ANNEX 1-E

FREDERICK HOUSE RIVER AT WANATANGO FALLS
HYDROLOGIC ANALYSES MEMORANDUM

HATCH™

Project Memo

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cc: H337950

Xeneca Power Development Inc.
Wanatango Falls Hydro Project

EA Hydrology Memo

1. Introduction

This memorandum presents the information requested by the Ministry of the Environment (MOE), under Hydrological Analysis, items a) to g) of Table 1, for the proposed Wanatango Falls Hydro Project on the Frederick House River. Wanatango Falls is located a short distance downstream of Frederick House Lake in Cochrane District of the Northeast Region of Ontario. The Frederick House River is regulated by Ontario Power Generation at Frederick House Lake and drains 2970 km^2 at Wanatango Falls.

Figure 1 shows details of the sub-basins draining to Wanatango Falls, while Figure 2 shows the hydrometeorological and hydrological station networks in the region.

A full listing of the hydrology requirements and the location in this document where they can be found area given in Appendix A. The stepwise procedures used to synthesize a long term daily flow series at Wanatango Falls and the software used to extract the information presented herein are listed in Appendix B.

Table 1 lists the information required by the MOE under Hydrological Analysis (as per project correspondence).

These analyses of existing data have been undertaken in support of the ongoing Environmental Assessment process and should not be used in the detailed engineering design without further review.

Seasons are defined as:

Winter	January 1 to March 31	Julian Day 1 to 90
Spring	April 1 to June 30	Julian Day 91 to 181
Summer	July 1 to September 30	Julian Day 182 to 273
Fall	October 1 to December 31	Julian Day 274 to 365

Table 1 Information Required under Hydrological Analysis

a)	Descriptive flow statistics using all available daily flows for all years: mean, median, minimum, maximum, flow exceeded 20% time, flow exceeded 80% time.
b)	Extreme low flow statistics: 7Q2 (2 year return period 7-day-average-low flow), 7Q10 (10 year return period 7-day-average-low flow) and 7Q20 (20 year return period 7-day-average-low flow).
c)	Flow duration curves and tables using total daily average flow data for the entire period, for all four seasons and for all twelve months.
d)	Flow duration curves and tables using daily baseflow data for the entire period, for all four seasons and for all twelve months.
e)	Flow duration curves derived using both the percentile method and the median of percentiles method. Both methods are incorporated into the flow analysis tool, developed by Schmidt and Metcalfe (2009), which can be downloaded for free from http://trentu.ca/iws/software.php.
f)	Flood frequency analysis using instantaneous maximum flow of each year for the entire period of records.
g)	Low flow frequency analysis using 7-day-average-low flow for the entire period of records.
h)	Altered flow of the bypass reach and the reach below tailrace, if applicable.
i)	Compensation flow for the bypass reach and the reach below tailrace, if applicable.

2. Descriptive Flow Statistics

Descriptive flow statistics for the Frederick House River at Wanatango Falls have been prepared using the Streamflow Analysis and Assessment Software (SAAS) from the Ontario Ministry of Natural Resources (MNR). Synthesis of the long term daily flow series for 1939-94 is described in *Wanatango Falls Hydropower Site – Hydrology Review*, Hatch (2009). The Water Survey of Canada streamflow station 04MD002, Frederick House River at Frederick House Dam, reported flows from 1939 to 1994, to give 56 years of data.

Figure 3 shows the superimposed daily hydrographs from these 56 years as well as for the median of each day of the year.

Table 2 shows the descriptive flow statistics using all available daily flows for all years.

Table 2 Descriptive Mean Daily Flow Statistics for Wanatango Falls

Parameter	Value	Units	Date of Occurrence
Mean Flow	33.2	m^3/s	-
Median Flow	27.0	m^3/s	-
Minimum Flow	0.027	m^3/s	9/1/1975
Maximum Flow	442	m^3/s	5/12/1960
Flow Exceeded 20% time	49.9	m^3/s	-
Flow Exceeded 80% time	4.95	m^3/s	-
Number of Zero Flow Days	0	-	-

It should be noted that 98% of the drainage area to Wanatango Falls is regulated by OPG at Frederick House Dam. This means that the flows reaching Wanatango Falls are not "natural" flows.

For example, the Very Low Minimum Flow in Table 2 is the result of zero outflow from Frederick House Dam and local inflow from only 64 km^2.

3. Extreme Low Flow Statistics

Low flow frequency analysis of 7-day average low flows has been undertaken using the Engsoft Low Flow Frequency Analysis software ESLOFFAN. This software reads the full daily flow series for Wanatango Falls and creates a 7-day (or 30-day) average flow series. The annual minima of this average flow series are then extracted for low flow frequency analysis using the 2-parameter Lognormal, 3-parameter Lognormal, Log Pearson III and Gumbel distributions.

Table 3 shows the annual 7-day average flow minima for the Frederick House River at Wanatango Falls.

Table 4 show $7Q_{T\text{-year}}$ extreme low flow statistics from the frequency analyses.

The four frequency distributions shown in Table 4 give similar annual 7-day average flow minima for the $7Q_2$, $7Q_{10}$ and $7Q_{20}$ extreme low flow statistics. The 3-parameter Lognormal distribution appears to give the best fit to the data in Table 3. The extreme low flow estimates from the 3-parameter Lognormal distribution are:

- $7Q_2$ 0.430 m^3/s
- $7Q_{10}$ 0.138 m^3/s
- $7Q_{20}$ 0.111 m^3/s

Table 3 Annual 7-day Average Flow Minima – Frederick House River at Wanatango Falls

Year	Month	7-day Average Flow (m^3/s)
1939	4	0.20
1940	8	0.20
1941	4	1.40
1942	9	1.20
1943	7	1.09
1944	8	2.33
1945	8	2.34
1946	4	1.01
1947	10	1.06
1948	11	0.84
1949	9	0.31
1950	1	0.50
1951	10	0.87
1952	11	0.50
1953	9	0.16
1954	8	0.54
1955	9	0.10
1956	9	1.01
1957	10	0.39
1958	8	0.33
1959	8	0.20
1960	11	1.84

Year	Month	7-day Average Flow (m^3/s)
1961	4	0.41
1962	10	0.37
1963	3	0.17
1964	7	1.93
1965	4	0.83
1966	7	0.37
1967	10	0.90
1968	8	0.70
1969	7	2.66
1970	4	0.60
1971	4	0.40
1972	10	0.77
1973	4	0.60
1974	4	0.47
1975	8	0.10
1976	11	0.19
1977	8	0.10
1978	4	1.54
1979	10	0.69
1980	1	0.20
1981	4	1.40
1982	4	0.29
1983	4	0.20
1984	9	0.10
1985	4	0.10
1986	3	0.30
1987	4	0.10
1988	4	1.67
1989	4	2.73
1990	4	0.46
1991	7	0.10
1992	4	0.27
1993	4	0.24
1994	4	0.99

Table 4 7-day Average Extreme Low Flow Statistics – Frederick House River at Wanatango Falls

Return Period (years)	Minimum 7-day Average Low Flow (m^3/s)			
	2 Parameter LogNormal	3 Parameter LogNormal	Log Pearson Type III	Gumbel
2	0.482	**0.430**	0.546	0.611
5	0.214	0.192	0.217	0.245
10	0.139	**0.138**	0.103	0.089
20	0.098	**0.111**	0.030	-
50	0.066	0.093	-	-
100	0.051	0.085	-	-

4. Total Daily Average Flow Duration Curves

SAAS v2.1.1 has been used to generate flow duration curves using total daily flow for the entire period of record, for all four seasons and for all twelve months. These flow duration curves are shown in Figures 4 to 6, respectively.

The flow duration analysis results used to prepare Figures 4 to 6 are given in Tables 5 and 6.

Table 5 Total Daily Average Flow Duration Analysis for All Four Seasons and the Period of Record

Percent of Time Exceeded	Total Daily Average Flow (m^3/s)				
	Winter	Spring	Summer	Fall	Period of Record
0.01	172	441	366	292	418
0.1	109	376	237	263	328
1	85.6	249	124	144	173
2	79.4	203	93.6	105	139
3	75.8	178	85.7	95.3	118
4	73.2	163	78.4	86.5	102
5	71.1	153	68.6	77.1	91.7
6	69.5	140	62.4	72.4	84.0
7	68.2	133	59.3	69.0	77.7
8	66.4	126	56.4	64.9	72.9
9	64.8	119	53.1	61.9	70.0
10	63.5	113	49.8	58.5	67.2
11	62.1	107	47.2	56.1	64.7
12	60.5	101	44.9	53.5	62.1
13	59.8	93.9	43.0	51.5	59.8
14	59.0	90.0	41.1	49.5	58.1
15	58.1	85.6	39.6	48.4	56.5
16	57.2	80.9	38.2	46.9	55.0
17	56.5	75.7	36.8	46.2	53.6
18	55.6	72.2	35.1	45.2	52.3
19	55.0	69.7	33.9	44.4	51.1

Percent of Time Exceeded	Total Daily Average Flow (m^3/s)				
	Winter	Spring	Summer	Fall	Period of Record
20	54.3	66.9	32.7	43.7	49.9
21	53.9	64.6	31.3	42.8	48.8
22	53.2	62.0	30.0	42.2	47.9
23	52.5	59.3	28.8	41.7	47.0
24	51.9	57.2	27.9	41.0	46.2
25	51.3	55.4	26.9	40.4	45.2
26	50.8	53.9	26.1	39.7	44.6
27	50.2	52.2	25.4	39.3	43.7
28	49.9	50.6	24.6	38.7	42.9
29	49.4	49.5	24.2	38.2	42.1
30	48.8	48.1	23.4	37.6	41.5
31	48.3	47.1	23.1	37.1	40.6
32	48.0	46.0	22.6	36.4	39.8
33	47.4	44.6	22.0	35.7	39.2
34	47.1	43.3	21.1	35.0	38.4
35	46.6	42.2	20.6	34.2	37.7
36	46.1	40.6	20.2	33.6	37.0
37	45.7	39.0	19.6	33.0	36.2
38	45.3	37.1	19.1	32.5	35.6
39	44.8	36.0	18.3	31.6	34.9
40	44.6	35.0	17.6	31.3	34.1
41	44.2	34.0	16.8	30.6	33.4
42	43.7	32.8	16.4	30.2	32.8
43	43.2	31.7	15.8	29.7	32.0
44	42.9	30.2	14.7	29.2	31.3
45	42.4	29.1	14.2	28.6	30.5
46	42.1	28.1	13.7	28.4	29.8
47	41.7	26.7	12.9	28.0	29.1
48	41.4	25.3	12.5	27.7	28.4
49	41.0	24.0	12.2	27.0	27.9
50	40.6	23.4	11.4	26.5	27.0
51	40.3	22.5	11.0	26.0	26.3
52	39.6	21.2	10.5	25.7	25.7
53	39.2	20.1	10.1	25.3	25.0
54	38.9	19.1	9.91	24.7	24.3
55	38.2	18.3	9.59	24.1	23.5
56	37.9	17.4	9.09	23.6	22.8
57	37.5	16.6	8.71	23.0	22.2
58	37.0	15.8	8.31	22.4	21.2
59	36.7	15.1	7.90	21.9	20.5
60	36.4	14.3	7.70	21.1	19.7
61	35.9	13.5	7.24	20.5	19.1

Percent of Time Exceeded	Total Daily Average Flow (m^3/s)				
	Winter	Spring	Summer	Fall	Period of Record
62	35.8	12.6	6.85	19.7	18.1
63	35.2	11.2	6.59	19.2	17.2
64	34.9	10.4	6.12	18.6	16.4
65	34.6	9.73	5.84	17.8	15.6
66	34.1	8.88	5.59	17.2	14.8
67	33.6	8.33	5.20	16.1	14.1
68	33.2	7.46	4.95	15.5	13.4
69	32.8	6.95	4.72	14.8	12.6
70	32.4	6.39	4.50	14.2	11.5
71	32.0	6.00	4.20	13.7	10.7
72	31.5	5.65	3.88	13.1	9.95
73	30.9	5.26	3.46	12.6	9.28
74	30.5	4.86	3.17	11.5	8.41
75	29.9	4.46	3.03	10.7	7.85
76	29.5	4.07	2.71	9.76	7.15
77	28.8	3.81	2.56	9.11	6.60
78	28.4	3.51	2.36	8.13	5.97
79	27.9	3.28	2.13	7.28	5.49
80	27.2	3.03	1.93	6.54	4.95
81	26.7	2.85	1.66	6.02	4.49
82	26.0	2.65	1.41	4.82	3.99
83	25.1	2.47	1.24	4.11	3.52
84	24.6	2.31	1.13	3.57	3.12
85	23.2	2.09	0.910	3.21	2.81
86	22.2	1.90	0.783	2.72	2.48
87	21.2	1.72	0.697	2.32	2.19
88	20.1	1.53	0.603	1.92	1.89
89	18.9	1.36	0.528	1.61	1.62
90	17.0	1.19	0.439	1.42	1.34
91	16.2	1.03	0.376	1.21	1.15
92	14.8	0.927	0.337	1.09	0.978
93	13.8	0.816	0.273	0.975	0.818
94	10.7	0.688	0.223	0.858	0.667
95	7.74	0.568	0.185	0.758	0.531
96	5.63	0.455	0.158	0.620	0.394
97	4.23	0.322	0.118	0.509	0.279
98	1.81	0.214	0.0940	0.379	0.191
99	0.352	0.182	0.0600	0.240	0.126
99.9	0.101	0.110	0.0270	0.135	0.0340

Table 6 Total Daily Average Flow Duration Analysis for All Twelve Months of the Year

Percent of Time Exceeded	Total Daily Average Flow (m^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.01	172	87.1	121	373	442	253	367	251	235	235	292	120
0.1	96.7	84.2	112	371	424	251	350	187	227	231	285	114
1	84.0	77.5	95.9	203	307	178	142	94.4	122	157	156	91.5
2	78.9	75.1	86.8	154	258	163	115	86.5	86.3	136	106	69.4
3	73.5	73.0	81.5	132	223	152	96.9	68.2	81.0	116	93.8	62.5
4	68.7	71.3	77.7	124	207	143	90.7	57.9	71.9	102	88.2	57.9
5	65.2	69.9	75.3	108	191	134	84.2	52.7	64.8	97.8	80.0	54.5
6	63.3	68.4	73.2	100.0	181	122	79.4	47.4	61.9	91.6	73.7	52.7
7	61.3	66.9	71.7	90.7	174	114	73.5	44.3	59.7	85.3	69.7	49.8
8	60.0	65.3	70.2	82.3	165	108	66.6	41.5	58.1	79.2	66.5	48.7
9	59.0	63.6	69.5	75.8	158	102	62.4	39.7	56.4	73.2	64.4	46.8
10	58.1	62.4	68.5	68.4	152	96.8	58.6	38.5	55.2	72.5	62.0	46.2
11	57.3	61.3	67.6	64.3	140	91.7	53.4	35.2	53.1	70.1	59.0	45.1
12	57.0	60.3	66.2	60.1	137	87.5	49.2	33.3	51.4	68.3	56.7	44.3
13	56.0	59.6	65.5	56.8	132	84.4	47.0	31.1	49.6	63.7	51.7	43.6
14	55.5	58.8	64.7	54.3	128	81.2	45.3	29.0	47.4	61.6	49.9	42.7
15	54.9	57.9	63.2	52.5	124	74.9	44.3	28.0	45.4	58.8	48.8	42.0
16	54.2	56.8	61.8	50.6	120	70.5	42.8	26.8	42.6	57.0	47.2	41.6
17	53.4	56.2	60.4	49.1	116	67.8	41.3	25.7	40.3	55.5	46.4	41.1
18	52.8	55.6	59.8	47.7	113	64.6	40.2	24.5	39.2	54.0	45.9	40.7
19	52.2	55.0	59.1	46.3	108	61.1	39.3	23.8	37.7	52.3	44.6	40.1
20	51.4	54.6	58.1	44.7	104	59.2	37.7	23.1	37.0	50.6	43.9	39.7
21	50.7	54.0	57.3	43.2	98.1	57.2	35.8	22.7	35.8	48.8	43.7	39.5
22	50.1	53.3	56.5	41.7	93.7	55.8	34.3	22.5	35.0	48.0	43.4	39.2
23	49.6	52.7	55.3	40.5	89.9	54.0	33.2	22.0	33.9	46.9	42.4	38.9
24	48.8	52.2	54.8	39.1	86.1	52.4	32.2	21.0	33.0	45.8	42.1	38.7
25	47.9	51.4	54.0	37.5	82.4	51.3	31.2	20.9	32.0	44.7	41.8	38.4
26	47.2	51.1	53.3	36.4	78.5	50.0	29.6	20.4	31.2	43.9	41.2	38.1
27	46.6	50.5	52.5	35.2	75.6	49.2	28.4	20.2	29.8	42.7	40.7	37.8
28	46.0	50.0	51.9	34.2	72.9	47.8	27.3	19.3	29.3	41.9	40.2	37.5
29	45.5	49.9	51.4	33.0	71.3	47.1	26.6	19.0	28.2	39.9	39.7	37.2
30	45.0	49.5	51.1	31.3	70.1	46.6	25.9	18.2	27.4	38.6	39.0	36.9
31	44.7	49.1	50.6	29.9	68.9	45.0	25.1	17.7	26.5	37.5	38.2	36.4
32	44.3	48.5	49.9	28.8	67.4	44.3	24.7	17.2	25.9	36.3	37.2	36.1
33	43.8	48.3	49.4	27.9	65.7	43.1	24.4	16.6	25.5	35.1	36.4	35.6
34	43.2	48.0	49.1	26.3	64.0	42.3	23.9	16.3	24.7	33.6	35.6	35.0
35	42.9	47.7	48.8	25.6	62.2	40.7	23.4	15.7	24.2	32.4	34.6	34.7
36	42.4	47.4	48.2	24.2	60.5	39.8	23.2	14.7	23.1	31.1	33.8	34.2
37	42.0	47.1	48.0	23.4	58.3	37.9	22.8	13.8	22.5	29.9	33.4	33.8
38	41.7	46.8	47.4	22.7	56.9	36.3	22.5	13.4	21.7	28.9	32.7	33.4
39	41.2	46.4	46.9	22.2	55.1	35.5	21.3	12.8	20.9	28.4	31.7	33.0

Percent of Time Exceeded	Total Daily Average Flow (m^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
40	40.7	46.0	46.5	21.2	53.9	35.1	20.8	12.4	19.6	27.8	31.3	32.9
41	40.4	45.9	46.1	20.3	52.8	34.1	20.5	12.3	19.1	27.1	30.7	32.4
42	40.3	45.5	45.5	19.7	51.1	33.3	20.1	11.8	18.0	26.7	30.2	31.7
43	39.6	45.2	45.1	18.9	49.5	32.5	19.7	11.1	17.3	26.1	29.7	31.6
44	39.3	44.7	44.6	18.1	48.2	32.1	19.2	10.9	16.4	25.6	29.5	31.3
45	39.1	44.6	44.3	17.4	47.1	30.6	18.6	10.6	15.8	25.0	28.7	30.8
46	38.4	44.3	43.7	16.7	46.1	29.1	17.7	10.2	14.9	24.6	28.3	30.4
47	38.1	43.7	43.1	16.1	44.8	28.5	17.1	10.1	14.4	24.1	27.7	30.2
48	37.9	43.4	42.6	15.7	43.0	27.6	16.6	9.96	14.0	23.6	26.8	29.9
49	37.7	43.1	42.3	15.1	41.8	26.9	16.0	9.73	12.8	22.9	26.2	29.6
50	37.3	43.0	42.1	14.2	39.4	25.7	14.7	9.62	12.1	22.5	25.8	29.1
51	37.0	42.6	41.7	12.9	37.2	24.9	14.1	9.08	11.3	22.3	25.1	28.8
52	36.7	42.1	41.3	12.3	35.6	23.9	13.7	8.82	11.0	21.4	24.4	28.5
53	36.5	41.8	40.9	11.1	34.3	23.2	13.4	8.34	10.5	20.8	23.8	28.4
54	36.2	41.4	40.3	10.2	32.5	22.2	12.9	7.96	10.1	20.5	23.0	28.3
55	36.0	41.1	39.5	9.70	31.1	21.4	12.5	7.70	9.93	19.9	22.2	28.2
56	35.8	40.6	39.2	8.95	29.5	20.5	12.3	7.17	9.16	19.2	21.3	27.9
57	35.3	40.3	38.7	8.59	28.2	19.8	11.3	6.73	9.04	18.8	20.5	27.4
58	35.1	39.9	38.0	8.38	25.5	18.7	10.2	6.26	8.35	18.3	20.3	26.9
59	34.8	39.5	37.6	7.28	23.8	18.3	9.87	5.93	8.10	17.3	19.3	26.5
60	34.6	39.1	37.0	6.97	22.5	17.5	9.49	5.81	7.71	16.1	18.2	26.0
61	34.2	38.6	36.6	6.36	20.7	16.9	8.93	5.62	7.69	15.5	17.6	25.7
62	33.7	37.9	36.1	5.82	18.6	16.5	8.39	5.34	7.39	14.5	16.5	25.5
63	33.3	37.6	35.8	5.26	16.1	15.8	8.09	5.05	6.99	14.0	16.0	25.4
64	32.8	36.9	35.2	4.82	14.2	15.2	7.79	4.73	6.72	13.0	15.3	25.0
65	32.5	36.6	34.6	4.31	13.0	14.9	7.31	4.51	6.51	12.7	14.4	24.3
66	32.0	36.1	34.1	3.96	11.8	14.3	6.85	4.23	6.01	11.9	14.1	23.7
67	31.6	35.8	33.5	3.81	10.6	13.8	6.44	3.99	5.69	11.2	13.7	23.5
68	31.2	35.2	32.8	3.53	9.70	13.4	6.09	3.62	5.07	10.0	13.5	23.0
69	30.8	34.9	32.1	3.34	8.79	11.9	5.77	3.23	4.86	8.80	13.2	22.7
70	30.1	34.6	31.8	3.00	7.92	11.0	5.38	3.11	4.32	8.12	12.8	22.1
71	29.9	34.2	30.7	2.82	7.20	10.0	5.15	2.79	4.11	7.49	12.2	21.4
72	29.4	33.9	29.9	2.63	6.77	9.76	4.93	2.63	3.47	6.92	11.2	19.9
73	28.8	33.5	29.3	2.43	6.23	8.65	4.81	2.43	3.17	6.24	10.7	19.3
74	28.4	33.2	28.7	2.26	5.74	7.67	4.64	2.25	3.04	5.88	10.2	19.1
75	28.1	32.9	28.1	2.10	5.29	7.07	4.53	2.05	2.70	4.92	9.54	18.2
76	27.7	32.7	27.5	1.92	5.00	6.71	4.32	1.84	2.45	4.02	9.12	17.8
77	27.3	32.4	26.9	1.77	4.71	6.25	4.01	1.52	2.21	3.50	8.34	17.4
78	26.9	32.1	25.8	1.63	4.33	6.02	3.60	1.26	2.03	3.05	7.92	16.9
79	26.5	31.5	24.9	1.48	4.08	5.69	3.27	1.19	1.80	2.72	6.75	15.6
80	26.0	31.2	23.8	1.32	3.82	5.49	3.11	1.13	1.52	2.34	5.73	15.0
81	25.3	30.7	22.2	1.20	3.58	5.17	2.90	0.947	1.38	2.09	4.55	14.6

Percent of Time Exceeded	Total Daily Average Flow (m^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
82	25.0	30.4	21.6	1.07	3.40	4.78	2.68	0.843	1.26	1.79	4.19	14.2
83	24.2	30.1	20.4	0.979	3.17	4.09	2.51	0.782	1.14	1.50	3.77	13.1
84	23.3	29.8	19.6	0.851	3.04	3.73	2.27	0.727	0.928	1.40	3.55	10.8
85	22.6	29.3	18.1	0.757	2.79	3.31	2.12	0.662	0.781	1.26	3.14	9.42
86	21.7	28.7	17.0	0.682	2.61	3.02	1.96	0.533	0.714	1.15	2.63	9.29
87	20.8	27.4	15.4	0.621	2.42	2.87	1.74	0.391	0.624	1.11	2.36	7.89
88	19.4	26.6	14.7	0.555	2.30	2.71	1.28	0.343	0.510	1.02	2.05	6.93
89	17.9	26.0	14.1	0.483	2.04	2.53	1.15	0.280	0.428	0.954	1.87	6.17
90	16.5	24.9	13.8	0.411	1.83	2.35	0.784	0.239	0.389	0.898	1.49	5.95
91	16.3	23.7	12.7	0.328	1.63	2.11	0.629	0.207	0.349	0.841	1.19	3.97
92	16.2	22.0	11.0	0.273	1.47	1.93	0.575	0.185	0.275	0.774	1.02	3.27
93	15.2	21.0	9.27	0.237	1.30	1.66	0.531	0.167	0.215	0.719	0.831	2.73
94	13.4	19.9	7.42	0.213	1.16	1.45	0.488	0.151	0.179	0.643	0.659	1.91
95	7.86	16.7	6.59	0.197	1.05	1.09	0.406	0.130	0.160	0.489	0.570	1.60
96	5.19	9.18	4.06	0.188	0.970	0.896	0.353	0.104	0.116	0.415	0.538	1.42
97	4.73	5.63	2.74	0.182	0.889	0.741	0.313	0.0906	0.101	0.367	0.410	1.07
98	1.95	2.22	1.77	0.166	0.806	0.568	0.264	0.0772	0.0741	0.303	0.329	1.01
99	0.207	1.34	0.148	0.131	0.638	0.430	0.185	0.0554	0.0340	0.217	0.199	0.671
99.9	0.123	0.107	0.0932	0.104	0.399	0.271	0.107	0.0305	0.0270	0.0880	0.153	0.464
99.99	0.123	0.106	0.0920	0.104	0.378	0.253	0.104	0.0280	0.0270	0.0850	0.0630	0.445

5. Daily Average Baseflow Flow Duration Curves

SAAS v2.1.1 separates baseflow using a recursive digital filtering procedure. The resulting daily average baseflow series is tabulated by SAAS and has been used to generate baseflow flow duration curves for the entire period of record, for all four seasons and for all twelve months. These baseflow flow duration curves are shown in Figures 7 to 9, respectively.

The flow duration analysis results used to prepare Figures 7 to 9 are given in Tables 7 and 8.

Table 7 Daily Average Baseflow Flow Duration Analysis for All Four Seasons and the Period of Record

Percent of Time Exceeded	Daily Average Baseflow (m^3/s)				
	Winter	Spring	Summer	Fall	Period of Record
0.01	57.3	99.8	62.0	104	104
0.1	53.6	97.7	60.9	101	93.0
1	48.2	68.0	33.5	56.5	53.0
2	46.7	54.9	26.8	45.1	46.1
3	45.8	43.3	23.7	40.0	43.2
4	44.7	37.4	22.3	37.8	41.2
5	43.9	34.6	20.7	36.5	39.6
6	43.2	32.6	19.7	34.5	38.0
7	42.6	31.0	18.5	32.3	36.7

Percent of Time Exceeded	Daily Average Baseflow (m^3/s)				
	Winter	Spring	Summer	Fall	Period of Record
8	42.1	29.5	17.6	30.8	35.7
9	41.5	28.2	17.0	29.8	34.7
10	40.9	27.2	16.4	28.5	33.9
11	40.5	25.9	16.0	28.2	32.9
12	40.0	25.0	15.6	27.0	32.1
13	39.5	24.0	15.0	26.3	31.2
14	38.8	23.1	14.5	25.2	30.4
15	38.3	22.5	14.0	24.6	29.7
16	38.0	21.6	13.5	24.2	28.9
17	37.5	20.8	12.8	23.6	28.2
18	37.1	20.1	12.2	23.2	27.3
19	36.6	19.4	11.7	22.7	26.5
20	36.2	19.0	11.3	22.0	25.7
21	35.8	18.5	10.7	21.3	25.0
22	35.5	18.0	10.1	20.7	24.4
23	35.2	17.2	9.71	20.2	23.7
24	34.9	16.7	9.39	19.8	23.1
25	34.6	15.9	8.93	19.3	22.5
26	34.3	15.3	8.61	19.0	21.8
27	34.1	14.8	8.34	18.5	21.1
28	33.8	14.1	8.03	18.1	20.5
29	33.5	13.8	7.83	17.5	19.9
30	33.3	13.4	7.55	17.1	19.4
31	33.0	12.8	7.35	16.9	18.9
32	32.7	12.3	7.12	16.5	18.4
33	32.4	11.8	6.89	15.9	17.7
34	32.1	11.3	6.71	15.5	17.1
35	31.9	10.9	6.53	15.1	16.6
36	31.5	10.4	6.30	14.6	16.1
37	31.1	9.97	6.09	14.1	15.5
38	30.8	9.55	5.84	13.8	15.0
39	30.5	9.23	5.67	13.4	14.5
40	30.2	8.91	5.53	13.1	14.0
41	30.0	8.45	5.36	12.7	13.6
42	29.7	8.12	5.15	12.3	13.1
43	29.4	7.74	4.94	12.0	12.5
44	29.1	7.44	4.78	11.7	12.1
45	28.8	7.19	4.67	11.3	11.6
46	28.4	6.90	4.57	11.0	11.1
47	28.0	6.48	4.48	10.6	10.6
48	27.6	6.19	4.38	10.3	10.2
49	27.1	5.95	4.30	9.93	9.72
50	26.8	5.71	4.18	9.72	9.27
51	26.6	5.50	4.05	9.25	8.85
52	26.2	5.30	3.87	8.85	8.40
53	25.8	5.17	3.70	8.38	7.99
54	25.5	4.99	3.50	7.94	7.65
55	25.2	4.80	3.27	7.61	7.32
56	25.0	4.61	3.11	7.23	7.01

Percent of Time Exceeded	Daily Average Baseflow (m^3/s)				
	Winter	Spring	Summer	Fall	Period of Record
57	24.6	4.41	2.96	6.95	6.70
58	24.3	4.22	2.75	6.60	6.34
59	23.8	4.02	2.62	6.29	6.10
60	23.5	3.82	2.52	6.14	5.79
61	23.1	3.60	2.40	5.91	5.54
62	22.7	3.34	2.30	5.63	5.30
63	22.4	3.18	2.19	5.43	5.04
64	21.9	2.98	2.11	5.12	4.79
65	21.6	2.81	2.03	4.82	4.56
66	21.2	2.64	1.98	4.42	4.37
67	20.8	2.49	1.91	4.10	4.18
68	20.3	2.37	1.85	3.77	3.92
69	19.8	2.24	1.79	3.54	3.66
70	19.5	2.10	1.70	3.32	3.38
71	19.2	1.94	1.62	3.08	3.12
72	18.8	1.82	1.52	2.86	2.89
73	18.2	1.71	1.44	2.70	2.69
74	17.5	1.56	1.37	2.49	2.49
75	16.8	1.45	1.26	2.30	2.32
76	16.3	1.35	1.09	2.14	2.16
77	15.6	1.24	0.957	1.96	2.00
78	15.0	1.17	0.871	1.86	1.88
79	14.4	1.10	0.785	1.66	1.77
80	13.9	1.03	0.720	1.52	1.60
81	13.5	0.968	0.620	1.40	1.47
82	12.9	0.925	0.547	1.24	1.34
83	12.2	0.872	0.470	1.12	1.20
84	11.4	0.806	0.422	1.02	1.09
85	10.6	0.757	0.374	0.943	0.976
86	9.69	0.686	0.340	0.874	0.897
87	8.88	0.632	0.313	0.829	0.809
88	8.15	0.564	0.290	0.761	0.722
89	7.41	0.526	0.266	0.706	0.643
90	6.64	0.466	0.246	0.661	0.566
91	5.88	0.434	0.210	0.620	0.482
92	4.92	0.393	0.184	0.568	0.418
93	4.32	0.339	0.162	0.507	0.360
94	3.54	0.267	0.142	0.438	0.312
95	2.47	0.223	0.114	0.380	0.259
96	1.50	0.198	0.0974	0.346	0.204
97	1.19	0.187	0.0789	0.323	0.175
98	0.869	0.178	0.0677	0.232	0.135
99	0.177	0.138	0.0353	0.153	0.0931
99.9	0.0994	0.104	0.0270	0.0689	0.0287

Table 8 Daily Average Baseflow Flow Duration Analysis for All Twelve Months of the Year

Percent of Time Exceeded	Daily Average Baseflow (m^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.01	47.6	52.2	57.3	83.9	96.1	99.8	36.3	58.5	62.0	67.8	104	69.7
0.1	47.3	52.1	56.1	83.7	92.8	99.6	36.3	57.1	61.8	66.8	104	66.6
1	44.0	48.6	49.3	75.0	66.2	63.6	30.2	24.2	53.5	56.2	81.9	38.2
2	43.2	47.5	47.1	36.3	59.7	47.8	27.4	20.1	30.4	43.8	52.7	37.5
3	42.3	47.0	45.7	31.7	52.0	41.8	25.0	18.9	26.6	41.1	49.3	36.7
4	41.4	46.6	44.0	29.9	45.1	38.7	23.3	17.7	24.4	38.8	42.9	36.4
5	40.5	46.1	43.1	28.3	40.9	35.9	22.7	17.0	22.3	36.5	40.0	35.7
6	39.5	45.6	42.2	25.7	36.5	34.4	22.3	16.6	20.9	33.5	39.0	31.8
7	38.5	45.2	41.9	23.2	34.3	33.2	21.2	16.1	19.2	32.5	34.4	30.6
8	37.5	44.7	41.2	21.2	31.8	31.7	20.4	15.7	17.7	30.6	32.1	29.7
9	36.8	44.3	40.2	19.3	30.6	30.7	19.6	15.4	16.9	28.5	31.1	29.0
10	36.3	44.0	39.6	17.4	28.6	29.7	18.8	14.9	15.8	26.2	30.2	28.4
11	35.9	43.5	38.7	16.5	27.8	28.7	18.1	14.4	15.0	22.8	29.1	28.3
12	35.7	43.2	38.1	15.6	27.1	27.7	17.5	13.8	14.6	20.7	27.8	28.1
13	35.3	42.7	37.6	15.1	26.1	26.8	17.0	13.2	14.0	19.8	26.3	27.5
14	35.1	42.3	37.0	14.8	25.3	25.8	16.5	12.5	13.4	19.0	25.1	27.0
15	34.8	42.0	36.4	14.1	24.5	25.0	16.2	11.7	12.8	18.3	24.6	26.6
16	34.5	41.6	36.0	13.8	23.7	24.4	15.9	10.9	12.1	17.9	24.2	26.3
17	34.3	41.2	35.7	13.5	22.5	23.7	15.6	10.4	11.6	17.4	23.5	25.7
18	34.1	40.9	35.4	12.9	22.0	23.3	15.2	9.92	11.3	17.1	22.7	25.2
19	33.9	40.7	35.2	12.4	21.2	22.9	14.7	9.70	10.5	16.8	21.9	24.8
20	33.6	40.6	34.9	11.9	20.7	22.5	14.2	9.48	9.49	16.4	21.4	24.6
21	33.3	40.2	34.7	11.2	19.9	21.9	13.5	9.13	8.76	15.9	21.0	24.3
22	33.0	40.0	34.3	10.8	19.3	21.1	12.9	8.86	8.30	15.4	20.6	24.1
23	32.7	39.7	34.1	10.3	18.7	20.7	12.4	8.62	7.90	15.0	20.3	23.8
24	32.2	39.4	33.8	9.73	18.0	20.3	12.1	8.48	7.72	14.5	20.0	23.5
25	31.8	39.0	33.5	9.37	17.4	19.9	11.8	8.27	7.51	14.1	19.6	23.4
26	31.4	38.6	33.3	9.02	16.6	19.5	11.5	8.05	7.38	13.6	19.1	23.2
27	31.0	38.4	32.9	8.66	15.7	19.2	11.0	7.92	7.23	13.2	18.7	23.1
28	30.9	38.2	32.7	8.28	15.1	19.0	10.6	7.63	7.04	12.9	18.2	22.8
29	30.6	38.0	32.3	7.86	14.4	18.7	10.2	7.39	6.84	12.4	17.4	22.6
30	30.2	37.8	32.0	7.53	13.7	18.5	9.93	7.11	6.69	12.0	16.7	21.9
31	30.0	37.5	31.7	7.21	13.2	18.3	9.62	6.80	6.50	11.7	15.9	21.5
32	29.7	37.2	31.3	6.78	12.8	17.9	9.19	6.48	6.24	11.3	15.2	20.8
33	29.5	36.9	30.9	6.43	12.3	17.6	8.86	6.12	5.99	11.0	14.5	20.3
34	29.2	36.6	30.4	6.11	12.0	17.1	8.41	5.75	5.80	10.7	14.1	19.9
35	28.9	36.2	30.1	5.92	11.6	17.0	8.04	5.54	5.71	10.5	13.5	19.7
36	28.7	35.9	29.9	5.66	11.1	16.3	7.83	5.41	5.62	10.1	13.2	19.4
37	28.3	35.5	29.6	5.41	10.6	15.7	7.44	5.23	5.54	9.89	13.1	19.1
38	28.1	35.0	29.3	5.17	10.2	15.2	7.20	4.98	5.36	9.66	12.7	19.1
39	27.7	34.5	29.0	4.98	9.80	14.4	6.94	4.79	5.24	9.37	12.4	18.7
40	27.4	34.3	28.6	4.79	9.44	14.0	6.79	4.70	4.99	8.89	12.2	18.3
41	26.9	34.1	28.0	4.50	9.22	13.8	6.69	4.57	4.85	8.58	12.0	17.9
42	26.7	33.9	27.8	4.27	8.69	13.4	6.58	4.49	4.72	8.20	11.8	17.5
43	26.3	33.6	27.3	4.03	8.29	12.7	6.38	4.33	4.63	7.83	11.5	17.2
44	26.0	33.3	27.1	3.84	7.99	12.0	6.21	4.11	4.51	7.59	11.3	17.0
45	25.8	33.1	26.8	3.70	7.63	11.6	6.05	3.92	4.29	7.16	11.1	16.9

Percent of Time Exceeded	Daily Average Baseflow (m^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
46	25.5	32.9	26.5	3.46	7.41	11.1	5.90	3.78	4.19	6.82	10.7	16.5
47	25.3	32.6	26.1	3.21	7.13	10.7	5.75	3.68	4.15	6.58	10.4	16.1
48	25.1	32.4	25.7	3.05	6.91	10.4	5.50	3.50	3.93	6.36	10.2	15.7
49	24.9	32.2	25.3	2.81	6.65	10.0	5.24	3.30	3.62	6.17	9.81	15.5
50	24.5	32.0	25.0	2.63	6.26	9.46	5.04	3.18	3.43	5.88	9.70	15.2
51	24.3	31.9	24.7	2.43	6.05	9.21	4.84	3.11	3.24	5.67	9.13	14.7
52	23.9	31.5	24.3	2.34	5.81	8.82	4.70	3.00	3.04	5.56	8.86	14.3
53	23.7	31.2	23.7	2.23	5.64	8.42	4.60	2.88	2.80	5.50	8.35	14.0
54	23.5	30.8	23.1	2.15	5.39	7.97	4.53	2.71	2.65	5.31	7.90	13.7
55	23.2	30.6	22.4	1.95	5.20	7.71	4.46	2.57	2.50	5.02	7.52	13.4
56	23.1	30.4	21.7	1.83	4.97	7.45	4.42	2.52	2.39	4.68	7.14	13.2
57	22.8	30.2	21.1	1.70	4.70	7.25	4.37	2.37	2.32	4.36	6.86	12.6
58	22.6	29.8	20.5	1.49	4.50	6.92	4.33	2.27	2.21	3.99	6.38	12.1
59	22.4	29.4	19.9	1.36	4.34	6.40	4.28	2.19	2.15	3.70	6.11	11.5
60	22.1	29.3	19.4	1.26	4.09	6.16	4.18	2.11	2.06	3.52	5.73	10.9
61	21.9	28.9	18.9	1.20	3.88	5.78	4.05	2.04	1.98	3.25	5.34	10.3
62	21.6	28.7	18.5	1.13	3.75	5.58	3.96	2.02	1.88	3.05	5.00	9.93
63	21.3	28.1	17.7	1.09	3.46	5.48	3.77	1.99	1.82	2.82	4.66	9.33
64	21.0	27.3	17.3	1.02	3.27	5.32	3.55	1.94	1.76	2.70	4.31	8.89
65	20.7	27.0	16.7	0.951	3.20	5.23	3.16	1.89	1.62	2.53	4.14	8.34
66	20.3	26.6	16.1	0.914	3.10	5.12	2.96	1.87	1.53	2.31	3.77	7.81
67	19.8	26.2	15.5	0.847	2.94	5.02	2.77	1.83	1.49	2.15	3.50	7.46
68	19.5	25.9	14.7	0.782	2.74	4.87	2.60	1.74	1.41	1.91	3.34	7.11
69	19.2	25.4	14.2	0.714	2.61	4.76	2.51	1.64	1.34	1.65	3.09	6.92
70	18.7	25.1	13.8	0.657	2.50	4.58	2.40	1.45	1.28	1.54	2.90	6.46
71	18.0	24.8	13.8	0.614	2.37	4.44	2.28	1.27	1.21	1.48	2.65	6.25
72	17.5	24.3	13.5	0.579	2.25	4.22	2.16	1.02	1.13	1.37	2.44	6.15
73	16.9	23.8	13.0	0.549	2.11	4.08	2.02	0.935	1.02	1.20	2.34	6.11
74	16.4	23.4	12.6	0.539	2.00	3.89	1.92	0.823	0.932	1.10	2.18	5.89
75	16.0	22.9	12.3	0.515	1.91	3.59	1.85	0.738	0.842	1.00	2.08	5.44
76	15.6	22.4	11.8	0.478	1.78	3.30	1.78	0.635	0.768	0.922	1.98	5.04
77	15.0	22.0	11.3	0.454	1.66	2.95	1.71	0.546	0.720	0.868	1.91	4.66
78	14.6	21.5	10.8	0.438	1.55	2.84	1.64	0.475	0.645	0.845	1.79	4.22
79	14.1	21.2	10.3	0.414	1.48	2.70	1.60	0.401	0.598	0.827	1.64	3.89
80	13.8	20.9	9.62	0.384	1.43	2.51	1.51	0.357	0.536	0.795	1.50	3.62
81	13.3	20.3	9.16	0.340	1.36	2.36	1.43	0.334	0.464	0.745	1.36	3.42
82	12.7	20.0	8.77	0.303	1.28	2.17	1.40	0.317	0.431	0.718	1.24	3.09
83	12.1	19.7	8.38	0.273	1.22	1.97	1.33	0.300	0.384	0.702	1.14	2.88
84	11.2	19.5	7.91	0.245	1.15	1.84	1.09	0.277	0.340	0.686	1.04	2.75
85	10.3	19.2	7.39	0.228	1.07	1.79	0.938	0.266	0.310	0.660	0.975	2.50
86	9.55	18.9	6.95	0.214	1.01	1.62	0.823	0.251	0.275	0.632	0.927	2.25
87	8.72	18.4	6.55	0.205	0.962	1.42	0.774	0.210	0.256	0.603	0.898	2.06
88	7.90	17.3	5.84	0.198	0.913	1.27	0.634	0.194	0.239	0.571	0.830	1.89
89	7.24	16.3	4.87	0.192	0.873	1.14	0.539	0.179	0.195	0.514	0.745	1.80
90	6.64	15.5	4.12	0.188	0.830	1.05	0.472	0.168	0.170	0.455	0.649	1.56
91	6.05	14.8	3.53	0.187	0.774	0.994	0.418	0.156	0.149	0.412	0.608	1.29
92	5.41	12.3	2.87	0.182	0.723	0.951	0.383	0.143	0.132	0.379	0.533	1.13
93	4.55	9.56	2.39	0.179	0.670	0.875	0.347	0.118	0.108	0.352	0.441	1.03
94	4.35	5.69	1.85	0.177	0.631	0.807	0.309	0.103	0.0985	0.340	0.382	0.905

Percent of Time Exceeded	Daily Average Baseflow (m^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
95	4.22	4.80	1.48	0.170	0.562	0.762	0.285	0.0790	0.0940	0.314	0.355	0.724
96	2.82	2.24	1.24	0.160	0.511	0.651	0.246	0.0752	0.0791	0.290	0.340	0.615
97	1.50	1.15	0.973	0.137	0.437	0.447	0.214	0.0657	0.0689	0.225	0.327	0.552
98	1.15	0.982	0.439	0.124	0.385	0.397	0.170	0.0565	0.0330	0.159	0.177	0.476
99	0.186	0.161	0.142	0.109	0.307	0.335	0.119	0.0375	0.0289	0.128	0.153	0.388
99.9	0.123	0.106	0.0921	0.104	0.189	0.252	0.0811	0.0273	0.0270	0.0762	0.0633	0.151
99.99	0.123	0.106	0.0920	0.104	0.179	0.248	0.0787	0.0270	0.0270	0.0759	0.0630	0.135

6. Median Annual Flow Duration Curves

SAAS v2.1.1 includes the option to generate median annual flow duration curves for the entire period of record, for all four seasons and for all twelve months. The median annual method calculates a flow duration curve (FDC) for each year (or month/season) of the period of record, records the value for each percent exceedance (0 to 100) on each year's FDC, calculates the median for each, and draws a FDC using the median values.

The median annual flow duration curves are shown in Figures 10 to 12, respectively.

The flow duration analysis results used to prepare Figures 10 to 12 are given in Tables 9 and 10.

Table 9 Median Annual Flow Duration Analysis for All Four Seasons and the Period of Record

Percent of Time Exceeded	Median Annual Flow (m^3/s)				
	Winter	Spring	Summer	Fall	Period of Record
0.01	71.4	163	78.8	66.5	175
0.1	71.4	163	78.8	66.5	175
1	70.1	162	78.3	64.4	155
2	67.2	157	75.0	62.8	128
3	64.2	152	68.1	61.0	104
4	62.4	141	62.2	57.9	91.8
5	61.8	136	59.3	57.2	84.6
6	61.7	127	56.3	55.3	78.3
7	60.4	112	50.8	54.3	71.9
8	59.9	108	48.0	51.5	69.1
9	59.8	106	44.1	50.5	65.7
10	59.5	102	42.4	48.5	64.2
11	59.2	97.3	41.5	47.5	61.7
12	59.0	88.7	39.3	45.9	59.6
13	58.8	84.1	38.2	44.4	57.2
14	57.7	80.9	37.4	43.9	56.2
15	57.4	79.8	36.1	43.8	54.7
16	57.3	75.5	35.0	43.6	53.2
17	55.7	71.3	33.0	42.6	52.3
18	55.2	70.0	32.1	42.0	50.6
19	54.7	67.7	31.4	40.8	49.4
20	54.4	65.1	30.4	40.2	48.2
21	54.0	61.1	29.0	40.1	47.3
22	53.6	56.9	28.4	39.6	46.5

Percent of Time Exceeded	Median Annual Flow (m^3/s)				
	Winter	Spring	Summer	Fall	Period of Record
23	52.5	53.9	28.1	38.9	45.9
24	51.6	53.4	27.5	38.5	44.8
25	51.0	52.2	26.4	38.1	44.5
26	50.6	51.7	25.4	37.6	44.0
27	49.8	50.1	25.1	37.1	42.8
28	49.7	49.3	24.6	36.0	42.2
29	48.5	47.6	24.3	35.1	41.7
30	48.1	45.7	24.3	34.4	40.5
31	47.5	45.0	24.0	33.3	39.7
32	47.1	43.9	23.4	32.8	38.5
33	47.0	43.4	23.2	31.8	37.8
34	46.9	42.6	22.3	31.6	37.5
35	46.5	41.3	21.4	30.9	36.8
36	46.2	40.4	20.8	30.6	35.9
37	45.9	37.8	19.4	30.4	35.1
38	45.9	36.7	19.4	30.2	34.7
39	45.9	36.0	19.2	29.9	34.0
40	45.8	35.6	19.1	29.7	33.4
41	45.1	35.3	18.9	29.6	32.6
42	44.9	34.1	17.7	28.9	31.9
43	44.5	33.3	16.9	28.7	31.5
44	44.1	32.4	16.5	28.1	30.6
45	43.3	31.5	16.4	27.8	29.8
46	43.2	30.3	16.4	27.2	28.7
47	42.9	29.4	16.1	26.4	28.4
48	42.5	28.6	15.1	26.3	27.8
49	42.2	27.5	14.1	25.4	27.3
50	42.0	26.2	13.7	25.2	26.7
51	41.7	25.6	12.9	25.0	26.4
52	41.6	23.7	12.5	24.9	26.2
53	41.0	22.4	12.0	24.8	25.1
54	40.9	20.5	11.4	24.8	23.9
55	40.4	19.7	11.0	24.5	23.4
56	40.4	18.4	10.5	24.1	22.9
57	39.6	18.1	10.2	21.7	21.8
58	39.4	17.6	10.1	21.3	20.6
59	38.6	17.0	10.1	21.2	19.5
60	37.8	15.8	9.85	21.1	19.2
61	37.6	14.9	9.19	20.4	19.1
62	37.5	14.9	8.38	19.2	18.1
63	36.8	13.8	7.61	17.7	17.7
64	36.5	13.4	6.94	17.1	17.1
65	36.3	12.3	6.87	16.5	16.4
66	35.9	11.2	6.19	15.7	15.7
67	34.7	9.93	5.97	15.3	14.5
68	34.6	9.81	5.47	15.3	13.6
69	34.5	9.58	5.34	15.3	12.4
70	34.3	8.81	5.30	15.3	11.7
71	34.2	7.85	4.85	14.2	10.9

Percent of Time Exceeded	Median Annual Flow (m^3/s)				
	Winter	Spring	Summer	Fall	Period of Record
72	33.6	7.26	4.71	14.2	10.5
73	33.1	6.19	4.47	14.0	9.86
74	32.6	5.53	4.33	13.2	9.50
75	31.9	5.27	4.24	13.1	8.78
76	31.2	5.03	4.00	12.6	8.14
77	30.8	4.94	4.00	11.6	7.40
78	30.6	4.82	3.81	10.1	6.20
79	30.6	4.73	3.50	8.65	6.07
80	30.4	4.61	3.38	7.15	5.77
81	28.9	4.14	3.11	7.10	5.03
82	28.0	3.81	2.91	6.80	4.81
83	27.9	3.75	2.71	6.41	4.43
84	27.7	3.53	2.67	6.39	4.15
85	27.4	3.26	2.43	5.80	3.49
86	27.0	3.05	2.27	5.53	3.22
87	26.0	2.96	2.24	4.14	3.00
88	26.0	2.65	2.13	3.34	2.73
89	26.0	2.29	2.10	3.24	2.64
90	25.2	1.96	1.91	2.58	2.51
91	24.6	1.77	1.88	2.37	2.27
92	23.1	1.47	1.57	2.25	1.89
93	21.8	1.24	1.53	2.13	1.50
94	20.9	1.04	1.30	1.96	1.35
95	19.8	1.00	1.11	1.58	1.08
96	19.7	0.877	0.988	1.32	0.862
97	18.4	0.744	0.719	1.19	0.759
98	16.5	0.615	0.676	1.07	0.652
99	13.6	0.467	0.642	0.922	0.334
99.9	12.6	0.407	0.548	0.823	0.192

Table 10 Median Annual Flow Duration Analysis for All Twelve Months of the Year

Percent of Time Exceeded	Median Annual Flow (m^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.01	52.1	53.5	62.9	59.2	134	90.4	60.8	28.8	44.8	55.7	53.1	46.4
0.1	52.1	53.5	62.9	59.2	134	90.4	60.8	28.8	44.8	55.7	53.1	46.4
1	52.1	53.5	62.9	59.2	134	90.4	60.8	28.8	44.8	55.7	53.1	46.4
2	52.1	53.5	62.6	59.1	134	90.3	59.2	27.7	44.2	55.7	53.0	46.3
3	51.8	53.3	62.0	58.7	132	90.0	54.7	26.4	42.4	54.9	52.1	46.1
4	51.5	53.2	61.4	57.6	130	89.7	51.8	25.9	41.4	54.3	51.2	45.9
5	51.4	53.1	60.0	57.4	129	89.3	49.8	25.1	40.8	54.2	51.1	45.0
6	51.1	53.0	59.0	56.6	127	88.6	49.6	24.7	39.7	53.9	49.4	44.8
7	50.6	52.9	58.3	55.7	126	84.7	48.5	24.2	38.7	53.6	47.8	43.8
8	49.2	52.8	57.7	52.2	122	82.8	48.2	23.0	38.0	53.2	46.8	42.6
9	48.5	52.8	57.3	50.5	119	80.1	47.0	22.8	37.7	52.1	46.6	41.4
10	47.5	52.6	56.9	49.4	118	79.1	45.4	22.7	37.5	51.0	46.5	41.1
11	46.0	52.4	56.7	48.8	118	78.1	42.1	22.4	37.3	48.6	46.5	40.8
12	45.8	52.2	56.4	48.2	114	77.2	40.8	22.4	37.2	48.1	45.7	40.5

Percent of Time Exceeded	Median Annual Flow (m^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
13	45.6	52.0	56.2	47.7	106	74.6	40.3	22.4	37.1	46.8	45.4	39.9
14	44.5	51.8	56.0	47.2	99.9	71.7	40.2	22.3	36.5	45.8	45.0	39.8
15	44.1	51.5	55.8	42.9	95.7	68.7	39.0	22.2	34.9	44.0	44.7	39.7
16	44.0	51.1	54.8	41.6	93.1	67.0	38.0	20.7	32.9	43.4	44.1	39.4
17	43.8	50.9	53.9	40.4	90.6	66.5	36.3	19.6	32.1	42.7	43.4	38.8
18	43.5	49.7	53.4	39.2	89.5	63.6	34.5	18.7	31.6	42.2	42.7	38.0
19	42.8	49.2	53.3	37.9	86.8	61.4	33.1	18.5	31.3	42.0	42.3	37.6
20	42.5	49.1	53.1	36.6	86.3	58.5	33.0	18.0	30.9	41.8	42.1	37.2
21	42.1	48.7	52.5	36.1	83.3	56.5	32.5	17.6	29.4	41.1	41.6	37.2
22	41.9	47.9	52.2	35.7	78.1	51.7	32.3	15.8	29.2	40.0	40.6	36.9
23	41.7	47.4	51.8	34.6	77.6	51.4	31.5	13.5	27.0	38.9	40.2	36.8
24	41.6	47.3	51.5	34.0	75.1	50.1	30.3	13.2	26.8	35.7	39.0	36.7
25	41.5	47.3	51.2	33.8	73.0	49.8	29.0	13.2	25.1	34.1	38.8	35.9
26	41.3	47.2	51.0	33.5	72.3	48.2	28.0	13.2	24.7	33.0	38.2	35.8
27	41.1	47.1	50.8	32.3	71.9	47.4	27.3	13.2	23.8	32.1	37.3	35.8
28	40.8	47.1	50.7	30.9	71.3	45.6	26.6	13.1	23.2	31.7	37.2	35.7
29	40.6	47.1	50.5	30.2	67.1	44.9	26.4	13.0	22.3	31.1	36.4	35.7
30	40.5	46.9	50.3	29.7	65.5	43.5	24.7	12.7	22.2	29.8	35.4	35.7
31	40.2	46.7	50.0	27.6	64.6	43.2	23.3	11.5	22.1	29.0	34.6	35.6
32	39.7	46.5	49.8	26.7	62.6	42.7	23.0	11.1	21.8	28.8	33.5	34.8
33	39.1	46.3	49.4	26.3	60.0	42.4	22.3	11.1	21.3	28.6	32.0	34.4
34	38.8	46.0	48.9	25.9	58.0	41.3	21.3	11.1	20.9	28.5	31.1	34.0
35	38.3	46.0	48.8	25.5	57.7	40.6	21.2	10.8	20.4	28.3	30.4	33.2
36	38.2	45.9	48.5	25.0	57.6	39.6	20.6	10.8	19.8	28.1	30.2	32.6
37	38.2	45.8	48.4	24.5	57.6	37.7	20.5	10.7	19.1	27.7	30.1	32.3
38	38.2	45.7	48.4	24.0	56.3	34.7	20.3	10.7	18.2	27.3	29.9	32.2
39	38.2	45.7	48.2	23.5	54.8	33.0	20.1	10.6	17.6	27.1	29.2	32.2
40	38.2	45.7	48.1	23.3	54.6	32.8	19.9	10.6	17.6	27.0	28.5	32.2
41	38.0	45.7	47.7	23.3	54.1	32.8	19.8	10.5	17.4	26.8	28.4	32.2
42	37.9	45.2	47.3	23.2	53.2	32.7	19.6	10.5	17.3	26.7	28.0	32.2
43	37.7	45.0	47.0	22.1	52.5	32.7	18.4	10.4	17.2	26.4	27.4	32.0
44	37.6	45.0	46.9	21.9	50.6	31.9	17.7	10.4	17.0	25.6	26.2	31.8
45	37.5	44.9	46.5	21.7	48.8	31.4	17.6	10.3	16.3	25.2	25.4	31.7
46	37.5	44.9	45.9	21.3	45.7	31.3	17.6	10.3	15.3	25.0	25.4	31.3
47	37.4	44.9	45.8	21.0	45.5	31.3	17.3	10.3	14.5	24.8	25.3	30.7
48	37.3	43.8	45.3	20.2	44.3	31.3	16.4	10.3	14.4	24.4	25.2	30.4
49	37.2	43.7	44.6	18.2	43.0	31.2	16.4	10.3	13.4	23.4	25.1	30.4
50	37.2	43.7	44.2	16.2	38.5	29.9	16.0	10.3	12.5	22.9	24.2	30.3
51	37.2	43.6	42.8	15.5	37.4	29.0	15.4	10.2	11.9	22.7	22.7	30.3
52	37.1	43.6	42.5	15.3	35.1	28.6	14.8	10.1	11.5	22.5	22.1	30.3
53	36.8	43.5	42.2	14.6	34.9	27.6	14.1	9.86	10.6	22.4	21.9	30.3
54	36.7	43.5	42.0	12.6	34.5	26.9	13.8	9.84	10.3	22.2	21.7	30.0
55	36.7	43.5	41.8	11.3	31.6	26.3	13.6	9.33	10.2	21.6	21.2	28.8
56	36.6	43.5	41.6	11.0	29.6	26.1	13.3	9.29	10.2	20.9	20.1	28.0
57	36.6	43.4	41.5	10.7	27.9	25.9	12.9	9.16	9.83	20.1	19.6	27.3
58	36.4	43.4	41.4	10.4	25.8	25.4	12.9	8.94	9.16	19.3	18.1	27.3
59	35.8	43.2	41.3	10.2	24.1	24.2	12.9	8.66	8.65	19.3	18.0	27.3
60	35.7	42.9	41.2	9.97	23.1	23.8	12.5	8.29	8.42	19.3	18.0	26.4
61	35.7	42.6	40.9	9.30	23.0	20.9	12.1	8.29	8.38	17.3	18.0	26.0

Percent of Time Exceeded	Median Annual Flow (m^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
62	35.7	42.3	40.4	8.24	22.9	18.0	11.7	8.29	8.30	17.2	17.9	25.9
63	35.7	42.0	40.0	7.58	21.8	18.0	11.4	8.05	7.82	17.1	17.2	25.5
64	35.3	41.7	39.6	7.28	18.9	18.0	11.2	7.87	7.71	17.1	16.9	25.5
65	35.3	41.4	39.0	6.89	16.8	18.0	10.9	7.86	7.62	17.1	16.9	25.5
66	35.3	41.2	38.3	5.99	13.7	18.0	9.73	7.68	7.33	17.1	16.7	25.4
67	35.3	40.1	38.0	4.88	12.6	17.1	9.47	6.38	7.28	17.1	16.2	24.1
68	35.2	39.8	37.3	4.40	11.7	16.8	9.19	5.82	7.25	17.1	15.7	23.7
69	35.1	39.5	36.5	4.17	11.0	16.3	8.83	5.66	6.71	15.4	15.3	23.3
70	34.3	39.2	36.2	3.98	10.9	15.9	8.74	5.65	5.46	15.3	14.9	23.2
71	33.8	39.0	36.2	3.80	10.8	15.8	7.91	5.15	5.25	15.3	14.6	23.2
72	33.5	38.9	36.2	3.58	9.50	15.0	7.53	5.06	5.20	15.3	14.4	23.1
73	33.5	38.8	36.0	3.48	8.16	14.5	7.37	4.81	5.14	15.0	13.8	23.1
74	33.4	38.8	35.7	3.40	7.48	14.5	7.29	4.45	4.75	14.7	13.8	23.1
75	33.4	38.7	35.4	2.74	7.01	14.4	7.28	4.42	4.25	14.4	13.7	23.1
76	33.3	38.6	34.7	2.46	6.65	14.3	7.20	4.37	4.23	12.8	13.5	23.0
77	33.0	38.1	33.9	2.24	6.50	13.1	6.56	4.26	4.22	12.5	13.3	22.9
78	32.8	36.7	33.2	2.11	6.36	12.6	5.83	4.12	4.21	12.2	13.0	22.8
79	32.5	35.8	32.8	1.99	6.21	12.4	5.54	3.74	4.17	11.7	12.7	22.5
80	32.4	35.4	32.6	1.95	5.90	11.7	5.24	3.46	4.16	9.91	12.7	22.4
81	32.2	35.2	32.4	1.90	5.49	10.8	5.01	3.20	4.16	8.12	12.2	21.9
82	32.1	35.0	31.7	1.84	5.42	9.75	4.81	3.15	4.14	7.32	11.4	21.2
83	31.0	34.9	31.3	1.79	5.38	9.71	4.74	3.09	4.05	7.09	10.7	21.1
84	30.9	34.8	30.2	1.68	5.18	9.26	4.71	3.01	3.80	6.37	10.5	20.8
85	30.0	34.8	30.1	1.56	4.86	9.19	4.71	2.93	3.56	6.33	9.41	20.5
86	28.9	34.8	29.5	1.46	4.59	9.00	4.62	2.88	3.46	6.30	9.36	20.1
87	27.6	34.8	28.6	1.37	4.45	8.82	4.57	2.81	3.36	6.28	9.36	18.7
88	27.5	34.7	28.1	1.30	4.19	8.63	4.55	2.73	3.14	6.26	9.35	18.5
89	27.3	34.6	27.6	1.06	4.09	8.52	4.53	2.63	3.10	5.88	8.89	17.8
90	27.1	34.5	27.5	1.03	4.02	8.44	4.50	2.46	2.97	5.65	8.84	16.5
91	27.0	34.5	25.8	0.973	3.95	8.36	4.48	2.19	2.77	4.49	8.17	15.8
92	26.6	34.3	25.4	0.815	3.82	8.28	4.45	2.14	2.48	4.14	7.41	15.8
93	26.3	34.1	22.6	0.730	3.75	8.23	4.44	2.05	2.30	4.09	7.19	15.8
94	25.4	33.8	22.2	0.645	3.66	8.17	4.42	2.00	2.06	4.05	7.12	15.7
95	25.2	33.7	21.6	0.590	3.47	6.98	3.70	1.99	1.71	3.80	7.05	15.7
96	24.8	33.7	21.1	0.548	3.24	6.21	3.39	1.91	1.65	3.34	6.91	15.6
97	24.6	32.9	19.9	0.490	3.10	5.85	3.38	1.91	1.60	3.22	6.54	14.7
98	24.0	32.9	19.7	0.438	3.07	5.49	3.37	1.83	1.46	3.09	5.54	14.6
99	23.5	32.7	19.5	0.413	2.96	5.46	2.90	1.83	1.29	2.89	5.53	14.6
99.9	23.5	32.7	19.5	0.413	2.96	5.46	2.90	1.83	1.29	2.89	5.53	14.6
99.99	23.5	32.7	19.5	0.413	2.96	5.46	2.90	1.83	1.29	2.89	5.53	14.6

7. Flood Frequency Analysis

Annual maximum total daily average flow data are available for the Frederick House River at Frederick House Dam from 1939 to 1994. There are no instantaneous maximum flow records. This means that, to make use of the full period of flood record, the instantaneous flow maxima must be estimated from the daily average flow maxima.

Reference to Figure 2 shows that there are a number of rivers flowing north, parallel to the Frederickhouse River, in the Northeast Region of Ontario. Instantaneous and daily annual flow maxima were downloaded from the Water Survey of Canada HYDAT site to analyze the variation of instantaneous flood peaks with daily flood maxima.

These flood maxima were divided by the drainage area at each streamflow station to normalize the data in l/s/km^2, for direct comparison between station records.

Table 11 shows the flood data analyzed.

Table 11 Daily and Instantaneous Flood Maxima in Northeast Ontario

River	Kabinakgami	Nagagami	Shekak	Groundhog	Missinaibi	Mattawiskwia
Nat/Reg	Nat	Nat	Nat	Reg	Nat	Nat
Year	04JA002	04JC002	04JC003	04LD001	04LJ001	04LK001
Area (km^2)	3780	2410	3290	11900	8940	1140
Daily	Instantaneous Peak l/s/km^2					
81.0	81.0					
70.4	70.6					
45.8	46.0					
64.0	64.0					
32.5	32.8					
52.4	52.4					
54.2	54.5					
53.4	53.7					
62.7	63.0					
50.5	51.6					
60.6	61.1					
66.7	66.9					
59.5	60.1					
89.9	90.2					
59.3	59.5					
58.2	58.2					
41.8	41.8					
70.4	70.9					
47.6	47.9					
55.6		56.0				
28.1		28.2				
40.7		40.8				
44.0		44.0				
41.5		41.9				
56.8		57.3				
37.6		37.8				
44.0		44.4				
55.6		56.0				
49.0		49.4				
68.5		68.9				
56.0		56.8				
33.9		34.2				
46.5		46.9				
55.2		55.6				
45.6		46.1				
48.5		49.8				

River	Kabinakgami	Nagagami	Shekak	Groundhog	Missinaibi	Mattawiskwia
Nat/Reg	Nat	Nat	Nat	Reg	Nat	Nat
Year	04JA002	04JC002	04JC003	04LD001	04LJ001	04LK001
Area (km^2)	3780	2410	3290	11900	8940	1140
Daily	Instantaneous Peak $l/s/km^2$					
52.3		52.7				
64.7		65.1				
48.5		49.4				
34.7		34.8				
99.6		102.1				
62.2		62.7				
34.5		35.5				
37.0		37.3				
93.8		94.2				
57.7		58.5				
28.0		28.4				
46.1		46.5				
41.0		41.9				
69.7		70.5				
37.4		38.0				
71.0		74.3				
46.5		46.9				
30.6		30.7				
58.9		59.3				
36.1		37.2				
48.5		49.4				
55.9			56.2			
93.0			93.9			
70.5			71.4			
44.1			44.4			
63.5			63.8			
49.2			49.8			
52.3			52.3			
56.8			57.1			
46.5			46.5			
57.1			57.4			
48.0			48.3			
62.9			63.2			
69.9			70.2			
62.6			62.9			
88.8			89.7			
76.6			76.9			
50.5			50.8			
58.7			59.3			
46.2			46.2			
62.0			62.3			
53.2			53.8			
41.6			41.6			
63.0				65.9		
104.2				106.7		
74.5				75.2		
68.7				69.2		
64.3				65.0		

River	Kabinakgami	Nagagami	Shekak	Groundhog	Missinaibi	Mattawiskwia
Nat/Reg	Nat	Nat	Nat	Reg	Nat	Nat
Year	04JA002	04JC002	04JC003	04LD001	04LJ001	04LK001
Area (km^2)	3780	2410	3290	11900	8940	1140
Daily	Instantaneous Peak $l/s/km^2$					
69.2				70.0		
97.5				98.3		
72.8				73.7		
71.0				71.3		
84.0				84.9		
98.3				103.4		
59.6				60.4		
35.8				36.1		
60.8				60.9		
72.9				74.6		
93.3				95.0		
76.5				77.3		
39.7				40.4		
70.4				71.1		
115.8						
68.2						
115.2					118.6	
133.1					134.2	
102.0					103.2	
87.1					89.4	
66.6					67.8	
109.3					110.0	
78.9					79.5	
105.5					106.4	
79.5					81.4	
100.4					102.3	
85.2					86.1	
86.1					87.1	
69.7					70.0	
89.9					93.7	
89.4					89.6	
78.2					78.5	
81.4					84.6	
130.9					135.3	
105.8					107.4	
115.2					116.3	
194.6					200.2	
101.0					101.6	
106.3					108.1	
97.3					97.7	
63.6					64.4	
120.8					125.3	
63.2					64.0	
55.5					56.0	
62.8					63.2	
103.4					104.7	
139.8					143.2	
108.3					109.7	

River	Kabinakgami	Nagagami	Shekak	Groundhog	Missinaibi	Mattawiskwia
Nat/Reg	Nat	Nat	Nat	Reg	Nat	Nat
Year	04JA002	04JC002	04JC003	04LD001	04LJ001	04LK001
Area (km^2)	3780	2410	3290	11900	8940	1140
Daily	Instantaneous Peak l/s/km^2					
82.9					84.9	
49.7					50.1	
55.8					56.3	
168.9					168.9	
107.6					108.3	
63.1					64.3	
80.3					80.8	
66.1					67.8	
132.0					133.1	
123.0					127.5	
91.2					95.1	
46.3					47.2	
91.2					91.9	
61.6					62.8	
72.0					72.6	
85.5						87.5
80.9						81.8
100.0						101.8
115.8						117.5
250.9						260.5
74.3						74.9
271.9						286.0
140.4						145.6
116.7						118.4
84.6						90.4
90.4						93.0

The range of drainage areas in Table 11 encompasses the drainage area of the Frederick House River at Wanatango Falls, 2970 km^2. Figure 13 shows the instantaneous flood peaks plotted against the daily peaks. A linear regression line fitted to these data points gives the following relationship:

Instantaneous Flood Peak = 1.02 x Daily Flood $R^2 = 0.9987$

Thus an instantaneous flood maxima series can be estimated for the Frederick House River at Wanatango Falls by increasing the daily maxima series by 2%.

The estimated instantaneous flood maxima at Wanatango Falls are shown in Table 12.

This 56-year instantaneous flood maxima series was entered into the SAAS model and also into Environment Canada's Consolidated Frequency Analysis software CFA3.1. In CFA3.1 the data set was tested for independence, trend, homogeneity and randomness and was found to be free of statistical inconsistencies, except for a slight dependence at the 5% significance level.

The data set was then subjected to parametric flood frequency analysis using the following frequency distributions:

- General Extreme Value (GEV)
- 3 parameter Lognormal
- Log Pearson Type III
- Wakeby.

Table 13 shows the flood frequency analysis results at Wanatango Falls.

Figure 14 shows the GEV distribution, which was found to give the best fit to the data.

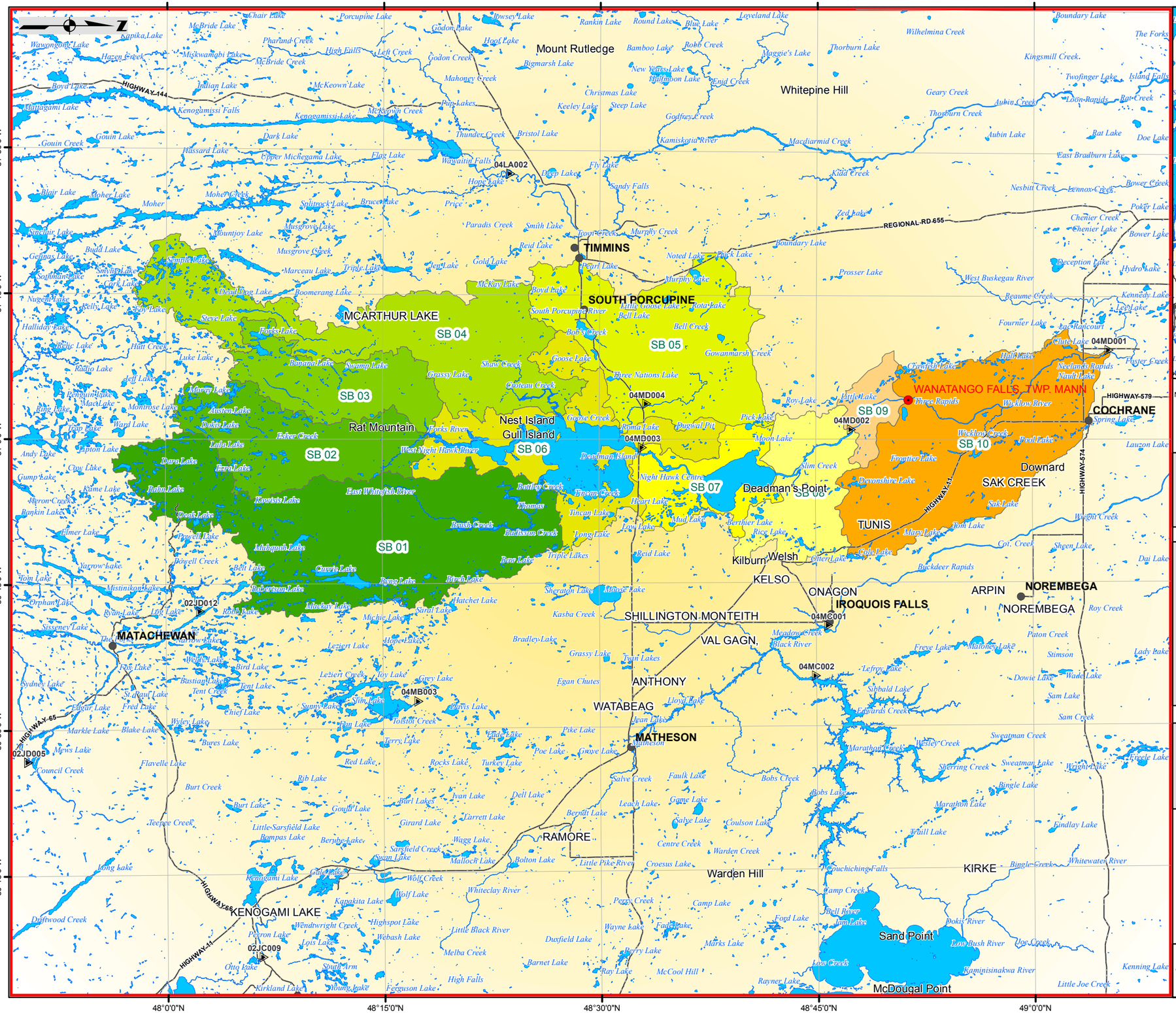
Table 12 Estimated Instantaneous Flood Maxima for the Frederick House River at Wanatango Falls

Year	Peak (m^3/s)	Year	Peak (m^3/s)
1939	286	1967	222
1940	196	1968	170
1941	163	1969	129
1942	204	1970	109
1943	159	1971	146
1944	159	1972	161
1945	187	1973	162
1946	220	1974	163
1947	352	1975	146
1948	145	1976	380
1949	176	1977	224
1950	193	1978	270
1951	164	1979	211
1952	176	1980	124
1953	142	1981	83.5
1954	182	1982	236
1955	84.3	1983	260
1956	248	1984	258
1957	374	1985	260
1958	181	1986	149
1959	138	1987	128
1960	451	1988	314
1961	240	1989	285
1962	189	1990	162
1963	175	1991	141
1964	186	1992	136
1965	183	1993	114
1966	240	1994	81.8

Table 13 Flood Frequency Analysis for the Frederick House River at Wanatango Falls

Return Period Years	Instantaneous Flood Peak in m^3/s			
	GEV	3 para Lognormal	Log Pearson III	Wakeby
1.003	73.0	69.8	70.5	53.5
1.050	103	101	102	97.4
1.250	135	135	136	142
2	180	183	183	178
5	247	250	249	246
10	295	295	294	297
20	344	338	337	349
50	412	394	394	417
100	467	437	437	469
200 (1)	526	481	482	521
500 (1)	609	539	542	591
1000 (1)	677	590	595	648

Note: (1) Flood estimates with a return period of greater than 100 year should be used with caution. The Flood flows are intended for use in the EA and shall not be used for engineering design without further review.



NOTES:

1. MAPPING INFORMATION SHOWN ON THE DRAWING HAS BEEN DERIVED FROM THE DIGITAL DATA FROM MNR DATABASE
2. PROJECTED COORDINATE SYSTEM IS NAD 1983, UTM ZONE 17N.

LEGEND

- WATER BODIES
- SUB-BASINS

SUB BASIN ID	DRAINAGE	AREA (km^2)
SB 01	WHITEFISH RIVER	737
SB 02	NIGHT HAWK RIVER	279
SB 03	FORKS RIVER	208
SB 04	REDSTONE RIVER	489
SB 05	PORCUPINE RIVER	444
SB 06	NIGHT HAWK LAKE LOCAL	379
SB 07	FREDERICKHOUSE LAKE LOCAL	169
SB 08	FREDERICKHOUSE DAM, 04MD002 LOCAL	201
SB 09	WANATANGO FALLS LOCAL	64
SB 10	WSC GAUGE 04MD001 LOCAL	559

DRAINAGE AREA SUMMARY:

LOCATION	AREA (km^2)
GAUGE - 04MD002	2906
WANATANGO FALLS	2970

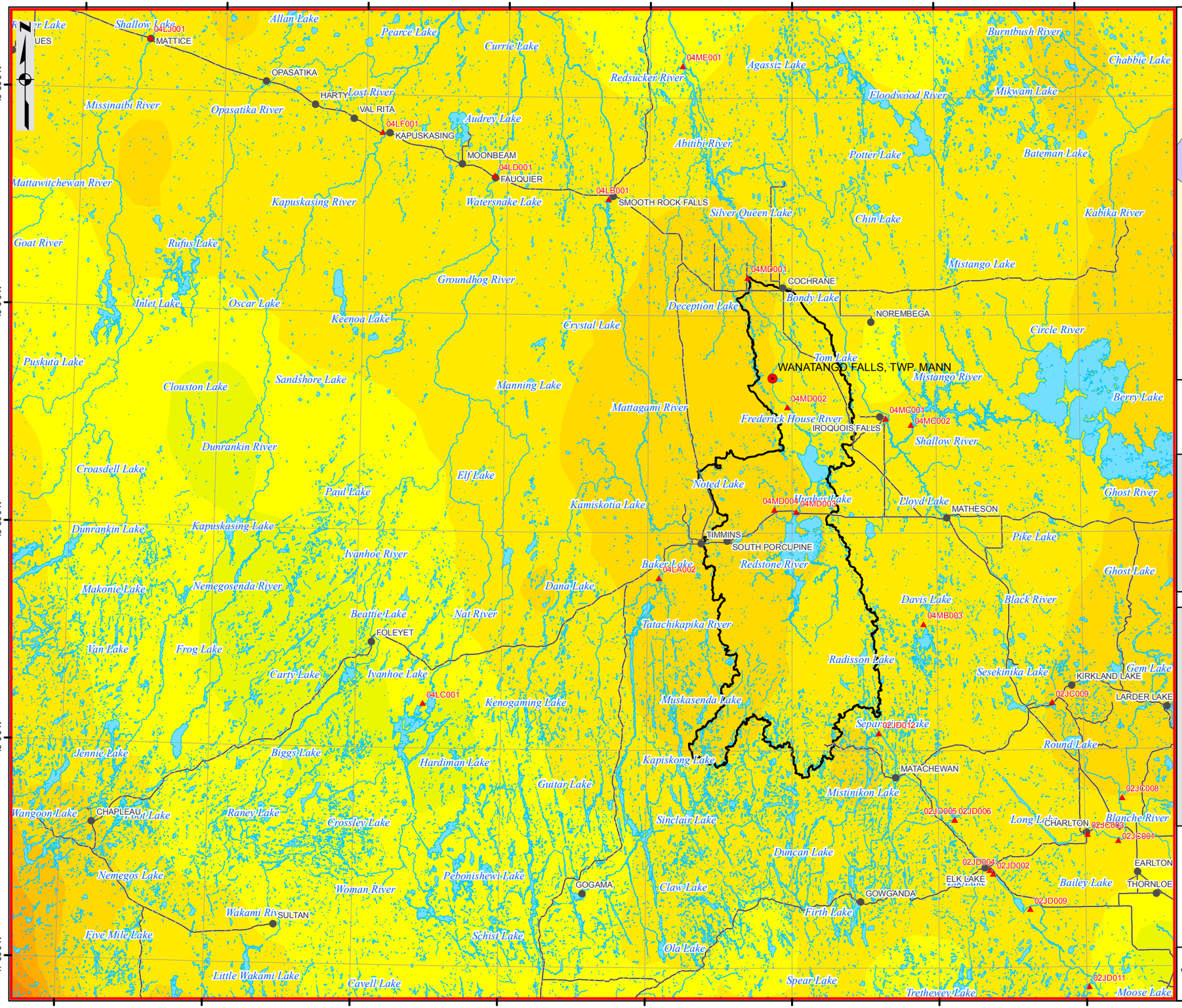
Xeneca Power Development Inc.

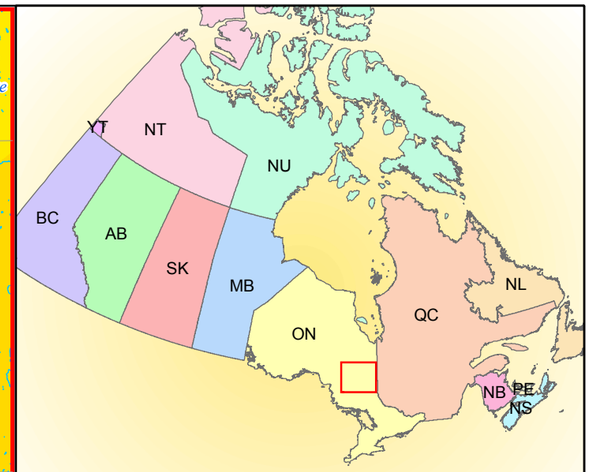
XENECA POWER FIGURE 1

WANATANGO FALLS HYDRO DEVELOPMENT
WANATANGO FALLS WATERSHED

HATCH™

D:\Projects\Xeneca\Wanatango\GIS\ArcMaps\Wanatango - Drainage Basin.mxd - 13-Aug-09 @ 12:58:38 Shawn





NOTES:
1. MAPPING INFORMATION SHOWN ON THE DRAWING HAS BEEN DERIVED FROM THE DIGITAL DATA FROM MNR DATABASE
2. PROJECTED COORDINATE SYSTEM IS NAD 1983, UTM ZONE 17N.
3. PRECIPIATION DERIVED USES MONTHLY CLIMATE DATA (1961-1990)
   SOURCE: CANADA GRIDDED CLIMATE DATA, RON HOPKINSON
   HTTP://WWW.CICS.UVIC.CA/CLIMATE/DATA.HTM

LEGEND

- POPULATED PLACES
- GAUGING STATION
- WATER BODIES
- ROAD NETWORK
- GAUGE 04MD001 WATERSHED

ANNUAL AVG. PRECIPITATION (MM)

451 - 478	692 - 717	931 - 957
479 - 505	718 - 744	958 - 983
506 - 531	745 - 771	984 - 1,010
532 - 558	772 - 797	1,011 - 1,036
559 - 584	798 - 824	1,037 - 1,063
585 - 611	825 - 850	1,064 - 1,090
612 - 638	851 - 877	1,091 - 1,116
639 - 664	878 - 903	1,117 - 1,143
665 - 691	904 - 930	1,144 - 1,169

Xeneca Power Development Inc.

0 1 : 1,000,000 50 Kms

XENECA POWER
WANATANGO FALLS HYDRO DEVELOPMENT
ANNUAL AVG. PRECIPITATION

FIGURE 2

HATCH™

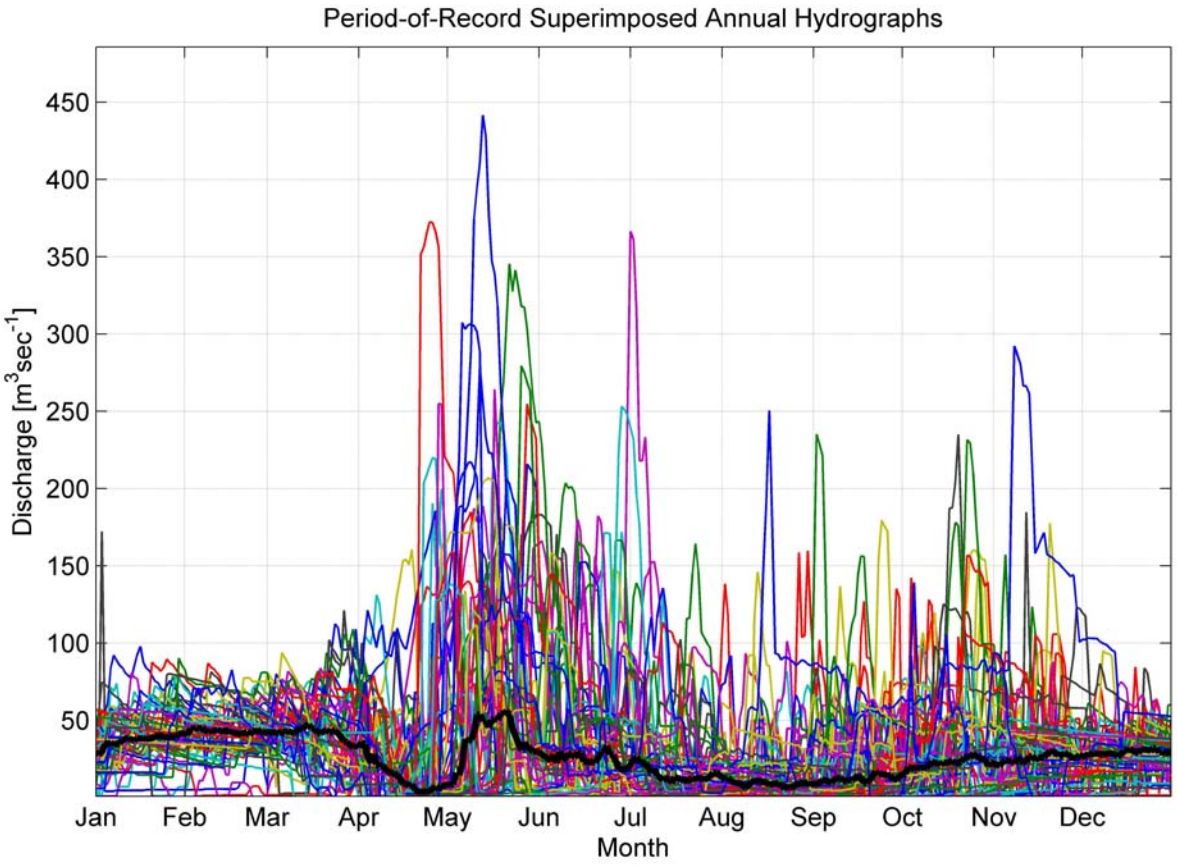


Figure 3 (SAAS) Superimposed Daily Hydrographs at Wanatango Falls

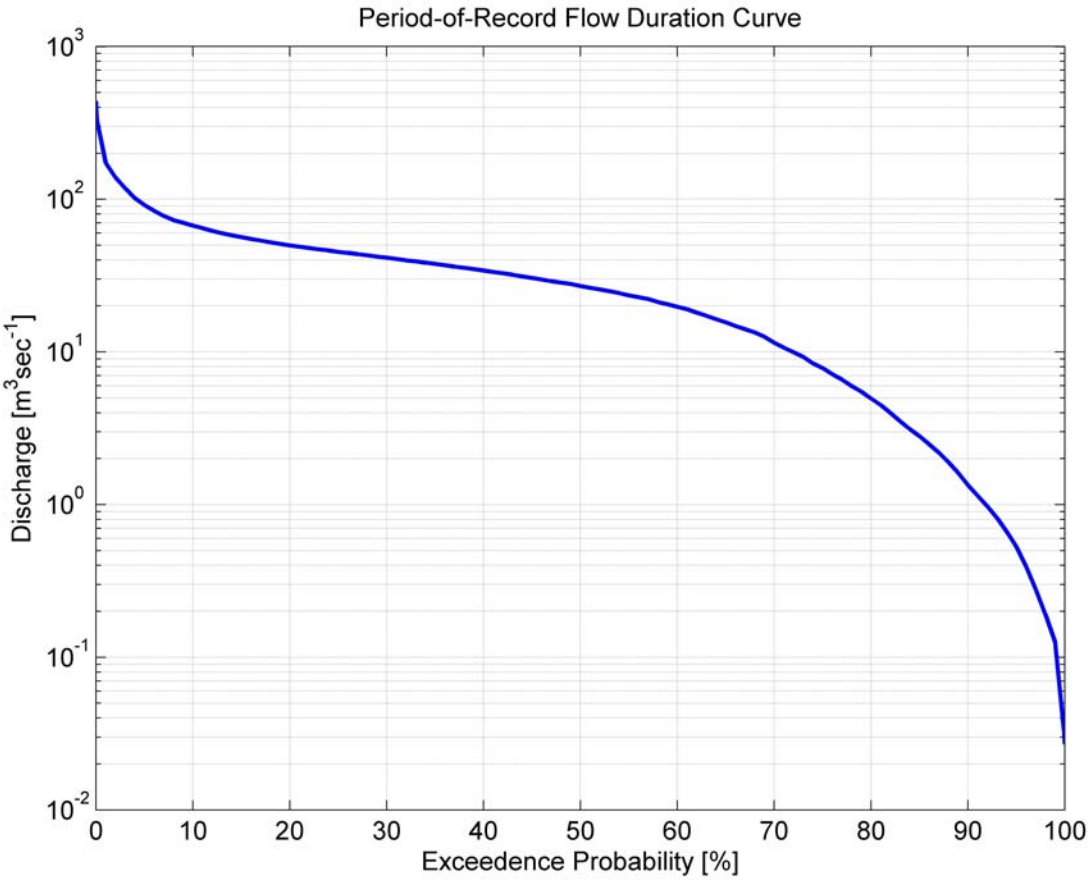


Figure 4 (SAAS) Period of Record Total Daily Average Flow Duration Curve

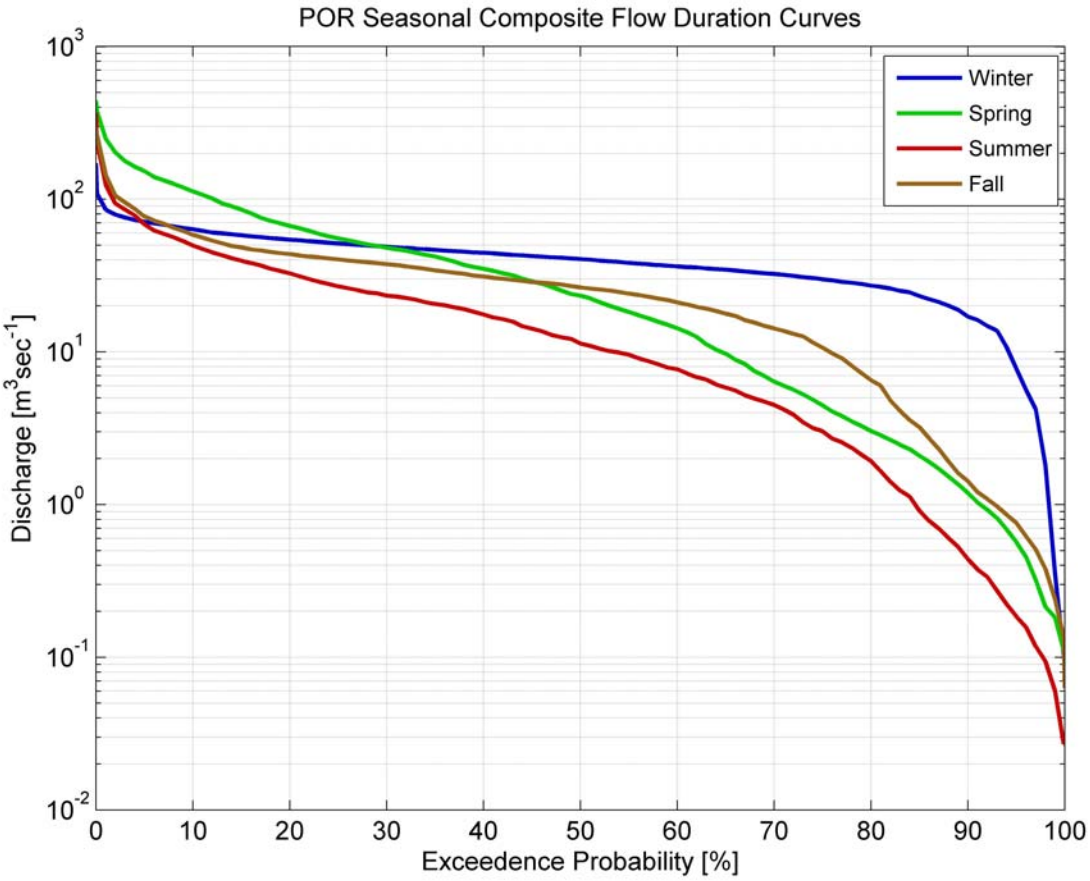


Figure 5 (SAAS) Period of Record Seasonal Composite Flow Duration Curves

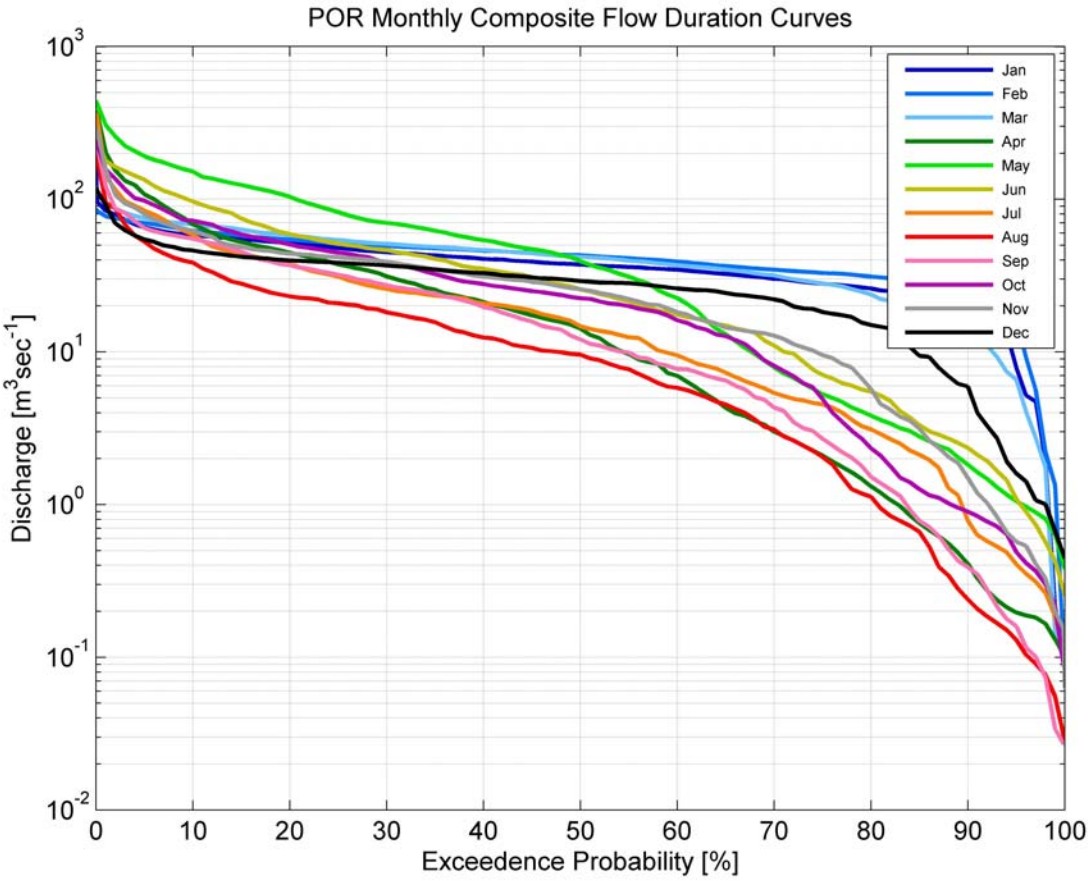


Figure 6 (SAAS) Period of Record Monthly Composite Flow Duration Curves

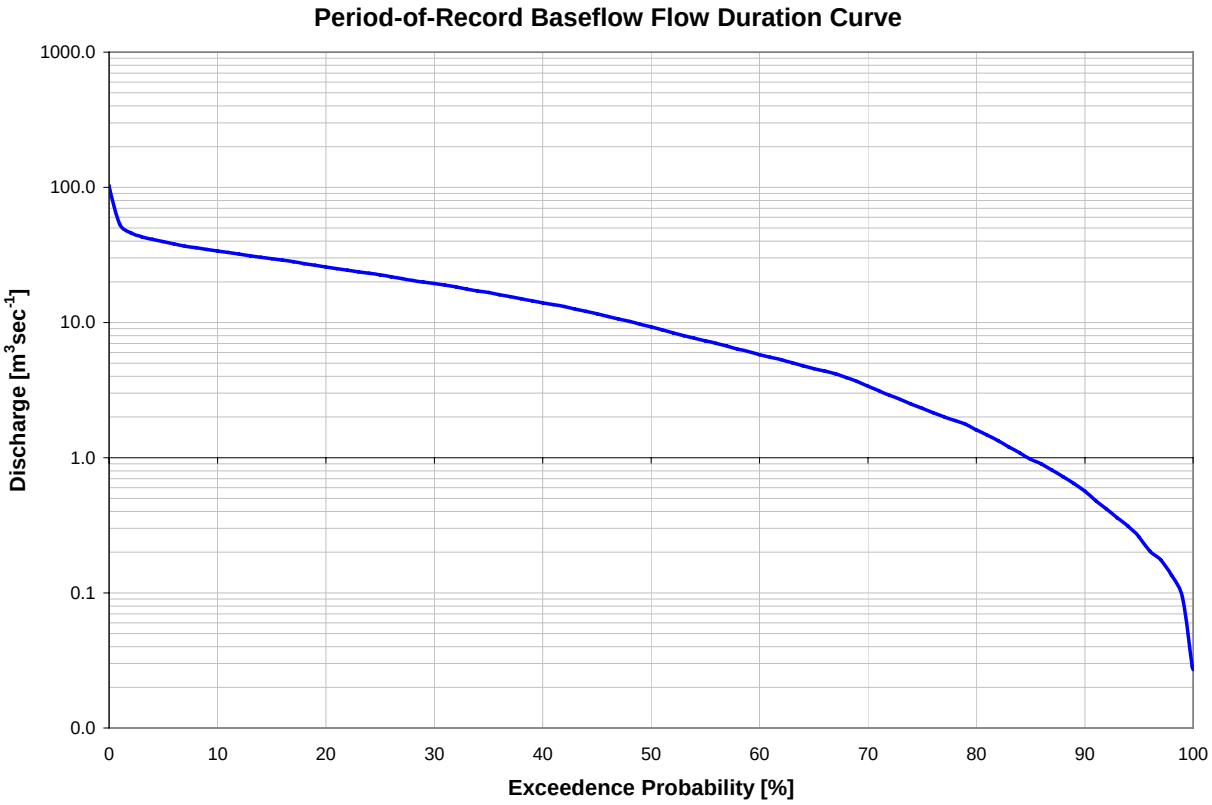


Figure 7 (SAAS) Period of Record Baseflow Flow Duration Curve

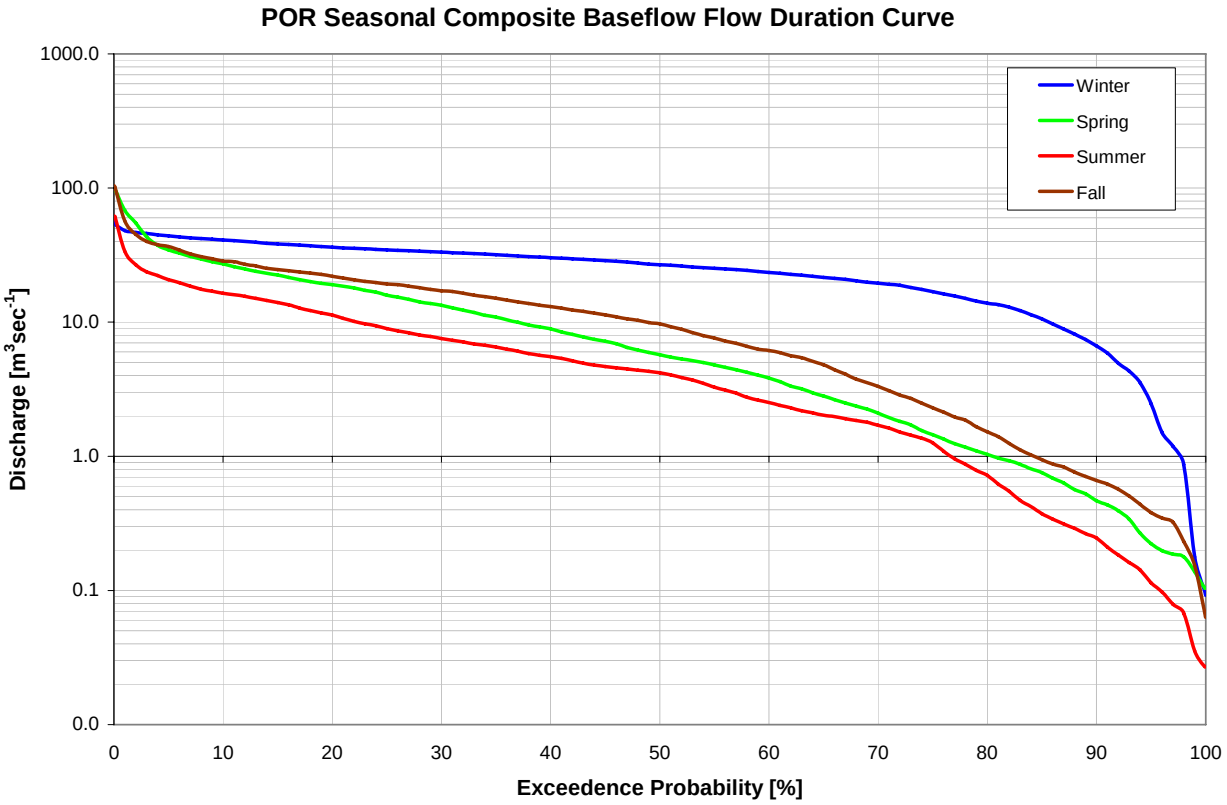


Figure 8 (SAAS) Period of Record Seasonal Composite Baseflow Flow Duration Curves

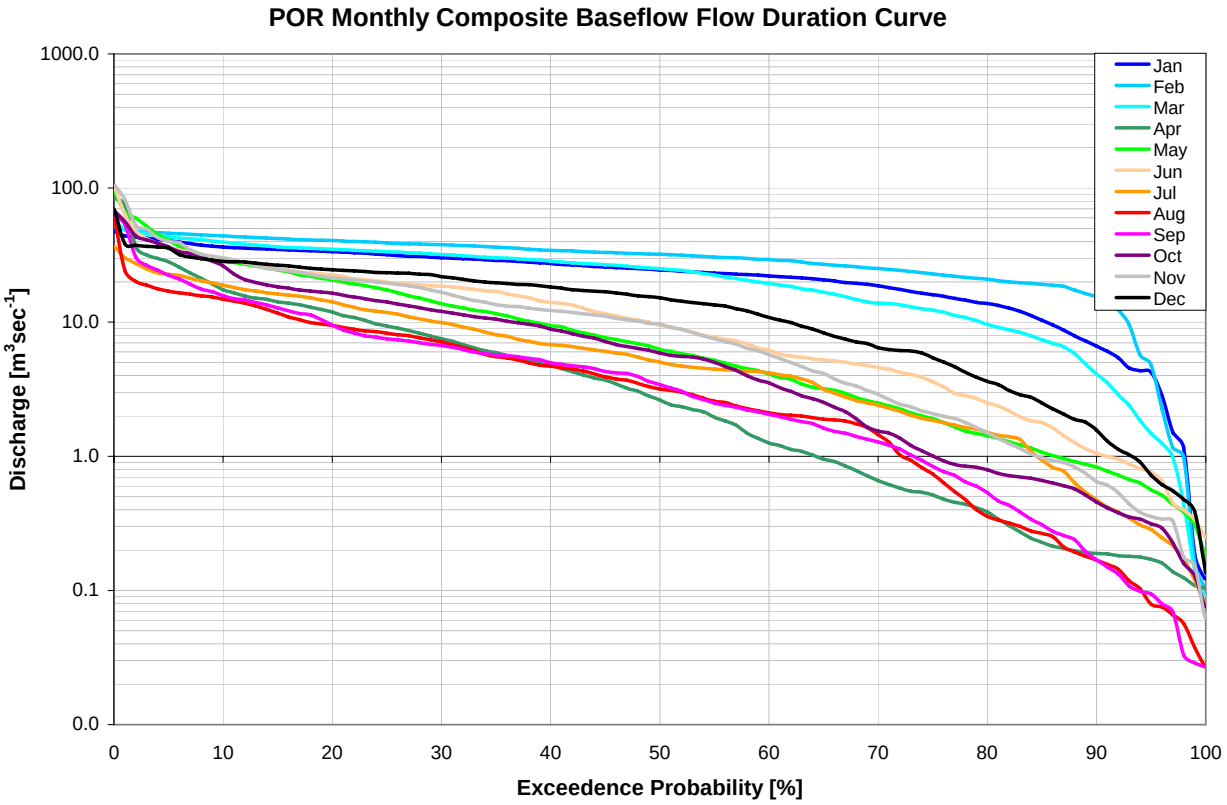


Figure 9 (SAAS) Period of Record Monthly Composite Baseflow Flow Duration Curves

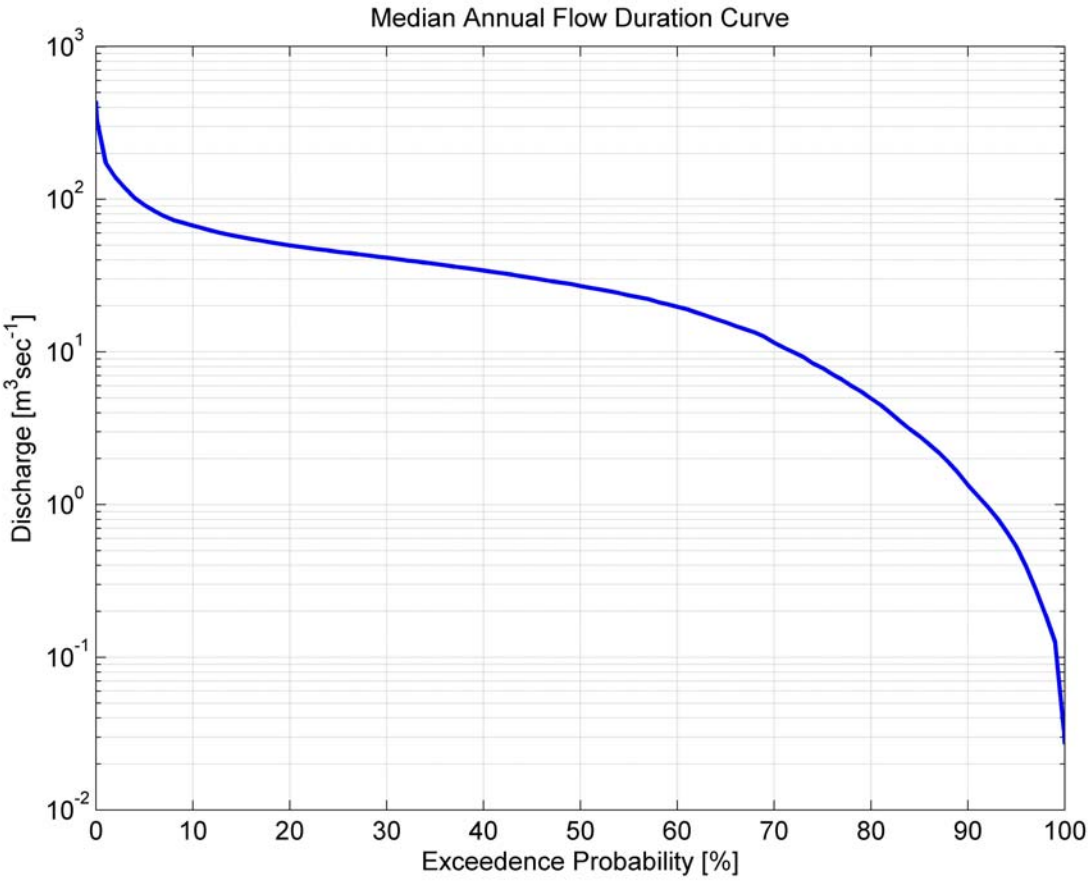


Figure 10 (SAAS) Median Annual Flow Duration Curve

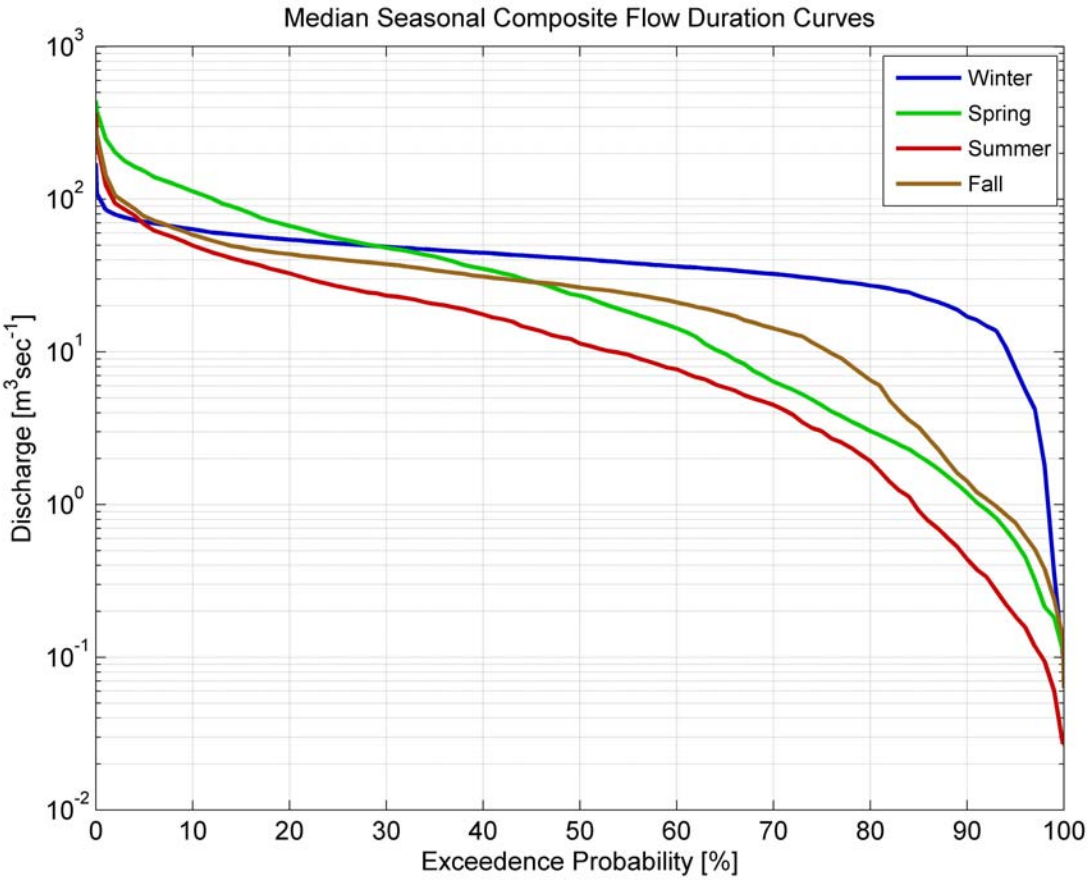


Figure 11 (SAAS) Median Seasonal Composite Flow Duration Curves

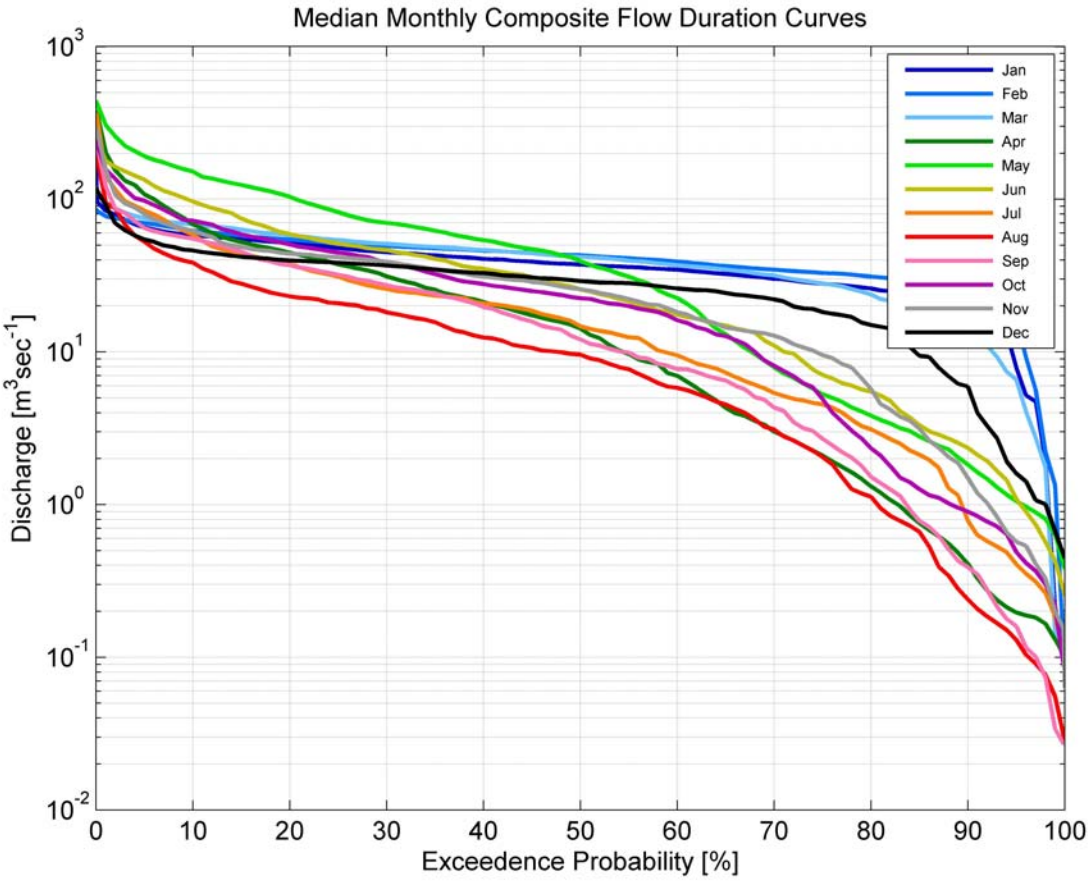


Figure 12 (SAAS) Median Monthly Composite Flow Duration Curves

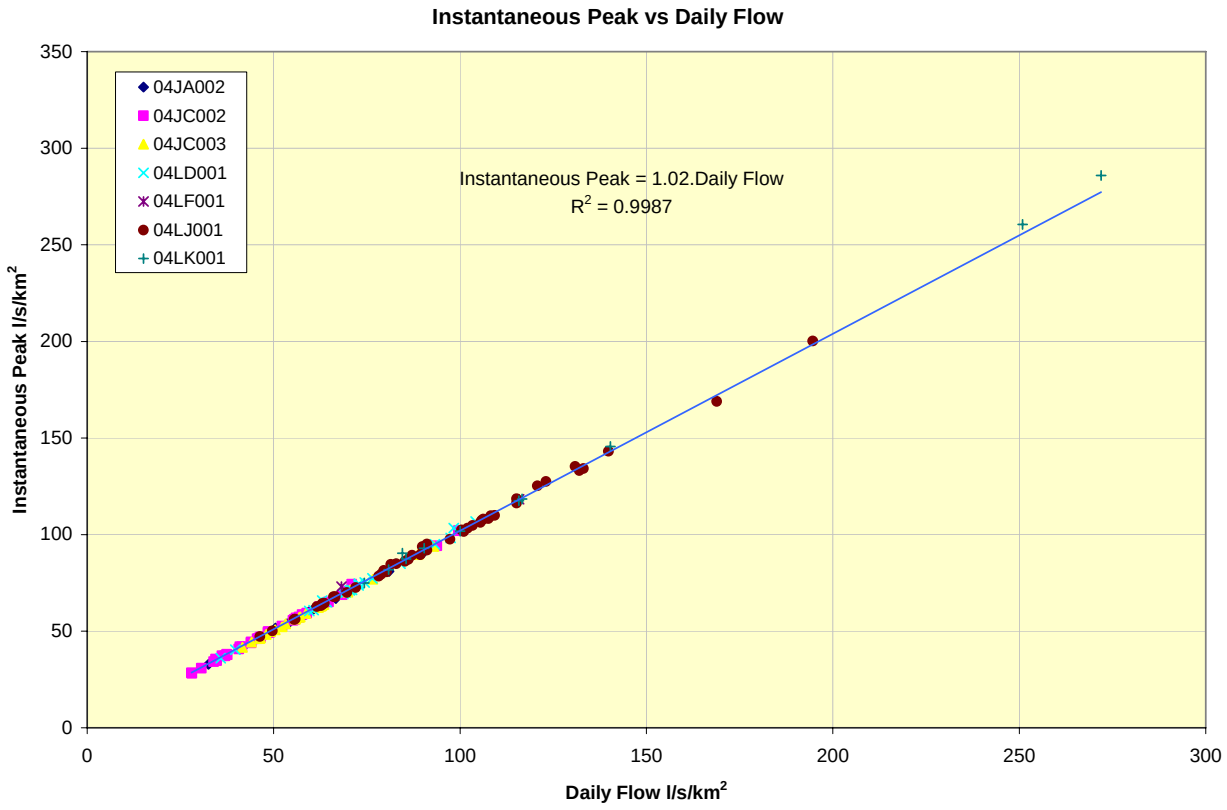


Figure 13 **Instantaneous Peaks vs Daily Flow for Rivers in Northeast Ontario Region**

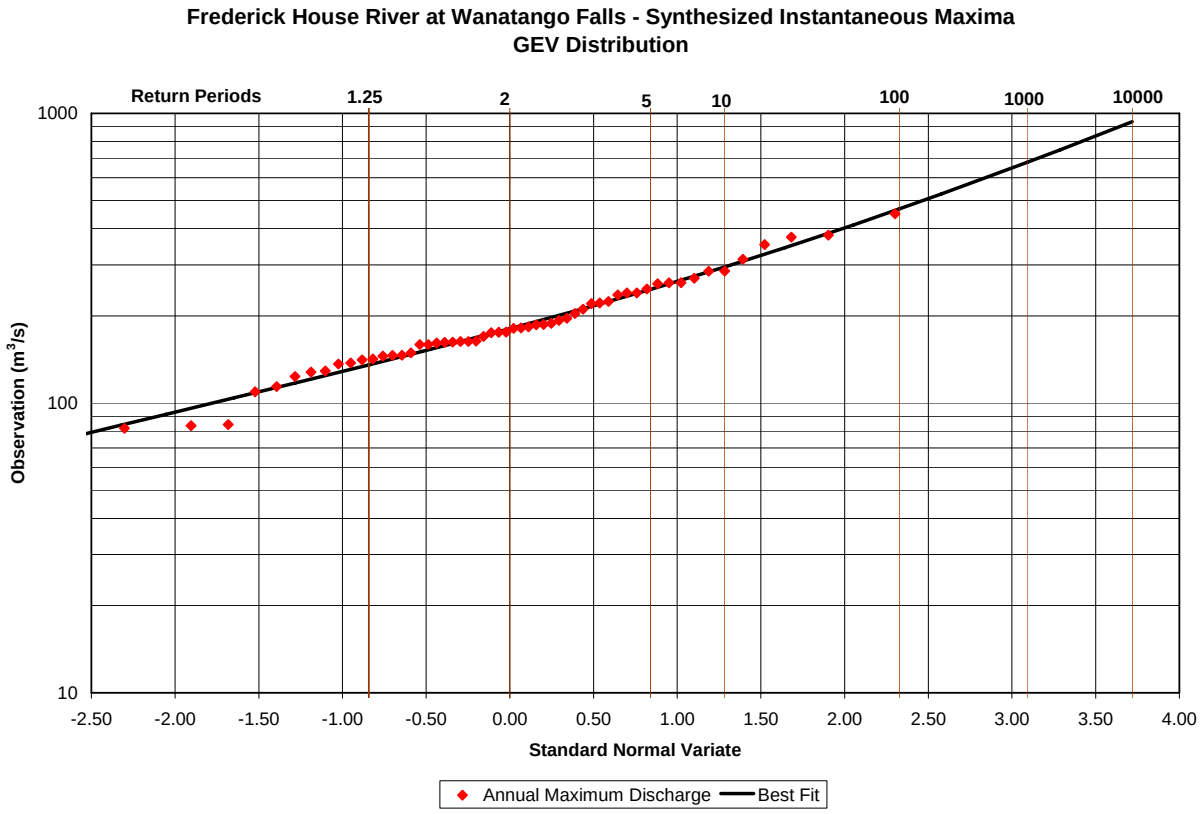


Figure 14 (CFA3.1) Instantaneous Flood Frequency Analyses for Wanatango Falls

Appendix A
MOE Hydrology Requirements

What information is required under hydrological analysis?	Location
a) Descriptive flow statistics using all available daily flows for all years: mean, median, minimum, maximum, flow exceeded 20% time, flow exceeded 80% time.	Hydrology Report
b) Extreme low flow statistics: $7Q_2$ (2 year return period 7-day-average-low flow), $7Q_{10}$ (10 year return period 7-day-average-low flow) and $7Q_{20}$ (20 year return period 7-day-average-low flow).	Section 3
c) Flow duration curves and tables using total daily average flow data for the entire period, for all four seasons and for all twelve months.	Section 4
d) Flow duration curves and tables using daily baseflow data for the entire period, for all four seasons and for all twelve months.	Section 5
e) Flow duration curves derived using both the percentile method and the median of percentiles method. Both methods are incorporated into the flow analysis tool, developed by Schmidt and Metcalfe (2009), which can be downloaded for free from http://trentu.ca/iws/software.php.	Section 6
f) Flood frequency analysis using instantaneous maximum flow of each year for the entire period of records.	Section 7
g) Low flow frequency analysis using 7-day-average-low flow for the entire period of records.	Section 3
h) Altered flow of the bypass reach and the reach below tailrace, if applicable.	n/a
i) Compensation flow for the bypass reach and the reach below tailrace, if applicable.	n/a

Appendix B
MOE Hydrology Requirement Calculation Procedures

Hydro Site Hydrology in Ontario

Daily Flow Series Synthesis

Long Term Average Flow

Step 1
Select regional stream flow station records for analysis

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Step 2
Check streamflow records for missing data - reject incomplete records

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Step 3
Screen streamflow records for statistical consistency - reject records significantly inconsistent at the 1% level

↓

Step 4
Select start and end years for flow comparison period

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Step 5
Adjust mean annual runoff (MAR) for streamflow stations to the selected comparison period

↓

Step 6
Estimate mean annual precipitation (MAP) for each river basin using Environment Canada GIS precipitation database

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Step 7
Estimate mean annual lake evaporation E_L for each river basin using E_L data for Ontario

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Step 8
Estimate actual evaporation adjustment factor C for each river basin from:
$C = (MAR - MAP)/E_L$

↓

Step 9
Estimate MAP and E_L for the hydro site river basin using Steps 6 and 7 methodology

↓

Step 10
Select actual evaporation adjustment factor C_{HS} for hydro site river basin based on lake density and land use

↓

Step 11
Calculate MAR_{HS} for hydro site river basin from:
$MAR_{HS} = MAP_{HS} - C_{HS}.E_{L\ (mm)}$

↓

Step 12
Calculate long term average flow (LTAF) for hydro site from:
$LTAF = MAR.DA_{HS}/31{,}558\ \ m^3/s$ (DA_{HS} is drainage area at hydro site in km^2)

Hydro Site Hydrology in Ontario

Daily Flow Series Synthesis

Representative Streamflow Record

Step 1
Select regional stream flow station records to convert the LTAF for the hydro site to a daily flow series

Step 2
Qualitatively assess the characteristics of each river basin:
- degree of regulation, natural or man-made
- drainage area and direction
- latitude and orientation
- drainage density
- lake coverage and land use

Step 3
The representative streamflow record should have a similar:
- seasonal flow pattern
- temporal flow distribution
- annual variability

as the ungauged hydro site

Step 4
For each streamflow record divide long term average monthly flow by the LTAF to get a dimensionless seasonal flow pattern

Step 5
For each streamflow record note the maximum month of the year and % LTAF and minimum month of the year and % LTAF

Step 6
For each streamflow record prepare a dimensionless daily flow/LTAF duration curve

Step 7
For each streamflow record note the shape of the curve a the percent excedance values at the extremes of the curve

Step 8
For each streamflow record plot the dimensionless historic histogam of mean annual flow/LTAF - patterns should be similar for rivers in the same region

Step 9
Qualitatively assess the characteristics of the river basin at the hydro site - see Step 2

Step 10
Select representative streamflow record that best fits the characteristics of the river basin at the hydro site

Step 11
If more than one streamflow record meets the criteria above select a record with the best measurement method from (best to worst):
1. Continuous (river section)
2. Continuous (at dam)
3. Manual
4. Powerplant

Step 12
Calculate daily flows for hydro site from daily flows at the selected representative streamflow station (RSS):

$$Flow_{HS} = Flow_{RSS} \cdot \frac{LTAF_{HS}}{LTAF_{RSS}}$$

Hydro Site Hydrology in Ontario

Ontario Ministry of the Environment Requirements	Input Data Source	Software	Comments
a) Descriptive flow statistics using all available daily flows for all years: mean, median, minimum, maximum, flow exceeded 20% time, flow exceeded 80% time.	Long term daily flow series synthesized for hydro site. Must be > 20 years.	SAASv2.1.1	The Hydrograph Explorer (Basic Table) and Flow Analysis (Flow Duration Curves) applications.
b) Extreme low flow statistics: $7Q_2$ (2 year return period 7-day-average-low flow), $7Q_{10}$ (10 year return period 7-day-average-low flow) and $7Q_{20}$ (20 year return period 7-day-average-low flow).	Long term daily flow series synthesized for hydro site. Must be > 20 years.	ENGSOFT/ ESLOFFAN	7-day average low flow frequency analysis application; 2LN, 3LN, Log Pearson and Gumbel distributions.
c) Flow duration curves and tables using total daily average flow data for the entire period, for all four seasons and for all twelve months.	Long term daily flow series synthesized for hydro site. Must be > 20 years.	SAASv2.1.1	Flow Analysis (Flow Duration Curves); period of record, seasonal and monthly applications.
d) Flow duration curves and tables using daily baseflow data for the entire period, for all four seasons and for all twelve months.	Long term daily flow series synthesized for hydro site. Must be > 20 years.	SAASv2.1.1	Flow Analysis (Baseflow analysis table); 1, 5, 25, 50, 75, 95 and 99% baseflow exceedance values for: period of record, seasonal and monthly applications.
e) Flow duration curves derived using both the percentile method and the median of percentiles method. Both methods are incorporated into the flow analysis tool, developed by Schmidt and Metcalfe (2009), which can be downloaded for free from http://trentu.ca/iws/software.php.	Long term daily flow series synthesized for hydro site. Must be > 20 years.	SAASv2.1.1	Flow Analysis (Flow Duration Curves); percentile and median of percentiles methods for; period of record, seasonal and monthly applications.
f) Flood frequency analysis using instantaneous maximum flow of each year for the entire period of records.	Long term instantaneous flood series synthesized for hydro site. Must be > 20 years.	CFA3.1	See Flood Frequency Analysis sheet
g) Low flow frequency analysis using 7-day-average-low flow for the entire period of records.	Long term daily flow series synthesized for hydro site. Must be > 20 years.	ENGSOFT/ ESLOFFAN	7-day average low flow frequency analysis application; 2LN, 3LN, Log Pearson and Gumbel distributions.
h) Altered flow of the bypass reach and the reach below tailrace, if applicable.	Design flow series.	To be defined in design phase	
i) Compensation flow for the bypass reach and the reach below tailrace, if applicable.	Design flow series.	To be defined in design phase	

Hydro Site Hydrology in Ontario

Flood Frequency Analysis

Step 1
Pre-process instantaneous annual flood peak series from synthesized daily flow series at the hydro site:
1. Select instantaneous and daily annual flood peaks from regional streamflow stations
2. Compare peaking factors (instantaneous/daily peaks) with:
- Drainage area
- Season
- Regulation (natural and man-made)
- Flood magnitude (divided by drainage area)
- previous and following day flows
3. Derive fuction to estimate instantaneous flood peaks from daily flood peaks
4. Use function to estimate instantaneous annual flood peak series from synthesized daily flow series at hydro site

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Step 2
Input the synthesized instantaneous flood peak series to the CFA3.1 software

↓

Step 3
Screen synthesized instantaneous flood peak series for statistical consistency, including:
- Independence
- Trend
- Homogeneity
- General Randomness

↓

Step 4
Test for high and low outliers and adjust accordingly

↓

Step 5
Perform parametric frequency analysis using:
- The General Extreme Value (GEV) Distribution
- The Three-Parameter Lognormal (3LN) Distribution
- The Log Pearson Type III Distribution
- The Wakeby Distribution

↓

Step 6
Select best fit frequency distribution

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Step 7
Plot and tabulate instantaneous flood peak estimates for hydro site

Hydro Site Hydrology in Ontario

Hydrological Software used in Analysis

Software	Title	Source	Year	Description
SAASv2.1.1	Streamflow Analysis and Assessment Software	Ontario Ministry of Natural Resources	2010	SAAS is a MATLAB application to analyze an annual maxima flow series, daily streamflow time-series and hourly streamflow time-series. The software produces tabular and graphic reports on: - flow hydrographs - flood frequency analysis - flow duration curves - baseflow - rate of change
ESLOFFAN	EngSoft LOw Flow Frequency ANalysis	ENGSOFT	1995	ESLOFFAN extracts the annual minimum 7-day or 30-day average flows from a HYDAT formatted daily flow series and undertakes low flow frequency analysis using the 2LN, 3LN, Log Pearson III and Gumbel distributions. The software produces tabular and graphic output for each distribution.
CFA 3.1	Consolidated Frequency Analysis	Environment Canada	2000	CFA 3.1imports an annual maxima flow series and stores it in a direct access file. The software performs the following tests on the data series: - Spearman rank order serial correlation coefficient test for independence - Spearman rank order correlation coefficient test for trend - Mann-Whitney split sample test for homogeneity - Runs above and below the median for general randomness Flood estimates are computed using the following distributions: - The General Extreme Value (GEV) Distribution - The Three-Parameter Lognormal (3LN) Distribution - The Log Pearson Type III Distribution - The Wakeby Distribution The software produces tabular and graphic output for each distribution.