.00	1,036,800
10UF001	7/8/1973		12.30	1,062,720
10UF001	7/9/1973		12.30	1,062,720
10UF001	7/10/1973		11.70	1,010,880
10UF001	7/11/1973		13.00	1,123,200
10UF001	7/12/1973		14.70	1,270,080
10UF001	7/13/1973		10.50	907,200
10UF001	7/14/1973		10.20	881,280
10UF001	7/15/1973		16.80	1,451,520
10UF001	7/16/1973		20.40	1,762,560
10UF001	7/17/1973		14.60	1,261,440
10UF001	7/18/1973		13.20	1,140,480
10UF001	7/28/1973		2.94	254,016
10UF001	7/29/1973		5.15	444,960
10UF001	7/30/1973		5.04	435,456
10UF001	7/31/1973		4.42	381,888
10UF001	8/1/1973		3.48	300,672
10UF001	8/2/1973		3.09	266,976
10UF001	8/3/1973		3.71	320,544
10UF001	8/4/1973		4.90	423,360
10UF001	8/5/1973		4.96	428,544

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	8/6/1973		4.50	388,800
10UF001	6/7/1974		4.39	379,296
10UF001	6/8/1974		4.96	428,544
10UF001	6/9/1974		5.01	432,864
10UF001	6/10/1974		5.64	487,296
10UF001	6/11/1974		6.03	520,992
10UF001	6/12/1974		6.29	543,456
10UF001	6/13/1974		5.95	514,080
10UF001	6/14/1974		5.04	435,456
10UF001	6/15/1974		6.97	602,208
10UF001	6/16/1974		6.82	589,248
10UF001	6/17/1974		5.69	491,616
10UF001	6/18/1974		5.32	459,648
10UF001	6/19/1974		5.80	501,120
10UF001	6/20/1974		4.67	403,488
10UF001	6/21/1974		3.57	308,448
10UF001	6/22/1974		2.58	222,912
10UF001	6/23/1974		2.00	172,800
10UF001	6/24/1974		2.33	201,312
10UF001	6/25/1974		2.82	243,648
10UF001	6/26/1974		13.90	1,200,960
10UF001	6/27/1974		16.80	1,451,520
10UF001	6/28/1974		10.30	889,920
10UF001	6/29/1974		5.66	489,024
10UF001	6/30/1974		5.24	452,736
10UF001	7/1/1974		5.47	472,608
10UF001	7/2/1974		4.87	420,768
10UF001	7/3/1974		4.79	413,856
10UF001	7/4/1974		4.36	376,704
10UF001	7/5/1974		4.59	396,576
10UF001	7/6/1974		5.78	499,392
10UF001	7/7/1974		6.09	526,176
10UF001	7/8/1974		5.86	506,304
10UF001	7/9/1974		5.24	452,736
10UF001	7/10/1974		4.25	367,200
10UF001	7/11/1974		3.09	266,976
10UF001	7/12/1974		3.68	317,952
10UF001	7/13/1974		9.00	777,600
10UF001	7/14/1974		12.00	1,036,800
10UF001	7/15/1974		8.16	705,024
10UF001	7/16/1974		7.76	670,464

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	7/17/1974		6.99	603,936
10UF001	7/18/1974		5.58	482,112
10UF001	7/19/1974		4.22	364,608
10UF001	7/20/1974		4.90	423,360
10UF001	7/21/1974		7.39	638,496
10UF001	7/22/1974		8.86	765,504
10UF001	7/23/1974		11.20	967,680
10UF001	7/24/1974		6.12	528,768
10UF001	7/25/1974		4.56	393,984
10UF001	7/26/1974		4.25	367,200
10UF001	7/27/1974		4.64	400,896
10UF001	7/28/1974		4.25	367,200
10UF001	7/29/1974		4.33	374,112
10UF001	7/30/1974		3.65	315,360
10UF001	7/31/1974		4.36	376,704
10UF001	8/1/1974		3.43	296,352
10UF001	8/2/1974		2.72	235,008
10UF001	8/3/1974		2.47	213,408
10UF001	8/4/1974		3.43	296,352
10UF001	8/5/1974		3.14	271,296
10UF001	8/6/1974		3.00	259,200
10UF001	8/7/1974		3.31	285,984
10UF001	8/8/1974		3.26	281,664
10UF001	8/9/1974		3.11	268,704
10UF001	8/10/1974		3.11	268,704
10UF001	8/11/1974		2.94	254,016
10UF001	8/12/1974		2.73	235,872
10UF001	8/13/1974		4.93	425,952
10UF001	8/14/1974		8.10	699,840
10UF001	8/15/1974		5.55	479,520
10UF001	8/16/1974		5.35	462,240
10UF001	8/17/1974		4.98	430,272
10UF001	8/18/1974		4.70	406,080
10UF001	8/19/1974		4.39	379,296
10UF001	8/20/1974		4.53	391,392
10UF001	8/21/1974		2.89	249,696
10UF001	8/22/1974		2.55	220,320
10UF001	8/23/1974		2.25	194,400
10UF001	8/24/1974		2.33	201,312
10UF001	6/25/1975		1.49	128,736
10UF001	6/26/1975		1.47	127,008

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	6/27/1975		1.30	112,320
10UF001	6/28/1975		1.40	120,960
10UF001	6/29/1975		2.61	225,504
10UF001	6/30/1975		4.62	399,168
10UF001	7/1/1975		3.31	285,984
10UF001	7/2/1975		5.38	464,832
10UF001	7/3/1975		2.92	252,288
10UF001	7/4/1975		2.79	241,056
10UF001	7/5/1975		2.97	256,608
10UF001	7/6/1975		2.89	249,696
10UF001	7/7/1975		3.57	308,448
10UF001	7/8/1975		4.47	386,208
10UF001	7/9/1975		4.70	406,080
10UF001	7/10/1975		3.91	337,824
10UF001	7/11/1975		3.88	335,232
10UF001	7/12/1975		3.82	330,048
10UF001	7/13/1975		6.57	567,648
10UF001	7/14/1975		5.61	484,704
10UF001	7/15/1975		5.75	496,800
10UF001	7/16/1975		5.04	435,456
10UF001	7/17/1975		4.13	356,832
10UF001	7/18/1975		3.94	340,416
10UF001	7/19/1975		4.05	349,920
10UF001	7/20/1975		3.65	315,360
10UF001	7/21/1975		4.16	359,424
10UF001	7/22/1975		3.99	344,736
10UF001	7/23/1975		3.57	308,448
10UF001	7/24/1975		3.23	279,072
10UF001	7/25/1975		2.86	247,104
10UF001	7/26/1975		3.28	283,392
10UF001	7/27/1975		3.26	281,664
10UF001	7/28/1975		2.92	252,288
10UF001	7/29/1975		2.92	252,288
10UF001	7/30/1975		2.28	196,992
10UF001	7/31/1975		2.62	226,368
10UF001	8/1/1975		2.44	210,816
10UF001	8/2/1975		3.23	279,072
10UF001	8/3/1975		2.62	226,368
10UF001	8/4/1975		2.92	252,288
10UF001	8/5/1975		4.16	359,424
10UF001	8/6/1975		5.78	499,392

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	8/7/1975		3.96	342,144
10UF001	8/8/1975		3.00	259,200
10UF001	8/9/1975		3.09	266,976
10UF001	8/10/1975		2.77	239,328
10UF001	8/11/1975		2.55	220,320
10UF001	8/12/1975		2.63	227,232
10UF001	8/13/1975		2.30	198,720
10UF001	8/14/1975		2.11	182,304
10UF001	8/15/1975		2.01	173,664
10UF001	8/16/1975		2.02	174,528
10UF001	8/17/1975		2.06	177,984
10UF001	8/18/1975		1.94	167,616
10UF001	8/19/1975		2.06	177,984
10UF001	8/20/1975		2.17	187,488
10UF001	8/21/1975		2.07	178,848
10UF001	8/22/1975		1.79	154,656
10UF001	8/23/1975		1.29	111,456
10UF001	8/24/1975		1.24	107,136
10UF001	8/25/1975		1.59	137,376
10UF001	8/26/1975		6.40	552,960
10UF001	8/27/1975		11.60	1,002,240
10UF001	8/28/1975		6.94	599,616
10UF001	8/29/1975		5.35	462,240
10UF001	8/30/1975		4.05	349,920
10UF001	8/31/1975		4.28	369,792
10UF001	9/1/1975		17.00	1,468,800
10UF001	9/2/1975		10.80	933,120
10UF001	9/3/1975		6.60	570,240
10UF001	9/4/1975		7.02	606,528
10UF001	9/5/1975		6.46	558,144
10UF001	9/6/1975		4.59	396,576
10UF001	9/7/1975		3.62	312,768
10UF001	9/8/1975		3.40	293,760
10UF001	9/9/1975		6.14	530,496
10UF001	9/10/1975		4.39	379,296
10UF001	9/11/1975		3.57	308,448
10UF001	9/12/1975		2.97	256,608
10UF001	9/13/1975		2.35	203,040
10UF001	9/14/1975		2.44	210,816
10UF001	9/15/1975		2.39	206,496
10UF001	9/16/1975		1.92	165,888

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	9/17/1975		1.63	140,832
10UF001	9/18/1975		1.37	118,368
10UF001	9/19/1975		1.38	119,232
10UF001	9/20/1975		1.22	105,408
10UF001	9/21/1975		0.84	72,403
10UF001	9/22/1975		1.01	87,264
10UF001	9/23/1975		0.97	83,635
10UF001	9/24/1975		0.92	79,747
10UF001	9/25/1975		0.82	70,675
10UF001	9/26/1975		0.45	38,621
10UF001	9/27/1975		0.34	29,376
10UF001	9/28/1975		0.27	22,982
10UF001	9/29/1975		0.22	18,835
10UF001	9/30/1975		0.18	15,379
10UF001	6/28/1976		12.80	1,105,920
10UF001	6/29/1976		10.80	933,120
10UF001	6/30/1976		9.88	853,632
10UF001	7/1/1976		7.42	641,088
10UF001	7/2/1976		6.12	528,768
10UF001	7/3/1976		3.40	293,760
10UF001	7/4/1976		3.23	279,072
10UF001	7/5/1976		4.11	355,104
10UF001	7/6/1976		5.35	462,240
10UF001	7/7/1976		6.29	543,456
10UF001	7/8/1976		13.50	1,166,400
10UF001	7/9/1976		15.80	1,365,120
10UF001	7/10/1976		9.26	800,064
10UF001	7/11/1976		10.80	933,120
10UF001	7/12/1976		8.72	753,408
10UF001	7/13/1976		7.02	606,528
10UF001	7/14/1976		5.75	496,800
10UF001	7/15/1976		5.64	487,296
10UF001	7/16/1976		5.49	474,336
10UF001	7/17/1976		5.38	464,832
10UF001	7/18/1976		7.73	667,872
10UF001	7/19/1976		6.00	518,400
10UF001	7/20/1976		4.81	415,584
10UF001	7/21/1976		3.31	285,984
10UF001	7/22/1976		3.09	266,976
10UF001	7/23/1976		2.89	249,696
10UF001	7/24/1976		2.18	188,352

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	7/25/1976		2.25	194,400
10UF001	7/26/1976		2.70	233,280
10UF001	7/27/1976		4.08	352,512
10UF001	7/28/1976		3.88	335,232
10UF001	7/29/1976		6.74	582,336
10UF001	7/30/1976		5.95	514,080
10UF001	7/31/1976		3.79	327,456
10UF001	8/1/1976		2.59	223,776
10UF001	8/2/1976		2.44	210,816
10UF001	8/3/1976		2.97	256,608
10UF001	8/4/1976		3.54	305,856
10UF001	8/5/1976		2.48	214,272
10UF001	8/6/1976		2.18	188,352
10UF001	8/7/1976		1.78	153,792
10UF001	8/8/1976		1.71	147,744
10UF001	8/9/1976		1.63	140,832
10UF001	8/10/1976		2.11	182,304
10UF001	8/11/1976		2.18	188,352
10UF001	8/12/1976		2.12	183,168
10UF001	8/13/1976		2.04	176,256
10UF001	8/14/1976		3.40	293,760
10UF001	8/15/1976		4.42	381,888
10UF001	8/16/1976		3.06	264,384
10UF001	8/17/1976		2.22	191,808
10UF001	8/18/1976		1.77	152,928
10UF001	8/19/1976		1.38	119,232
10UF001	8/20/1976		1.14	98,496
10UF001	8/21/1976		1.51	130,464
10UF001	8/22/1976		9.49	819,936
10UF001	8/23/1976		8.01	692,064
10UF001	8/24/1976		4.45	384,480
10UF001	8/25/1976		2.89	249,696
10UF001	8/26/1976		3.11	268,704
10UF001	8/27/1976		2.42	209,088
10UF001	8/28/1976		1.53	132,192
10UF001	8/29/1976		1.46	126,144
10UF001	8/30/1976		0.97	83,635
10UF001	8/31/1976		0.60	51,840
10UF001	7/1/1977		10.10	872,640
10UF001	7/2/1977		13.80	1,192,320
10UF001	7/3/1977		22.30	1,926,720

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	7/4/1977		16.80	1,451,520
10UF001	7/5/1977		15.20	1,313,280
10UF001	7/6/1977		10.50	907,200
10UF001	7/7/1977		8.58	741,312
10UF001	7/8/1977		8.78	758,592
10UF001	7/9/1977		7.39	638,496
10UF001	7/10/1977		7.16	618,624
10UF001	7/11/1977		8.27	714,528
10UF001	7/12/1977		10.20	881,280
10UF001	7/13/1977		7.36	635,904
10UF001	7/14/1977		7.99	690,336
10UF001	7/15/1977		8.33	719,712
10UF001	7/16/1977		9.74	841,536
10UF001	7/17/1977		11.10	959,040
10UF001	7/18/1977		7.87	679,968
10UF001	7/19/1977		5.30	457,920
10UF001	7/20/1977		5.38	464,832
10UF001	7/21/1977		4.56	393,984
10UF001	7/22/1977		3.88	335,232
10UF001	7/23/1977		4.73	408,672
10UF001	7/24/1977		4.28	369,792
10UF001	7/25/1977		3.88	335,232
10UF001	7/26/1977		3.43	296,352
10UF001	7/27/1977		3.20	276,480
10UF001	7/28/1977		3.20	276,480
10UF001	7/29/1977		3.26	281,664
10UF001	7/30/1977		2.62	226,368
10UF001	7/31/1977		1.88	162,432
10UF001	8/1/1977		3.28	283,392
10UF001	8/2/1977		9.09	785,376
10UF001	8/3/1977		8.58	741,312
10UF001	8/4/1977		6.80	587,520
10UF001	8/5/1977		4.59	396,576
10UF001	8/6/1977		4.05	349,920
10UF001	8/7/1977		4.05	349,920
10UF001	8/8/1977		3.14	271,296
10UF001	8/9/1977		2.32	200,448
10UF001	8/10/1977		2.04	176,256
10UF001	8/11/1977		2.21	190,944
10UF001	8/12/1977		2.36	203,904
10UF001	8/13/1977		2.49	215,136

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	8/14/1977		2.50	216,000
10UF001	8/15/1977		2.35	203,040
10UF001	8/16/1977		1.81	156,384
10UF001	8/17/1977		1.76	152,064
10UF001	8/18/1977		1.85	159,840
10UF001	8/19/1977		1.71	147,744
10UF001	8/20/1977		1.70	146,880
10UF001	8/21/1977		1.60	138,240
10UF001	8/22/1977		1.53	132,192
10UF001	8/23/1977		1.47	127,008
10UF001	8/24/1977		1.37	118,368
10UF001	8/25/1977		1.20	103,680
10UF001	8/26/1977		1.29	111,456
10UF001	8/27/1977		1.22	105,408
10UF001	8/28/1977		1.11	95,904
10UF001	8/29/1977		0.95	82,426
10UF001	8/30/1977		0.97	83,635
10UF001	8/31/1977		0.92	79,056
10UF001	9/1/1977		0.83	71,971
10UF001	9/2/1977		0.75	64,368
10UF001	9/3/1977		0.66	57,283
10UF001	9/4/1977		0.63	54,086
10UF001	9/5/1977		0.63	54,086
10UF001	9/6/1977		0.64	55,037
10UF001	9/7/1977		1.55	133,920
10UF001	9/8/1977		1.45	125,280
10UF001	9/9/1977		0.92	79,488
10UF001	9/10/1977		0.87	74,909
10UF001	9/11/1977		0.77	66,269
10UF001	9/12/1977		0.77	66,787
10UF001	9/13/1977		0.83	71,971
10UF001	9/14/1977		0.95	82,426
10UF001	9/15/1977		1.03	88,992
10UF001	9/16/1977		0.97	83,894
10UF001	9/17/1977		0.63	54,086
10UF001	9/18/1977		0.50	42,854
10UF001	9/19/1977		0.42	36,202
10UF001	9/20/1977		0.36	30,845
10UF001	9/21/1977		0.34	29,376
10UF001	9/22/1977		0.33	28,858
10UF001	9/23/1977		0.30	25,920

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	9/24/1977		0.20	17,626
10UF001	9/25/1977		0.11	9,763
10UF001	9/26/1977		0.09	7,344
10UF001	9/27/1977		0.06	5,357
10UF001	9/28/1977		0.04	3,456
10UF001	9/29/1977		0.00	0
10UF001	9/30/1977		0.00	0
10UF001	7/8/1978		14.60	1,261,440
10UF001	7/9/1978		12.40	1,071,360
10UF001	7/10/1978		10.30	889,920
10UF001	7/11/1978		11.80	1,019,520
10UF001	7/12/1978		13.20	1,140,480
10UF001	9/8/1978		1.02	88,128
10UF001	7/20/1979		7.08	611,712
10UF001	7/21/1979		5.77	498,528
10UF001	7/22/1979		7.51	648,864
10UF001	7/23/1979		6.62	571,968
10UF001	7/24/1979		5.28	456,192
10UF001	7/25/1979		7.01	605,664
10UF001	7/26/1979		8.72	753,408
10UF001	7/27/1979		8.72	753,408
10UF001	7/28/1979		9.72	839,808
10UF001	7/29/1979		11.30	976,320
10UF001	7/30/1979		19.70	1,702,080
10UF001	7/31/1979		9.49	819,936
10UF001	8/1/1979		7.53	650,592
10UF001	8/2/1979		5.34	461,376
10UF001	8/3/1979		4.66	402,624
10UF001	8/4/1979		4.51	389,664
10UF001	8/5/1979		3.63	313,632
10UF001	8/6/1979		7.23	624,672
10UF001	8/7/1979		12.10	1,045,440
10UF001	8/8/1979		13.20	1,140,480
10UF001	8/9/1979		11.30	976,320
10UF001	8/10/1979		8.78	758,592
10UF001	8/11/1979		7.08	611,712
10UF001	8/12/1979		5.95	514,080
10UF001	8/13/1979		4.87	420,768
10UF001	8/14/1979		3.96	342,144
10UF001	8/15/1979		3.14	271,296
10UF001	8/16/1979		2.63	227,232

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	8/17/1979		2.12	183,168
10UF001	8/18/1979		1.73	149,472
10UF001	8/19/1979		1.39	120,096
10UF001	8/20/1979		1.16	100,224
10UF001	8/21/1979		0.95	81,994
10UF001	8/22/1979		1.47	127,008
10UF001	8/23/1979		2.66	229,824
10UF001	8/24/1979		2.07	178,848
10UF001	8/25/1979		1.78	153,792
10UF001	8/26/1979		1.72	148,608
10UF001	8/27/1979		4.73	408,672
10UF001	8/28/1979		3.12	269,568
10UF001	8/29/1979		2.52	217,728
10UF001	8/30/1979		3.02	260,928
10UF001	8/31/1979		15.10	1,304,640
10UF001	9/1/1979		9.03	780,192
10UF001	9/2/1979		6.48	559,872
10UF001	9/3/1979		8.76	756,864
10UF001	9/4/1979		11.90	1,028,160
10UF001	9/5/1979		15.30	1,321,920
10UF001	9/6/1979		9.91	856,224
10UF001	9/7/1979		7.22	623,808
10UF001	9/8/1979		5.10	440,640
10UF001	9/9/1979		3.68	317,952
10UF001	9/10/1979		2.61	225,504
10UF001	9/11/1979		2.17	187,488
10UF001	9/12/1979		2.02	174,528
10UF001	9/13/1979		1.95	168,480
10UF001	9/14/1979		2.24	193,536
10UF001	9/15/1979		2.75	237,600
10UF001	9/16/1979		3.45	298,080
10UF001	9/17/1979		2.55	220,320
10UF001	9/18/1979		1.87	161,568
10UF001	9/19/1979		1.42	122,688
10UF001	9/20/1979		1.08	93,312
10UF001	9/21/1979		0.81	69,725
10UF001	9/22/1979		0.57	48,902
10UF001	9/23/1979		0.43	37,411
10UF001	9/24/1979		0.26	22,032
10UF001	9/25/1979		0.77	66,096
10UF001	9/26/1979		0.55	47,693

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	9/27/1979		0.43	37,411
10UF001	9/28/1979		0.32	27,648
10UF001	9/29/1979		0.29	25,229
10UF001	9/30/1979		0.27	22,982
10UF001	6/27/1980		8.61	743,904
10UF001	6/28/1980		9.07	783,648
10UF001	6/29/1980		9.76	843,264
10UF001	6/30/1980		9.36	808,704
10UF001	7/1/1980		8.90	768,960
10UF001	7/2/1980		10.20	881,280
10UF001	7/3/1980		11.80	1,019,520
10UF001	7/4/1980		8.20	708,480
10UF001	7/5/1980		7.38	637,632
10UF001	7/6/1980		6.79	586,656
10UF001	7/7/1980		6.50	561,600
10UF001	7/8/1980		6.28	542,592
10UF001	7/9/1980		6.20	535,680
10UF001	7/10/1980		4.78	412,992
10UF001	7/11/1980		3.80	328,320
10UF001	7/12/1980		4.28	369,792
10UF001	7/13/1980		4.66	402,624
10UF001	7/14/1980		6.38	551,232
10UF001	7/15/1980		7.08	611,712
10UF001	7/16/1980		5.81	501,984
10UF001	7/17/1980		4.50	388,800
10UF001	7/18/1980		5.77	498,528
10UF001	7/19/1980		5.61	484,704
10UF001	7/20/1980		4.01	346,464
10UF001	7/21/1980		5.16	445,824
10UF001	7/22/1980		3.43	296,352
10UF001	7/23/1980		3.23	279,072
10UF001	7/24/1980		4.29	370,656
10UF001	7/25/1980		3.31	285,984
10UF001	7/26/1980		4.52	390,528
10UF001	7/27/1980		5.60	483,840
10UF001	7/28/1980		4.77	412,128
10UF001	7/29/1980		4.10	354,240
10UF001	7/30/1980		4.61	398,304
10UF001	7/31/1980		4.45	384,480
10UF001	8/1/1980		4.60	397,440
10UF001	8/2/1980		4.58	395,712

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	8/3/1980		4.05	349,920
10UF001	8/4/1980		3.76	324,864
10UF001	8/5/1980		3.92	338,688
10UF001	8/6/1980		3.71	320,544
10UF001	8/7/1980		3.08	266,112
10UF001	8/8/1980		2.32	200,448
10UF001	8/9/1980		1.97	170,208
10UF001	8/10/1980		2.02	174,528
10UF001	8/11/1980		1.97	170,208
10UF001	8/12/1980		3.28	283,392
10UF001	8/13/1980		3.47	299,808
10UF001	8/14/1980		3.22	278,208
10UF001	8/15/1980		2.56	221,184
10UF001	8/16/1980		1.73	149,472
10UF001	8/17/1980		4.43	382,752
10UF001	8/18/1980		5.10	440,640
10UF001	8/19/1980		4.17	360,288
10UF001	8/20/1980		5.05	436,320
10UF001	8/21/1980		4.70	406,080
10UF001	8/22/1980		3.39	292,896
10UF001	8/23/1980		3.04	262,656
10UF001	8/24/1980		3.27	282,528
10UF001	8/25/1980		2.80	241,920
10UF001	8/26/1980		4.03	348,192
10UF001	8/27/1980		6.13	529,632
10UF001	8/28/1980		3.84	331,776
10UF001	8/29/1980		2.58	222,912
10UF001	8/30/1980		2.12	183,168
10UF001	8/31/1980		1.67	144,288
10UF001	9/1/1980		1.43	123,552
10UF001	9/2/1980		1.33	114,912
10UF001	9/3/1980		1.20	103,680
10UF001	9/4/1980		1.16	100,224
10UF001	9/5/1980		1.05	90,720
10UF001	9/6/1980		1.00	86,400
10UF001	9/7/1980		0.98	84,672
10UF001	9/8/1980		0.86	74,390
10UF001	9/9/1980		0.92	79,747
10UF001	9/10/1980		0.90	77,846
10UF001	9/11/1980		0.93	80,179
10UF001	9/12/1980		0.86	73,872

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	9/13/1980		0.78	67,392
10UF001	9/14/1980		0.69	59,530
10UF001	9/15/1980		0.50	43,200
10UF001	9/16/1980		0.41	34,992
10UF001	9/17/1980		0.42	36,374
10UF001	9/18/1980		0.41	35,165
10UF001	9/19/1980		0.44	37,584
10UF001	9/20/1980		0.40	34,301
10UF001	9/21/1980		0.32	27,389
10UF001	9/22/1980		0.42	36,202
10UF001	9/23/1980		0.36	30,758
10UF001	9/24/1980		0.31	27,043
10UF001	9/25/1980		0.28	24,278
10UF001	9/26/1980		0.26	22,291
10UF001	9/27/1980		0.23	20,218
10UF001	9/28/1980		0.21	18,403
10UF001	9/29/1980		0.19	16,762
10UF001	9/30/1980		0.18	15,466
10UF001	6/24/1981		7.05	609,120
10UF001	6/25/1981		5.92	511,488
10UF001	6/26/1981		6.35	548,640
10UF001	6/27/1981		7.69	664,416
10UF001	6/28/1981		7.78	672,192
10UF001	6/29/1981		13.40	1,157,760
10UF001	6/30/1981		14.80	1,278,720
10UF001	7/1/1981		9.76	843,264
10UF001	7/2/1981		9.69	837,216
10UF001	7/3/1981		6.15	531,360
10UF001	7/4/1981		5.25	453,600
10UF001	7/5/1981		5.34	461,376
10UF001	7/6/1981		7.96	687,744
10UF001	7/7/1981		9.76	843,264
10UF001	7/8/1981		4.67	403,488
10UF001	7/9/1981		4.41	381,024
10UF001	7/10/1981		3.74	323,136
10UF001	7/11/1981		3.99	344,736
10UF001	7/12/1981		4.45	384,480
10UF001	7/13/1981		4.85	419,040
10UF001	7/14/1981		3.87	334,368
10UF001	7/15/1981		3.32	286,848
10UF001	7/16/1981		4.55	393,120

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	7/17/1981		3.32	286,848
10UF001	7/18/1981		2.32	200,448
10UF001	7/19/1981		2.55	220,320
10UF001	7/20/1981		3.94	340,416
10UF001	7/21/1981		4.93	425,952
10UF001	7/22/1981		7.33	633,312
10UF001	7/23/1981		4.95	427,680
10UF001	7/24/1981		4.69	405,216
10UF001	7/25/1981		4.38	378,432
10UF001	7/26/1981		2.80	241,920
10UF001	7/27/1981		2.42	209,088
10UF001	7/28/1981		2.45	211,680
10UF001	7/29/1981		16.30	1,408,320
10UF001	7/30/1981		14.70	1,270,080
10UF001	7/31/1981		12.10	1,045,440
10UF001	8/1/1981		6.92	597,888
10UF001	8/2/1981		4.63	400,032
10UF001	8/3/1981		4.21	363,744
10UF001	8/4/1981		3.78	326,592
10UF001	8/5/1981		3.18	274,752
10UF001	8/6/1981		4.23	365,472
10UF001	8/7/1981		7.41	640,224
10UF001	8/8/1981		5.19	448,416
10UF001	8/9/1981		4.30	371,520
10UF001	8/10/1981		3.42	295,488
10UF001	8/11/1981		4.75	410,400
10UF001	8/12/1981		6.10	527,040
10UF001	8/13/1981		8.44	729,216
10UF001	8/14/1981		4.72	407,808
10UF001	8/15/1981		3.42	295,488
10UF001	8/16/1981		2.60	224,640
10UF001	8/17/1981		2.51	216,864
10UF001	8/18/1981		2.51	216,864
10UF001	8/19/1981		2.33	201,312
10UF001	8/20/1981		2.34	202,176
10UF001	8/21/1981		3.31	285,984
10UF001	8/22/1981		1.96	169,344
10UF001	8/23/1981		1.65	142,560
10UF001	8/24/1981		1.51	130,464
10UF001	8/25/1981		1.40	120,960
10UF001	8/26/1981		1.29	111,456

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	8/27/1981		1.21	104,544
10UF001	8/28/1981		1.15	99,360
10UF001	8/29/1981		1.06	91,584
10UF001	8/30/1981		0.91	78,710
10UF001	8/31/1981		0.79	67,824
10UF001	9/1/1981		2.35	203,040
10UF001	9/2/1981		12.10	1,045,440
10UF001	9/3/1981		5.28	456,192
10UF001	9/4/1981		6.10	527,040
10UF001	9/5/1981		7.72	667,008
10UF001	9/6/1981		4.28	369,792
10UF001	9/7/1981		3.56	307,584
10UF001	9/8/1981		2.77	239,328
10UF001	9/9/1981		2.44	210,816
10UF001	9/10/1981		2.18	188,352
10UF001	9/11/1981		7.93	685,152
10UF001	9/12/1981		20.30	1,753,920
10UF001	9/13/1981		3.96	342,144
10UF001	9/14/1981		3.11	268,704
10UF001	9/15/1981		2.69	232,416
10UF001	9/16/1981		2.44	210,816
10UF001	9/17/1981		2.27	196,128
10UF001	9/18/1981		2.12	183,168
10UF001	9/19/1981		2.03	175,392
10UF001	6/1/1982		0.00	0
10UF001	6/2/1982		0.00	0
10UF001	6/3/1982		0.00	0
10UF001	6/4/1982		0.00	0
10UF001	6/5/1982		0.00	0
10UF001	6/6/1982		0.00	0
10UF001	6/7/1982		0.00	0
10UF001	6/8/1982		0.00	0
10UF001	6/9/1982		0.00	0
10UF001	6/10/1982		0.00	0
10UF001	6/11/1982		0.00	0
10UF001	6/12/1982		0.00	0
10UF001	6/13/1982		0.00	0
10UF001	6/14/1982		0.02	1,728
10UF001	6/15/1982		0.05	4,320
10UF001	6/16/1982		0.30	25,920
10UF001	6/17/1982		0.90	77,760

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	6/18/1982		2.50	216,000
10UF001	6/19/1982		4.00	345,600
10UF001	6/20/1982		9.70	838,080
10UF001	6/21/1982		20.00	1,728,000
10UF001	6/22/1982		18.00	1,555,200
10UF001	6/23/1982		16.50	1,425,600
10UF001	6/24/1982		15.00	1,296,000
10UF001	6/25/1982		13.90	1,200,960
10UF001	6/26/1982		13.20	1,140,480
10UF001	6/27/1982		13.30	1,149,120
10UF001	6/28/1982		14.00	1,209,600
10UF001	6/29/1982		13.00	1,123,200
10UF001	6/30/1982		13.00	1,123,200
10UF001	7/1/1982		9.81	847,584
10UF001	7/2/1982		6.51	562,464
10UF001	7/3/1982		5.93	512,352
10UF001	7/4/1982		6.29	543,456
10UF001	7/5/1982		6.23	538,272
10UF001	7/6/1982		6.36	549,504
10UF001	7/7/1982		6.89	595,296
10UF001	7/8/1982		6.87	593,568
10UF001	7/9/1982		6.77	584,928
10UF001	7/10/1982		8.14	703,296
10UF001	7/11/1982		9.80	846,720
10UF001	7/12/1982		6.33	546,912
10UF001	7/13/1982		5.66	489,024
10UF001	7/14/1982		6.55	565,920
10UF001	7/15/1982		6.46	558,144
10UF001	7/16/1982		6.72	580,608
10UF001	7/17/1982		6.23	538,272
10UF001	7/18/1982		5.36	463,104
10UF001	7/19/1982		4.17	360,288
10UF001	7/20/1982		3.53	304,992
10UF001	7/21/1982		3.94	340,416
10UF001	7/22/1982		5.10	440,640
10UF001	7/23/1982		6.45	557,280
10UF001	7/24/1982		4.44	383,616
10UF001	7/25/1982		4.26	368,064
10UF001	7/26/1982		3.40	293,760
10UF001	7/27/1982		4.34	374,976
10UF001	7/28/1982		3.53	304,992

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	7/29/1982		2.68	231,552
10UF001	7/30/1982		5.56	480,384
10UF001	7/31/1982		21.20	1,831,680
10UF001	8/1/1982		17.50	1,512,000
10UF001	8/2/1982		14.60	1,261,440
10UF001	8/3/1982		10.30	889,920
10UF001	8/4/1982		7.75	669,600
10UF001	8/5/1982		6.18	533,952
10UF001	8/6/1982		5.12	442,368
10UF001	8/7/1982		5.13	443,232
10UF001	8/8/1982		4.61	398,304
10UF001	8/9/1982		3.19	275,616
10UF001	8/10/1982		5.14	444,096
10UF001	8/11/1982		16.40	1,416,960
10UF001	8/12/1982		9.62	831,168
10UF001	8/13/1982		5.81	501,984
10UF001	8/14/1982		4.44	383,616
10UF001	8/15/1982		3.51	303,264
10UF001	8/16/1982		2.90	250,560
10UF001	8/17/1982		2.51	216,864
10UF001	8/18/1982		2.59	223,776
10UF001	8/19/1982		2.19	189,216
10UF001	8/20/1982		1.97	170,208
10UF001	8/21/1982		1.91	165,024
10UF001	8/22/1982		1.92	165,888
10UF001	8/23/1982		2.11	182,304
10UF001	8/24/1982		2.01	173,664
10UF001	8/25/1982		1.88	162,432
10UF001	8/26/1982		1.70	146,880
10UF001	8/27/1982		1.70	146,880
10UF001	8/28/1982		1.59	137,376
10UF001	8/29/1982		1.39	120,096
10UF001	8/30/1982		1.22	105,408
10UF001	8/31/1982		1.12	96,768
10UF001	9/1/1982		0.99	85,190
10UF001	9/2/1982		0.92	79,574
10UF001	9/3/1982		0.89	76,982
10UF001	9/4/1982		0.83	71,366
10UF001	9/5/1982		0.75	65,059
10UF001	9/6/1982		0.71	61,430
10UF001	9/7/1982		0.70	60,653

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	9/8/1982		0.72	61,862
10UF001	9/9/1982		0.66	57,197
10UF001	9/10/1982		0.47	40,608
10UF001	9/11/1982		0.48	41,731
10UF001	9/12/1982		0.50	43,027
10UF001	9/13/1982		0.31	26,438
10UF001	9/14/1982		0.30	26,006
10UF001	9/15/1982		0.36	31,277
10UF001	9/16/1982		0.38	32,400
10UF001	9/17/1982		0.39	33,264
10UF001	9/18/1982		0.40	34,128
10UF001	9/19/1982		0.41	34,992
10UF001	9/20/1982		0.37	31,968
10UF001	9/21/1982		0.34	29,376
10UF001	9/22/1982		0.31	26,784
10UF001	9/23/1982		0.29	25,056
10UF001	9/24/1982		0.27	23,328
10UF001	9/25/1982		0.25	21,600
10UF001	9/26/1982		0.24	20,736
10UF001	9/27/1982		0.23	19,699
10UF001	9/28/1982		0.22	18,576
10UF001	9/29/1982		0.21	17,712
10UF001	9/30/1982		0.20	16,848
10UF001	6/1/1983		0.00	0
10UF001	6/2/1983		0.00	0
10UF001	6/3/1983		0.00	0
10UF001	6/4/1983		0.00	0
10UF001	6/5/1983		0.00	0
10UF001	6/6/1983		0.00	0
10UF001	6/7/1983		0.00	0
10UF001	6/8/1983		0.00	0
10UF001	6/9/1983		0.00	0
10UF001	6/10/1983		0.00	0
10UF001	6/11/1983		0.02	1,728
10UF001	6/12/1983		0.08	6,912
10UF001	6/13/1983		0.22	19,008
10UF001	6/14/1983		0.32	27,648
10UF001	6/15/1983		0.48	41,472
10UF001	6/16/1983		0.70	60,480
10UF001	6/17/1983		1.00	86,400
10UF001	6/18/1983		1.50	129,600

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	6/19/1983		2.30	198,720
10UF001	6/20/1983		3.50	302,400
10UF001	6/21/1983		5.00	432,000
10UF001	6/22/1983		7.00	604,800
10UF001	6/23/1983		8.99	776,736
10UF001	6/24/1983		10.10	872,640
10UF001	6/25/1983		10.90	941,760
10UF001	6/26/1983		12.70	1,097,280
10UF001	6/27/1983		9.85	851,040
10UF001	6/28/1983		7.15	617,760
10UF001	6/29/1983		9.42	813,888
10UF001	6/30/1983		13.00	1,123,200
10UF001	7/1/1983		8.88	767,232
10UF001	7/2/1983		8.74	755,136
10UF001	7/3/1983		6.38	551,232
10UF001	7/4/1983		6.92	597,888
10UF001	7/5/1983		7.58	654,912
10UF001	7/6/1983		6.83	590,112
10UF001	7/7/1983		4.91	424,224
10UF001	7/8/1983		6.73	581,472
10UF001	7/9/1983		7.21	622,944
10UF001	7/10/1983		7.97	688,608
10UF001	7/11/1983		13.40	1,157,760
10UF001	7/12/1983		8.55	738,720
10UF001	7/13/1983		5.78	499,392
10UF001	7/14/1983		5.82	502,848
10UF001	7/15/1983		6.31	545,184
10UF001	7/16/1983		6.58	568,512
10UF001	7/17/1983		7.70	665,280
10UF001	7/18/1983		6.80	587,520
10UF001	7/19/1983		5.40	466,560
10UF001	7/20/1983		4.30	371,520
10UF001	7/21/1983		3.40	293,760
10UF001	7/22/1983		2.70	233,280
10UF001	7/23/1983		2.10	181,440
10UF001	7/24/1983		1.70	146,880
10UF001	7/25/1983		1.40	120,960
10UF001	7/26/1983		1.90	164,160
10UF001	7/27/1983		2.90	250,560
10UF001	7/28/1983		4.20	362,880
10UF001	7/29/1983		5.80	501,120

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	7/30/1983		8.50	734,400
10UF001	7/31/1983		12.00	1,036,800
10UF001	8/1/1983		11.00	950,400
10UF001	8/2/1983		10.00	864,000
10UF001	8/3/1983		9.00	777,600
10UF001	8/4/1983		8.00	691,200
10UF001	8/5/1983		7.00	604,800
10UF001	8/6/1983		6.00	518,400
10UF001	8/7/1983		5.40	466,560
10UF001	8/8/1983		4.80	414,720
10UF001	8/9/1983		4.40	380,160
10UF001	8/10/1983		3.80	328,320
10UF001	8/11/1983		4.10	354,240
10UF001	8/12/1983		4.50	388,800
10UF001	8/13/1983		4.90	423,360
10UF001	8/14/1983		5.30	457,920
10UF001	8/15/1983		6.00	518,400
10UF001	8/16/1983		5.50	475,200
10UF001	8/17/1983		4.80	414,720
10UF001	8/18/1983		3.90	336,960
10UF001	8/19/1983		3.40	293,760
10UF001	8/20/1983		2.90	250,560
10UF001	8/21/1983		2.50	216,000
10UF001	8/22/1983		2.20	190,080
10UF001	8/23/1983		1.93	166,752
10UF001	8/24/1983		2.02	174,528
10UF001	8/25/1983		1.95	168,480
10UF001	8/26/1983		1.76	152,064
10UF001	8/27/1983		1.56	134,784
10UF001	8/28/1983		1.42	122,688
10UF001	8/29/1983		1.24	107,136
10UF001	8/30/1983		1.16	100,224
10UF001	8/31/1983		1.16	100,224
10UF001	9/1/1983		1.54	133,056
10UF001	9/2/1983		1.41	121,824
10UF001	9/3/1983		1.18	101,952
10UF001	9/4/1983		1.17	101,088
10UF001	9/5/1983		0.95	81,994
10UF001	9/6/1983		0.81	69,552
10UF001	9/7/1983		0.74	64,022
10UF001	9/8/1983		0.68	58,579

PANGNIRTUNG - DUVAL RIVER DISCHARGE MONITORING (1973 - 1983)
Station 10UF001 (Lat: 66° 04' 03" N, Long: 65° 41' 10" W)

ID	Date		Instantaneous Flow Value (m3/s)	Daily Discharge Volume (m3)
10UF001	9/9/1983		0.62	53,395
10UF001	9/10/1983		0.59	50,803
10UF001	9/11/1983		0.51	43,632
10UF001	9/12/1983		0.51	43,632
10UF001	9/13/1983		0.47	40,176
10UF001	9/14/1983		0.43	37,152
10UF001	9/15/1983		0.40	34,560
10UF001	9/16/1983		0.38	32,400
10UF001	9/17/1983		0.35	30,240
10UF001	9/18/1983		0.33	28,512
10UF001	9/19/1983		0.31	26,784
10UF001	9/20/1983		0.29	25,315
10UF001	9/21/1983		0.28	23,760
10UF001	9/22/1983		0.27	22,896
10UF001	9/23/1983		0.26	22,032
10UF001	9/24/1983		0.25	21,427
10UF001	9/25/1983		0.24	20,736
10UF001	9/26/1983		0.24	20,304
10UF001	9/27/1983		0.23	19,699
10UF001	9/28/1983		0.22	19,267
10UF001	9/29/1983		0.22	18,922
10UF001	9/30/1983		0.22	18,576

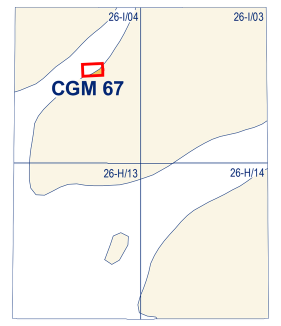
Appendix D – Seasonal Surface Displacement Map and Surficial Geology Map

Abstract

This map shows the spatial distribution of the relative ground surface displacement between the major terrain units during one summer in the area of Pangnirtung. The ground displacement was derived using interferometric synthetic aperture radar (InSAR) data for the summer of 2011. Stable ground represents locations where either no vertical change was calculated or where displacement was within the expected range of error (± 0.5 cm). Very low, low, moderate, and high downward displacement represents surface lowering on the order of 0.5 to 2, 2 to 4.5, 4.5 to 8.5, and 8.5 to 10 cm, respectively. Upward displacement represents a surface rise of 0.5 to 3 cm. Areas of no data result from a loss of interferometric coherence. These are typically water and other relatively smooth surfaces from which there is no radar return, or where there has been significant ground surface disturbance and the radar returns cannot be correlated. The InSAR results correspond well with the expected displacement associated with the characteristics of the major terrain units. The displacement reflects seasonal settlement caused by thawing of ice in the active layer or in the near-surface permafrost.

Résumé

Cette carte montre la distribution spatiale et relative, entre les différentes unités de terrain, des déplacements à la surface du sol au cours d'un été pour la région de Pangnirtung. Le déplacement à la surface du sol a été obtenu en utilisant les données de l'interférométrie radar à ouverture synthétique (InSAR) de l'été 2011. Un sol stable représente une zone où il n'y a pas de changement verticale dans le déplacement de la surface ou là où le déplacement est compris à l'intérieur de la marge d'erreur (± 0,5 cm). Des déplacements vers le bas très faibles, faibles, modérés et élevés représentent des diminutions de la surface d'élévation de l'ordre de 0,5 à 2, 2 à 4,5, 4,5 à 8,5 et 8,5 à 10 cm respectivement. Un déplacement vers le haut représente l'augmentation de la surface d'élévation de 0,5 à 3 cm. Les zones sans données sont le résultat d'une perte de cohérence interférométrique. Ces zones sont typiquement les étendues d'eau et les surfaces relativement lisses à partir desquelles il n'y a pas de réflexion radar ainsi que les zones où la perturbation de la surface du sol est importante. Dans ce cas, la réflexion radar ne peut être corrélée. Une bonne corrélation existe entre les données InSAR et les déplacements qui sont susceptibles de survenir selon la connaissance des caractéristiques des principales unités de terrain. Le déplacement est causé par le tassement au dégel du mollisol ou du pergélisol riche en glace près de la surface.



National Topographic System reference

Cover illustration:
The beautiful landscape surrounding the hamlet of Pangnirtung, Photograph by A.-S. Carbonneau. 2011-013

Printed map:
Catalogue No. M183-1/67-2011E
ISBN 978-0-660-20181-8
Digital map:
Catalogue No. M183-1/67-2011E-PDF
ISBN 978-1-100-19879-8

doi:10.4095/289607

Natural Resources Canada Ressources naturelles Canada

CANADIAN GEOSCIENCE MAP 67

(preliminary version)

SEASONAL SURFACE DISPLACEMENT DERIVED FROM INSAR

PANGNIRTUNG

Nunavut

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Canadian Geoscience Maps
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Canada

SOIL MOISTURE

Soil moisture may affect the penetration depth of a radar wave and hence the InSAR measurements (Nolan and Fatland, 2003). A radar wave may penetrate dry soils, reflecting off the dry/wet interface; this can result in the displacement signal representing the movement of the moisture front rather than surface displacement. To account for the influence of soil moisture, volumetric moisture content was measured at several sites on May 31, 2010 and on August 4 and 5, 2011 (Table 1). Although different years, these values provide a qualitative sense of how volumetric water content progresses over a summer season. For wet soils, i.e. volumetric water contents above 30%, fluctuations in water content do not affect the penetration depth (Nolan and Fatland, 2003). Results show that most of the measured moisture contents of the spring snowmelt season and half of the late summer moisture contents were high enough to preclude penetration of the radar wave. For values less than 30%, some penetration is theoretically possible, however, according to the modelled example of Rabus et al. (2010) it is highly probable that any penetration will fall within our estimated margin of error for the InSAR measurement (± 0.5 cm). Therefore, soil moisture changes do not appear to be a significant factor influencing the interpretation of these InSAR results.

CORRELATION WITH SURFICIAL GEOLOGY

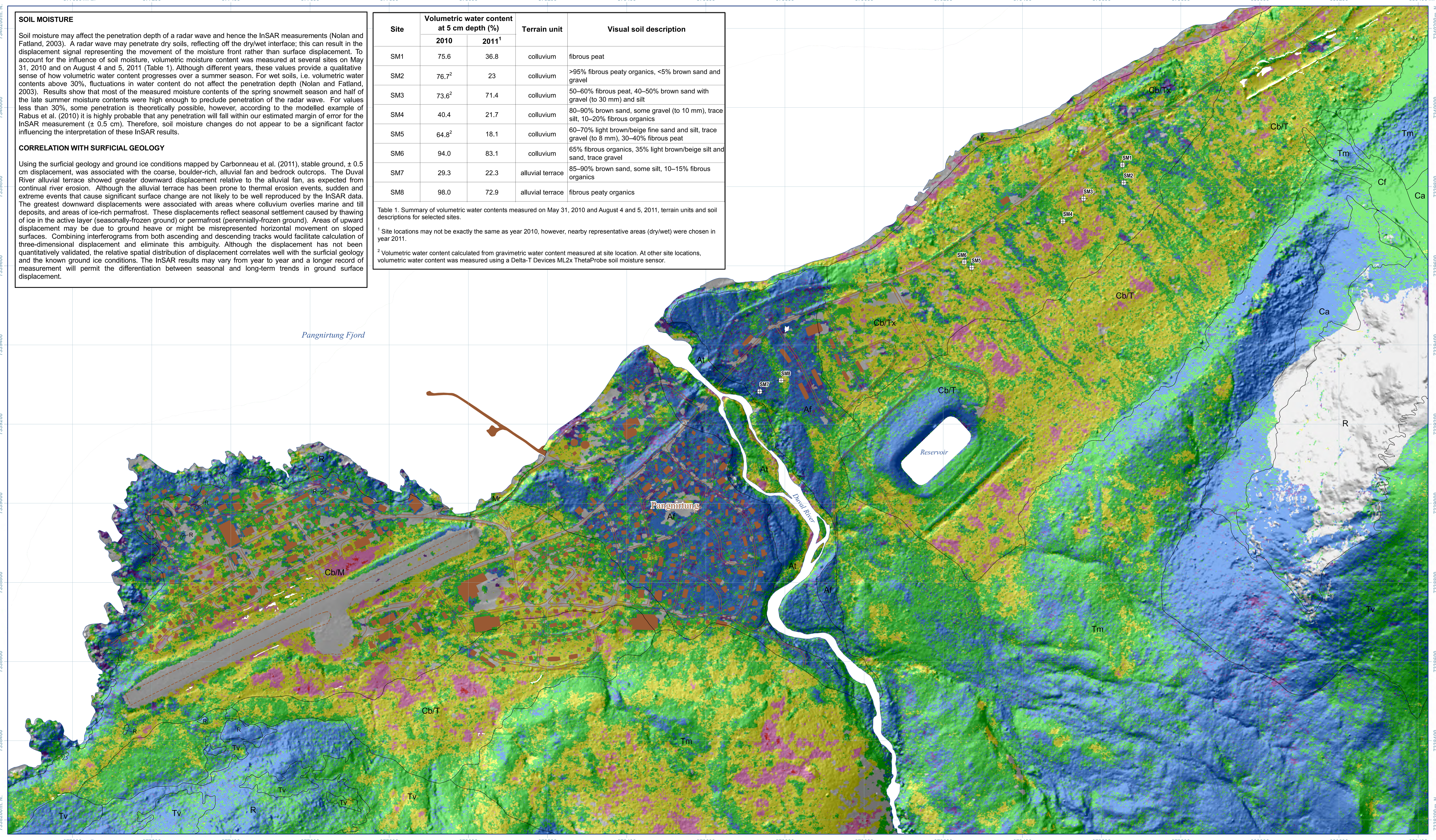
Using the surficial geology and ground ice conditions mapped by Carbonneau et al. (2011), stable ground, ± 0.5 cm displacement, was associated with the coarse, boulder-rich, alluvial fan and bedrock outcrops. The Duval River alluvial terrace showed greater downward displacement relative to the alluvial fan, as expected from continual river erosion. Although the alluvial terrace has been prone to thermal erosion events, sudden and extreme events that cause significant surface change are not likely to be well reproduced by the InSAR data. The greatest downward displacements were associated with areas where colluvium overlies marine and till deposits, and areas of ice-rich permafrost. These displacements reflect seasonal settlement caused by thawing of ice in the active layer (seasonally-frozen ground) or permafrost (perennially-frozen ground). Areas of upward displacement may be due to ground heave or might be misrepresented horizontal movement on sloped surfaces. Combining interferograms from both ascending and descending tracks would facilitate calculation of three-dimensional displacement and eliminate this ambiguity. Although the displacement has not been quantitatively validated, the relative spatial distribution of displacement correlates well with the surficial geology and the known ground ice conditions. The InSAR results may vary from year to year and a longer record of measurement will permit the differentiation between seasonal and long-term trends in ground surface displacement.

Site	Volumetric water content at 5 cm depth (%)		Terrain unit	Visual soil description
	2010	2011[1]		
SM1	75.6	36.8	colluvium	fibrous peat
SM2	76.7[2]	23	colluvium	>95% fibrous peaty organics, <5% brown sand and gravel
SM3	73.6[2]	71.4	colluvium	50–60% fibrous peat, 40–50% brown sand with gravel (to 30 mm) and silt
SM4	40.4	21.7	colluvium	80–90% brown sand, some gravel (to 10 mm), trace silt, 10–20% fibrous organics
SM5	64.8[2]	18.1	colluvium	60–70% light brown/beige fine sand and silt, trace gravel (to 8 mm), 30–40% fibrous peat
SM6	94.0	83.1	colluvium	65% fibrous organics, 35% light brown/beige silt and sand, trace gravel
SM7	29.3	22.3	alluvial terrace	85–90% brown sand, some silt, 10–15% fibrous organics
SM8	98.0	72.9	alluvial terrace	fibrous peaty organics

Table 1. Summary of volumetric water contents measured on May 31, 2010 and August 4 and 5, 2011, terrain units and soil descriptions for selected sites.

[1] Site locations may not be exactly the same as year 2010, however, nearby representative areas (dry/wet) were chosen in year 2011.

[2] Volumetric water content calculated from gravimetric water content measured at site location. At other site locations, volumetric water content was measured using a Delta-T Devices ML2x ThetaProbe soil moisture sensor.



Relative surface displacement

- Upward displacement (+0.5 to 3 cm)
- Stable (+0.5 to -0.5 cm)
- Very low downward displacement (-0.5 to -2 cm)
- Low downward displacement (-2 to -4.5 cm)
- Moderate downward displacement (-4.5 to -8.5 cm)
- High downward displacement (-8.5 to -10 cm)
- Loss of InSAR coherence.

Af — Geological contacts and label unit, for definition of the geological units below, *see* Canadian Geoscience Map 65 (Carbonneau et al., 2012).

Af	Fan sediments
At	Alluvial terraces
Ca	Talus
Cb/Mn	Colluvial blanket (Cb) over littoral to nearshore sediments (Mn)
Cb/T	Colluvial blanket (Cb) over reworked till (Tx)
Cb/Tx	Colluvial blanket (Cb) over till (T)
Cf	Bouldery debris flow
Mr	Beach sediments
R	Bedrock
Tm	Lateral moraine
Tv	Till veneer

Site — Soil moisture measurement

DISCLAIMER

ACKNOWLEDGMENTS

This work was supported through collaboration between the Canada-Nunavut Geoscience Office, Université Laval, and Natural Resources Canada (Geological Survey of Canada and Canada Centre for Remote Sensing). Additional resources were provided through the Canadian Space Agency Government Related Initiatives Program. Special thanks go to D. Mate, Chief Geologist at the Canada-Nunavut Geoscience Office. The authors also wish to thank the Community of Pangnirtung, in particular to Messrs R. Mongeau, J. Uniushagak, N. Maniapik, and S. Akpaliatuk, and to E. L'Hérault, P. Gosselin, G.A. Oldenborger, and C. Falardeau Marcoux for their research assistance during the field campaigns. Finally, the authors thank R. Boivin for her help with the digital cartography.

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Recommended citation:
Short, N., LeBlanc, A.-M., Sladen, W.E., Carbonneau, A.-S., and Allard, M., 2012. Seasonal surface displacement derived from InSAR, Pangnirtung, Nunavut; Geological Survey of Canada, Canadian Geoscience Map 67 (preliminary version), scale 1:5 000. doi:10.4095/289607

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InSAR data by N. Short, 2011

Geology by A.-S. Carbonneau and M. Allard

Cartography (surficial geology) by A.-S. Carbonneau, P. Gosselin, and R. Boivin

Map projection Universal Transverse Mercator, zone 20. North America Datum 1983

Infrastructure and base data provided through the Digital Mapping Data Base, property of the Government of Nunavut.

Ground Control Points provided by Université Laval.

Seasonal ground displacement was derived for Pangnirtung using interferometric synthetic aperture radar (InSAR) data from the summer of 2011. RADARSAT-2 Spotlight scenes on an ascending orbit were acquired on June 12, July 6, July 30, August 23, and September 16. The data were interferometrically stacked and the three months of summer vertical displacement calculated according to the methodology outlined in Short et al. (2011). Each displacement measurement represents an area of approximately 1.5 x 1.5 m on the ground.

CANADIAN GEOSCIENCE MAP 67

SEASONAL SURFACE DISPLACEMENT DERIVED FROM INSAR

PANGNIRTUNG

Nunavut

1:5 000

100 0 100 200 300 400 m

Shaded relief image prepared by A.-S. Carbonneau and derived from digital elevation model created from 50 cm Worldview-2 stereo satellite images acquired July 10, 2010. 1m DEM created using a proprietary stereo image matching process by PhotoSat Information Ltd. Illumination: azimuth 315°, altitude 45°, vertical factor 1x

Proximity of the North Magnetic Pole causes the magnetic compass to be erratic in this area. Magnetic declination 2012, 33°20'W, decreasing 29.2' annually.

The Geological Survey of Canada welcomes corrections or additional information from users.

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CANADIAN GEOSCIENCE MAP 67
(preliminary version)
SEASONAL SURFACE DISPLACEMENT DERIVED FROM INSAR
PANGNIRTUNG
Nunavut

Four trim marks around perimeter of map sheet. Trim map sheet first, then fold at folding marks.

Cover and additional panels are 17cm wide when folded.

ACKNOWLEDGMENTS

This work was produced under the Nunavut Climate Change Partnership Project (Mate and Reinhart, 2011) and supported through collaboration between the Canada-Nunavut Geoscience Office, Université Laval and Natural Resources Canada (Geological Survey of Canada). It also benefitted from geoscience, logistical, and helicopter support from the Geo-mapping for Energy and Minerals (GEM) Program, Cumberland Peninsula project. In particular the authors would like to thank Dr. M. Sanborn-Barrie, Dr. A. Dyke, and M. Young from the GEM Cumberland Peninsula project. The authors would also like to express their thanks to the community of Pangnirtung, in particular to Messrs R. Mongeau, J. Uniushagak, N. Maniapik, and S. Akpaliatuk. This work formed the basis of a M.Sc. thesis (A.-S. Carbonneau, in prep.).

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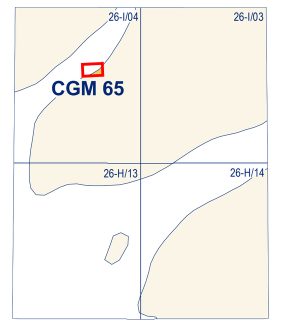
Abstract

The map of surficial geology and periglacial features in Pangnirtung was done to help decision-makers, planners and engineers to better adapt the community to the impacts of climate change. The dominant surface unit on the map consists of colluvium deposits which are ice-rich sandy sediments deposited by overland-flow during snowmelt. Buried soils as old as 7080 cal BP were found imbedded in a colluvium layer. In the eastern sector of town, colluvium 1 to 4 metres thick covers till and a network of ice wedges. It also covers ice-rich marine silts and bedrock in the western sector. The central sector of town is occupied by a coarse, boulder-rich, Holocene outwash fan deposited by the Duval River. An alluvial terrace with boulders and some eroded channels were incised by the river in the fan. Bedrock and thick till deposits are found in the upper river valley and on the slopes of the fjord.

Résumé

La carte des conditions du pergélisol et des formes périglaciaires de Pangnirtung a été produite pour aider les décideurs, les urbanistes et les ingénieurs à mieux adapter la communauté aux impacts des changements climatiques. Des colluvions sableuses riches en glace et mises en place lors du ruissellement printanier occupent la plus grande superficie sur la carte. Des lits de matière organique enfouis et atteignant 7080 cal BP y sont interstratifiés. Dans le secteur est du village, les colluvions, d'une épaisseur de un à quatre mètres, recouvrent un dépôt de till et un réseau de coins de glace. Les colluvions recouvrent des dépôts marins silteux et le roc dans le secteur ouest. Un paléo-cône de déjection d'âge holocène et composé de sable et gravier a été mis en place par la rivière Duval dans le centre du village. Celui-ci a ensuite été incisé par la rivière, entaillant une terrasse alluviale et des chenaux fluviatiles. Un épais dépôt de till et du roc sont retrouvés en amont de la rivière, ainsi que sur les versants de la vallée glaciaire.



National Topographic System reference

Cover illustration:
The beautiful landscape surrounding the hamlet of Pangnirtung. Photograph by A.-S. Carbonneau. 2011-013

Printed map:
Catalogue No. M183-1/65-2011E
ISBN 978-0-660-20141-2
Digital map:
Catalogue No. M183-1/65-2011E-PDF
ISBN 978-1-100-19601-5

doi:10.4095/289504

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CANADIAN GEOSCIENCE MAP 65

(preliminary version)

SURFICIAL GEOLOGY AND PERIGLACIAL FEATURES

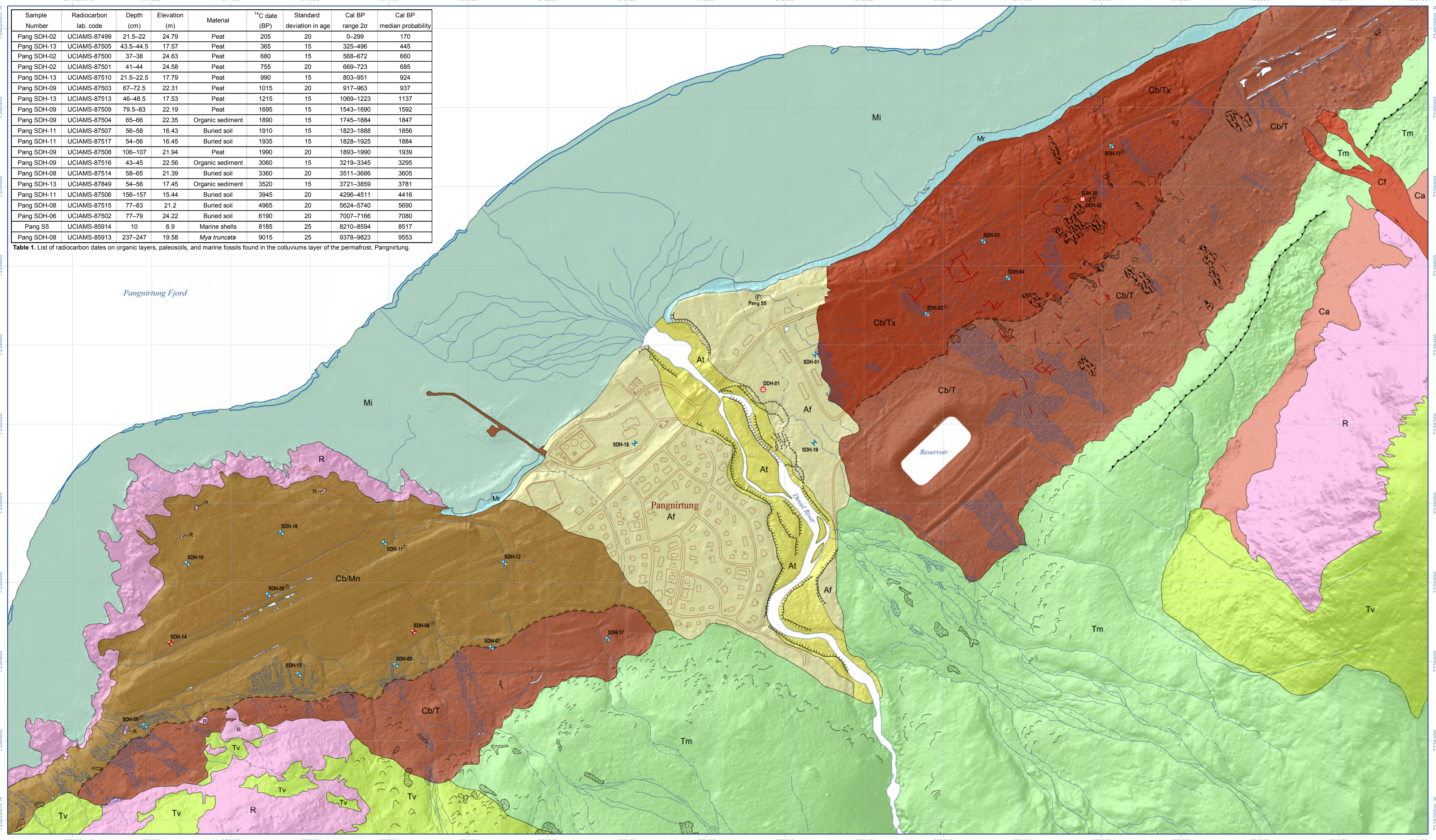
PANGNIRTUNG

Nunavut

1:5 000

Sample Number	Radiocarbon lab. code	Depth (cm)	Elevation (m)	Material	^{14}C date (BP)	Standard deviation in age	Cal BP range 2σ	Cal BP median probability
Pang SDH-02	UCIAMS-87499	21.5–22	24.79	Peat	205	20	0–299	170
Pang SDH-13	UCIAMS-87505	43.5–44.5	17.57	Peat	365	15	325–496	445
Pang SDH-02	UCIAMS-87500	37–38	24.63	Peat	680	15	568–672	660
Pang SDH-02	UCIAMS-87501	41–44	24.58	Peat	755	20	669–723	685
Pang SDH-13	UCIAMS-87510	21.5–22.5	17.79	Peat	990	15	803–951	924
Pang SDH-09	UCIAMS-87503	67–72.5	22.31	Peat	1015	20	917–963	937
Pang SDH-13	UCIAMS-87513	46–48.5	17.53	Peat	1215	15	1069–1223	1137
Pang SDH-09	UCIAMS-87509	79.5–83	22.19	Peat	1695	15	1543–1690	1592
Pang SDH-09	UCIAMS-87504	65–66	22.35	Organic sediment	1890	15	1745–1884	1847
Pang SDH-11	UCIAMS-87507	56–58	16.43	Buried soil	1910	15	1823–1888	1856
Pang SDH-11	UCIAMS-87517	54–56	16.45	Buried soil	1935	15	1828–1925	1884
Pang SDH-09	UCIAMS-87508	106–107	21.94	Peat	1990	20	1893–1990	1939
Pang SDH-09	UCIAMS-87516	43–45	22.56	Organic sediment	3060	15	3219–3345	3295
Pang SDH-08	UCIAMS-87514	58–65	21.39	Buried soil	3360	20	3511–3686	3605
Pang SDH-13	UCIAMS-87849	54–56	17.45	Organic sediment	3520	15	3721–3859	3781
Pang SDH-11	UCIAMS-87506	156–157	15.44	Buried soil	3945	20	4296–4511	4416
Pang SDH-08	UCIAMS-87515	77–83	21.2	Buried soil	4965	20	5624–5740	5690
Pang SDH-06	UCIAMS-87502	77–79	24.22	Buried soil	6190	20	7007–7166	7080
Pang S5	UCIAMS-85914	10	6.9	Marine shells	8185	25	8210–8594	8517
Pang SDH-08	UCIAMS-85913	237–247	19.58	*Mya truncata*	9015	25	9378–9823	9553

Table 1. List of radiocarbon dates on organic layers, paleosoils, and marine fossils found in the colluviums layer of the permafrost, Pangnirtung.



QUATERNARY

HOLOCENE SEDIMENTS

Colluvial deposits

Ca — ***Talus:*** *generally active accumulations of blocks and rubble, as much as 50 m thick forming talus (scree) aprons at angle of repose below cliffs derived from rock falls.*

Cf — ***Bouldery debris flow:*** *blocky to gravelly debris-flow accumulations mixed with scree, 1–50 m thick, traversed by narrow channels and debris levees; interrupt scree slopes (Ca) at the exits of prominent debris hopper in cliff; surface slopes less than angle of repose but steeper than those of alluvial fans.*

Cb/Mn — ***Colluvial blanket*** (Cb) ***over littoral to nearshore sediments*** (Mn)***:*** *colluvium made of sand and gravel layers up to 4 m thick. The underlying marine sediments are composed of gravel, sand and silt; 2–15 m thick depending on the bedrock topography, formed near or at the ice margin.*

Cb/Tx — ***Colluvial blanket*** (Cb) ***over reworked till*** (Tx)***:*** *colluvium made of sand and gravel layers up to 4 m thick on top of pre-existing washed till deposits below the marine limit. A thin peat layer (5 to 25 cm) overlies the colluvial deposit. Affected by periglacial processes such as gelifluction lobes and frost boils. Ice wedges occasionally present in the near surface permafrost.*

Cb/T — ***Colluvial blanket*** (Cb) ***over till*** (T)***:*** *colluvium made of sand and gravel layers up to 4 m thick underlain by a till composed of sand gravel and boulders in a silty-sand matrix; more than 20 m thick. A thin peat layer (5 to 25 cm) overlies the colluvial deposit. Affected by periglacial processes such as gelifluction lobes, frost boils and block fields. Ice wedges occasionally present in the near surface permafrost.*

Alluvial sediments

Af — ***Fan sediments:*** *the fan was built by the Duval River and debris flows during the Holocene forming channels and levees, the sediment consists of gravel, sand, and boulders with detrical organic layers and buried soils.*

At — ***Alluvial terraces:*** *gravel, sand, and boulders in terraces; 1–10 m thick, above limit of actual flooding. Formed during the Late Holocene. Affected by tension cracks along the banks of Duval River.*

Marine sediments

Mi — ***Intertidal sediments:*** *silt and sandy silt deposited in the intertidal zone; mostly boulder mudflats. No permafrost is expected.*

Mr — ***Beach sediments:*** *littoral and nearshore sediments deposited as beaches. Permafrost may be present.*

PLEISTOCENE AND EARLY HOLOCENE

Glacial sediments (Till): *sediments deposited in subglacial and ice-marginal environments.*

Tm — ***Lateral moraine:*** *5–40 m high ridges and hummocks comprised of thick till, forming lateral moraines regarded as the youngest of the Duval moraines during ice-marginal recession. Gelifluction lobes present on the slopes of the moraine. Block fields may also be present.*

Tv — ***Till veneer:*** *Diamicton with silty sand matrix, 0.5–2 m thick and discontinuous; insufficiently thick to mask the relief of underlying bedrock surface.*

PRE-QUATERNARY

R — *Bedrock (Precambrian).*

Frost boil areas

Blockfields: Localized lag concentrations of boulders due to wavewash or fluvial erosion of till matrix

String-structured drainage networks: Poorly organized surface drainage networks

Geological contact

Boulder barricade

Limit of glaciomarine submergence - approximate

Moraine ridge: lateral

Tension cracks caused by collapse of terrain due to thermal erosion

Fluvial terrace scarp

Frost crack (ice wedges)

Gelifluction lobe and sheet terminal margins

Rills and watertracks; running throughout all arctic summer

Rills and watertracks; running occasionally during spring melt

Name — *Radiocarbon dated sample location*

Name — *Thermistor cable location*

Name — *Permafrost coring site*

Name — *Permafrost coring site with radiocarbon dated sample*

Name — *Permafrost coring site with thermistor cable installed*

Name — *Permafrost coring site with thermistor cable installed and radiocarbon dated sample*

Note: Considering the practical importance of shallow depth geological formations and permafrost conditions, three composite map units (Cb/Mn, Cb/T, Cb/Tx) appear on the map.

Recommended citation:
Carbonneau, A.-S., Allard, M., LeBlanc, A.-M., L'Hérault, E., Mate, D., Oldenborger, G. A., Gosselin, P., and Sladen, W. E., 2012. Surficial geology and periglacial features, Pangnirtung, Nunavut; Geological Survey of Canada, Canadian Geoscience Map 65 (preliminary version), scale 1:5 000. doi:10.4095/289504

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Cartes géoscientifiques du Canada

Preliminary

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Surficial and periglacial-permafrost geology mapping based on ground surveys (2009–2010; M. Allard, A-S. Carbonneau, E.L'Hérault, A-M. LeBlanc, and P. Gosselin), and air photo interpretation by A.-S. Carbonneau and M. Allard using 1:6000 scale black and white vertical photos, flight line A24493, August 20, 1976, photos 50–56 and 1:3000 scale black and white vertical photos, flight line A25553, August 1, 1980, photos 96–108.

Cartography by A.-S. Carbonneau, P. Gosselin, and R. Boivin

This project was mandated by the Government of Nunavut.

Ground Control Points provided by Unversité Laval.

Map projection Universal Transverse Mercator, zone 20. North America Datum 1983

Infrastructure and base data provided through the Digital Mapping Data Base, property of the Government of Nunavut.

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PANGNIRTUNG

Nunavut

1:5 000

100 0 100 200 300 400 m

Preliminary

Shaded relief image prepared by A.-S. Carbonneau and derived from digital elevation model created from 50 cm Worldview-2 stereo satellite images acquired July 10, 2010. 1 m DEM created using a proprietary stereo image matching process by PhotoSat Information Ltd.

Illumination: azimuth 315°, altitude 45°, vertical factor 1x.

Proximity of the North Magnetic Pole causes the magnetic compass to be erratic in this area. Magnetic declination 2012, 33°20'W, decreasing 29.2' annually.

Preliminary

The Geological Survey of Canada welcomes corrections or additional information from users.

This publication, including digital data, can be downloaded free of charge from GeoPub (http://geopub.nrcan.gc.ca/). It is also available from the Geological Survey of Canada Bookstore (http://gsc.nrcan.gc.ca/bookstore).

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(preliminary version)
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PANGNIRTUNG
Nunavut

Four trim marks around perimeter of map sheet. Trim map sheet first, then fold at folding marks.

Cover and additional panels are 17cm wide when folded.