Volume 1 Annex V1-7 Type A Water Licence Applications

Package P5-2

Climate and Hydrological Parameters Summary Report, Hope Bay Project

TMAC RESOURCES

Climate and Hydrological Parameters Summary Report, Hope Bay Project

Prepared for

TMAC Resources Inc.

Prepared by

SRK Consulting (Canada) Inc.
1CT022.013
November 2017

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Change Log

The following table provides an overview of material changes to this report from the previous version issued as Appendix V3-2B as part of the DEIS for Phase 2 of the Hope Bay Project dated December 2016.

Changes by Section

Information Request, Technical Comment, or Other Change	Section	Comments
Other	Complete Report	Updated hydrology to include data from September 2015 to Dec 31, 2016.
Other	6.6	New information from the hydrology update to Dec 31, 2016 resulted in a change in the inter-annual trend for evaporation. This trend is now statistically significant.
INAC-TRC7	3.3	Inclusion of an “apples-to-apples” comparison between Cambridge Bay A (without under-catch) and site specific precipitation. Explanation as to why unadjusted Cambridge Bay A data is suitable to be used for the site precipitation.
INAC-TRC7 / INAC-IR17	3.6	Inclusion of an explanation as to why the presented Inflow Design Flood (IDF) does not use daily under-catch corrections.
INAC-TRC8	6.5	Monthly evaporation is divided by water season (i.e. ice cover season, melting season, and open water season) as defined by the snowmelt model.
INAC-IR18	6.8	Inclusion of a discussion on the effect of ice cover on lake evaporation.

1 Introduction

1.1 Background

The Hope Bay Project (the Project) is a gold mining and milling undertaking of TMAC Resources Inc. The Project is located 705 km northeast of Yellowknife and 153 km southwest of Cambridge Bay in Nunavut Territory, and is situated east of Bathurst Inlet. The Project comprises of three distinct areas of known mineralization plus extensive exploration potential and targets. The three areas that host mineral resources are Doris, Madrid, and Boston.

The Project consists of two phases” Phase 1 (Doris project), which is currently being carried out under an existing Water Licence, and Phase 2 (Madrid-Boston project) which is in the environmental assessment and regulatory stage. Phase 1 includes mining and infrastructure at Doris, while Phase 2 includes mining and infrastructure at Madrid and Boston located approximately 10 and 60 km due south from Doris, respectively.

1.2 Project History

Work at the Project site dates back to 1964 when the first exploration was carried out in the area focusing on showings at Ida Point, Ida Bay and Roberts Lake to the north. Three different exploration companies continued exploration through the 1970s and 1980s, but the first exploration drilling only started in 1992. This exploration drilling led to the first site infrastructure at Boston, in the form of an exploration camp on the northeastern shores of Aimaokatalok Lake in 1993. Subsequently, underground development was carried out at Boston in 1996 and 1997 to extract a bulk sample.

Exploration drilling expanded to Madrid and Doris in 1999, and a new exploration camp was constructed on the eastern shore of Windy Lake. In 2006, a Project Certificate (NIRB No. 003) was obtained to start a mine at Doris, and the associated Water Licence (2AM-DOH0713) was issued in 2007. Construction commenced the same year. Construction was slowed down as the Project transitioned in ownership in 2008, but resumed in 2010; however, in 2012 the Project was placed in care and maintenance prior to starting commercial production. Another ownership change in 2013 resulted in recommencement of construction, with planned commercial production scheduled for early 2017.

1.3 Objectives

Over the Project history there has been various campaigns to collect baseline climate and hydrology data. This work was not carried out in a consistent manner, and data was not continuously being updated as new data was collected. As a result there are considerable contradictory and inconsistent data in historic reports. The purpose of this report is to provide a clear description of all past baseline reports, and a consistent basis for baseline climate and hydrological parameters to be used in design and analysis of the Madrid-Boston project. This report provides current climate conditions. Climate change projections for the Project are documented in SRK (2017).

The climate and hydrological parameters assessed in this report include air temperature, water temperature, wind speed, wind direction, precipitation and evaporation.

2 Meteorology Data

2.1 Site Data

The meteorological data used for this analysis are divided into information that has been captured at the Project site, and regional information that is publicly available. Table 1 provides details on the Project site meteorological stations, while Table 2 provides information on what was collected, and periods of data collection. Table 3 summarizes the most relevant regional meteorological stations from Environment Canada (EC) and from Indigenous and Northern Affairs Canada (INAC), also presented on Figure 1 and Figure 2. These stations are used as reference to estimate site specific meteorological parameters when site data is not available or not complete. Regional data is also used for comparison purposes.

For this assessment SRK used data obtained from tables and appendices of the various reports described in Section 2.3, as well as meteorological records provided by ERM.

Table 1: Site Meteorological Station Details

Station	Location(1)	Data Collected	Station Details
Doris meteorological station	7558557 N, 433281 E	Air temperature, relative humidity, wind speed and direction, rainfall, winter precipitation (i.e. snowfall/snow water equivalent), solar radiation, and barometric pressure.	Station installed February 2004. This station consisted of two 3 m high tripods. Station upgraded August 2009 to a 10 m tower which meets the Meteorological Service of Canada Standards. Temperature sensor was malfunctioning from installation until November 2004. There are no studies to account for station under-catch for precipitation.
Doris Lake micro-meteorological (evaporation) station	Doris Lake	Air temperature, relative humidity, wind speed and direction, rainfall, solar radiation, net radiation, water temperature.	Station first installed July 2009. Installed only for open water seasons, typically installed in July and removed in September.
Boston meteorological station	7505312 N, 441207 E	Air temperature, relative humidity, wind speed and direction, rainfall, and solar radiation.	Station installed August 1993 southeast of camp near Stickleback Lake. The 10 m tower fell over in October 1999 and was not repaired until June 2000. Temperature sensor malfunction in 2005. Station relocated in 2006. Snow depth sensors added in 2009. Snowfall is not measured. There are no studies to account for station under-catch for precipitation.
Roberts Bay meteorological station	Potential port site	Wind speed and direction.	Wind speed and direction sensors on 3 m tripod. Continuous data collected during the summer months of 1997, 1998 and 2000 (Rescan 2001).
Windy meteorological station	Windy Camp	Pan Evaporation.	Data collected in 1995 and 1996. No station details available.

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Note(s):

(1) Coordinate system is UTM, WGS 84, Zone 13

Table 2: Available Site Data

Station	Parameter	Available Data[(1)]	Comments	Reference
Windy	Pan Evaporation	1995, 1996	Golder 2009 notes, significant data collection problems (reading errors, numerous days of missing data, unrecorded water removal). Data incomplete and was not used.	Golder 2009, Rescan 2001
Boston	Air Temperature	April 1993 to May 2002, July 2006 to September 2010, January 2012 to December 2016	April 1993 to May 2002 data only available monthly. Numerous days of missing data, and data collection errors 1993 and 1994, therefore this data was not included in the analysis.	Rescan 2001, 2002, 2009, and 2010, AMEC 2003, ERM 2016-1, ERM 2017-2
	Rainfall	April 1993 to May 2002, July 2006 to September 2009, January 2012 to September 2016	April 1993 to May 2002 data only available monthly. Numerous days of missing data, and data collection errors 1993 to 1996. No rainfall data collected October 2009 to September 2010.	Rescan 2001, 2002, 2009 and 2010, ERM 2015-1, 2016-2, and 2017-1, AMEC 2003.
	Snow water equivalent	April 1993 to May 2002	Calculated from ultrasonic gauge. Data only available monthly. AMEC (2003) notes that this data is unreliable, and not measured but instead based on calculations and assumptions which are not clear.	Rescan 2001, 2002, AMEC 2003.
	Wind Speed and Direction	August 1993 to February 1999, June 2000 to September 2001, July 2006 to September 2010, January 2012 to December 2016	Collected every 12 hours in 1993, and at various hourly intervals in 1994. Only partial years of data collected in 1993 to 1997 and 1999. Incorrect wind directions recorded January through March 1998.	Rescan 2001, 2002, 2009 and 2010, ERM 2016-3, 2016-4, 2016-10, 2016-12 and 2017-2
	Pan Evaporation	1997, 1998, 2000	Open water season only. AMEC 2003 notes significant data collection problems (reading errors, numerous days of missing data, unrecorded water removal) for all years except 1997. The single complete year of data was used as a benchmark comparison for calculated values.	AMEC 2003
N/A	Snow Surveys	2004 to 2008	Measured show depth, snow water equivalent and snow density at various locations on the Project site that represent different terrain conditions (open lake, exposed low land, sheltered lowland, North aspect, East aspect, South aspect, West aspect).	Rescan 2009, 2010
Doris	Air Temperature	November 2004 to December 2016	Station switched to EC standard system August 13, 2009.	Rescan 2009, 2010, 2011, 2012, ERM 2014-1, 2014-2, 2016-9 and 2017-2
	Rainfall	March 2004 to November 2013 and May 2014 to December 2016	Missing data in winter 2013/2014 due to adaptor freezing and no winter maintenance due to the site being on care and maintenance.	Rescan 2009, 2010, 2011, ERM 2014-1, 2014-2, 2016-6 and 2017-1

Station	Parameter	Available Data(1)	Comments	Reference
	Wind Speed and Direction	March 2004 to December 2016	Monthly average hourly, maximum and minimum instantaneous values. Sensor height raised from 3 m to 10 m August 13, 2009. Data obtained from the 3 m high sensor adjusted to be comparable with data from 10 m sensor.	Rescan 2009, 2010, 2011, 2012, ERM 2014-1, 2014-2, 2015-2, 2016-7, 2016-8, 2016-9 and 2017-2
	Lake Evaporation	Open water seasons 2009 to 2016	Calculated total monthly and average daily evaporation rates, based on data collected using the Doris Lake micro-meteorological station.	Rescan 2009, 2010, 2011, 2012, ERM 2014-1, 2014-2, 2016-5 and 2017-3
Roberts Bay	Wind Speed and Direction	Summer and fall 1997, 1998 and 2000	Data obtained using 3 m high sensor adjusted, to be comparable with data from 10 m sensors. Used for comparison.	Rescan 2001, 2002, and ERM 2016-11

Source: \\srk.ad\dfs\na\van\Projects\01_SITES\Hope.Bay\1CT022.004_Phase 2 DEIS - Engineering Support\!080_Deliverables\Hydrology Report\[HBClimateReportReview.xlsx]

Note(s):

(1) Data collection at the Doris and Boston stations is continuing, the stated end dates are the last dates when data was available.

Table 3: Relevant Regional Meteorological Stations, Sorted by Distance from Doris

Station Name	Environment Canada ID	Source	Lat. (deg)	Lon. (deg)	Elev. (masl)	Dist. from Doris (km)	Dist. from Boston (km)	Hourly Record Length	Daily Record Length
Cape Peel West	2400697	EC	69.04	-107.82	165	112	165	1994-2016	1993-2016
Cambridge Bay A	2400600	EC	69.11	-105.14	31	124	170	1953-2015	1929-2015
Cambridge Bay A	2400601	EC	69.11	-105.14	31	124	170	2015-2017	2015-2017
Cambridge Bay GSN	2400602	EC	69.11	-105.14	19	124	170	2002-2016	2002-2016
Walker Bay	-	INAC	68.36	-108.10	451	157	184	-	1959-1981
Hat Island	2302370	EC	68.32	-100.09	36	271	274	1994-2016	1959-2016
Lupin A	23026HN	EC	65.76	-111.25	490	333	301	1982-2006	1982-2006
Lupin CS	230N002	EC	65.76	-111.25	488	333	301	1997-2016	1997-2016
Kugluktuk A	2300902	EC	67.82	-115.14	23	358	370	1978-2014	1977-2014
Klugluktuk Climate	2300904	EC	67.82	-115.14	23	358	370	2005-2016	2004-2016
Ekati A	220N001	EC	64.70	-110.61	468	422	381	1997-2016	1998-2011
Gjoa Have Climate	2302340	EC	68.64	-95.85	42	446	451	2003-2016	2003-2016
Lupin	-	INAC	65.75	-115.25	488	461	445	-	2004-2006
Salmita	-	INAC	64.05	-111.17	441	500	457	-	1994-2008
Croker River	230J01Q	EC	69.28	-119.22	69	526	555	1994-2016	1993-2016
Holman CS	2502505	EC	70.76	-117.80	30	526	568	2000-2016	2000-2016
Shepherd Bay A	2303685	EC	68.82	-93.43	43	544	551	1973-2016	1957-2016
Toloyoak A	2403854	EC	69.55	-93.58	27	547	561	1984-2015	1984-2015
Colomac	-	INAC	64.43	-115.07	358	560	532	-	2000-2007
Silver Bear	-	INAC	65.62	-118.12	188	576	566	-	2005-2007
Baker Lake A	2300500	EC	64.30	-96.08	19	637	598	1953-2013	1946-2013
Discovery	-	INAC	63.20	-113.77	291	640	603	-	2005-2007
Yellowknife A	2204100	EC	62.46	-114.44	206	729	691	1953-2013	1942-2013
Pocket Lake	-	INAC	62.50	-114.38	210	769	730	-	1994-2007
Nanisivik	-	INAC	73.03	-84.55	355	976	1006	-	1993-2002
Fort Simpson	2202101	EC	61.76	-121.24	169	987	962	1963-2014	1963-2014

2.2 Reanalysis

The regional meteorological station and site data was complemented with data obtained from reanalysis (NASA 2017). Reanalysis creates data sets, extending for several decades, for the entire planet by combining satellite information, land records and numerical models that simulate the earth's climatic conditions. Reanalysis can provide meteorological data including precipitation, temperature, wind speed, solar radiation; and, relative humidity.

State-of-the-art publicly available reanalysis data was obtained from:

1) **Modern-Era Retrospective Analysis for Research and Applications (MERRA)** provided by the National Aeronautics and Space Administration (NASA 2017). MERRA includes daily data from 1983 to present (2017) for the entire world, based on a 0.5 degree latitude by 0.5 degree longitude grid; and

2) **ERA-Interim** provided by the European Centre for Medium-Range Weather Forecast (ECMWF). ERA-Interim includes sub-daily data from 1979 to present (2017) for the entire world, based on a 0.75 degree latitude by 0.75 degree longitude grid.

Because of the grid size of 0.5 degrees to 0.75 degrees (approximately 50 to 80 km.), Doris and Boston are represented in two different climatic cells. For the analyses described in the sections below Doris and Boston are represented by data obtained directly from these climatic cells.

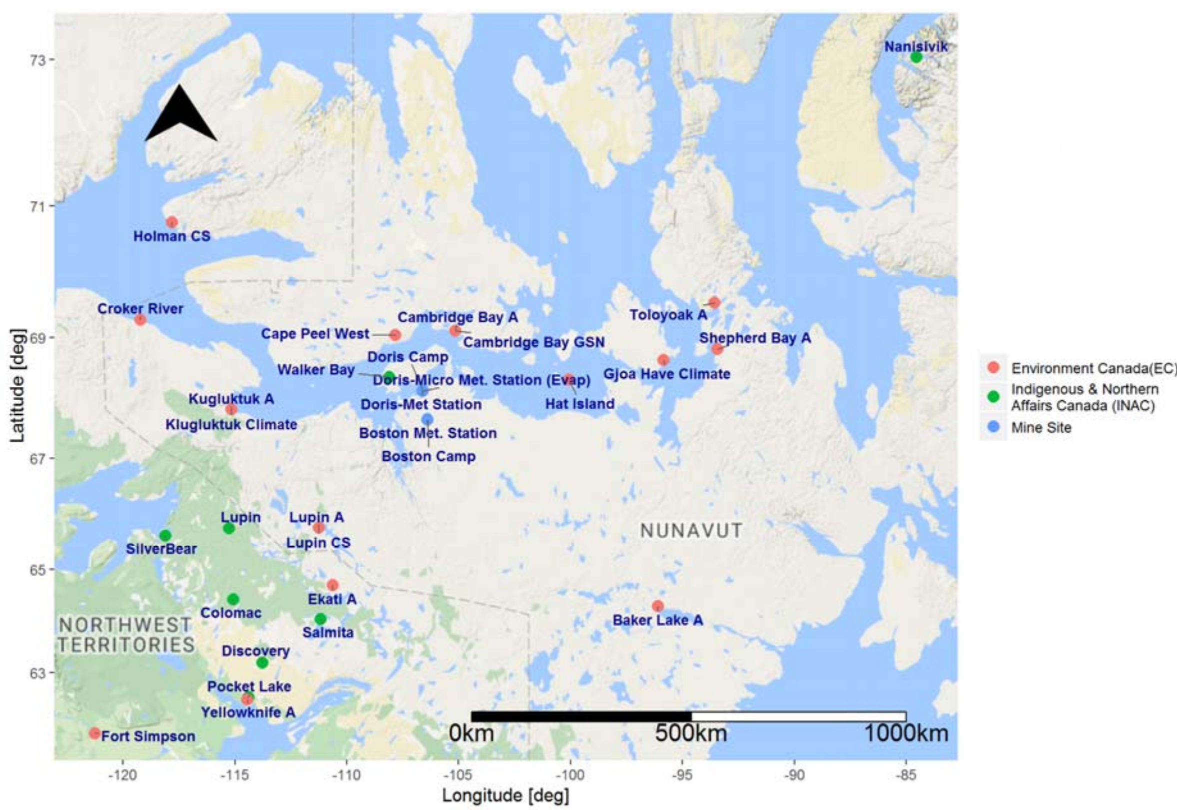


Figure 1: Regional Meteorological Stations

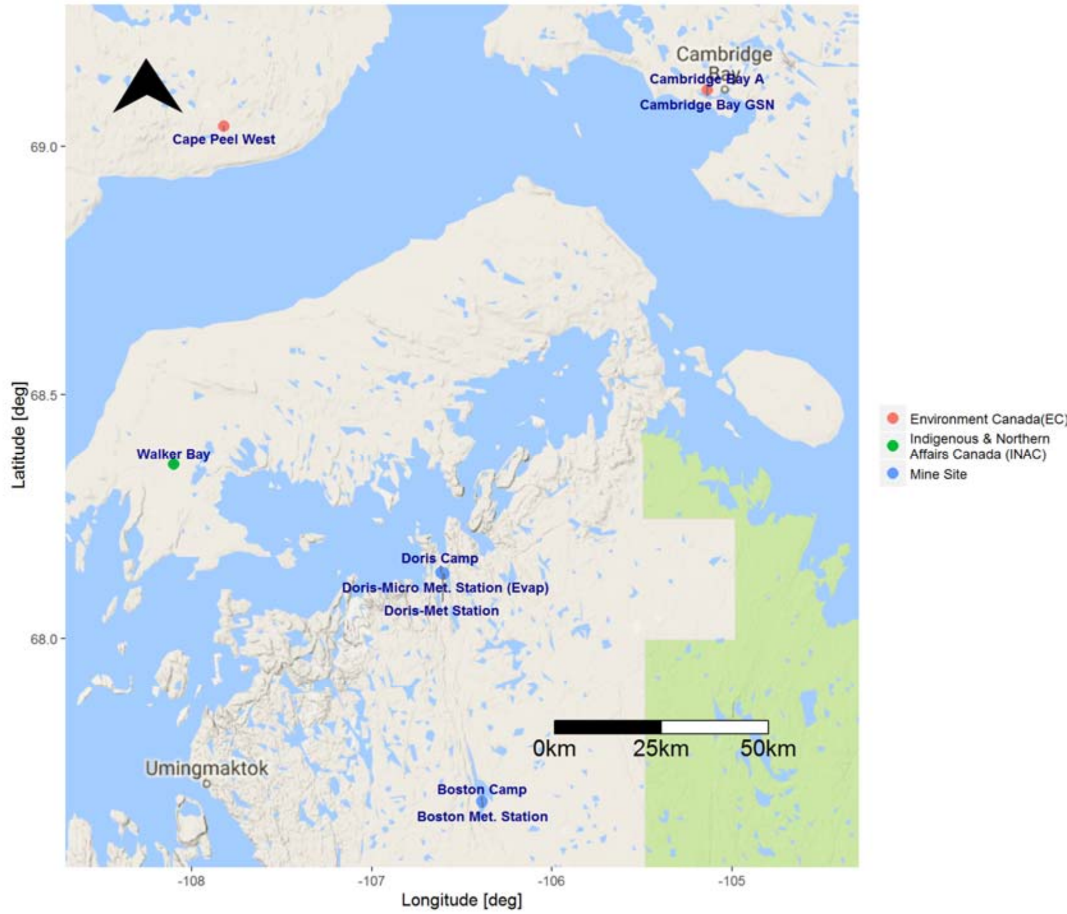


Figure 2: Closest Meteorological Stations around Doris and Boston

2.3 Review of Historic Data Analysis Reports

Project specific climate and hydrology baseline data has been presented many times between 2001 and 2016; however, only a few reports have analyzed the available data in order to develop values for design and analysis. This section provides a concise description of the historic data analysis reports in the context of the parameters of concern. This review intentionally focusses on the factual data presented, and does not make any judgments related to the values, or the quality of the information.

2.3.1 2003 Initial Baseline Analysis - AMEC (2003)

The AMEC (2003) meteorology and hydrology baseline report was the first data analysis report prepared with the specific goal of presenting baseline information for Doris. It compiles the available information from Boston (as there was no Doris specific data available at that time), and presents a synthesis of meteorological parameters based on regional and site-specific information.

AMEC (2003) was primarily based on site information provided by “1993 – 2002 Data Compilation Report for Meteorology and Hydrology” by Rescan (2002). This last report included site meteorological parameters and comprised a description with the quality of their presented records.

The following pertinent facts from AMEC’s work can be highlighted:

- The data set used in the baseline reports ends in June 2001.
- ***Regional Stations***: Regional data used Environment Canada (EC) meteorological stations Kugluktuk A, Lupin A and Cambridge Bay A.
- ***Air Temperature*** was correlated with Kugluktuk A, Lupin A and Cambridge Bay A EC meteorological stations using Boston air temperature data from 1995 to 2001.
- ***Precipitation***: Rainfall data was correlated with Kugluktuk A, Lupin A and Cambridge Bay A EC meteorological stations using Boston rainfall data from 1996 to 2001; Due to numerous days of missing data, and data collection errors, Boston precipitation records from 1993 to 1996 were not used in this correlation. This correlation was used to derive monthly and annual rainfall, snowfall and total precipitation between 1959 and 2001, where:
  - Site snowfall data was disregarded because assumptions used in its collection could not be verified. As a result snowfall was estimated using regional data only, using the same regression as rainfall.
  - Regional under-catch factors were presented, but they were not compared with site specific measurements at Boston station.
- ***Extreme Event Precipitation*** with return periods from 2 to 500 years (24-hour rainfall depth), were developed using a correlation between site data and Kugluktuk A, Lupin A and Cambridge Bay A regional stations. These values did not include under-catch.
- ***Evaporation***: Only 1997 site data was used to estimate evaporation. The other years were not used because the information presented numerous data collection errors, reading errors, and days with missing data. Because the poor quality in the site records, annual evaporation data was benchmarked with from other projects in the region. The report suggests an annual lake evaporation value of 220 mm for the Project site.

2.3.2 2006 Baseline Update – Golder Associates (2006)

Golder (2006) prepared an update of the AMEC (2003) baseline analysis for the Doris area. This update included an update to the regional analysis, to 2006, using data from INAC’s Walker Bay station as well as data from the Kugluktuk A, Lupin A and Cambridge Bay A stations. Pertinent facts about the data include:

- Report uses new site data to confirm the AMEC (2003) baseline values, including:
  - Doris Station measurements May 2003 to September 2006,
  - Boston Station measurements July 2006 to September 2006, and

  - Spring snow surveys conducted in 2004, 2005 and 2006;

- ***Regional Stations:*** The regional analysis included information from INAC Walker Bay. INAC Walker Bay data includes monthly rainfall from 1996 to 2005; and snow on ground values from 1999 to 2005.
- ***Precipitation:*** Analysis using the additional site information and additional regional station concluded that the Doris mean annual precipitation value presented in AMEC (2003) is reasonable. Additionally monthly snow water equivalents are provided from 1995 to 2002 at Boston Camp and annual snow water equivalents are provided for 2004 to 2006.
- ***Evaporation:*** No additional evaporation measurements were collected on site since the AMEC (2003) baseline report. Monthly lake evaporation was estimated at Doris, based on Morton methodology (Morton 1983), using data from 1997, and 2004 to 2005. The mean annual lake evaporation value obtained from this method (233 mm) is only slightly higher than the baseline value of (220 mm); therefore, given the sparsely available data the report concluded that it is still reasonable to use the value presented in the AMEC (2003) baseline report.

2.3.3 2008 Baseline Update – Golder Associates (2009)

Golder (2009) presents an important update of the baseline meteorological parameters at Doris, based on new regional and site specific data collected since the 2006 update (Golder 2006). This report characterizes climate parameters including precipitation, and lake evaporation. The pertinent information from this document include:

- ***Site Data:*** The report uses Doris station data from 2004 to 2008, specifically the data includes:
  - Continuous air temperature and rainfall data from February 2004 to December 2008,
  - Spring Snow Water Equivalent (SWE) values from 2004 to 2008. These data were collected for different terrains types such as open lake, exposed land, low land, North aspect, East aspect, South aspect and West aspect,
  - Wind speed and direction frequencies 2004 to 2008, and
  - Relative humidity and solar radiation February 2004 to December 2008;
- ***Regional Stations:*** Regional data from Cambridge Bay A, Lupin A, Kugluktuk A, and INAC Walker Bay stations was used.
- ***Air Temperature:*** The report develops a correlation for mean daily air temperature between Doris Station data (February 2004 to December 2008) and Cambridge Bay A data. This correlation is used to derive a Doris precipitation record from 1949 to 2008, the report presents maximum, minimum and monthly derived average temperature. The derived mean annual air temperature was −12.4°C.

- ***Precipitation:*** The report suggests monthly precipitation data from Doris can be estimated as Cambridge Bay A monthly precipitation data adjusted by a factor of 1.11. This correction factor was estimated based on a comparison of continuous rainfall data from February 2004 to December 2008 collected at the Doris station and concurrent (under catch corrected) data at Cambridge Bay A. No concurrent snowfall measurements were available for the two sites. Mean annual precipitation was estimated to be 232.5 mm.

- ***Extreme Precipitation:*** Annual precipitation values (adjusted for under catch) for the 200-wet year to the 200-dry year were developed based on the derived precipitation records. Short duration precipitation intensities for return periods of 2 to 100 years and durations of five minutes to 24 hours were presented using Cambridge Bay A station data from 1970 to 1990.

- ***Snow Water Equivalent (SWE):*** The SWE at Doris was estimated from 1949 to 2008 based on the annual snowfall records at Cambridge Bay A and measured SWE at Doris for the period of 2004 to 2008. This estimation was implemented with the expression: Annual snowfall at Cambridge Bay A x monthly estimated under-catch factor at Cambridge Bay A x 0.77 (estimated sublimation factor from 2004 to 2008) = Annual Doris SWE.

- ***Evaporation:*** No additional pan evaporation measurements have been performed since AMEC (2003); therefore, site records consist of one complete year (1997). The monthly lake evaporation estimation, based on Morton methodology (Morton 1983), described in Golder (2009) was updated for three additional years of Doris Lake data (1997, and 2004 to 2008). The mean annual lake evaporation value obtained was 241 mm, which is thought to be reasonable when compared with calculated lake evaporation at Colomac, Discovery, Lupin, Nanisivik, Pocket Lake, Salmita, and Silver Bear stations.

- ***Wind**:* At Doris, hourly and maximum wind speed, and wind direction records are available from 2004 to 2008. The predominant Doris wind directions are west and west-northwest. The Doris wind data was compared with concurrent Cambridge Bay A station data and the two data sets were found to have different frequency patterns.

- ***Relative Humidity and Solar Radiation**:* Monthly relative humidity and solar radiation at Doris was recorded between 2004 to 2008. The Doris monthly relative humidity was compared with monthly relative humidity at Cambridge Bay A, but no correlations were presented.

3 Total Precipitation

3.1 Definitions

Total Precipitation: Total precipitation is the total rainfall, and snowfall measured as snow water equivalent.

Snow water equivalent (SWE): Snow densities vary due to depositional method, temperature and season. The snow water equivalent is the amount of water within the snowpack. SWE is typically reported in millimetres.

Under-catch (UC): Local wind vortices around meteorological stations can reduce the amount of precipitation captured by the station as rainfall or snowfall. The numerical factor to correct this loss is called under-catch factor. The efficiency of each meteorological station depends on the station configuration.

Environment Canada publishes monthly under-catch factors for specific stations and parameters, the adjusted data are then described as adjusted and homogenized Canadian climate data (AHCCD) (EC 2016). The corrections are monthly values for parameters such as total precipitation, snowfall and rainfall. So far, no studies have measured or estimated under-catch correction for the Boston or Doris meteorological stations, and it is not appropriate to assume that the under-catch correction for other sites will be applicable to the site.

Equation 1 presents the calculation to convert measured precipitation to actual precipitation using the under-catch factor.

$$\boldsymbol{Precipitation_{Actual} = Precipitation_{Measured} \times Undercatch_{Factor}}$$

Equation 1

3.2 Site-Specific Rainfall

The available monthly precipitation records for Boston and Doris are presented in Figure 3, where the color gradient reflects the number of months in the year that have data. At Boston, only 2007 has a complete twelve-month dataset, while for Doris complete datasets are available between 2004 and 2011 (Rescan 2009, 2010, 2011, ERM 2014-1, 2014-2, 2016-6 and 2017-1). Even though twelve months of data is stated to be available (because the station was fully functional for the entire period), in all cases rainfall data was only recorded during summer months, and the rainfall measurements presented have not been corrected for under-catch.

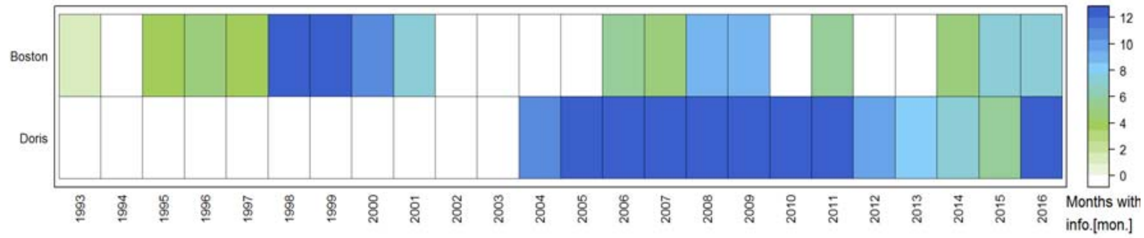


Figure 3: Summary of Monthly Rainfall Records for Boston and Doris

As described in Table 2 and Figure 3, the precipitation record for Doris and Boston are short and incomplete; therefore, supplementation of these records is required for performing engineering design and analysis.

3.3 Regional Precipitation

Regional meteorological stations used in previous reports include Cambridge Bay A, Lupin A, Kugluktuk A, and Shepherd Bay A. Cambridge Bay A (Cambridge Bay A Station ID 2400600 was complemented with Cambridge Bay A Station ID 2400601 for information after year 2015). Th available precipitation data at these stations is presented in Figure 4, where the color gradient reflects the number of days in the year that have data. Location information of each of the regional meteorological stations is listed in Table 3.

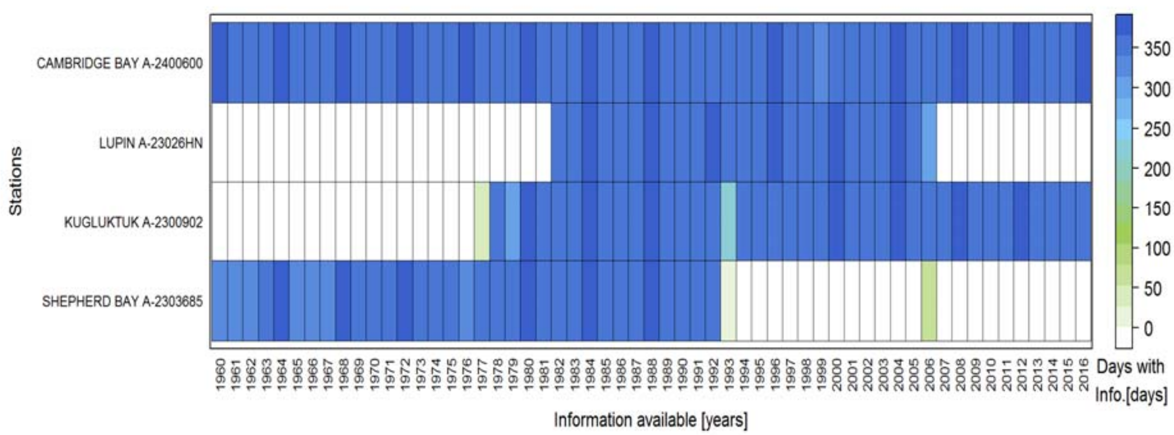


Figure 4: Historical Records Available for Regional Precipitation

Table 4 presents the mean annual precipitation with correction for under-catch. The meteorological station, Lupin A, which was used in the AMEC meteorological report (AMEC 2003) does not have under-catch corrections from Environment and Climate Change Canada (ECCC), and was not included in this review. ECCC does provide under-catch corrections for Cambridge Bay A Station ID 2400600, but does not for Cambridge Bay A Station ID 2400601, therefore, only Cambridge Bay A Station ID 2400600 was used with available information up to year 2015. Figure 5 presents the mean monthly precipitation based on all available records, this data is summarized in Table 4.

Table 4: Mean Monthly Precipitation Corrected for Under-catch at Regional Meteorological Stations

Station Name	Precipitation (mm)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Cambridge Bay A	10	9	11	11	14	18	28	31	26	24	16	11	210
Kugluktuk A	18	15	18	18	20	22	40	47	36	37	22	19	313
Shepard Bay A	10	8	10	13	14	18	27	39	30	33	16	12	231

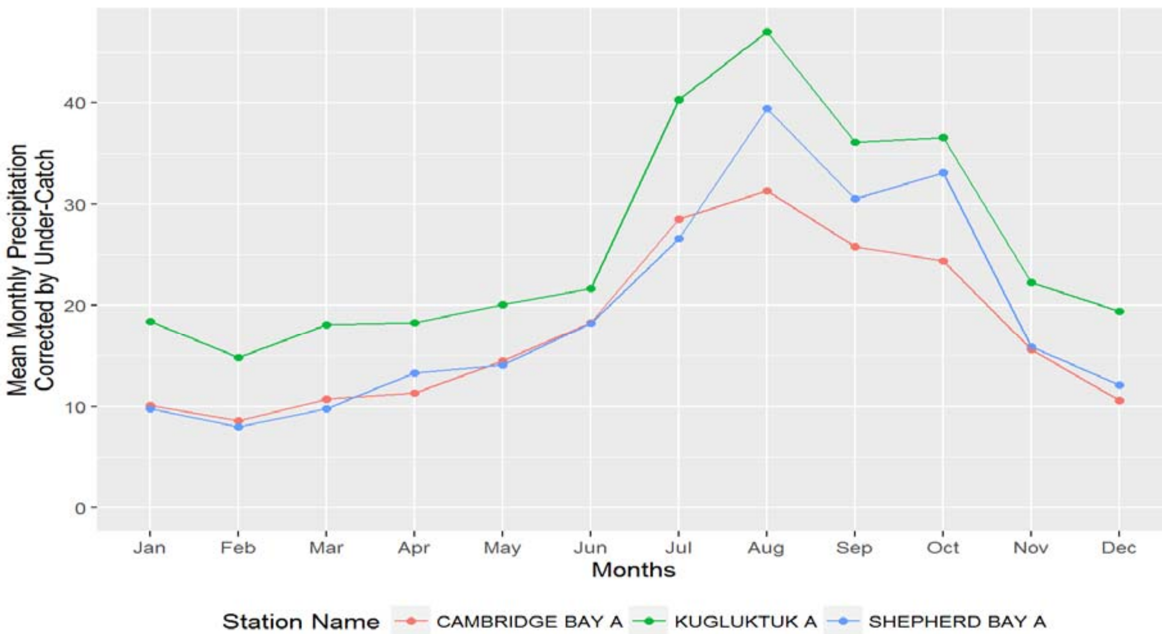


Figure 5: Mean Monthly Precipitation Corrected for Under-catch at Regional Meteorological Stations

Figure 6 presents the monthly rainfall correlation between Doris and Boston for the years where data is available at both stations. In Figure 6, the regression line for the monthly values is shown in blue, the relationship $y = x$ is shown in red, and the grey region represents the 95% confidence interval. Even though the values display significant dispersion, they tend to be aligned about the red line. This suggests that the rainfall values at these two stations display similar trends. Due to the absence of additional information and the moderate correlation between measured values, it will be assumed that these two locations have similar rainfall.

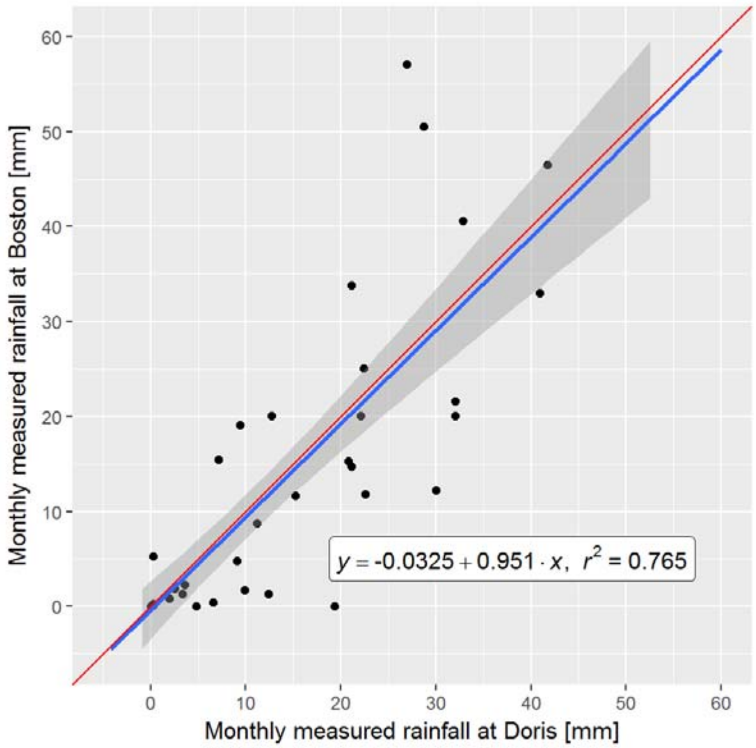


Figure 6: Overall Monthly Rainfall Correlation for Measured Data at Doris and Boston

Figure 7 is a correlation matrix for the available monthly rainfall information at different local (Doris and Boston) and regional (Cambridge Bay A and Kugluktuk A) stations. The bottom-left section contains the (x, y) pair point scatter plots while the upper-right section contains the correlation values, which are similar in magnitude to the r^2 values for their respective pair point figures. The stars in upper-right reflect results of a correlation test; three stars indicate a strong correlation and zero stars indicate that there is no correlation between variables. The diagonal of the matrix presents the frequency figures for the variables. Light green presents the graph and correlation for the local stations; light red the relationship between the regional stations and the site; and light blue the relationship between the regional stations.

Figure 7 illustrates an important correlation between stations. The strongest relationships between stations are between the measured values at Doris and Boston (in light green), followed by Cambridge Bay A and Kugluktuk A. Shepherd Bay A was not included in the analysis as the station's last records are from 1993 before site data was available, and Lupin A was not included because it does not have under-catch correction. Based on the proximity between stations and correlation values, Cambridge Bay A station is suggested to be used for supplementing Doris and Boston rainfall estimates.

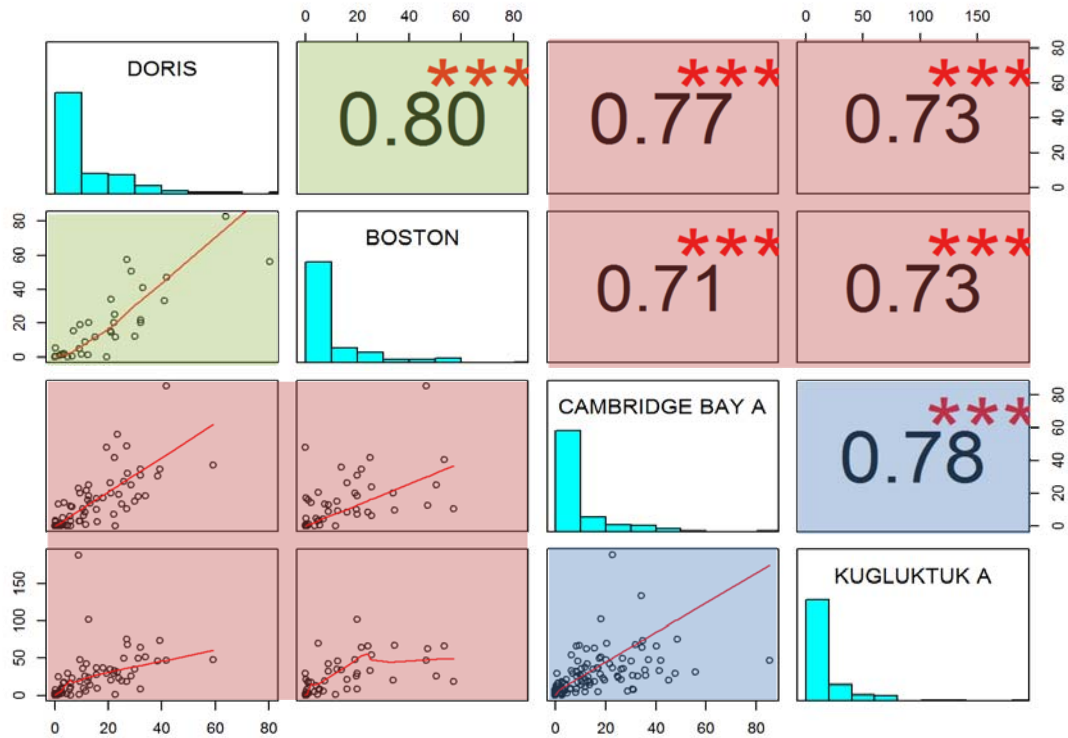


Figure 7: Pearson Correlations between Local and Regional Stations for Monthly Rainfall

In Figure 8, the blue dashed-line indicates where monthly rainfall at Cambridge Bay A, and the site would be equal (i.e., where y = x). Both graphs also present a Theil-Sen regression (Sen 1968). This regression is a non-parametric technique that is insensitive to outliers. Figure 8 demonstrates that the fit is suitable, and as a result, direct use of Cambridge Bay A is applicable. This supports the Pearson correlation matrix approach presented Figure 7, confirming that Cambridge Bay A is the most representative data set for site precipitation and has a reasonable correlation without the need for any corrections or adjustment factors.

Site precipitation data cannot be specifically corrected for under-catch because the under-catch corrections for Doris and Boston are unknown. Consequently, use of Cambridge Bay A precipitation for site precipitation without any corrections or adjustment factors is recommended.

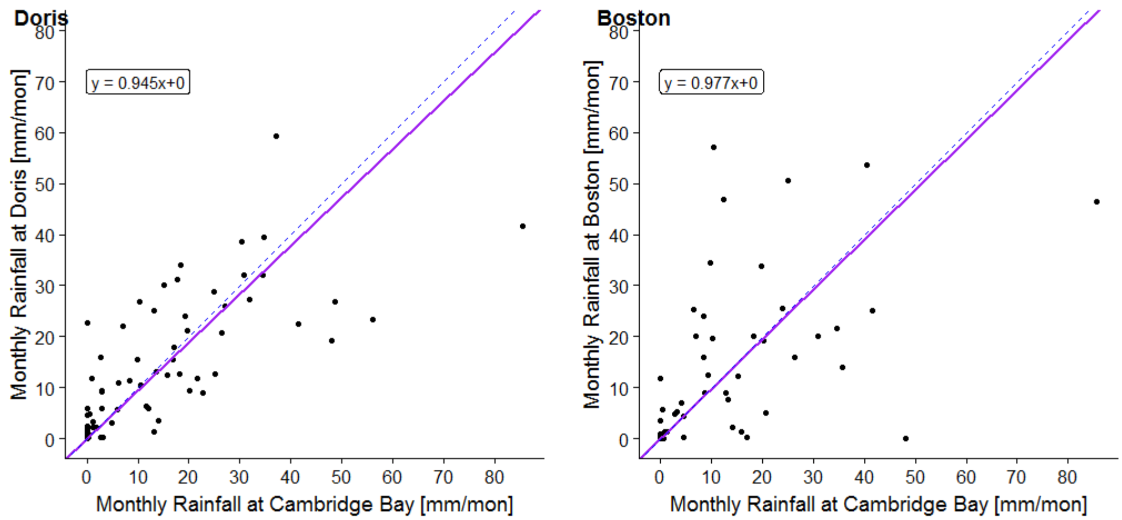


Figure 8: Monthly Rainfall Comparison between the site and Cambridge Bay A.

3.4 Mean Annual Precipitation

Given the good correlation that exists between Cambridge Bay A data and the datasets measured at Boston and Doris, and the length of the Cambridge Bay A record (dating back to 1929), it is recommended to directly use the Cambridge Bay A data for mean annual precipitation data, including monthly and daily under-catch corrected total precipitation values. These mean monthly values are presented in Table 5.

The predicted mean annual precipitation of 210 mm (Table 5) is similar to the 233 mm and 208 mm predicted in the 2008 baseline report (Golder 2009) and 2003 baseline report (AMEC 2003), respectively. Therefore, the estimated MAP value of 210 mm is reasonable to use in analysis.

Table 5: Mean monthly under-catch corrected total precipitation at Doris and Boston

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Rainfall (mm)	0	0	0	0	2	12	28	30	15	2	0	0	89
SWE (mm)	10	9	11	11	12	6	0	2	11	23	16	11	120
Total Precipitation (mm)	10	9	11	11	14	18	29	31	26	24	16	11	210

3.5 Frequency Analysis for Annual Precipitation

Table 6 lists the extreme annual precipitation values for Cambridge Bay A, to be used for Doris and Boston. These values were calculated using data spanning between 1949 and 2014. For this analysis, a year is considered a complete year when at least 360 days of data is available. Data from 1929 to 1948, and 2015 was not used in this analysis, as complete years were not available.

The frequency analyses were developed using Normal, Log Normal, Generalized Extreme Value (GEV), Gumbel, Pearson III, and Log Pearson III probabilistic distributions. The selection of the distribution parameters were prepared with the L-moments methodology. The L-moments approach suggests a more resistant estimation to outliers when compared with typical estimations. The selection of the best-fit distributions was prepared based on: Akaike Information Criterion, Corrected Akaike Information Criterion, Anderson-Darling Criterion, and Bayesian Information Criterion as described by Laio et al. (2009). These best-fit distributions were implemented by the statistical software R, version 3.3.1 (i386 - w64).

Table 6: Extreme Annual Precipitation at Doris and Boston

Return Period (years)	Annual Precipitation (mm)
200 Wet	324
100 Wet	311
50 Wet	297
25 Wet	282
20 Wet	277
10 Wet	261
5 Wet	243
Average (MAP)	210
2 Wet	210
3 Dry	195
5 Dry	182
10 Dry	168
20 Dry	158
25 Dry	155
50 Dry	147
100 Dry	140
200 Dry	134

3.6 Short Duration Precipitation Events

3.6.1 Maximum Precipitation 24 Hours by Month

Since Cambridge Bay A is considered representative of the precipitation at Doris and Boston, precipitation data from 1949 to 2016 were used to prepare a frequency analysis of the daily maximum precipitation by month. Cambridge Bay A (Station ID 2400600) was complemented with Cambridge Bay A (Station ID 2400601) for information after 2015. The daily information obtained from the Environment Canada website was correct to 24-hour information with the correction factor of 1.12 (NOAA 1963).

Table 7 displays the maximum 24-hour precipitation per month at Cambridge Bay A. This table is used to account for the maximum annual precipitation (Section 3.6.2) as well as estimate the maximum 24-hour precipitation for June (required for Section 3.7.2). From Table 7, the maximum annual precipitation is associated with the month of July, where this maximum precipitation is received as rainfall. The historical July under-catch corrections for the maximum monthly precipitation at Cambridge Bay A has median of +0.36 mm/day, but only available for Cambridge Bay A (Station ID 2400600) and estimated from daily under-catch corrections (ECCC 2017-1).

Application of under-catch corrections can be important during snow conditions, where the error can be significant. However, for this site, the maximum monthly rainfall is in July and the +0.36 mm/day corrections are from wind at orifice level, wetting at funnel area, evaporation, and wetting of the container (under-catch reasons from Mekis and Vincent, 2011); which are not relevant for extreme precipitation conditions, consequently for this section (Short duration Precipitation Events) daily under-catch values were not implemented.

SRK is not aware of any case-study with IDF corrections based on under-catch, and therefore it was not implemented as per EC (2014) for Cambridge Bay A. Consequently, these unadjusted Cambridge Bay A values can be used to represent the Doris and Boston sites for short precipitation values.

Table 7: Cambridge Bay A maximum 24-hour Precipitation by Month

Return Period (years)	Maximum 24-Hour Precipitation (mm)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2 Wet	1.6	1.5	2.1	2.1	3.3	5.6	8.4	8.3	6.8	4.1	2.6	1.9	14.2
5 Wet	2.9	2.8	3.9	4.2	6.3	11.1	15.5	14.1	10.9	6.8	4.6	3.6	23.6
10 Wet	4.3	3.8	5.3	6.1	8.6	15.3	21.5	18.4	13.8	9.0	6.2	5.0	29.8
25 Wet	6.8	5.4	7.3	9.1	11.4	21.1	31.0	24.6	17.6	12.0	8.3	6.9	37.6
50 Wet	9.6	6.7	9.1	11.8	13.6	25.9	39.8	29.6	20.6	14.5	10.1	8.6	43.5
100 Wet	13.5	8.1	10.9	14.9	15.7	31.0	50.4	34.9	23.7	17.2	12.0	10.4	49.2
200 Wet	18.8	9.6	13.0	18.4	17.8	36.5	63.1	40.6	26.8	20.1	14.1	12.3	63.1
500 Wet	29.2	11.8	15.9	23.8	20.5	44.4	83.9	48.7	31.2	24.4	17.0	15.2	83.9
1000 Wet	40.7	13.7	18.4	28.5	22.5	50.9	103.5	55.4	34.6	27.8	19.4	17.6	103.5

3.6.2 Site Precipitation-Duration-Frequency Curves

EC provides a precipitation-duration-frequency curve for Cambridge Bay A with return periods from 2 to 100 years (EC 2014). SRK updated this analysis using Cambridge Bay A data from 1949 to 2016 to develop a frequency analysis for return periods from 200 to 1,000 years. Cambridge Bay A (Station ID 2400600) was complemented with Cambridge Bay A (Station ID 2400601) for information after 2015.

The precipitation-duration-frequency curve is presented in Table 8. Based on the correlation described in Section 3.3, the Cambridge Bay A values can be used to represent the Doris and Boston site values.

Table 8: Precipitation-Duration-Frequency Curve for Cambridge Bay A (mm)

Storm Duration	Return Period (years)								
	2	5	10	25	50	100	200	500	1000
5 min	1.2	2.1	2.6	3.3	3.9	4.4	5.5	7.4	9.1
10 min	1.6	2.7	3.5	4.4	5.1	5.8	7.3	9.7	12.0
15 min	2.0	3.3	4.2	5.3	6.1	6.9	8.9	11.8	14.5
30 min	2.8	4.3	5.3	6.6	7.5	8.5	11.3	15.1	18.6
1 hr	4.2	6.1	7.4	9.0	10.2	11.4	15.9	21.1	26.0
2 hr	6.0	8.9	10.8	13.2	15.0	16.8	23.1	30.8	37.9
6 hr	9.8	14.6	17.8	21.7	24.7	27.6	38.0	50.5	62.3
12 hr	12.4	19.4	24.1	30.0	34.4	38.7	51.3	68.2	84.2
24 hr	14.2	23.6	29.8	37.6	43.5	49.2	63.1	83.9	103.5

3.7 Probable Maximum Precipitation

3.7.1 Annual Probable Maximum Precipitation

The annual probable maximum precipitation (PMP) was calculated using the Hershfield methodology (WMO 2009) and the historical precipitation record (1949 to 2016) from the Cambridge Bay A meteorological station (ECCC 2017-1). The Hershfield methodology requires the daily maximum 24-hour precipitation for at least ten years of record. The annual PMP was estimated to be 180 mm.

3.7.2 Spring Probable Maximum Precipitation

In areas where snow accumulates during the winter, spring rainfall on snowpack could create a higher probable maximum flood (PMF) than a PMF calculated using the annual PMP values and no snowpack. However, given the seasonality of rainfall (highest rainfall is typically in the summer or fall) using the annual PMP value on snow pack would overestimate the PMF. Therefore, a spring PMP is developed to determine the probable maximum precipitation in the spring when snow may still be on the ground. To develop the spring PMP the critical snowmelt month is determined, as that is when the highest runoff associated with freshet can be expected.

The critical snowmelt month is the month which, during a normal hydraulic year, has the highest daily snowmelt.

To calculate the spring PMP, the Canadian Dam Association (CDA) recommends calculating monthly seasonality of the 1:100-year return period rainfall to determine a factor to apply to the annual PMP (CDA 2007). The critical snowmelt month was determined to be June, based on the snowmelt model (Section 4). Based on the frequency analysis (Table 7), the 1:100 year June rainfall is equal to 31.0 mm.

The annual 1:100 year rainfall depth was calculated to be 49.2 mm (Table 8). Using these values, and the summer PMP value, Equation 2 was used to calculate a spring PMP of 115 mm.

$$Spring_{PMP} = Annual_{PMP} \times \frac{100yr\ Rainfall\ Depth_{June}}{100yr\ Rainfall\ Depth_{Annual}}$$ **Equation 2**

4 Snowmelt

4.1 Methodology

As described in Section 2, information on snowmelt and snow water equivalent on site is very scarce; therefore, other sources of information are needed to derive site values to be used in engineering design and analysis.

Snowmelt was estimated using a subroutine in R (CRAN 2017) called SnowMelt from the library EcoHydRology (Walter et al. 2005), which is a daily energy snowmelt model. This hydrological model is based on meteorological parameters such as daily maximum and minimum air temperatures, wind speed and total precipitation.

Reanalysis is the preferred source of snowmelt data because it provides continuous daily values from 1979 to 2016, and all information is obtained from the same source. Site meteorological records do not provide sufficient continuous daily values for maximum and minimum air temperatures, wind speed and total precipitation needed for snowmelt estimation (Table 2). Estimating snowmelt from the available regional data is also not ideal because Cambridge Bay A is the preferred regional station for temperature and precipitation (Sections 3 and 5), and Cambridge Bay GSN is the preferred regional station for daily wind speed (Section 0), and Cambridge Bay GSN data is only available after 2003.

The model hydrological inputs were obtained from the ERA-Interim climate reanalysis from 1979 to 2016 in sub-daily and daily intervals (ECMWF 2017). The model also required the latitude and longitude of the site and topographical slope and aspect of the terrain. The geological parameters were obtained from the USGS GTopo30 which provides worldwide topographical information with 30 arc-second spacing (USGS 2015).

4.2 Comparison with Site Information

Rescan (2009) presented a summary of the Hope Bay Belt snow surveys from 2004 to 2008. This information included values obtained for stations characterized as open lake, exposed lowland, sheltered lowland, North aspect, East aspect, South aspect and West aspect around Doris and Boston. The dataset is however small, and in most cases the data does not differentiate explicitly between samples at Doris or Boston.

To compare the snowmelt model with the site information, the parameters snow depth, snow water equivalent and snow density were compared with the snow survey data (Figure 9, Figure 10, and Figure 11). In these figures, the estimated parameters for Boston and Doris are displayed in orange and green respectively, and blue dots represent site measurements. The Doris and Boston values are different, because reanalysis, presents slightly different values for these locations, as described in Section 2.2. The samples (blue dots) showed high variability for every parameter.

Based on Figure 9 to Figure 11, the snowmelt model presents values in-line with site information and it is considered appropriate its use. However, because of the variability in the site measurements, the accuracy of the snowmelt model cannot be fully assessed, and the snowmelt information provided should be used cautiously.

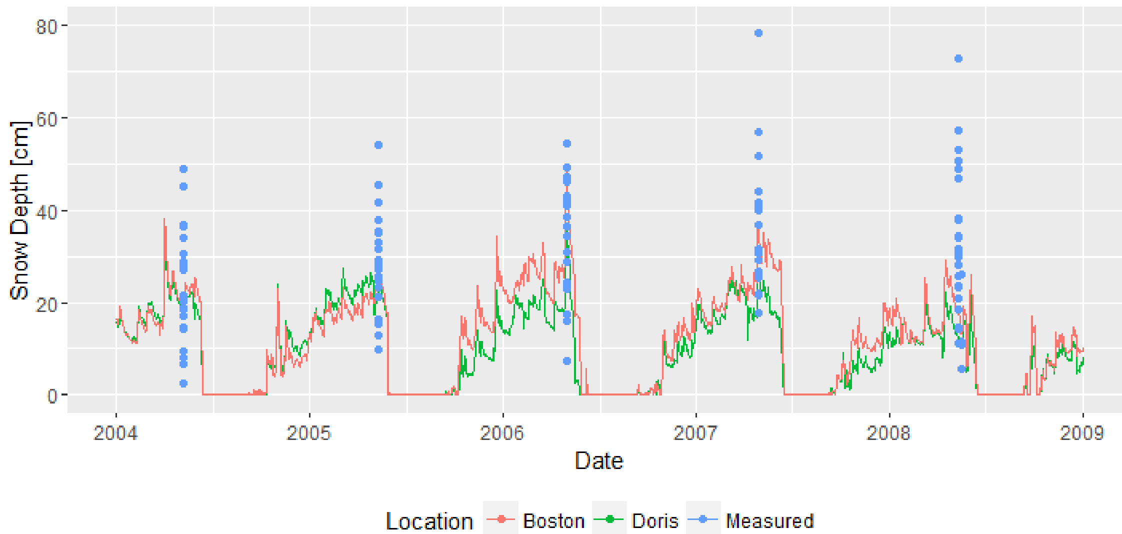


Figure 9: Snowmelt Model at Doris and Boston: Measured Versus Modelled Snow Depth

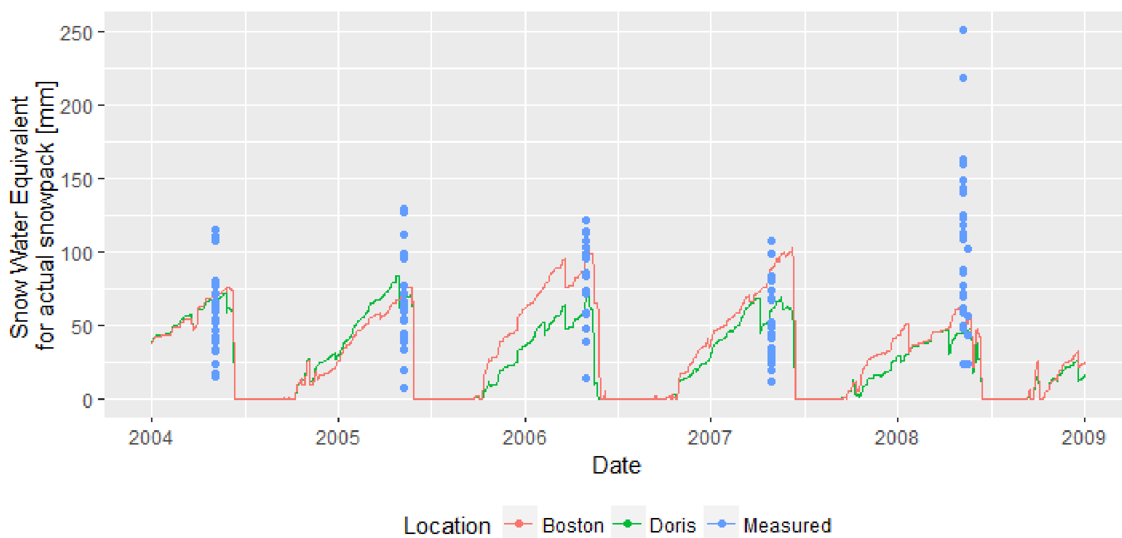


Figure 10: Snowmelt Model for Doris and Boston: Measured Versus Modelled SWE

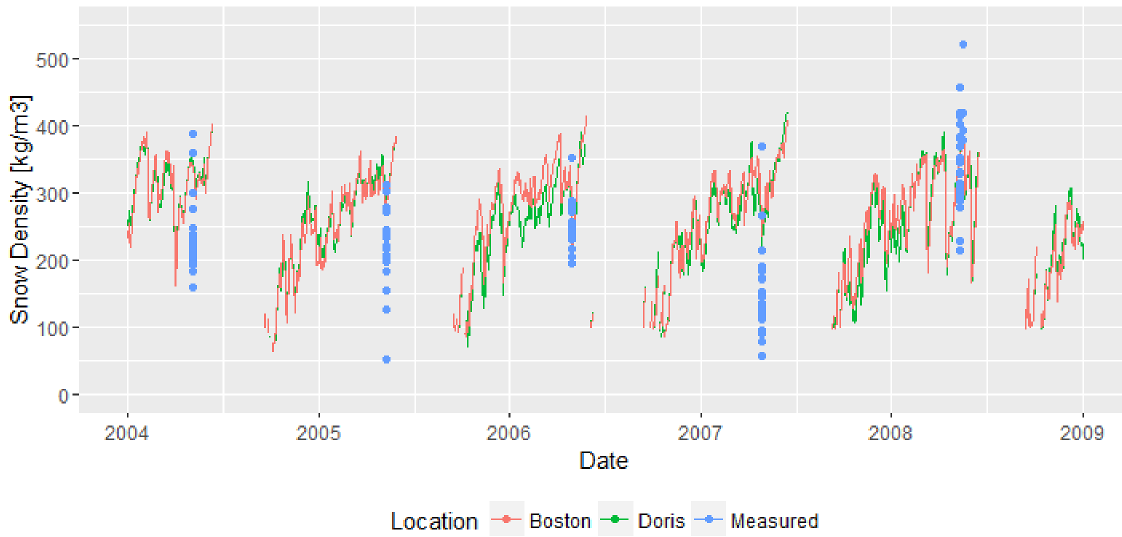


Figure 11: Snowmelt Model for Doris and Boston: Measured Versus Modelled Snow Density

4.3 Results

In an average hydrological year, the maximum daily snowmelt expected for each month is presented in Table 9. The average hydrological year, maximum daily snowmelt at Boston is 18 mm, and 17 mm at Doris.

Table 10 provides the monthly average snowpack, and Table 11 provides a frequency analysis for the maximum annual SWE of the snowpack.

Table 9: Average Year – Maximum Daily Snowmelt per Month

Location	Maximum Daily Snowmelt per Month (mm/day)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Boston	0	0	4	7	10	18	0	0	2	4	0	2
Doris	0	2	2	8	11	17	0	0	1	4	3	2

Table 10: Monthly Average Snowpack per Month (cm)

Location	Monthly Average Snowpack per Month (cm)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Boston	19	21	23	28	29	18	0	0	5	15	19	21
Doris	16	17	21	24	24	16	0	0	5	12	16	17

Table 11: Frequency Analysis for Annual SWE

Return Period (years)	Annual SWE (mm)	
	Boston	Doris
1000	167	202
500	161	187
200	151	166
100	144	151
50	136	135
25	126	119
20	123	114
10	112	98
5	99	82
2	73	56

5 Air Temperature

5.1 Available Site information

As described in Section 2 and summarized in Table 2, air temperature data for Doris is available from 2004 to 2016. Air temperature for Boston is available from 1993 to 2016 (with some years of missing or incomplete data). For the air temperature analysis only months with less than 5 days of missing data were considered complete. Figure 12 compiles the months with information available at Boston and Doris, where a white square means no information and a blue square, a complete year with 12 months of data.

Due to their short duration and periods of missing data, neither of these data sets is sufficient for engineering design and analysis; therefore, site information is supplemented with data from other sources to derive a data set for use in analysis and design.

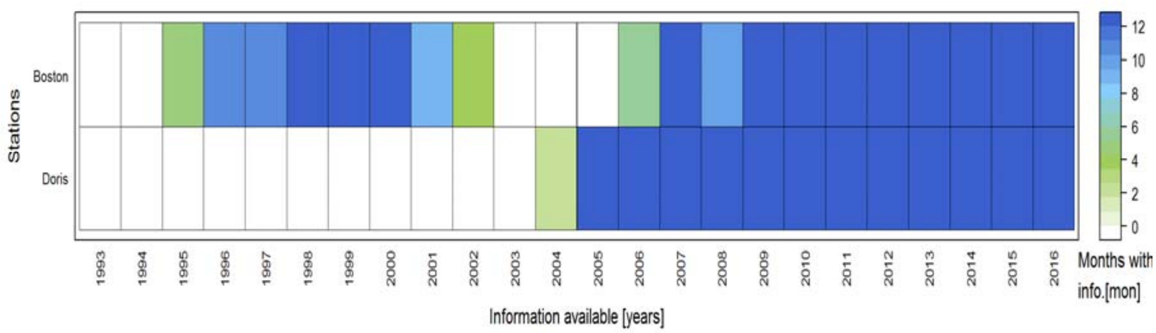


Figure 12: Site Temperature Records Available in Months with Information

5.2 Other Data Sources

In previous reports (Section 2) the regional stations used in the temperature analysis included Cambridge Bay A, Kugluktuk A, Lupin A, and Shepherd Bay A (Cambridge Bay A Station ID 2400600 was complemented with Cambridge Bay A Station ID 2400601 for information after year 2015). A summary of available temperature data for each of these regional stations is presented in Figure 13, where the color gradient reflects the number of days in the year that have temperature data.

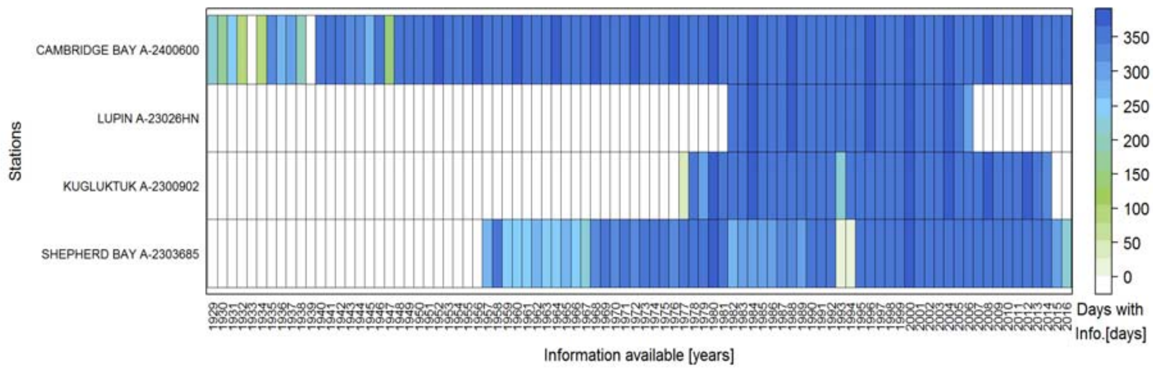


Figure 13: Historical Air Temperature Records Available in the Region

Figure 14 is a correlation matrix for the available daily temperature data from the local and regional stations and the MERRA reanalysis data. The bottom-left section contains the (x, y) pair point scatter plots while the upper-right section contains the correlation values, which are similar in magnitude to the r^2 values for their respective pair point figures. The stars in upper-right reflect results of a correlation test; three stars indicate a strong correlation and zero stars indicate that there is no correlation between variables. The diagonal of the matrix presents the frequency figures for the variables.

The correlation matrix illustrates important correlations between the regional daily values and the reanalysis values. The strongest relationships are between by MERRA and Cambridge Bay A data. The temperature distributions (cyan bars in Figure 14) display similarities, which suggest that the temperature on the region is quite consistent at a daily time scale. Based on this review, the data at Cambridge Bay A is representative of the region and as it is the closest regional meteorological station to the site, it is recommended to use this station as a base of temperature analyses.

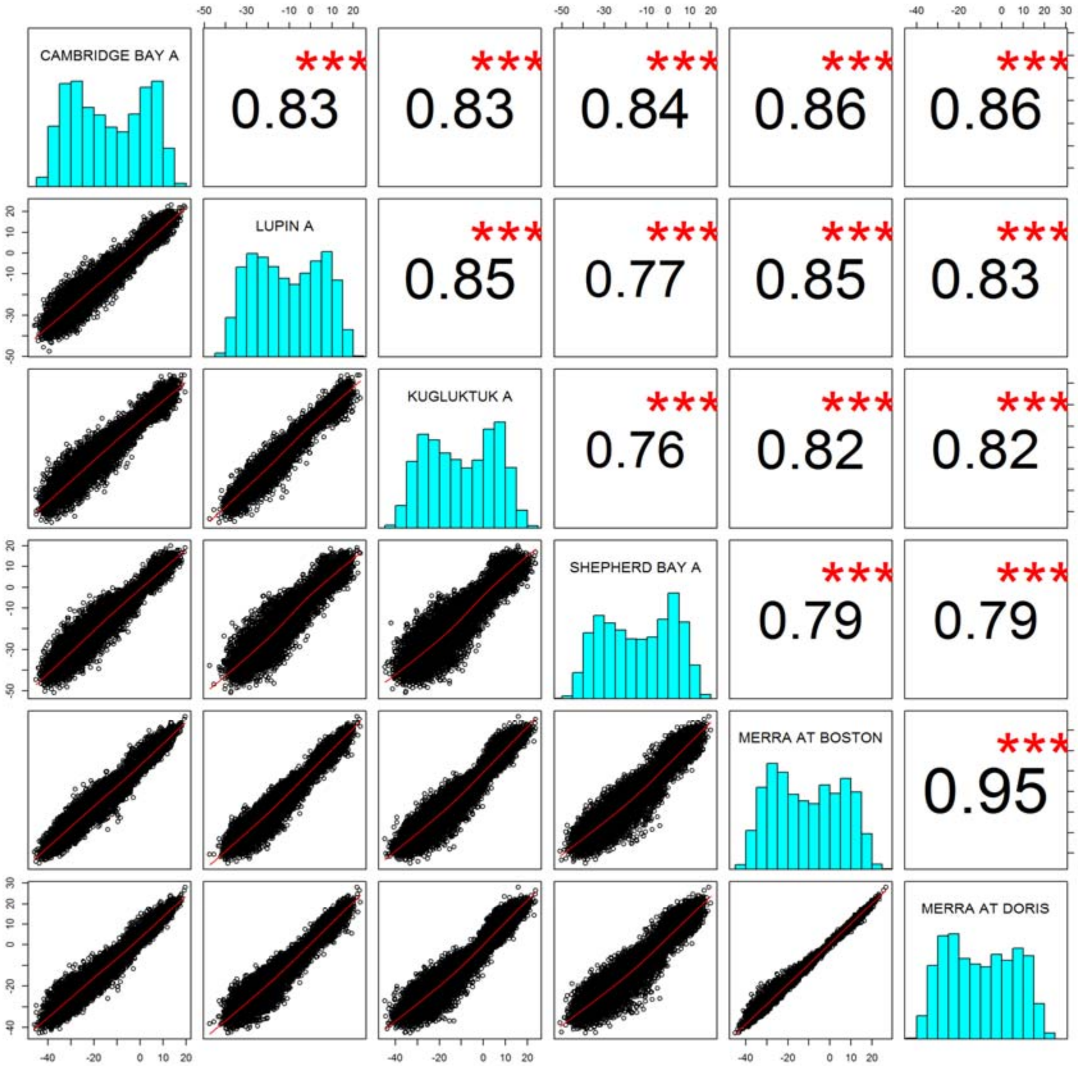


Figure 14: Correlation Matrix for Mean Daily Air Temperature at Regional Meteorological Stations

5.3 Site-Specific Air Temperature

Boston and Doris data was compared with the closest regional station to the site, Cambridge Bay A, and the information from reanalysis MERRA (NASA 2017). Figure 15 presents a linear relationship between monthly temperature values at Doris, Boston and Cambridge Bay A and reanalysis MERRA. A reference line, $y = x$, is shown in red.

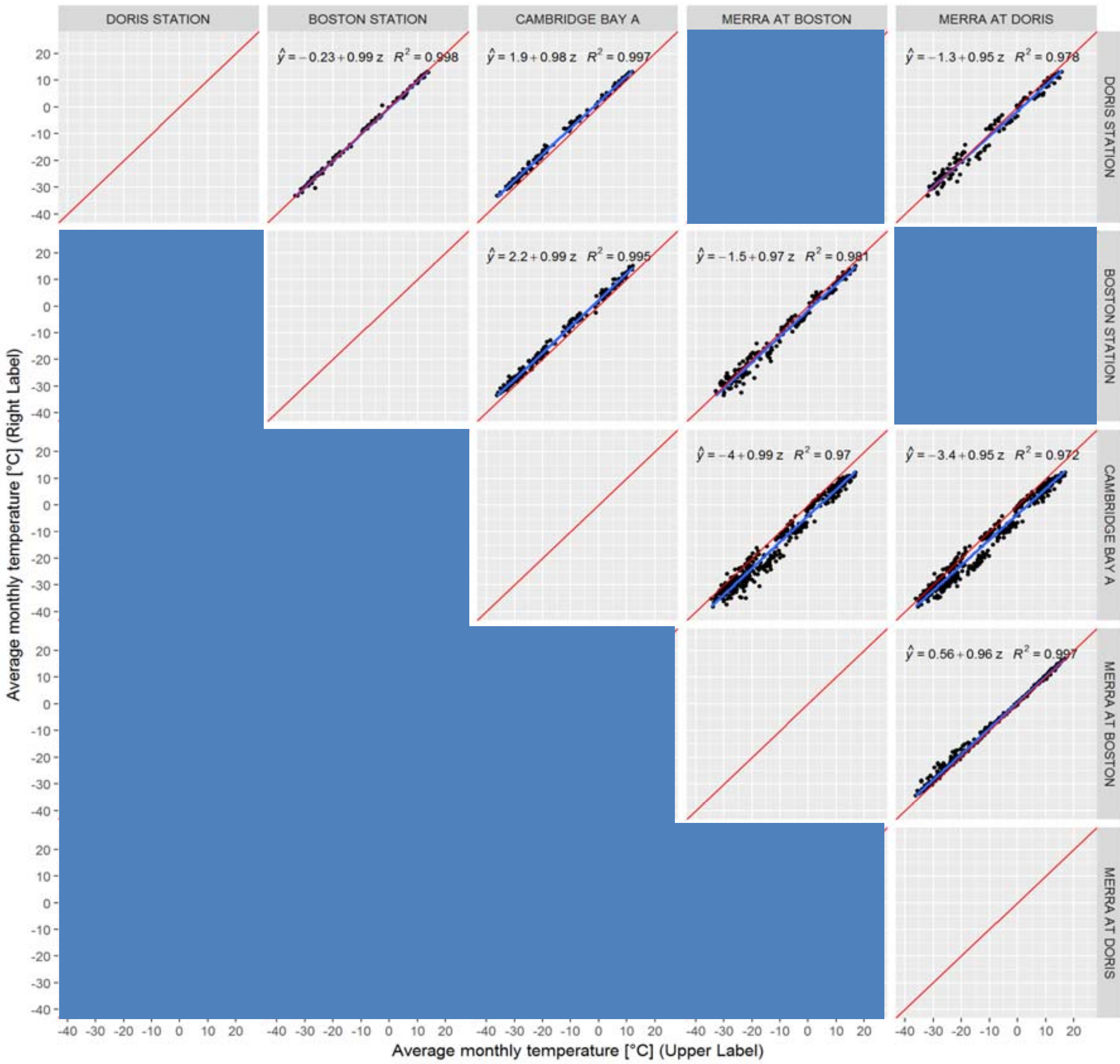


Figure 15: Linear Mean Monthly Temperature: Doris, Boston, Cambridge Bay A and MERRA

These linear regressions present the following conclusions:

- All of the relationships are parallel to the $y = x$ line.
- Doris and Boston present similar values with a monthly correction close to 0.2°C, where:

$$T_{Doris} = T_{Boston} - 0.23°C.$$ **Equation 3**

- Cambridge Bay A presents similar values to Doris and Boston. Cambridge Bay A has a monthly correction difference of +2.0°C with Doris and +2.2°C with Boston:

$$T_{Doris} = T_{CambridgeBayA} + 1.9°C$$ **Equation 4**

and

$$T_{Boston} = T_{CambridgeBayA} + 2.2°C.$$ **Equation 5**

- Cambridge Bay A shows less dispersion than MERRA at Boston or MERRA at Doris when compared with measured information at Boston or Doris, respectively.

These relationships are similar to the linear regression presented by Golder (2009), where:

$$T_{Doris} = 0.966 \cdot T_{CambridgeBayA} + 1.726°C; \quad \textbf{Equation 6}$$

The relationship in Golder (2009) was obtained based on daily values from 2004 to 2008. Figure 16 illustrates the linear regression (in red) from the analysis in Figure 15, and the relationship $y = x$ (in purple) and the Golder (2009) relationship (in dotted green). The temperature relationship obtained from monthly values are similar to those obtained from daily values.

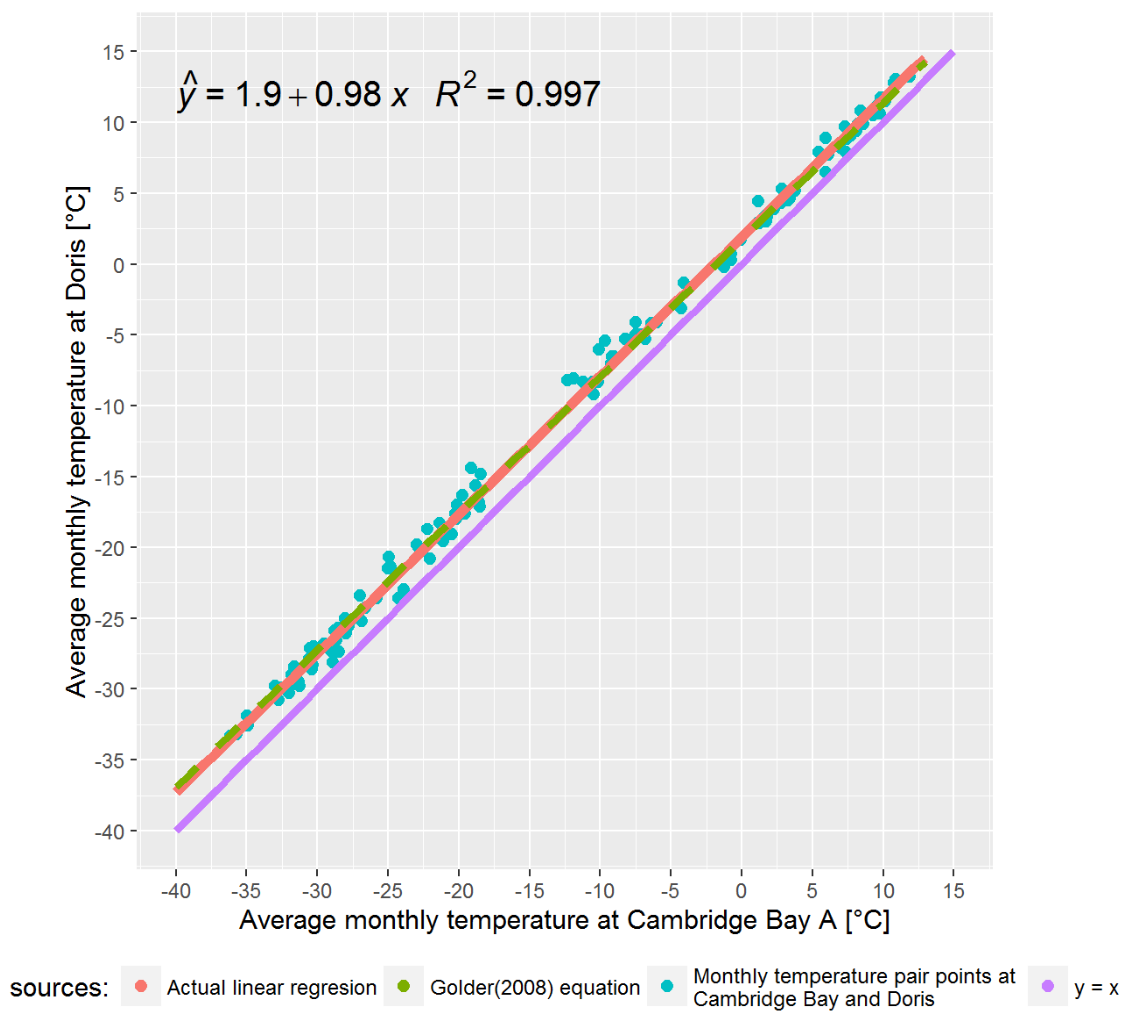


Figure 16: Linear Relationship between Doris and Cambridge Bay A Comparison with Golder (2009)

5.4 Doris and Boston Air Temperature

Based on the regional and site specific air temperature correlations, it can be concluded that because of the good correlation between regional values of daily and monthly air temperature, Cambridge Bay A, should be used as the base for site specific air temperature analyses. The reanalysis data is also considered appropriate as an additional substitute for site specific air temperature data.

Although air temperatures for Doris and Boston are similar, there are slight monthly and daily differences which should be expressed as follows:

- For Boston:

$$\boldsymbol{T_{Boston} = T_{CambridgeBayA} + 2.2°C}$$ **Equation 7**

or,

$$\boldsymbol{T_{Boston} = T_{Doris} + 0.23°C}$$ **Equation 8**

- For Doris:

$$\boldsymbol{T_{Doris} = T_{CambridgeBayA} + 1.9°C}$$ **Equation 9**

or,

$$\boldsymbol{T_{Doris} = T_{Boston} - 0.23°C}$$ **Equation 10**

Based on this correlation, the mean annual air temperature (MAAT) for 1981 to 2010 is estimated to be −11.9°C at Doris and −11.7°C at Boston. This is similar to the MAAT of the regional stations during the same time period with MAAT of −13.9°C, −10.3°C, and −10.9°C at Cambridge Bay A, Kugaluktuk A, and Lupin A, respectively.

6 Evaporation

6.1 Definitions

Lake evaporation refers to evaporation from a free-water surface, and is not a parameter that is directly measured. The only direct measurement of evaporation is **pan evaporation**, which refers to a standardized measurement using a Class-A evaporation pan. Pan evaporation is converted to lake evaporation using site specific pan-factors. Lake evaporation is typically equivalent to the maximum possible evaporation at a site, and is therefore also called **potential evaporation**.

Actual evaporation refers to evaporation from land surfaces, and is less than potential evaporation as the moisture available to evaporate is in limited supply. If vegetation is present, the amount of moisture loss can be further increased via transpiration. The combined evaporation and transpiration moisture loss is also termed evapotranspiration. **Actual evapotranspiration** (Actual ET) is typically calculated or estimated using primary metrological parameters via empirical methods.

6.2 Available Site Data

Site evaporation data is limited as described in Table 2. Pan evaporation was collected at Windy and Boston, but data collection errors and missing data, results in only one year of usable pan evaporation data (from Boston in 1997).

More recently, Doris micro-meteorological station has been used to estimate lake evaporation during the open water seasons between 2009 and 2016. The Doris micro-meteorological station data is calculated based on meteorological parameters with Priestley and Penman methodologies. Due to the short record, and the technical limitations associated to the record availability during the open water season, these records are not sufficient to provide values for design and analysis. The Doris micro-meteorological station evaporation values were used to validate calculated evaporation values.

6.3 Methodology

For this project, Morton's methodology (Morton 1983) was the preferred methodology for estimating evaporation and evapotranspiration. Morton's methodology requires: temperature, solar radiation, relative humidity, dew point temperature; and, mean annual precipitation.

The evaporation rates were estimated using the evapotranspiration computer model library in R, which was developed by the University of Adelaide, Australia (Guo et al 2014). Morton's complementary relationships for areal evapotranspiration (CRAE) and wet-surface evaporation (CRWE) methodologies (Morton 1983) were used to estimate potential evapotranspiration, and lake and pan evaporation, respectively.

6.4 Regional Evaporation

Although Cambridge Bay A is the closest meteorological station to site, and shows good site-correlation for total precipitation and air temperature data, the Cambridge Bay A station does not record solar radiation and therefore cannot be used for evaporation calculations. The closest stations with the data required to calculate evaporation are Yellowknife A and Fort Simpson A, located 730 km and 980 km from the site, respectively. Table 12 and Table 13 provide an estimate of evaporation at Yellowknife A and Fort Simpson A.

Table 12: Calculated Evaporation at Yellowknife A

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Actual ET (mm)	0	0	21	22	33	42	43	31	16	12	0	0	220
Lake Evaporation (mm)	0	0	13	37	74	104	110	76	31	9	0	0	455
Pan Evaporation (mm)	0	0	6	50	108	156	166	113	45	5	0	0	648

Table 13: Calculated Evaporation at Fort Simpson A

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Actual ET (mm)	0	0	19	20	28	46	55	32	15	13	0	0	228
Lake Evaporation (mm)	0	0	11	40	79	105	108	75	32	8	0	0	458
Pan Evaporation (mm)	0	0	3	58	120	155	152	111	48	2	0	0	649

6.5 Site-Specific Evaporation

Site specific evaporation was calculated with Morton's method using MERRA reanalysis data. This approach was deemed suitable due to the adequate correlation between site specific air temperature and MERRA data (Section 5).

The results of the evaporation estimations are presented in Table 14 and Table 15. The evaporation differences in the monthly and annual values are based on the differences in source information from MERRA. MERRA presents meteorological information within a grid of 0.5 by 0.5 degrees latitude and longitude, and Doris and Boston are located in two separate grid cells; and therefore, the meteorological information is different. These results represent monthly averages, from a monthly evaporation time series spanning from 1983 to 2015. Table 14 and Table 16 show pan coefficients of 0.78 and 0.83 obtained for Doris and Boston, respectively.

The snowmelt model for the site (as presented in Section 4) considers full ice cover from October through April, melting conditions in May and June, and open water conditions between July and September. There is zero lake evaporation during the ice cover season (October through April), but there is lake evaporation during melting conditions (May and June) and open water conditions

(July to September). The evaporation through the water seasons are presented in Table 15 and Table 17 for Doris and Boston respectively.

Table 14: Mean Monthly Evaporation at Doris

Parameter	Ice Cover Season				Melting Season		Open Water Season			Ice Cover Season			Total Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Actual ET (mm)	0	0	0	0	45	42	29	18	19	0	0	0	152
Lake Evaporation (mm)	0	0	0	0	36	84	89	56	19	0	0	0	284
Pan Evaporation (mm)	0	0	0	0	31	102	128	85	19	0	0	0	364

Table 15: Mean Monthly Evaporation by seasons at Doris

Parameter	Evap. during Ice Cover Season [mm]	Evap. during Melting Cond. [mm]	Evap. during Open Water Season [mm]	Fraction of Evaporation during Melting Season [%]	Fraction of Evaporation during Open Water Season [%]
Actual ET (mm)	0	87	66	57%	43%
Lake Evaporation (mm)	0	120	164	42%	58%
Pan Evaporation (mm)	0	133	232	37%	64%

Table 16: Mean Monthly Evaporation at Boston

Parameter	Ice Cover Season				Melting Season		Open Water Season			Ice Cover Season			Total Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Actual ET (mm)	0	0	0	0	43	56	40	23	20	0	0	0	182
Lake Evaporation (mm)	0	0	0	0	32	87	93	59	20	0	0	0	291
Pan Evaporation (mm)	0	0	0	0	26	99	123	83	19	0	0	0	350

Table 17: Mean Monthly Evaporation by seasons at Boston

Parameter	Evap. during Ice Cover Season [mm]	Evap. during Melting Cond. [mm]	Evap. during Open Water Season [mm]	Fraction of Evaporation during Melting Season [%]	Fraction of Evaporation during Open Water Season [%]
Actual ET (mm)	0	99	83	54%	46%
Lake Evaporation (mm)	0	119	172	41%	59%
Pan Evaporation (mm)	0	125	225	36%	64%

6.6 Inter-Annual Lake Evaporation Variability

The annual lake evaporation was calculated at Boston and Doris as it is shown in Figure 17 and Figure 18, respectively. The annual values tend to be relatively constant with small yearly variability.

To understand if a statistical trend was observed in the time series of annual evaporation, different linear regression methods were used: 1) ordinary least squares (Maidment 1993), 2) quantile regression (Koenker and Bassett 1978), 3) Mann-Kendall (Mann 1945) (Sen 1968) 4) Pre-whitening Mann-Kendall (Zhang 2000), 5) Pre-whitening Mann-Kendall (Yue et al 2002).

For Boston, all the Mann-Kendall based methodologies suggest statistical significance to define an increasing trend (>95% statistical significance/P-value<0.05). In the case of Doris, all five methodologies, with the exception of ordinary least squares, suggest statistical significance to define an increasing trend (>95% statistical significance/P-value<0.05).

Figure 17 and Figure 18 present annual lake evaporation for Boston and Doris respectively, these figures include also their respective lineal regression of the statistical significant trends as included in the figure’s legend. Consequently, based on the analysis from Section 6.5, annual lake evaporation was estimated to be 284 mm at Doris and 291 mm at Boston (Table 14 and Table 16).

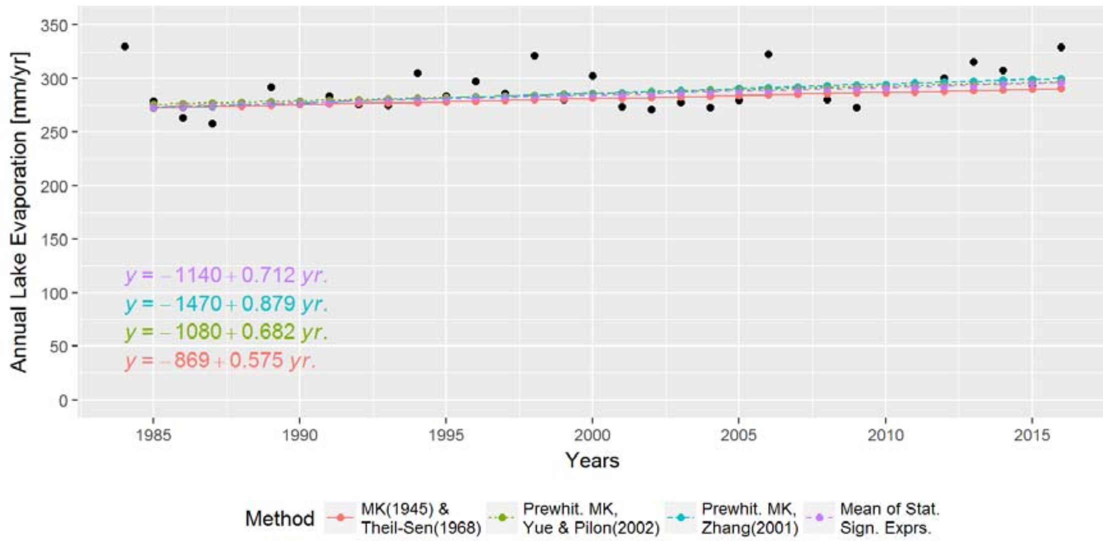


Figure 17: Annual Lake Evaporation at Boston from Morton's Methodology

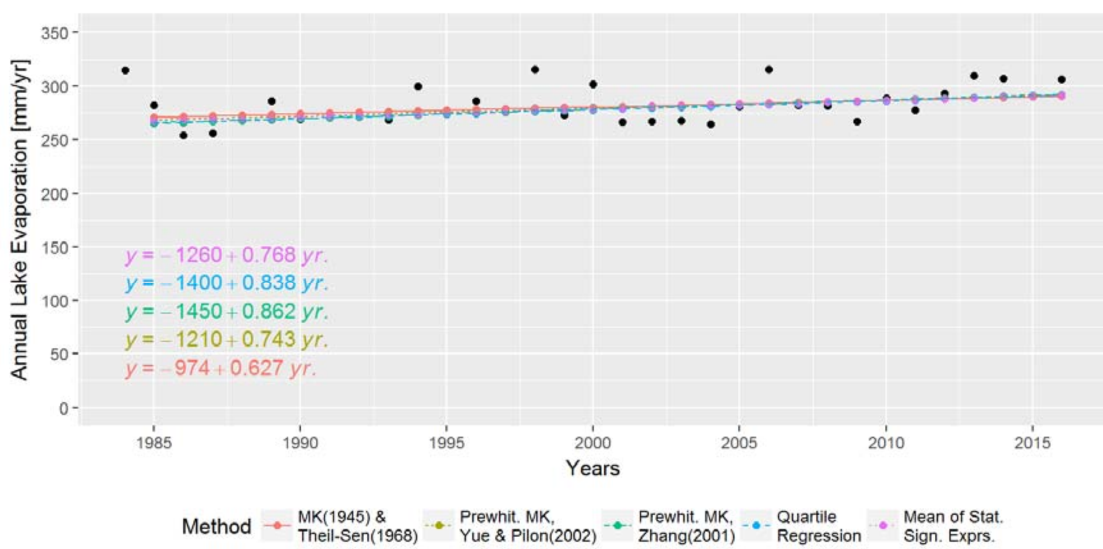


Figure 18: Annual Lake Evaporation at Doris from Morton's Methodology

6.7 Comparison with Previous Studies

Lake evaporation was estimated to be 284 mm/year at Doris and 291 mm/year at Boston (Table 14 and Table 16).

Figure 19 shows the annual lake evaporation presented in AMEC (2003) and Golder (2009). The red and blue line in Figure 19 are the annual lake evaporation values for Doris and Boston (Section 6.5). Based on this figure the estimated site values are similar to the regional values presented in the historic data analysis reports.

Lake evaporation, during the open water season from 2009 to 2016 was calculated for Doris Lake using data measured at the Doris Lake micro-meteorology station and the Penman Combination and Priestly-Taylor methods (Rescan 2009, 2010, 2011 and 2012. ERM 2016-5, and 2017-3). Figure 20 shows the annual open water season lake evaporation estimates based on the Doris Lake micro-meteorology station results, compared with the estimates developed for Boston and Doris in Section 6.5. The Doris Lake micro-meteorology station evaporation values are similar to the estimated values for Doris and Boston for the years 2009, 2010, 2011, 2013 and 2016; however, for 2012, 2014 and 2015 the lake station values are significantly lower than the estimated values.

Therefore, based on the previous studies with regional benchmarking and local estimations, the monthly and annual Morton estimations for evaporation presented in Table 14 and Table 16 are considered appropriate for the Boston and Doris.

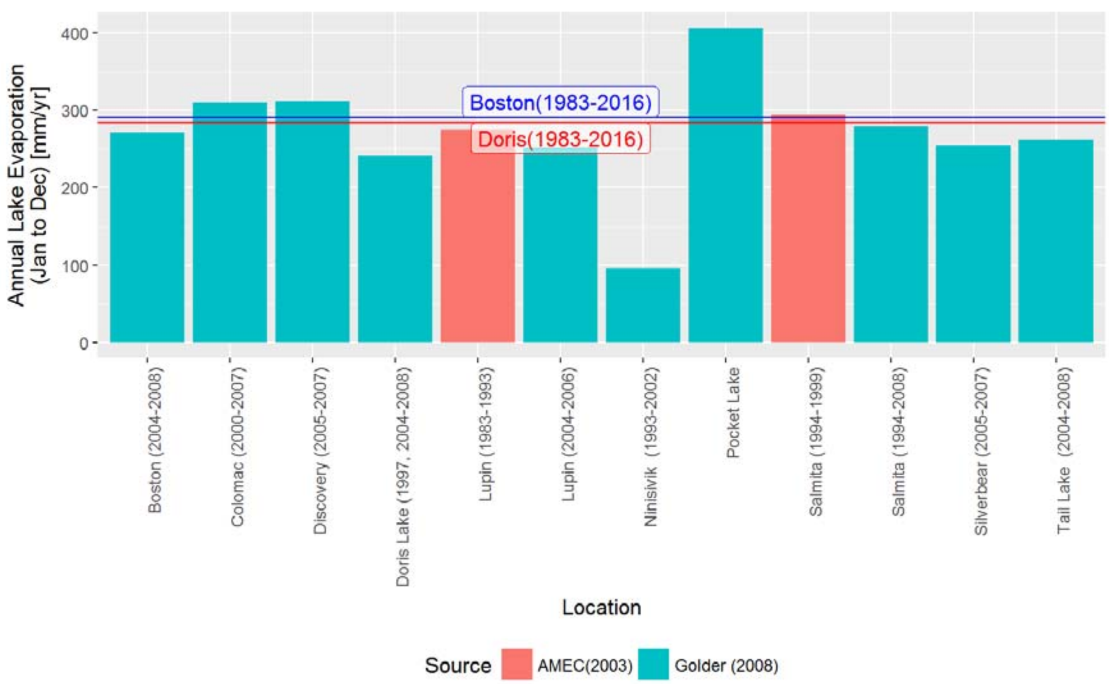


Figure 19: Annual Lake Evaporation Comparison with AMEC (2003) and Golder (2008)

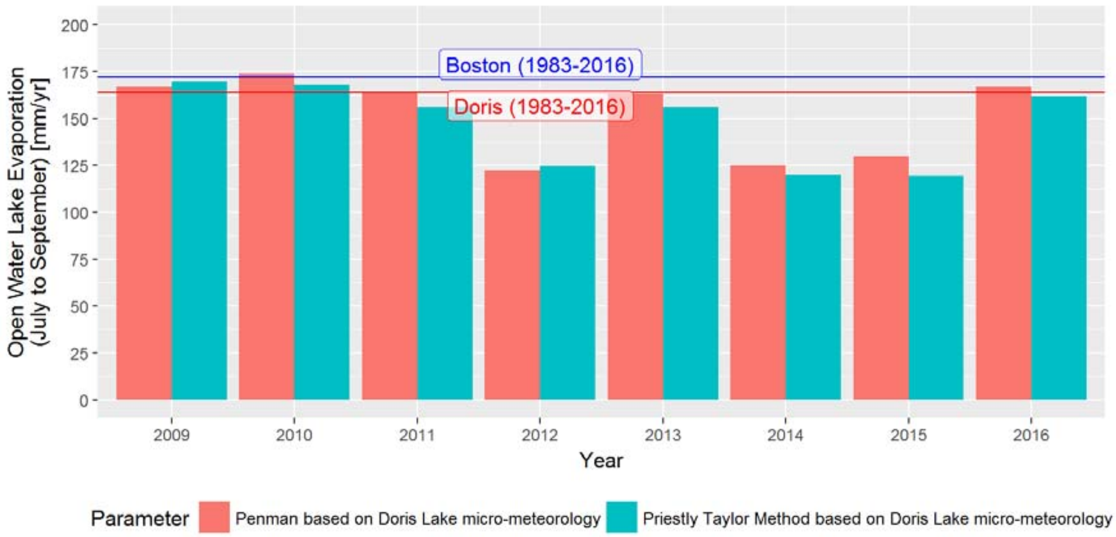


Figure 20: Open Water Lake Evaporation Comparison with ERM (2015, 2017) Estimations

6.8 Effect of Ice cover in Lake Evaporation

The snowmelt model for the site presents full ice cover from October - April, melting conditions in May and June with an open water season between July and September. Ice-covered lakes will affect the seasonality of evaporation and therefore the overall local energy and water balance; however, the implications of ice-cover conditions go beyond simply limiting lake evaporation losses.

From the report "The Influence of Lakes on the Regional Energy and Water Balance of the Central Mackenzie River Basin" by Rouse *et al*. (2008), Figure 21 shows average evaporation patterns for a region with and without lakes.

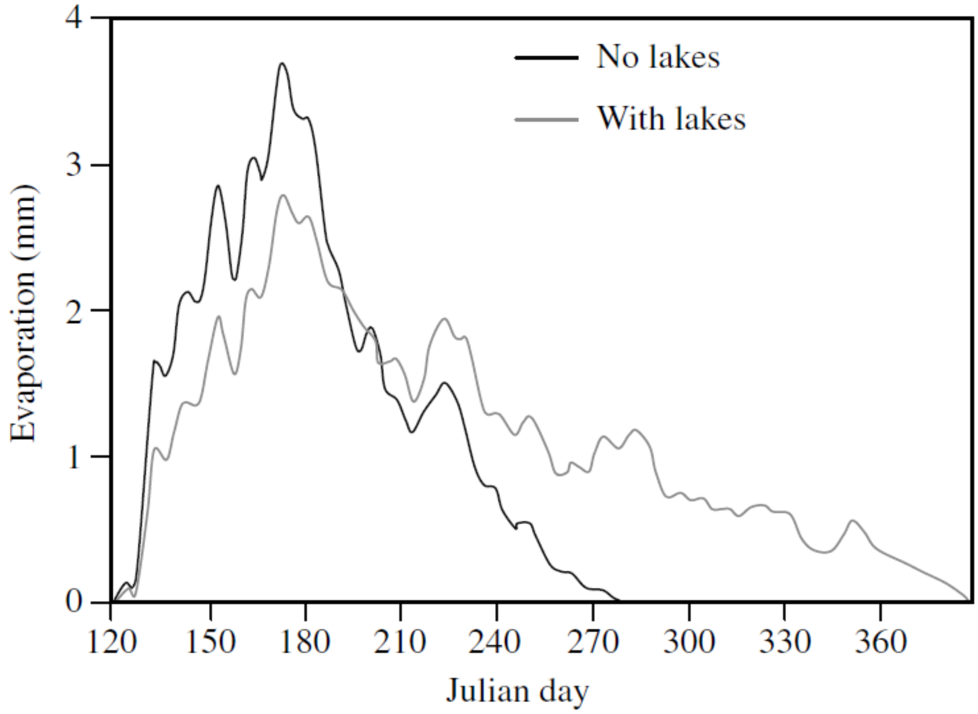


Figure 21: Average evaporation for no lake and lake regions (Rouse *et al*., 2008)

Rouse *et al*. (2008) states that during the beginning of winter, medium and large-sized lakes remain ice-free in the early winter. During this period, the open water absorbs little solar radiation but experience large net long wave radiation loss (evaporation) from their warm surface waters. In the context of regional water balance, Table 18 shows that as lake coverage increases, the overall evaporation of their region increases with a subsequent reduction in the overall water balance.

Because, the site does include many large lakes and as a result in accordance with Rouse *et al*. (2008) is it expected that the evaporation would be greater. SRK is confident that the regional evaporation numbers as presented in Section 6.5 are representative for the site, and ice cover conditions will not reduce the overall estimations of lake evaporation at the site.

Table 18: Comparative annual water balances calculated for the region with no lakes and the region with lakes for different magnitudes of regional evaporation (Rouse *et al*. 2008)

Lake Size	P	No Lakes		Lakes	
		E	WB	E	WB
Small	296	150	146	221	74
Average	272	238	34	298	-26
Large	302	253	49	339	-37

Note:

P = precipitation (Yellowknife)

E = average regional evaporation

WB = P-E Water Balance

7 Wind Speed, Direction and Gust

7.1 Available Site Information

A summary of the available hourly wind speed and wind direction records for Boston, Doris and Roberts Bay are presented in Figure 22, where the color gradient reflects the number of days in the year that have data.

At Boston, hourly wind data is available continuously from 2000 to 2001 and 2006 to present (December 2016). Hourly wind speed and direction values are also available intermittently between April 1994 and February 2000.

At Doris, continuous wind speed and wind direction records are available from 2004 to present; however, data collected from 2004 to 2008 was obtained at 3 m elevation, before the station was raised to 10 m in 2009. Subsequently, data from 2004 to 2008 has been adjusted based upon a U.S. Army Corps of Engineers (1989) correction factor of 1.18, to be comparable with the data collected from the 10 m station.

Hourly wind speed and wind direction data was also collected at Roberts Bay during the summer and fall of 1997, 1998 and 2000, with a 3 m high sensor. This data was adjusted for sensor height, and the adjusted data demonstrates slightly higher values than those measured at Boston during the same periods. Due to the short time period of these records, the values were only used for comparison purposes.

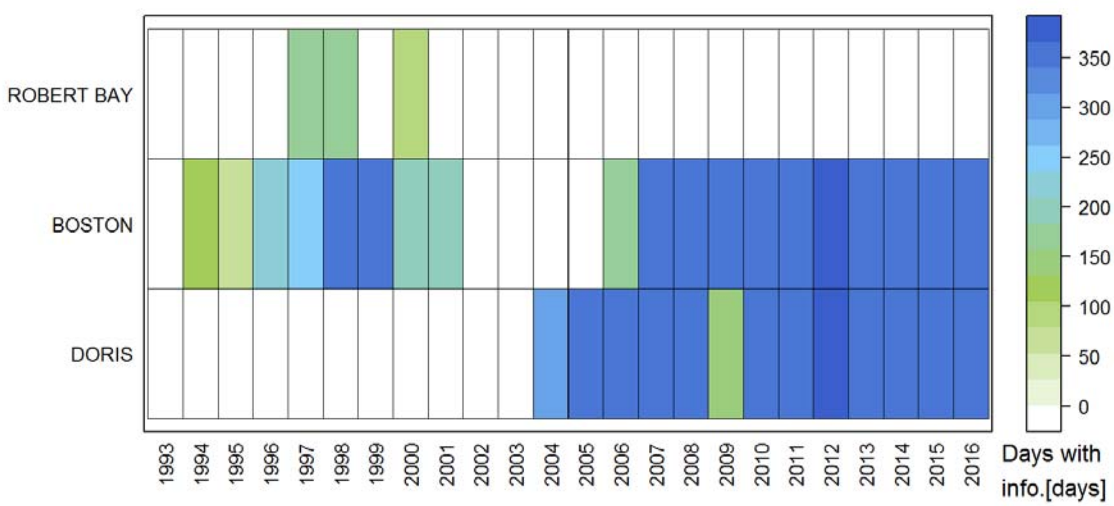


Figure 22: Number of Days with Daily Records at Site

7.2 Regional Analysis – Wind Speed and Direction

Unlike total precipitation and air temperature, previous work has not included a regional analysis for wind speed. Wind measurements on site have been compared with Cambridge Bay A climate normals (Golder 2009), but an analysis was not completed.

A regional analysis has not been previously performed to indicate which regional station provides the best analogue to the Project site, regional hourly wind speed data was obtained from the closest meteorological stations to the Project. These stations are within a similar geographical range as the regional stations used for total precipitation and temperature analyses. This data was then compared to the site stations. A summary of the available data from the select regional stations is presented in Figure 23, where the color gradient reflects the total number of days in the year that have data.

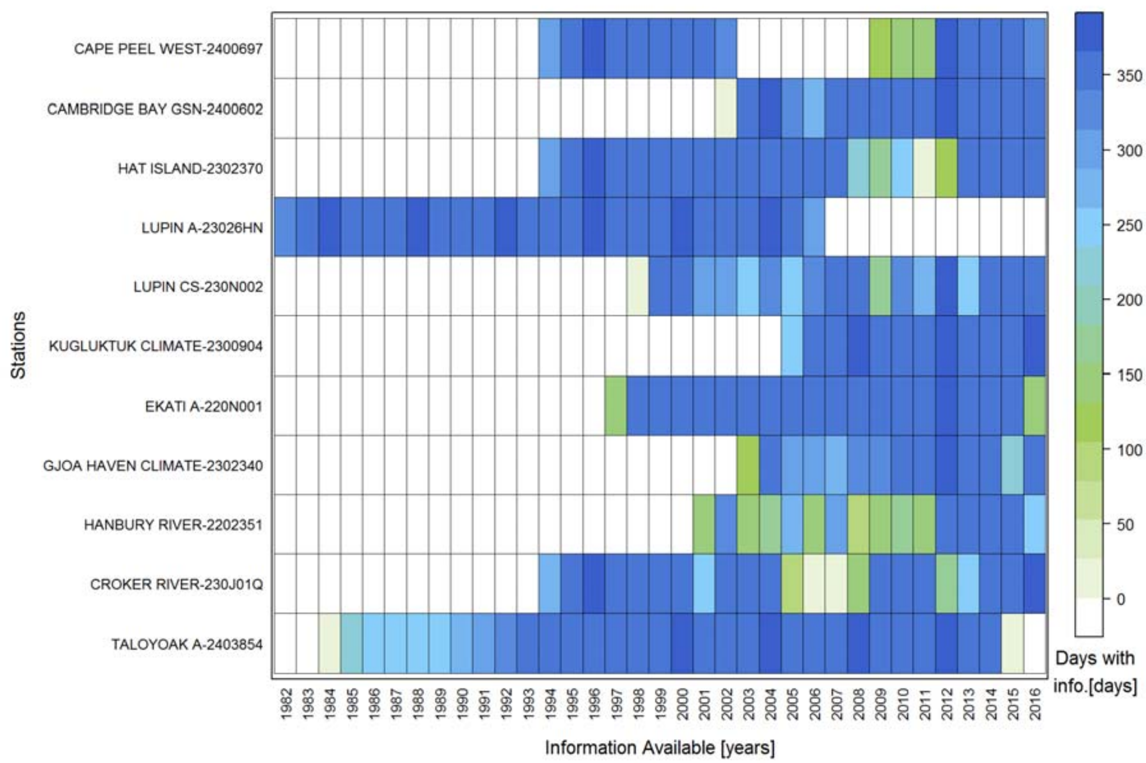


Figure 23: Days in a Year with Hourly Wind Speed Data from Regional Meteorological Stations

7.2.1 Site-Specific Wind Direction

Figure 24 presents a correlation matrix for the available daily wind direction data at the different regional stations. The bottom-left section contains the (x, y) pair point scatter plots while the upper-right section contains the Pearson correlation values, which are similar in magnitude to the r^2 values for their respective pair point figures. The stars in the upper-right reflect results of a correlation test; three stars indicate a strong correlation and zero stars indicate that there is no correlation between the variables. The diagonal of the matrix presents the frequency figures for the variables.

In Figure 24, the Doris and Boston stations, (in light red), demonstrate similar distributions with high correlation values of 0.75. From the diagonal figure, the frequency distribution of each station highlights a specific similarity between the local stations and the regional stations Cape Peel West and Cambridge Bay GSN (in light yellow), where the highest regional correlations are with the stations Cape Peel West followed by Cambridge Bay GSN. Cambridge Bay A, which was used as the regional station for temperature analogues, has only intermittent wind speed and direction data available after 1975; and therefore, was not used in the wind speed and wind direction analysis.

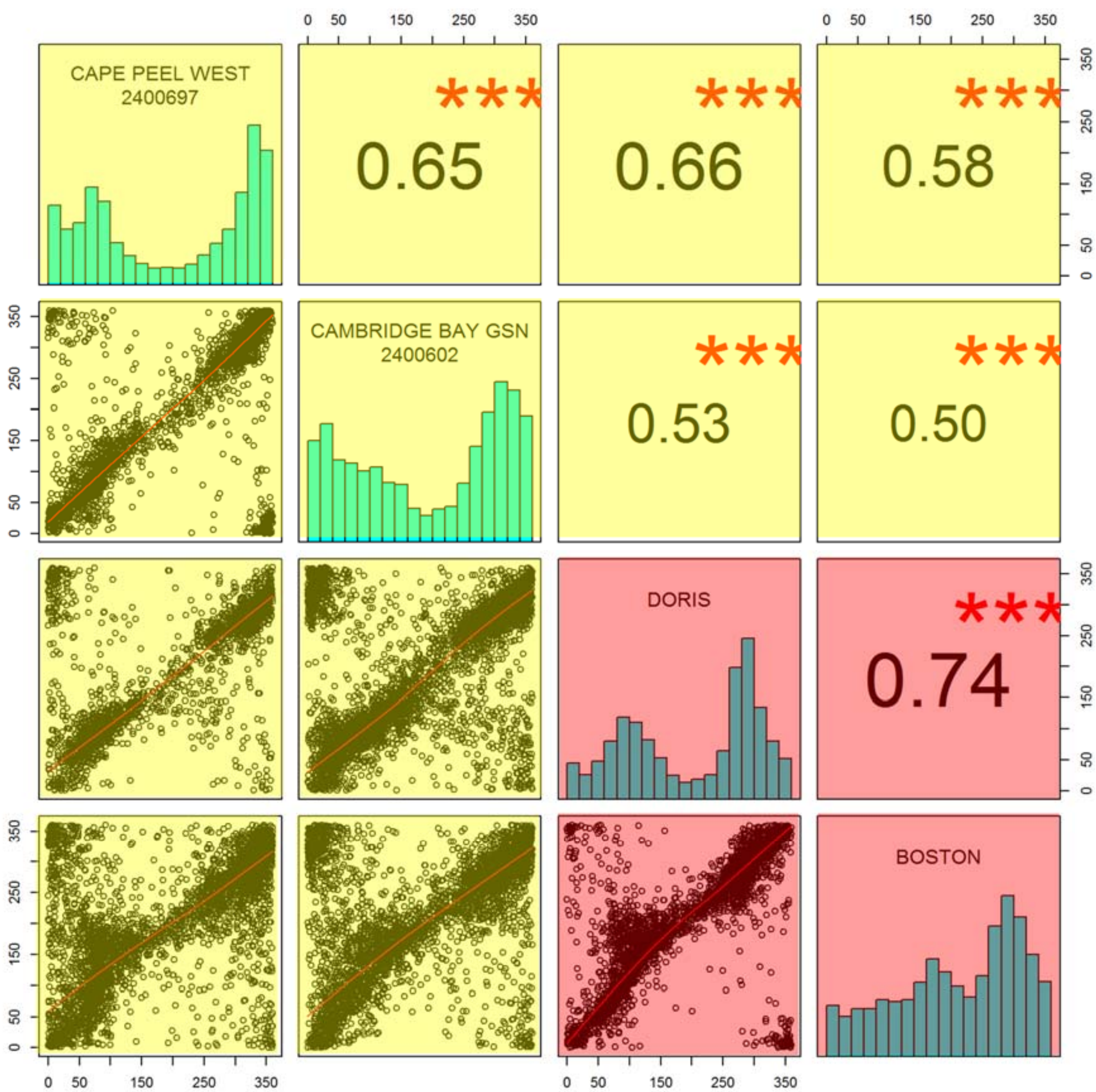


Figure 24: Correlation Matrix between the Daily Wind Direction Values (in degrees) at the RegioMeteorological Station and at the Site Stations

Based on this analysis, it is recommended that Cape Peel West and Cambridge Bay GSN are the regional stations be used when no local information is available at Boston or Doris.

Table 19 and Table 20 present the monthly average wind direction for Doris and Boston respectively, demonstrating a predominant wind direction of west, west-northwest.

Figure 25, Figure 27 and Figure 29 present monthly wind roses for Doris, Boston and Roberts Bay based on the daily records. The figures for Doris and Boston show similar tendencies with the highest wind speed recorded from December to April, in addition to a predominant Westerly wind direction. During May to October, there is a reduction in wind velocities, with no predominant direction exhibited; however, there is a tendency to be on the East-West axis. Lastly, in November and December, the winds are predominantly Westerly.

Monthly wind roses for Roberts Bay are provided in Figure 29, an annual wind rose for Roberts Bay was not developed because data at this station was only collected during the summer and fall. The monthly wind directions measured at Roberts Bay does not tend to be aligned with monthly values at Doris or Boston.

Figure 26 and Figure 28 shows the annual wind roses for Doris and Boston, respectively. These wind roses were developed using all available wind data. Even though more data was collected during the summer, the seasonal different is not considered as important, and consequently the annual wind roses are considered as site representative.

Table 19: Monthly Average Wind Direction for Doris

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2004	-	-	WNW	NW	WNW	WNW	WNW	NW	NE	NNW	WSW	W
2005	W	NW	NW	ENE	NNW	NNW	WNW	WNW	N	ENE	NNW	ESE
2006	W	W	ESE	ESE	SE	WNW	NW	ENE	NW	NW	WNW	S
2007	NE	WNW	NW	ESE	NNE	N	N	NNW	NNW	E	NNW	NW
2008	WNW	WNW	WNW	NW	E	N	NNW	NW	NNW	SW	N	WNW
2009	-	-	-	-	-	-	-	NNW	SSE	NNE	ESE	WNW
2010	W	ESE	E	ESE	WNW	N	NNE	NW	NE	NNE	NNW	WSW
2011	WSW	W	SW	W	E	NW	NE	ENE	E	ESE	WNW	W
2012	ESE	SW	S	W	ENE	NNE	NNE	WNW	WSW	N	W	NW
2013	W	NNE	SSW	WSW	SE	WNW	NW	SE	ENE	ENE	SE	W
2014	W	WNW	W	NW	S	NE	NNW	WNW	NNW	E	W	N
2015	WNW	WNW	WNW	NNE	NNW	NNW	NNE	E	ENE	WNW	NE	SSW
2016	WNW	WNW	WNW	WNW	NNE	E	WSW	N	WSW	WNW	ESE	W

Table 20: Monthly Average Wind Direction for Boston

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1993	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	ESE	WSW	SW	-	-	-	-	-
1995	-	-	-	-	-	-	-	-	-	-	NW	WSW
1996	WNW	SW	WNW	NW	W	SW	SW	-	-	-	-	-
1997	-	-	-	-	WNW	E	E	WNW	-	-	-	-
1998	-	-	-	SSW	NE	ENE	N	SSW	W	WSW	SSW	WNW
1999	SW	SSE	SSW	SSW	ENE	NNW	WNW	N	W	ESE	SSE	ENE
2000	-	-	-	-	-	-	SE	W	NNE	ESE	SW	WSW
2001	SW	WSW	SSW	WSW	ENE	NW	-	-	-	-	-	-
2002	-	-	-	-	-	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	NNW	WSW	W	WNW	W	SSW
2007	WSW	W	WNW	SSW	S	NNW	NNW	NNW	NW	SE	WNW	WSW
2008	WSW	W	W	WSW	SSE	NNW	WNW	NW	NW	SW	WSW	WNW
2009	WNW	W	WNW	W	WNW	NNE	WSW	W	S	NNE	SSE	WNW
2010	WSW	SW	S	SSE	WNW	NE	NNE	NW	SW	NNW	W	WSW
2011	WSW	W	WSW	W	SE	NW	NE	ENE	SE	SSE	WNW	W
2012	SW	W	SW	WSW	ENE	NNE	N	WNW	W	NW	W	WSW
2013	W	W	WSW	W	SSE	W	NW	SW	E	S	WSW	W
2014	W	WNW	W	W	SW	NE	NNW	NNW	NNW	-	WNW	WNW
2015	W	W	W	W	NW	NNW	NNE	E	ESE	W	WSW	SW
2016	W	WNW	W	W	NNE	SW	WSW	NNW	WSW	W	SW	W

Table 21: Monthly Average Wind Direction for Roberts Bay

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1997	-	-	-	-	-	-	SSE	WNW	SE	N	SW	-
1998	-	-	-	-	-	NE	NNW	SSW	WNW	WNW	SSW	-
1999	-	-	-	-	-	-	-	-	-	-	-	-
2000	-	-	-	-	-	-	SSW	WNW	-	-	-	-

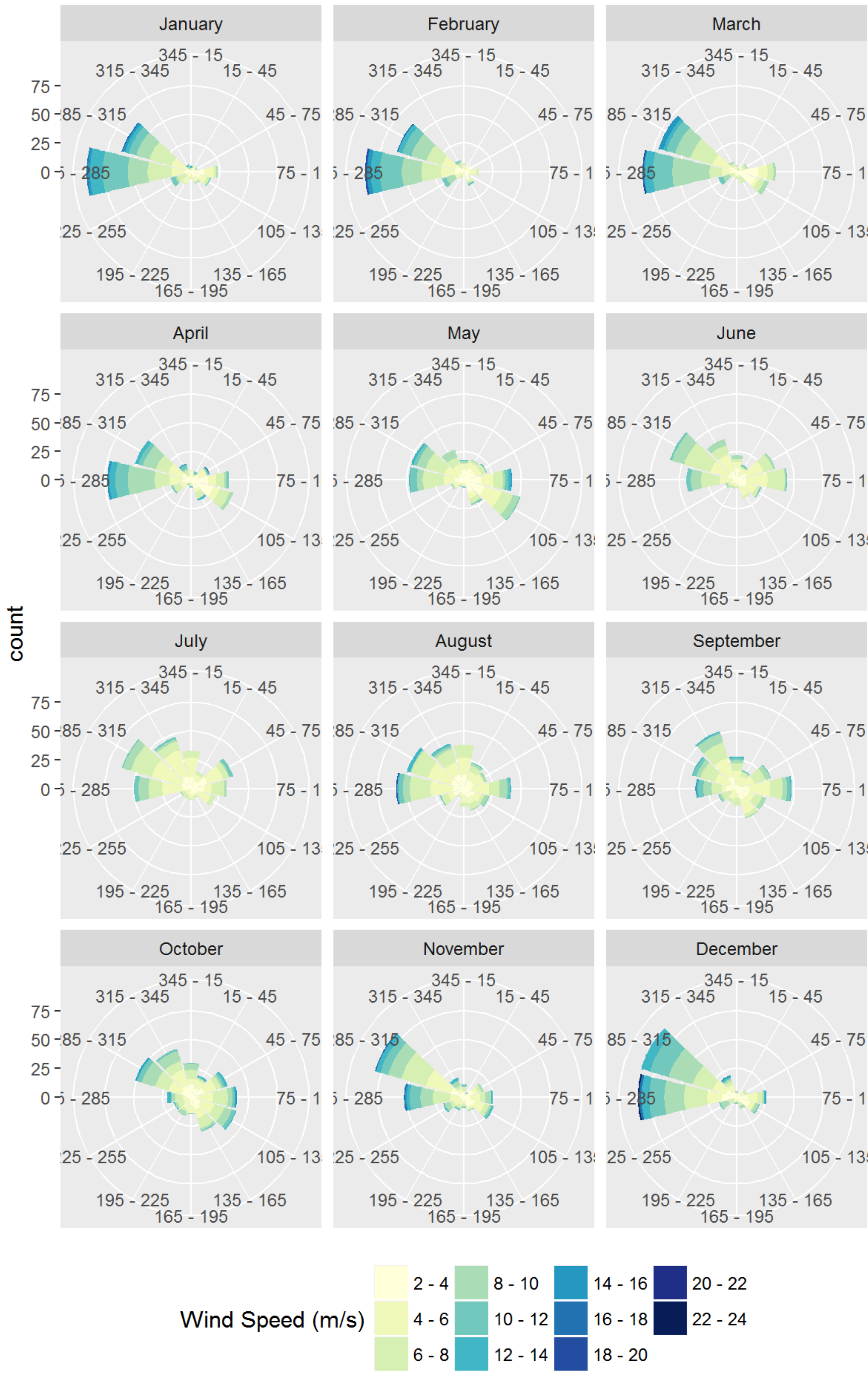


Figure 25: Monthly Wind Roses for Doris Meteorological Station

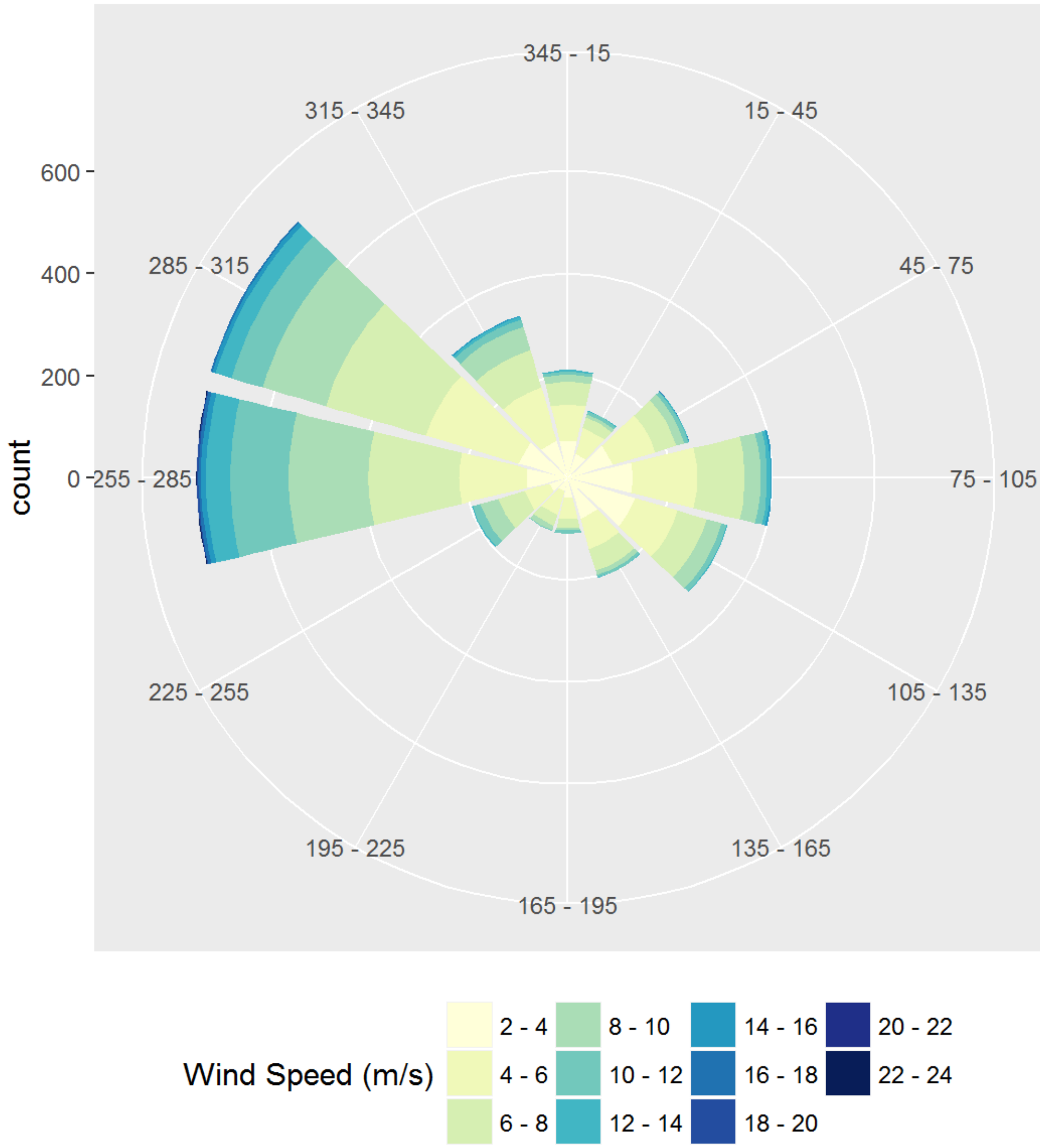


Figure 26: Annual Wind Rose for Doris Meteorological Station

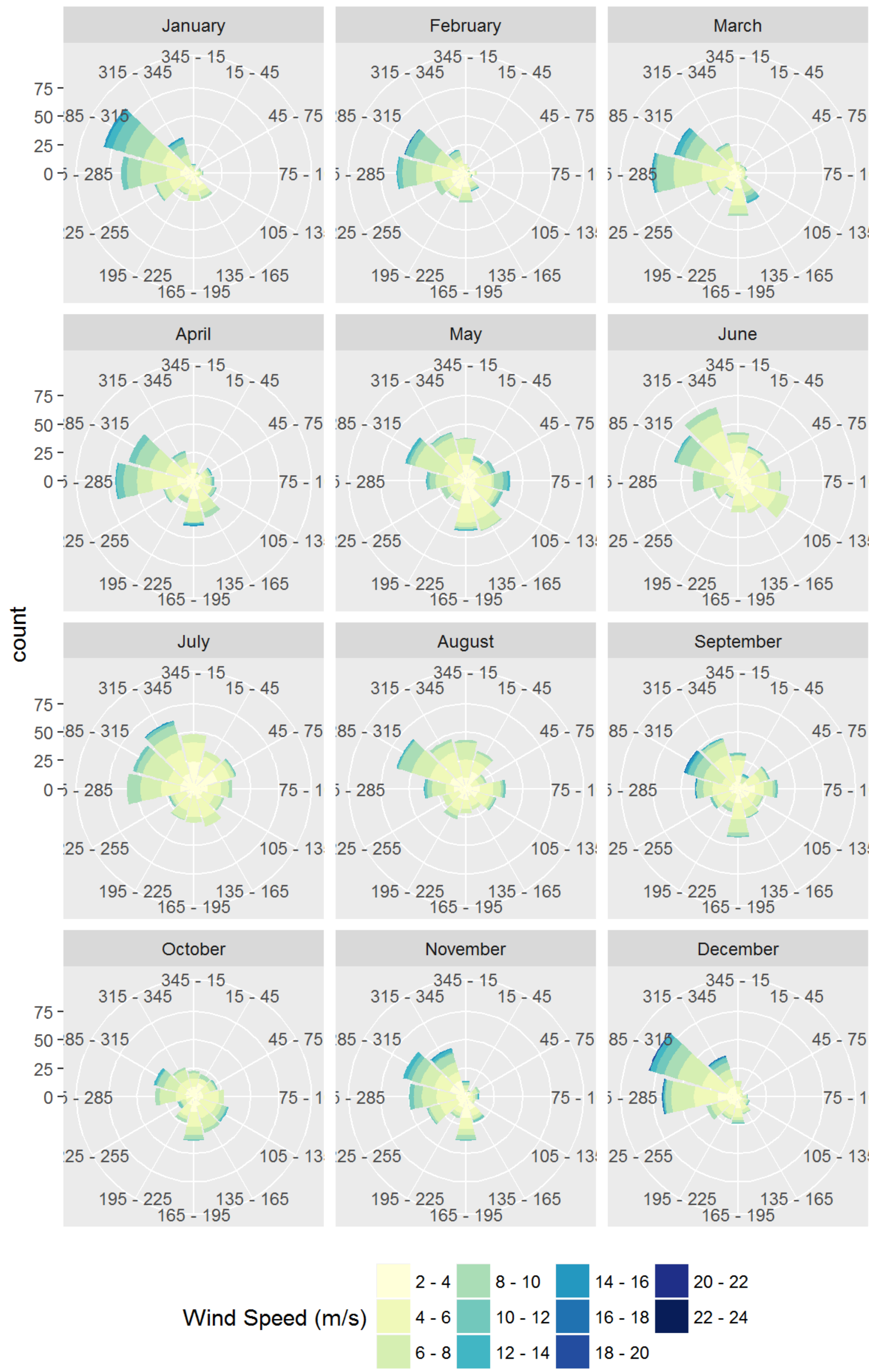


Figure 27: Monthly Wind Roses for Boston Meteorological Station

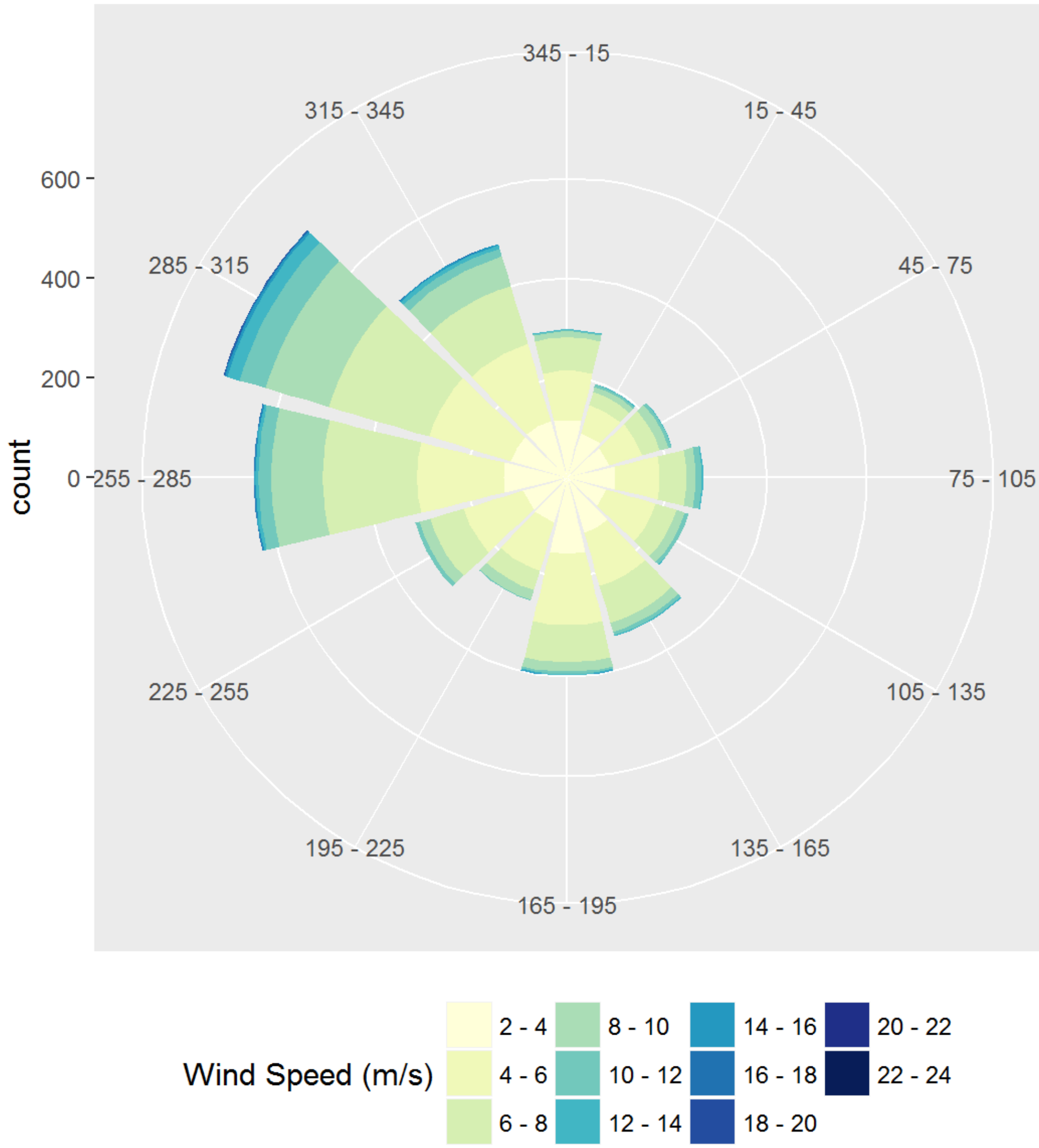


Figure 28: Annual Wind Rose for Boston Meteorological Station

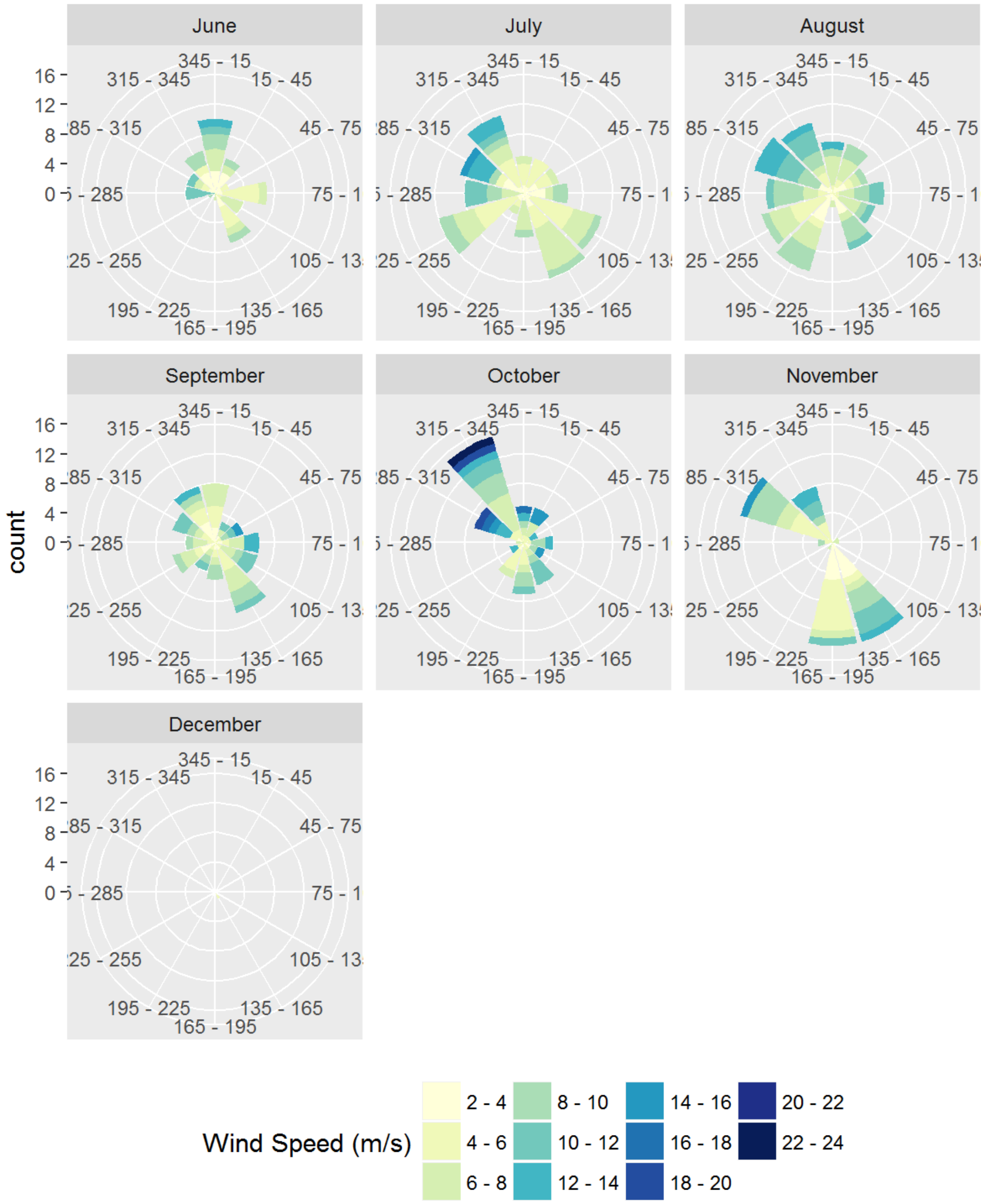


Figure 29: Monthly Wind Roses for Roberts Bay Station

7.2.2 Site-Specific - Wind Speed

Similar to wind direction, the daily regional wind speed data was correlated with daily Boston and Doris data. Figure 30 is a correlation matrix for the available daily wind speed data at the different stations. The bottom-left section contains the (*x,y*) pair point scatter plots while the upper-right section contains the Pearson correlation values, which are similar in magnitude to the r^2 values for their respective pair point figures. The stars in the upper-right reflect results of a correlation test; three stars indicate a strong correlation and zero stars indicate that there is no correlation between variables. The diagonal of the matrix presents the frequency figures for the variables. As with wind direction, the best correlations are between the local site stations at Doris and Boston (in light red) followed by the Cape Peel West and the Cambridge Bay GSN stations (in light yellow) (Figure 30). Doris and Boston are highly correlated with a Pearson correlation of 0.87; followed by regional correlations of 0.76 to 0.58 for Cape Peel West and 0.69 to 0.72 for Cambridge Bay GSN.

Figure 31 and Figure 32 present the linear relationships for daily wind speed at these selected stations: Doris, Boston with Cape Peel West and Cambridge Bay GSN. In these figures, the wind speed dispersion is lower in the Cambridge Bay GSN meteorological station than in the Cape Peel West, and the values from Cambridge Bay GSN tend to follow the relationship *y=x* (presented in red).

From these figures, the linear regressions for Cape Peel West and Cambridge Bay GSN have similar correlations (dispersion and R^2) with Doris and Boston than Cambridge Bay GSN; however, Cambridge Bay GSN tends to present slightly more conservative values and closer than the *y=x* relationship; which results in mean values closer to the expected values at Doris and Boston. Thus, it is recommended that data from Cambridge Bay GSN be used as an analogue for Doris and Boston when site data is not available.

Table 22 and Table 23 present the annual monthly wind speeds and monthly average wind speed during the recording period at Doris and Boston respectively.

Table 24 shows the available information wind speed averages at Roberts Bay.

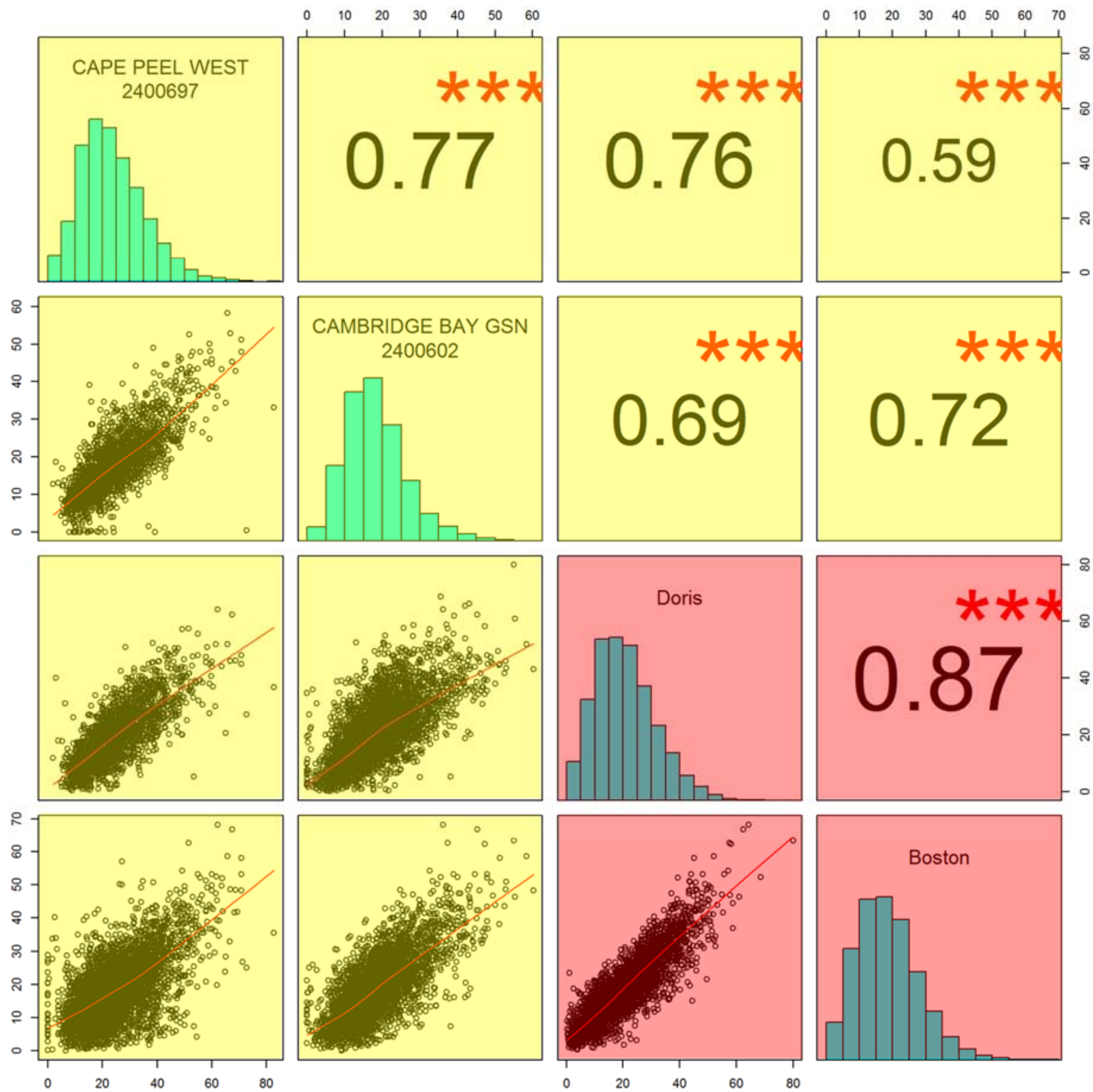


Figure 30: Correlation Matrix between Daily Wind Speed Values (in km/hr) at the Regional Meteorological Stations and at the Site Stations

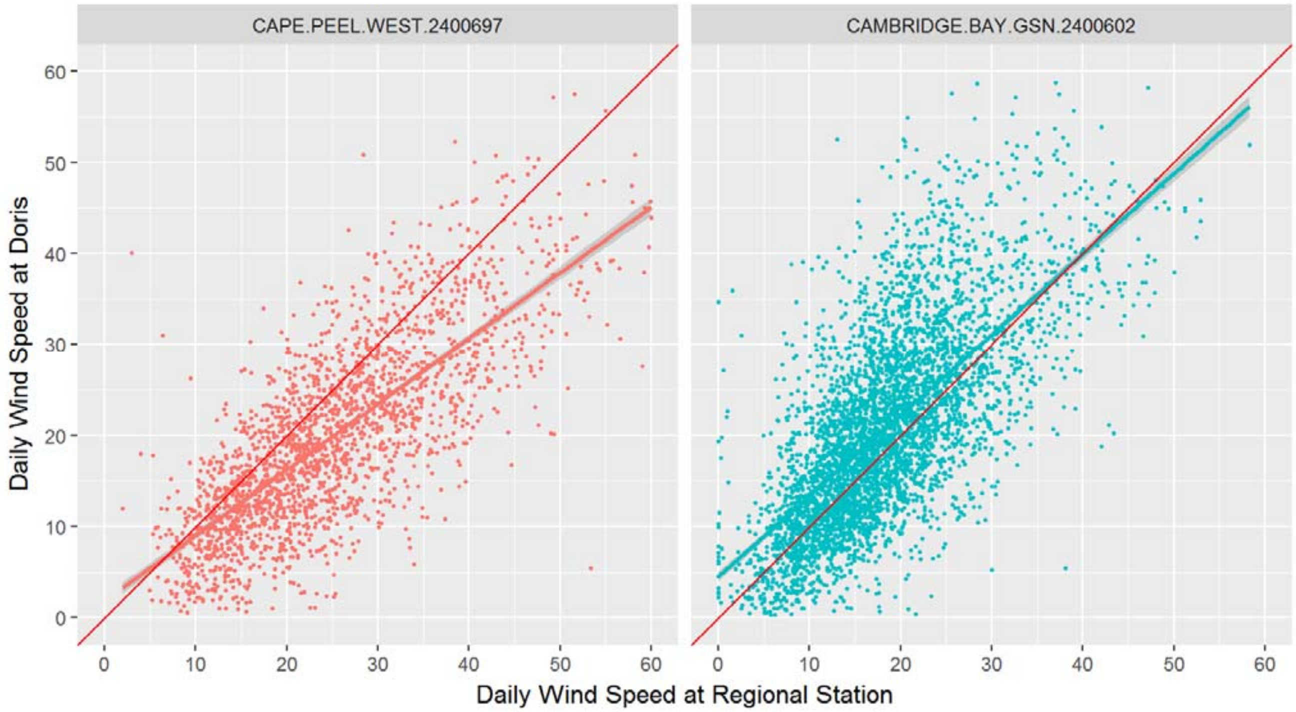


Figure 31: Daily Wind Speeds at Doris Compared with Cape Peel West and Cambridge Bay GSN

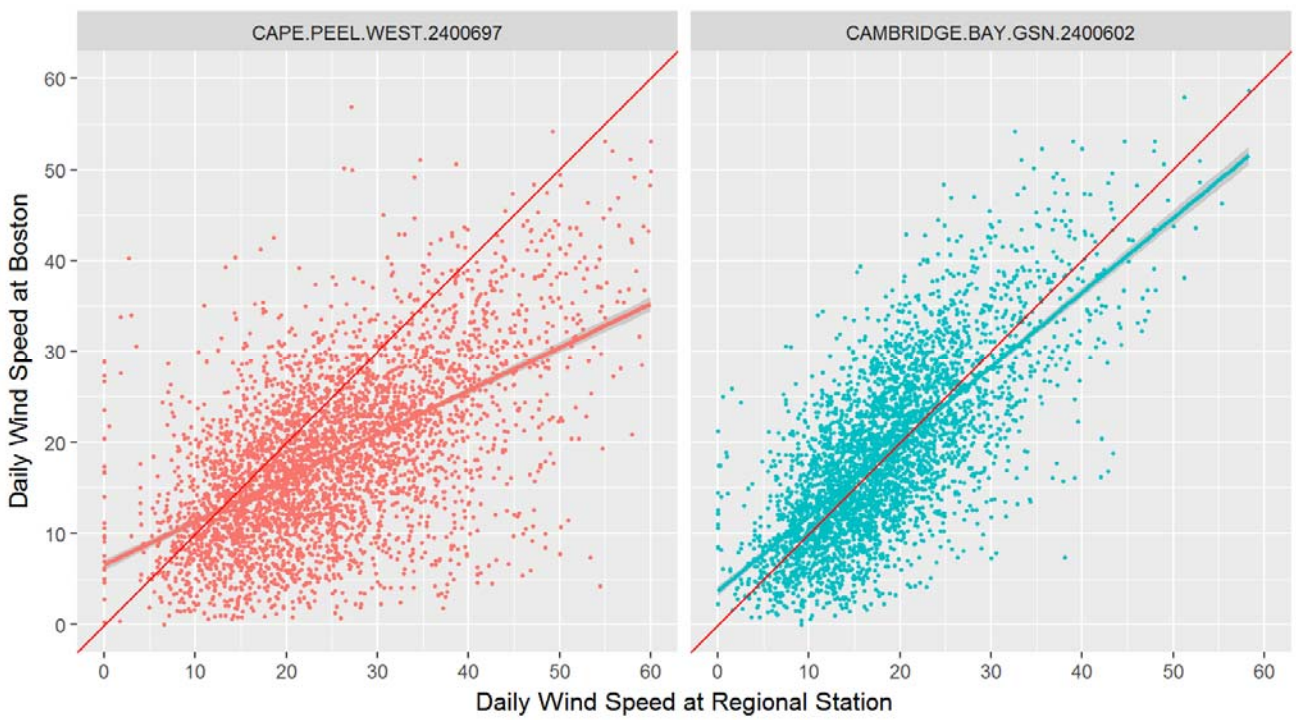


Figure 32: Daily Wind Speeds at Boston Compared with Cape Peel West and Cambridge Bay GSN

Table 22: Monthly Wind Speed at Doris

Year	Wind Speed (m/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2004	-	-	7.00	6.47	6.13	6.96	5.49	5.91	6.91	6.77	6.32	7.36
2005	7.12	5.89	5.71	5.24	5.98	5.38	6.09	6.00	5.00	6.27	5.93	4.38
2006	6.01	7.39	3.39	5.47	5.69	5.89	5.91	5.21	5.06	6.21	6.06	6.41
2007	5.15	7.40	6.79	5.27	7.17	5.55	5.15	6.60	5.69	6.90	6.57	6.81
2008	7.42	6.57	7.44	7.05	6.22	5.84	5.44	6.73	6.88	6.68	4.39	7.80
2009	-	-	-	-	-	-	-	4.47	6.36	5.20	5.77	7.42
2010	6.10	3.68	5.53	5.21	4.68	5.76	5.58	4.46	5.14	5.42	5.77	5.67
2011	5.53	7.18	5.58	6.87	5.08	6.03	4.9	5.49	5.85	5.83	6.30	5.67
2012	5.39	5.23	5.69	4.97	4.40	4.68	4.72	4.87	5.95	4.56	5.92	4.30
2013	7.38	4.36	5.60	7.82	4.99	4.75	5.75	5.26	5.15	6.39	4.27	7.30
2014	5.85	7.78	7.15	5.34	5.21	5.06	4.60	4.64	6.44	4.73	6.81	5.90
2015	6.49	6.92	6.03	4.62	5.17	5.59	4.75	5.67	5.85	5.52	5.59	4.28
2016	5.47	6.35	5.15	5.10	5.41	6.16	6.15	4.09	5.80	4.55	4.14	5.83
Avg.	6.24	6.24	5.99	5.85	5.52	5.59	5.31	5.44	5.86	5.87	5.83	6.28

Table 23: Monthly Wind Speed at Boston

Year	Wind Speed (m/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1993	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	4.89	5.84	5.64	-	-	-	-	-
1995	-	-	-	-	-	-	-	-	-	-	6.10	3.67
1996	5.63	4.78	6.01	4.61	4.99	5.46	5.23	-	-	-	-	-
1997	-	-	-	-	5.25	4.99	5.74	5.95	-	-	-	-
1998	-	-	-	4.29	5.65	4.26	4.59	5.74	4.65	6.44	4.18	4.78
1999	5.66	2.91	5.87	5.71	5.23	4.88	5.64	4.74	5.02	2.85	2.23	2.37
2000	-	-	-	-	-	-	4.70	5.26	6.81	3.96	4.37	4.96
2001	5.62	4.68	5.18	5.81	6.11	5.09	-	-	-	-	-	-
2002	-	-	-	-	-	-	-	-	-	-	-	-
2003	-	-	-	-	-	-	-	-	-	-	-	-
2004	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	5.47	4.62	4.71	5.21	5.15	5.44
2007	3.88	5.25	5.59	4.39	5.64	5.04	4.31	6.01	4.95	5.54	4.90	5.22
2008	5.67	4.63	5.33	5.30	5.57	5.04	4.83	5.81	5.95	5.88	3.20	5.71
2009	6.75	4.77	3.60	5.23	5.56	4.86	5.79	4.72	6.19	4.73	5.98	6.98
2010	60	4.06	5.04	5.50	4.37	5.69	5.21	4.54	4.86	5.88	6.09	5.16
2011	5.02	6.77	5.38	6.31	4.89	5.84	4.46	5.22	6.06	5.61	5.84	5.56
2012	4.99	4.78	4.71	4.70	3.86	4.42	4.76	5.03	5.91	4.59	5.85	3.43
2013	5.93	3.25	5.72	6.98	5.14	4.85	5.75	4.88	4.80	5.93	4.20	6.15
2014	5.74	6.60	6.39	4.75	5.54	4.90	4.73	4.85	6.21	-	6.58	5.84
2015	6.48	6.00	5.35	3.91	5.44	5.62	4.56	5.49	6.33	5.37	5.74	4.04
2016	4.19	5.25	4.41	4.19	5.14	5.94	6.25	4.30	5.74	4.68	4.51	5.50
Avg.	5.50	4.90	5.28	5.12	5.21	5.17	5.16	5.15	5.58	5.13	5.00	4.99

Table 24: Monthly Wind Speed at Roberts Bay

Year	Wind Speed (m/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1997	-	-	-	-	-	-	7.25	7.77	6.32	9.04	6.95	-
1998	-	-	-	-	-	5.87	6.41	7.45	6.65	9.44	6.28	-
1999	-	-	-	-	-	-	-	-	-	-	-	-
2000	-	-	-	-	-	-	5.74	6.79	-	-	-	-
Avg.	-	-	-	-	-	5.87	6.46	7.34	6.48	9.24	6.62	-

7.3 Regional Analysis – Wind Gust

As with wind speed and wind direction, no previous regional analysis of wind gusts has been performed. In order to maintain consistency with wind speed, the closest regional stations were evaluated as potential analogues with site. For this analysis, continuous annual records of daily gust values are required. Due to the scarce amount of continuous data, regional stations were selected from stations with a minimum of three years of complete data, resulting in the selection of ten stations for further analysis. A year was considered a complete year for wind gust analysis when more than 200 days of data were available. The available information is presented in Figure 33, where the color gradient reflects the number of days in the year with data.

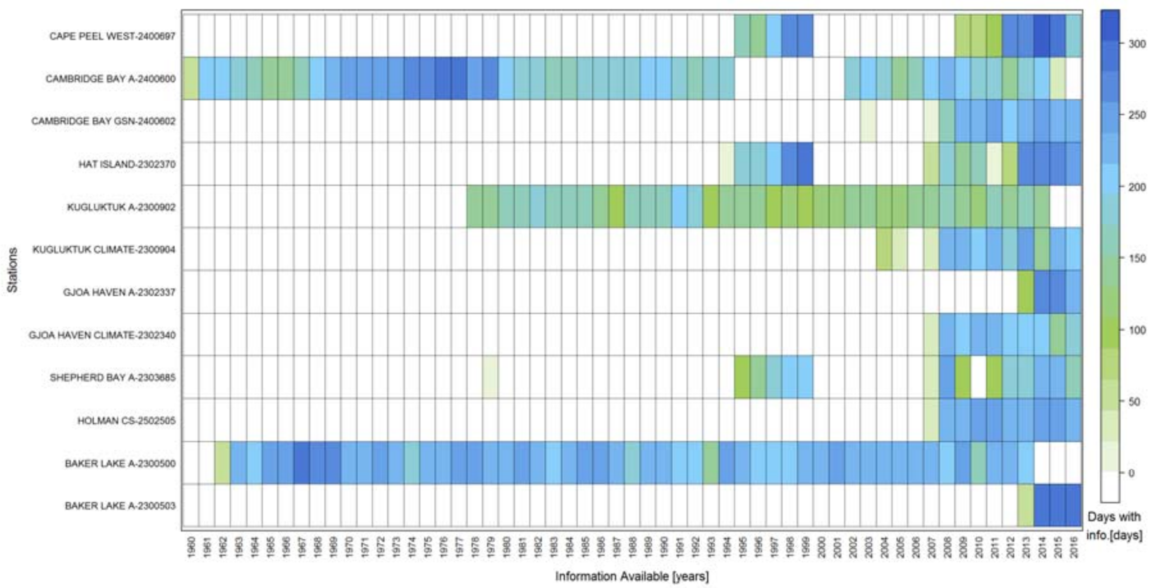


Figure 33: Number of Days in a Year with Daily Wind Gust Data from Regional Environment Canada Meteorological Stations

7.3.1 Site-Specific Wind Gust

The daily regional wind gust data was correlated with daily data at Doris and Boston. Figure 34 is a correlation matrix for the available daily average wind gust information at the different stations. The bottom-left section contains the (x, y) pair point scatter plots; the upper-right section contains the Kendall correlation values, which are similar in magnitude to the r^2 values for their respective pair point figures. The stars in the upper-right section reflect results of a correlation test; three stars indicate a strong correlation and zero stars indicate that there is no correlation between variables. The diagonal of the matrix presents the frequency figures for the variables.

The best correlation is observed between the Boston and Doris stations (in light red) followed by the Cambridge Bay GSN, Cambridge Bay A and Cape Peel West stations (in light yellow) with similar Pearson correlations of 0.54 to 0.58.

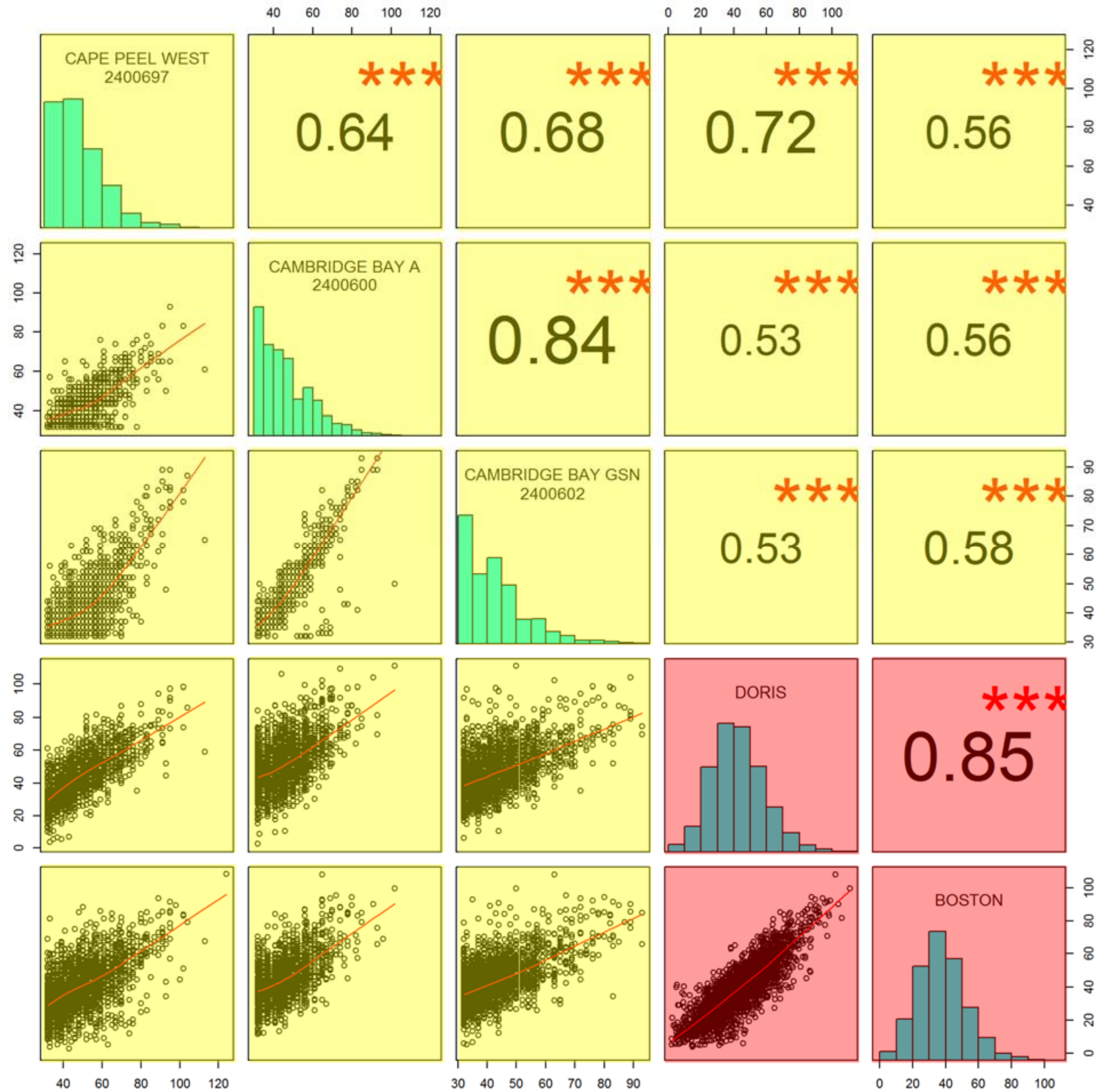


Figure 34: Correlation Matrix between the Daily Wind Speed at the Regional Meteorological Stations and at the Site

While Figure 34 indicates that Cape Peel West, Cambridge Bay A and Cambridge Bay GSN stations have good correlations with site data, and can be used to represent the site data; a comparison of site daily gust speed data to regional gust speed data (Figure 35 and Figure 36), indicate that direct usage of regional data would underestimate wind gust speeds. Therefore, relationships were developed to adjust regional records, to values closer to site records. The equation used to convert the regional gust values to site values, can be seen below, the linear coefficients m and n can be obtained from Table 25:

$$\boldsymbol{Wind\ Gust\ Speed\ Corrected} = \boldsymbol{m\ x\ Wind\ Gust\ Speed\ Original} + \boldsymbol{n}$$ **Equation 11**

Table 25: Linear Coefficient to be Adjusted the Wind Gust Speeds

Coefficients	Regional Stations		
	Cape Peel West	Cambridge Bay A	Cambridge Bay GSN
m	0.6794	0.6889	0.7408
n	8.557	16.84	12.36

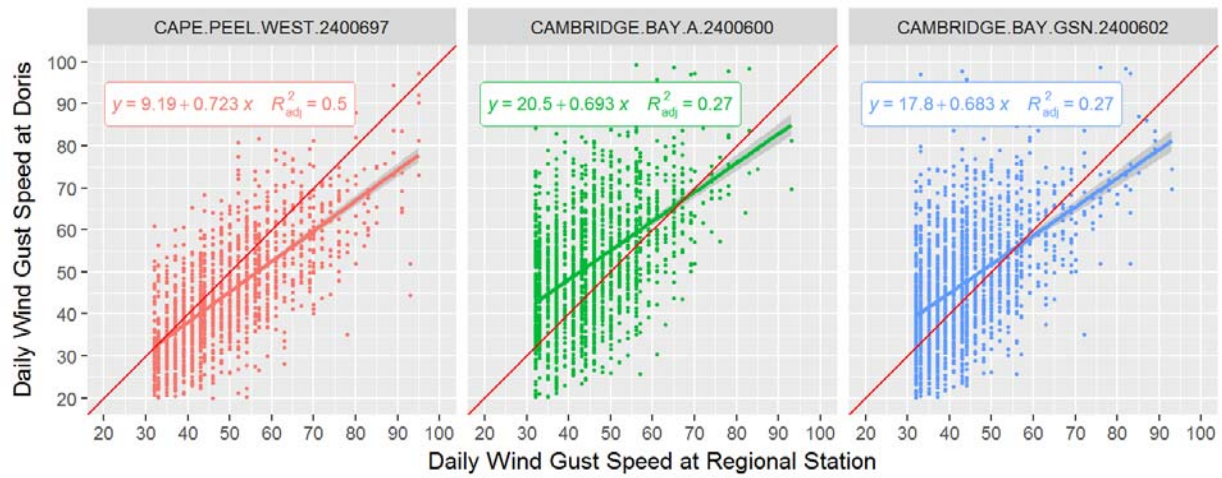


Figure 35: Daily Wind Gusts at Doris Compared with Cape Peel West and Cambridge Bay GSN

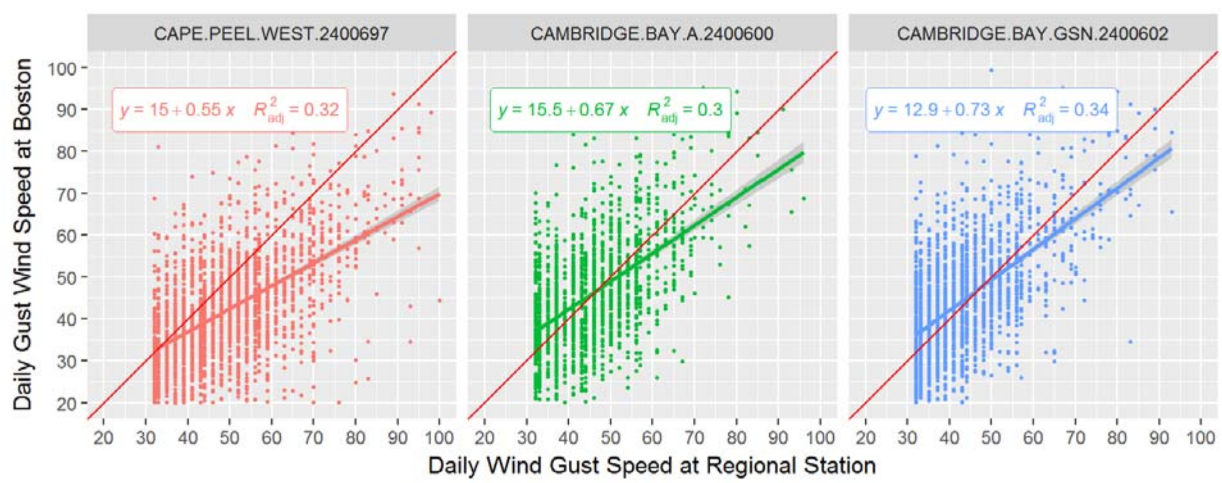


Figure 36: Daily Wind Gusts at Boston Compared with Cape Peel West and Cambridge Bay GSN

Figure 37 and Figure 38 present the relationships for daily wind gust speed at Doris, Boston with Cape Peel West, Cambridge Bay A and Cambridge Bay GSN following the linear adjustment, with the ideal relationship $y = x$ highlighted with a red line. Based on Figure 37 and Figure 38, the best regional station to represent site wind gust speed is Cape Peel West (adjusted values). Cambridge Bay GSN, then Cambridge Bay A could also be used to represent site values if Cape Peel West data is not available.

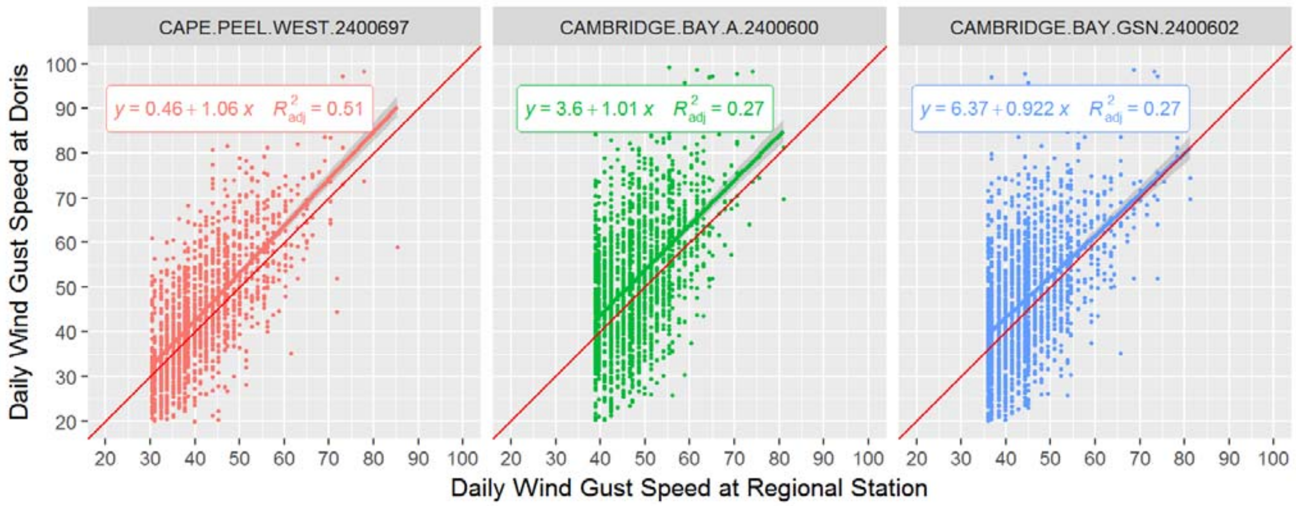


Figure 37**: Adjusted Daily Wind Gust Relationship between Doris and Cape Peel West and Cambridge Bay GSN, Regional Information Adjusted Based on Table 25**

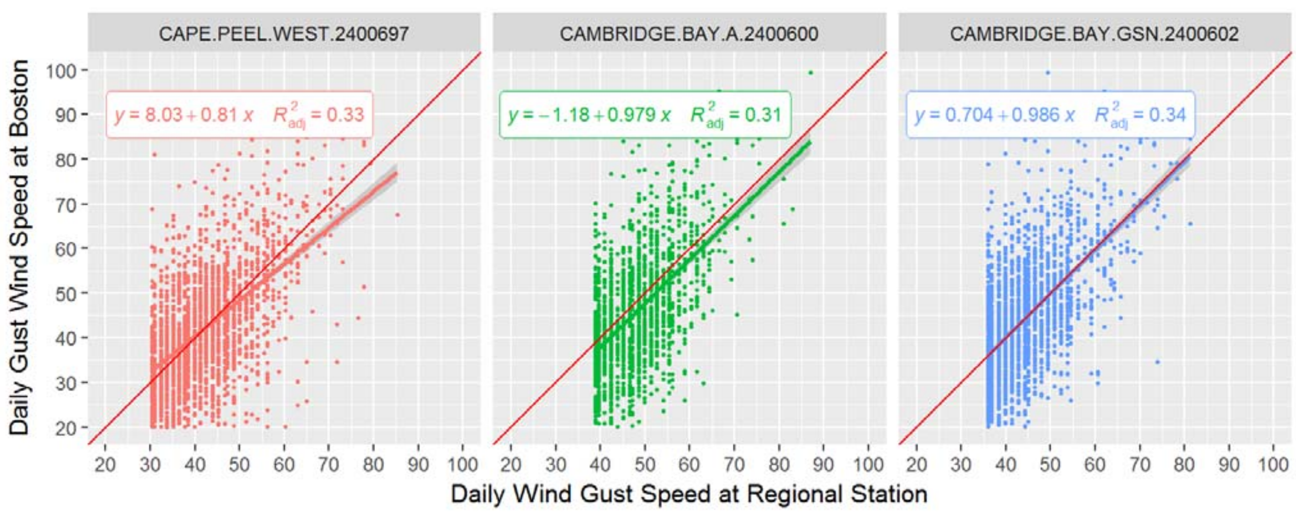


Figure 38: Adjusted Daily Wind Gust Relationship between Boston and Cape Peel West and Cambridge Bay GSN, Regional Information Adjusted Based on Table 25

7.3.2 Wind Gust - Frequency Analysis

Based on the analysis presented in Section 7.3.1, adjusted data from the Cape Peel West, Cambridge Bay A, Cambridge Bay GSN, Doris and Boston stations were compiled (Table 26). The maximum gust wind speed from all these stations was selected for each year, and frequency analyses were prepared based on these annual maxima The annual maxima per station is presented in Figure 39. Due to the limited amount of data available for this analysis a year is considered to be complete when at least 200 days of information were available, not the full 365.

Figure 39 and Table 26 show similar maximum values for every year and station; except Doris values between 2004 and 2008 (in red circle). The Doris values between 2004 and 2008 were obtained from a 3 m tripod and adjusted based on an elevation relationship (USACE 1989). This sensor height adjustment appears to have over-estimated the Doris values; however, because of the limited amount of data and the fact that over-estimation of these values is conservative, the adjusted Doris values were included in the frequency analysis.

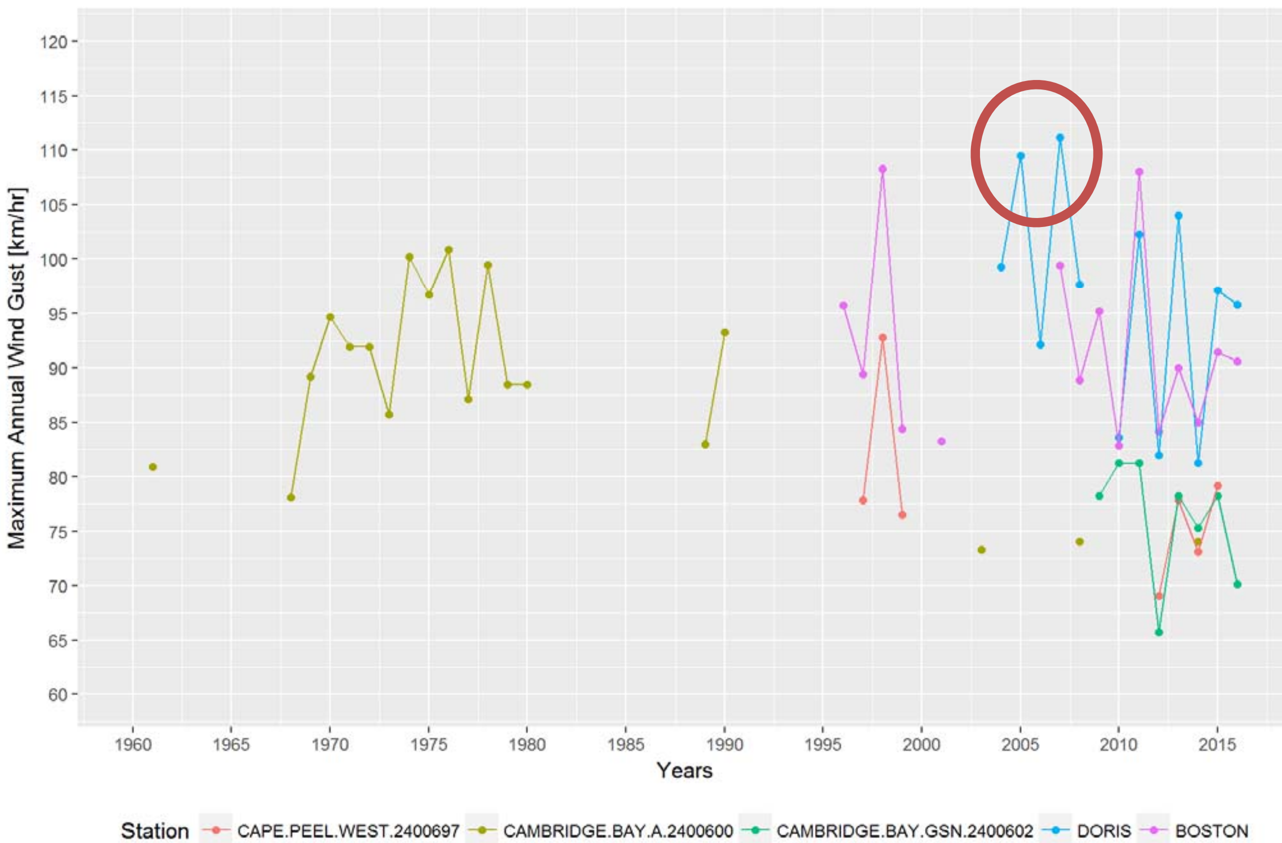


Figure 39: Maximum Annual Wind Gust (km/hr) in the Regional and Local Stations

Table 26: Maximum Annual Wind Gust Speed per Station

Year	Wind Gust Speed (km/hr)				
	CAPE PEEL WEST 2400697	CAMBRIDGE BAY A 2400600	CAMBRIDGE BAY GSN 2400602	DORIS	BOSTON
1961	-	80.91	-	-	-
1962	-	-	-	-	-
1963	-	-	-	-	-
1964	-	-	-	-	-
1965	-	-	-	-	-
1966	-	-	-	-	-
1967	-	-	-	-	-
1968	-	78.15	-	-	-
1969	-	89.17	-	-	-
1970	-	94.68	-	-	-
1971	-	91.93	-	-	-
1972	-	91.93	-	-	-
1973	-	85.73	-	-	-
1974	-	100.20	-	-	-
1975	-	96.75	-	-	-
1976	-	100.90	-	-	-
1977	-	87.11	-	-	-
1978	-	99.51	-	-	-
1979	-	88.48	-	-	-
1980	-	88.48	-	-	-
1981	-	-	-	-	-
1982	-	-	-	-	-
1983	-	-	-	-	-
1984	-	-	-	-	-
1985	-	-	-	-	-
1986	-	-	-	-	-
1987	-	-	-	-	-
1988	-	-	-	-	-
1989	-	82.97	-	-	-
1990	-	93.31	-	-	-
1991	-	-	-	-	-
1992	-	-	-	-	-
1993	-	-	-	-	-
1994	-	-	-	-	-
1995	-	-	-	-	-

Year	Wind Gust Speed (km/hr)				
	CAPE PEEL WEST 2400697	**CAMBRIDGE BAY A 2400600**	**CAMBRIDGE BAY GSN 2400602**	**DORIS**	**BOSTON**
1996	-	-	-	-	95.72
1997	77.85	-	-	-	89.42
1998	92.80	-	-	-	108.30
1999	76.49	-	-	-	84.38
2000	-	-	-	-	-
2001	-	-	-	-	83.27
2002	-	-	-	-	-
2003	-	73.33	-	-	-
2004	-	-	-	99.25*	-
2005	-	-	-	109.50*	-
2006	-	-	-	92.12*	-
2007	-	-	-	111.10*	99.43
2008	-	74.02	-	97.71*	88.85
2009	-	-	78.28	-	95.22
2010	-	-	81.25	83.60	82.87
2011	-	-	81.25	102.30	108.00
2012	69.02	-	65.69	82.00	84.10
2013	77.85	-	78.28	104.00	90.00
2014	73.10	74.02	75.32	81.29	85.00
2015	79.21	-	78.28	97.17	91.44
2016	-	-	70.14	95.84	90.61

Note: * These values were adjusted with a correction factor of 1.18 because the values were obtained from a 3 m tripod instead of a 10 m tower.

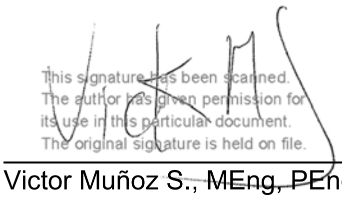
The frequency analyses used to develop gust speed for Doris and Boston were developed using Normal, Log Normal, Generalized Extreme Value (GEV), Gumbel, Pearson III, and Log Pearson III probabilistic distributions. The selection of the distribution parameters was prepared with the L-moments methodology. The L-moments approach suggests a more resistant estimation to outliers when compared with typical estimations. The selection of the best-fit distributions was prepared based on: Akaike Information Criterion, Corrected Akaike Information Criterion, Anderson-Darling Criterion, and Bayesian Information Criterion as described by Laio et al. (2009). These best-fit distributions were implemented by the statistical software R, version 3.3.1 (i386- w64).

The frequency analysis for gust wind speed is presented in Table 27.

Table 27: Frequency Analysis for the Gust Wind Speed at Doris and Boston

Return Period (years)	Gust Speed for Doris & Boston	
	km/hr	m/s
1000	125.7	34.9
500	123.1	34.2
200	119.5	33.2
100	116.5	32.4
50	113.4	31.5
25	110.1	30.6
20	108.9	30.3
10	105.0	29.2
5	100.5	27.9
2	92.3	25.7

This report, “Hope Bay Climate and Hydrological Parameters Summary Report”, was prepared by SRK Consulting (Canada) Inc.



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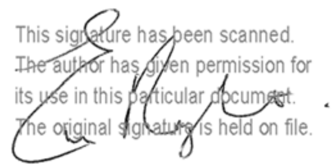

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Principal Consultant

All data used as source material plus the text, tables, figures, and attachments of this document have been reviewed and prepared in accordance with generally accepted professional engineering and environmental practices.

8 References

AMEC Earth and Environmental Ltd. 2003. Meteorology and Hydrology Baseline, Doris North Project Revision 1, Supporting Document 'D' to the Final Environmental Impact Statement. Report Prepared for Miramar Hope Bay Ltd. Project No.: VM00259. August 2003.

[CDA 2007] Canadian Dam Association. 2007. Dam Safety Guidelines.

[CRAN 2017] Comprehensive R Archive Network. 2016. Download, source code for the language R. https://cran.r-project.org/.

[EC 2014] Environment Canada. 2014. Short Duration Rainfall Intensity-Duration-Frequency Data for Cambridge Bay A.

[EC 2015]. Environment Canada. 2015. 1981-2010 Climate Normals & Averages. Accessed 2015. http://climate.weather.gc.ca/climate_normals/index_e.html.

[EC 2016] Environment Canada. 2016. Adjusted and Homogenized Canadian Climate Data (AHCCD). http://www.ec.gc.ca/dccha-ahccd/.

[ECCC 2017-1]. Environment and Climate Change Canada 2017. Historical Meteorological Data. Accessed 2017. http://climate.weather.gc.ca/historical_data/search_historic_data_e.html.

[ECCC 2017-2] Environment and Climate Change Canada. 2017. Adjusted and Homogenized Canadian Climate Data Daily (AHCCD). ftp://ccrp.tor.ec.gc.ca/pub/EC_data/AHCCD_daily

ERM Rescan. 2014-1. Doris North Project 2013 Compliance Monitoring Program – Meteorology. Prepared for TMAC Resources. Project No.: 0194098-0002. February 2014.

ERM Rescan. 2014-2. Doris North Project 2014 Meteorology Compliance Monitoring Program. Prepared for TMAC Resources. Project No.: 0246616-0002. December 2014.

ERM Rescan. 2015-1. Hope Bay Project Draft Environmental Impact Statement. Chapter 4: Climate and Meteorology.

ERM Rescan. 2015-2. Data: Doris mean hourly windspeed and wind direction January 1, 2012 to November 2, 2015 and Boston mean hourly windspeed and wind direction January 1, 2013 to July 23, 2015. Filename: Doris and Boston Hourly Wind 2013 to 2015.xlsx. December 2, 2015

ERM Rescan. 2016-1. Data: Boston average daily temperature September 1, 2010 to January 31, 2012. Filename: Boston Daily Air Temperature September 2010 - January 2012.xlsx. September 13, 2016.

ERM Rescan. 2016-2. Data: Boston monthly rainfall January 2012 to June 2016. Filename: Boston Monthly Rainfall 2012 - 2016.xlsx. September 13, 2016.

ERM Rescan. 2016-3. Data: Boston hourly windspeed and direction January 1, 2009 to December 31, 2013. Filename: Boston Wind Speed and Direction 2009 - 2013.xlsx. September 13, 2016.

ERM Rescan. 2016-4. Data: Boston hourly windspeed and direction June 18, 2000 to October 1, 2001. Filename: Boston Wind Speed and Direction June 2000 - September 2001.xlsx. September 13, 2016.

ERM Rescan. 2016-5. Data: Doris average daily evaporation and total monthly evaporation July, August and September 2015. Filename: Doris Lake Evaporation 2015.xlsx. September 13, 2016.

ERM Rescan. 2016-6. Data: Doris monthly rainfall September 2014 to July 2016. Filename: Doris Monthly Rainfall September 2014 - July 2016.xlsx. September 13, 2016.

ERM Rescan. 2016-7. Data: Doris hourly windspeed and direction August 1, 2009 to January 31, 2012. Filename: Doris Wind Speed and Direction August 2009 - January 2012.xlsx. September 13, 2016.

ERM Rescan. 2016-8. Data: Doris hourly windspeed, direction, maximum windspeed and time of maximum wind speed February 27, 2004 to January 1, 2009. Filename: Doris Wind Speed and Direction February 2004 - 2008.xlsx. September 29, 2016

ERM Rescan. 2016-9. Data: Doris and Boston daily mean, max, mine temperature and daily mean and max gust windspeed. Filename: daily 2012 to 2016, Doris and Boston, wind, temp; for SRK.xlsx. May 12, 2016.

ERM Rescan. 2016-10. Data: Boston hourly windspeed and wind direction July 2, 2006 to December 31, 2008. Filename: Boston Wind Speed and Direction July 1, 2006 - Dec 31, 2008.xlsx. September 26, 2016.

ERM Rescan. 2016-11. Data: Roberts Bay hourly windspeed and wind direction June 20, 2000 to September 12, 2000. Filename: Roberts Bay Wind Speed and Direction June 20, 2000 - Sept 12, 2000.xlsx. September 26, 2016

ERM Rescan. 2016-12. Data: Boston hourly windspeed and direction June 18, 2000 to September 20, 2001. Filename: Boston Wind Speed and Direction June 2000 - September 2001.xlsx. September 19, 2016

ERM Rescan. 2017-1. Data: Doris and Boston monthly rainfall January 2015 to May, 2017. Filename: Doris and Boston Monthly Rainfall Data.xlsx. August 22, 2017

ERM Rescan. 2017-2. Data: Doris and Boston daily/hourly temperature, wind speed, wind direction and wind gust January 2012 to June 2017. Filename: Doris and Boston Wind and Temp Data.xlsx. August 22, 2017

ERM Rescan. 2017-3. Data: Doris monthly open water season evaporation July 2009 to September 2016 Filename: Doris Lake Evaporation Data.xlsx. August 22, 2017

[ECMWF 2017] European Centre for Medium-Range Weather Forecasts. 2016. ERA-Interim dataset (January 1979 to present). http://www.ecmwf.int/en/forecasts/datasets/era-interim-dataset-january-1979-present.

Golder Associates Ltd. 2006. Doris North Project - Hydroclimatic Parameter Re-Evaluation. Edmonton.

Golder Associates Ltd. 2009. Doris Project Area - 2008 Hydrology Baseline Update. Edmonton.

Guo, Danlu, and Seth Westra. 2014. Evapotranspiration. The Comprehensive R Archive Network (CRAN). June. Accessed December 2014. http://cran.r-project.org/web/packages/Evapotranspiration/index.html.

Koenker, R.W., and G.W. Bassett. 1978. Regression quantiles. Econometrica (46) 44-50.

Laio, Francesco, Guiliano Di Baldassarre, and Alberto Montanari. 2009. Model selection techniques for the frequency analysis of hydrological extremes. Water Resources Research 45.

Maidment, David. 1993. Handbook of Hydrology. McGraw-Hill.

Mann, H.B. 1945. Non-parametric tests against trend. Econometrica (13) 163-171.

Mekis and Vincent 2011, An Overview of the second generation adjusted daily precipitation dataset for trend analysis in Canada, Atmosphere-Ocean (2) 2011,163-177

Morton, F.I. 1983. Operation Estimated of Areal Evapotranspiration and their significance to the science and practice of hydrology. Journal of Hydrology 66: 1-76.

[NASA 2017] National Aeronautics and Space Administration. 2017. Prediction of Worldwide Energy Resource. http://power.larc.nasa.gov/.

[NOAA 1963]. National Oceanic and Atmospheric Administration. 1963. Rainfall Frequency Atlas of the United States. Washington DC.

Rescan Environmental Services Ltd. 2001. 2000 Supplemental Environmental Baseline Data Report Hope Bay Belt Project. March 2001

Rescan Environmental Services Ltd. 2002. 1993 - 2002 Data Compilation Report for Meteorology and Hydrology. Prepared for Hope Bay Joint Venture. May 2002.

Rescan Environmental Services Ltd. 2009. 2009 Meteorology Baseline Report, Hope Bay Belt Project. Prepared for Hope Bay Mining Limited. Project No.: 1009-002-02. December 2009.

Rescan Environmental Services Ltd. 2010. Doris North Gold Mine Project 2010 Meteorology Compliance Report. Prepared for Hope Bay Mining Limited. Project No.: 1009-002-02. November 2010.

Rescan Environmental Services Ltd. 2011. Doris North Gold Mine Project. 2011 Meteorology Compliance Report. Hope Bay Mining Limited.

Rescan Environmental Services Ltd. 2012. Doris North Gold Mine Project: Hydrology Compliance Report 2012. Prepared for Hope Bay Mining Limited. Project No.: 1009-008-04. December 2012.

Rouse Wayne R, Binyamin Jacqueline, Blanken Peter, Bussieres Normand, Duguay Claude, Oswald Claire, Schertzer William and Spence Christopher, 2008, The influence of Lakes on the regional energy and water balance of the Central Mackenzie river basin

Sen, Pranab Kumar. 1968. Estimates of the regression coefficient based on Kendall's Tau. Journal of the American Statistical Association (Taylor & Francis, Ltd.) Vol. 63 N° 324, Pp. 1379-1389.

SRK Consulting (Canada) Inc. 2017. Hope Bay Project, Climate Change Analysis Approach. Report prepared for TMAC Resources Inc. Project No.: 1CT022.013. November 2017.

[USACE 1989]. U.S. Army Corps of Engineers. 1989. Water Levels and Wave Heights for Coastal Engineering Design.

[USGS 2015]. U.S. Geological Survey. 2015. Earth Explorer (GTopo30). U.S. Geological Survey. December. http://earthexplorer.usgs.gov/.

Walter, M.T., E.S. Brooks, M.K. McCool, L.G. King, M. Molnau, and J. Boll. 2005. Process-based snowmelt modeling: Does it require more input data than temperature-index modeling? Journal of Hydrology 300 (1-4):65-75.

[WMO] World Meteorological Organization, 2009. Manal on Estimation of Probable Maximum Precipitation (PMP). WMO-No. 1045.

Yue, S., Pilon, P., Phinney, B., and Cavadias, G. 2002. The influence of autocorrelation on the ability to detect trend in hydrological series. Hydrological Processes 16(9): 1807–1829, doi:10.1002/hyp.1095

Zhang, X., Vincent, L.A., Hogg, W.D., and Niitsoo, A. 2000. Temperature and precipitation trends in Canada during the 20th century. Atmosphere-Ocean 38(3): 395–429, doi:10.1080/07055900.2000.9649654