Appendix G – Hydrological and Water Balance Study

1. **Hydrological and Water Balance Study Report (EXP) – Grise Fiord (March 18, 2022)**

High Arctic Water Supply & Treatment

Government of Nunavut

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Hydrological and Water Balance Study Report – Grise Fiord

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Business Case for New Water Treatment Facilities and Associated Infrastructures at Grise Fiord

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1 Introduction

1.1 Overview

EXP was retained by the Government of Nunavut – Department of Community and Government Services (GN – CGS) to complete a Business Case for New Water Treatment Facilities and Associated Infrastructures at: Pond Inlet, Arctic Bay, and Grise Fiord.

As part of the project scope, a hydrological and water balance study has been completed for Grise Fiord to determine whether the existing water sources and watershed can provide enough water each year to meet the current and future needs the communities over a 20-year horizon. The water sources that were assessed for Grise Fiord include:

- Grise Fiord
  - Runoff collection basin filled from a seasonal snowpack melt (current source)
  - Airport River seasonal runoff

1.2 Objectives

The objective of this study is to complete a hydrological and water balance study to determine the suitability of the community's existing and potential water sources over a 20-year horizon to the year 2043. The specific tasks of this study include:

- Summary of the hydrologic regime of the system
- Climate characterization and potential impacts on water supply from climate change
- Water balance study evaluating the watershed of the water source against community requirements
- Recommendations for the current water source and its sustainability for the community over the 20-year horizon including identification of secondary sources as required

2 Previous Investigations

2.1 Hydrology Assessment (Draft) – Grise Fiord, Nunavut (Arktis Piusitippaa Inc., 2014)

A desktop study in 2014 provides a high-level hydrological assessment of the potable water source (runoff-fed stream) for the Hamlet of Grise Fiord, Nunavut. Watershed delineation, water supply modelling and a water balance assessment were completed for the snow melt fed stream. The assessment of the study identified that the current water supply relies on snow melt and precipitation; the snow melt and precipitation is susceptible to yearly variations in snowpack and seasonal precipitation, which would directly influence the amount of recharge. Under these circumstances, the community is vulnerable to water shortages due to changing precipitation conditions.

Parameters that were used in the study include:

- Watershed area = 220, 000 m^2
- Precipitation data
  - Weather station in Grise Fiord and Resolute (used to fill in gaps where two or months of missing data)
  - Average annual precipitation (1991-2007) = 177 mm/year
- Evapotranspiration (ET) rate = 192 mm/year (value based on single study performed in Nanisivik by Aboriginal Affairs and Northern Development Canada in 2000)
- Assumed glacier melt – assumed to be equal to that of the Meighen Ice Cap on Meighen Island (Queen Elizabeth Islands) due to the relatively small size of the ice cap
  - Average net balance of Meighen Ice Cap = -160 mm
- Estimated annual runoff from local precipitation and glacier above and behind the mountains of the community = 145 mm. (177mm-192mm+160mm)

However, it appears that the water balance calculations overestimated evapotranspiration losses and inflows due to glacier melt. These discrepancies will be discussed in the subsequent sections within this report.

2.2 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:

- Based on PCIC datasets, Grise Fiord showed statistically increasing precipitation trends
- Overall increasing trends in evapotranspiration (22 out of 24 communities)
- 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:
  - Grise Fiord
    - high/medium level water supply vulnerability threat

    - 27.3 ha (273,000 m^2) – watershed area (glacier melt)
- Most influential factor regarding water supply vulnerability threat levels appears to be the size of the source watershed

3 Background

3.1 Community and Existing Water Supply System

3.1.1 Grise Fiord

The Hamlet of Grise Fiord, Nunavut is located at 76°25’ N latitude and 82°53’ W longitude on the southern section of Ellesmere Island. An aerial view of the community is shown in Figure 3-1 below.

In Grise Fiord the primary water source is melt water from surface runoff which is available for about 45 to 50 days a year during the summer from mid-June to the beginning of August. The runoff is collected in a small collection basin where a hose runs overland to two heated water storage tanks (approximately 4,000,000 litres each) that hold the community’s annual storage. In recent years, there have been structural issues with the tanks, likely due to settlement issues. In the past, tanks were being filled at only 50% capacity. Remediation actions were taken in 2020 but issues persist. The community noted that the tank was leaking in the summer of 2021 and is currently completely empty. A fleet of two trucks distribute water to the community. Chlorination is the only method being used for treatment/disinfection

The community has identified a secondary water source (Airport River) about 400 m northwest of the storage tanks that runs through the west side of the community. On October 15, 2020, the community requested to add Airport River as a secondary water source to the water license. This secondary source has not been recognized by public health authorities as suitable for potable water supply purposes. GN-CGS noted that water drawn from this source may be stored separately and designated for fire demand and other non-potable uses until complete bacteriological and chemical analysis has been completed and approved for use.

Historical documentation and past reports have noted that the existing water basin is recharged by ‘glacier’ melt during a few weeks in the summer. However, reviewing satellite imagery and topographic information, there is little evidence that the runoff basin receives any glacier melt. Historical satellite imagery and topographic information indicate that there are no ice caps within the runoff basin catchment area. The closest ice caps to the community drain into the Airport River watershed. It is likely that the recharge of the existing basin is solely attributed to snow melt and surface runoff. A photo of the existing collection basin is shown in Figure 3-2.

Figure 3-1: Grise Fiord Water Sources

Figure 3-2: Grise Fiord Existing Collection Basin

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
- 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., the inlets for each water source)
- It should be noted that the existing runoff water source for Grise Fiord could not be delineated using ArcGIS and was delineated manually using available topographic maps and existing information.

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 precipitation (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.

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 have been provided using information prepared by the Nunavut Bureau of Statistics (2014).

The 2020 Nunavut Draft Guideline Document "Water Treatment Plant Design" 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. As a comparison, the GNWT water supply standard is 90 lpcd.

Annual historical water use records were reviewed between 2008 to 2020 to determine the actual average recorded daily demands. For Grise Fiord, average recorded daily demand between 2008-2020 was 112 lpcd. However, as determined during the water emergency in 2021, it is very likely that a number of buildings are not being billed for water and billing records are inaccurate. Tank levels and daily truck counts were measured during this period and water usage was approximately 135 lpcd which is higher than historical billing records indicate. The community has implemented some water conservation measures such as installing high water level indicators on the household tanks to reduce risk of overflow and water wastage. Under these measures, water usage has been estimated at around 105-110 lpcd.

The 2020 Nunavut Draft Guideline Document "Water Treatment Plant Design" 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. This consumption rate of 120 lpcd is an appropriate design value as the community has implemented water conservation measures to reduce water use (estimated 105-110 lpcd) and a conservative estimate on population growth has also been considered.

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

	Grise Fiord	
Year	Population	Water Use (m^3/year) *
2021	169	7,423
2043	***200 *****	***8,760***

* Water use based on design value of 120 lpcd

** Based on projections, the population of Grise Fiord is projected to decrease in 2043 – for this study, a conservative value of 200 persons has been used as the population in 2043

3.2.3.3 *Meteorology / Precipitation Data*

- Historical data between 1984 and 2020 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
  - 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 dataset.
  - At many of these weather stations, 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 from the water balance analysis.
  - 30-year Climate Normal Datasets (1981-2010) are available on the Environment and Climate Change Canada website and have been provided to compare average annual precipitation values for other High Arctic communities. With the exception of Hall Beach (68° N), the listed communities are all north of 70° latitude and provide a snapshot of the range of precipitation values that can be found in similar High Arctic environments:
    - Resolute, NU
    - Alert, NU
    - Hall Beach, NU
    - Alert, NU
    - Pond Inlet, NU
    - Nanisivik, NU

Table 3-2: Estimated Annual Precipitation for Study Communities

Annual Precipitation (mm/year)	*Grise Fiord*
Minimum (mm/year)	87
Maximum (mm/year)	304
Median (mm/year)	187
Mean (mm/year)	197
3-year low average	124
5-year low average	132
10-year low average	145
3-year high average	291
5-year high average	281

For context regarding the distribution of precipitation within a year, average monthly precipitation values for various Nunavut weather stations are summarized in Table 3-3 below.

Table 3-3: Average Monthly Precipitation between 1981-2010 for Nunavut Communities

	Average Monthly Precipitation between 1981-2010 (mm)												*Total (mm)*
Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
RESOLUTE	4	4	7	7	9	15	28	34	23	16	10	6	161
ALERT	7	7	8	11	12	12	32	18	22	13	10	7	158
HALL BEACH	6	5	7	12	16	18	26	44	29	24	19	9	215
EUREKA	3	3	2	4	3	8	15	16	10	8	4	4	79
POND INLET	5	4	7	11	9	16	32	39	20	25	14	9	189
NANISIVIK	5	5	8	11	24	25	46	45	38	37	18	7	271

3.2.3.4 ***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 Grise Fiord. For this assignment, a literature review was completed using past research that investigated annual ET in High Arctic environments in Nunavut (above 70°N latitude) and specifically for intermittent river and ephemeral stream systems. These values have been listed in Table 3-4, below.

Table 3-4: Reported Annual ET Rates (mm/year) in High Arctic Environments

Location	Lat (°N)	Long (°W)	Year	Reported Annual ET Rate (mm/year)	Reference Paper
Resolute, NU	74.7	95.0	1978 (July 1 - Aug 31)	61	1
			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	1
			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	1
Ellesmere Island, NU	80.8	72.7	1975 (July 6 - Aug 17)	27	1
Heather Creek, Ellesmere Island, NU	80.0	84.5	1990-1991	86	2
Hot Weather Creek, Ellesmere Island, NU	80.0	84.5	1997	56	3
Devon Island, NU	76.0	85.0	1972-1974	81	2
Bathurst Island, NU	75.7	98.7	2008-2010, 2012	103	2
Melville Island, NU	74.9	109.5	2007-2009	81	2
Ross Point, Melville Island, NU	74.0	107.0	1986	43	2

[1] Kane, D.L., Gieck, R.E., & Hinzman, L.D. (1990). Evapotranspiration from a Small Alaskan Arctic Watershed. *Nordic Hydrology, 21, 253-272.*

[2] 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.*

[3] 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 3-5, below.

Table 3-5: Calculated ET Values Used for Water Balance Calculations

ET Parameter	ET (mm/year)
Minimum ET	27
Maximum ET	103
Median ET	61
Average ET	65
3-year high ET	86

In a previous hydrology study of Grise Fiord (2014), a representative evapotranspiration (ET) rate of 192 mm/year was used. However, this was based off a study in Nanisivik by Aboriginal Affairs and Northern Development Canada (2000) investigating ET rates at open-mine sites in the Northwest Territories and Nunavut. This value is likely to be largely overestimated since the single study was investigating ET rates for an open-water (lake) source – losses from lakes are much larger than losses from terrestrial surfaces.

As a comparison, wetland treatment studies conducted by Dalhousie University and the Government of Nunavut Community and Government Services (GN-CGS) in 2015-2017 estimated annual ET rates from Sanikiluaq, Cape Dorset and Nauujat to be 91, 63 and 65 mm/year, respectively. All three of these Nunavut communities are south of 70°N latitude – ET rates greatly decrease with increasing latitude because of the decrease of solar irradiance and air temperature. The annual surface irradiance in the High Arctic is approximately 2500 $MJ{\bullet}m^{-2}yr^{-1}$ which is almost 60% less than communities in the south (Wang et al., 2015). Typically, communities further south (below 70°N latitude) would experience higher ET values, which illustrates that the chosen ET values for the High Arctic communities are appropriate for the conservative approach applied for the purposes of this screening study.

3.2.3.5 *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 and above average values for evapotranspiration (ET). The worst-case would be represented as Scenario 1, with minimum precipitation and maximum ET.

Table 3-6: 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 Grise Fiord

4.1.1 Watershed Delineation

The watershed areas for the existing runoff source and Airport River are shown in Figure 4-1, below. Table 4-1 presents the delineated watershed areas for the two water sources.

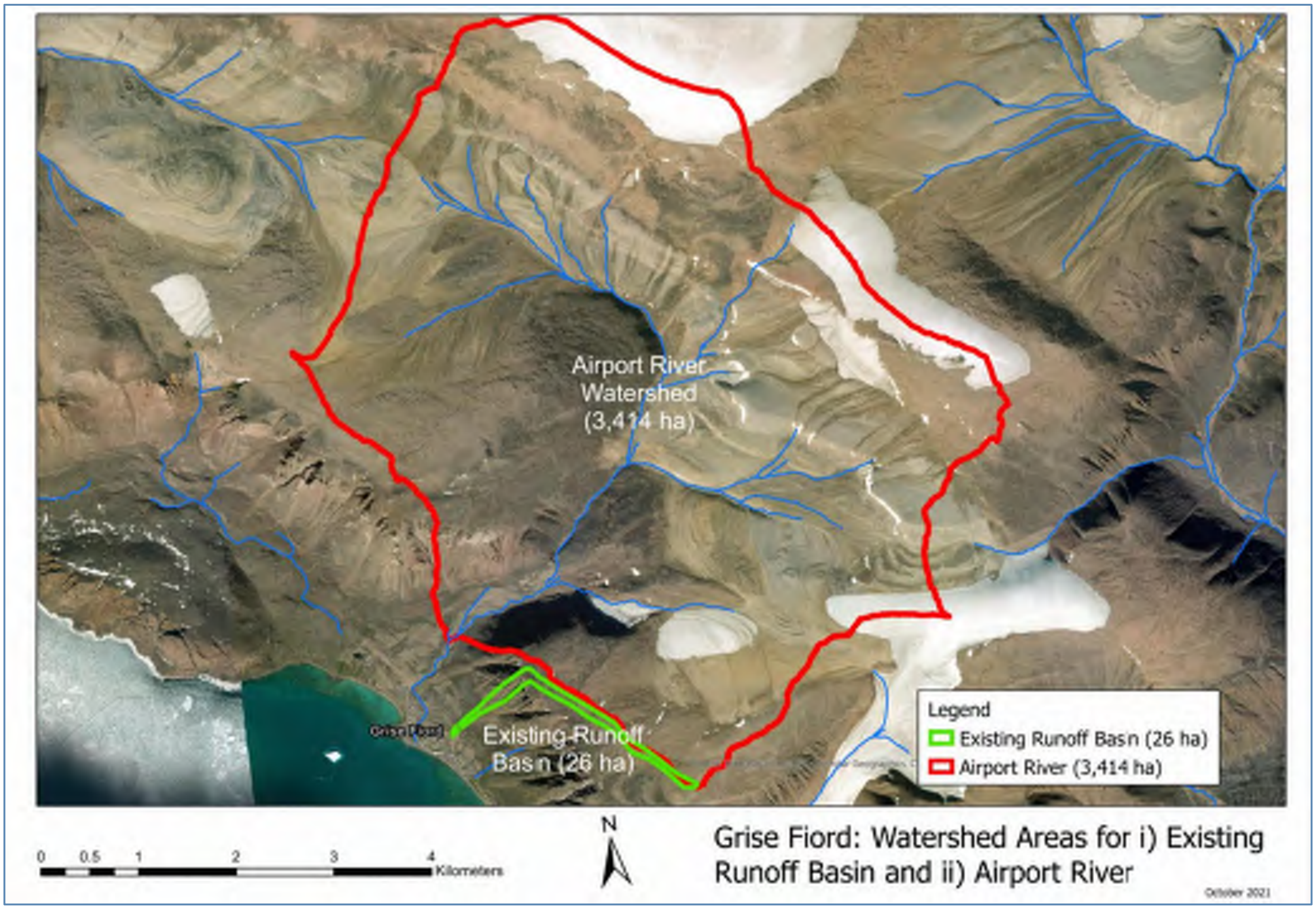


Figure 4-1: Grise Fiord Watersheds

Table 4-1: Grise Fiord Delineated Watershed Areas

Community	Water Source	Watershed Area (m^2)	Watershed Area (ha)
Grise Fiord	Runoff Basin	262,473	26
	Airport River	34,139,893	3,414

4.1.2 Water Balance and Water Source Assessment

The results showing the amount of potential annual runoff for the community of Grise Fiord are presented in Table 4-2, below.

As discussed previously, a review of historical satellite imagery and topographic information indicate that the existing water basin recharge is likely attributed to snow melt and surface runoff (not glacier melt). As a conservative approach, only annual precipitation values have been used as water inputs in the water balance calculations.

Table 4-2: Grise Fiord Potential Runoff Analysis

Scenario No.	Precipitation Scenario	ET Scenario	Precipitation (mm/year)	Estimated ET (mm/year)	Potential Runoff (mm/year)
1	minimum	maximum	87	103	-16
2	minimum	3-year high	87	86	1
3	minimum	average	87	65	22
4	3-year low	maximum	124	103	21
5	3-year low	3-year high	124	86	38
6	3-year low	average	124	65	59
7	5-year low	maximum	132	103	29
8	5-year low	3-year high	132	86	46
9	5-year low	average	132	65	67
10	10-year low	maximum	145	103	42
11	10-year low	3-year high	145	86	59
12	10-year low	average	145	65	80
13	Median	maximum	187	103	84
14	Median	3-year high	187	86	101
15	Median	average	187	65	122

The results of the water balance analysis for the two water sources for Grise Fiord are presented in Table 4-3, below.

Table 4-3: Grise Fiord Water Balance Analysis

GRISE FIORD		EXISTING RUNOFF SOURCE		AIRPORT RIVER	
Scenario No.	2043 Water Use (m^3/year)	Runoff (m^3/year)	ΔS > 0	Runoff (m^3/year)	ΔS > 0
1	8,760	-4,095	NO	-532,582	NO
2	8,760	367	NO	47,796	YES

3	8,760	5,879	NO	764,734	YES
4	8,760	5,416	NO	704,420	YES
5	8,760	9,878	YES	1,284,798	YES
6	8,760	15,390	YES	2,001,736	YES
7	8,760	7,654	NO	995,519	YES
8	8,760	12,116	YES	1,575,897	YES
9	8,760	17,628	YES	2,292,835	YES
10	8,760	11,047	YES	1,436,948	YES
11	8,760	15,510	YES	2,017,326	YES
12	8,760	21,021	YES	2,734,264	YES
13	8,760	21,956	YES	2,855,802	YES
14	8,760	26,418	YES	3,436,180	YES
15	8,760	31,930	YES	4,153,118	YES

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 model:

- for the existing runoff source, the water source cannot meet the community's water supply needs in 5 out of the 15 scenarios where the community is experiencing either minimum precipitation and/or maximum ET
- for Airport River, the only instance where water supply needs are not met occurs if the community experiences the worst-case scenario (Scenario 1 - minimum recorded precipitation and highest ET).

5 Discussion

5.1 Hydrologic Regime

Snow constitutes the majority of the total annual precipitation in the community of Grise Fiord. The watershed basins within Grise Fiord are associated with snowfall and snowmelt-generated runoff, which characterizes a nival regime streamflow. These nival regimes are characterized by very low or negligible winter flows (typically from October to early May). 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) and decreases substantially throughout the summer.

Runoff ratio, the ratio between runoff and precipitation, are typically high for polar deserts and glacierized basins (Young and Woo, 2004). In the late spring/summer, high solar radiation causes rapid snowmelt where over 80-90% of the annual runoff flow occurs within a few weeks period. Timing and duration of the melt season depends on the weather and end-of-winter snow conditions. After snowmelt, flow generally declines rapidly. The presence of permafrost at shallow depths prevents infiltration.

5.2 Grise Fiord

5.2.1 Water Balance Scenarios

Water Balance Scenarios for Grise Fiord were studied for 2 water sources:

i. Existing surface water runoff basin

ii. Airport River

Based on the water balance assessment, the existing runoff source cannot meet the community's water supply needs in 5 out of the 15 scenarios, where the community is experiencing either minimum precipitation and/or maximum ET. This is likely due to the small catchment area for the existing runoff basin (262,473 m^2).

In a study investigating vulnerability levels of municipal drinking water supplies for the communities in Nunavut, Hayward et al. (2020), 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 high- to medium- level water supply vulnerability threat for Grise Fiord based on the worst-case scenario assessment (minimum precipitation and maximum ET scenario) which is consistent with the results from this assessment (assuming using only the existing runoff basin).

For the alternative water source, Airport River, the only instance where water supply needs are not met occurs if the community experiences the worst-case scenario (Scenario 1 - minimum recorded precipitation and highest ET). The catchment area for Airport River is quite large at 34,139,893 m^2. In general, any net-positive annual runoff for Airport River will provide sufficient water supply for the community's water supply needs.

Based on catchment areas, the following net positive annual runoffs would be required to meet the 2043 annual water demand for the community (8,760 m^3/year):

i. Existing runoff basin – 33 mm

ii. Airport River – 0.3 mm

Historical documentation and past reports have noted that the existing water basin is recharged by 'glacier' melt during a few weeks in the summer. However, reviewing satellite imagery and topographic information, there is no evidence that the runoff basin receives any glacier melt. Historical satellite imagery and watershed delineation using topographic information shows that there are no ice fields within the existing runoff basin catchment area. The closest ice fields to the community drain into the Airport River watershed. It is likely that the recharge of the existing basin is solely attributed to snow melt and surface runoff.

The existing source and community supply is vulnerable and susceptible to changes in precipitation and ET. To improve the resiliency of the community's water supply, it is recommended to use Airport River as either the primary or secondary source.

5.2.2 Operational Considerations and Recommendations

As noted above, it is recommended to use Airport River as either the primary or secondary water source for the community of Grise Fiord over the next 20 years. Airport River provides a much larger catchment area compared to the existing runoff source and can be used as a reliable water source. The Airport River watershed contains visible ice fields that will provide additional water quantity inputs.

Airport river is approximately 300 m away from the existing storage tanks and runs through the west side of the community. This secondary source has not been recognized by public health authorities as suitable for potable water supply purposes. Additional water quality sampling including complete bacteriological and chemical analysis is recommended to confirm the Airport River as a viable potable water source.

In determining the location of a new intake to access the Airport River, the proximity of the airport needs to be considered. In the vicinity of the airport, the river widens considerably but increases the risk of industrial (fuel) contamination. Upstream of the airport, the terrain for construction is more challenging but the risk of contamination is greatly reduced. Depending on the location of the new water treatment plant, upgrades to access the river and intake infrastructure are likely required.

In Grise Fiord the primary water source is melt water which is available for about 45 to 50 days a year during the summer from mid-June to the beginning of August. It has been reported that in some years, this window is as short as three weeks. Thus, the community needs their raw water storage to last for 12 months. Currently, the community has two heated welded steel tanks with an operational capacity of approximately 4,000 m^3/tank (8,000 m^3 in total). One tank was built around 1986 (Tank A) and the other in 2002 (Tank B). However, structural/settlement issues were identified with Tank B in 2020. Remediation actions were taken in 2020 but issues persist. The community noted that the tank was leaking in the summer of 2021 and is currently completely empty.

As Grise Fiord collects its annual supply of drinking water over the period of a few weeks in the summer, the new WTP will require the construction of new raw water storage tanks with a total capacity of approximately 9,650 m3. The potential to reuse the existing raw water tanks is not possible due to notable and ongoing settlement and structural issues.

5.2.3 Recommended Sampling Program

In addition to water quality samples, a field program to quantify the estimated flow rate of the Airport River is recommended for next season and may include the following:

- The flow regime and water quality are not well understood for the Airport River water source and requires further investigation
    - Flow quantification (flow gauges) and timing dates during the flow/melt period
        - Measuring flow areas and depths of flow during the flow period to provide information for the design of the intake and truck pad infrastructure
    - Water quality analysis

        - Recommend sampling at a minimum twice weekly (preferably daily) during the flow season to understand the temporal water quality fluctuations that occur over the flow period and to confirm optimal dates for raw water collection

- Testing to determine an appropriate location for the new raw water intake at the Airport River
    - Water quality sampling upstream and downstream of the Airport runway to investigate if there is any fuel/chemical contamination coming from the surrounding development

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 community of Grise Fiord with consideration to climate change, population growth, and existing water infrastructure. This study focuses solely on water quantity and does 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.

Evapotranspiration 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 evapotranspiration rates in similar High 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 and micro-topographical features have a significant influence on evapotranspiration rates. There is a large spatial and temporal variability in geomorphic and climatic drivers of evapotranspiration which makes it difficult to predict evapotranspiration rates in the absence of any field data. As precipitation and evapotranspiration 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 all the sites. As discussed previously, the existing water source at Grise Fiord was noted to be recharged by 'glacier' melt. However, available imagery and topographic information suggest that this is incorrect, and that the watershed is only being recharged via snowmelt and runoff. The nearby Grise Fiord glaciers and ice caps have not been quantified and known characteristics are very limited. As such, these potential water inputs have been omitted from the water balance analysis.

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.

7 Conclusions

7.1 Grise Fiord

For the community of Grise Fiord. it is recommended to use Airport River as either the primary or secondary water source. Airport River provides a much larger catchment area compared to the existing runoff source and can be used as a reliable water source.

Airport River has not been recognized by public health authorities as suitable for potable water supply purposes or used in the past as a potable water source and thus, additional water quality sampling including comprehensive bacteriological and chemical analysis is recommended. This includes multiple samples at potential locations for a new water intake at both upstream and downstream of the airport to identify and quantify the risk of industrial (fuel) contamination.

In addition to water quality samples, a field program to quantify the estimated flow rate of the Airport River is recommended for next season and may include the following:

- The flow regime and water quality are not well understood for the Airport River water source and requires further investigation
    - Flow quantification (flow gauges) and timing dates during the flow/melt period
        - Measuring flow areas and depths of flow during the flow period to provide information for the design of the intake and truck pad infrastructure
    - Water quality analysis
        - Recommend sampling at a minimum twice weekly (preferably daily) during the flow season to understand the temporal water quality fluctuations that occur over the flow period and to confirm optimal dates for raw water collection
- Testing to determine an appropriate location for the new raw water intake at the Airport River
    - Water quality sampling upstream and downstream of the Airport runway to investigate if there is any fuel/chemical contamination coming from the surrounding development

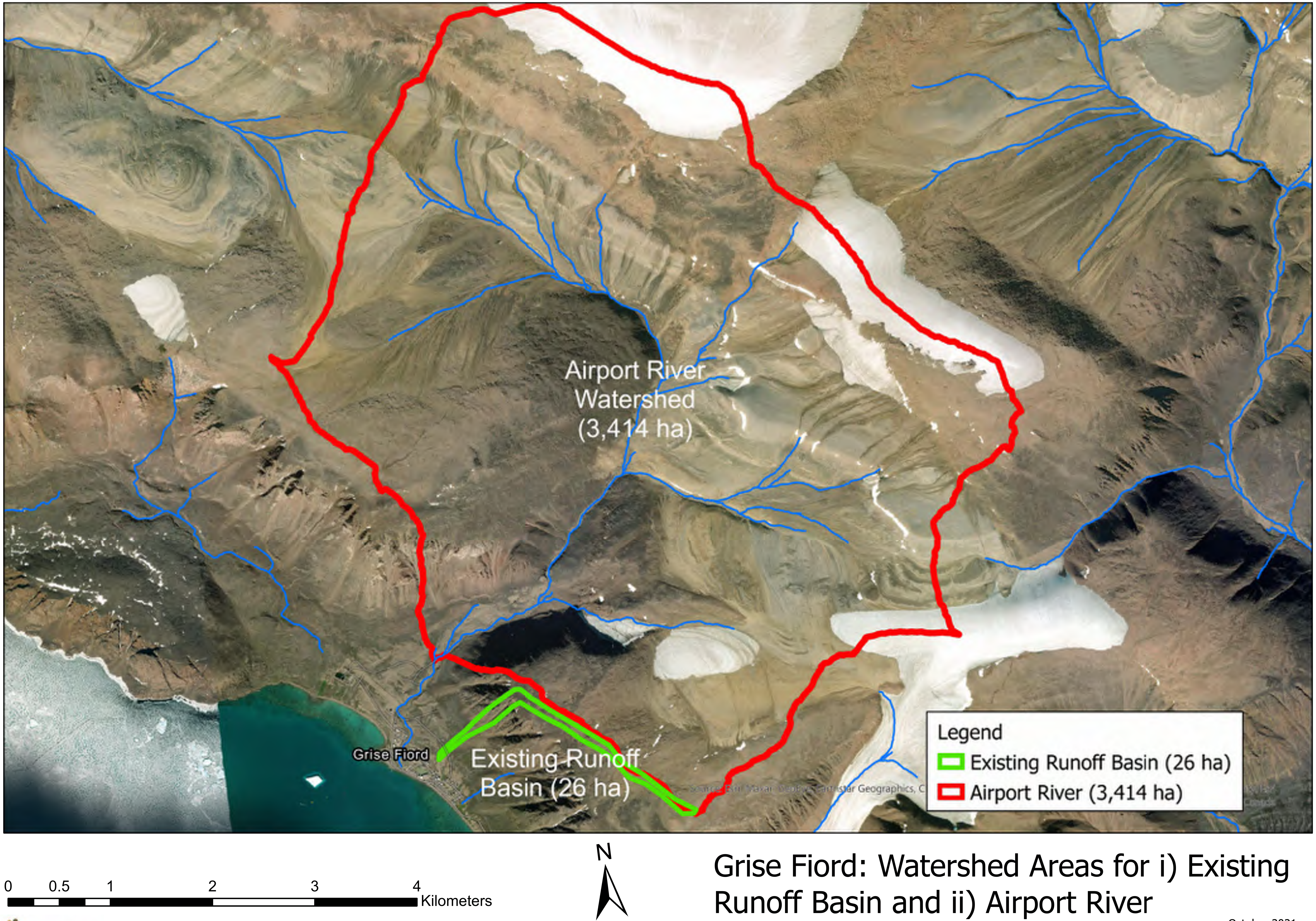
Depending on the location of the new water treatment plant, upgrades to access the river and intake infrastructure are likely required.

As Grise Fiord collects its annual supply of drinking water over the period of a few weeks in the summer, the new WTP will require the construction of new raw water storage tanks with a total capacity of approximately 9,650 m3. The potential to reuse the existing raw water tanks is not possible due to notable and ongoing settlement and structural issues.

8 References

- Arktis Piusitippaa Inc. (2014). Hydrology Assessment Grise Fiord, Nunavut, Draft. Pond Inlet, NU, November 17, 2014.
- Centre for Water Resource Studies (2017). Wetland Treatment Area Study in Cape Dorset, Nunavut. Dalhousie University, Halifax, NS, January 2017.
- Centre for Water Resource Studies (2017). Wetland Treatment Area Study in Naujaat, Nunavut. Dalhousie University, Halifax, NS, January 2017.
- Centre for Water Resource Studies (2017). Wetland Treatment Area Study in Sanikiluaq, Nunavut. Dalhousie University, Halifax, NS, February 2017.
- Cold Regions Utilities Monograph, 1996.
- Good Engineering Practice for Northern Water and Sewer Systems (2nd Edition), 2017.
- Hayward, J., Johnston, L., Jackson, A., & Jamieson, R. (2020). Hydrological Analysis of Municipal Source Water Availability in the Canadian Arctic Terriotiry of Nunavut. *Journal of Arctic Institute of North America*, 74(1), 30-41.
- Kane, D.L., Gieck, R.E., & Hinzman, L.D. (1990). Evapotranspiration from a Small Alaskan Arctic Watershed. *Nordic Hydrology, 21, 253-272.*
- Wang, S., Pan, M., Mu, Q., Shi, X., Mao, J., Brummer, C., Jassal, R.S., Krishnan, P., Li, J. & Black, T.A. (2015). Comparing Evapotranspiration from Eddy Covariance Measurements, Water Budgets, Remote Sensing, and Land Surface Models over Canada. *Journal of Hydrometeorology, 16, 1540-1560.*
- Water Treatment Plant Design, Nunavut Guideline Document (Phase 4), Dillon Consulting Limited, August 2020.
- 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.*
- Young, K.L. & Woo, M.K. (2004). Queen Elizabeth Islands: water balance investigations. *Northern Research Basins Water Balance, 290, 152-163.*

Appendix A – Watershed Delineation Maps



Grise Fiord: Watershed Areas for i) Existing Runoff Basin and ii) Airport River

October 2021

exp.

Appendix B – Precipitation Data

Compiled Precipitation Data from Environment Canada Historical Records

** data omitted if more than 3 months missing from a year

** Nanisavik data used

Year	Annual Precipitation (mm) Arctic Bay / Nanisavik	Pond Inlet	Grise Fiord
1977			
1978	188.6		
1979	238.8		
1980			
1981	211.6		
1982	211.7		
1983	210.1		
1984	306.5	162.4	
1985	320.6	256.1	270
1986	151.5	191	217.3
1987	236.1	185	
1988	221.9		
1989	216.4	159.5	
1990	136.8	178.1	
1991	319.4	197.8	296.3
1992	149.3	199.8	138.4
1993	235.7	102.2	105.9
1994	227.4		149.1
1995	210.3	247	222.9
1996		252.4	220.7
1997		207	157
1998		247.1	148.5
1999		142.2	87.4
2000	229.6	114.8	141.4
2001	196.3	120.4	193.9
2002	361.4	297.6	235.2
2003	333.3	227.4	179.4
2004	304.7	230	228.6
2005	501.6	225.2	177.2
2006	455.4	192.4	165.9
2007	455.4		
2008		244.2	
2009		155.6	151.1
2010		149.2	303.6
2011		96.4	168.9
2012	114.5	190.7	295.5
2013		124.7	279.9
2014		184.7	126.6
2015		122.8	
2016		194.9	264.7
2017		476.3	
2018	112.1	219.3	167
2019	125.1	188.3	218.7
2020	98.6	133.1	204.5

Annual Precipitation (mm/year)	Arctic Bay / Nanisivik	Pond Inlet	Grise Fiord
Minimum (mm/year)	99	96	87
Maximum (mm/year)	502	476	304
Median (mm/year)	222	191	187
Mean (mm/year)	244	195	197
3-year low average	137	123	143
5-year low average	150	129	146
10-year low average	179	145	156
3-year high average	338	249	272
5-year high average	328	244	256

Longitude (x)	Latitude (y)	Station Name	Climate ID	
-85.01	72.99	ARCTIC BAY CS	2400404	
-82.9	76.42	GRISE FIORD CLIMATE	2402351	
-84.62	72.98	NANISIVIK A	2402730	
-77.96	72.69	POND INLET CLIMATE	2403204	
-77.97	72.69	POND INLET A	2403201	**1975-2007

Grise Fiord Historical Precipitation Data

Station Name	Grise Fiord Climate
Climate ID	2402351
WMO ID	71971
Latitude	76°25'22.040" N
Longlitude	82°54'08.020" W
Elevation	44.50m

Year	Annual Precipitation (mm)	Used for Analysis (Y or N)	Comments
1984	99.8	N	* 7 months missing
1985	270	Y	* 2 months missing
1986	217.3	Y	*2 months missing
1987	76.8	N	* 6 months missing
1988	116	N	* 4 months missing
1989	38.6	N	*4 months missing
1990	102.8	N	*4 months missing
1991	296.3	Y	
1992	138.4	Y	*1 month missing
1993	105.9	Y	
1994	149.1	Y	
1995	222.9	Y	
1996	220.7	Y	* 2 months missing
1997	157	Y	*1 month missing
1998	148.5	Y	
1999	87.4	Y	*1 month missing
2000	141.4	Y	
2001	193.9	Y	
2002	235.2	Y	
2003	179.4	Y	
2004	228.6	Y	
2005	177.2	Y	
2006	165.9	Y	
2007	61.7	N	*3 months missing
2008	43.2	N	* 5 months missing
2009	151.1	Y	
2010	303.6	Y	
2011	168.9	Y	
2012	295.5	Y	
2013	279.9	Y	
2014	126.6	Y	*71 days missing
2015	86.3	N	*161 days missing
2016	264.7	Y	*60 days missing
2017	132.9	N	*95 days missing
2018	167	Y	*31 days missing
2019	218.7	Y	*43 days missing
2020	204.5	Y	

	Total Precip (mm/year)
min	87.4
max	303.6
median	179.4
mean	197.0