KEEYASK GENERATION PROJECT

STAGE IV STUDIES - PHYSICAL ENVIRONMENT

HISTORICAL CLIMATE ANALYSIS

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PREPARED FOR:
HYDRO POWER PLANNING DEPARTMENT
POWER PROJECTS DEVELOPMENT DIVISION
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KEEYASK
Hydropower Limited Partnership

Manitoba Hydro

Keeyask Generating Station (Axis GR-4)
Physical Environment Studies

Technical Memorandum GN-9.5.1
Rev. 0, February 29, 2012

Historical Climate Analysis
Manitoba Hydro File 00195-11100-00175_01

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KEEYASK GENERATING STATION
PHYSICAL ENVIRONMENT STUDIES
TECHNICAL MEMORANDUM GN-9.5.1
HISTORICAL CLIMATE ANALYSIS

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INTEROFFICE MEMORANDUM

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DATE 02/29/2012

FILE 00195-11100-00175_01

SUBJECT Memo # GN-9.5.1

Enclosed is the Historical Climate Analysis Technical Memorandum # GN-9.5.1 for the Keeyask Generation Project Stage IV Studies- Physical Environment. The objective of this study was to characterize the existing climate and identifying any significant climate trends in the immediate Keeyask Generating Station study area. The data to undertake this study was obtained from the Gillam and Thompson Environment Canada Airport meteorological stations.

This technical memorandum is to be used in support of the Keeyask Generating Station Environmental Impact Statement. In order to provide appropriate interpretation and guidance, please consult the Water Resources Engineering Department prior to external distribution.

If you have any questions regarding this report please feel free to contact me at 204-360-6318 or at kkoenig@hydro.mb.ca.

Regards,

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EXECUTIVE SUMMARY

Historical Climate Analysis memo No. GN-9.5.1 characterizes the climate in terms of precipitation, temperature and wind and identifies any significant climate trends with respect to temperature, precipitation and wind in the immediate Keeyask Generating Station (Keeyask) study area. The two meteorological stations closest to Keeyask that maintain a comprehensive long-term record are the Gillam and Thompson Airport meteorological stations (Gillam A and Thompson A). Gillam A is located on the east side of Stephens Lake approximately 35 km east of the Keeyask study area and Thompson A is located on the north side of Paint Lake Provincial Park approximately 177 km south-west of Keeyask study area. Gillam A is considered to be representative of the Keeyask climate while the analysis of Thompson A is included for comparative purposes.

The average annual temperature in this study area for the period of 1971 to 2000 is approximately −4.2°C and −3.2ºC for Gillam A and Thompson A respectively. The annual average precipitation is 499 mm at Gillam A and 517 mm at Thompson A. Rainfall accounts for approximately 63% of the total annual precipitation while snowfall accounts for 37% at Gillam A and 67% rainfall and 33% snowfall at Thompson A. Average wind speed in the study area ranges from 14.0 km/hr to 17.8 km/hr at Gillam A and 9.5 km/h to 13.2 km/h at Thompson A. On an annual basis, the predominant wind direction is from the west.

A trend analysis was performed on temperature, precipitation and wind data for the Gillam A and Thompson A using the adjusted historical Canadian Climate Data. Adjusted historical data are specifically designed for climate change analysis over Canada as well as for performing trend analysis on climate variables. The Mann-Kendall test for trend against randomness (Wang et al., 2001 and Zhang et al., 2000) was carried out for the time series of monthly mean precipitation, minimum temperature, maximum temperature, average temperature and mean monthly wind speeds to determine the statistical significance of each trend.

Statistically significant upward seasonal trends were observed for minimum, maximum and mean temperatures at Gillam A. Thompson A indicates significant upward trends for mean and maximum temperature in winter. In comparison to Gillam A, Thompson A exhibited generally larger upward trends for the winter season. A significant downward trend was observed for annual precipitation at Thompson A while Gillam A did not indicate any significant precipitation trends. For mean wind speed, no significant trends were found at Gillam A, however, significant upward trends were found at Thompson A.

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1 INTRODUCTION

In accordance with the requirements for the Keeyask Generating Station Project (Keeyask) Environmental Impact Studies, this memo aims to characterize the existing climate of the Keeyask study area (in terms of **precipitation**, temperature, and wind) and to identify any climate trends. This information will assist in determining the potential effects of climate on the project itself. The information presented needs to be taken in perspective as it is understood that historical climate will not necessarily be representative of future climate due to **climate change**.

1.1 STUDY AREA

Within the Keeyask site there are two meteorological stations that maintain a comprehensive long-term record; Gillam Airport, (Gillam A) with Environment Canada ID#:5061001 and Thompson Airport, (Thompson A) with Environment Canada ID#:5062922. Gillam A is located on the east side of Stephens Lake approximately 35 km east of the Keeyask study area, and Thompson A is located on the north side of Paint Lake Provincial Park approximately 177 km south-west of Keeyask study area (Figure 1). The climate data obtained from the Gillam A meteorological station has been relied upon as indicative of the long-term conditions found within the Keeyask study area, while Thompson A has been used for comparative purposes.

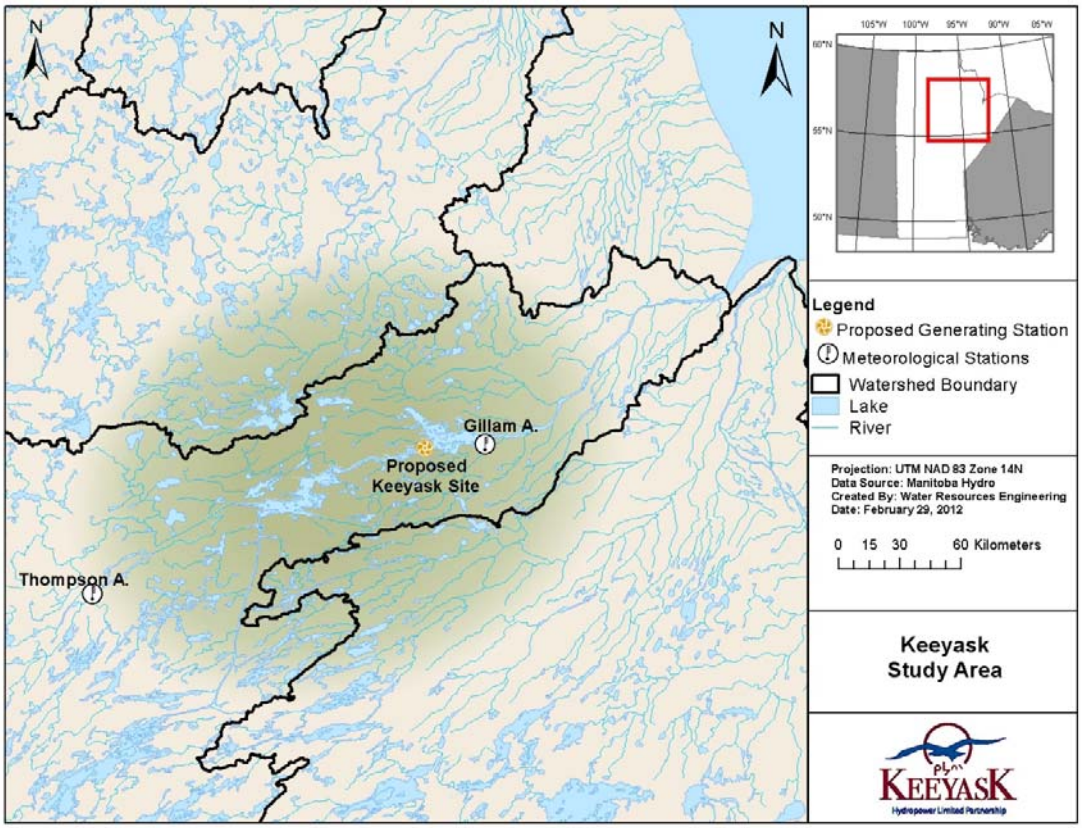

Figure 1: Study Location

2 EXISTING ENVIRONMENT

2.1 ENVIRONMENTAL INFLUENCES

The Keeyask study area is located within a colder subdivision of the High Boreal Eco-climatic Region in Manitoba (Smith et al., 1998). Keeyask is also located within the sub-arctic climate zone which is characterized by long, usually very cold winters, and short, cool to mild summers (Smith et al., 1998).

2.2 CLIMATE NORMALS

2.2.1 APPROACH AND METHODOLOGY

Climate normals from Environment Canada are used to describe the climatic characteristics of the study area. Climate Normals are arithmetic calculations based on weather observations at a given location over a specified time period. The World Meteorological Organization (WMO) describes normals as averages of climatological data computed for periods of 30 consecutive years. The WMO considers thirty years as a

sufficient amount of time to eliminate year-to-year variations (i.e. natural climate variability) and has set the current thirty year period to 1971-2000.

Climate normals representing averages (i.e. temperature and wind data) were calculated by applying the '3/5' rule that states if more than 3 consecutive daily values are missing or more than 5 daily values (in total) in a given month are missing, the monthly mean should not be computed and the year-month mean should be considered missing (Environment Canada, 2005). For normals representing totals (i.e. precipitation data), an individual month must be 100% complete (Environment Canada, 2005). The climate normals in this study were calculated by Environment Canada for the period of 1971-2000.

2010 Homogenized temperature and adjusted precipitation data over the 1971-2000 period was used to evaluate if any changes to instrumentation, station relocations and changes to observing practices were present during this period (Environment Canada, 2010). If significant changes exist then adjustments to the climate normals for the 1971-2000 period would be required. Homogenized and adjusted data was obtained from Environment Canada.

Growing degree days are a measure of heat accumulation typically used to predict the growth of vegetation or the life cycle of insects. Growing degree days are calculated by averaging the daily maximum and minimum temperatures and then subtracting a threshold base temperature. The base temperature is defined as the minimum temperature the organism requires for growth. Since not all organisms respond to temperature equally, the base temperature is species dependent. Typically a base temperature of 5°C or 10°C is used. An average growing degree days for the 1971-2000 period was calculated using both base temperatures.

The frost-free season is the period normally free of sub-freezing temperatures. **Frost-free days** are calculated as the number of consecutive days where the minimum temperature is above 0°C. In other words it is the period from the last frost in spring to the first frost in autumn. The measure of frost-free days are typically used to determine the length of the growing season for vegetation.

2.2.2 TEMPERATURE

2.2.2.1 NORMALS AND EXTREMES

The average annual temperature in this study area is approximately −4.2°C and −3.2ºC for Gillam A and Thompson A respectively. Table 1 along with Figure 2 and Figure 3 show the temperature climate normals for the Gillam A and Thompson A meteorological stations. An examination of extreme events indicates that isolated temperature events occur outside of the established normals. For example, the most pronounced extreme

maximum and extreme minimum recordings at Gillam A were +36.8°C in June of 2002 and -46.1°C in January 1975. Thompson A recorded extreme values of +37.4°C in June 1995 and −48.9°C in January 1968.

- For the winter months of December, January and February average daily temperatures for the two stations range from -25.8°C to -20.4°C. The average daily minimum temperatures range between -30.5°C and -27.0°C and daily maximums between -21.0°C and -13.7°C. The most extreme minimum daily temperature recorded, -48.9ºC, occurred at Thompson A on January 8, 1968. The most extreme maximum daily temperature recorded, +8.2ºC, occurred at Thompson A on February 28, 1993.

- For the spring months of March, April and May average daily temperatures for the two stations range from -15.1°C and 6.5°C. The average daily minimum temperatures range between -21.9°C to -0.4°C and daily maximums between -8.2°C to +13.4°C. The most extreme minimum daily temperature recorded, -48.3°C, occurred at Thompson A on March 1, 1972. The most extreme maximum daily temperature recorded, +32.6°C, occurred at Thompson A on May 27, 1986.

- For the summer months of June, July and August average daily temperatures for the two stations range from +11.4°C and +15.8°C. The average daily minimum temperatures range between +5.0°C to +9.2°C and daily maximums between +17.8°C and +22.7°C. The most extreme minimum daily temperature recorded, -10.2°C, occurred at Gillam A. on June 2, 1977. The most extreme maximum daily temperature recorded, +37.4°C, occurred at Thompson A on June 18, 1995.

- For the autumn months of September, October and November average daily temperatures for the two stations range from -12.1°C and +7.2°C. The average daily minimum temperatures range between -16.6°C to +2.6°C and daily maximums between -8.1°C to +12.8°C. The most extreme minimum daily temperature recorded, -41.1°C, occurred at Thompson A, on November 28, 1985. The most extreme maximum daily temperature recorded, +32.2°C, occurred at Thompson A on September 6, 1967.

The winter freeze-up (or winter condition) begins when the cumulated air temperatures (also called the freezing index) start to decrease. Winter conditions correspond, approximately, to the period when average daily temperatures remain below 0°C. In the study area, winter conditions are considered to exist during the five-month period of November through March. Correspondingly, summer conditions are recognized as the four-month period of June through September, when the mean daily minimum temperatures exceed 0°C. April, May and October comprise short intermediary periods between the dominant seasonal conditions of winter and summer. April, May and October

are characterized by mean daily maximum temperatures above 0°C, and mean daily minimum temperatures below 0°C.

Table 1: Temperature Normals (1971-2000) and Extremes at Gillam A and Thompson A

Sta.	Temp (°C)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yr
Gillam A	Avg	-25.8	-22.0	-15.1	-4.7	4.4	11.4	15.3	13.9	7.0	-0.4	-12.1	-22.5	-4.2
	Std Dev	3.5	3.7	3.3	3.0	2.2	1.8	1.5	1.7	1.8	2.1	3.4	3.9	1.2
	Max	-21.0	-16.3	-8.2	1.7	10.5	17.8	21.4	19.6	11.4	3.1	-8.1	-17.8	1.2
	Min	-30.5	-27.7	-21.9	-11.1	-1.8	5.0	9.2	8.2	2.6	-4.0	-16.1	-27.1	-9.6
	Extr Max	2.9	4.6	19.0	28.7	32.4	**36.8**	35.2	35.1	31.0	22.4	9.5	2.6	
	Date (yyyy/dd)	2003/ 07	1996/ 22	2000/ 14	1980/ 30	1986/ 27	**2002/ 29**	2007/ 24	1991/ 11	1996/ 01	1984/ 10	1978/ 01	1999/ 25	
	Extr Min	**-46.1**	-45.0	-42.6	-32.2	-22.8	-10.2	-1.7	-1.7	-9.1	-26.9	-39.4	-45.1	
	Date (yyyy/dd)	**1975/ 21**	1972/ 16+	1995/ 08	1977/ 06	1983/ 15	1977/ 02	1972/ 02	1979/ 23	1981/ 29	1997/ 30	1989/ 24	2004/ 24	
Thompson A	Avg	-24.9	-20.4	-12.9	-2.2	6.5	12.6	15.8	14.1	7.2	0.0	-12.0	-22	-3.2
	Std Dev	3.6	3.9	3.2	2.8	2.1	1.6	1.4	1.9	1.6	2.0	3.7	4.0	1.1
	Max	-19.4	-13.7	-5.2	4.9	13.4	19.7	22.7	21.0	12.8	4.3	-7.3	-16.7	3.0
	Min	-30.5	-27.0	-20.5	-9.2	-0.4	5.5	8.9	7.2	1.5	-4.3	-16.6	-27.2	-9.4
	Extr Max	8.1	8.2	19.1	29.4	32.6	**37.4**	35.9	34.6	32.2	24.6	13.4	5.0	
	Date (yyyy/dd)	1993/ 30	1993/ 28	1995/ 07	1980/ 30	1986/ 27	**1995/ 18**	1989/ 22	1991/ 11	1967/ 06	1984/ 09	1978/ 02	1988/ 01	
	Extr Min	**-48.9**	-47.8	-48.3	-34.4	-18.3	-5.6	-1.1	-3.5	-11.1	-27.1	-41.1	-47.6	
	Date (yyyy/dd)	**1968/ 08**	1974/ 01+	1972/ 01	1967/ 01	1969/ 19	2000/ 06	1968/ 05	1977/ 24	1974/ 28	1997/ 30	1985/ 28	1990/ 20	

Dates denoted with a "+" indicate that the extreme has occurred multiple times. The date shown corresponds to the first occurrence.

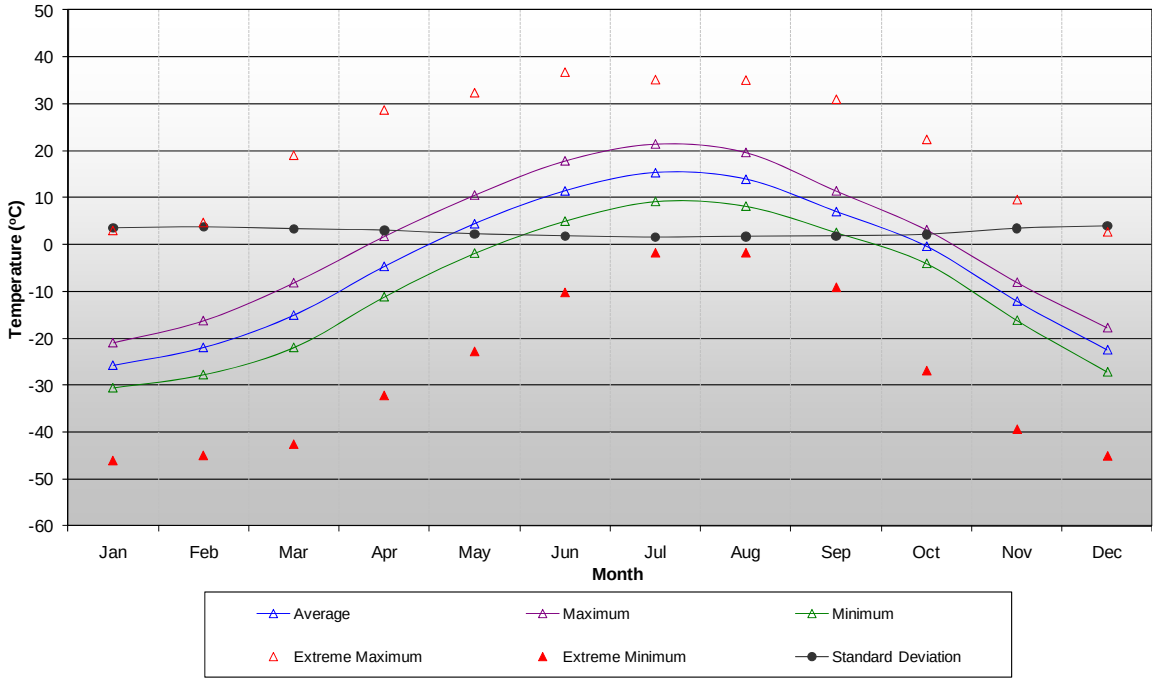

Figure 2: Temperature Characteristics for Gillam A, Manitoba (1971-2000)

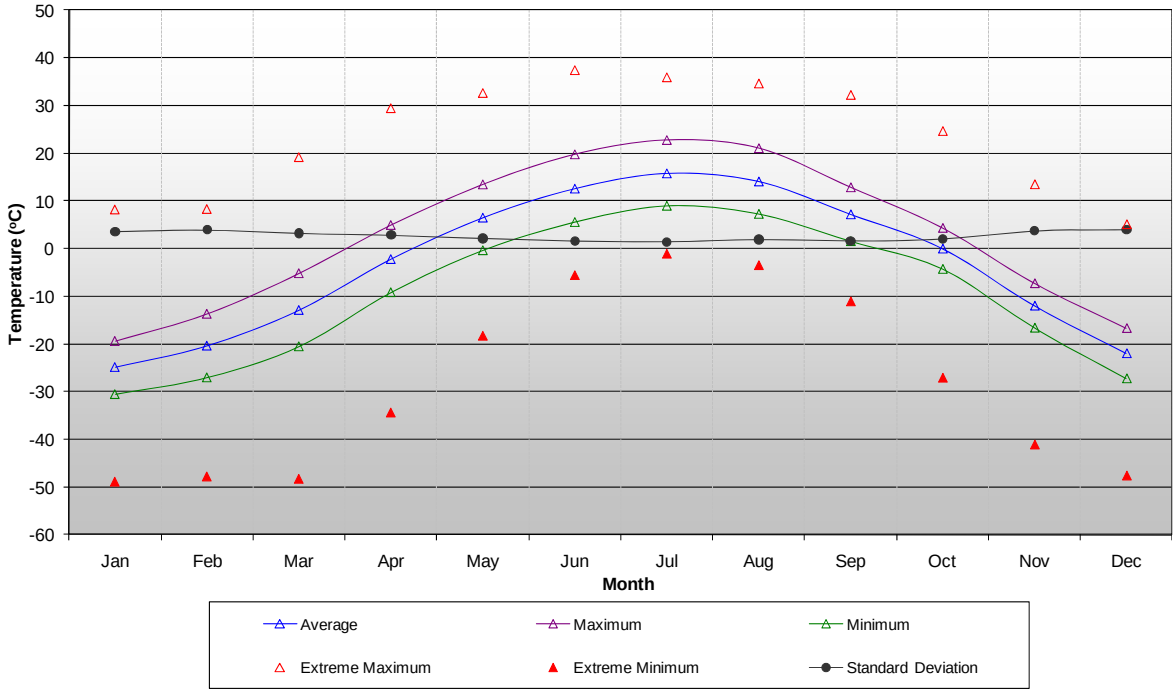

Figure 3: Temperature Characteristics for Thompson A, Manitoba (1971-2000)

2.2.2.2 FROST-FREE DAYS

The average of frost-free days at Gillam A is 91.9 days and 70.0 days at Thompson A for the period of 1971-2000. These values fall into the frost-free range reported for the northern forest zone of Canada which is between 60 to 110 days.

2.2.2.3 GROWING DEGREE DAYS

The total accumulated growing degree days with a 5°C threshold base temperature range from 969.6 at Gillam A to 1058.9 at Thompson A (Table 2). Using a 10°C base temperature the accumulated growing degree days range from 428.6 at Gillam A. and 476.8 at Thompson A. The higher total growing degree days at Thompson A reflect the warmer conditions experienced at this location.

Table 2: Growing Degree Days at Gillam A and Thompson A

Station	Base Temp	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yr
Gillam A	5°C	0.0	0.0	0.1	8.2	66.9	198.5	320.0	277.2	87.9	10.6	0.0	0.0	969.6
	10°C	0.0	0.0	0.0	1.7	20.5	86.3	167.8	130.3	20.7	1.3	0.0	0.0	428.6
Thompson A	5°C	0.0	0.0	0.2	12.3	95.3	230.2	334.9	282.3	90.7	12.8	0.2	0.0	1058.9
	10°C	0.0	0.0	0.0	1.7	30.8	102.8	180.8	137.4	22.1	1.2	0.0	0.0	476.8

2.2.2.4 HOMOGENIZED AVERAGE TEMPERATURE

A comparison between the homogenized average temperature to the non-homogenized record for the 1971-2000 time period indicates that no adjustments were made to the data record.

2.2.3 PRECIPITATION

2.2.3.1 NORMALS AND EXTREMES

Precipitation normals for the study area, including rainfall and snowfall records along with the extreme daily events of precipitation, rainfall, and snowfall are presented in Table 3 and Figures 4 and 5.

Average annual precipitation in the study area is approximately 499 mm at Gillam A and 517 mm at Thompson A. The precipitation over the months of November through April is mainly in the form of snowfall. Almost all months of the year record precipitation in the form of snowfall except for the month of July and August at Gillam A and July at Thompson A. At Gillam A rainfall accounts for approximately 63% of the total annual precipitation while snowfall accounts for 37% while at Thompson A total precipitation is comprised of 67% rainfall and 33% snowfall.

The maximum daily precipitation, falling in the form of rain, was 64.4 mm in the month of July (2000) in Gillam A and 75.3 mm at Thompson A in the month of August (1997). The maximum daily snowfall was 36.6 cm in May, 1988 at Gillam A and 45.7 cm in October, 1970 at Thompson A.

The average snow depth for both stations is greatest in the months of January to March; ranging from 41 cm to 56 cm (Table 3).

Table 3: Precipitation Characteristics (1971-2000) at Gillam A and Thompson A, Manitoba

Sta.	Precipitation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yr
Gillam A	Rainfall (mm)	0.0	0.0	0.5	3.8	29.8	51.2	81.8	77.2	48.7	19.2	1.2	0.1	313.5
	Snowfall (cm)	23.4	27.5	27.0	23.4	16.6	3.0	0.0	0.0	7.1	24.2	43.9	32.5	228.6
	Total Precip (mm)	17.5	21.2	20.3	23.2	44.2	53.9	81.8	77.2	55.0	40.9	37.5	26.7	499.4
	Avg Snow Depth (cm)	43.0	52.0	56.0	29.0	3.0	0.0	0.0	0.0	0.0	2.0	15.0	30.0	19.0
	Extr Rainfall (mm)	0.2	0.2	6.4	14.5	46.0	48.7	64.4	52.1	36.8	27.0	9.1	1.0	
	Date (yyyy/dd)	1987 / 08+	1981 / 19+	2004 / 09	1976 / 29	1988 / 31	1980 / 24	2000 / 08	1975 / 25	1999 / 18	1997 / 09	1974 / 08	1987 / 09	
	Extr Snowfall (cm)	18.8	29.0	24.0	32.0	36.6	9.0	0.0	0.5	16.6	21.6	27.0	18.2	
	Date (yyyy/dd)	1976 / 18	1999 / 11	1983 / 07	1973 / 21	1988 / 03	1992 / 04	1971 / 01+	1976 / 27	1992 / 21	1994 / 23	1983 / 24	1990 / 05	
	Extr Precip (mm)	17.5	23.8	18.6	34.3	46.0	48.7	64.4	52.1	36.8	30.6	21.6	17.2	
	Date (yyyy/dd)	1976 / 18	1999 / 11	1983 / 07	1973 / 21	1988 / 31	1980 / 24	2000 / 08	1975 / 25	1999 / 18	1997 / 09	2004 / 20	1990 / 05	
	Extr Snow Depth (cm)	102.0	107.0	102.0	89.0	56.0	8.0	0.0	0.0	15.0	55.0	66.0	97.0	
	Date (yyyy/dd)	1972 / 01+	1972 / 12+	1972 / 01+	1981 / 08	1981 / 01	1985 / 01	1971 / 01+	1971 / 01+	1984 / 23	1996 / 23	1971 / 26+	1971 / 21+	
Thompson A	Rainfall (mm)	0.1	0.2	0.8	6.2	33.0	67.9	86.1	73.7	58.5	19.9	1.6	0.2	348.2
	Snowfall (cm)	21.1	18.0	21.6	20.8	12.0	1.4	0.0	0.1	3.9	22.1	35.0	30.2	186.2
	Total Precip (mm)	18.2	15.9	20.6	26.0	44.4	69.4	86.1	73.9	62.4	41.4	32.8	26.3	517.4
	Avg Snow Depth (cm)	41.0	45.0	42.0	15.0	1.0	0.0	0.0	0.0	0.0	2.0	15.0	30.0	16.0
	Extr Rainfall (mm)	0.8	1.8	20.6	22.6	34.3	46.4	52.6	75.3	62.0	31.0	13.7	1.8	
	Date (yyyy/dd)	1987 / 04	1975 / 24	1968 / 27	1989 / 23	1986 / 12	1985 / 08	1981 /23	1997 / 25	1980 / 15	1984 / 17	1974 / 08	1967 / 18	
	Extr Snowfall (cm)	14.5	13.0	26.4	26.0	38.8	16.5	0.0	3.8	13.3	45.7	26.2	21.6	
	Date (yyyy/dd)	1968 / 25	1982 / 21+	1996 / 16	1991 / 06	1988 / 03	1969 / 11	1967 / 01+	1976 / 27	1982 / 29	1970 / 06	1990 / 22	1996 / 12	
	Extr Precip (mm)	14.5	11.4	22.8	24.8	34.3	46.4	52.6	75.3	62.0	45.0	28.3	15.8	
	Date (yyyy/dd)	1968 / 25	1982 / 21	1996 / 16	1991 / 30	1986 / 12	1985 / 08	1981 / 23	1997 / 25	1980 / 15	1970 / 06	1990 / 02	1986 / 02+	
	Extr Snow Depth (cm)	91.0	91.0	84.0	91.0	46.0	13.0	0.0	0.0	13.0	61.0	74.0	79.0	
	Date (yyyy/dd)	1968 / 29+	1968 / 01+	1982 / 16	1967 / 17+	1967 / 01+	1969 / 12+	1967 / 01+	1967 / 01+	1972 / 23	1970 / 12+	1971 / 24+	1971 / 16+	

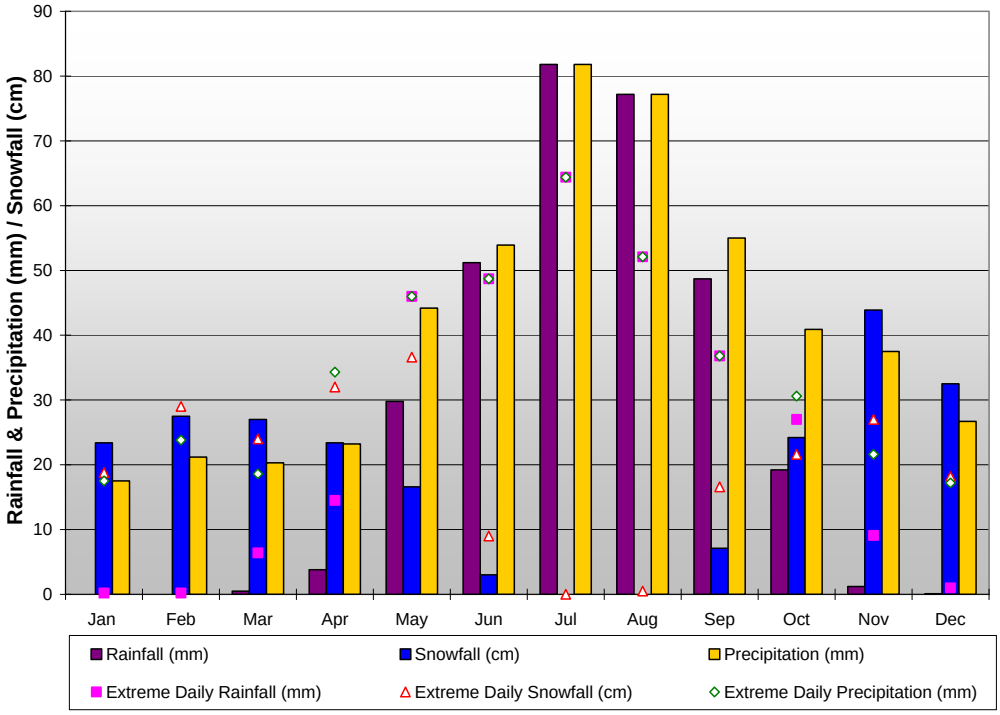

Figure 4: Precipitation Characteristics for Gillam A, Manitoba (1971-2000)

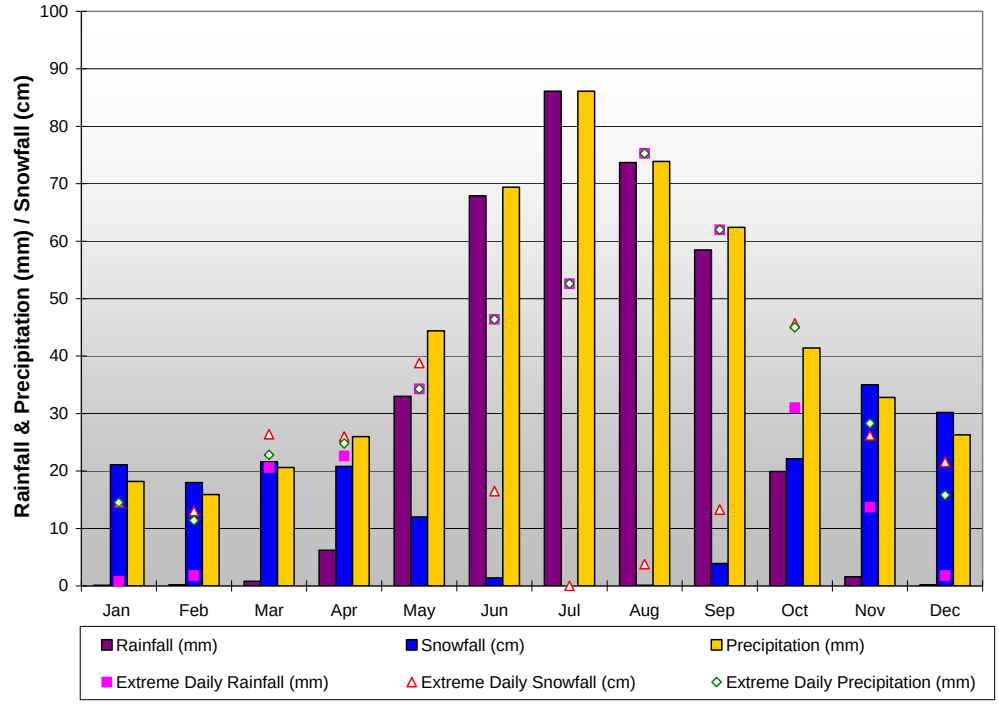

Figure 5: Precipitation Characteristics for Thompson A, Manitoba (1971-2000)

Note: Caution should be taken when comparing total rainfall (mm), snowfall (cm) and precipitation (mm) in Table 3 since they are not reported with the same units of measure.

To properly convert a snowfall measurement from cm into a liquid equivalent in mm, the density of the snow must be determined.

2.2.3.2 ADJUSTED AVERAGE PRECIPITATION

In general, the adjustment to the 1971-2000 precipitation record is small compared to the yearly total (Figure 6). The largest adjustment was made at Gillam A for November (3%). The largest adjustments were made in the months where snow is the dominant form of precipitation since snow measurements are prone to measurement error due to wind speed and snow density.

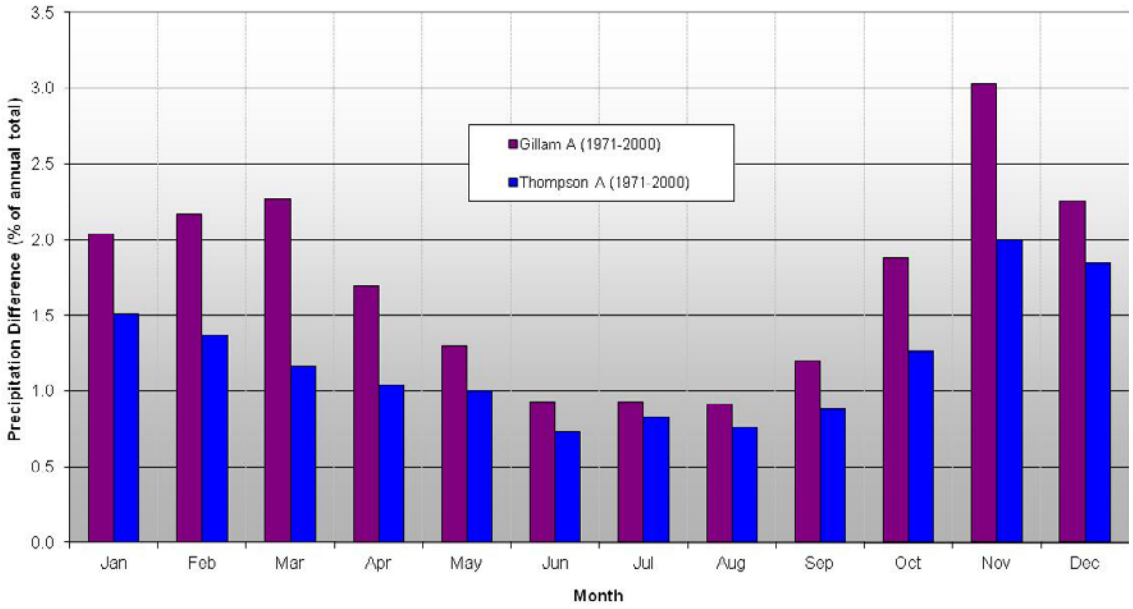

Figure 6: Monthly Total Precipitation Adjustments as a Percentage of Yearly Total Precipitation

2.2.4 WIND

2.2.4.1 WIND NORMALS AND EXTREMES

Table 4, Figures 7, 8, 9 and 10 show the wind normals and the wind roses for hourly wind speed in the study area, respectively. The wind roses show the frequency of winds blowing from the predominant directions. The length of each "spoke" around the circle is related to the frequency that the wind blows from a particular direction per unit time. Each concentric circle represents a different frequency, emanating from zero at the center to higher frequencies at the outer circles.

Average monthly wind speed in the study area ranges from 14.0 km/hr to 17.8 km/hr with an annual predominant wind direction of west at Gillam A and 9.5 km/h to 13.2 km/h with predominant direction of west at Thompson A.

Winter months (December, January, and February) are predominately comprised of the lowest average wind speeds at approximately 14.0 km/hr to 14.8 km/hr with a most frequent direction of west at Gillam A and 9.5 km/h to 10.6 km/h with a most frequent direction of west at Thompson A.

Spring (March, April and May) has average speeds slightly higher than winter ranging from 14.0 km/hr to 15.4 km/hr with a most frequent wind direction of north-east at Gillam A and from 11.6 km/h to 13.2 km/h with most frequent direction of north-east at Thompson A.

Summer (June, July and August) experiences average wind speeds that range from 15.1 km/h to 15.8 km/h with a most frequent direction of north-east at Gillam A and from 10.7 km/h to 12.2 km/h with a most frequent direction of west at Thompson A.

Autumn (September, October and November) wind speeds range from 16.4 km/h to 17.8 km/h with a most frequent direction of north-west at Gillam A and from 10.5 km/h to 11.5 km/h with a most frequent direction of west at Thompson A.

Overall, Gillam A experiences higher average wind speeds compared to Thompson A. The maximum hourly wind speed recorded was 83 km/hr in September (1981) at Gillam A while the maximum hourly average wind speed at Thompson A was 61 km/hr in September (1969).

Table 4: Wind Normals for Gillam A and Thompson A, Manitoba (1971-2000)

Sta.	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yr
Gillam A	Speed (km/h)	14.8	14	14	15.1	15.4	15.8	15.1	15.7	17.4	17.8	16.4	14	15.5
	Most Freq Dir[n]	W	W	NE	NE	NE	NE	NE	NW	NW	NW	NW	W	NE
	Extr Max Hrly Speed (km/h)	67	65	76	61	67	67	74	70	83	63	64	65	
	Date (yyyy/dd)	1989/ 27	1982/ 21	1982/ 13	1987/ 28	1993/ 10	1993/ 26	1991/ 22+	1997/ 05	1981/ 27	1997/ 13	1971/ 06	1999/ 25	
	Extr Max Gust Speed (km/h)	89	78	91	83	100	96	107	96	91	81	74	96	
	Date (yyyy/dd)	1989/ 27	1982/ 21	1990/ 01	1987/ 28	1993/ 09	1987/ 13	1991/ 22	1986/ 19	1981/ 26+	1986/ 10+	1979/ 01+	1999/ 25	
Thompson A	Speed (km/h)	10.3	10.6	11.6	13.1	13.2	12.2	11	10.7	11.5	11.4	10.5	9.5	11.3
	Most Freq Dir[n]	W	W	NE	NE	NE	NE	W	W	W	W	W	W	W
	Extr Max Hrly Speed (km/h)	48	54	48	52	59	48	50	56	61	58	52	56	
	Date (yyyy/dd)	1984/ 24+	1988/ 27	1984/ 10	1985/ 20	1993/ 10	1967/ 02+	1968/ 13	1986/ 19+	1969/ 04	1967/ 01	1983/ 05	1999/ 25	
	Extr Max Gust Speed (km/h)	81	74	83	87	93	130	105	93	82	80	80	95	
	Date (yyyy/dd)	1989/ 27	1988/ 22+	1990/ 01	2001/ 25	1994/ 07	1975/ 28	1967/ 20	1999/ 27	2000/ 10	1988/ 09	1969/ 27	1999/ 25	

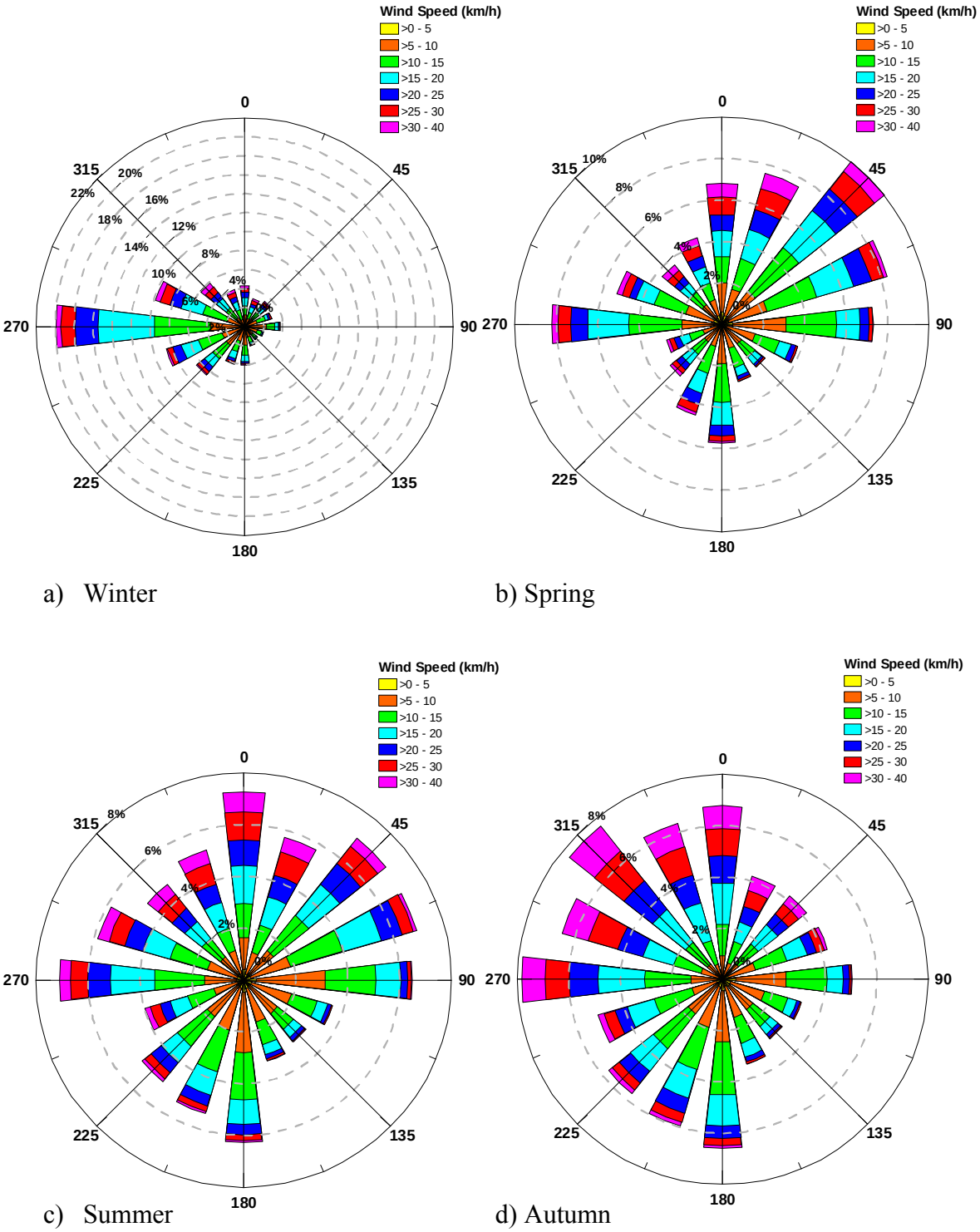

Figure 7: Gillam A Seasonal Wind Rose for Hourly Wind Speed (1971-2000)

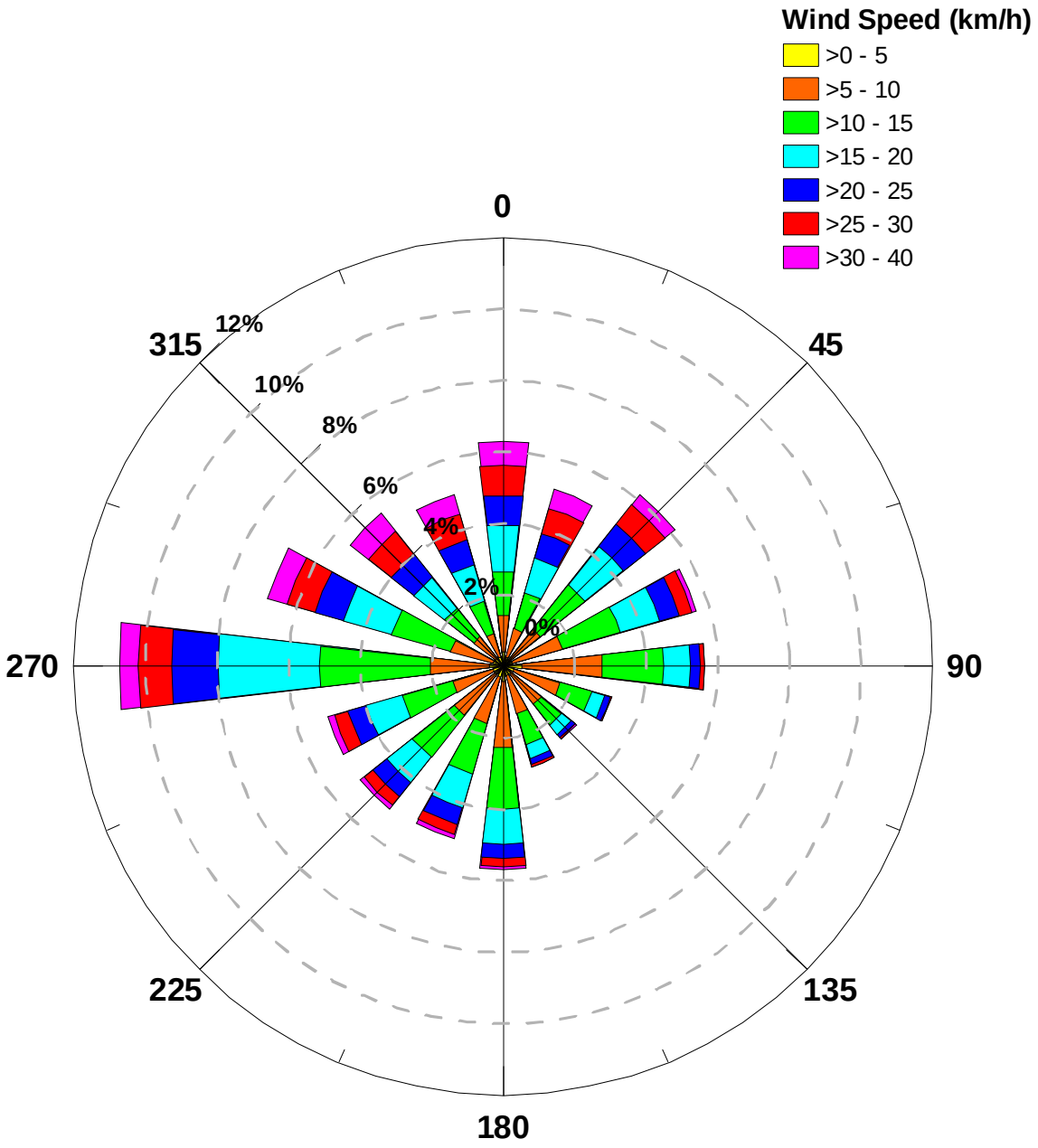

Figure 8: Annual Wind Rose for Hourly Wind Speed at Gillam A, Manitoba (1971-2000)

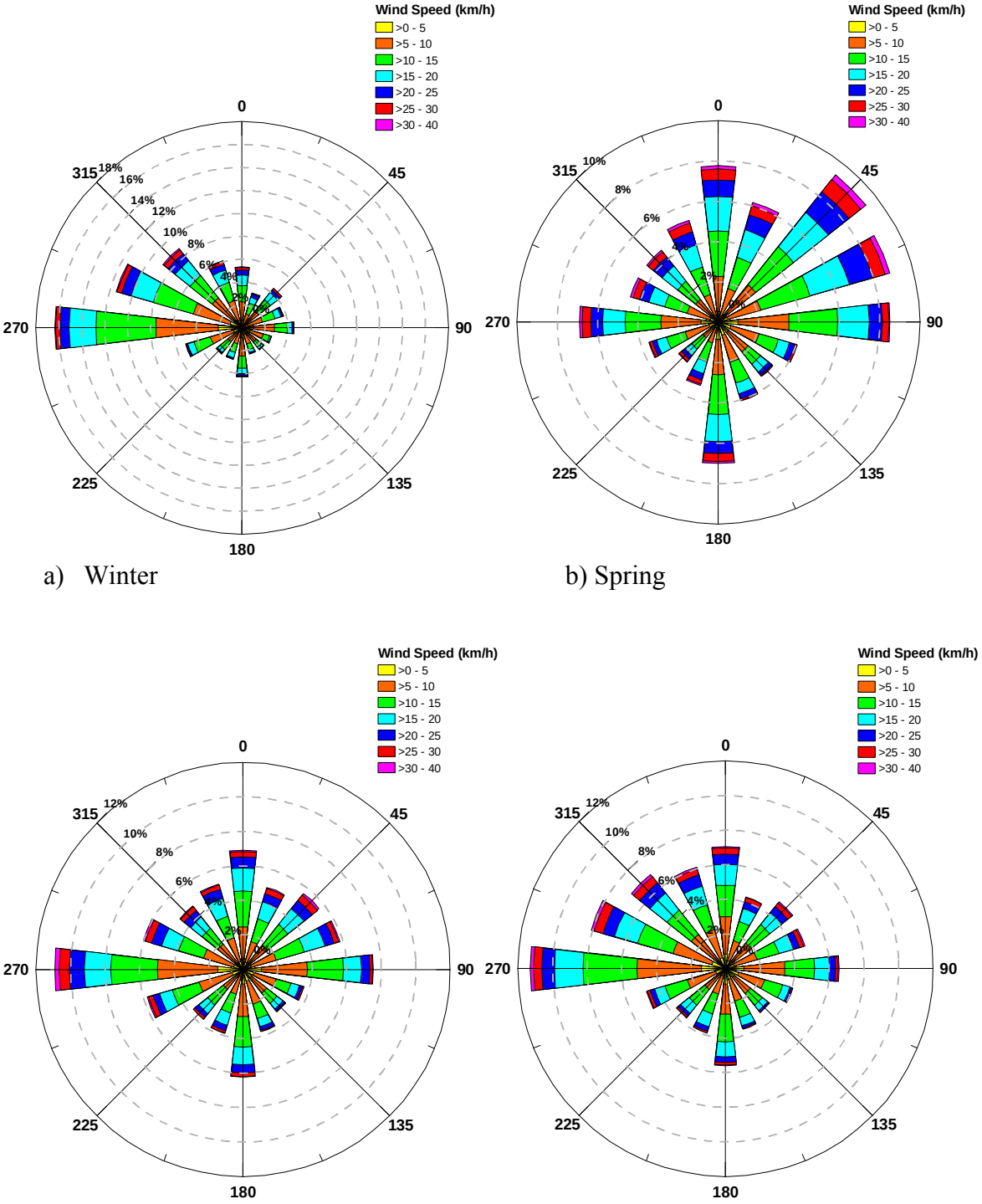

Figure 9: Thompson A Seasonal Wind Rose for Hourly Wind (1971-2000)

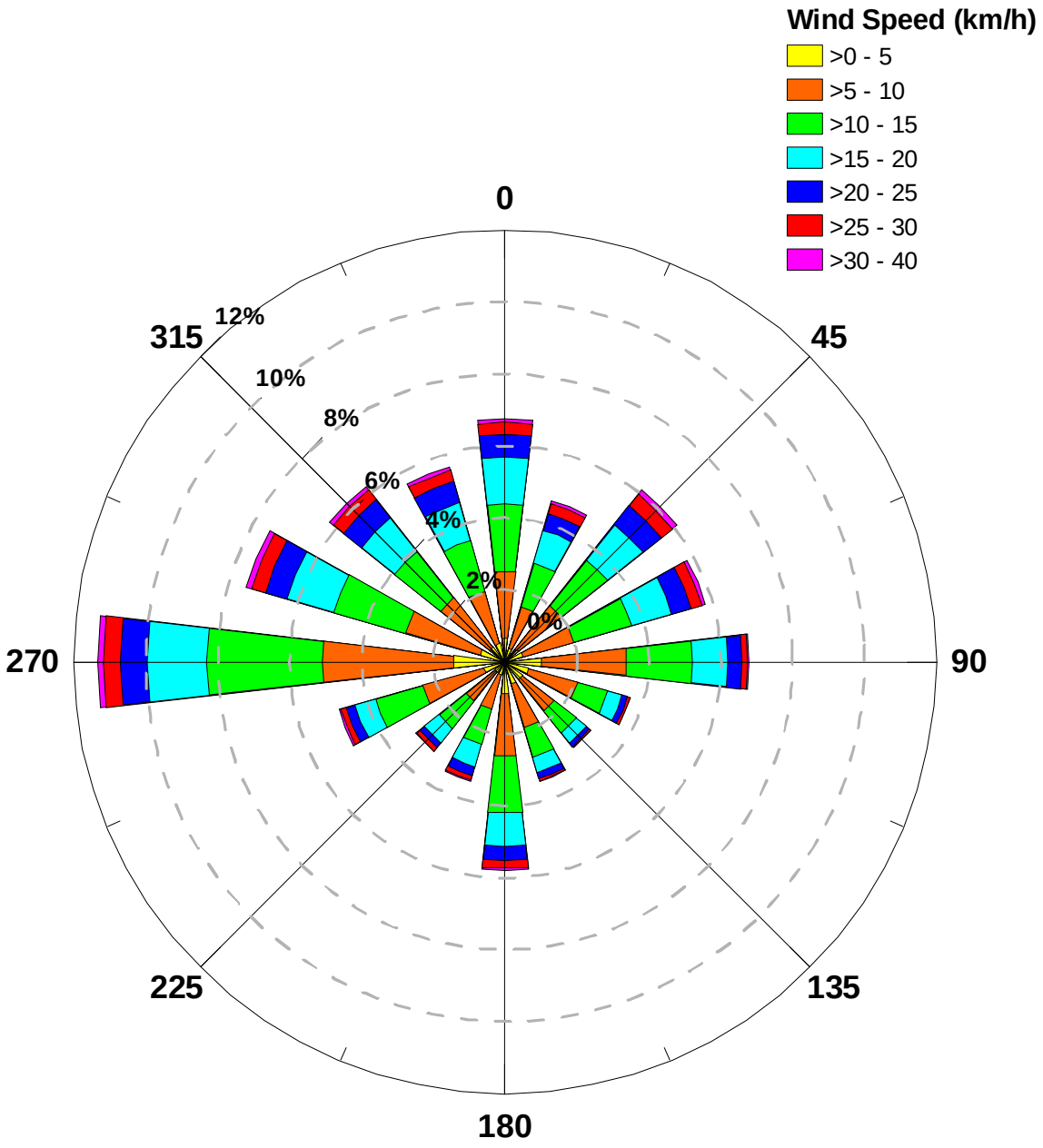

Figure 10: Annual Wind Rose for Hourly Wind Speed at Thompson A, Manitoba (1971-2000)

2.3 HISTORICAL CLIMATE TRENDS

2.3.1 DATA AND METHODOLOGY

A trend analysis of historical climate data for the Gillam A and Thompson A stations was performed on temperature, precipitation and wind data. Homogenized data is specifically designed for climate change analysis over Canada as well as for performing trend analysis on climate variables. Homogenized and adjusted data sets were produced and provided by Environment Canada (Environment Canada, 2010). **Heterogeneities** are accounted for due to changes in instrumentation, station relocation and changes to measurement techniques that may be present in the data during the period of record (Vincent et al., 2002 and Mekis et al., 2011). The trend analysis considers each month separately in addition to the annual and seasonal trends. Seasons are divided into three month periods: Winter (December, January and February), spring (March, April and May), summer (June, July and August) and autumn (September, October and November).

- For temperature, a regression model was used to remove the known heterogeneities in the station data due to changes to instrument, station relocations and changes to observing practices (Vincent et al., 2002). For Gillam A, a step was identified and corrected in the minimum temperature series in 1970 due to the joining of two station observations.

- With respect to precipitation data, adjustments were applied separately for rain and snow data. For rain data, corrections were applied for wind undercatch, evaporation and gauge specific wetting losses. Snow density corrections were applied to snow ruler measurements. Heterogeneities from station relocation were carefully minimized and trace precipitation were properly accounted (Mekis and Vincent, 2011). For the Gillam A record, data from two stations were combined to generate an adjusted time series from 1943-2010, however, a gap in the record is observed from 1962-1966.

- Heterogeneities in the wind speed data due to the changes in anemometer height and type, location and instrumentation were corrected (Wan et al., 2009). A change point was detected and adjusted due to instrumentation changes in 1979 for Gillam A and in 1970 for Thompson A.

In this study, a computer program implementing the **Mann-Kendall test** for trend against randomness (Wang et al., 2001 and Zhang et al., 2000) was used to analyze the time series of minimum temperature, maximum temperature, mean temperature, monthly precipitation and average wind speed values to determine both the magnitude and **statistical significance** of each trend. The effects of **serial correlation** were also taken into account in the trend analysis program. For temperature data, a record period of at

least 42 years was used (1943-2008 for Gillam A and 1967-2008 for Thompson A). Since several years of precipitation data is missing at Gillam A, only data from 1967-2010 was examined. Precipitation trend analyses considered data that spans a minimum of 39 years (1967-2009 for Gillam A and 1968-2006 for Thompson A). For wind, a record period of at least 38 years was used (1971-2008 for Gillam A and 1971-2008 for Thompson A). Date ranges used in the trend analyses are identified in Table 5, Table 6, Table 7, Table 8 and Table 9. Differences in date ranges exist due to data availability and reliability concerns.

All trends were assessed for statistical significance at the 5% level using a critical standard normal **Z-statistic** value of 1.96. A two-sided test for trend compared this critical Z-value to those Z-values obtained from the historical climate data, with trends being accepted on the condition that $|Z| \geq Z_{cr}$. A positive value of Z indicates an increasing trend, whereas a negative value identifies a decreasing trend. The following sections will report on significant trends only (bolded in tables).

Trend analyses were performed on the homogenized temperature, adjusted precipitation and homogenized wind speed data for the entire period of record available. The objective of the trend analyses was to identify trends in the record that were due to a climate change signal.

2.3.2 TEMPERATURE TRENDS

Temperature trends for Gillam A and Thompson A are summarized in Table 5 and Table 6 respectively. Trends are reported in degree Celsius per decade (ºC/dec.).

Annually: Significant upward trends were detected for mean and maximum temperature at both Gillam A and Thompson A. In addition, significant upward trend in minimum temperature was detected at Thompson A.

Seasonally: Significant upward trends were detected for minimum and mean temperature in winter, spring and summer for Gillam A. Spring and summer also shows significant upward trends for maximum temperature at Gillam A. Thompson A indicates significant upward trends for mean and maximum temperature in winter. No significant trends were detected at either location for autumn.

Monthly: Significant upward trends were detected in January for the two locations and April, May and June at Gillam A.

Table 5: Summary of Temperature Trends at Gillam A

	Period	Gillam A					
		T_{min}		T_{mean}		T_{max}	
		°C/dec.	Z-S	°C/dec.	Z-S	°C/dec.	Z-S
January	1943-2008	0.50	**2.19**	0.46	**2.26**	0.42	1.91
February	1943-2008	0.31	1.42	0.28	1.32	0.26	1.15
March	1943-2008	0.25	0.88	0.18	0.88	0.25	1.12
April	1943-2008	0.36	1.56	0.43	**1.96**	0.43	**2.13**
May	1943-2008	0.33	**2.09**	0.33	**2.15**	0.40	**2.00**
June	1943-2008	0.27	**2.24**	0.32	**2.69**	0.39	**2.77**
July	1943-2008	0.10	1.20	0.14	1.52	0.11	0.92
August	1943-2008	0.10	1.12	0.11	1.10	0.14	1.12
September	1943-2008	0.03	0.54	0.12	1.06	0.20	1.35
October	1943-2008	-0.15	-0.92	-0.10	-0.44	0.06	0.41
November	1943-2008	0.03	0.16	0.08	0.45	0.15	0.82
December	1943-2008	0.16	0.41	0.08	0.42	0.00	0.08
Annual	1943-2008	0.14	1.70	0.16	**2.39**	0.17	**2.46**
Winter	1944-2008	0.40	**2.37**	0.25	**2.13**	0.22	1.72
Spring	1943-2008	0.31	**2.15**	0.40	**2.56**	0.41	**2.73**
Summer	1943-2008	0.17	**2.34**	0.21	**2.33**	0.24	**2.14**
Autumn	1943-2008	-0.01	-0.08	0.00	0.07	0.10	0.79

ºC/dec. = degree Celsius per decade; Z-S = Z-Statistics; Bold Z-Statistics indicate significant trend

Table 6: Summary of Temperature Trends at Thompson A

	Period	Thompson A					
		T_{min}		T_{mean}		T_{max}	
		°C/dec.	Z-S	°C/dec.	Z-S	°C/dec.	Z-S
January	1967-2008	0.95	1.91	0.97	**2.15**	1.03	**2.23**
February	1967-2008	0.70	1.14	0.52	1.02	0.50	0.86
March	1967-2008	0.67	1.28	0.57	1.07	0.35	0.77
April	1967-2008	0.01	0.02	0.01	0.01	0.23	0.55
May	1967-2008	0.02	0.06	0.00	0.03	0.00	-0.03
June	1967-2008	-0.06	-0.24	0.11	0.39	0.33	1.22
July	1967-2008	0.26	1.22	0.24	1.13	0.27	1.24
August	1967-2008	0.39	1.86	0.31	1.41	0.28	0.79
September	1967-2008	0.12	0.46	0.27	1.28	0.44	1.34
October	1967-2008	0.19	0.92	0.29	1.32	0.44	1.54
November	1967-2008	0.06	0.17	0.11	0.28	0.10	0.18
December	1967-2008	0.40	0.73	0.39	0.75	0.60	1.12
Annual	1967-2008	0.26	**1.99**	0.33	**2.22**	0.33	**2.36**
Winter	1968-2008	0.70	1.91	0.75	**2.11**	0.64	**2.33**
Spring	1967-2008	0.21	0.55	0.13	0.42	0.13	0.39
Summer	1967-2008	0.20	1.40	0.30	1.80	0.38	1.90
Autumn	1967-2008	0.08	0.41	0.13	0.81	0.25	1.25

ºC/dec. = degree Celsius per decade; Z-S = Z-Statistics; Bold Z-Statistics indicate significant trend

2.3.2.1 PRECIPITATION TRENDS

Precipitation trends for Gillam A and Thompson A can be found in Table 7 and Table 8 respectively. Trends are reported in millimeters per year (mm/year). A significant downward trend in precipitation was detected annually for Thompson A. No other significant trends were identified for precipitation at Gillam A and Thompson A.

Table 7: Summary of Precipitation Trends at Gillam A

	Gillam A		
	Period 1	mm/year	Z-S
January	1967-2010	0.07	0.72
February	1967-2010	-0.04	-0.13
March	1967-2010	0.12	0.50
April	1967-2010	-0.34	-1.72
May	1967-2010	-0.42	-1.43
June	1967-2010	-0.31	-0.88
July	1967-2010	0.04	0.05
August	1967-2009	-0.31	-0.61
September	1967-2010	0.16	0.29
October	1967-2010	0.03	0.04
November	1967-2010	0.29	0.90
December	1967-2010	-0.32	-1.38
Annual	1967-2009	-0.57	-0.39
Winter	1967-2010	-0.26	-0.80
Spring	1967-2010	-0.41	-0.78
Summer	1967-2009	-0.10	-0.17
Autumn	1967-2010	0.28	0.34

Z-S = Z-Statistics; Bold Z-Statistics indicate significant trend

Table 8: Summary of Precipitation Trends at Thompson A

	Thompson A		
	Period	mm/year	Z-S
January	1968-2007	0.09	0.48
February	1968-2007	0.13	0.63
March	1968-2007	0.14	0.73
April	1967-2007	-0.09	-0.31
May	1967-2007	0.25	0.64
June	1967-2007	-0.32	-0.94
July	1967-2007	-0.30	-0.52
August	1967-2007	-0.43	-0.81
September	1967-2007	-0.01	-0.01
October	1967-2007	-0.69	-1.76
November	1967-2007	-0.11	-0.38
December	1967-2006	-0.47	-1.93
Annual	1968-2006	-3.13	**-2.14**
Winter	1968-2007	-0.25	-0.92
Spring	1968-2007	0.37	0.59
Summer	1967-2007	-1.16	-1.34
Autumn	1967-2007	-0.58	-0.93

Z-S = Z-Statistics; Bold Z-Statistics indicate significant trend

2.3.2.2 WIND TRENDS

Mean wind speed trends for Gillam A and Thompson A can be found in Table 9. Trends are reported in kilometers per hour per decade (km/h/dec.).

Significant upward trends in mean wind speed were observed at Thompson A on an annual basis as well as in the winter season. February, March and August indicated upward trends on a monthly basis.

No significant trends were detected at Gillam A.

Table 9: Summary of Mean Wind Speed Trends at Gillam A and Thompson A

	Gillam A			Thompson A		
	Period	km/h/dec.	Z-S	Period	km/h/dec.	Z-S
January	1971-2008	-0.89	-0.68	1971-2008	0.32	1.35
February	1971-2008	0.40	0.72	1971-2008	0.72	**2.66**
March	1971-2008	0.30	1.06	1971-2008	0.46	**2.25**
April	1971-2008	0.18	0.80	1971-2008	0.27	0.77
May	1971-2008	0.03	0.04	1971-2008	0.23	0.98
June	1971-2008	-1.09	-1.47	1971-2008	0.24	0.80
July	1971-2008	-1.68	-1.66	1971-2008	0.04	0.17
August	1971-2008	-0.69	-0.27	1971-2008	0.39	**2.20**
September	1971-2008	-1.27	-1.56	1971-2008	0.16	0.59
October	1971-2008	-1.53	-1.76	1971-2008	-0.01	-0.07
November	1971-2008	-1.14	-0.80	1971-2008	0.33	1.48
December	1971-2008	0.40	0.64	1971-2008	0.43	1.50
Annual	1971-2008	0.01	0.09	1971-2008	0.37	**2.86**
Winter	1971-2008	0.10	0.37	1971-2008	0.48	**2.41**
Spring	1971-2008	0.13	0.41	1971-2008	0.23	1.03
Summer	1971-2008	-1.00	-1.43	1971-2008	0.27	1.66
Autumn	1971-2008	-0.99	-1.57	1971-2008	0.19	0.69

Z-S = Z-Statistics; Bold Z-Statistics indicate significant trend

2.3.3 OTHER TREND STUDIES OF INTEREST

To verify the results obtained in this study, it is interesting to compare the results with similar studies. One study of particular relevance analyzed temperature and precipitation trends in Canada during the 20th century (Zhang et al., 2000). Station data was gridded using a statistical optimal interpolation technique, which is useful for data-sparse regions like northern Manitoba. The Mann-Kendall test for trend against randomness was used to detect significant trends. In the study, Zhang et al. (2000) detected the greatest warming in the spring, followed by the summer as well as annually for daily maximum temperatures in the Gillam and Thompson area.

2.3.4 REMARKS

The results obtained in this trend analysis, while insightful, are only preliminary. Further study is required to form a more comprehensive analysis. This could include analyzing data from other stations near Gillam A and Thompson A as well as investigating the data using other variables and levels of significance.

3 CONCLUSIONS AND RECOMMENDATIONS

This study characterized the existing climate and identified significant climate trends in the Keeyask study area. Two Environment Canada meteorological stations, Gillam A and Thompson A, were analyzed in this report. Gillam A is considered to be representative of the Keeyask climate while the analysis of Thompson A is included for comparative purposes.

The average annual temperature normals are approximately −4.2°C and −3.2ºC for Gillam A and Thompson A respectively. The average annual precipitation normals are 499 mm at Gillam A and 517 mm at Thompson A. Normal wind speed in the study area ranges

from 14.0 km/hr to 17.8 km/hr with predominant direction of west at Gillam A station. Normal winds speeds at the Thompson A station range from 9.5 km/h to 13.2 km/h with a predominant direction of west.

Environment Canada homogenized and adjusted data was used for analyzing temperature, precipitation and wind speed trends. The time frame used in the analysis varied between parameters and stations. Where possible, the longest record period was used. The analysis was done monthly, seasonally and annually. The following summarizes the significant trends that were detected;

- Significant upward temperature trends were detected for both Gillam A and Thompson A in minimum, mean and maximum temperature time series. However, not every month/season/annum series exhibited a significant trend.

- Significant downward trends were detected for annual precipitation at Thompson A but no significant trends were detected at Gillam A. Due to missing values in the Gillam record, the trend analysis did not use the entire homogenized precipitation record.

- Average wind speeds exhibited significant upward trends for Thompson A on an annual basis as well as in the winter and during several individual months. No significant trends for wind speed were observed at Gillam A.

It is important to note that the historical climate may not be representative of future climate conditions due to climate change. As such, the information presented in this report should be used with caution and accompanied with a clear understanding of climate change and climatic influences.

For a more complete trend analysis, it is recommended that more stations be used within the Nelson River basin to obtain a comprehensive understanding of the climate trends that may or may not impact the Keeyask project.

4 GLOSSARY

GLOSSARY

Climate change	Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.
Degree-days	Days of average temperature over a specified threshold temperature multiplied by the number of °C the daily average exceeds the threshold temperature.
Extremes	Extreme values refer to the absolute greatest value on record for a certain parameter. In the case of temperature, there is an extreme value for both the maximum and minimum temperatures observed in the record period. Extremes are accompanied by the date of occurrence. In instances where the same extreme value has occurred multiple times, the first date of occurrence is recorded.
Frost-free days	The number of consecutive days where the minimum temperature is above 0°C. In other words it is the period from the last frost in spring to the first frost in autumn.
Heterogeneities	Biases totally unrelated to changes in climate that, left uncorrected, can lead to inaccurate predictions of climate trends as part of climate change studies. For example differences in measurement techniques (i.e. instrument relocation, gauge undercatch, and trace measurements).
Homogenized data	Data that is free of variations due to non-climatic factors.
Mann-Kendall test	A nonparametric test for randomness against trend.

Maximum temperatures	Maximum monthly, seasonal and/or annual average temperatures calculated from daily maximum station records.
Mean temperatures	Mean monthly, seasonal and/or annual average temperatures calculated from daily mean station records.
Minimum temperatures	Minimum monthly, seasonal and/or annual average temperatures calculated from daily minimum station records.
Precipitation	Refers to *total* precipitation, or the sum of all the different precipitation types (i.e. rain, snow, ice pellets, drizzle, etc.).
Serial correlation	The correlation of a variable with itself over successive time intervals.
Statistical significance	A fixed probability of wrongly rejecting the null hypothesis of a statistical hypothesis test if it is in fact true.
Wind speed	The speed of motion of air in km/h, usually observed at 10 metres above the ground. It represents the average speed during the two-minute period ending at the time of observation.
Wind direction	The direction from which the wind is blowing with respect to north (360 degrees on the compass). For example, an easterly wind is blowing from the east, not toward the east. It represents the average direction during the two minute period ending at the time of observation and may be expressed to the nearest 10 degrees, or to one of the 16 points of the compass (N, NE, WNW, etc.).
Z-statistic value	A quantity calculated from a sample of data, whose value is used to decide whether or not a null hypothesis should be rejected in a particular hypothesis test.

5 REFERENCES

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6 APPENDIX A - ABBREVIATIONS

ABBREVIATIONS

Avg.....Average

˚C .....Degrees Celsius

ºC/dec…… .....Degrees Celsius per Decade

cm.....Centimeters

Dir^n…….Direction

Extr .....Extreme

Freq. .....Frequent

km/h .....Kilometers per Hour

km/h/dec.....Kilometers per Hour per Decade

Max. .....Maximum

Min. .....Minimum

mm .....Millimeters

mm/year .....Millimeters per Year

Precip .....Precipitation

Sta. .....Station

Std Dev.....Standard Deviation

Temp .....Temperature

T_{max} .....Maximum Temperature

T_{mean} .....Mean Temperature

T_{min} .....Minimum Temperature

WMO .....World Meteorological Organization