Ontario

Extreme Flow Statistics

Flood Flow and Low Flow Statistics for the Southwestern Hudson Bay and Nelson River Watersheds

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Ministry of Natural Resources and Forestry

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Additional Information

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Executive Summary

Estimates for single-station annual flood and low-flow frequency have been calculated for the Water Survey of Canada's HYDAT gauges in the Hudson-James Bay and the Nelson River watershed systems that lie within the Province of Ontario. The resultant statistics include:

- the flood magnitude with recurrence intervals of 1:2, 1:5, 1:10, 1:20, 1:50, 1:100, 1:200 and 1:500 years, and
- the *n*-day drought severity (1, 3, 7, 15 and 30 days) with recurrence intervals of 1:2, 1:5, 1:10, 1:20, 1:50, 1:100 years.

The flood magnitude statistics can be used for applications such as flood plain delineation and design of hydraulic structures. The drought severity statistics can be used for applications such as water abstraction and effluent dilution.

The estimated flow statistics are distributed as an MS Access Personal Geodatabase and will be included in Ontario Flow Assessment Tool (OFAT) III web application.

The following document details how the above statistics were estimated, the structure of the final data packages (as distributed) and considerations on appropriate data use and data limitations.

Key Words

Flood, drought, flood flow, low flow, frequency, statistics, watershed, stream gauge, Far North, OFAT

Revision History

Date	Edition/Version	Section	Description
2012-12-08	0.1	WRIP	Initial Draft
2013-02-27	1.0	WRIP	Final

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List of Acronyms

CFA: Consolidated Frequency Analysis

EVI: Extreme Volatility Index

EVR: Extreme Volatility Ratio

HOMS: Hydrological Operational Multipurpose System

HYDAT: The archive for Canadian Hydrometric Data

K: Frequency factor

Km: Kilometres

LFA: Low Flow Frequency Analysis

3LN: Three Parameter Lognormal

Mm: Millimetres

M: Rank

m^3/s: cubic metre per second

N: Sample size

N: Factor

NESI: North East Science and Information

OFAT: Ontario Flow Assessment Tool

P(F): Probability of an event F

POT: Peak Over Threshold

QD1 and QD3: Daily mean flows on days 1 and 3

QD2: Annual maximum daily mean flow

sq. km: Square Kilometres

R: Ratio of magnitude of the 100-year event to the 2-year event

t: Student's statistical value at the 90 percent level of significance with (Y-6) degrees of freedom

T: Return period in years

Y: Minimum accepted years of record

WRIP: Water Resources Information Program

y: Variate

σ: Standard Deviation

°: Degrees

1 Introduction

1.1 Preamble

The Ontario Ministry of Natural Resources and Forestry, Far North Branch and the former Water Resources Information Program (WRIP), in cooperation with North East Science and Information (NESI) have re-developed the Ontario Flow Assessment Tool (OFAT) as a web-based software tool (OFAT III). The re-development was undertaken in the project entitled, “Flow Assessment Methods and Tools Far North Information Knowledge Management Project 20” within the Far North Planning Initiative.

The regional hydrological models implemented in OFAT III were modeled in 1985 for flood flows and in 1995 for low flows. Since then, more new gauges have been installed and the record lengths have increased necessitating an update to the flow statistics and understanding of the flood flows and low flows.

To gain this understanding, single-station annual flood and low flow frequency analysis for the gauges of Nelson and Hudson Bay watershed system were undertaken. This technical document details the flood flow and low flow analysis of the gauges in the afore-mentioned secondary watersheds.

1.2 Overview of Flood/Low Flow Frequency Analysis

The likelihood of a given flood or drought magnitude is necessary to design, verify and evaluate the construction, performance and operation of any water related projects. Flood flows on the higher extreme provide design flow values for hydraulic structures and flood plain delineation whereas low flows on the lower extreme provide the limiting flow values for water abstraction, effluent dilution and protecting the aquatic system. Some application areas are:

- Design of in-stream structures (culverts, bridges, spillways, etc.)
- Floodplain delineation and management
- Municipal and industrial uses (design of water supplies)
- Determining the waste water effluent dilution potential of a receiving stream

- Predicting the impact of stream diversions on minimum flow requirements for spawning and migrating fish
- Environment impact assessment studies
- River navigation
- Reservoir operation (determine minimum downstream release requirements) and aquatic based recreation
- Irrigation facilities
- Mitigating the conflict between in-stream water use and water withdrawal demand
- Engineering feasibility assessment or design and operation of structures
- Viability of projects that require water to be abstracted or for in-stream use.

1.3 Objective

The objective of this project is to estimate:

1. The flood magnitude with recurrence intervals of 1:2, 1:5, 1:10, 1:20, 1:50, 1:100, 1:200 and 1:500 years for the gauges of Nelson and Hudson-James Bay Watershed Systems that lie within the Province of Ontario.
2. The n-day drought severity (1,3,7,15 and 30 days) with recurrence intervals of 1:2, 1:5, 1:10, 1:20, 1:50, 1:100 years for the gauges of Nelson and Hudson-James Bay Watershed Systems that lie within the Province of Ontario.

1.4 Province of Ontario and the Study Area

The Province of Ontario extends approximately from 42°N to 57° N latitude and from 75° W to 95°W longitude with three primary watersheds: Great Lakes, Nelson and Southwestern Hudson-James Bay. Ontario has three main climatic regions: southwestern Ontario is typical of a moderate humid continental climate, central and eastern Ontario is characteristic of a more severe humid continental climate and the northernmost parts of Ontario (north of 50°N) are within a sub-arctic climate region (Köppen *Dfa Dfb Dfc*).There are four seasons: spring, summer, fall and winter. The annual average temperature decreases with increasing latitude. January temperatures average -6 °C and those of July average 20 °C. Total annual precipitation decreases in amount from 864 mm in the south-west to less than 508 mm in the most northern portions of the Province.

Northern Ontario falls into two physiographic regions, namely the Canadian Shield and the Hudson Bay Lowlands. River systems in the region drain to the Nelson and Southwestern Hudson-James Bay watersheds. The Southwestern Hudson Bay Lowlands is predominantly a low relief area with poor drainage. The land is mainly wetland dominated with lower percentages of forest cover in comparison to the boreal forest region. Peat land hydrology plays a large factor in the overall hydrology of the lowlands. Water is retained in a watershed due to the high percentage of wetland and therefore exhibits a very slow response to rainfall and snow melt.

The Canadian Shield area is typically dominated by thin soil cover over bedrock. The area is dominated by a mix of forest, wetlands, lakes and rivers with little agriculture. Relief is much greater than other regions resulting in greater and more rapid runoff.

The Albany, Severn, and Attawapiskat rivers are the longest river systems within the Southwestern Hudson Bay / James Bay watershed system. The Albany River, with a drainage area of 135200 sq. km, flows northeast from Lake St. Joseph to Southwestern Hudson Bay. It is 982 km long to the head of the Cat River. Severn River is also 982 km long to the head of Black Birch River, with a smaller drainage area of 102800 sq. km. Attawapiskat River to the head of Bow Lake is 748 km long and has a drainage area of 50500 sq. km. The above rivers drain to Southwestern Hudson-James Bay watershed system whereas the English River is the longest river system in the Nelson River watershed system at 615 km in length and a drainage area of 52300 sq. km (The Atlas of Canada, 2012).

2 Methodology and Analysis

2.1 Methods/Governing Equations (Return Period – Return Level)

There are two methods available to estimate the magnitude of flood/low flows.

They are:

1. Mathematical method using frequency factors
2. Graphical method using probability papers.

These are described in the following sections.

2.1.1 Mathematical Method Using Frequency Factors

Before discussing the frequency factors, the general concept of recurrence interval is described below. A recurrence Interval or Return Period for flood flow is defined as:

> An annual maximum event has a return period (or recurrence interval) of T years if its magnitude is equalled or exceeded once, on the average, every T years. The reciprocal of T is the exceedance probability, 1- F, of the event, that is, the probability that the event is equalled or exceeded in any one year (Bedient, 2002).

The probability (*P*) that an event (*F*) will occur in any year (*T*) is expressed mathematically as:

$$P(F) = \frac{1}{T}$$

Return Period is the reciprocal of probability and is expressed mathematically as:

$$T = \frac{1}{P}$$

The recurrences intervals (return periods) calculated are: 2, 5, 10, 25, 50, 100, 200, and 500 years (annual-exceedance probabilities of 0.50, 0.20, 0.10, 0.04, 0.02, 0.01, 0.005, and 0.002, respectively).

Flood data are analysed either with the use of the Central Limit Theorem or the Extreme Value Theorem. These two theorems lead to the log-probability law and extreme value law respectively. The log-probability law states that the logarithms of the values are normally distributed; the extreme value theorem states that the instantaneous annual maximum approaches a definite pattern of frequency distribution when the number of observations in each year is large. Based on the above two laws, distributions are chosen to fit the data. The distributions used for the present study are: the Generalized Extreme Value, the Log-Pearson Type III distribution of the extreme value law and the Three-Parameter Lognormal from the log-probability law. The statistical details of the distribution and the way the program handles different cases for this can be found in the Consolidated Frequency Analysis (CFA) user manual (Pilon, 1985).

The same theory is applied to low flow frequency analysis as well. The major difference from flood frequency is that instead of using the exceedance probability, the non-exceedance probability is used to obtain the probabilities. This is because the return period event is the value that will not be exceeded. The series of annual low flow data are analysed using the Extreme Value Theorem/Central Limit Theorem. The distribution used is the 3- Parameter Gumbel Type III distribution. The acceptable lower boundary is set between zero and the minimum observed flows and the drought severity estimation stops when the drought value reaches zero. The estimation of the three parameters of the distribution proceeds in the sequence: the maximum likelihood, the method of smallest observed drought and the method of moments. For unusual occurrences where Gumbel Type III cannot provide results the Three Parameter Lognormal (3LN) distribution was used. For the technical details of the distributions and the methodologies, please refer to the Low Flow Frequency Analysis (LFA) user manual (Condie, 1982) and the associated technical paper referenced.

The principal characteristic of any frequency distribution used for flood and low flow frequency analyses is that the distribution has three, but not more than three parameters. Distributions with fewer than three parameters provide insufficient flexibility whereas those with more than three parameters are complex and less reliable. All of the above mentioned distributions used for estimation have only three parameters.

The general equation for estimating the return level in terms of the frequency factor, K for hydrological studies is given by Chow (1964). It is expressed mathematically as:

$$y = \bar{y} + \sigma K$$

The variate, y is represented by the mean plus the departure, σK (product of standard deviation, σ and the frequency factor, K). The frequency factor is a function of a recurrence interval and depends on the type of distribution.

2.1.2 Graphical Method Using Probability Papers

The fundamental principle of the graphical method is to develop a linear relationship between the recurrence interval and the event magnitude. The present study uses the Cunnae plotting position to plot data on the probability paper. The plotting formula is:

$$T = \frac{(N + 0.2)}{(m - 0.4)}$$

where N is the sample size and m the rank, starting with rank 1 for the highest. The graphical output in the probability graph displays the data points (sample series of flood/drought) and the plotted function of the distribution in question.

The plot is used as a visual check to see the goodness of fit of the distribution to the sample series of flood/drought. Therefore both mathematical and graphical methods are used to make the decision on the distribution and therefore the return period-return level values.

2.1.3 General Procedure for Frequency Analysis

The series of historical annual maxima/minima are used for the frequency analysis. The general procedure as shown in Figure 1 for the frequency analysis involves:

1. Prepare an annual maximum/minimum series.
2. Test the data for the assumptions of the Central Limit Theorem/Extreme Value Theorem. The assumptions are that the data should be random (independent and identically distributed), homogeneous and stationary. Non-parametric type tests are conducted.
3. Test the data for low and high outliers and treating the outliers.
4. Fit the data to one or more statistical distributions: (i) 3 Parameter Log Normal, ii) Weibull, iii) Generalized Extreme Value, iv) Log Pearson Type III) and estimate the parameters of the distribution using an appropriate method: (i) the maximum likelihood, ii) the method of moments, iii) the method of smallest observed drought.
5. Select the distribution that best fit the data from Step 4.
6. Compute the Return Period Return Level (magnitude associated with the specific exceedance/ non-exceedance) values using the parameters from the best fit distribution from Step 5.

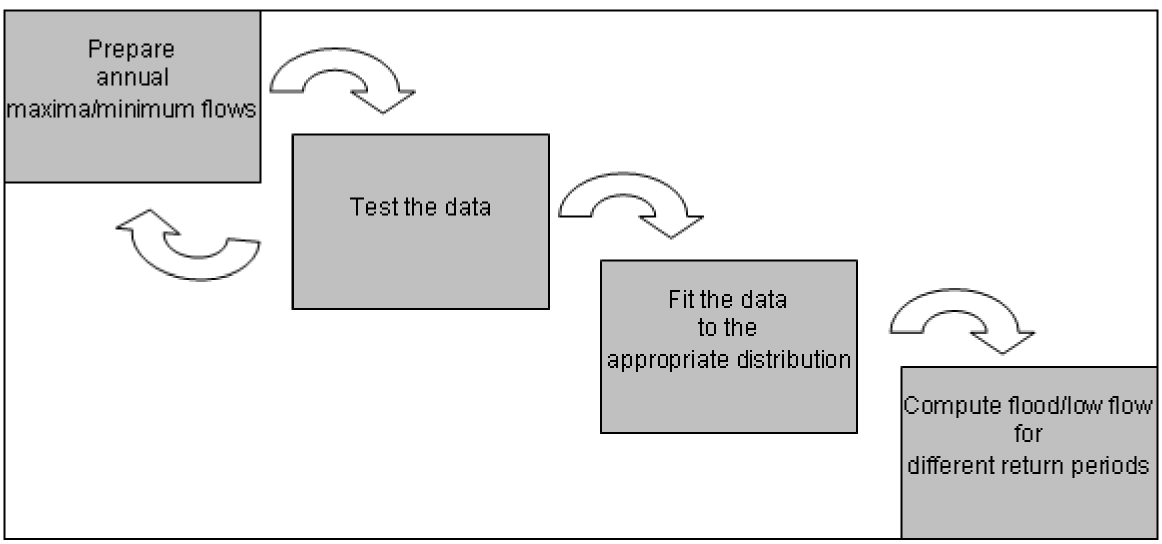


Figure 1. General Procedure for Frequency Analysis

2.2 Data Source and Gauging Stations

Historic stream flow records from the Water Survey of Canada HYDAT data base up to December 31, 2010 were utilized for estimating the magnitude of frequency. The time convention used in Canada for reporting stream flow data is the calendar year from January 1 to December 31.

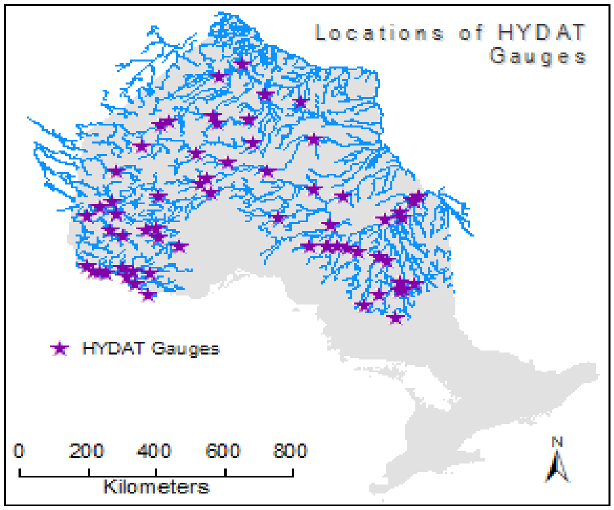


Figure 2. Location of Hydrometric (HYDAT) Gauges in the Hudson-James Bay and Nelson River Systems that lie within the Province of Ontario

Active stream gauge stations with more than 10 years of record, both regulated and natural, along with the six newly installed gauges (flood flow) were selected for frequency analysis. The six gauges used were: 05PC022 (LA VALLEE RIVER NEAR BURRISS), 05PC023 (PINEWOOD RIVER AT HIGHWAY NO. 617), 04LA003 (TATACHIKAPIKA RIVER NEAR TIMMINS), 04LA006 (MOLLIE RIVER AT HIGHWAY NO. 144), 04LB002 (KAMISKOTIA RIVER ABOVE ENID CREEK), 04LE002 (NEMEGOSENDA RIVER NEAR CHAPLEAU). Discontinued gauges (natural) with more than 10 years of record were also used in frequency studies for reference. Table 1 details the list of stations used. The years of data for each gauge station for flood flows and low flows are given in Appendix A and Appendix B.

Table 1. List of Water Survey of Canada HYDAT Gauging Stations

Station Name	HYDAT	Active / Discontinued	Regulation Type	Latitude (Decimal)	Longitude (Decimal)
ABITIBI RIVER AT ONAKAWANA	04ME003	Active	Regulated	50.60292	-81.41464
ALBANY RIVER BELOW ACHAPI LAKE	04GC002	Active	Regulated	51.36658	-89.42228
ALBANY RIVER NEAR HAT ISLAND	04HA001	Active	Regulated	51.33056	-83.83333
ASHEWEIG RIVER ABOVE LONG DOG LAKE	04DB002	Discontinued	Natural	53.52778	-89.29444
ASHEWEIG RIVER AT STRAIGHT LAKE	04DB001	Active	Natural	53.71175	-87.95339
ATIKOKAN RIVER AT ATIKOKAN	05PB018	Active	Natural	48.75197	-91.58408
ATTAWAPISKAT RIVER BELOW ATTAWAPISKAT LAKE	04FB001	Active	Natural	52.08611	-87.06667
ATTAWAPISKAT RIVER BELOW MUKETEI RIVER	04FC001	Active	Natural	53.09131	-85.07225
BASSWOOD RIVER NEAR WINTON	05PA012	Active	Natural	48.08256	-91.65117
BERENS RIVER ABOVE BERENS LAKE	05RC001	Active	Natural	51.80983	-93.52122
BRIGHTSAND RIVER AT MOBERLEY	04GB005	Active	Natural	49.62361	-90.57194
CAT RIVER BELOW WESLEYAN LAKE	04GA002	Active	Natural	51.17378	-91.59458
CEDAR RIVER BELOW WABASKANG LAKE	05QE008	Active	Natural	50.50756	-93.25858
CHUKUNI RIVER NEAR EAR FALLS	05QC001	Active	Regulated	50.87311	-93.48389
ENGLISH RIVER AT UMFREVILLE	05QA002	Active	Natural	49.87339	-91.45992
ENGLISH RIVER NEAR SIOUX LOOKOUT	05QA001	Discontinued	Natural	50.07083	-91.94444
FAWN RIVER BELOW BIG TROUT LAKE	04CE002	Discontinued	Natural	53.76667	-89.55000
GROUNDHOG RIVER AT FAUQUIER	04LD001	Active	Regulated	49.31378	-82.04314

Station Name	HYDAT	Active / Discontinued	Regulation Type	Latitude (Decimal)	Longitude (Decimal)
HALFWAY CREEK AT MOOSONEE	04KA002	Discontinued	Natural	51.25444	-80.65389
IVANHOE RIVER AT FOLEYET	04LC003	Active	Natural	48.25021	-82.44381
KABINAKAGAMI RIVER AT HIGHWAY NO. 11	04JA002	Discontinued	Natural	49.74417	-84.10361
KAMISKOTIA RIVER ABOVE ENID CREEK	04LB002	Active	Natural	48.62683	-81.62892
KAPUSKASING RIVER AT KAPUSKASING	04LF001	Active	Regulated	49.41442	-82.43994
KAWINOGANS RIVER NEAR PICKLE CROW	04FA002	Active	Natural	51.64831	-89.88692
KENOGAMI RIVER NEAR MAMMAMATTAWA	04JG001	Active	Regulated	50.42286	-84.38153
KWATABOAHEGAN RIVER NEAR THE MOUTH	04KA001	Active	Natural	51.16083	-80.86394
LA VALLEE RIVER NEAR BURRISS	05PC022	Active	Natural	48.67844	-93.66522
LITTLE CURRENT RIVER AT PERCY LAKE	04JF001	Active	Natural	50.65833	-86.53194
LONG-LEGGED RIVER BELOW LONG-LEGGED LAKE	05QE012	Active	Natural	50.677	-93.97019
MATTAGAMI RIVER NEAR TIMMINS	04LA002	Active	Regulated	48.40431	-81.44836
MATTAWISHKWIA RIVER AT HEARST	04LK001	Active	Natural	49.68278	-83.65556
MISSINAIBI RIVER AT MATTICE	04LJ001	Active	Natural	49.61392	-83.26667
MISSINAIBI RIVER BELOW WABOOSE RIVER	04LM001	Active	Natural	50.58544	-82.09100
MOLLIE RIVER AT HIGHWAY NO. 144	04LA006	Active	Natural	47.49611	-81.84878
MOOSE RIVER ABOVE MOOSE RIVER	04LG004	Active	Regulated	50.75158	-81.45139
MUSWABIK RIVER AT OUTLET OF MUSWABIK LAKE	04GF001	Discontinued	Natural	51.52556	-85.07028
NAGAGAMI RIVER AT HIGHWAY NO. 11	04JC002	Active	Natural	49.77289	-84.53694

Station Name	HYDAT	Active / Discontinued	Regulation Type	Latitude (Decimal)	Longitude (Decimal)
NAMAKAN RIVER AT OUTLET OF LAC LA CROIX	05PA006	Active	Natural	48.38256	-92.17631
NEMEGOSENDA RIVER NEAR CHAPLEAU	04LE002	Active	Natural	47.93817	-83.06069
NORTH FRENCH RIVER NEAR THE MOUTH	04MF001	Active	Natural	51.07672	-80.76408
OGOKI RIVER ABOVE WHITECLAY LAKE	04GB004	Active	Natural	50.86842	-88.93161
OTOSKWIN RIVER BELOW BADESDAWA LAKE	04FA001	Active	Natural	51.82325	-89.60214
PAGWACHUAN RIVER AT HIGHWAY NO. 11	04JD005	Active	Natural	49.76419	-85.22619
PINEIMUTA RIVER AT EYES LAKE	04FA003	Active	Natural	52.30828	-88.76033
PINEWOOD RIVER AT HIGHWAY NO. 617	05PC023	Active	Natural	48.79802	-94.18452
PIPESTONE RIVER ABOVE RAINY LAKE	05PB015	Discontinued	Natural	48.56861	-92.52417
PIPESTONE RIVER AT KARL LAKE	04DA001	Active	Natural	52.58058	-90.18669
PORCUPINE RIVER AT HOYLE	04MD004	Active	Natural	48.55014	-81.05431
RAINY RIVER AT FORT FRANCES	05PC019	Active	Regulated	48.60853	-93.40344
RAINY RIVER AT MANITOU RAPIDS	05PC018	Active	Natural	48.63447	-93.91336
ROSEBERRY RIVER ABOVE ROSEBERRY LAKES	04CA003	Active	Natural	52.65508	-92.53242
SACHIGO RIVER BELOW BEAVERSTONE RIVER	04CD001	Discontinued	Natural	54.99028	-89.34444
SEINE RIVER AT STURGEON FALLS GENERATING STATION	05PB009	Active	Regulated	48.74444	-92.28472
SEVERN RIVER AT LIMESTONE RAPIDS	04CC001	Discontinued	Natural	55.375	-88.32500
SEVERN RIVER AT OUTLET OF MUSKRAT DAM LAKE	04CA002	Active	Natural	53.48947	-91.51022
SHAMATTAWA RIVER AT OUTLET OF SHAMATTAWA LAKE	04DC002	Active	Natural	54.28975	-85.65153

Station Name	HYDAT	Active / Discontinued	Regulation Type	Latitude (Decimal)	Longitude (Decimal)
SHEKAK RIVER AT HIGHWAY NO. 11	04JC003	Discontinued	Natural	49.75556	-84.40667
STURGEON RIVER AT MCDOUGALL MILLS	05QA004	Active	Natural	50.16728	-91.54075
STURGEON RIVER AT OUTLET OF SALVESEN LAKE	05QE009	Active	Natural	50.35225	-94.46641
TATACHIKAPIKA RIVER NEAR TIMMINS	04LA003	Active	Natural	48.32972	-81.58017
TURTLE RIVER NEAR MINE CENTRE	05PB014	Active	Natural	48.85022	-92.72383
WABIGOON RIVER AT DRYDEN	05QD016	Active	Regulated	49.82917	-92.87083
WABIGOON RIVER NEAR QUIBELL	05QD006	Active	Regulated	49.95783	-93.40053
WINDIGO RIVER ABOVE MUSKRAT DAM LAKE	04CB001	Active	Natural	53.35019	-91.79161
WINISK RIVER AT KANUCHUAN RAPIDS	04DA002	Discontinued	Natural	52.95833	-87.70417
WINISK RIVER BELOW ASHEWEIG RIVER TRIBUTARY	04DC001	Active	Natural	54.49961	-87.22769

2.3 Flood Flow Frequency Analysis

2.3.1 Parameter Used

Annual flood is the highest momentary peak discharge in a water year/calendar year (Dalrymple, 1960). This flood, technically called annual maximum peak instantaneous flow, is used for frequency estimation. It is useful for the design flood estimation as it is the representation of the highest floods stage encountered at the stream reach. Data from previous flood frequency studies conducted by Moin and Shaw (1985) were updated to 2010 with the same methodology Sangal (1981) used in filling missing records.

2.3.2 Estimation of Maximum Instantaneous Flow Data from Maximum Mean Flow Data

The maximum instantaneous flow value is estimated using a method developed by Sangal (1981). The method uses variables that are the mean daily flows of three consecutive days with the maximum daily flow occupying the middle position. A parameter, the value of which lies between zero and two, is designated as base factor K and has a governing influence on the estimated peak.

The following equation was used to infill missing data;

$$\text{PredictedFlow, QPP} = \frac{(QD1 + QD3)}{2} + \frac{(QD2 - QD1 - QD3)}{(1 - 2\alpha)}$$

where

- QD1, QD2 and QD3: daily mean flows on days 1, 2 and 3 respectively
- QD2: annual maximum daily mean flow
- K : base factor, (1-2α)
- When α = 0 (or k=1) the equation reduces to;

$$\text{PredictedFlow, QPP} = \frac{(4QD2 - QD1 - QD3)}{2}$$

2.3.3 Understanding the Flood Characteristics of a Watershed

Before conducting the flood frequency estimation, a user can make inferences about the flood characteristics of the watershed. It is imperative to calculate some intermediate values in the calculation of the flood magnitude. The importance of these values lies in the fact that it provides an understanding of the data and the flood return period–return level. It also gives an understanding of the population (gauges that lie within the region). The intermediate values estimated are: mean annual flood, flood coefficient, coefficient of variation, coefficient of skew and the flood envelope chart.

The mean annual flood is the mean of the sample (maximum instantaneous peak flow) and it represents the 2.33 year recurrence interval. This value is the nexus point in connecting the flood generating mechanism with the drainage area.

The Flood Coefficient expresses the relationship of the annual mean flood to the watershed drainage area. To get this value, exponential regression analysis is established with the annual mean flood and the drainage area. The equation is given below:

$$\text{Coefficient of Flood} = \frac{\text{Mean Annual Flood}}{(\text{Drainage Area})^{n}}$$

The Coefficient of Variation gives the ratios of the large floods to the mean flood. It is the relative variation from the mean or, in other words, the degree of dispersion. If this ratio is small, then the flood magnitude variability is marginal. It is expressed as the ratio of the standard deviation to the mean. The value is independent of the sample size. In other words the coefficient computed from a small or large sample will be the same.

$$\text{Coefficient of Variation } (C_v) = \frac{\text{Standard Deviation } (\sigma)}{\text{Mean } (\mu)}$$

The Coefficient of Skew of flood is a measure of the asymmetry of the probability distribution around the mean. In general, all the stream flow data forms skewed curves and the Coefficient of Skew is the measure of the curvature of the flood. Unlike the Coefficient of Variation, the Coefficient of Skew depends on the sample size. So the value has to be adjusted using the formula that accounts for the sample size. The factor, F as given by Foster is: $F = 1 + \frac{8.5}{n}$. The adjustment is made by multiplying the computed coefficient by the factor, F.

$$\text{Coefficient of Skew } (C_{s(computed)}) = \frac{n}{(n-1)(n-2)} \sum \left[\frac{x_i - \bar{x}}{\sigma} \right]^3$$

The Flood Envelope Curve depicts the extreme floods that have occurred in a region and is constructed by plotting the maximum known floods of each gauge station against the drainage area. A smooth curve enveloping the plotted points is the Flood Envelope Curve for the region. The Envelope Curve can then be used in estimating the maximum flood that would occur in a watershed of a certain size in the region.

The Flood Envelope Curve is a variation in the Creager chart (unit discharge ($m^3/s/km^2$) against drainage area based on “unusual discharges of flood” for approximately 730 rivers in the United States and 30 in other countries of which 22 records are from Canada.

The steps used to construct the envelope curves are as follows:

- For all gauging stations in the study, the maximum recorded discharge is tabulated against the effective drainage area.
- The tabulated data are plotted on log-log paper.
- A line is drawn enclosing the upper limit of all of the plotted points to define the envelope curve.

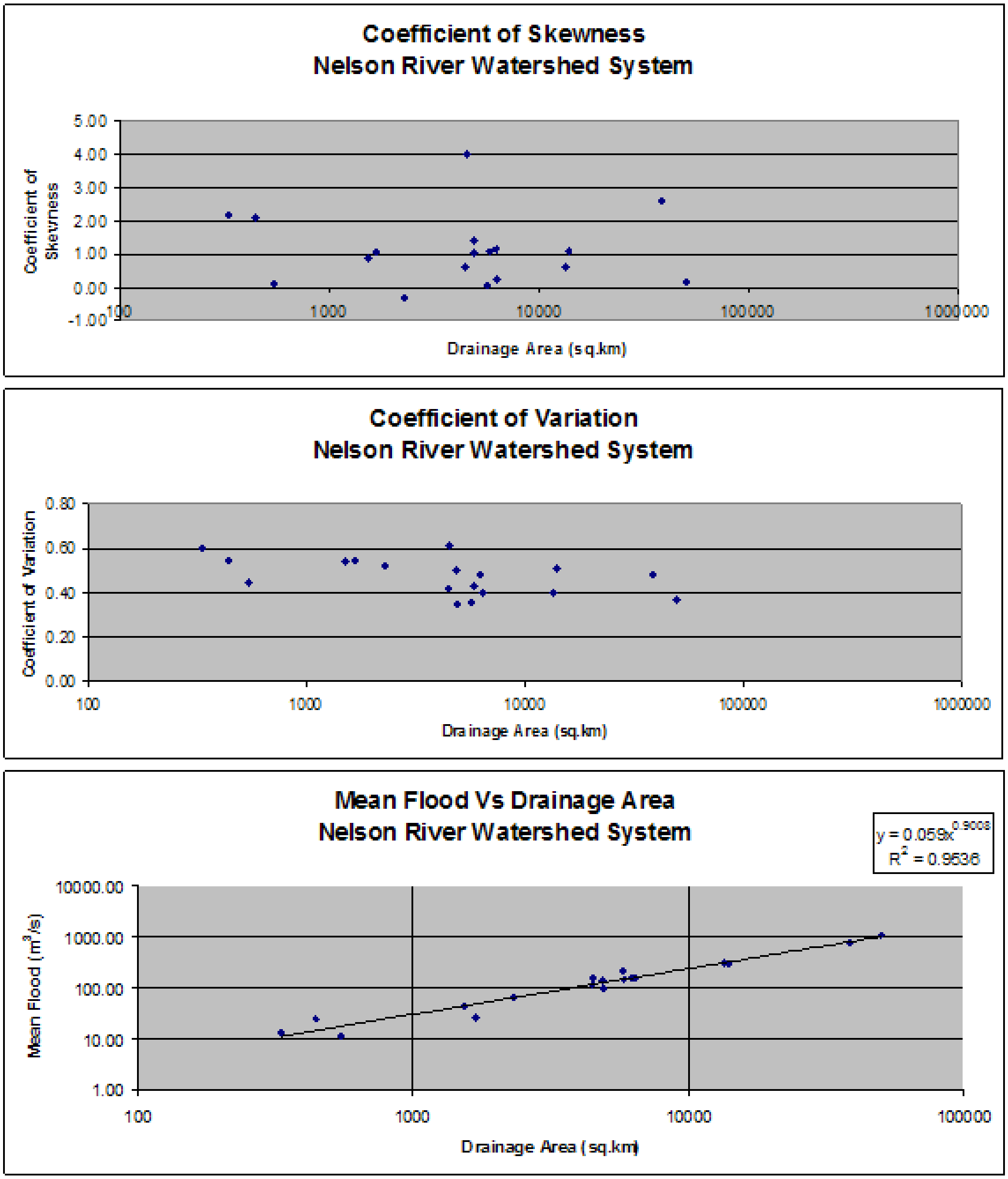


Figure 3. Flood characteristics of the Nelson River Watershed System

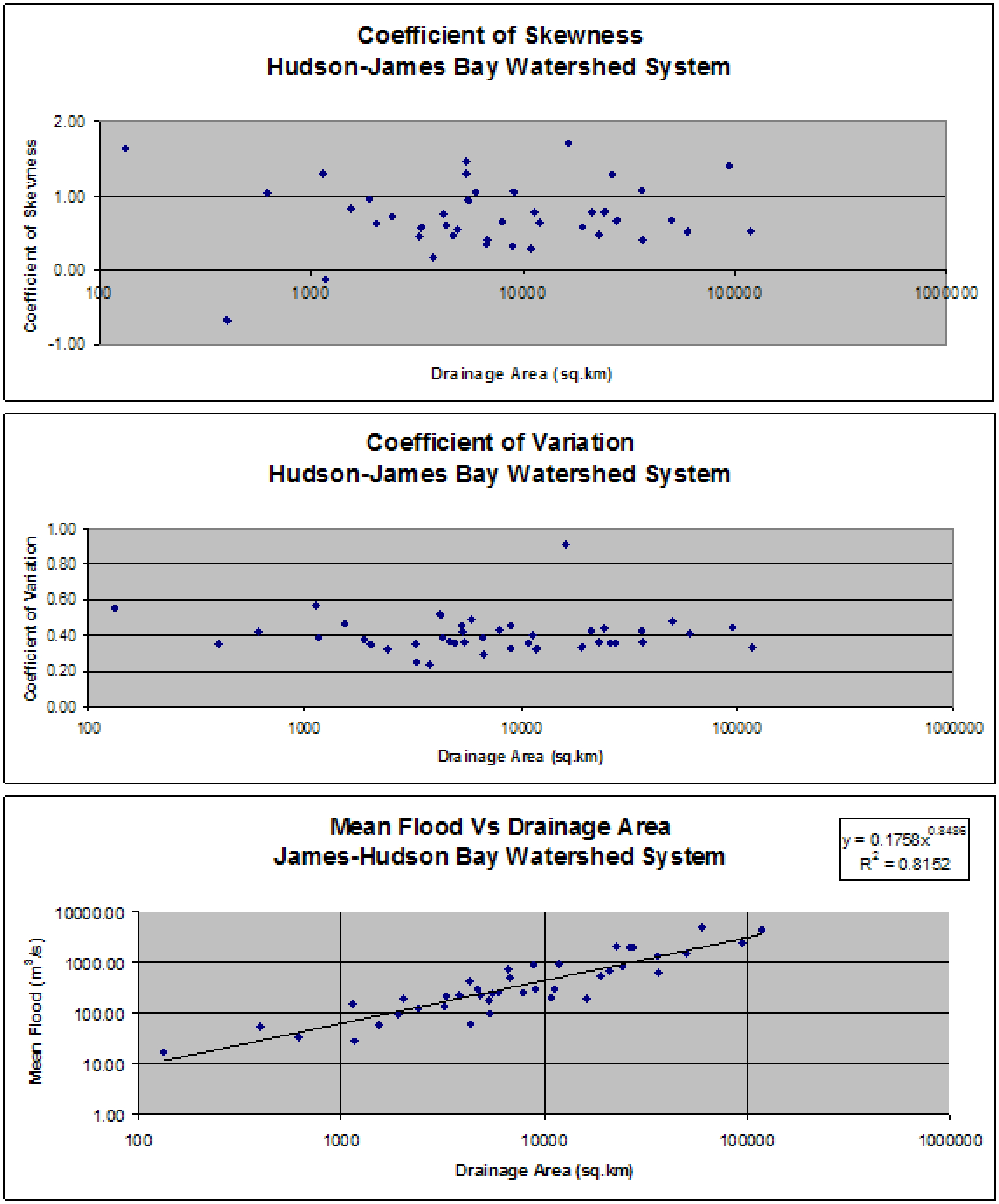


Figure 4. Flood characteristics of the Hudson-James Bay Watershed System

Figure 3 and Figure 4 show the mean flood, coefficient of variation and coefficient of skewness of the Nelson River and Southwestern Hudson-Bay watershed system respectively. The figures show that the coefficient of variation range between the value

0.2 and 0.6. The data is positively skewed except for three gauges. The exponential relationship between the mean flood and the drainage area is given below.

Southwestern Hudson-James Bay Watershed System

Mean Flood, $y = 0.1758 * (\text{Drainage Area})^{0.8486}$; $R^2 = 0.8152$

Nelson River Watershed System

Mean Flood, $y = 0.059 * (\text{Drainage Area})^{0.9008}$; $R^2 = 0.9536$

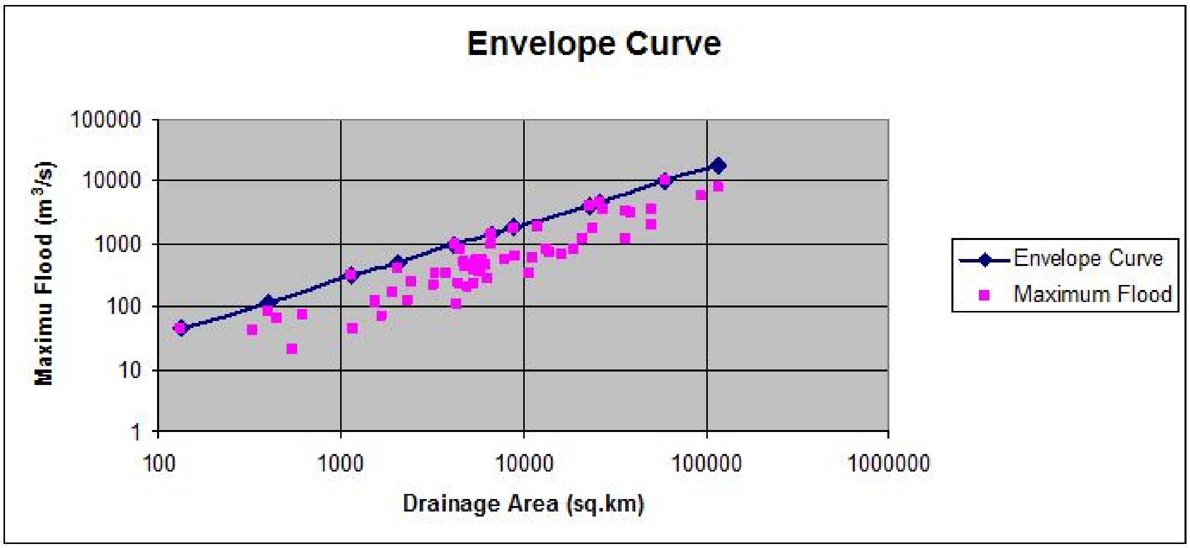


Figure 5. Envelope Curve for Nelson and Southwestern Hudson Bay Watershed System

The Envelope Curve for the two watershed systems is shown in Figure 5. The maximum observed flood ranged between 44 m^3/s for a drainage area of 133 sq. km to 18070 m^3/s for a drainage area of 118, 000 sq.km.

2.3.4 Software Used

Consolidated Frequency Analysis (CFA) version 3.1 (Environment Canada) written in FORTRAN 77 was used for frequency analysis of gauge stations with more than 10 years of record. The software is the HOMS[1] component (181.2.02) for floods and flood frequency analysis. Annual maximum instantaneous discharge, the year and month of

[1] HOMS: Hydrological Operational Multipurpose System established by the World Meteorological Organization for the transfer of technology in hydrology and water resources.

its occurrence constitute the data required for analysis. The probability distributions used for the analysis are: the Generalized Extreme Value, the Three-Parameter Lognormal, the Log-Pearson Type III and the Weibull.

The software used for the Extreme Value Analysis is Extremes Toolkit

("extRemes")[2], Weather and Climate Applications of Extreme Value Statistics Version 1.57; a statistics package available through the open source software R. This software was used for six newly installed gauges that have less than 10 years of data. Peak Over Threshold (POT) method was used in frequency analysis. This approach combines the number of times at which high-threshold exceedances occur by the Poisson process and the number of excess values over the threshold by the Generalized Pareto Distribution. The POT method gives identical results as that of the annual series for a higher return period (>10 years). Daily flow values above a certain threshold flow value constitute the data required for the analysis.

2.3.5 Statistical Tests

In order for the frequency analysis to be valid the data must be independent and identically distributed. In other words, the data should satisfy the following statistical criteria: randomness, independence, stationarity (trend) and homogeneity. The tests conducted are namely:

- The Spearman Rank Order Serial Correlation Coefficient Test for Independence
- The Spearman Rank Order Correlation Coefficient Test for Trend
- The Mann-Whitney Split Sample Test for Homogeneity
- Runs above and below the median for General Randomness.

[2] Written and maintained by Eric Gilleland and developed in conjunction with NCAR's (National Center for Atmospheric Research)Weather and Climate Impact Assessment Science Program (WCIAP), concerned with improving the scientific basis of assessments of the impacts of weather and climate on society (e.g., those of the U.N. Intergovernmental Panel on Climate Change, IPCC).

The null hypothesis for each of the tests at a significance level of 5% (if not at 1%) were tested to see whether the computed test value lies within the region of rejection. Data were removed from earlier years until all tests passed with a minimum at the 1 % significance level. The Grubbs and Beck outlier test was carried out to detect outliers. The lower outliers are retro-fitted by using the inbuilt capability of the program.

2.3.6 Selection of Probability Distribution Function

The probability distributions, namely the Generalized Extreme Value, the Three-Parameter Log Normal, and the Log-Pearson Type III were fitted to the data and the flow values for each of these distributions were estimated.

As different distributions produce a considerable range of flood estimates, the assessment of fit was subjectively made by testing the Coefficient of Skewness and the Coefficient of Kurtosis together with the visual examination of the plots. First, the coefficients of skewness and kurtosis of the log transformed data were tested against the theoretical values of 0.0 and 3.00 respectively. Then the goodness of fit was checked with the plot on lognormal probability scale showing the data points and the plotted function of each of three distributions. It is seen that the 3 Parameter Log Normal Distribution gives a better fit even though the Generalized Extreme Distribution and Log-Person Type 3 Distribution are also comparable. Further to that, studies carried out in the past by Moin and Shaw (1985) and Cumming Cockburn Limited for MNR (2000) identified the Three-Parameter Log Normal (3PLN) Distribution as the best fit to flood flows in Ontario. Hence the flow values based on the Three-Parameter Log Normal (3PLN) was reported and taken for OFAT III.

2.3.7 Ratio of Q_{100}/Q_2 year Flood and Extreme Volatility Index

Extreme Volatility is computed as the ratio of two return levels (e.g. Q_{100}/Q_2 year flood). It is also called the Measure of Surprise or Extreme Volatility Ratio. A normalized measure is termed the Extreme Volatility Index.

Extreme Volatility Ratio, EVR = Q_{100}/Q_2

Extreme Volatility Index, EVI = 1-(1/EVR)

The value of Extreme Volatility Index is calculated as a value between 0 and 1. The value for the watersheds of study ranged from 0.36 to 0.75 (with an average of 0.58). The ratio of Q_{100}/Q_2 year flood ranged from 1.6 to 4.0 (with an average of 2.5 and standard deviation of 0.6) with the exception of one sample, 04GC002 (ALBANY RIVER BELOW ACHAPI LAKE) which provided a high value of 0.94 and 17 for the Extreme Volatility Index and Q_{100}/Q_2 year flood respectively.

2.3.8 Length of Record

The adequacy of the length of record for 90 % significance level was tested using the equation from Schwab (1993). The equation is:

$$Y = (4.30t * \log_{10} R)^2 + 6$$

Where Y = minimum accepted years of record

t = Student's statistical value at the 90 percent level of significance with (Y-6) degrees of freedom

R= ratio of magnitude of the 100-year event to the 2-year event

The length of record required based on the above equations for each station was calculated and identified that 7 stations lack adequate record length. The ratio of 100 to 2-year flood is the sensitive parameter. The length of record increases with the variance of the distribution which varies from stream to stream and with the return period.

The sample summary along with the values of the Extreme Volatility Index and the years of record required are given in Table 2.

Table 2. Flood Flow Sample Summary and Analysis Values

HYDAT	Drainage Area (km.sq)	Mean Flood (m3/s)	Coefficient of Flood	Standard Deviation	Coefficient of Variation	Coefficient of Skewness	Coefficient of Kurtosis	Max Flood (m3/s)	Q100 / Q2	Extreme Volatility Index	Years of Data	Years of Data Required
04ME003	27500	1943.00	0.55	689.82	0.36	0.68	2.86	3428.00	2.31	0.57	41	13
04GC002	16300	195.00	0.08	178.56	0.92	1.71	5.77	677.00	17.07	0.94	18	90
04HA001	118000	4644.23	0.41	1530.89	0.33	0.53	3.88	8070.00	1.93	0.48	39	10
04DB002	3240	136.90	0.21	48.40	0.35	0.45	3.40	214.00	2.27	0.56	10	17
04DB001	7950	254.61	0.19	109.00	0.43	0.65	3.53	564.00	2.66	0.62	38	16
04FB001	24200	830.76	0.26	369.19	0.44	0.78	3.40	1735.00	2.79	0.64	29	17
04FC001	36000	1374.76	0.31	595.98	0.43	1.07	4.64	3234.00	2.62	0.62	37	15
04GB005	1170	28.05	0.10	11.01	0.39	-0.12	2.06	44.00	1.55	0.36	21	8
04GA002	5390	99.92	0.10	45.48	0.46	1.47	5.41	229.00	2.45	0.59	23	14
04CE002	4350	60.30	0.07	23.09	0.38	0.61	3.25	111.00	2.38	0.58	23	14
04LD001	11900	937.97	0.51	306.09	0.33	0.64	3.56	1834.00	2.04	0.51	77	11
04KA002	133	15.95	0.32	8.82	0.55	1.65	7.96	44.00	3.31	0.70	20	22
04JA002	3780	226.25	0.31	52.34	0.23	0.17	2.71	341.00	1.61	0.38	36	8
04LF001	6760	508.24	0.44	151.94	0.30	0.41	3.60	969.00	1.83	0.45	78	10
04FA002	1540	57.81	0.16	27.02	0.47	0.83	3.40	122.00	3.59	0.72	26	23
04JG001	26200	1981.39	0.58	712.45	0.36	1.30	8.60	4595.00	1.99	0.50	31	11

HYDAT	Drainage Area (km.sq)	Mean Flood (m3/s)	Coefficient of Flood	Standard Deviation	Coefficient of Variation	Coefficient of Skewness	Coefficient of Kurtosis	Max Flood (m3/s)	Q100 / Q2	Extreme Volatility Index	Years of Data	Years of Data Required
04KA001	4250	418.13	0.52	215.71	0.52	0.75	3.32	999.00	3.04	0.67	38	18
04JF001	5360	177.66	0.18	75.17	0.42	1.31	5.11	388.00	2.54	0.61	29	15
04LA002	5540	241.38	0.24	88.64	0.37	0.95	5.90	542.00	2.24	0.55	37	13
04LK001	1140	145.85	0.52	83.07	0.57	1.30	5.05	326.00	3.45	0.71	13	25
04LJ001	8940	877.88	0.61	292.99	0.33	0.33	3.44	1790.00	2.00	0.50	91	11
04LM001	22900	2024.84	0.66	738.88	0.36	0.47	3.51	4025.00	2.19	0.54	37	12
04LG004	60100	5067.83	0.76	2073.46	0.41	0.51	3.62	10305.00	2.32	0.57	24	13
04GF001	1890	90.50	0.22	34.07	0.38	0.96	5.04	168.00	2.23	0.55	16	13
04JC002	2410	122.38	0.24	39.71	0.32	0.73	4.20	246.00	2.18	0.54	37	12
04MF001	6680	743.96	0.65	291.84	0.39	0.36	2.97	1425.00	2.19	0.54	44	12
04GB004	11200	288.57	0.17	117.26	0.41	0.79	3.96	614.00	2.53	0.60	37	15
04FA001	9010	301.79	0.21	137.07	0.45	1.06	4.19	640.00	2.94	0.66	29	18
04JD005	2020	192.35	0.44	67.27	0.35	0.64	4.92	396.00	1.97	0.49	43	11
04FA003	4900	228.55	0.26	81.13	0.36	0.55	3.57	451.00	1.87	0.47	40	10
04DA001	5960	252.41	0.24	122.92	0.49	1.06	3.71	559.00	3.21	0.69	39	20
04MD004	401	53.10	0.44	18.58	0.35	-0.66	3.85	82.60	1.57	0.36	21	8
04CA003	619	32.31	0.19	13.80	0.43	1.04	4.45	72.90	2.73	0.63	32	16

HYDAT	Drainage Area (km.sq)	Mean Flood (m3/s)	Coefficient of Flood	Standard Deviation	Coefficient of Variation	Coefficient of Skewness	Coefficient of Kurtosis	Max Flood (m3/s)	Q100 / Q2	Extreme Volatility Index	Years of Data	Years of Data Required
04CD001	21100	684.36	0.24	295.78	0.43	0.78	3.66	1192.00	4.03	0.75	11	34
04CC001	94300	2370.61	0.25	1068.41	0.45	1.40	6.78	5655.00	2.59	0.61	23	16
04CA002	36500	616.27	0.14	224.98	0.37	0.40	3.45	1197.00	2.10	0.52	30	12
04DC002	4710	286.74	0.33	103.91	0.36	0.47	3.22	530.00	2.11	0.53	35	12
04JC003	3290	210.84	0.32	53.46	0.25	0.58	2.99	343.00	1.90	0.47	37	10
04CB001	10800	203.43	0.12	72.61	0.36	0.29	2.68	341.00	2.06	0.51	30	11
04DA002	19000	519.70	0.20	175.13	0.34	0.58	4.00	835.00	2.16	0.54	10	15
04DC001	50000	1483.92	0.26	719.87	0.49	0.67	3.25	3445.00	3.09	0.68	37	19
05PB018	332	12.56	0.12	7.53	0.60	2.17	10.57	40.80	3.40	0.71	27	21
05PA012	4510	159.36	0.19	97.68	0.61	3.98	27.63	809.00	2.97	0.66	81	17
05RC001	5730	217.33	0.21	77.96	0.36	0.04	2.40	355.00	1.88	0.47	21	10
05QE008	1690	25.63	0.07	13.99	0.55	1.08	4.58	71.00	3.46	0.71	40	21
05QC001	4920	95.55	0.11	33.17	0.35	1.03	6.81	205.00	1.98	0.50	47	11
05QA002	6230	159.26	0.15	76.82	0.48	1.13	4.85	449.00	2.86	0.65	88	17
05QE012	548	10.90	0.07	4.87	0.45	0.13	2.61	21.00	2.17	0.54	31	12
05PA006	13400	306.77	0.15	123.05	0.40	0.61	4.78	800.00	2.16	0.54	88	12
05PC019	38600	770.11	0.16	374.54	0.49	2.58	19.72	3114.00	2.43	0.59	88	14

HYDAT	Drainage Area (km.sq)	Mean Flood (m3/s)	Coefficient of Flood	Standard Deviation	Coefficient of Variation	Coefficient of Skewness	Coefficient of Kurtosis	Max Flood (m3/s)	Q100 / Q2	Extreme Volatility Index	Years of Data	Years of Data Required
05PC018	50200	1067.98	0.19	394.53	0.37	0.15	2.66	2030.00	1.96	0.49	82	10
05PB009	5880	144.85	0.14	62.31	0.43	1.07	5.48	372.00	2.84	0.65	47	17
05QA004	4450	112.00	0.14	47.28	0.42	0.60	3.10	226.00	2.74	0.63	48	16
05PB014	4870	130.82	0.15	65.79	0.50	1.43	7.66	440.00	2.81	0.64	89	16
05QD016	2300	63.70	0.13	33.06	0.52	-0.28	2.20	121.00	1.85	0.46	40	10
05QD006	6370	156.46	0.14	62.21	0.40	0.24	2.38	276.00	2.21	0.55	57	12
05QA001	13900	283.21	0.14	144.00	0.51	1.07	4.11	719.00	3.17	0.68	61	19
05PB015	443	24.40	0.19	13.31	0.55	2.08	9.91	65.30	3.38	0.70	15	23
05QE009	1530	43.13	0.12	23.33	0.54	0.85	4.16	115.00	3.04	0.67	46	18

2.4 Low Flow Frequency Analysis

2.4.1 Parameters Used

The severity of drought is defined in two dimensions: the annual minimum discharge for a given duration/period in days and the drought severity in T- years. The given durations for each gauge station are the moving average of 1, 3, 7, 15 and 30 consecutive days. The annual minimum flow/discharge for each year is the minimum value derived from daily flow values for the given duration and is represented as:

$nQ_{\text{moving average}} = [Q_{i(n)}]$ where n= 1, 3, 7, 15, 30 days

$nQ_{min} = \min [nQ_{\text{moving average}}]$ i = 1, 2, 3….365

2.4.2 Understanding Drought (Low Flow) Characteristics of Watershed

Similar to the flood characteristics of the watershed, the drought or the low flow characteristics the Mean Annual Flood, the Flood Coefficient, the Coefficient of Variation, the Coefficient of Skew and the Flood Envelope Curve for 7-day annual minimum are shown in Figure 6, Figure 7 and Figure 8 for the Nelson River and Southwestern Hudson-James Bay watershed systems. The relationship between mean drought and drainage area are given below:

Southwestern Hudson-James Bay Watershed System

Mean Drought, $y = 0.0005 * (\text{Drainage Area})^{1.1402}$; $R^2 = 0.869$

Nelson River Watershed System

Mean Drought, $y = 0.0009 * (\text{Drainage Area})^{1.1157}$; $R^2 = 0.9617$

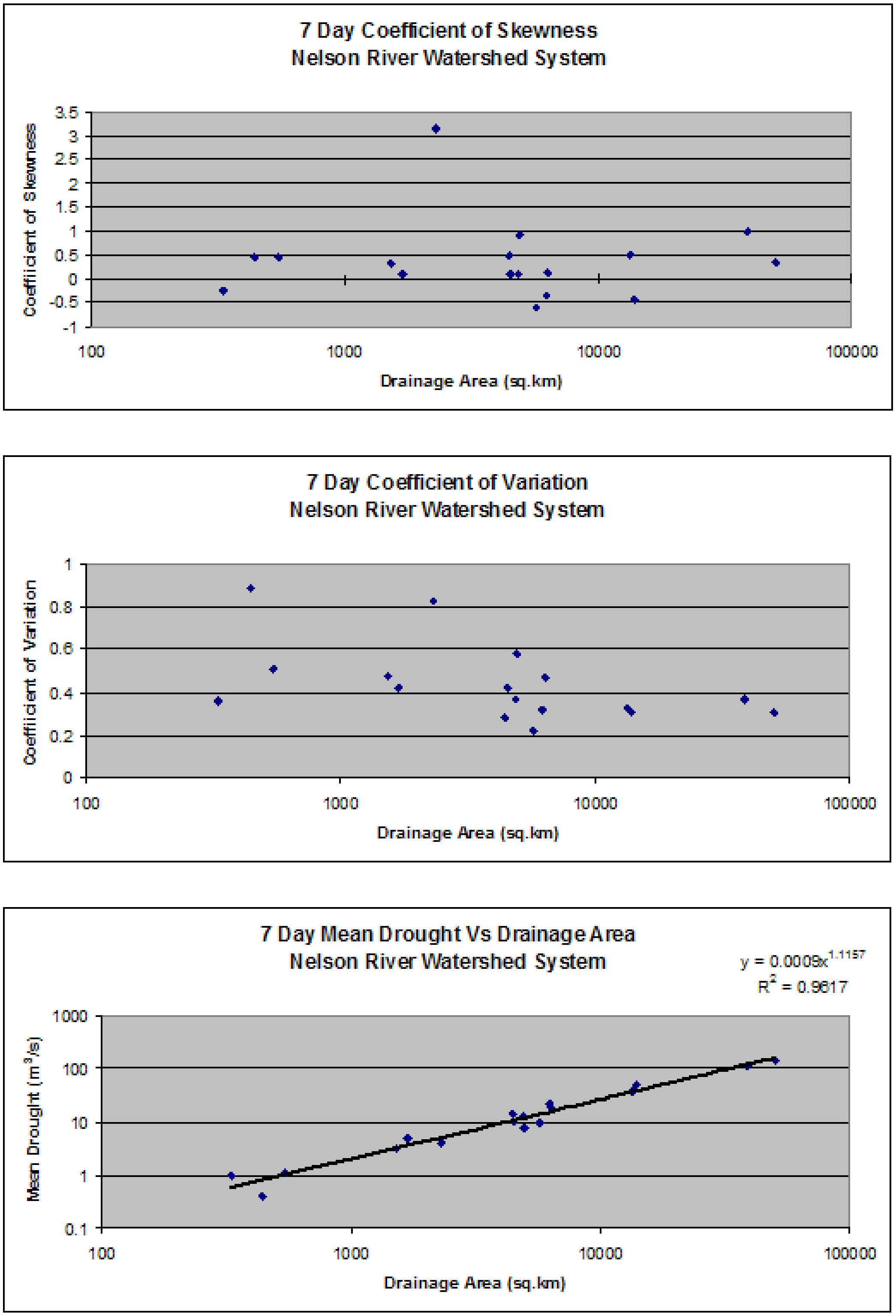
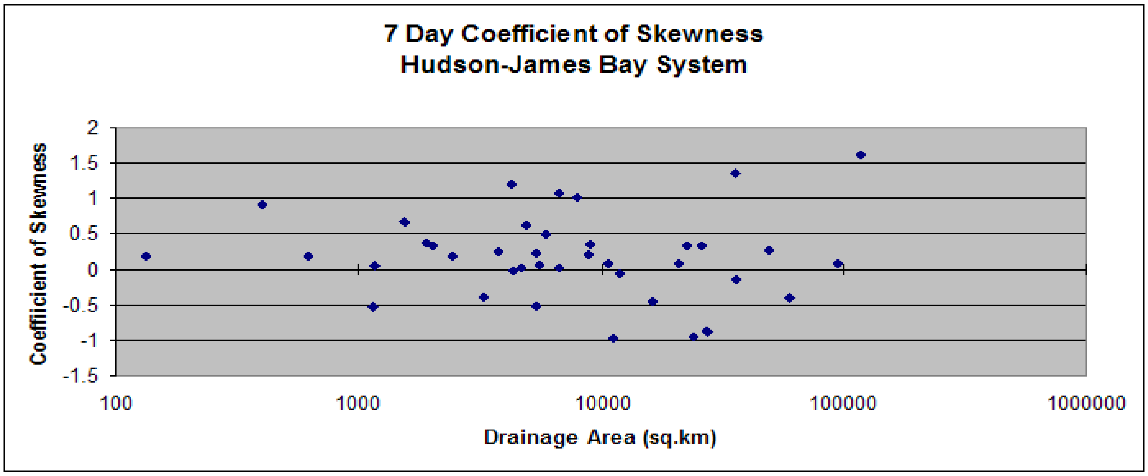
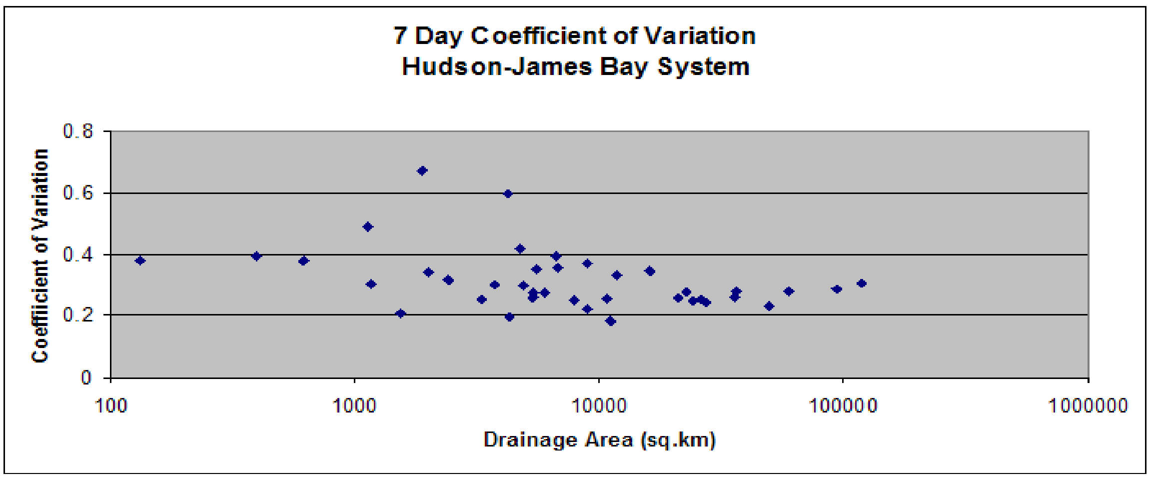


Figure 6. Drought characteristics of the Nelson River Watershed System





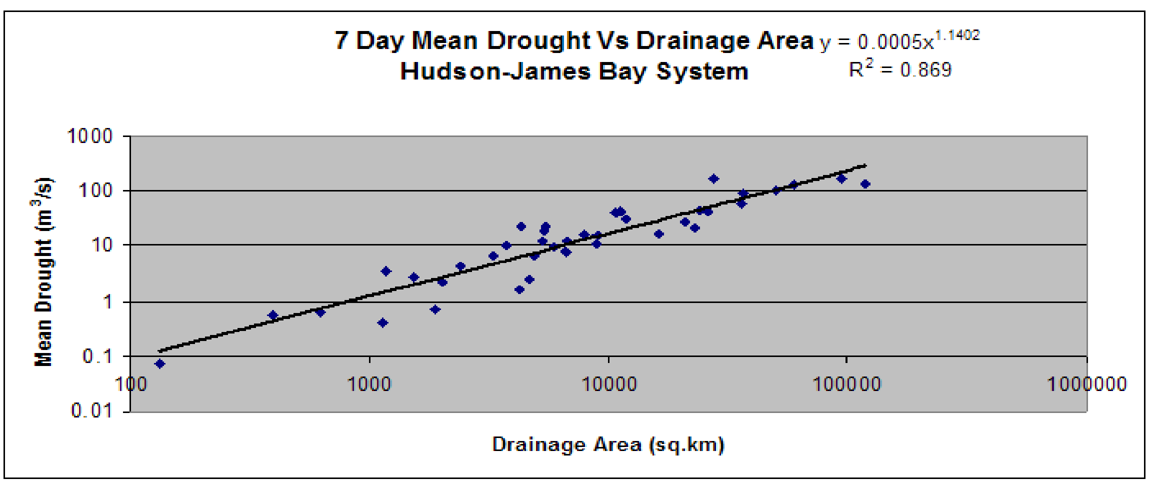
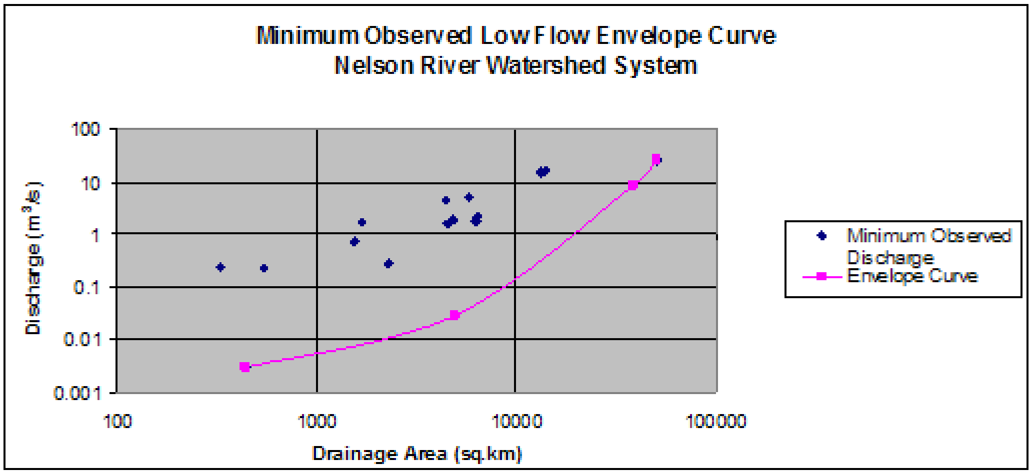


Figure 7. Drought Characteristics of the Southwestern Hudson-James Bay Watershed System



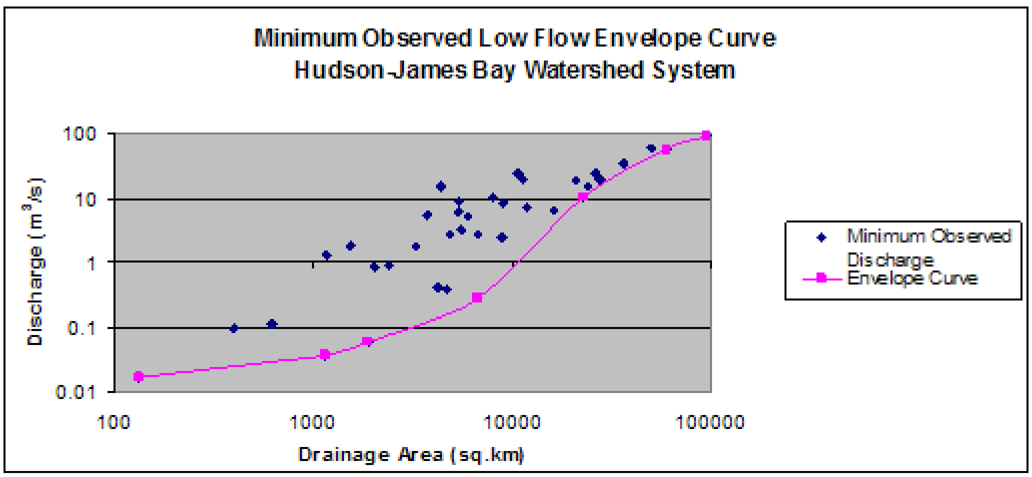


Figure 8. Drought Envelope Curves of the Nelson River and the Southwestern Hudson-James Bay Watershed System

2.4.3 Software Used

The Low Flow Frequency Analysis (LFA) Package (1994) version 2.0, Climate/Water Information Branch Atmospheric Environment Service, Environment Canada written in FORTRAN 77 was used for the low flow frequency analysis for gauging stations with more than 10 years of record. The probability distribution used for the analysis was the Gumbel Type III (Weibull) and three parameter lognormal (3LN) distribution. The software was the HOMS[3] component (I80.2.03) for low flows using annual minimum n-day discharge data.

2.4.4 Statistical Tests

Similar to the flood frequency analysis, statistical tests were conducted prior to conducting low flow frequency analysis. The tests conducted were namely:

- The Spearman Rank Order Serial Correlation Coefficient Test for Independence
- The Spearman Rank Order Correlation Coefficient Test for Trend
- The Mann-Whitney Split Sample Test for Homogeneity
- Runs above and below the median for General Randomness

Similar to the flood frequency analysis, the null hypothesis of each statistical test was evaluated at a significance level of 5% (if not at 1%) to see whether the computed test value lies within the region of rejection. Data were removed from the earlier years until all the tests were passed at the minimum of the 1% significant level.

2.4.5 Relationship between Drought Duration and Severity

The relationship between the drought duration and severity for each gauge is provided through the summary and interpolation chart of the low flows for the associated stream reach. For illustrative purposes, Figure 9 and Figure 10 shows the relationship between the drought duration and the severity of drought for 04FB001 (ATTAWAPISKAT RIVER BELOW ATTAWAPISKAT LAKE) and 04DC001 (WINISK RIVER BELOW ASHEWEIG RIVER TRIBUTARY). These curves could be used as a framework from which a drought of any duration ranging from a moving average of 1 to 30 consecutive days can be determined for 2, 5, 10 and 20 years of return period. Return periods of 50 years and higher are not graphed because of the large uncertainties associated with their estimates.

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[3] HOMS: Hydrological Operational Multipurpose System established by the World Meteorological Organization for the transfer of technology in hydrology and water resources.

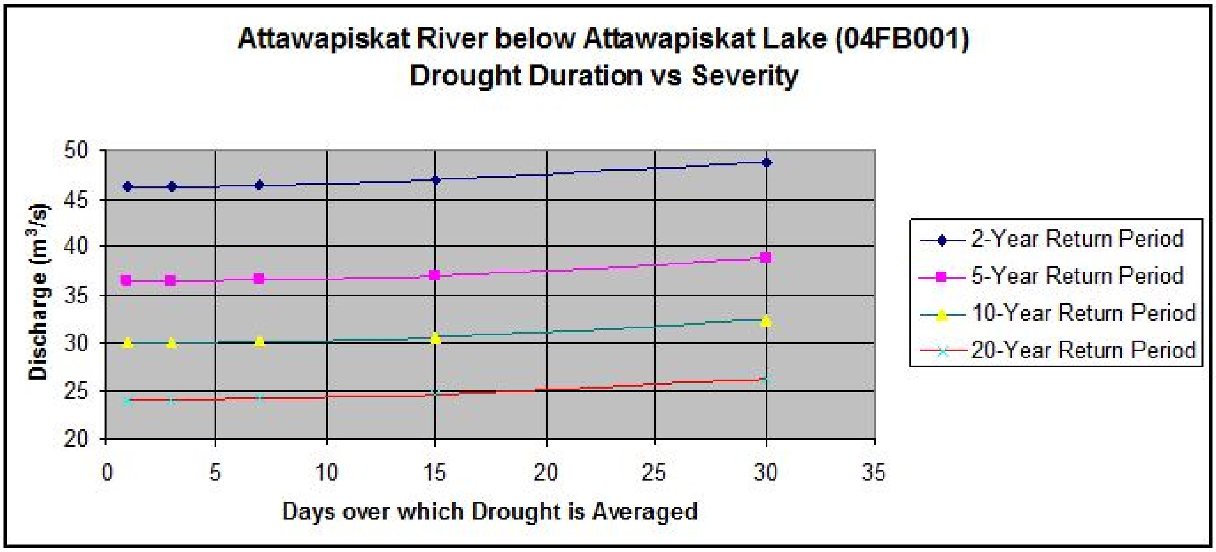

Figure 9. Relationship between Drought Duration and Severity of the Attawapiskat River below Attawapiskat Lake (04FB001)

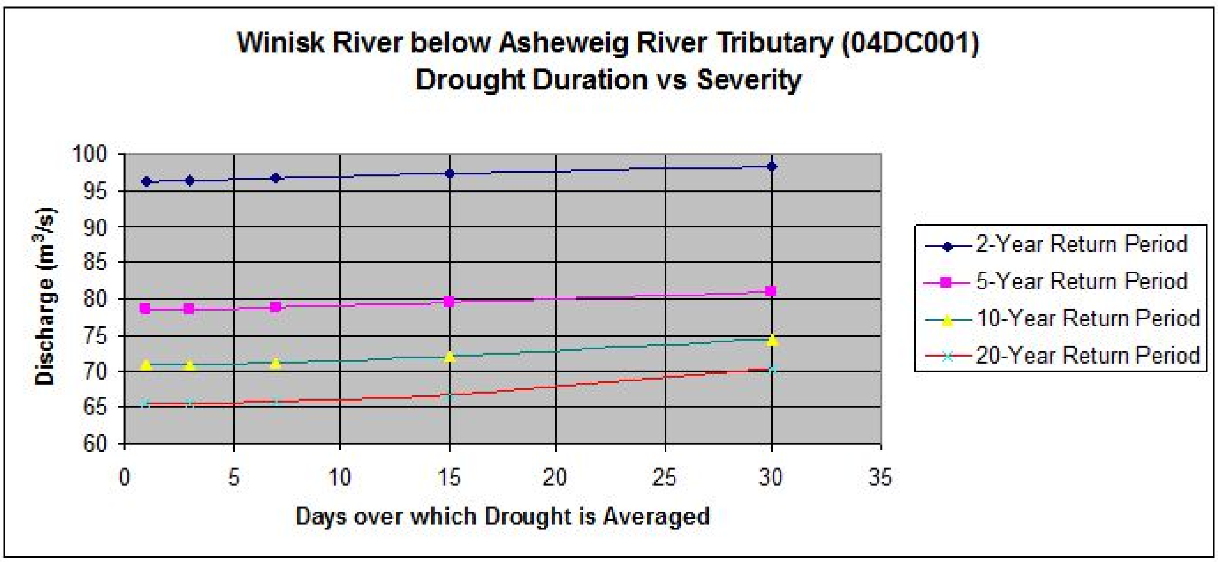

Figure 10. Relationship between Drought Duration and Severity of the Winisk River below Asheweig River Tributary (04DC001)

2.4.6 Envelope Curves (Drought Severity vs Drainage Area)

Envelope Curves were also made for the 2, 5, 10 and 20 year return periods. The 1, 3, 7, 15 and 30 day low flows are so close that a single curve was prepared for each return period. These curves provide a lower limit of low flows. Similar curves are made for the province of New Brunswick. Low flow estimation guidelines for New Brunswick state that “during design, remember that low flow Envelope Curves almost always provide an underestimate of low flows. However, for several design situations, a conservative estimate as provided by Envelope Curves might prove to be useful to at least provide a reasonable starting point.” The drought Envelope Curves with return period of 2,5,10 and 20 years are shown in Figure 11 and Figure 12 for the Nelson River and the Southwestern Hudson-James Bay watershed systems.

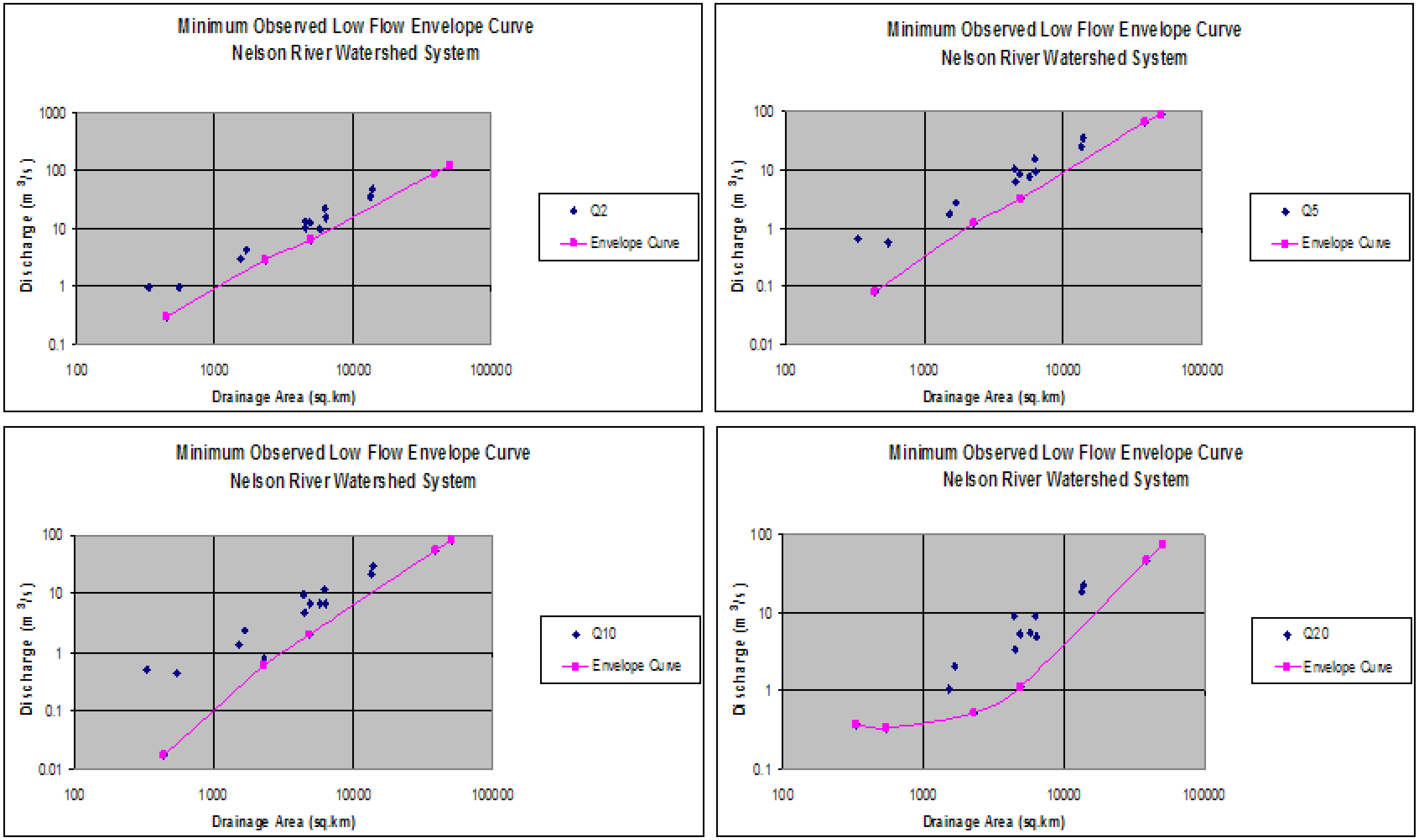

Figure 11. Drought Envelope Curve for the Nelson River Watershed System

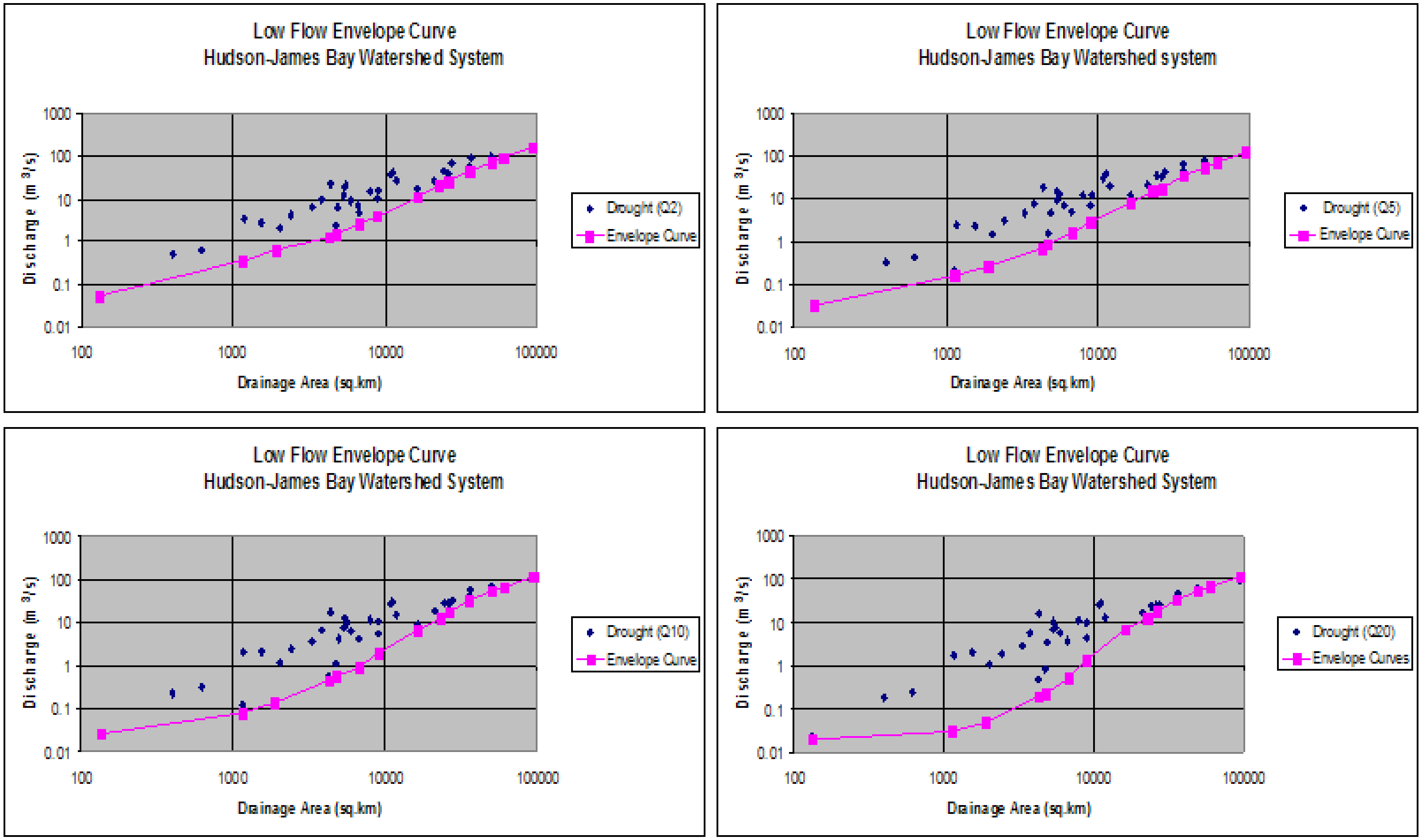

Figure 12. Drought Envelope Curves for the Southwestern Hudson-James Bay Watershed System

2.4.7 The $7Q_{20}$ and the Ratio $7Q_2/7Q_{20}$ Low Flow

The $7Q_{20}$ value is tied to the regulatory framework for Permit To Take Water (2007) and Approval of Sewage Works (2010). The gauge station, 05PB015 (PIPESTONE RIVER ABOVE RAINY LAKE) is the only gauge station with a $7Q_{20}$ value of zero. This station is a discontinued gauging station that was natural and had more than 10 years of record. The ratio of $7Q_2$ /$7Q_{20}$ was analysed by McLean and Watt in 2005 for central Ontario and came to the following conclusions:

"Interpretation of the ratio $7Q_2$ /$7Q_{20}$ is that basins with values close to one do not show a great deal of variation between the median low flow years and extreme low flow years, whereas basins with ratios close to zero show a considerable difference. Basins with low flow ratios (0.3) are generally fine-grained and flat lying. Streams with high ratios (>0.7) contain more coarse-grained materials and are flatter than the average basin in the study area."

The minimum, average and maximum values ($7Q_2$ /$7Q_{20}$) for the Hudson Bay-James River watershed system are 0.14, 0.53 and 0.73 respectively and that of the Nelson River watershed system are 0.19, 0.42 and 0.69 respectively.

The sample summary along with the values of the 7Q2 /7Q20 are given in Table 3.

Table 3. Low Flow Sample Summary and Analysis Values

HYDAT	Drainage Area (km sq)	Mean Drought (m3/s)	Standard Deviation	Coefficient of Variation	Coefficient of Skewness	Coefficient of Kurtosis	Years of Data	7Q20 / 7Q2
04ME003	27500	162.228	39.597	0.244	-0.868	6.105	41	0.54
04GC002	16300	16.428	5.635	0.343	-0.455	2.926	19	0.40
04HA001	118000	135.220	41.628	0.308	1.634	7.098	36	0.65
04DB001	7950	16.226	4.065	0.250	1.018	4.734	39	0.73
04FB001	24200	44.805	11.087	0.247	-0.955	4.910	28	0.52
04FC001	36000	57.562	14.981	0.260	1.350	6.352	39	0.70
04GB005	1170	3.547	1.074	0.303	0.053	3.509	21	0.52
04CE002	4350	23.383	4.612	0.197	-0.027	3.059	22	0.70
04LD001	11900	30.659	10.084	0.329	-0.053	2.927	74	0.46
04KA002	133	0.072	0.027	0.377	0.193	3.996	19	0.45
04JA002	3780	12.054	4.269	0.354	0.025	4.030	36	0.58
04LF001	6760	2.860	0.586	0.205	0.666	4.128	78	0.40
04FA002	1540	42.036	10.726	0.255	0.331	2.772	25	0.71
04JG001	26200	1.593	0.949	0.596	1.208	4.980	30	0.66
04KA001	4250	12.120	3.296	0.272	0.228	4.114	37	0.38
04JF001	5360	23.086	8.084	0.350	0.063	3.100	28	0.59
04LA002	5540	0.401	0.196	0.490	-0.526	4.075	32	0.42
04LK001	1140	19.369	4.978	0.257	-0.513	2.901	12	0.15

HYDAT	Drainage Area (km sq)	Mean Drought (m3/s)	Standard Deviation	Coefficient of Variation	Coefficient of Skewness	Coefficient of Kurtosis	Years of Data	7Q20 / 7Q2
04GA002	5390	10.861	4.001	0.368	0.204	3.336	35	0.53
04LJ001	8940	20.944	5.794	0.277	0.335	2.972	90	0.43
04LM001	22900	131.625	36.614	0.278	-0.392	2.936	37	0.61
04LG004	60100	0.724	0.487	0.673	0.374	3.039	23	0.51
04GF001	1890	4.259	1.336	0.314	0.180	3.166	16	0.14
04JC002	2410	7.908	3.094	0.391	1.090	4.565	60	0.50
04MF001	6680	42.524	7.843	0.184	-0.986	4.811	44	0.50
04GB004	11200	15.632	3.467	0.222	0.362	3.680	37	0.64
04FA001	9010	6.479	1.939	0.299	0.617	3.293	32	0.66
04FA003	4900	9.482	2.579	0.272	0.491	2.525	38	0.57
04DA001	5960	0.576	0.227	0.394	0.913	4.596	44	0.65
04MD004	401	0.651	0.246	0.377	0.196	4.132	20	0.57
04CA003	619	27.401	7.099	0.259	0.085	2.647	31	0.40
04CD001	21100	163.954	46.837	0.286	0.074	2.519	10	0.67
04CC001	94300	2.243	0.766	0.341	0.323	2.710	21	0.62
04JD005	2020	89.552	24.826	0.277	-0.150	3.232	43	0.53
04CA002	36500	2.470	1.028	0.416	0.018	2.980	30	0.54
04DC002	4710	6.624	1.698	0.256	-0.393	3.525	37	0.35
04JC003	3290	40.460	10.302	0.255	0.083	2.080	36	0.55

HYDAT	Drainage Area (km sq)	Mean Drought (m3/s)	Standard Deviation	Coefficient of Variation	Coefficient of Skewness	Coefficient of Kurtosis	Years of Data	7Q20 / 7Q2
04CB001	10800	98.586	22.447	0.228	0.277	2.786	31	0.68
04DC001	50000	3.500	1.108	0.317	0.730	6.021	36	0.68
05PB018	332	0.996	0.363	0.364	-0.258	3.213	26	0.39
05PA012	4510	10.531	4.459	0.423	0.097	2.912	83	0.34
05RC001	5730	9.711	2.168	0.223	-0.592	3.441	22	0.56
05QD006	6370	18.489	8.712	0.471	0.144	2.206	57	0.34
05QE008	1690	4.949	2.091	0.422	0.096	2.014	41	0.46
05QC001	4920	7.726	4.470	0.579	0.917	5.674	45	0.19
05QA002	6230	22.152	7.118	0.321	-0.362	3.182	89	0.43
05QE012	548	1.118	0.571	0.511	0.462	2.706	31	0.40
05PA006	13400	36.613	11.945	0.326	0.499	3.295	88	0.54
05PC019	38600	113.941	41.739	0.366	0.998	5.498	105	0.45
05QA004	4450	14.373	4.058	0.282	0.474	2.471	49	0.69
05PB014	4870	12.953	4.731	0.365	0.109	2.553	87	0.42
05QD016	2300	3.990	3.304	0.828	3.150	16.535	40	0.23
05QA001	13900	49.097	15.191	0.309	-0.443	3.070	60	0.45
05PB015	443	0.401	0.356	0.887	0.443	2.870	11	0.00
05QE009	1530	3.202	1.526	0.477	0.327	2.494	46	0.36
05PC018	50200	144.591	44.784	0.310	0.343	3.046	82	0.52

3 Single Station Flood/Low Flow Frequency Estimation Data Packages

The Single Station Flood/Low Flow Frequency Estimation Data Package and the metadata are stored and distributed through Land Information Ontario (LIO) (http://www.ontario.ca/environment-and-energy/land-information-ontario). In LIO, the metadata information of the package can be accessed through the LIO Metadata Management Tool (https://www.javacoeapp.lrc.gov.on.ca/geonetwork/srv/en/main.home?uuid=1bcabfe3-47ed-461b-ac00-653c365b53f2).

The data is stored in an ESRI 9.3 Personal Geodatabase, "FrequencyAnalysis.mdb". The database consists of a GIS point shapefile named "Gauge.shp" that stores the information of the HYDAT coordinates, one table for flood flow statistics and five tables for low flow statistics. The details are given below:

Table 4. Feature Data Sets Included in the Personal Geodatabase "FrequencyAnalysis.mdb"

Name	**Type**	**Information**
Gauges	Point shapefile	Gauge locations
LIO_FloodFlows	Table	Flood flow statistics
LIO_LowFlow_1Day	Table	Low flow statistics for annual 1 day minimum
LIO_LowFlow_3Day	Table	Low flow statistics for annual 3 day minimum
LIO_LowFlow_7Day	Table	Low flow statistics for annual 7 day minimum
LIO_LowFlow_15Day	Table	Low flow statistics for annual 15 day minimum
LIO_LowFlow_30Day	Table	Low flow statistics for annual 30 day minimum

For practical use, in the ESRI ArcMap GIS environment the shapefile, "Gauges.shp" can be related to the flood/low flow frequency tables. The primary key for all data sets is the HYDAT-ID and the "relate" function will associate the shapefile with the flow statistics tables. See the ArcMap Help for assistance in establishing relationship between tables.

4 Recommended Data Uses and Considerations

4.1 Recommended Data Uses

4.1.1 Ontario Flow Assessment Tools (OFAT III)

The flood/low flow estimates of the HYDAT gauges of the Southwestern Hudson-James Bay and the Nelson River watershed systems will be displayed within the OFAT III web application.

4.1.2 Other Data Uses

The flow statistics data product can be used for a wide range of business uses in Ontario. A list of business uses is provided below in association with the Ministry that administers the business operation:

Ministry of Natural Resources and Forestry

- Approval under the Lakes & Rivers Improvement Act (2010)
  - Sections 14 and 16: Lakes and Rivers Improvement Act (LRIA) 1927 and Ontario Regulation 454/96
- Flooding Hazard Limit
  - Natural Hazard Policies of the Provincial Policy Statement of the Planning Act (2002)
- Adaptive Management
  - Natural Channel System: Adaptive Management of Stream Corridors in Ontario
- Ontario Low Water Response
- Water Budget
  - Section 15 (2) Clean Water Act (2006)
  - Water Budget and Water Quantity Risk Assessment Guide (2011)
- Climate Change
  - Guide for Assessment of Hydrologic Effects of Climate Change in Ontario, 2010

Ministry of Environment

- Permit To Take Water (2007)
    - Section 34: Ontario Water Resources Act, R.S.O. 1990 and Water Taking Regulation O. Reg. 387/04
- Approval of Sewage Works (2010)
    - Section 53: Ontario Water Resources Act R.S.O. 1990
- Peak Flow Rate Criteria
    - Storm Water Management Planning and Design Manual (2003)

Ministry of Transportation

- Design Flood for River and Stream Crossing based on Risk MTO Drainage Management Manual (1997)

4.2 Data Use Considerations

1. The HYDAT gauge locations, coordinates, are snapped to the river network in OFAT III. The drainage area as given by the Water Survey of Canada and that from OFAT III may differ slightly.
2. The flow values in the regulated gauges are not converted to natural flows.
3. The estimated values are only for the HYDAT gauge locations, not for ungauged locations of a river reach.

5 Definitions

Envelope Curves

Envelope curves are used to provide rough estimate of the upper/lower limit of flow to be expected at any point within a region.

Flood Frequency

Flood frequency is the relationship between flood magnitude and the probability that a flood of that size will be exceeded.

Low/Drought Flow Frequency

Flood frequency is the relationship between drought severity and the probability that a drought of that severity will not be exceeded. Probabilities of low flows can be assessed in a manner similar to the way that flood frequencies are expressed.

Mean Annual Flood/Drought

The mean annual flood/drought is the mean of the annual floods observed at a stream gauging station.

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Appendix A: Years of Record for each HYDAT Stream Gauge for Flood Flow Analysis

STATION NAME	HYDAT NO	PERIOD OF RECORD
		1919 1930 1940 1950 1960 1970 1980 1990 2000 2010
ABITIBI RIVER AT ONAKAWANA	04ME003	##$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$############$$$
ALBANY RIVER BELOW ACHAPI LAKE	04GC002	##$$$$$$$$$$$$$$$$#########################$$$
ALBANY RIVER NEAR HAT ISLAND	04HA001	##$$$$$$$$$$$$$$$$$$$$$$$$$$$$$####$$#$$$$$$$$$$
ASHEWEIG RIVER ABOVE LONG DOG LAKE	04DB002	###$$$$$$$$$$###################################
ASHEWEIG RIVER AT STRAIGHT LAKE	04DB001	##$$$$$$$$$$$$$$$$$$$$$$$$$$$$$#####$$$$$#$$$$$$
ATIKOKAN RIVER AT ATIKOKAN	05PB018	##$$$$$$$$$$$$$$$$$$$$$$$$$$$$
ATTAWAPISKAT RIVER BELOW ATTAWAPISKAT LAKE	04FB001	###$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$#################
ATTAWAPISKAT RIVER BELOW MUKETEI RIVER	04FC001	##$$$$$$$$$$$$$$$$$$$$$$$$$$$####$$$$$#$#$$$$$
BASSWOOD RIVER NEAR WINTON	05PA012	###########$$$
BERENS RIVER ABOVE BERENS LAKE	05RC001	##$$$$$$$$$$$$$$$$$$###########$$$
BRIGHTSAND RIVER AT MOBERLEY	04GB005	###$$$$$$$$$$$$$$$$$$$###############$$$
CAT RIVER BELOW WESLEYAN LAKE	04GA002	##$$$$$$$$$$$$$$$$$$$$$$$$
CEDAR RIVER BELOW WABASKANG LAKE	05QE008	##$$
CHUKUNI RIVER NEAR EAR FALLS	05QC001	###$$$
ENGLISH RIVER AT UMFREVILLE	05QA002	###$$$
ENGLISH RIVER NEAR SIOUX LOOKOUT	05QA001	###$$#############################
FAWN RIVER BELOW BIG TROUT LAKE	04CE002	##$$$$$$$$$$$$$$$$$$$$$$$$####################
GROUNDHOG RIVER AT FAUQUIER	04LD001	##$$$##############$$$
HALFWAY CREEK AT MOOSONEE	04KA002	###$$$$$$$$$$$$$$$$$$$$$##############
IVANHOE RIVER AT FOLEYET	04LC003	##$$$$$$$$$$
KABINAKAGAMI RIVER AT HIGHWAY NO. 11	04JA002	#################################$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$#########################
KAMISKOTIA RIVER ABOVE ENID CREEK	04LB002	##$$
KAPUSKASING RIVER AT KAPUSKASING	04LF001	$$###############$$$
KAWINOGANS RIVER NEAR PICKLE CROW	04FA002	###$$$$$$$$$$$$$$$$$$$$$$$$$$$##################
KENOGAMI RIVER NEAR MAMMAMATTAWA	04JG001	###$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$##############$$$
KWATABOAHEGAN RIVER NEAR THE MOUTH	04KA001	##$$
LA VALLEE RIVER NEAR BURRISS	05PC022	##$$$$
LITTLE CURRENT RIVER AT PERCY LAKE	04JF001	##$$$$$$$$$$$$$$$$$$$$$$$$$$$##############$$$
LONG-LEGGED RIVER BELOW LONG-LEGGED LAKE	05QE012	##$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

STATION NAME	HYDAT NO
MATTAGAMI RIVER NEAR TIMMINS	04LA002
MATTAWISHKWIA RIVER AT HEARST	04LK001
MISSINAIBI RIVER AT MATTICE	04LJ001
MISSINAIBI RIVER BELOW WABOOSE RIVER	04LM001
MOLLIE RIVER AT HIGHWAY NO. 144	04LA006
MOOSE RIVER ABOVE MOOSE RIVER	04LG004
MUSWABIK RIVER AT OUTLET OF MUSWABIK LAKE	04GF001
NAGAGAMI RIVER AT HIGHWAY NO. 11	04JC002
NAMAKAN RIVER AT OUTLET OF LAC LA CROIX	05PA006
NEMEGOSENDA RIVER NEAR CHAPLEAU	04LE002
NORTH FRENCH RIVER NEAR THE MOUTH	04MF001
OGOKI RIVER ABOVE WHITECLAY LAKE	04GB004
OTOSKWIN RIVER BELOW BADESDAWA LAKE	04FA001
PAGWACHUAN RIVER AT HIGHWAY NO. 11	04JD005
PINEIMUTA RIVER AT EYES LAKE	04FA003
PINEWOOD RIVER AT HIGHWAY NO. 617	05PC023
PIPESTONE RIVER ABOVE RAINY LAKE	05PB015
PIPESTONE RIVER AT KARL LAKE	04DA001
PORCUPINE RIVER AT HOYLE	04MD004
RAINY RIVER AT FORT FRANCES	05PC019
RAINY RIVER AT MANITOU RAPIDS	05PC018
ROSEBERRY RIVER ABOVE ROSEBERRY LAKES	04CA003
SACHIGO RIVER BELOW BEAVERSTONE RIVER	04CD001
SEINE RIVER AT STURGEON FALLS G. STATION	05PB009
SEVERN RIVER AT LIMESTONE RAPIDS	04CC001
SEVERN RIVER AT OUTLET OF MUSKRAT DAM LAKE	04CA002
SHAMATTAWA RIVER AT OUTLET OF SHAMATTAWA LAKE	04DC002
SHEKAK RIVER AT HIGHWAY NO. 11	04JC003
STURGEON RIVER AT MCDOUGALL MILLS	05QA004
STURGEON RIVER AT OUTLET OF SALVESEN LAKE	05QE009
TATACHIKAPIKA RIVER NEAR TIMMINS	04LA003

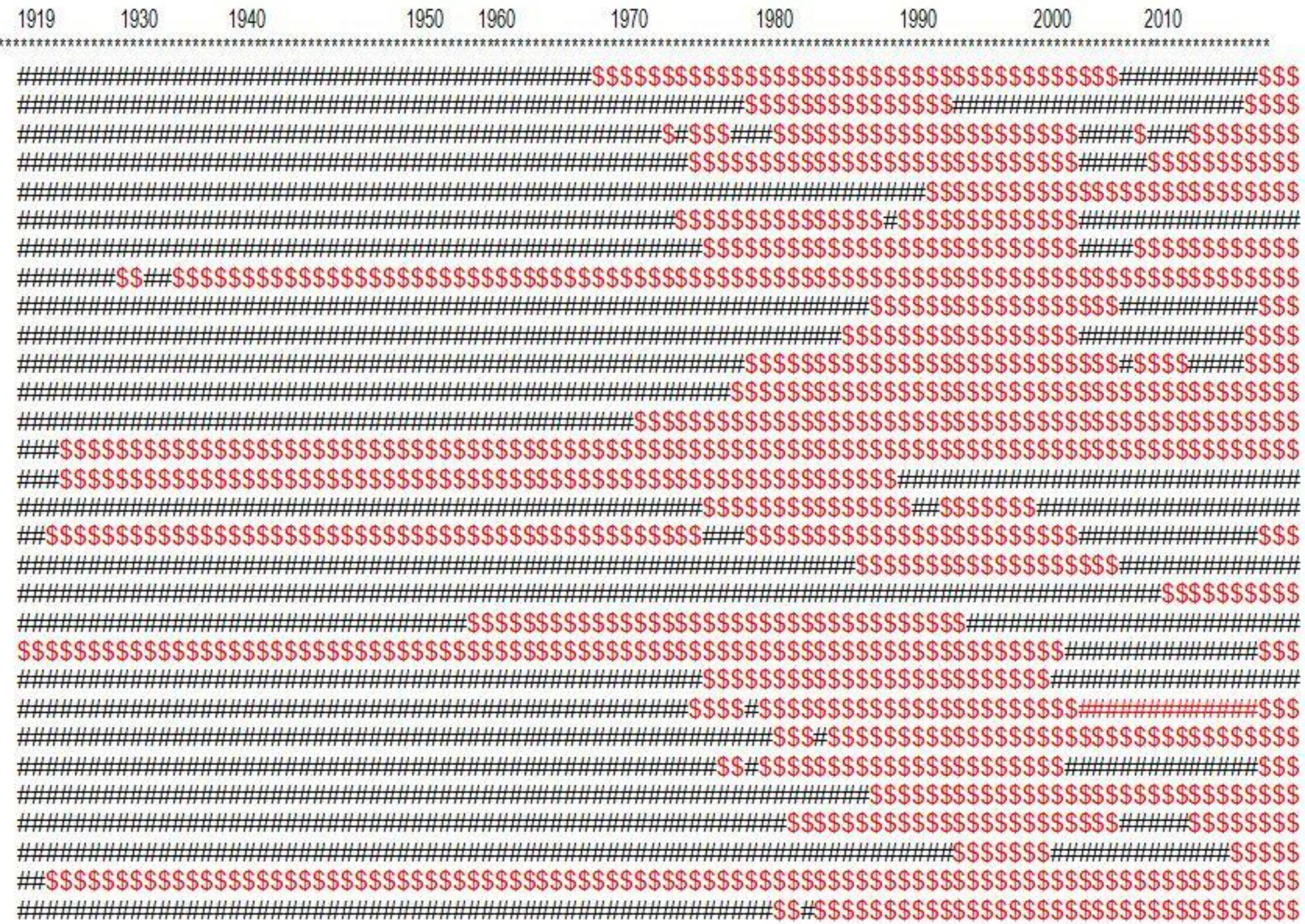
PERIOD OF RECORD

STATION NAME	HYDAT NO	PERIOD OF RECORD
		1919 1930 1940 1950 1960 1970 1980 1990 2000 2010
TURTLE RIVER NEAR MINE CENTRE	05PB014	##$$
WABIGOON RIVER AT DRYDEN	05QD016	##$$
WABIGOON RIVER NEAR QUIBELL	05QD006	##$$
WINDIGO RIVER ABOVE MUSKRAT DAM LAKE	04CB001	##$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$############$$$
WINISK RIVER AT KANUCHUAN RAPIDS	04DA002	###$$$$$$$$$$###
WINISK RIVER BELOW ASHEWEIG RIVER TRIBUTARY	04DC001	##$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$#####$$$$$$#$#$$$

Note:
#: No record
$: With Record

Appendix B: Years of Record for each HYDAT Stream Gauge for Drought Flow Analysis

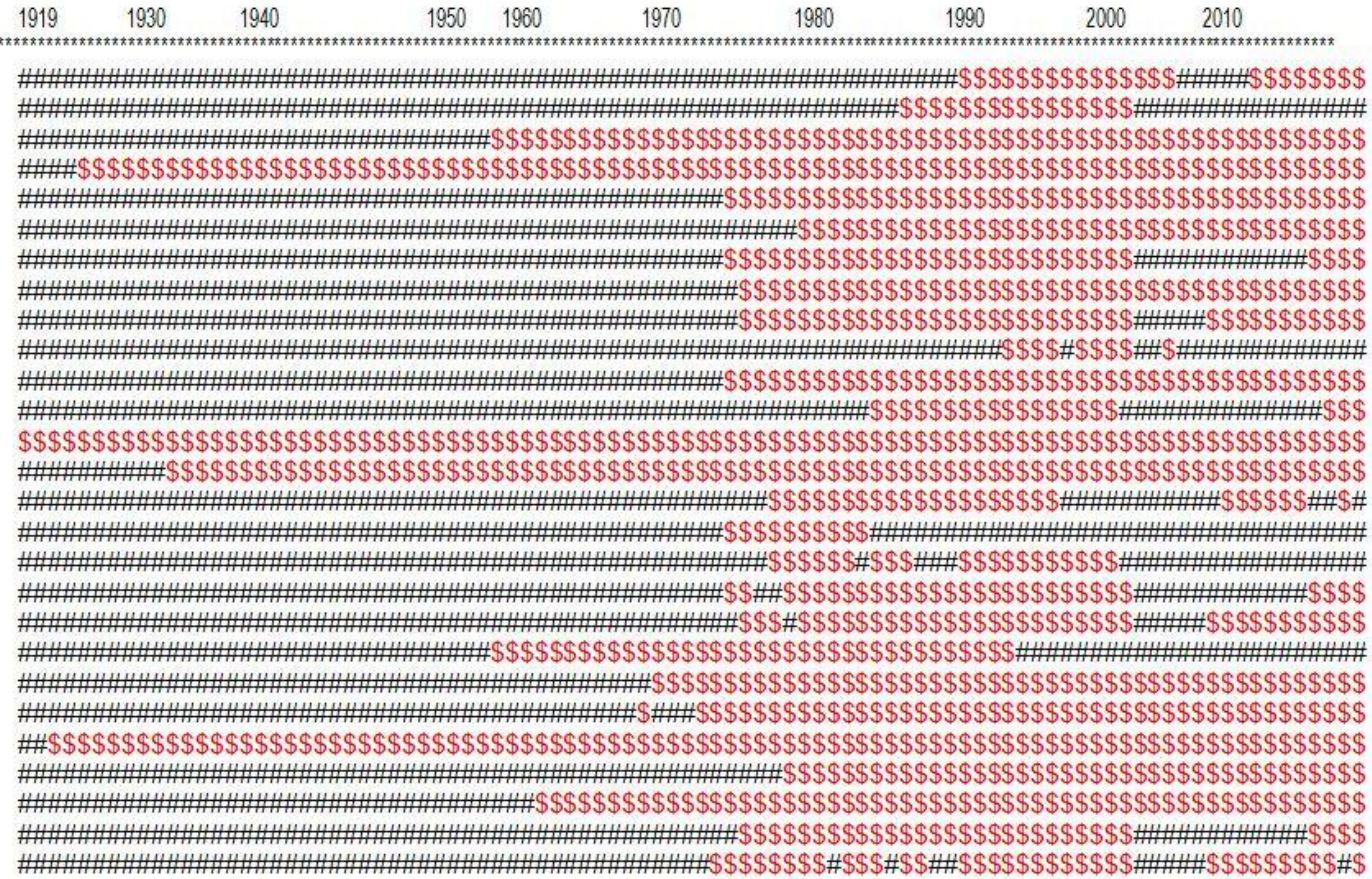
PERIOD OF RECORD



STATION NAME	HYDAT NO
ABITIBI RIVER AT ONAKAWANA	04ME003
ALBANY RIVER BELOW ACHAPI LAKE	04GC002
ALBANY RIVER NEAR HAT ISLAND	04HA001
ASHEWEIG RIVER AT STRAIGHT LAKE	04DB001
ATIKOKAN RIVER AT ATIKOKAN	05PB018
ATTAWAPISKAT RIVER BELOW ATTAWAPISKAT LAKE	04FB001
ATTAWAPISKAT RIVER BELOW MUKETEI RIVER	04FC001
BASSWOOD RIVER NEAR WINTON	05PA012
BERENS RIVER ABOVE BERENS LAKE	05RC001
BRIGHTSAND RIVER AT MOBERLEY	04GB005
CAT RIVER BELOW WESLEYAN LAKE	04GA002
CEDAR RIVER BELOW WABASKANG LAKE	05QE008
CHUKUNI RIVER NEAR EAR FALLS	05QC001
ENGLISH RIVER AT UMFREVILLE	05QA002
ENGLISH RIVER NEAR SIOUX LOOKOUT	05QA001
FAWN RIVER BELOW BIG TROUT LAKE	04CE002
GROUNDHOG RIVER AT FAUQUIER	04LD001
HALFWAY CREEK AT MOOSONEE	04KA002
IVANHOE RIVER AT FOLEYET	04LC003
KABINAKAGAMI RIVER AT HIGHWAY NO. 11	04JA002
KAPUSKASING RIVER AT KAPUSKASING	04LF001
KAWINOGANS RIVER NEAR PICKLE CROW	04FA002
KENOGAMI RIVER NEAR MAMMAMATTAWA	04JG001
KWATABOAHEGAN RIVER NEAR THE MOUTH	04KA001
LITTLE CURRENT RIVER AT PERCY LAKE	04JF001
LONG-LEGGED RIVER BELOW LONG-LEGGED LAKE	05QE012
MATTAGAMI RIVER NEAR TIMMINS	04LA002
MATTAWISHKWIA RIVER AT HEARST	04LK001
MISSINAIBI RIVER AT MATTICE	04LJ001
MISSINAIBI RIVER BELOW WABOOSE RIVER	04LM001

STATION NAME	HYDAT NO
MOOSE RIVER ABOVE MOOSE RIVER	04LG004
MUSWABIK RIVER AT OUTLET OF MUSWABIK LAKE	04GF001
NAGAGAMI RIVER AT HIGHWAY NO. 11	04JC002
NAMAKAN RIVER AT OUTLET OF LAC LA CROIX	05PA006
NORTH FRENCH RIVER NEAR THE MOUTH	04MF001
OGOKI RIVER ABOVE WHITECLAY LAKE	04GB004
OTOSKWIN RIVER BELOW BADESDAWA LAKE	04FA001
PAGWACHUAN RIVER AT HIGHWAY NO. 11	04JD005
PINEIMUTA RIVER AT EYES LAKE	04FA003
PIPESTONE RIVER ABOVE RAINY LAKE	05PB015
PIPESTONE RIVER AT KARL LAKE	04DA001
PORCUPINE RIVER AT HOYLE	04MD004
RAINY RIVER AT FORT FRANCES	05PC019*
RAINY RIVER AT MANITOU RAPIDS	05PC018
ROSEBERRY RIVER ABOVE ROSEBERRY LAKES	04CA003
SACHIGO RIVER BELOW BEAVERSTONE RIVER	04CD001
SEVERN RIVER AT LIMESTONE RAPIDS	04CC001
SEVERN RIVER AT OUTLET OF MUSKRAT DAM LAKE	04CA002
SHAMATTAWA RIVER AT OUTLET OF SHAMATTAWA LAKE	04DC002
SHEKAK RIVER AT HIGHWAY NO. 11	04JC003
STURGEON RIVER AT MCDOUGALL MILLS	05QA004
STURGEON RIVER AT OUTLET OF SALVESEN LAKE	05QE009
TURTLE RIVER NEAR MINE CENTRE	05PB014
WABIGOON RIVER AT DRYDEN	05QD016
WABIGOON RIVER NEAR QUIBELL	05QD006
WINDIGO RIVER ABOVE MUSKRAT DAM LAKE	04CB001
WINISK RIVER BELOW ASHEWEIG RIVER TRIBUTARY	04DC001

PERIOD OF RECORD



Note:
#: No record
$: With record
* year starts at 1906