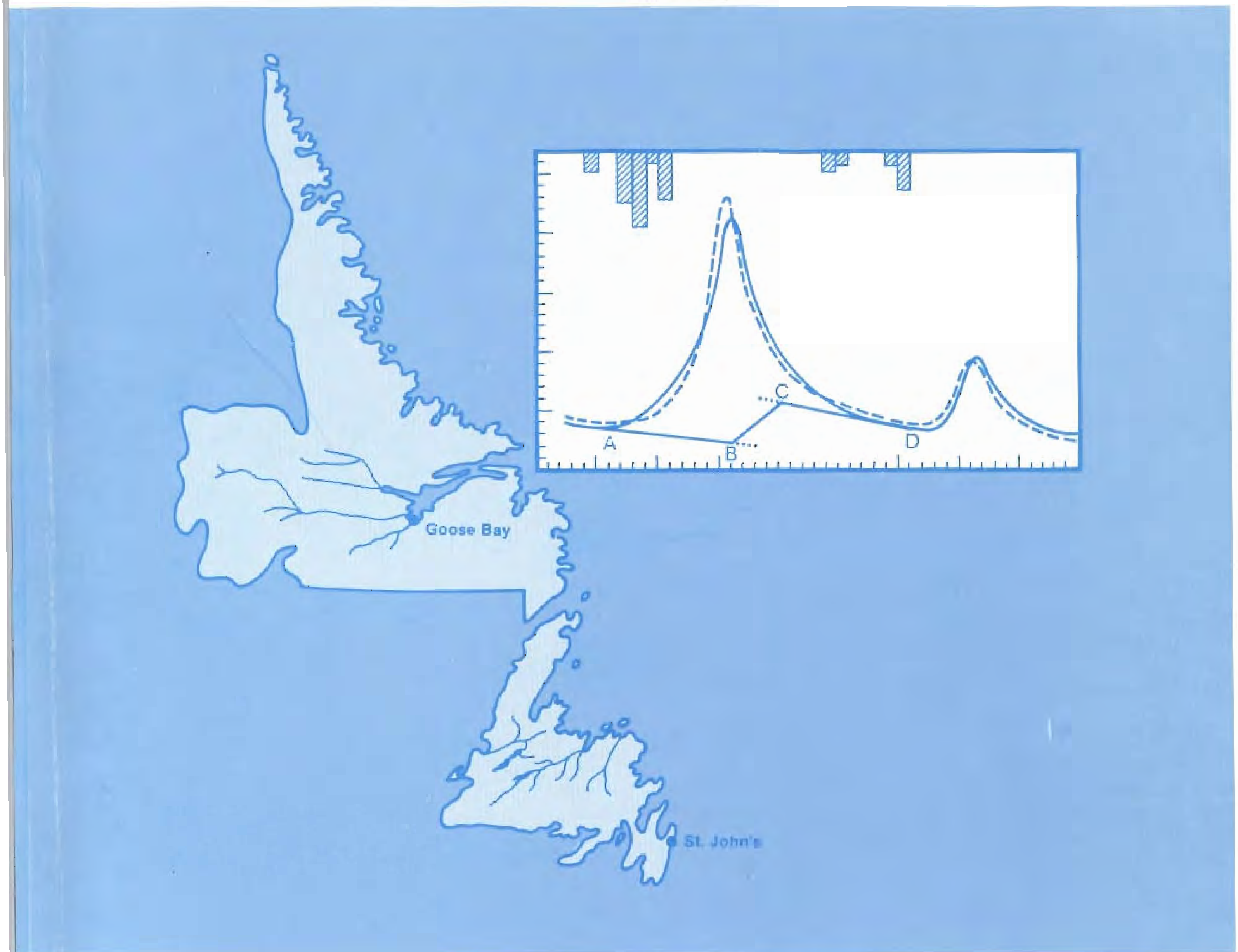
Characteristics and Estimation of Minimum Streamflows for the Island of Newfoundland



Government of Newfoundland and Labrador
Department of Environment and Lands
Water Resources Division

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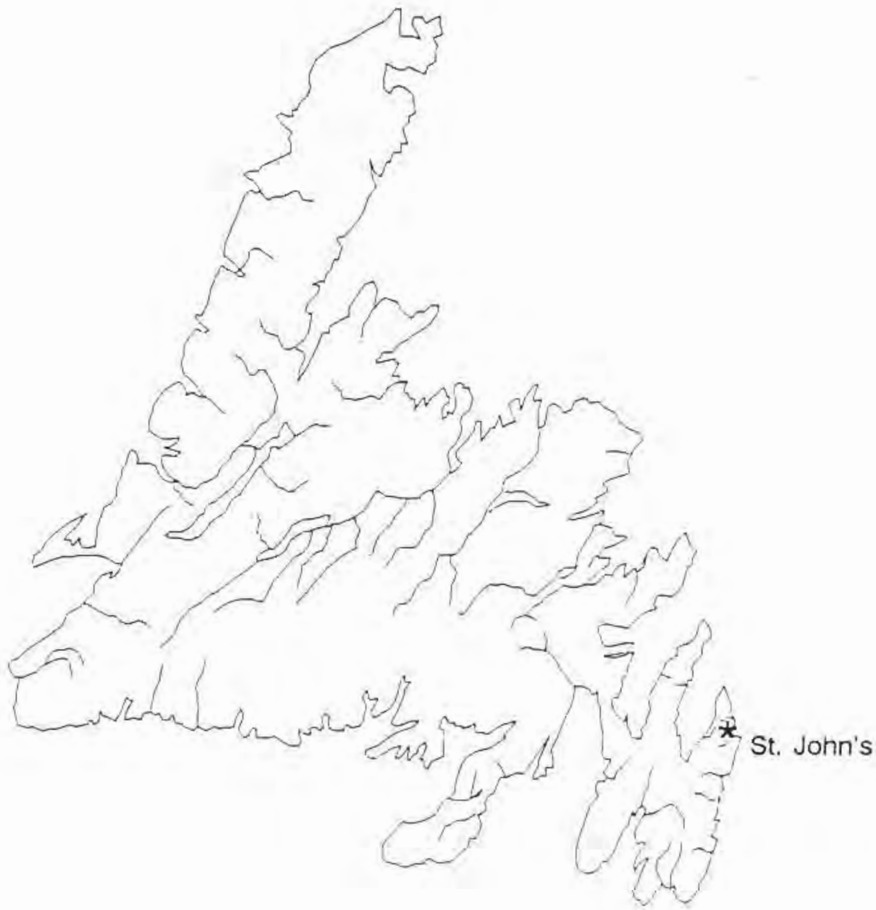

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SUMMARY

The objectives of the study were to quantify the characteristics of low stream flows for the Island of Newfoundland and to develop equations which could be used to estimate low flows of various durations and return periods on ungauged streams.

At each of thirty-nine gauging stations selected for the study, daily flows over the period of record were analyzed to obtain the minimum summer and winter N-day flows. The selected durations, N, of the low flow periods were 1, 7, 15 and 30 days.

The Gumbel Type III distribution was fitted to all winter and summer low flow series. The summer low flows were in most cases smaller than the winter low flows of the same duration and return period. The exceptions were the low flow estimates at three stations on the northern tip of the Northern Peninsula and three stations in southwestern Newfoundland.

The regional mean summer 1-day low flows per unit area were 5.4 $l/s/km^2$ on the Avalon and Burin Peninsulas, 3.1 $l/s/km^2$ on the north-central part of the Island, 4.7 $l/s/km^2$ on the Northern Peninsula and 5.1 $l/s/km^2$ on the southwestern corner of the Island. The corresponding values for the summer 30-day low flow series were 11 $l/s/km^2$, 7.3 $l/s/km^2$, 5 $l/s/km^2$ and 10.5 $l/s/km^2$. For about 5% of the winter low flow series and 20% of the summer low flow series, there was a finite probability of zero flow.

Regression analysis between the frequency estimates of low flows and watershed parameters were carried out separately in three regions of the Island. These regions were (A) the Avalon and Burin Peninsulas and southwest Newfoundland, (B) the north-central region of the Island and (C) the Humber Valley - Northern Peninsula region. These three regions had distinct hydrologic, climatic and physiographic characteristics.

The correlation coefficients for most of the regression equations derived were above 0.9. The percentage difference between frequency and regression estimates, in most cases, ranged between -50% and +50%. Some percentage differences were very high, of the order of 100%. These occurred mostly for the cases where the frequency estimate of the low flow was very close to zero and the difference between the frequency and regression estimates was almost equal to the frequency estimate itself.

The regression equations were tested on twenty-one watersheds with between four and seven years of flow data. These flow records were not used in deriving the regression equations. The results indicate that the performance of the regression equations, while not wholly satisfactory, was reasonable given the shortness of the flow records used in the test.

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Chapter 1

INTRODUCTION

1.1 General

The management of surface water resources would be relatively simple if stream flows were constant in time; the main decision to be made would be the allocation of the perfectly known flows to the various users. The reality, however, is that stream flows are naturally variable; they vary both during a year and from year to year. In the face of these uncertainties water management decisions can only be made with predicted estimates of stream flows.

This report describes the characteristics of low stream flows for the Island of Newfoundland. Equations which may be used to predict the expected low flow of given duration and return period on ungauged streams are then presented.

The characteristics and estimation of low flows are important for several water resources engineering and management applications such as estimating available water supply for municipal and industrial uses, determining the waste-water effluent dilution potential of a receiving stream, predicting the impact of stream diversions on the minimum flow requirements for spawning and migrating fish and, generally, for environmental impact assessment studies.

1.2 Objectives of Study

The objectives of this study are as follows:

(1) Description of the low flow hydrology of Newfoundland. This includes a frequency analysis of summer and winter low flows of various durations.

(2) Development of equations relating frequency estimates of low flows to climatic, physiographic and land cover characteristics of watersheds. Such equations are useful for estimating low flows on ungauged streams.

1.3 Characterising Low Flows

A reduction in stream flows is caused by either a decrease in rainfall amounts received or by long periods of below freezing temperatures during which all precipitation is in the form of snow and is not available for runoff until temperatures go above the freezing mark.

A low flow condition, for design purposes, can be defined as a period during which the average stream flow is a minimum for the year. Unlike floods, where the magnitude of the annual instantaneous peak flow is the primary characteristic under study, the magnitude and duration of low flow events are equally important. The duration of the low flow is usually measured in days and is expressed as an N-day low flow period. The magnitude of the low flow is expressed as the average daily flow (in m^3/s or l/s) over N continuous days.

The magnitude and duration of low flows vary from year to year and are, therefore, stochastic in nature. For this reason, low flows are described in terms of probabilities, more specifically, in terms of return periods expressed in years. For example, a low flow with duration N-day, magnitude x m^3/s and return period T years is the mean flow rate over N continuous days that one expects to be at or below x m^3/s, on the average, at least once every T years. The particular combination of duration and return period chosen for characterising a low flow is primarily a function of the intended water management or engineering application.

Low flows can also be calculated on the basis of seasons. This is done because, first, the N-day annual low flow at a gauged section of a river may not occur during the same season for the entire period of record and, second, low flows from rivers in different regions of the Island may occur during different seasons because of differences in climate. The low flows from the different seasons are analyzed separately and their frequency estimates are qualified accordingly.

Another method of characterising low flows is by means of flow duration curves. These curves represent the percent of time during an average year that a flow of given magnitude has been exceeded. This method does not give any information on the duration of low flows, but, the flow duration curves can be used to compare low flow characteristics of various regions.

Low flows usually occur during periods of low or no precipitation or during extended periods of below freezing temperatures. During these periods drainage area, extent and type of vegetation cover, soil characteristics, amount of storage available in ponds and lakes and other factors may affect the magnitude of low flows. Characterising low flows in terms of some of the significant factors is a useful exercise. In the absence of flow data, a very common situation, these expressions provide an objective and consistent method of estimating low flows in ungauged streams.

1.4 Database for Analyzing Low Flows

The analysis of low flows was carried out on daily stream flows which had not been affected by regulation or diversion. The database on daily flows from 39 gauged watersheds, available from the Water Resources Branch of Environment Canada [1], was used. Climatic data at various locations on the Island were obtained from Atmospheric Environment Services of Environment Canada [2]. A database on the physiographic and land cover characteristics of the 39 gauged watersheds, developed by the Water Resources Division, Newfoundland Department of Environment and Lands, was available [3].

1.5 Outline of Report

The general characteristics of mean monthly flows, mean annual flows, 1-day, 7-day, 15-day and 30-day low flows as well as the frequency of occurrence by month and season of the N-day low flows are given in Chapter 2. The flow duration curves at the thirty-nine gauging stations are presented in Appendix A.

The frequency estimates of low flows of various durations and return periods are given in Chapter 3. These estimates are used to quantitatively characterise low flows on the Island.

In Chapter 4, equations relating frequency estimates of low flows to watershed characteristics are presented. These expressions can be used to estimate low flows on ungauged streams.

In Chapter 5, the predictive equations given in Chapter 4 are applied on 21 watersheds which were not used in the derivation of the equations, but for which some frequency estimates of low flows are available. The results of the analysis are discussed.

The findings of the study are summarised and recommendations are presented in Chapter 6.

Chapter 2

GENERAL CHARACTERISTICS OF LOW FLOWS

2.1 Introduction

In this chapter, some general characteristics of runoff, precipitation and low flows in Newfoundland are described.

2.2 Stream Flow Data

The database on stream flows consisted of daily flows from 39 gauged watersheds in Newfoundland for their respective periods of record. Table 2.1 lists these watersheds together with the locations of the gauges, the watersheds' drainage areas and the record length available for each station. Figure 2.1 shows the locations of the 39 gauging stations and the areas they drain.

Of the 39 watersheds, 12 are located on the Avalon and Burin Peninsulas, 12 in the central region of the Island, 9 within the Humber Valley - Northern Peninsula region and 6 in the southwestern region of the Island. The drainage areas of the watersheds range from 3.9 km^2 to 4400 km^2; 12 of the watersheds have areas less than 100 km^2, 14 watersheds have areas between 100 km^2 and 400 km^2 and 13 watersheds are between 400 km^2 and 4400 km^2 in area. The daily flow record lengths vary from 8 years to 40 years. Of the 39 gauging stations, 13 stations have from 8 to 10 years of data, 6 stations have from 11 to 20 years of data and 20 stations have from 21 to 40 years of data. The average length of the flow records is 19 years.

2.3 Mean Monthly and Annual Flows

Table 2.2a shows the mean monthly and annual flows for each station in the data base and Table 2.2b shows the same flows on a per unit area basis. The unit mean annual flows vary between 0.023 $m^3/s/km^2$ and 0.066 $m^3/s/km^2$ on the Island. There are, however, regional differences. The lowest unit mean annual flows occur on the north-central part of the Island, the range is from 0.023 $m^3/s/km^2$ to 0.045 $m^3/s/km^2$. The highest unit mean annual flows occur on the southwestern part of the Island, the range is from 0.032 $m^3/s/km^2$ to 0.066 $m^3/s/km^2$.

Table 2.1 Drainage Area and Period of Record at Gauging Stations Included in Study

Station Number	Station Name	Station Location Latitude	Longitude	Drainage Area (km^2)	Period of Record	Number of Years in Record
02ZM006	NORTHEAST POND RIVER AT NORTHEAST POND	N47 38 06	W52 50 14	3.9	1953 - 1989	37
02ZL003	SPOUT COVE BROOK NEAR SPOUT COVE	N47 48 43	W53 09 15	10.8	1979 - 1989	11
02ZG004	RATTLE BROOK NEAR BOAT HARBOUR	N47 27 02	W54 51 18	42.7	1981 - 1989	9
02ZH002	COME BY CHANCE RIVER NEAR GOOBIES	N47 55 07	W53 56 59	43.3	1970 - 1989	20
02ZN001	NORTHWEST BROOK AT NORTHWEST POND	N46 51 08	W53 18 11	53.3	1967 - 1980 , 1982 - 1989	22
02ZM009	SEAL COVE BROOK NEAR CAPPAHAYDEN	N46 50 50	W52 58 27	53.6	1979 - 1989	11
02ZK002	NORTHEAST RIVER NEAR PLACENTIA	N47 16 26	W53 50 27	89.6	1979 - 1989	11
02ZG003	SALMONIER RIVER NEAR LAMALINE	N46 52 29	W55 46 39	115	1980 - 1989	10
02ZG002	TIDES BROOK BELOW FRESHWATER POND	N47 07 38	W55 15 54	166	1977 - 1989	13
02ZG001	GARNISH RIVER NEAR GARNISH	N47 12 50	W55 19 45	205	1959 - 1989	31
02ZK001	ROCKY RIVER NEAR COLINET	N47 13 29	W53 34 06	285	1950 - 1989	40
02ZH001	PIPERS HOLE RIVER AT MOTHERS BROOK	N47 56 49	W54 17 08	764	1953 - 1989	37
02YS003	SOUTHWEST BROOK AT TERRA NOVA NATIONAL PARK	N48 36 25	W53 58 50	36.7	1968 - 1989	22
02YP001	SHOAL ARM BROOK NEAR BADGER BAY	N49 22 18	W55 48 44	63.8	1982 - 1989	8
02ZJ001	SOUTHERN BAY RIVER NEAR SOUTHERN BAY	N48 22 44	W53 40 36	67.4	1976 - 1989	14
02YO006	PETERS RIVER NEAR BOTWOOD	N49 06 21	W55 24 38	177	1981 - 1989	9
02YR001	MIDDLE BROOK NEAR GAMBO	N48 48 28	W54 13 28	267	1959 - 1989	31
02YR002	RAGGED HARBOUR RIVER NEAR MUSGRAVE HARBOUR	N49 23 35	W54 06 25	399	1978 - 1989	12
02YN002	LLOYDS RIVER BELOW KING GEORGE IV LAKE	N48 14 32	W57 49 41	469	1981 - 1989	9
02YR003	INDIAN BAY BROOK NEAR NORTHWEST ARM	N49 02 24	W53 53 00	554	1981 - 1989	9
02ZF001	BAY DU NORD RIVER AT BIG FALLS	N47 44 48	W55 26 30	1170	1952 - 1979 , 1981 - 1989	37
02YS001	TERRA NOVA RIVER AT EIGHT MILE BRIDGES	N48 26 30	W54 22 21	1290	1955 - 1978 , 1980 - 1984	29
02ZE001	SALMON RIVER AT LONG POND	N47 56 40	W55 54 50	2640	1950 - 1964	15
02YQ001	GANDER RIVER AT BIG SHUTE	N49 00 55	W54 51 13	4400	1950 - 1989	40
02YM003	SOUTH WEST BROOK NEAR BAIE VERTE	N49 53 37	W56 13 22	93.2	1980 - 1989	10
02YD002	NORTHEAST BROOK NEAR RODDICKTON	N50 55 44	W56 06 44	200	1980 - 1989	10
02YD001	BEAVER BROOK NEAR RODDICKTON	N50 54 51	W56 09 26	237	1960 - 1978	19
02YK005	SHEFFIELD BROOK NEAR TRANS CANADA HIGHWAY	N49 20 11	W56 39 56	391	1973 - 1989	17
02YK002	LEWASEECHJEECH BROOK AT LITTLE GRAND LAKE	N48 37 20	W57 56 00	470	1956 - 1966 , 1973 - 1980 , 1982 - 1989	27
02YK004	HINDS BROOK NEAR GRAND LAKE	N49 04 21	W57 10 46	529	1957 - 1966 , 1969 - 1977	19
02YF001	CAT ARM RIVER ABOVE GREAT CAT ARM	N50 04 33	W56 55 22	611	1969 - 1981	13
02YC001	TORRENT RIVER AT BRISTOL'S POOL	N50 36 27	W57 09 04	624	1960 - 1989	30
02YL001	UPPER HUMBER RIVER NEAR REIDVILLE	N49 14 26	W57 21 45	2110	1953 - 1989	37
02ZA002	HIGHLANDS RIVER AT TRANS-CANADA HIGHWAY	N48 06 33	W58 47 04	72	1982 - 1989	8
02ZA003	LITTLE CODROY RIVER NEAR DOYLES	N47 49 19	W59 11 40	139	1982 - 1989	8
02ZB001	ISLE AUX MORTS RIVER BELOW HIGHWAY BRIDGE	N47 36 50	W59 00 33	205	1963 - 1989	27
02ZC002	GRANDY BROOK BELOW TOP POND BROOK	N47 51 27	W57 44 00	230	1982 - 1989	8
02ZA001	LITTLE BARACHOIS BROOK NEAR ST. GEORGE'S	N48 26 44	W58 23 55	343	1979 - 1989	11
02YJ001	HARRYS RIVER BELOW HIGHWAY BRIDGE	N48 34 31	W58 21 48	640	1969 - 1989	21

Figure 2.1 Locations of Watersheds and Gauging Stations for Low Flow Study

Table 2.2a Mean Monthly and Annual Flows at Gauging Stations

Station Number	Drainage Area (km^2)	Mean Monthly Flow (m^3/s) Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual Flow (m^3/s)	Mean Annual Runoff (mm)
O2ZM006	3.9	0.14	0.14	0.17	0.25	0.18	0.09	0.04	0.07	0.08	0.13	0.17	0.16	0.13	1080
O2ZL003	10.8	0.46	0.44	0.62	0.74	0.50	0.33	0.28	0.21	0.36	0.42	0.48	0.42	0.44	1280
O2ZG004	42.7	2.54	2.59	2.73	3.52	2.10	1.97	1.50	0.79	1.70	1.85	2.46	2.19	2.18	1600
O2ZH002	43.3	1.77	1.95	2.27	3.35	2.17	1.28	0.96	1.05	1.20	2.05	2.35	2.10	1.87	1360
O2ZN001	53.3	3.53	3.45	4.04	4.66	3.35	2.22	1.79	1.98	2.51	3.20	3.60	3.67	3.14	1860
O2ZM009	53.6	3.67	3.07	4.48	4.90	3.27	2.17	1.77	1.60	2.50	2.82	3.38	3.45	3.10	1820
O2ZK002	89.6	5.33	5.54	6.12	6.73	4.48	3.43	3.02	2.25	3.26	4.53	4.96	4.51	4.51	1590
O2ZG003	115.0	4.92	4.69	7.80	8.84	4.33	4.55	3.47	2.54	4.23	4.34	5.25	4.83	4.98	1370
O2ZG002	166.0	10.40	8.25	10.90	15.20	8.08	5.96	4.66	3.39	5.74	7.96	8.29	8.81	8.20	1560
O2ZG001	205.0	9.43	9.63	10.40	14.50	9.73	6.53	4.77	5.31	6.62	8.58	10.50	10.60	8.86	1360
O2ZK001	285.0	14.70	13.90	13.50	15.80	10.20	6.95	5.05	6.10	7.35	11.40	14.50	14.70	11.20	1240
O2ZH001	764.0	27.30	28.40	32.10	49.20	31.00	14.30	9.60	9.70	13.20	22.10	33.00	30.60	24.90	1030
O2YS003	36.7	0.82	1.05	1.29	2.23	1.59	0.75	0.46	0.51	0.65	1.05	1.24	1.00	1.05	900
O2YP001	63.8	1.13	0.79	1.94	4.45	5.92	1.83	0.79	1.04	0.95	1.02	1.21	0.87	1.83	900
O2ZJ001	67.4	2.36	2.01	2.87	4.59	3.46	1.30	0.88	0.59	1.06	1.74	2.11	2.04	2.10	980
O2YO006	177.0	2.95	3.42	5.62	13.50	8.21	3.97	1.36	2.70	2.02	3.33	3.24	2.59	4.40	780
O2YR001	267.0	6.36	5.98	7.41	13.50	14.60	6.70	3.20	2.11	2.36	4.04	6.73	6.99	6.71	790
O2YR002	399.0	9.82	8.83	11.90	23.60	16.40	5.38	1.85	2.33	3.71	6.73	8.85	9.15	9.05	720
O2YN002	469.0	18.80	12.60	13.00	43.30	56.50	21.00	8.73	11.20	9.88	15.20	24.70	19.70	21.20	1430
O2YR003	554.0	12.80	12.30	15.30	32.50	25.70	10.60	5.32	4.15	5.51	9.55	9.26	11.80	12.90	730
O2ZF001	1170.0	48.40	44.10	42.90	65.20	58.40	29.20	20.50	20.40	22.20	30.90	47.20	51.90	40.10	1080
O2YS001	1290.0	41.40	33.00	32.30	66.10	65.10	26.60	17.20	20.10	22.30	31.90	43.90	46.00	36.70	900
O2ZE001	2640.0	98.80	82.00	81.90	124.00	160.00	85.10	49.80	40.20	39.10	56.80	102.00	107.00	85.80	1020
O2YQ001	4400.0	109.00	96.40	104.00	231.00	261.00	103.00	54.20	52.50	55.20	86.90	132.00	130.00	118.00	850
O2YM003	93.2	1.06	0.81	1.71	6.47	9.20	2.76	0.78	1.37	0.76	2.17	2.70	1.67	2.63	890
O2YD002	200.0	2.05	1.61	2.76	9.04	19.00	11.50	2.22	1.92	1.69	3.44	5.73	4.44	5.46	860
O2YD001	237.0	2.69	2.13	2.43	6.93	33.40	24.40	5.34	4.28	4.32	7.08	8.55	5.45	8.99	1200
O2YK005	391.0	6.24	4.96	6.53	18.40	36.30	13.90	6.14	6.00	4.39	8.72	10.70	8.39	10.90	880
O2YK002	470.0	12.80	7.94	8.94	23.50	44.40	21.10	9.62	10.20	11.40	17.80	21.80	16.20	17.30	1160
O2YK004	529.0	10.90	8.83	8.23	16.50	47.40	27.10	9.68	7.11	7.53	14.10	19.90	17.90	16.50	980
O2YF001	611.0	9.06	7.00	8.54	15.60	96.80	72.80	16.60	15.10	16.10	26.90	26.70	17.40	27.60	1420
O2YC001	624.0	9.75	8.05	8.16	20.10	70.80	61.50	21.70	20.70	18.90	24.60	25.40	16.90	25.60	1290
O2YL001	2110.0	43.10	37.20	40.40	104.00	252.00	157.00	49.20	40.30	52.00	83.40	94.50	62.60	82.70	1240
O2ZA002	72.0	2.36	1.50	1.62	6.46	5.81	2.56	0.92	1.30	1.39	1.71	3.00	2.56	2.60	1140
O2ZA003	139.0	7.26	3.67	5.10	18.60	14.00	8.08	3.79	4.76	5.58	6.18	9.80	8.58	7.96	1810
O2ZB001	205.0	7.58	6.37	7.79	20.90	30.50	15.20	7.67	8.45	10.10	14.90	19.00	14.50	13.60	2090
O2ZC002	230.0	13.80	8.79	10.40	36.20	27.30	15.60	7.82	9.93	9.76	11.70	16.40	11.60	14.90	2040
O2ZA001	343.0	10.40	6.34	9.97	24.00	20.60	9.66	4.34	6.38	6.85	9.09	12.80	10.80	11.00	1010
O2YJ001	640.0	17.50	15.40	16.60	37.50	64.90	29.20	13.60	15.30	16.80	24.80	31.40	25.60	26.00	1280

Table 2.2b Unit Mean Monthly and Annual Flows at Gauging Stations

Station Number	Drainage Area	Unit Mean Monthly Flow												Unit Mean	Mean Annual
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Flow	Runoff
	(km^2)	(m^3/s/km^2)												(m^3/s/km^2)	(mm)
O2ZM006	3.9	0.036	0.037	0.043	0.065	0.046	0.023	0.011	0.018	0.021	0.034	0.044	0.040	0.034	1080
O2ZL003	10.8	0.043	0.041	0.058	0.069	0.046	0.030	0.026	0.020	0.033	0.039	0.045	0.039	0.041	1280
O2ZG004	42.7	0.059	0.061	0.064	0.082	0.049	0.046	0.035	0.019	0.040	0.043	0.058	0.051	0.051	1600
O2ZH002	43.3	0.041	0.045	0.052	0.077	0.050	0.030	0.022	0.024	0.028	0.047	0.054	0.048	0.043	1360
O2ZN001	53.3	0.066	0.065	0.076	0.087	0.063	0.042	0.034	0.037	0.047	0.060	0.068	0.069	0.059	1860
O2ZM009	53.6	0.068	0.057	0.084	0.091	0.061	0.040	0.033	0.030	0.047	0.053	0.063	0.064	0.058	1820
O2ZK002	89.6	0.059	0.062	0.068	0.075	0.050	0.038	0.034	0.025	0.036	0.051	0.055	0.050	0.050	1590
O2ZG003	115.0	0.043	0.041	0.068	0.077	0.038	0.040	0.030	0.022	0.037	0.038	0.046	0.042	0.043	1370
O2ZG002	166.0	0.063	0.050	0.066	0.092	0.049	0.036	0.028	0.020	0.035	0.048	0.050	0.053	0.049	1560
O2ZG001	205.0	0.046	0.047	0.051	0.071	0.047	0.032	0.023	0.026	0.032	0.042	0.051	0.052	0.043	1360
O2ZK001	285.0	0.052	0.049	0.047	0.055	0.036	0.024	0.018	0.021	0.026	0.040	0.051	0.052	0.039	1240
O2ZH001	764.0	0.036	0.037	0.042	0.064	0.041	0.019	0.013	0.013	0.017	0.029	0.043	0.040	0.033	1030
O2YS003	36.7	0.022	0.029	0.035	0.061	0.043	0.020	0.012	0.014	0.018	0.029	0.034	0.027	0.029	900
O2YP001	63.8	0.018	0.012	0.030	0.070	0.093	0.029	0.012	0.016	0.015	0.016	0.019	0.014	0.029	900
O2ZJ001	67.4	0.035	0.030	0.043	0.068	0.051	0.019	0.013	0.009	0.016	0.026	0.031	0.030	0.031	980
O2YO006	177.0	0.017	0.019	0.032	0.076	0.046	0.022	0.008	0.015	0.011	0.019	0.018	0.015	0.025	780
O2YR001	267.0	0.024	0.022	0.028	0.051	0.055	0.025	0.012	0.008	0.009	0.015	0.025	0.026	0.025	790
O2YR002	399.0	0.025	0.022	0.030	0.059	0.041	0.013	0.005	0.006	0.009	0.017	0.022	0.023	0.023	720
O2YN002	469.0	0.040	0.027	0.028	0.092	0.120	0.045	0.019	0.024	0.021	0.032	0.053	0.042	0.045	1430
O2YR003	554.0	0.023	0.022	0.028	0.059	0.046	0.019	0.010	0.007	0.010	0.017	0.017	0.021	0.023	730
O2ZF001	1170.0	0.041	0.038	0.037	0.056	0.050	0.025	0.018	0.017	0.019	0.026	0.040	0.044	0.034	1080
O2YS001	1290.0	0.032	0.026	0.025	0.051	0.050	0.021	0.013	0.016	0.017	0.025	0.034	0.036	0.028	900
O2ZE001	2640.0	0.037	0.031	0.031	0.047	0.061	0.032	0.019	0.015	0.015	0.022	0.039	0.041	0.033	1020
O2YQ001	4400.0	0.025	0.022	0.024	0.053	0.059	0.023	0.012	0.012	0.013	0.020	0.030	0.030	0.027	850
O2YM003	93.2	0.011	0.009	0.018	0.069	0.099	0.030	0.008	0.015	0.008	0.023	0.029	0.018	0.028	890
O2YD002	200.0	0.010	0.008	0.014	0.045	0.095	0.058	0.011	0.010	0.008	0.017	0.029	0.022	0.027	860
O2YD001	237.0	0.011	0.009	0.010	0.029	0.141	0.103	0.023	0.018	0.018	0.030	0.036	0.023	0.038	1200
O2YK005	391.0	0.016	0.013	0.017	0.047	0.093	0.036	0.016	0.015	0.011	0.022	0.027	0.021	0.028	880
O2YK002	470.0	0.027	0.017	0.019	0.050	0.094	0.045	0.020	0.022	0.024	0.038	0.046	0.034	0.037	1160
O2YK004	529.0	0.021	0.017	0.016	0.031	0.090	0.051	0.018	0.013	0.014	0.027	0.038	0.034	0.031	980
O2YF001	611.0	0.015	0.011	0.014	0.026	0.158	0.119	0.027	0.025	0.026	0.044	0.044	0.028	0.045	1420
O2YC001	624.0	0.016	0.013	0.013	0.032	0.113	0.099	0.035	0.033	0.030	0.039	0.041	0.027	0.041	1290
O2YL001	2110.0	0.020	0.018	0.019	0.049	0.119	0.074	0.023	0.019	0.025	0.040	0.045	0.030	0.039	1240
O2ZA002	72.0	0.033	0.021	0.023	0.090	0.081	0.036	0.013	0.018	0.019	0.024	0.042	0.036	0.036	1140
O2ZA003	139.0	0.052	0.026	0.037	0.134	0.101	0.058	0.027	0.034	0.040	0.044	0.071	0.062	0.057	1810
O2ZB001	205.0	0.037	0.031	0.038	0.102	0.149	0.074	0.037	0.041	0.049	0.073	0.093	0.071	0.066	2090
O2ZC002	230.0	0.060	0.038	0.045	0.157	0.119	0.068	0.034	0.043	0.042	0.051	0.071	0.050	0.065	2040
O2ZA001	343.0	0.030	0.018	0.029	0.070	0.060	0.028	0.013	0.019	0.020	0.027	0.037	0.031	0.032	1010
O2YJ001	640.0	0.027	0.024	0.026	0.059	0.101	0.046	0.021	0.024	0.026	0.039	0.049	0.040	0.041	1280

The mean annual runoff, expressed in mm, is highest in the southwestern region of the Island where it ranges from 1300 mm to 2100 mm. The lowest mean annual runoffs, between 700 mm and 900 mm, occur in the north-central area of the Island. On the Avalon and Burin Peninsulas, the range of the mean annual runoff is from 1000 mm to 1900 mm. On the Northern Peninsula, mean annual runoff is between 1100 mm and 1400 mm.

As expected, unit mean monthly flows show large variations, both temporally and spatially. They range from 0.005 $m^3/s/km^2$ to 0.158 $m^3/s/km^2$ depending on month of year and region of Newfoundland. The watersheds on the Avalon Peninsula and on the southwestern corner of the Island yield the higher unit mean monthly flows, while the watersheds in the north-central part of the Island tend to have the lower unit mean monthly flows. On a temporal basis, the higher unit mean monthly flows tend to occur between the months of April and June, which corresponds to the snowmelt season. The lower unit mean monthly flows occur during two periods, one between January and March, i.e. during the winter season prior to snowmelt and the other between July and September, i.e. during the summer season when there are usually higher losses due to increased evapotranspiration rates.

Figures 2.2, 2.3, 2.4 and 2.5, respectively, show the mean monthly and annual flows for two stations from each of four regions of Newfoundland. It can be observed from the figures that, on the average, on the Avalon and Burin Peninsulas, the low mean monthly flows are lower during the summer than during the winter. The situation is the same on the north-central part of the Island. However, on the west and southwest coasts of the Island, the plots show that the winter mean monthly flows can be as low as the summer mean monthly flows.

2.4 Precipitation Patterns across the Island

The normal (1951 to 1980) annual precipitation amounts at climatic station(s) closest to the hydrometric gauging stations are shown in Table 2.3. The mean annual runoff at the hydrometric stations are also included. According to the values presented in Table 2.3, the southwestern region of the Island receives the highest amount of precipitation, between 1200 mm and 1700 mm. The north-central part of the Island receives the lowest amount of precipitation, between 800 mm and 1100 mm. On the Avalon and Burin peninsulas, the normal annual precipitation is between 1200 mm and 1600 mm and on the Northern Peninsula it ranges from 900 mm to 1200 mm.

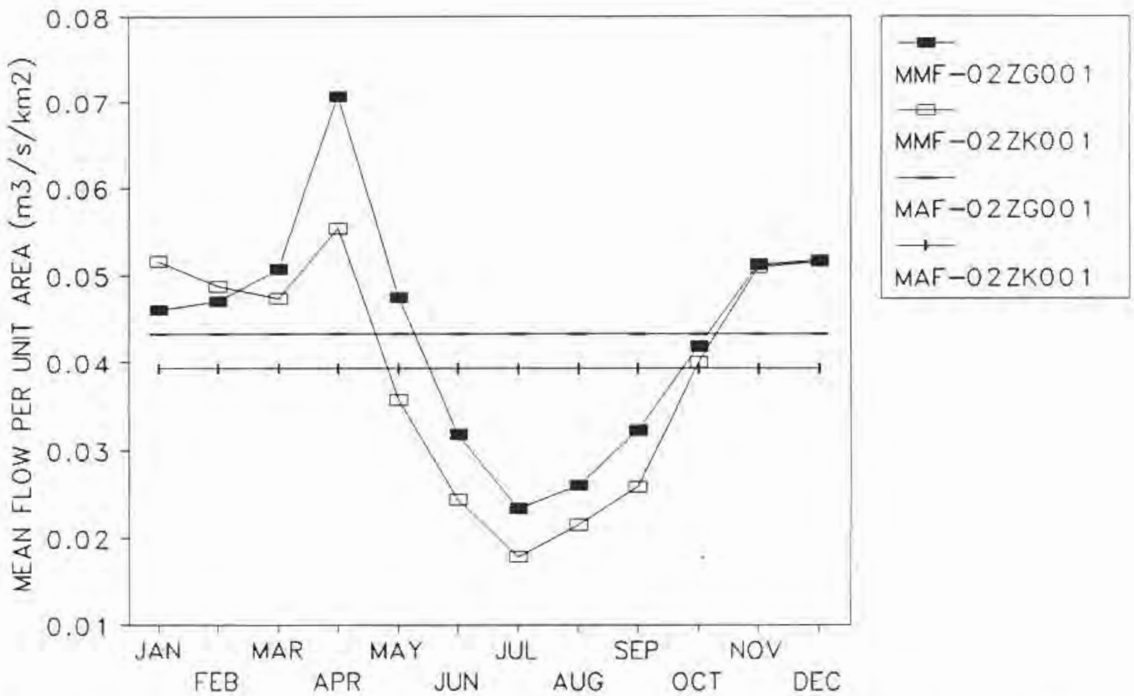

Figure 2.2 **Variation in Mean Monthly Flows at Two Gauging Stations in Eastern Newfoundland.**

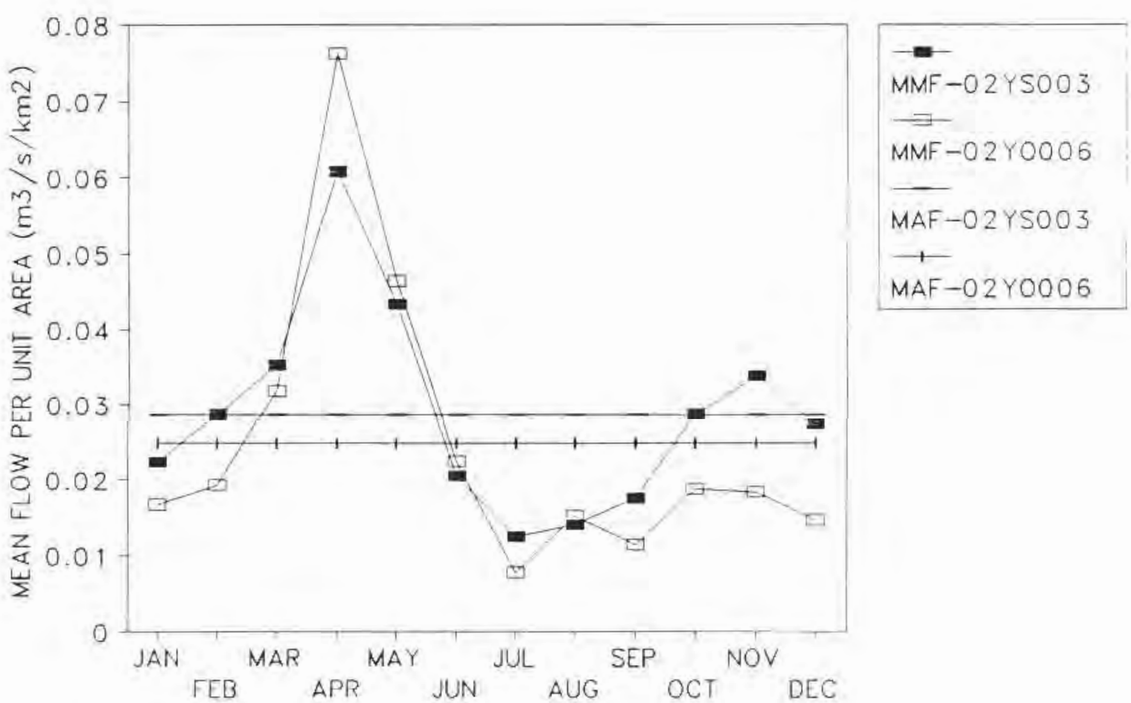

Figure 2.3 **Variation in Mean Monthly Flows at Two Gauging Stations in North Central Newfoundland.**

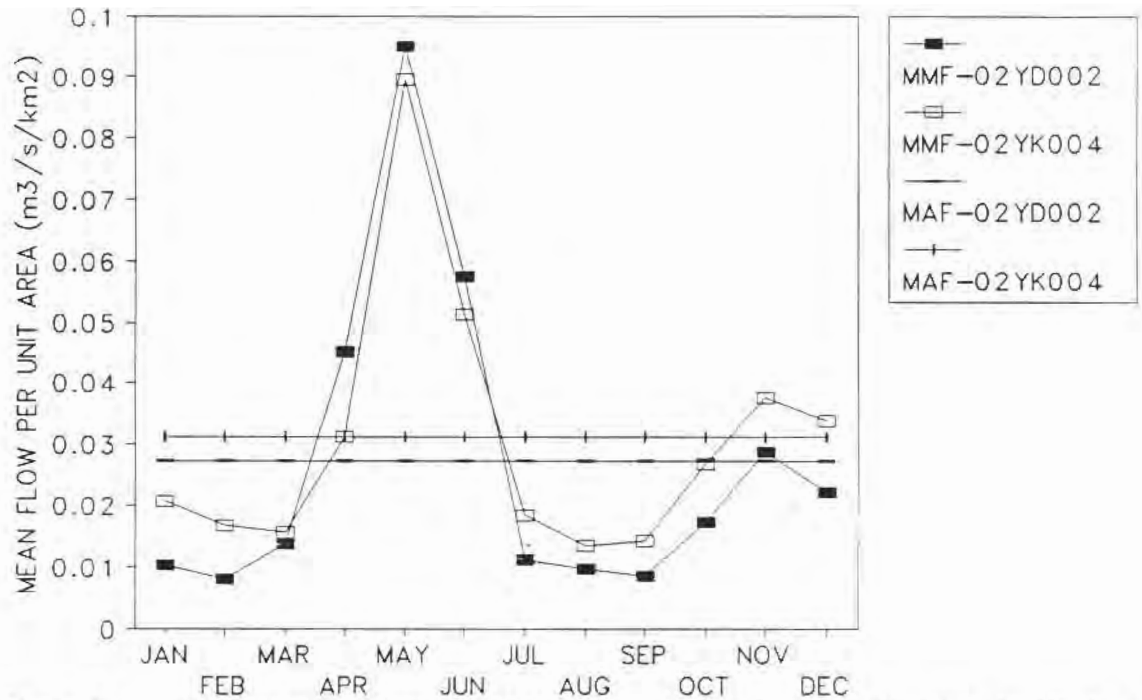

Figure 2.4 **Variation in Mean Monthly Flows at Two Gauging Stations in Western Newfoundland.**

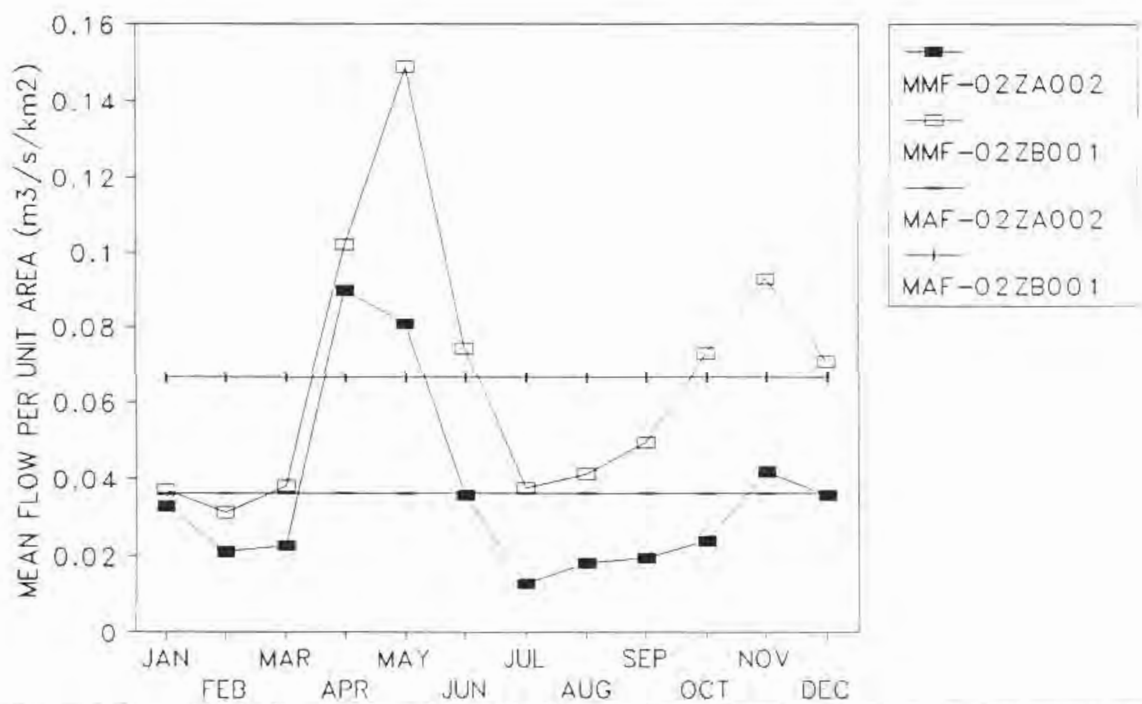

Figure 2.5 **Variation in Mean Monthly Flows at Two Gauging Stations in Southwestern Newfoundland.**

Table 2.3 Precipitation and Runoff at Recording Stations

Station Number	Closest Climatic Station(s)	Total Precipitation (mm)	Mean Runoff (mm)
O2ZM006	St. John's A.	1516.7	1091.3
	Logy Bay	888.2	
O2ZL003	New Chelsea	1217.9	1278.9
O2ZG004	W Brook St. Lawrence	1470.2	1591.4
	Arnold's Cove	1281.3	
O2ZH002	Come-By-Chance	1128.0	1363.5
	Sunnyside	1275.5	
	Arnold's Cove	1281.3	
O2ZN001	St. Shotts	1465.0	1871.7
	Cape Race	1386.8	
O2ZM009	Cape Broyle	1515.9	1817.2
	Cape Race	1386.8	
O2ZK002	Long Harbour	1309.1	1585.2
O2ZG003	W Brook St. Lawrence	1470.2	1364.8
	St. Lawrence	1447.3	
	Grand Bank	1302.0	
O2ZG002	St. Lawrence	1447.3	1544.2
	W Brook St. Lawrence	1470.2	
O2ZG001	St. Lawrence	1447.3	1364.5
	W Brook St. Lawrence	1470.2	
	Grand Bank	1302.0	
O2ZK001	Colinet	1430.0	1234.6
	Salmonier	1387.8	
O2ZH001	Sunnyside	1275.5	1031.4
	Come-By-Chance	1128.0	
	Arnold's Cove	1281.3	
O2YS003	Bonavista	978.3	903.1
	Terra Nova Nat Park	1124.7	
O2YP001	Springdale	962.4	906.3
O2ZJ001	Bonavista	978.3	974.2
	Lockston	1270.3	
O2YO006	Botwood	976.7	784.5
	Rattl.Bk Norris Arm	1123.7	
O2YR001	Gander Int'l A	1126.8	787.0
	Terra Nova Nat Park	1124.7	
O2YR002	Fogo	767.0	713.9
	Twillingate	944.2	
O2YN002	Burnt Pond	1305.2	1428.9
	Buchans	1081.8	
	Buchans A	1026.8	

Table 2.3 (Cont.) Precipitation and Runoff at Recording Stations

Station Number	Closest Climatic Station(s)	Total Precipitation (mm)	Mean Runoff (mm)
O2YR003	Fogo	767.0	733.6
	Terra Nova Nat Park	1124.7	
O2ZF001	Bay D'Espoir Gen Stn	1492.2	1079.9
O2YS001	Terra Nova Nat Park	1124.7	908.5
O2ZE001	Burnt Pond	1305.2	1022.1
	Bay D'Espoir Gen Stn	1492.2	
	Buchans	1081.8	
O2YQ001	Fogo	767.0	845.6
	Gander Int'l A	1126.8	
	Terra Nova Nat Park	1124.7	
O2YM003	Baie Verte	1070.5	945.6
O2YD002	Roddickton	836.8	861.7
O2YD001	Roddickton	836.8	1190.8
O2YK005	Buchans	1081.8	881.3
	Buchans A	1026.8	
O2YK002	Corner Brook	1133.1	1153.5
	Deer Lake	1034.8	
O2YK004	Buchans	1081.8	972.3
	Buchans A	1026.8	
	Deer Lake	1034.8	
O2YF001	Baie Verte	1070.5	1418.9
	Roddickton	836.8	
O2YC001	Daniels Harbour	1066.3	1295.1
	Plum Point	1009.1	
O2YL001	Deer Lake A	1063.3	1268.3
	Deer Lake	1034.8	
O2ZA002	Port Aux Basques	1444.5	1138.6
O2ZA003	Port Aux Basques	1444.5	1805.3
O2ZB001	Burgeo	1679.2	2093.6
	Burgeo 2	1577.3	
	Port Aux Basques	1444.5	
O2ZC002	Burnt Pond	1305.2	2047.6
	Burgeo	1679.2	
	Burgeo 2	1577.3	
O2ZA001	Stephenville A	1216.1	1006.5
O2YJ001	Stephenville A	1216.1	1269.7
	Corner Brook	1133.1	

A comparison between mean annual runoff and normal annual precipitation shows that in many instances mean annual runoff exceeds the normal annual precipitation. This anomaly is explained as follows: most precipitation gauges are located on the coast for ease of access, while the headwaters of most watersheds are at much higher elevations. Due to orographic effects, one would expect precipitation to be higher at higher altitudes. The precipitation gauges may therefore be recording lower amounts of the actual precipitation on the entire watersheds.

2.5 Flow Duration Curves

The flow duration curve of daily, weekly or monthly flows during a specified period is a plot of the magnitude of flow against the percentage of the total time during the specified period that discharges were at or below specific values. It is assumed that the runoff pattern did not change during the period under consideration. A flow duration curve represents the flow characteristics of a stream and, if based on a sufficiently long period of record, can be used to estimate the percentage of time that flows will be at or below a given value. However, the curve does not give the chronological order of the flows, i.e., it is not correct to multiply the percent of time by the number of days in a year and assume that the given flows will be smaller than the given value for the resulting continuous number of days.

The shape of the flow duration curve is determined by the hydrologic and geologic characteristics of the watershed. A curve with a steep slope suggests a highly variable stream whose flow is largely from direct flow. A curve with a flat slope indicates the presence of surface or groundwater storage which tends to dampen the variations in stream flows. The slope of the lower end of the duration curve shows the characteristics of the perennial storage in the drainage basin; a flat slope at the lower end indicates a large amount of storage and a steep slope indicates a negligible amount of storage. In the latter case, there is a relatively higher probability of zero flow.

The flow duration curves at the 39 gauging stations based on daily flows for the period of record are given in Appendix A.

2.6 N-Day Low Flows

The N-day low flow is defined as the lowest daily flow, averaged over a period of N continuous days, within a specified period. This period can be the entire year or a particular portion of it. The discussion on mean monthly flows in the previous sections suggests that low flows can occur either in the summer or winter season. For the purposes of this report, the N-day low flows were calculated (1) for the summer season, which was defined as the period between July and December, both months inclusive and (2) for the winter season, which was defined as the period between January and June, both months inclusive. The low flow of a particular duration on an annual basis for a particular year would be the lower of the summer and winter low flows of the same duration. Four durations of low flows were investigated: 1-day, 7-day, 15-day and 30-day. When the duration of the low flow period was greater than one day and overlapped both the summer and winter seasons, the position of the mid-point of the duration relative to the defined limits of the seasons was used to determine the season to which that particular low flow belonged. The low flows were estimated strictly on a calendar basis, i.e., low flow periods which overlapped the end of one year and the beginning of the following year were not considered.

Percentage of occurrence of low flows by month

The months of occurrence of the annual low flows (i.e. the lower of the summer and winter low flows) of the different durations for each station were noted. For each of the four regions (Avalon and Burin Peninsulas, North-Central Newfoundland, Humber Valley and Northern Peninsula region and Southwestern region) the number of low flows recorded for each station was totalled. The percentages of the monthly occurrences were then determined. Figures 2.6 and 2.7 show the monthly distribution of the low flows of two durations (1-day and 30-day) in each region. These figures confirm that in the eastern regions of the Island, the low flows tend to occur mostly during the summer season, between July and October. For the western region of the Island, especially the Northern Peninsula, however, the distribution seems to be more evenly spread between the winter season (January to March) and the summer season (July to September).

Magnitude of low flows

Tables 2.4, 2.5, 2.6 and 2.7, respectively, show the minimum, maximum and average winter and summer unit low flows (flows per unit area) of durations 1-day, 7-day, 15-day and 30-day for the 39 gauging stations. Figures 2.8 and 2.9 graphically illustrate the variation in the average 1-day and 30-day winter and summer unit low flows.

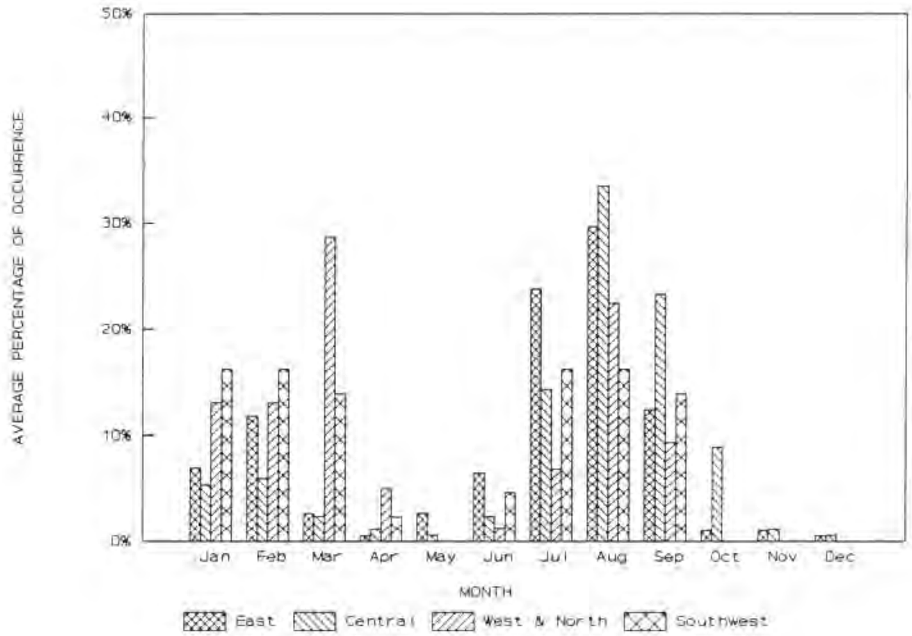

Figure 2.6 Percentage Occurrence of 1-day Low Flows by Month and Region.

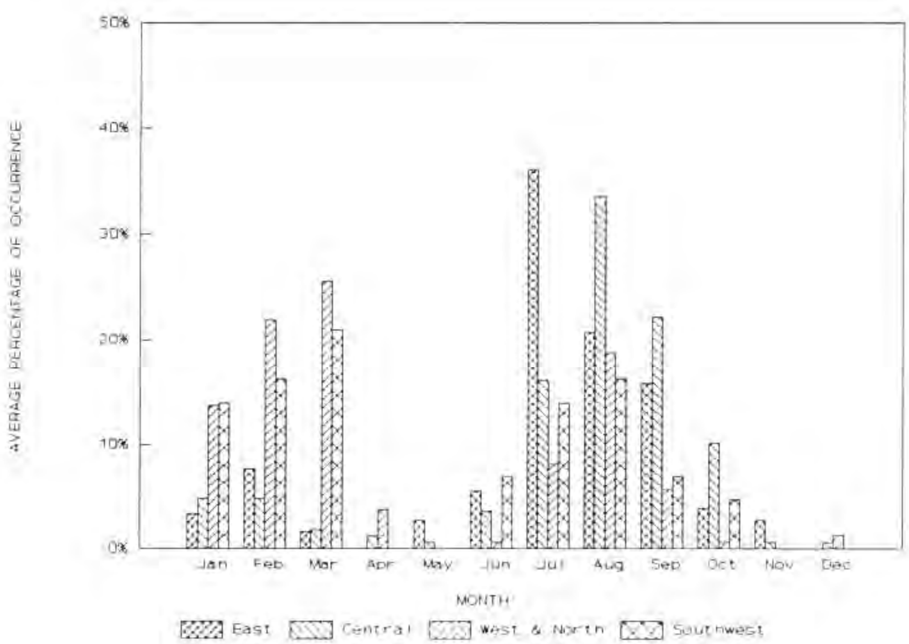

Figure 2.7 Percentage Occurrence of 30-day Low Flows by Month and Region.

Table 2.4 Summary Characteristics of 1-day Low Flow Series

Station Number	Drainage Area	Winter			Summer		
		Minimum 1-day Flow	Maximum 1-day Flow	Average 1-day Flow	Minimum 1-day Flow	Maximum 1-day Flow	Average 1-day Flow
	(km^2)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
02ZM006	3.9	0.003	0.028	0.02	0.000	0.029	0.01
02ZL003	10.8	0.044	0.167	0.09	0.007	0.159	0.04
02ZG004	42.7	0.171	0.490	0.31	0.013	0.247	0.14
02ZH002	43.3	0.022	0.418	0.21	0.013	0.595	0.15
02ZN001	53.3	0.247	0.878	0.57	0.160	0.919	0.55
02ZM009	53.6	0.339	1.110	0.60	0.116	0.859	0.46
02ZK002	89.6	0.562	2.010	0.92	0.135	1.360	0.57
02ZG003	115.0	0.221	1.150	0.55	0.053	0.756	0.38
02ZG002	166.0	0.215	4.150	1.89	0.289	2.720	1.17
02ZG001	205.0	0.881	3.950	1.93	0.062	3.400	1.38
02ZK001	285.0	0.934	4.630	2.52	0.204	3.560	1.23
02ZH001	764.0	2.890	12.000	5.93	0.085	10.200	2.67
02YS003	36.7	0.075	0.270	0.16	0.018	0.282	0.10
02YP001	63.8	0.150	0.520	0.28	0.015	0.290	0.17
02ZJ001	67.4	0.089	0.580	0.33	0.006	0.596	0.13
02YO006	177.0	0.330	1.220	0.68	0.131	0.556	0.35
02YR001	267.0	1.200	4.960	2.77	0.079	3.280	1.00
02YR002	399.0	0.715	5.200	2.35	0.033	3.400	0.67
02YN002	469.0	2.250	6.600	4.12	1.830	5.500	2.74
02YR003	554.0	2.700	10.500	5.37	0.339	3.750	2.34
02ZF001	1170.0	7.870	30.500	17.58	1.200	20.700	9.41
02YS001	1290.0	2.280	22.000	11.77	1.750	19.400	7.12
02ZE001	2640.0	15.700	49.600	34.15	3.110	40.200	17.82
02YQ001	4400.0	9.770	75.400	39.98	2.780	61.200	22.10
02YM003	93.2	0.078	0.460	0.22	0.002	0.374	0.09
02YD002	200.0	0.100	2.100	0.67	0.030	2.840	0.66
02YD001	237.0	0.218	1.740	0.71	0.300	1.930	1.10
02YK005	391.0	0.670	4.200	1.98	0.524	4.330	2.16
02YK002	470.0	1.760	6.370	3.39	1.030	6.880	3.17
02YK004	529.0	2.150	7.650	4.12	1.400	6.030	3.87
02YF001	611.0	0.680	3.850	1.80	0.770	4.670	2.60
02YC001	624.0	1.980	7.280	4.11	3.400	11.300	7.11
02YL001	2110.0	4.930	20.900	10.07	1.840	23.200	9.27
02ZA002	72.0	0.180	0.480	0.32	0.081	0.371	0.26
02ZA003	139.0	0.269	1.900	0.84	0.622	1.850	1.02
02ZB001	205.0	0.340	2.720	1.23	0.343	2.210	1.05
02ZC002	230.0	0.215	2.360	1.07	0.486	2.180	1.17
02ZA001	343.0	1.150	3.150	1.97	0.791	2.610	1.52
02YJ001	640.0	2.500	9.900	5.55	1.550	10.200	5.68

Table 2.5 Summary Characteristics of 7–day Low Flow Series

Station Number	Drainage Area	Winter			Summer		
		Minimum 7–day Flow	Maximum 7–day Flow	Average 7–day Flow	Minimum 7–day Flow	Maximum 7–day Flow	Average 7–day Flow
	(km^2)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
02ZM006	3.9	0.005	0.036	0.02	0.000	0.032	0.01
02ZL003	10.8	0.051	0.207	0.10	0.010	0.225	0.05
02ZG004	42.7	0.188	0.588	0.37	0.021	0.302	0.19
02ZH002	43.3	0.028	0.481	0.25	0.016	0.663	0.18
02ZN001	53.3	0.263	1.073	0.67	0.172	1.045	0.63
02ZM009	53.6	0.392	1.249	0.73	0.125	0.922	0.53
02ZK002	89.6	0.660	2.317	1.14	0.146	1.720	0.70
02ZG003	115.0	0.244	1.481	0.67	0.064	0.854	0.47
02ZG002	166.0	0.317	4.903	2.17	0.312	2.937	1.33
02ZG001	205.0	1.071	4.674	2.29	0.081	4.370	1.58
02ZK001	285.0	1.068	5.371	3.00	0.263	4.324	1.50
02ZH001	764.0	3.017	15.157	6.80	0.107	11.657	3.02
02YS003	36.7	0.080	0.330	0.18	0.020	0.320	0.12
02YP001	63.8	0.167	0.567	0.32	0.018	0.343	0.20
02ZJ001	67.4	0.106	0.683	0.39	0.010	0.768	0.16
02YO006	177.0	0.346	1.359	0.78	0.149	0.663	0.40
02YR001	267.0	1.250	5.274	2.97	0.097	3.706	1.10
02YR002	399.0	0.717	6.429	2.59	0.045	3.570	0.73
02YN002	469.0	2.401	7.714	4.51	1.973	5.633	2.92
02YR003	554.0	3.031	10.333	5.83	0.370	3.899	2.52
02ZF001	1170.0	8.019	33.186	19.02	1.506	22.286	10.12
02YS001	1290.0	3.020	24.014	12.63	1.787	20.671	8.03
02ZE001	2640.0	16.200	51.371	35.07	3.631	42.243	18.84
02YQ001	4400.0	10.910	80.529	41.99	3.181	68.443	23.53
02YM003	93.2	0.084	0.509	0.24	0.004	0.462	0.11
02YD002	200.0	0.127	2.181	0.72	0.054	2.986	0.74
02YD001	237.0	0.229	1.761	0.76	0.337	2.371	1.24
02YK005	391.0	0.722	4.614	2.24	0.583	4.910	2.36
02YK002	470.0	1.829	6.689	3.59	1.174	7.639	3.54
02YK004	529.0	2.234	7.939	4.34	1.486	6.789	4.14
02YF001	611.0	0.696	4.189	1.91	0.890	5.804	3.05
02YC001	624.0	2.109	7.373	4.27	3.650	12.000	7.50
02YL001	2110.0	5.013	22.286	10.84	2.916	25.086	10.51
02ZA002	72.0	0.216	0.549	0.37	0.120	0.428	0.29
02ZA003	139.0	0.289	2.617	1.01	0.798	2.103	1.18
02ZB001	205.0	0.373	3.157	1.39	0.420	2.517	1.35
02ZC002	230.0	0.242	2.751	1.24	0.671	2.874	1.45
02ZA001	343.0	1.264	3.561	2.22	0.873	2.849	1.65
02YJ001	640.0	2.764	10.729	6.13	2.826	11.000	6.43

Table 2.6 Summary Characteristics of 15-day Low Flow Series

Station Number	Drainage Area	Winter			Summer		
		Minimum 15-day Flow	Maximum 15-day Flow	Average 15-day Flow	Minimum 15-day Flow	Maximum 15-day Flow	Average 15-day Flow
	(km^2)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
02ZM006	3.9	0.006	0.056	0.02	0.000	0.042	0.01
02ZL003	10.8	0.070	0.284	0.13	0.014	0.027	0.06
02ZG004	42.7	0.229	0.759	0.48	0.034	0.416	0.25
02ZH002	43.3	0.065	0.930	0.34	0.021	0.817	0.23
02ZN001	53.3	0.295	1.645	0.87	0.199	1.419	0.74
02ZM009	53.6	0.488	1.506	0.96	0.147	1.137	0.64
02ZK002	89.6	0.742	2.672	1.38	0.185	2.394	0.90
02ZG003	115.0	0.288	2.110	0.90	0.072	1.084	0.62
02ZG002	166.0	1.227	5.573	2.58	0.348	3.287	1.53
02ZG001	205.0	1.131	5.759	2.82	0.087	4.990	1.87
02ZK001	285.0	1.146	6.100	3.65	0.286	6.015	1.87
02ZH001	764.0	3.149	20.873	7.96	0.144	13.667	3.55
02YS003	36.7	0.085	0.510	0.22	0.032	0.372	0.15
02YP001	63.8	0.199	0.655	0.37	0.028	0.364	0.22
02ZJ001	67.4	0.114	1.114	0.50	0.013	0.873	0.19
02YO006	177.0	0.375	1.791	0.97	0.157	0.781	0.48
02YR001	267.0	1.326	6.934	3.26	0.116	4.025	1.17
02YR002	399.0	0.746	8.551	3.09	0.055	3.721	0.79
02YN002	469.0	2.547	10.120	5.25	2.100	6.041	3.24
02YR003	554.0	3.147	12.721	7.05	0.392	3.993	2.67
02ZF001	1170.0	8.324	36.480	21.05	1.539	23.493	10.99
02YS001	1290.0	3.605	27.933	13.82	1.835	24.200	9.16
02ZE001	2640.0	16.967	54.847	37.31	3.703	45.027	19.96
02YQ001	4400.0	11.665	92.893	45.77	3.464	76.393	25.36
02YM003	93.2	0.094	0.623	0.29	0.008	0.769	0.17
02YD002	200.0	0.156	2.299	0.81	0.089	3.281	0.83
02YD001	237.0	0.247	1.792	0.83	0.384	2.647	1.40
02YK005	391.0	0.806	5.390	2.49	0.640	5.732	2.59
02YK002	470.0	1.903	7.287	3.94	1.252	8.229	3.98
02YK004	529.0	2.365	8.407	4.62	1.615	7.611	4.50
02YF001	611.0	0.723	4.544	2.10	1.025	8.369	3.74
02YC001	624.0	2.119	7.665	4.48	4.280	13.073	8.24
02YL001	2110.0	5.150	25.800	12.11	3.348	34.107	12.68
02ZA002	72.0	0.298	0.733	0.46	0.123	0.523	0.34
02ZA003	139.0	0.331	4.495	1.36	0.866	2.506	1.35
02ZB001	205.0	0.428	4.237	1.70	0.508	3.375	1.70
02ZC002	230.0	0.292	3.924	1.58	0.898	3.571	1.90
02ZA001	343.0	1.341	4.479	2.74	0.906	3.453	1.85
02YJ001	640.0	3.366	12.353	7.11	3.447	12.705	7.21

Table 2.7 Summary Characteristics of 30-day Low Flow Series

Station Number	Drainage Area	Winter			Summer		
		Minimum 30-day Flow	Maximum 30-day Flow	Average 30-day Flow	Minimum 30-day Flow	Maximum 30-day Flow	Average 30-day Flow
	(km^2)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
02ZM006	3.9	0.008	0.093	0.05	0.000	0.059	0.02
02ZL003	10.8	0.092	0.302	0.17	0.030	0.382	0.09
02ZG004	42.7	0.442	2.115	0.84	0.066	0.593	0.41
02ZH002	43.3	0.098	1.244	0.61	0.028	1.392	0.39
02ZN001	53.3	0.443	2.075	1.32	0.238	1.959	0.94
02ZM009	53.6	0.805	2.087	1.43	0.195	1.450	0.85
02ZK002	89.6	1.200	2.997	2.02	0.315	3.096	1.20
02ZG003	115.0	0.479	3.376	2.03	0.111	2.056	1.13
02ZG002	166.0	2.193	6.722	3.79	0.398	3.901	1.94
02ZG001	205.0	1.315	7.011	4.14	0.105	5.386	2.33
02ZK001	285.0	1.837	9.647	5.16	0.395	8.067	2.64
02ZH001	764.0	3.430	23.243	11.13	0.175	20.020	4.54
02YS003	36.7	0.096	0.750	0.37	0.062	0.786	0.22
02YP001	63.8	0.285	0.812	0.50	0.040	0.473	0.29
02ZJ001	67.4	0.327	1.563	0.79	0.018	1.599	0.28
02YO006	177.0	0.497	2.535	1.45	0.170	1.052	0.66
02YR001	267.0	1.629	7.683	3.78	0.128	5.015	1.37
02YR002	399.0	1.370	10.082	3.98	0.064	4.497	0.94
02YN002	469.0	2.888	13.178	6.99	2.564	7.049	4.16
02YR003	554.0	3.740	16.530	8.36	0.442	4.372	2.91
02ZF001	1170.0	8.770	38.410	24.80	1.871	24.023	12.50
02YS001	1290.0	5.959	31.750	16.82	1.978	27.287	10.71
02ZE001	2640.0	17.970	65.577	43.62	3.939	51.723	22.45
02YQ001	4400.0	13.399	114.913	53.94	3.952	93.970	29.13
02YM003	93.2	0.149	0.804	0.38	0.011	1.129	0.27
02YD002	200.0	0.254	2.465	0.97	0.104	3.342	0.99
02YD001	237.0	0.283	2.083	0.94	0.440	4.472	1.91
02YK005	391.0	1.497	8.012	3.06	0.720	6.664	2.95
02YK002	470.0	1.942	8.653	4.84	1.486	11.270	5.12
02YK004	529.0	2.751	9.556	5.15	1.892	8.639	5.00
02YF001	611.0	0.784	4.770	2.59	1.442	16.677	5.78
02YC001	624.0	2.243	11.334	4.95	5.742	15.050	10.44
02YL001	2110.0	5.280	29.923	14.95	4.652	48.483	17.73
02ZA002	72.0	0.435	1.344	0.77	0.190	0.641	0.44
02ZA003	139.0	0.578	4.936	2.15	1.008	3.020	1.73
02ZB001	205.0	0.646	7.042	2.63	0.752	7.089	3.02
02ZC002	230.0	1.138	6.817	2.98	1.564	5.325	2.89
02ZA001	343.0	1.729	7.023	3.80	1.045	4.917	2.29
02YJ001	640.0	4.537	15.143	9.15	4.517	15.056	8.74

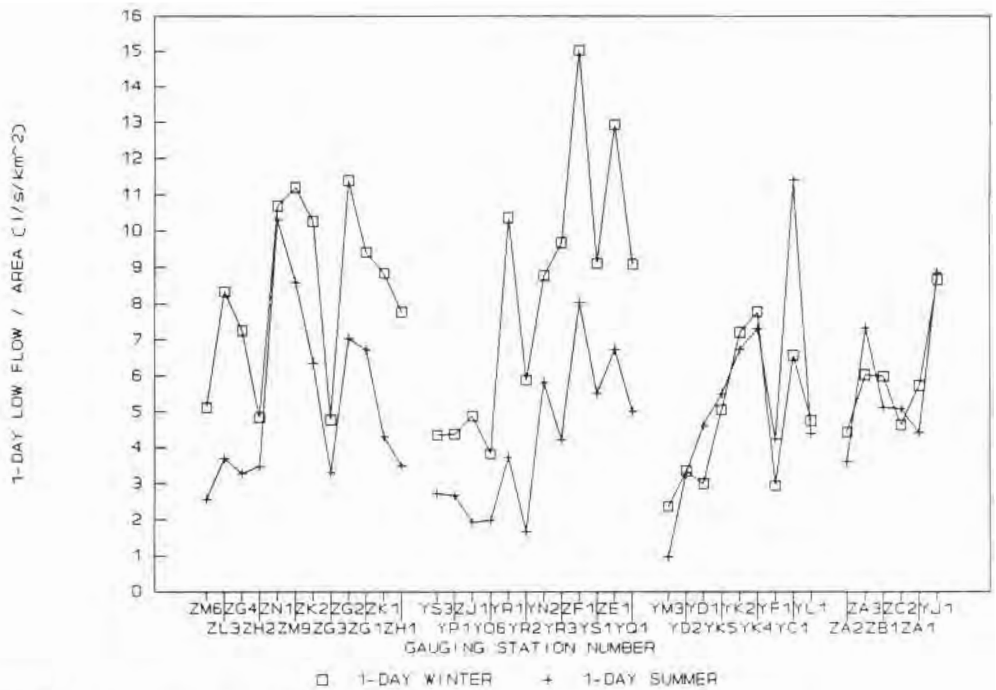

Figure 2.8 Average 1 - day Unit Low Flows at Gauging Stations.

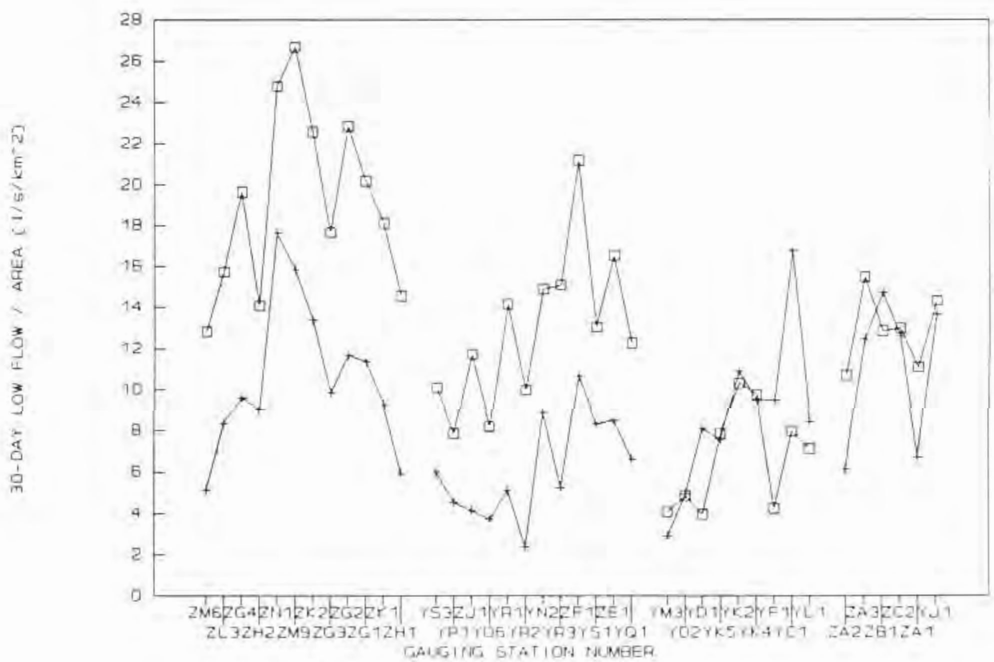

Figure 2.9 Average 30 - day Unit Low Flows at Gauging Stations.

From the aforementioned tables and figures the following observations can be made: (1) in the eastern half of the Island, most of the north-central and the southwestern regions of the Island, the summer low flows are lower than the winter low flows, (2) on the Northern Peninsula, the winter low flows can be as low as or lower than the summer low flows, (3) the range of the minimum low flows is from 0 $l/s/km^2$ and 11 $l/s/km^2$, and (4) there can be sharp differences between unit flows from watersheds which may not differ by much in terms of drainage areas.

Chapter 3

FREQUENCY ANALYSIS OF LOW FLOWS

3.1 Introduction

The results of frequency analyses of low flows of various durations for streams on the Island of Newfoundland are presented in this chapter.

3.2 Frequency Analysis of Low Flows

The objective of the frequency analysis was to obtain estimates of low flows for various return periods. There were four steps to the frequency analysis: (1) testing the data in each series (i.e. for each station, duration and season) for serial independence, (2) selecting a probability density function to model the low flows, (3) calculating the parameters of the selected probability density function for each series and (4) estimating the low flows for various return periods for the selected probability distribution and its calculated parameters.

3.2.1 Testing Low Flow Series for Serial Independence

For a frequency analysis of a set of data, it is assumed that each member of the set is independently and identically distributed. A computer program, developed in-house, was used to test each low flow series for serial independence. Of the 312 series (39 stations, 4 summer durations and 4 winter durations) 18 series failed the test for serial independence at the 5% significance level and out of these 18 series, 1 series (station 02YD002 and its 30-day summer series) also failed the test for independence at the 1% significance level. The 18 low flow series were from a total of 8 stations. The results are summarized in Table 3.1.

An investigation of flows from the stations whose summer low flow series failed the test for independence showed that the years for which low flow records are available do, indeed, exhibit some persistent downward trend. Stations nearby also showed the same trend for the overlapping period of record. However, the data from the entire period of record at the latter stations did not exhibit any statistically significant serial correlation. The serial correlation detected in the low flow series is very likely significant only because of the shortness of the period of record. They were, therefore, retained for frequency analyses.

Table 3.1 Low Flow Series Which Failed the Test for Independence

Station Number	Season	N-Day Flow Period	Record Length (Years)	Failed at 5%	Failed at 1%
02ZG004	Winter	15	9	YES	NO
02ZG004	Summer	7	9	YES	NO
02ZG004	Summer	15	9	YES	NO
02ZG004	Summer	30	9	YES	NO
02ZM009	Summer	1	11	YES	NO
02ZM009	Summer	7	11	YES	NO
02YD002	Summer	1	10	YES	NO
02YD002	Summer	7	10	YES	NO
02YD002	Summer	15	10	YES	NO
02YD002	Summer	30	10	YES	YES
02ZA002	Summer	1	8	YES	NO
02ZC002	Summer	1	8	YES	NO
02ZC002	Summer	7	8	YES	NO
02ZC002	Summer	15	8	YES	NO
02ZG002	Winter	15	13	YES	NO
02ZG002	Winter	30	13	YES	NO
02ZH001	Winter	30	37	YES	NO
02YS003	Winter	30	22	YES	NO

3.2.2 Choice of Probability Density Function and Fitting Method

This discussion on the choice of probability density function (PDF) for fitting the low flow series and the fitting methods is extracted from the report "Low Flow Frequency Analysis" report published by Environment Canada [4]. Four PDFs were investigated, namely, the Pearson Type III, the Pearson Type V, the Gumbel Type III and the three-parameter Log-Normal. The parameters of each PDF were estimated by the methods of moments and maximum likelihood. In addition, the method of the smallest observed flow was used for the Gumbel Type III PDF and the median method was used for the three-parameter Log-Normal PDF. The criterion of acceptable fit was that the lower bound parameter of the distribution should lie between zero and the minimum observed flow.

The low flow data from 38 Canadian rivers were analyzed according to the above methodology. The results indicated that the greatest number of acceptable fits was obtained with the Gumbel Type III fit using the method of maximum likelihood for estimating the parameters and the second greatest number of acceptable fits was obtained with the Gumbel III fit using the method of smallest observed flow for estimating the parameters.

It was, therefore, recommended that the Gumbel Type III distribution be used to fit series of low flows, however, the other distributions should not be totally rejected but considered as "standby methods".

The criterion that the lower bound of the distribution should be lie between zero and the minimum observed flow for the distribution to be considered acceptable was further investigated. At the end of the investigation, it was concluded that the criterion should not be strictly adhered to, that is, negative lower bounds for the distribution, although a physical impossibility, can be accepted and, sometimes, may even result in a better fit.

3.2.3 The Gumbel Type III Distribution Function

The Gumbel Type III distribution is a variation of the Fisher and Tippett's third asymptotic distribution of extreme values and is often referred to in hydrology as the Gumbel Type III distribution [4]. The probability density function is

$$p(x) = a(x-e)^{a-1}(b-e)^{-a}\exp[-\{(x-e)/(b-e)\}^{a}]$$

where e is the lower bound or displacement parameter, referred to as epsilon in the text, b is the characteristic drought or a location parameter, referred to as beta in the text, and a is the scale parameter, referred to as alpha in the text. The density function is integrable and results in

$$P(x) \quad = \quad 1 - \exp[-\{(x-e)/(b-e)\}^a]$$

which gives the probability of non-exceedence of x. The value of x for a given probability of non-exceedence is given by

$$x \quad = \quad e + (b-e)[-\ln\{1-P(x)\}]^{1/a}$$

3.2.4 Estimating Frequency of Low Flows

Calculated low flow data for the four durations (1-day, 7-day, 15-day and 30-day) and for all years of record and for the winter and summer seasons, as discussed in Chapter 2, were used as input data into the Low Flow Frequency Analysis (LFA) computer program, developed by Environment Canada [5], to obtain the frequency estimates of low flows for various return periods.

In the LFA program the Gumbel Type III distribution is first selected to model low flows. The parameters of the distribution are estimated by (1) the method of maximum likelihood, (2) the method of the smallest observed drought and (3) the method of moments. If an appropriate solution for the estimation of the parameters via the three methods cannot be found, then the three parameter lognormal distribution fitted by the method of moments is used.

3.3 Results of Frequency Analysis

The results of the frequency analysis on the 1-, 7-, 15-, and 30-day low flows for winter and summer periods are presented as follows: the mean and standard deviation are shown in Tables 3.2 (winter) and 3.3 (summer), the coefficients of variation and of skewness are shown in Tables 3.4 (winter) and 3.5 (summer), the location (beta), scale (alpha) and displacement (epsilon) parameters are listed in Tables 3.6 (winter) and 3.7 (summer), the frequency estimates of return periods 2, 5, 10, 20 and 50 years are shown in Tables 3.8 (1-day, winter), 3.9 (7-day, winter), 3.10 (15-day, winter), 3.11 (30-day, winter), 3.12 (1-day, summer), 3.13 (7-day, summer), 3.14 (15-day, summer) and 3.15 (30-day, summer).

Table 3.2 Mean and Standard Deviation of Winter Low Flow Series

Station Number	Drainage Area	Probability Density	1 - Day		7 - Day		15 - Day		30 - Day	
			MEAN	STDV*	MEAN	STDV*	MEAN	STDV*	MEAN	STDV*
	(km^2)	Function*	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
02ZM006	3.9	G III	0.02	0.0065	0.02	0.0075	0.02	0.0098	0.05	0.0219
02ZL003	10.8	G III	0.09	0.0382	0.10	0.0457	0.13	0.0623	0.17	0.0726
02ZG004	42.7	G III	0.31	0.1036	0.37	0.1255	0.48	0.1754	0.84	0.2158
02ZH002	43.3	G III	0.21	0.0957	0.25	0.1113	0.34	0.1962	0.61	0.2542
02ZN001	53.3	G III	0.57	0.1765	0.67	0.2378	0.87	0.3803	1.32	0.5343
02ZM009	53.6	G III	0.60	0.2499	0.73	0.3045	0.96	0.3504	1.43	0.4318
02ZK002	89.6	G III	0.92	0.4541	1.14	0.4875	1.38	0.5289	2.02	0.6112
02ZG003	115	G III	0.55	0.2873	0.67	0.3505	0.90	0.5083	2.03	0.7300
02ZG002	166	G III	1.89	1.0918	2.17	1.2895	2.58	1.3165	3.79	1.4939
02ZG001	205	G III	1.93	0.8261	2.29	1.0476	2.82	1.3302	4.14	1.6258
02ZK001	285	G III	2.52	0.9365	3.00	1.0335	3.65	1.2054	5.16	1.7103
02ZH001	764	G III	5.93	2.0359	6.80	2.6381	7.96	3.3569	11.13	4.5671
02YS003	36.7	G III	0.16	0.0595	0.18	0.0714	0.22	0.1082	0.37	0.1732
02YP001	63.8	G III	0.28	0.1120	0.32	0.1239	0.37	0.1520	0.50	0.1817
02ZJ001	67.4	G III	0.33	0.1435	0.39	0.1667	0.50	0.2577	0.79	0.3482
02YO006	177	G III	0.68	0.3024	0.78	0.3372	0.97	0.5059	1.45	0.6410
02YR001	267	G III	2.77	1.0808	2.97	1.1475	3.26	1.3472	3.78	1.5458
02YR002	399	G III	2.35	1.1879	2.59	1.4315	3.09	1.9434	3.98	2.2973
02YN002	469	G III	4.12	1.4560	4.51	1.7015	5.25	2.3300	6.99	3.6894
02YR003	554	G III	5.37	2.3953	5.83	2.3302	7.05	3.1568	8.36	3.9674
02ZF001	1170	G III	17.58	5.5939	19.02	6.1406	21.05	6.9322	24.80	7.4262
02YS001	1290	G III	11.77	4.6264	12.63	4.8232	13.82	5.3372	16.82	6.6229
02ZE001	2640	G III	34.15	10.4770	35.07	10.8176	37.31	11.6236	43.62	14.6807
02YQ001	4400	G III	39.98	15.9752	41.99	17.2386	45.77	19.5600	53.94	24.7454
02YM003	93.2	G III	0.22	0.1284	0.24	0.1528	0.29	0.1876	0.38	0.2418
02YD002	200	G III	0.67	0.5805	0.72	0.5964	0.81	0.6348	0.97	0.6805
02YD001	237	G III	0.71	0.4447	0.76	0.4630	0.83	0.4837	0.94	0.5227
02YK005	391	G III	1.98	0.9068	2.24	1.1337	2.49	1.3421	3.06	1.8509
02YK002	470	G III	3.39	1.0927	3.59	1.1375	3.94	1.3003	4.84	1.8260
02YK004	529	G III	4.12	1.4686	4.34	1.5068	4.62	1.5950	5.15	1.7820
02YF001	611	G III	1.80	0.9145	1.91	0.9862	2.10	1.1110	2.59	1.6110
02YC001	624	G III	4.11	1.3381	4.27	1.3654	4.48	1.4454	4.95	1.8518
02YL001	2110	G III	10.07	3.4882	10.84	3.6789	12.11	4.4187	14.95	5.9064
02ZA002	72	G III	0.32	0.1027	0.37	0.1136	0.46	0.1600	0.77	0.2992
02ZA003	139	G III	0.84	0.4792	1.01	0.7016	1.36	1.3119	2.15	1.6231
02ZB001	205	G III	1.23	0.5683	1.39	0.6728	1.70	0.9170	2.63	1.6214
02ZC002	230	G III	1.07	0.6466	1.24	0.7595	1.58	1.1119	2.98	1.9259
02ZA001	343	G III	1.97	0.6558	2.22	0.7867	2.74	1.1967	3.80	1.9221
02YJ001	640	G III	5.55	1.8628	6.13	2.0401	7.11	2.5034	9.15	3.5906

* Notes

STDV – Standard Deviation

Probability Density Function = G III Gumbel Type III

Table 3.3 Mean and Standard Deviation of Summer Low Flow Series

Station Number	Drainage Area	Probability Densisty Function*	1 - Day		7 - Day		15 - Day		30 - Day	
			MEAN	STDV*	MEAN	STDV*	MEAN	STDV*	MEAN	STDV*
	(km^2)		(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
02ZM006	3.9	G III	0.01	0.0048	0.01	0.0056	0.01	0.0081	0.02	0.0141
02ZL003	10.8	G III	0.04	0.0420	0.05	0.0599	0.06	0.0728	0.09	0.1038
02ZG004	42.7	G III	0.14	0.0659	0.19	0.0842	0.25	0.1145	0.41	0.1845
02ZH002	43.3	G III	0.15	0.1403	0.18	0.1605	0.23	0.2098	0.39	0.3377
02ZN001	53.3	G III	0.55	0.1878	0.63	0.2159	0.74	0.2717	0.94	0.3729
02ZM009	53.6	G III	0.46	0.2274	0.53	0.2380	0.64	0.2909	0.85	0.3625
02ZK002	89.6	G III	0.57	0.3071	0.70	0.3905	0.90	0.5540	1.20	0.7179
02ZG003	115	G III	0.38	0.2000	0.47	0.2171	0.62	0.2683	1.13	0.5759
02ZG002	166	G III	1.17	0.6506	1.33	0.6995	1.53	0.7711	1.94	1.0077
02ZG001	205	G III	1.38	0.7021	1.58	0.8702	1.87	1.0475	2.33	1.1498
02ZK001	285	G III	1.23	0.7516	1.50	0.9389	1.87	1.1931	2.64	1.6754
02ZH001	764	G III	2.67	1.8616	3.02	2.1422	3.55	2.7489	4.54	3.8384
02YS003	36.7	G III	0.10	0.0689	0.12	0.0812	0.15	0.0898	0.22	0.1558
02YP001	63.8	G III	0.17	0.0958	0.20	0.1096	0.22	0.1192	0.29	0.1560
02ZJ001	67.4	G III	0.13	0.1570	0.16	0.1975	0.19	0.2203	0.28	0.4091
02YO006	177	G III	0.35	0.1467	0.40	0.1623	0.48	0.1858	0.66	0.2614
02YR001	267	G III	1.00	0.6688	1.10	0.7445	1.17	0.8115	1.37	0.9943
02YR002	399	G III	0.67	0.8647	0.73	0.9045	0.79	0.9397	0.94	1.1328
02YN002	469	G III	2.74	1.1098	2.92	1.1274	3.24	1.1816	4.16	1.3399
02YR003	554	G III	2.34	1.2831	2.52	1.3437	2.67	1.3799	2.91	1.3877
02ZF001	1170	G III	9.41	3.7756	10.12	4.0615	10.99	4.4639	12.50	5.0650
02YS001	1290	G III	7.12	3.8549	8.03	4.1337	9.16	5.3217	10.71	6.3908
02ZE001	2640	G III	17.82	9.7689	18.84	10.4235	19.96	11.2104	22.45	13.0399
02YQ001	4400	G III	22.10	12.5043	23.53	13.4797	25.36	14.8518	29.13	17.6846
02YM003	93.2	G III	0.09	0.1079	0.11	0.1319	0.17	0.2286	0.27	0.3342
02YD002	200	G III	0.66	0.8146	0.74	0.8494	0.83	0.9270	0.99	0.9492
02YD001	237	G III	1.10	0.3563	1.24	0.4352	1.40	0.5200	1.91	0.9895
02YK005	391	G III	2.16	1.0062	2.36	1.1395	2.59	1.2773	2.95	1.4643
02YK002	470	G III	3.17	1.3607	3.54	1.5633	3.98	1.7425	5.12	2.5674
02YK004	529	G III	3.87	1.5499	4.14	1.6418	4.50	1.8774	5.00	2.1140
02YF001	611	G III	2.60	1.1808	3.05	1.4573	3.74	2.1341	5.78	4.3613
02YC001	624	G III	7.11	2.1048	7.50	2.2379	8.24	2.4817	10.44	3.3069
02YL001	2110	G III	9.27	5.2053	10.51	5.6474	12.68	7.3871	17.73	9.7201
02ZA002	72	G III	0.26	0.1017	0.29	0.1035	0.34	0.1328	0.44	0.1452
02ZA003	139	G III	1.02	0.4389	1.18	0.4821	1.35	0.5684	1.73	0.6974
02ZB001	205	G III	1.05	0.4706	1.35	0.6636	1.70	0.8851	3.02	1.6568
02ZC002	230	G III	1.17	0.7673	1.45	0.8282	1.90	0.8458	2.89	1.3854
02ZA001	343	G III	1.52	0.4871	1.65	0.5306	1.85	0.6784	2.29	1.0676
02YJ001	640	G III	5.68	2.4541	6.43	2.5856	7.21	2.9950	8.74	3.6882

* Notes
STDV - Standard Deviation
Probability Density Function = G III: Gumbel Type III

Table 3.4 Coefficients of Skewness and Variation of Winter Low Flow Series

Station Number	Drainage Area (km^2)	Probability Density Function*	1 - Day SKEW*	1 - Day CV*	7 - Day SKEW*	7 - Day CV*	15 - Day SKEW*	15 - Day CV*	30 - Day SKEW*	30 - Day CV*
02ZM006	3.9	G III	-0.1383	0.4331	0.0768	0.3998	0.7709	0.3991	0.2803	0.4500
02ZL003	10.8	G III	0.5888	0.4187	1.0520	0.4384	1.7569	0.4933	0.9759	0.4243
02ZG004	42.7	G III	0.2380	0.3295	0.1244	0.3397	0.0789	0.3690	-0.3683	0.2582
02ZH002	43.3	G III	0.1671	0.4466	0.2023	0.4504	1.6591	0.5835	0.5341	0.4201
02ZN001	53.3	G III	-0.1795	0.3096	-0.1006	0.3523	0.3895	0.4382	0.0869	0.4040
02ZM009	53.6	G III	0.9310	0.4136	0.8927	0.4194	0.4752	0.3661	0.2120	0.3026
02ZK002	89.6	G III	1.4970	0.4919	1.5859	0.4280	1.5035	0.3833	0.3092	0.3029
02ZG003	115	G III	0.9341	0.5208	1.4121	0.5223	1.5233	0.5622	-0.4404	0.3597
02ZG002	166	G III	0.6731	0.5764	0.9289	0.5946	1.3009	0.5098	0.9001	0.3941
02ZG001	205	G III	0.9704	0.4280	0.9805	0.4571	0.7157	0.4721	0.2496	0.3928
02ZK001	285	G III	0.3310	0.3715	0.3458	0.3447	0.0774	0.3303	0.1347	0.3314
02ZH001	764	G III	0.8501	0.3434	1.2280	0.3879	1.6393	0.4219	0.6323	0.4103
02YS003	36.7	G III	0.4689	0.3805	0.6346	0.3968	1.2498	0.4840	0.9468	0.4631
02YP001	63.8	G III	1.4276	0.3941	1.2828	0.3914	1.0454	0.4098	0.5237	0.3603
02ZJ001	67.4	G III	0.1741	0.4320	0.1314	0.4293	0.8831	0.5131	0.5578	0.4428
02YO006	177	G III	0.7945	0.4441	0.6108	0.4341	0.5535	0.5193	0.4792	0.4434
02YR001	267	G III	0.5872	0.3897	0.4795	0.3857	0.6912	0.4127	0.5564	0.4093
02YR002	399	G III	1.2743	0.5059	1.7984	0.5524	2.1387	0.6284	1.7687	0.5772
02YN002	469	G III	0.5277	0.3538	0.6959	0.3777	1.0601	0.4435	1.0997	0.5280
02YR003	554	G III	1.3581	0.4463	0.7814	0.4000	0.5828	0.4476	1.1053	0.4746
02ZF001	1170	G III	0.1798	0.3181	0.1620	0.3229	0.1516	0.3293	-0.1140	0.2995
02YS001	1290	G III	0.3243	0.3932	0.4061	0.3819	0.5314	0.3862	0.3544	0.3938
02ZE001	2640	G III	-0.5620	0.3068	-0.4406	0.3085	-0.4152	0.3116	-0.2529	0.3366
02YQ001	4400	G III	0.3502	0.3996	0.4393	0.4106	0.4526	0.4273	0.5183	0.4588
02YM003	93.2	G III	1.0930	0.5951	1.1406	0.6308	1.0953	0.6579	0.8993	0.6350
02YD002	200	G III	1.8530	0.8656	1.8184	0.8340	1.5493	0.7852	1.3291	0.6999
02YD001	237	G III	1.0843	0.6296	0.9411	0.6125	0.7358	0.5855	0.8216	0.5590
02YK005	391	G III	0.9388	0.4573	0.9426	0.5053	1.1387	0.5383	1.7244	0.6044
02YK002	470	G III	1.1075	0.3228	0.9505	0.3169	0.8060	0.3299	0.7134	0.3769
02YK004	529	G III	0.9462	0.3564	0.9141	0.3471	0.8497	0.3450	0.8236	0.3458
02YF001	611	G III	0.9961	0.5089	1.0526	0.5151	0.9812	0.5291	1.2648	0.6224
02YC001	624	G III	0.6323	0.3253	0.5258	0.3196	0.4637	0.3226	1.4079	0.3743
02YL001	2110	G III	1.0069	0.3462	0.9567	0.3394	0.9996	0.3648	0.6713	0.3950
02ZA002	72	G III	0.3055	0.3194	0.0785	0.3052	0.5034	0.3443	0.9954	0.3895
02ZA003	139	G III	1.6772	0.5688	2.0602	0.6975	2.4583	0.9652	1.2205	0.7561
02ZB001	205	G III	1.1568	0.4606	1.1287	0.4832	1.2451	0.5400	1.1693	0.6168
02ZC002	230	G III	1.0374	0.6032	1.0167	0.6130	1.3785	0.7032	1.1916	0.6470
02ZA001	343	G III	0.4089	0.3332	0.2997	0.3544	0.3760	0.4364	0.5827	0.5061
02YJ001	640	G III	0.3133	0.3358	0.2002	0.3326	0.2854	0.3522	0.3103	0.3923

* Notes

Probability Density Function = G III: Gumbel Type III

SKEW – Coefficient of Skewness

CV – Coefficient of Variation

Table 3.5 Coefficients of Skewness and Variation of Summer Low Flow Series

Station Number	Drainage Area (km^2)	Probability Density Function*	1 – Day SKEW*	1 – Day CV*	7 – Day SKEW*	7 – Day CV*	15 – Day SKEW*	15 – Day CV*	30 – Day SKEW*	30 – Day CV*
02ZM006	3.9	G III	2.3371	0.6143	1.8022	0.6006	1.9649	0.6773	1.8525	0.7695
02ZL003	10.8	G III	2.8751	1.1319	2.9628	1.2000	2.8751	1.1500	2.6178	1.1393
02ZG004	42.7	G III	-0.5197	0.4702	-0.6416	0.4520	-0.5130	0.4596	-0.9997	0.4527
02ZH002	43.3	G III	2.2443	0.9626	2.0529	0.9025	2.0017	0.8991	1.6526	0.8583
02ZN001	53.3	G III	0.0090	0.3385	0.0178	0.3450	0.3543	0.3670	0.6800	0.3983
02ZM009	53.6	G III	-0.0200	0.4911	-0.2562	0.4522	-0.0937	0.4533	-0.1735	0.4260
02ZK002	89.6	G III	1.5895	0.5374	1.6962	0.5559	2.0469	0.6132	1.9125	0.5980
02ZG003	115	G III	0.3513	0.5278	-0.1306	0.4589	-0.3802	0.4347	0.1843	0.5118
02ZG002	166	G III	0.8395	0.5572	0.6478	0.5274	0.5477	0.5043	0.3877	0.5183
02ZG001	205	G III	0.7179	0.5091	1.1701	0.5518	1.0197	0.5604	0.3236	0.4926
02ZK001	285	G III	1.1153	0.6105	1.0909	0.6264	1.2302	0.6373	0.9512	0.6349
02ZH001	764	G III	2.1552	0.6981	2.1218	0.7083	2.1651	0.7735	2.4475	0.8460
02YS003	36.7	G III	1.3236	0.6990	0.9811	0.6596	0.9004	0.6088	2.3808	0.7082
02YP001	63.8	G III	-0.2085	0.5708	-0.2187	0.5599	-0.2612	0.5338	-0.0342	0.5461
02ZJ001	67.4	G III	2.3261	1.1957	2.5478	1.2104	2.6189	1.1679	2.9956	1.4706
02YO006	177	G III	-0.1485	0.4167	-0.0823	0.4008	-0.1539	0.3901	-0.4920	0.3946
02YR001	267	G III	1.2899	0.6659	1.4313	0.6796	1.4735	0.6909	1.6985	0.7275
02YR002	399	G III	2.9596	1.2826	2.8969	1.2318	2.8429	1.1905	2.8507	1.2010
02YN002	469	G III	2.2774	0.4050	2.0142	0.3858	1.9001	0.3648	1.1712	0.3220
02YR003	554	G III	-0.7092	0.5491	-0.7707	0.5321	-0.8180	0.5168	-0.8103	0.4776
02ZF001	1170	G III	0.3947	0.4013	0.4180	0.4014	0.2800	0.4063	-0.0001	0.4053
02YS001	1290	G III	1.1536	0.5417	0.9814	0.5147	1.1307	0.5810	0.9338	0.5969
02ZE001	2640	G III	0.6811	0.5481	0.7574	0.5533	0.7877	0.5615	0.8743	0.5808
02YQ001	4400	G III	1.0146	0.5658	1.1755	0.5728	1.2596	0.5856	1.4448	0.6071
02YM003	93.2	G III	2.4085	1.2095	2.5431	1.2205	2.4363	1.3510	2.2678	1.2349
02YD002	200	G III	2.4931	1.2259	2.4078	1.1501	2.4055	1.1189	1.8788	0.9542
02YD001	237	G III	0.0501	0.3239	0.3899	0.3519	0.2584	0.3722	1.1472	0.5179
02YK005	391	G III	0.4333	0.4655	0.5798	0.4821	0.8162	0.4937	0.9379	0.4970
02YK002	470	G III	0.7939	0.4292	0.7296	0.4411	0.6684	0.4384	0.8278	0.5013
02YK004	529	G III	0.1401	0.4007	0.1253	0.3964	0.1546	0.4171	0.1925	0.4225
02YF001	611	G III	0.1184	0.4533	0.2887	0.4783	0.8822	0.5711	1.5393	0.7544
02YC001	624	G III	0.2570	0.2958	0.2744	0.2985	0.3143	0.3011	0.4849	0.3166
02YL001	2110	G III	1.3121	0.5612	1.2626	0.5374	1.3261	0.5827	1.2300	0.5482
02ZA002	72	G III	-0.8393	0.3870	-0.6337	0.3535	-0.3122	0.3866	-0.3942	0.3286
02ZA003	139	G III	1.3449	0.4311	1.4280	0.4087	1.6000	0.4216	1.0578	0.4040
02ZB001	205	G III	0.5930	0.4466	0.5012	0.4920	0.5908	0.5200	0.6667	0.5483
02ZC002	230	G III	0.5290	0.6586	0.7591	0.5722	1.0797	0.4445	1.0352	0.4801
02ZA001	343	G III	0.7398	0.3195	0.8358	0.3219	1.1521	0.3673	1.4914	0.4671
02YJ001	640	G III	0.5470	0.4323	0.5403	0.4018	0.6112	0.4157	0.6229	0.4218

* Notes

Probability Density Function = G III : Gumbel Type III

SKEW – Coefficient of Skewness

CV – Coefficient of Variation

Table 3.6 Parameters of Gumbel Type III PDF for Winter Low Flow Series

Station	Drainage	1 - Day			7 - Day			15 - Day			30 - Day		
Number	Area (km^2)	BETA*	ALPH*	EPSL*	BETA*	ALPH*	EPSL*	BETA*	ALPH*	EPSL*	BETA*	ALPH*	EPSL*
02ZM006	3.9	0.0173	3.4882	-0.0047	0.0211	2.8929	-0.0008	0.0274	2.3220	0.0031	0.0549	2.4054	0.0001
02ZL003	10.8	0.0985	1.6623	0.0294	0.1113	1.4764	0.0379	0.1262	0.9928	0.0645	0.1791	1.3100	0.0769
02ZG004	42.7	0.3327	1.6272	0.1518	0.3991	2.0421	0.1382	0.5097	1.7475	0.1860	0.9162	5.3203	-0.0880
02ZH002	43.3	0.2452	3.0359	-0.0460	0.2822	2.9176	-0.0447	0.3677	1.5438	0.0495	0.6818	2.6779	-0.0230
02ZN001	53.3	0.6329	3.8879	-0.0133	0.7531	3.1542	0.0258	0.9445	1.7378	0.2284	1.4642	2.2290	0.2328
02ZM009	53.6	0.6273	1.2525	0.2931	0.7607	1.3240	0.3267	1.0036	1.4167	0.4590	1.5108	1.7163	0.7221
02ZK002	89.6	0.9539	1.1769	0.3906	1.1610	1.1134	0.5971	1.4265	1.2613	0.7214	2.0838	1.3192	1.1621
02ZG003	115	0.5965	1.4882	0.1316	0.7054	1.2966	0.2268	0.9530	1.2912	0.2636	2.2944	4.9211	-0.9968
02ZG002	166	2.1345	1.8892	-0.0267	2.4051	1.6621	0.1418	2.6634	1.1594	1.0604	3.9158	1.2263	1.9680
02ZG001	205	1.9930	1.2076	0.8682	2.3957	1.2745	0.9664	2.8898	1.1402	1.1187	4.5677	2.1924	0.8336
02ZK001	285	2.7460	1.9910	0.7524	3.2834	2.3071	0.7851	4.0429	3.0418	0.3519	5.6966	2.8119	0.7982
02ZH001	764	6.2997	1.6322	2.6468	7.2262	1.5288	2.8791	8.5090	1.5499	2.9767	12.1879	1.9215	2.8104
02YS003	36.7	0.1640	1.3752	0.0710	0.1909	1.5004	0.0725	0.2356	1.3303	0.0812	0.4121	1.8590	0.0714
02YP001	63.8	0.2940	1.2630	0.1444	0.3277	1.2717	0.1605	0.3979	1.5824	0.1358	0.5454	1.8625	0.1783
02ZJ001	67.4	0.3723	2.4281	0.0208	0.4355	2.4688	0.0219	0.5549	1.7845	0.0700	0.8586	1.7466	0.1969
02YO006	177	0.7342	1.5805	0.2136	0.8599	2.0086	0.1291	1.0711	1.6554	0.1587	1.5888	1.9429	0.3114
02YR001	267	2.9491	1.5272	1.1310	3.1808	1.6092	1.1504	3.4717	1.4903	1.2418	3.9641	1.3571	1.5612
02YR002	399	2.5447	1.5775	0.5833	2.8014	1.4952	0.5959	3.3109	1.3566	0.6462	4.0926	1.1364	1.3343
02YN002	469	4.4781	2.0267	1.2967	4.8845	1.8395	1.4868	5.6657	1.5837	1.6462	7.5236	1.4434	1.7436
02YR003	554	5.7177	1.4488	1.9503	6.2917	1.7037	1.9691	7.7563	1.8409	1.4481	9.0691	1.5926	2.1864
02ZF001	1170	19.1612	2.3867	5.3118	20.7980	2.4838	5.0757	23.1070	2.5673	4.8468	27.4565	3.8386	0.0073
02YS001	1290	13.1975	2.7487	0.1433	14.0728	2.6059	1.0550	15.3407	2.4251	1.7851	18.4909	2.1049	3.7536
02ZE001	2640	38.0351	4.0910	-3.9610	39.5689	9.5707	-47.2452	42.0851	8.4797	-41.4601	48.9971	4.4526	-10.5115
02YQ001	4400	44.4551	2.3524	5.1593	46.4962	2.1666	6.9931	50.6300	2.0501	7.9564	59.4377	1.8562	9.9419
02YM003	93.2	0.2315	1.3569	0.0434	0.2554	1.2310	0.0552	0.2993	1.1991	0.0612	0.3898	1.0923	0.1169
02YD002	200	0.7010	1.1338	0.0138	0.7477	1.1395	0.0371	0.8597	1.2158	0.0404	1.0389	1.2706	0.1138
02YD001	237	0.7425	1.2259	0.1513	0.7818	1.1480	0.1859	0.8875	1.3721	0.1703	0.9781	1.2259	0.2717
02YK005	391	2.1456	1.6284	0.5732	2.4040	1.4475	0.6529	2.6429	1.3318	0.7555	2.9652	0.8834	1.4310
02YK002	470	3.5852	1.6390	1.6708	3.8170	1.7301	1.7044	4.2093	1.7651	1.7426	5.2325	1.8040	1.7072
02YK004	529	4.2991	1.3712	2.0584	4.5713	1.5017	2.1044	4.8788	1.5354	2.2087	5.3642	1.3581	2.6409
02YF001	611	1.8656	1.2091	0.6560	1.9997	1.2470	0.6638	2.1943	1.2419	0.6873	2.7691	1.3192	0.4827
02YC001	624	4.4068	1.8489	1.7434	4.5849	1.9160	1.7764	4.8308	2.0215	1.7173	5.2771	1.6236	2.0418
02YL001	2110	10.6821	1.5867	4.7082	11.5944	1.7532	4.6776	13.0120	1.7420	4.7677	16.2489	1.8390	4.5944
02ZA002	72	0.3405	1.6839	0.1591	0.3928	1.6663	0.1920	0.4831	1.3306	0.2538	0.8174	1.5264	0.3203
02ZA003	139	0.9479	1.8208	0.0002	1.0775	1.2840	0.1120	1.2786	0.8644	0.2290	2.2498	1.1649	0.2617
02ZB001	205	1.3517	1.7751	0.2805	1.5222	1.6899	0.3152	1.8420	1.5089	0.3813	2.7567	1.2155	0.6215
02ZC002	230	1.2660	2.5412	-0.4615	1.4613	2.4481	-0.5030	1.7986	1.6782	-0.2337	3.0834	1.1418	0.7829
02ZA001	343	2.0986	1.6968	0.8868	2.3622	1.6038	0.9878	2.9294	1.4898	0.9907	3.9925	1.2821	1.3522
02YJ001	640	6.0100	2.0823	1.9318	6.6570	2.1511	2.0784	7.5707	1.6449	3.0424	9.7768	1.5685	3.6430

* Notes
BETA – Beta
ALPH – Alpha
EPSL – Epsilon

Table 3.7 Parameters of Gumbel Type III PDF for Summer Low Flow Series

Station	Drainage	1 – Day			7 – Day			15 – Day			30 – Day		
Number	Area (km^2)	BETA*	ALPH*	EPSL*	BETA*	ALPH*	EPSL*	BETA*	ALPH*	EPSL*	BETA*	ALPH*	EPSL*
02ZM006	3.9	0.0091	2.0688	−0.0017	0.0109	2.1602	−0.0022	0.0136	1.7425	−0.0017	0.0203	1.4351	−0.0016
02ZL003	10.8	0.0329	0.7850	0.0045	0.0415	0.7049	0.0086	0.0534	0.7161	0.0122	0.0726	0.6282	0.0286
02ZG004	42.7	0.1647	5.7696	−0.1664	0.2204	10.1996	−0.4820	0.2940	7.3095	−0.4106	0.4898	40.6534	−5.5491
02ZH002	43.3	0.1455	0.9952	0.0061	0.1837	1.0988	0.0151	0.2406	1.0933	0.0199	0.4075	1.1103	0.0226
02ZN001	53.3	0.6188	3.4375	−0.0133	0.6992	3.4164	−0.0266	0.8239	2.7592	0.0553	1.0400	2.3705	0.1132
02ZM009	53.6	0.5262	2.4503	−0.0254	0.6099	4.0494	−0.2678	0.7360	3.2317	−0.1557	0.9764	3.8559	−0.3196
02ZK002	89.6	0.6280	1.6889	0.0872	0.7746	1.6971	0.0853	0.9844	1.5012	0.1350	1.2845	1.3734	0.2713
02ZG003	115	0.4331	2.3859	−0.0460	0.5475	3.8298	−0.2302	0.7149	4.8765	−0.4721	1.3021	2.9097	−0.3356
02ZG002	166	1.2502	1.3955	0.2394	1.4572	1.6829	0.1929	1.7015	1.9208	0.1452	2.1729	1.9391	0.1270
02ZG001	205	1.5756	2.3840	−0.2004	1.7873	2.0261	−0.1075	2.1221	2.0229	−0.1515	2.6854	2.7246	−0.5552
02ZK001	285	1.3326	1.4143	0.1743	1.6047	1.3297	0.2321	2.0149	1.3559	0.2495	2.8315	1.3352	0.3442
02ZH001	764	2.9603	1.5311	−0.0140	3.3490	1.4993	0.0184	3.8804	1.3649	0.0801	4.8827	1.2637	0.1248
02YS003	36.7	0.1031	1.1736	0.0171	0.1315	1.2984	0.0177	0.1574	1.3153	0.0293	0.2248	1.0756	0.0525
02YP001	63.8	0.2100	20.9859	−1.4526	0.2380	4.7666	−0.2624	0.2697	5.0635	−0.3031	0.3529	12.6010	−1.3290
02ZJ001	67.4	0.1196	0.8382	0.0004	0.1460	0.8127	0.0038	0.1722	0.8372	0.0052	0.2131	0.6688	0.0129
02YO006	177	0.3972	2.9671	−0.0119	0.4549	2.9838	−0.0035	0.5386	3.6410	−0.0870	0.7628	6.5590	−0.6991
02YR001	267	1.1008	1.4566	0.0469	1.1935	1.4058	0.0690	1.2697	1.3509	0.0917	1.4646	1.2850	0.1076
02YR002	399	0.5842	0.7784	0.0083	0.6505	0.8010	0.0158	0.7126	0.8228	0.0210	0.8472	0.8168	0.0242
02YN002	469	2.6904	0.8996	1.7433	2.8884	0.9308	1.8740	3.2980	1.1262	1.9113	4.4228	1.6788	1.9730
02YR003	554	2.8383	5.1224	−3.3903	3.0772	7.0328	−5.5061	3.2622	11.6114	−10.5427	3.5106	16.1742	−15.3399
02ZF001	1170	10.6111	2.8999	−0.7802	11.3949	2.8275	−0.5737	12.4178	2.9356	−1.0602	14.2269	3.3743	−2.6599
02YS001	1290	7.6600	1.4451	1.5323	8.8113	1.6727	1.2990	9.9032	1.4389	1.5611	11.5361	1.3953	1.6866
02ZE001	2640	19.9044	1.8406	0.7675	20.8333	1.7060	1.7146	22.0564	1.6785	1.8042	24.6675	1.5886	2.3015
02YQ001	4400	24.5361	1.6987	1.5459	26.0198	1.6446	2.0880	27.9541	1.5952	2.4298	31.9546	1.5266	2.9939
02YM003	93.2	0.0830	0.8731	−0.0047	0.0990	0.8488	−0.0034	0.1422	0.7504	0.0001	0.2451	0.8338	−0.0065
02YD002	200	0.6033	0.8363	−0.0132	0.6887	0.8701	0.0017	0.7694	0.8597	0.0345	1.0179	1.0595	−0.0104
02YD001	237	1.2232	3.6239	−0.0579	1.3742	2.9368	0.0623	1.5586	2.8404	0.0614	2.0988	1.6892	0.3285
02YK005	391	2.4063	2.0499	0.2460	2.6135	1.8652	0.3609	2.8479	1.7715	0.4421	3.2434	1.7658	0.4946
02YK002	470	3.4747	1.8888	0.7124	3.8830	1.8421	0.7797	4.3693	1.9058	0.8057	5.5603	1.5805	1.1152
02YK004	529	4.2346	1.9827	0.9978	4.5521	2.0923	0.9705	4.9044	1.8271	1.2273	5.3839	1.6179	1.6104
02YF001	611	2.9314	2.4138	0.0627	3.4679	2.4036	−0.2411	4.1463	1.6583	0.2912	5.9632	1.1047	0.9701
02YC001	624	7.6934	2.3122	2.6300	8.0723	2.1292	3.0592	8.7766	1.8104	3.9327	10.9525	1.4892	5.4422
02YL001	2110	10.1508	1.5591	1.5978	11.2818	1.4231	2.7271	13.4443	1.3000	3.1856	19.0037	1.3990	4.3176
02ZA002	72	0.3074	17.9096	−1.2128	0.3368	9.9127	−0.5604	0.3913	4.6991	−0.1556	0.4962	5.7027	−0.2129
02ZA003	139	1.0265	1.0461	0.5591	1.1527	0.8755	0.7589	1.3377	0.9576	0.8040	1.8008	1.3020	0.8257
02ZB001	205	1.1492	1.7478	0.2564	1.4411	1.4276	0.3767	1.8035	1.3320	0.4774	3.2388	1.3933	0.6842
02ZC002	230	1.1704	1.0165	0.3852	1.4830	1.1085	0.5305	2.0839	1.7855	0.4423	2.9615	1.1403	1.3096
02ZA001	343	1.6310	1.8956	0.6672	1.7544	1.7742	0.7638	1.9620	1.6008	0.8146	2.4473	1.4687	0.7437
02YJ001	640	6.2758	2.0332	1.0339	6.8188	1.4672	2.6670	7.3996	1.1702	3.4035	9.1051	1.2700	4.0940

* Notes
BETA – Beta
ALPH – Alpha
EPSL – Epsilon

Table 3.8 Frequency Estimates of Winter 1-day Low Flows

Station Number	Drainage Area (km^2)	Probability Density Function*	MEAN (m^3/s)	Q2* (m^3/s)	Q5* (m^3/s)	Q10* (m^3/s)	Q20* (m^3/s)	Q50* (m^3/s)
02ZM006	3.9	G III	0.02	0.015	0.010	0.007	0.005	0.003
02ZL003	10.8	G III	0.09	0.085	0.057	0.047	0.041	0.036
02ZG004	42.7	G III	0.31	0.296	0.224	0.197	0.181	0.168
02ZH002	43.3	G III	0.21	0.212	0.132	0.093	0.063	0.035
02ZN001	53.3	G III	0.57	0.575	0.426	0.349	0.288	0.224
02ZM009	53.6	G III	0.60	0.542	0.394	0.349	0.324	0.308
02ZK002	89.6	G III	0.92	0.803	0.548	0.474	0.436	0.411
02ZG003	115	G III	0.55	0.495	0.301	0.234	0.195	0.165
02ZG002	166	G III	1.89	1.753	0.950	0.630	0.422	0.247
02ZG001	205	G III	1.93	1.699	1.193	1.043	0.964	0.913
02ZK001	285	G III	2.52	2.411	1.691	1.396	1.201	1.033
02ZH001	764	G III	5.93	5.565	4.104	3.567	3.239	2.981
02YS003	36.7	G III	0.16	0.142	0.102	0.089	0.082	0.076
02YP001	63.8	G III	0.28	0.256	0.190	0.170	0.159	0.151
02ZJ001	67.4	G III	0.33	0.323	0.210	0.160	0.124	0.091
02YO006	177	G III	0.68	0.626	0.415	0.339	0.293	0.258
02YR001	267	G III	2.77	2.561	1.812	1.548	1.391	1.272
02YR002	399	G III	2.35	2.138	1.341	1.054	0.882	0.749
02YN002	469	G III	4.12	3.952	2.814	2.345	2.031	1.761
02YR003	554	G III	5.37	4.876	3.288	2.747	2.435	2.205
02ZF001	1170	G III	17.58	17.190	12.700	10.710	9.302	8.012
02YS001	1290	G III	11.77	11.570	7.707	5.900	4.574	3.300
02ZE001	2640	G III	34.15	34.440	25.140	20.270	16.360	12.220
02YQ001	4400	G III	39.98	38.790	25.930	20.260	16.280	12.640
02YM003	93.2	G III	0.22	0.187	0.106	0.079	0.065	0.054
02YD002	200	G III	0.67	0.511	0.197	0.108	0.064	0.036
02YD001	237	G III	0.71	0.590	0.325	0.246	0.204	0.176
02YK005	391	G III	1.98	1.829	1.199	0.968	0.827	0.716
02YK002	470	G III	3.39	3.202	2.437	2.156	1.983	1.848
02YK004	529	G III	4.12	3.774	2.809	2.493	2.315	2.189
02YF001	611	G III	1.80	1.549	1.006	0.844	0.760	0.704
02YC001	624	G III	4.11	3.928	2.927	2.532	2.278	2.066
02YL001	2110	G III	10.07	9.450	7.029	6.155	5.627	5.219
02ZA002	72	G III	0.32	0.305	0.234	0.207	0.190	0.177
02ZA003	139	G III	0.84	0.775	0.416	0.276	0.186	0.111
02ZB001	205	G III	1.23	1.152	0.741	0.582	0.481	0.399
02ZC002	230	G III	1.07	1.034	0.496	0.251	0.075	0.000
02ZA001	343	G III	1.97	1.863	1.387	1.209	1.097	1.008
02YJ001	640	G III	5.55	5.352	3.916	3.316	2.911	2.558

* Notes

Q2, Q5, Q10, Q20, Q50 = Low Flows for Return Periods of 2, 5, 10, 20, 50 Years, Respectively.

Probability Density Function = G III , Gumbel Type III

Table 3.9 Frequency Estimates of Winter 7-day Low Flows

Station Number	Drainage Area (km^2)	Probability Density Function*	MEAN (m^3/s)	Q2* (m^3/s)	Q5* (m^3/s)	Q10* (m^3/s)	Q20* (m^3/s)	Q50* (m^3/s)
02ZM006	3.9	G III	0.02	0.019	0.012	0.009	0.007	0.005
02ZL003	10.8	G III	0.10	0.095	0.065	0.054	0.048	0.043
02ZG004	42.7	G III	0.37	0.356	0.263	0.225	0.199	0.177
02ZH002	43.3	G III	0.25	0.244	0.151	0.106	0.073	0.041
02ZN001	53.3	G III	0.67	0.673	0.478	0.382	0.309	0.237
02ZM009	53.6	G III	0.73	0.656	0.466	0.406	0.373	0.349
02ZK002	89.6	G III	1.14	1.003	0.744	0.672	0.636	0.614
02ZG003	115	G III	0.67	0.588	0.377	0.311	0.275	0.250
02ZG002	166	G III	2.17	1.957	1.060	0.726	0.521	0.358
02ZG001	205	G III	2.29	2.038	1.407	1.211	1.105	1.033
02ZK001	285	G III	3.00	2.916	2.089	1.727	1.475	1.245
02ZH001	764	G III	6.80	6.300	4.509	3.877	3.502	3.218
02YS003	36.7	G III	0.18	0.165	0.116	0.099	0.089	0.081
02YP001	63.8	G III	0.32	0.286	0.212	0.189	0.177	0.168
02ZJ001	67.4	G III	0.39	0.378	0.247	0.188	0.146	0.107
02YO006	177	G III	0.78	0.738	0.475	0.367	0.296	0.234
02YR001	267	G III	2.97	2.767	1.950	1.652	1.471	1.330
02YR002	399	G III	2.59	2.322	1.405	1.086	0.898	0.758
02YN002	469	G III	4.51	4.271	2.990	2.487	2.163	1.894
02YR003	554	G III	5.83	5.455	3.761	3.123	2.725	2.407
02ZF001	1170	G III	19.02	18.640	13.670	11.430	9.831	8.343
02YS001	1290	G III	12.63	12.360	8.376	6.544	5.219	3.967
02ZE001	2640	G III	35.07	36.310	26.980	21.380	16.410	10.500
02YQ001	4400	G III	41.99	40.350	26.760	20.970	17.020	13.520
02YM003	93.2	G III	0.24	0.204	0.114	0.087	0.073	0.064
02YD002	200	G III	0.72	0.552	0.228	0.136	0.090	0.060
02YD001	237	G III	0.76	0.619	0.347	0.270	0.231	0.206
02YK005	391	G III	2.24	2.012	1.274	1.023	0.878	0.771
02YK002	470	G III	3.59	3.414	2.592	2.280	2.084	1.926
02YK004	529	G III	4.34	4.037	3.013	2.656	2.446	2.288
02YF001	611	G III	1.91	1.659	1.065	0.884	0.787	0.722
02YC001	624	G III	4.27	4.096	3.060	2.644	2.372	2.143
02YL001	2110	G III	10.84	10.290	7.618	6.594	5.949	5.425
02ZA002	72	G III	0.37	0.353	0.274	0.244	0.226	0.211
02ZA003	139	G III	1.01	0.838	0.412	0.279	0.208	0.158
02ZB001	205	G III	1.39	1.287	0.812	0.634	0.523	0.435
02ZC002	230	G III	1.24	1.188	0.561	0.280	0.081	0.000
02ZA001	343	G III	2.22	2.081	1.527	1.326	1.203	1.108
02YJ001	640	G III	6.13	5.940	4.358	3.687	3.229	2.825

* Notes

Q2, Q5, Q10, Q20, Q50 = Low Flows for Return Periods of 2, 5, 10, 20, 50 Years, Respectively

Probability Density Function = G III: Gumbel Type III

Table 3.10 Frequency Estimates of Winter 15-day Low Flows

Station Number	Drainage Area (km^2)	Probability Density Function*	MEAN (m^3/s)	Q2* (m^3/s)	Q5* (m^3/s)	Q10* (m^3/s)	Q20* (m^3/s)	Q50* (m^3/s)
02ZM006	3.9	G III	0.02	0.024	0.016	0.012	0.010	0.008
02ZL003	10.8	G III	0.13	0.107	0.078	0.071	0.068	0.066
02ZG004	42.7	G III	0.48	0.448	0.323	0.275	0.245	0.221
02ZH002	43.3	G III	0.34	0.300	0.170	0.124	0.096	0.075
02ZN001	53.3	G III	0.87	0.808	0.530	0.425	0.358	0.304
02ZM009	53.6	G III	0.96	0.879	0.648	0.570	0.526	0.494
02ZK002	89.6	G III	1.38	1.249	0.936	0.840	0.788	0.753
02ZG003	115	G III	0.90	0.783	0.479	0.384	0.333	0.297
02ZG002	166	G III	2.58	2.229	1.500	1.291	1.184	1.116
02ZG001	205	G III	2.82	2.403	1.594	1.365	1.250	1.176
02ZK001	285	G III	3.65	3.624	2.606	2.113	1.742	1.375
02ZH001	764	G III	7.96	7.344	5.079	4.272	3.791	3.423
02YS003	36.7	G III	0.22	0.198	0.131	0.110	0.098	0.090
02YP001	63.8	G III	0.37	0.344	0.237	0.199	0.176	0.158
02ZJ001	67.4	G III	0.50	0.465	0.279	0.207	0.162	0.124
02YO006	177	G III	0.97	0.890	0.527	0.393	0.310	0.245
02YR001	267	G III	3.26	2.986	2.057	1.734	1.546	1.404
02YR002	399	G III	3.09	2.680	1.528	1.154	0.945	0.796
02YN002	469	G III	5.25	4.835	3.205	2.617	2.262	1.988
02YR003	554	G III	7.05	6.618	4.241	3.306	2.705	2.206
02ZF001	1170	G III	21.05	20.680	15.030	12.450	10.590	8.841
02YS001	1290	G III	13.82	13.440	9.088	7.145	5.768	4.498
02ZE001	2640	G III	37.31	38.550	28.540	22.610	17.400	11.270
02YQ001	4400	G III	45.77	43.640	28.490	22.190	17.980	14.320
02YM003	93.2	G III	0.29	0.237	0.129	0.098	0.081	0.070
02YD002	200	G III	0.81	0.646	0.279	0.169	0.112	0.074
02YD001	237	G III	0.83	0.719	0.411	0.309	0.253	0.212
02YK005	391	G III	2.49	2.189	1.368	1.104	0.958	0.856
02YK002	470	G III	3.94	3.747	2.797	2.432	2.201	2.013
02YK004	529	G III	4.62	4.312	3.214	2.825	2.595	2.419
02YF001	611	G III	2.10	1.809	1.138	0.933	0.825	0.752
02YC001	624	G III	4.48	4.315	3.200	2.740	2.434	2.169
02YL001	2110	G III	12.11	11.450	8.253	7.033	6.266	5.645
02ZA002	72	G III	0.46	0.428	0.328	0.296	0.278	0.266
02ZA003	139	G III	1.36	0.916	0.414	0.307	0.263	0.241
02ZB001	205	G III	1.70	1.527	0.922	0.710	0.585	0.491
02ZC002	230	G III	1.58	1.400	0.598	0.298	0.113	0.000
02ZA001	343	G III	2.74	2.507	1.699	1.419	1.255	1.132
02YJ001	640	G III	7.11	6.666	4.862	4.195	3.787	3.465

* Notes

Q2, Q5, Q10, Q20, Q50 = Low Flows for Return Periods of 2, 5, 10, 20, 50 Years, Respectively.

Probability Density Function = G III : Gumbel Type III

Table 3.11 Frequency Estimates of Winter 30-day Low Flows

Station Number	Drainage Area (km^2)	Probability Density Function*	MEAN (m^3/s)	Q2* (m^3/s)	Q5* (m^3/s)	Q10* (m^3/s)	Q20* (m^3/s)	Q50* (m^3/s)
02ZM006	3.9	G III	0.05	0.047	0.030	0.022	0.016	0.011
02ZL003	10.8	G III	0.17	0.154	0.109	0.095	0.088	0.082
02ZG004	42.7	G III	0.84	0.849	0.670	0.570	0.487	0.394
02ZH002	43.3	G III	0.61	0.592	0.380	0.281	0.209	0.141
02ZN001	53.3	G III	1.32	1.277	0.861	0.681	0.558	0.447
02ZM009	53.6	G III	1.43	1.359	1.051	0.935	0.862	0.803
02ZK002	89.6	G III	2.02	1.860	1.458	1.329	1.259	1.210
02ZG003	115	G III	2.03	2.058	1.430	1.087	0.803	0.493
02ZG002	166	G III	3.79	3.413	2.541	2.279	2.141	2.049
02ZG001	205	G III	4.14	3.993	2.717	2.171	1.797	1.463
02ZK001	285	G III	5.16	5.098	3.672	2.999	2.502	2.021
02ZH001	764	G III	11.13	10.560	7.107	5.718	4.809	4.041
02YS003	36.7	G III	0.37	0.351	0.223	0.173	0.140	0.113
02YP001	63.8	G III	0.50	0.480	0.342	0.288	0.253	0.223
02ZJ001	67.4	G III	0.79	0.733	0.477	0.379	0.318	0.268
02YO006	177	G III	1.45	1.369	0.902	0.713	0.588	0.483
02YR001	267	G III	3.78	3.395	2.357	2.019	1.830	1.697
02YR002	399	G III	3.98	3.332	2.071	1.715	1.536	1.423
02YN002	469	G III	6.99	6.227	3.788	2.959	2.482	2.131
02YR003	554	G III	8.36	7.654	4.870	3.862	3.252	2.780
02ZF001	1170	G III	24.80	24.960	18.580	15.280	12.670	9.940
02YS001	1290	G III	16.82	16.140	10.980	8.813	7.348	6.062
02ZE001	2640	G III	43.62	44.290	31.980	25.390	20.030	14.260
02YQ001	4400	G III	53.94	50.570	32.000	24.670	19.930	15.990
02YM003	93.2	G III	0.38	0.312	0.186	0.152	0.135	0.125
02YD002	200	G III	0.97	0.807	0.398	0.271	0.203	0.157
02YD001	237	G III	0.94	0.796	0.480	0.384	0.334	0.301
02YK005	391	G III	3.06	2.444	1.712	1.551	1.484	1.450
02YK002	470	G III	4.84	4.584	3.242	2.720	2.387	2.113
02YK004	529	G III	5.15	4.720	3.543	3.160	2.947	2.795
02YF001	611	G III	2.59	2.215	1.216	0.898	0.723	0.601
02YC001	624	G III	4.95	4.623	3.326	2.851	2.561	2.334
02YL001	2110	G III	14.95	14.140	9.750	8.022	6.912	5.991
02ZA002	72	G III	0.77	0.711	0.506	0.434	0.391	0.359
02ZA003	139	G III	2.15	1.713	0.810	0.550	0.417	0.331
02ZB001	205	G III	2.63	2.201	1.243	0.957	0.807	0.708
02ZC002	230	G III	2.98	2.452	1.401	1.103	0.954	0.858
02ZA001	343	G III	3.80	3.336	2.172	1.809	1.613	1.478
02YJ001	640	G III	9.15	8.499	6.000	5.104	4.566	4.153

* Notes:

Q2, Q5, Q10, Q20, Q50 = Low Flows for Return Periods of 2, 5, 10, 20, 50 Years, Respectively

Probability Density Function = G III , Gumbel Type III

Table 3.12 Frequency Estimates of Summer 1-day Low Flows

Station Number	Drainage Area (km^2)	Probability Density Function*	MEAN (m^3/s)	Q2* (m^3/s)	Q5* (m^3/s)	Q10* (m^3/s)	Q20* (m^3/s)	Q50* (m^3/s)
02ZM006	3.9	G III	0.01	0.007	0.004	0.002	0.001	0.000
02ZL003	10.8	G III	0.04	0.022	0.009	0.006	0.005	0.005
02ZG004	42.7	G III	0.14	0.144	0.089	0.058	0.032	0.002
02ZH002	43.3	G III	0.15	0.103	0.037	0.021	0.013	0.009
02ZN001	53.3	G III	0.55	0.555	0.395	0.315	0.253	0.190
02ZM009	53.6	G III	0.46	0.450	0.274	0.195	0.139	0.087
02ZK002	89.6	G III	0.57	0.523	0.310	0.230	0.180	0.141
02ZG003	115	G III	0.38	0.365	0.210	0.141	0.092	0.047
02ZG002	166	G III	1.17	1.017	0.584	0.441	0.360	0.301
02ZG001	205	G III	1.38	1.323	0.746	0.491	0.310	0.145
02ZK001	285	G III	1.23	1.068	0.575	0.410	0.316	0.248
02ZH001	764	G III	2.67	2.327	1.103	0.670	0.414	0.219
02YS003	36.7	G III	0.10	0.080	0.041	0.030	0.024	0.020
02YP001	63.8	G III	0.17	0.181	0.095	0.041	0.000	0.000
02ZJ001	67.4	G III	0.13	0.077	0.020	0.009	0.004	0.002
02YO006	177	G III	0.35	0.350	0.235	0.180	0.138	0.098
02YR001	267	G III	1.00	0.866	0.423	0.272	0.184	0.119
02YR002	399	G III	0.67	0.368	0.092	0.040	0.021	0.012
02YN002	469	G III	2.74	2.373	1.922	1.821	1.778	1.756
02YR003	554	G III	2.34	2.408	1.257	0.624	0.098	0.000
02ZF001	1170	G III	9.41	9.259	6.011	4.463	3.310	2.186
02YS001	1290	G III	7.12	6.287	3.703	2.824	2.317	1.944
02ZE001	2640	G III	17.82	16.450	9.239	6.403	4.579	3.065
02YQ001	4400	G III	22.10	20.070	11.050	7.658	5.547	3.858
02YM003	93.2	G III	0.09	0.053	0.011	0.002	0.000	0.000
02YD002	200	G III	0.66	0.385	0.089	0.029	0.005	0.000
02YD001	237	G III	1.10	1.100	0.789	0.631	0.507	0.379
02YK005	391	G III	2.16	2.053	1.285	0.967	0.753	0.568
02YK002	470	G III	3.17	2.988	1.961	1.552	1.286	1.062
02YK004	529	G III	3.87	3.688	2.517	2.038	1.721	1.450
02YF001	611	G III	2.60	2.527	1.604	1.192	0.901	0.632
02YC001	624	G III	7.11	6.951	5.277	4.543	4.031	3.567
02YL001	2110	G III	9.27	8.359	4.866	3.618	2.871	2.298
02ZA002	72	G III	0.26	0.277	0.185	0.128	0.075	0.010
02ZA003	139	G III	1.02	0.888	0.671	0.613	0.586	0.570
02ZB001	205	G III	1.05	0.980	0.635	0.503	0.420	0.352
02ZC002	230	G III	1.17	0.933	0.565	0.471	0.427	0.402
02ZA001	343	G III	1.52	1.462	1.104	0.961	0.868	0.790
02YJ001	640	G III	5.68	5.411	3.541	2.767	2.250	1.803

* Notes

Q2, Q5, Q10, Q20, Q50 = Low Flows for Return Periods of 2, 5, 10, 20, 50 Years, Respectively.

Probability Density Function = G III , Gumbel Type III.

Table 3.13 Frequency Estimates of Summer 7-day Low Flows

Station Number	Drainage Area (km^2)	Probability Density Function*	MEAN (m^3/s)	Q2* (m^3/s)	Q5* (m^3/s)	Q10* (m^3/s)	Q20* (m^3/s)	Q50* (m^3/s)
02ZM006	3.9	G III	0.01	0.009	0.004	0.002	0.001	0.000
02ZL003	10.8	G III	0.05	0.028	0.013	0.010	0.009	0.009
02ZG004	42.7	G III	0.19	0.196	0.124	0.081	0.043	0.000
02ZH002	43.3	G III	0.18	0.136	0.058	0.037	0.026	0.020
02ZN001	53.3	G III	0.63	0.625	0.441	0.349	0.278	0.205
02ZM009	53.6	G III	0.53	0.534	0.338	0.236	0.154	0.067
02ZK002	89.6	G III	0.70	0.641	0.370	0.268	0.205	0.154
02ZG003	115	G III	0.47	0.477	0.296	0.202	0.128	0.051
02ZG002	166	G III	1.33	1.210	0.711	0.525	0.409	0.317
02ZG001	205	G III	1.58	1.474	0.796	0.517	0.330	0.169
02ZK001	285	G III	1.50	1.274	0.676	0.485	0.379	0.305
02ZH001	764	G III	3.02	2.627	1.243	0.761	0.478	0.265
02YS003	36.7	G III	0.12	0.104	0.054	0.038	0.029	0.023
02YP001	63.8	G III	0.20	0.201	0.103	0.050	0.006	0.000
02ZJ001	67.4	G III	0.16	0.094	0.026	0.013	0.008	0.005
02YO006	177	G III	0.40	0.402	0.274	0.212	0.166	0.120
02YR001	267	G III	1.10	0.935	0.456	0.296	0.205	0.139
02YR002	399	G III	0.73	0.417	0.113	0.054	0.031	0.021
02YN002	469	G III	2.92	2.558	2.077	1.964	1.916	1.889
02YR003	554	G III	2.52	2.641	1.429	0.727	0.120	0.000
02ZF001	1170	G III	10.12	9.940	6.468	4.826	3.613	2.437
02YS001	1290	G III	8.03	7.333	4.363	3.256	2.571	2.028
02ZE001	2640	G III	18.84	17.140	9.651	6.827	5.067	3.656
02YQ001	4400	G III	23.53	21.240	11.700	8.179	6.020	4.319
02YM003	93.2	G III	0.11	0.063	0.014	0.004	0.000	0.000
02YD002	200	G III	0.74	0.453	0.124	0.054	0.024	0.010
02YD001	237	G III	1.24	1.220	0.849	0.672	0.539	0.410
02YK005	391	G III	2.36	2.212	1.369	1.035	0.819	0.639
02YK002	470	G III	3.54	3.323	2.154	1.694	1.399	1.153
02YK004	529	G III	4.14	3.977	2.719	2.192	1.837	1.525
02YF001	611	G III	3.05	2.943	1.746	1.213	0.837	0.490
02YC001	624	G III	7.50	7.280	5.538	4.801	4.302	3.861
02YL001	2110	G III	10.51	9.340	5.709	4.487	3.788	3.279
02ZA002	72	G III	0.29	0.304	0.211	0.155	0.105	0.045
02ZA003	139	G III	1.18	1.018	0.830	0.789	0.772	0.763
02ZB001	205	G III	1.35	1.200	0.749	0.597	0.510	0.446
02ZC002	230	G III	1.45	1.215	0.777	0.656	0.596	0.559
02ZA001	343	G III	1.65	1.569	1.189	1.042	0.950	0.874
02YJ001	640	G III	6.43	5.901	4.161	3.563	3.215	2.958

* Notes

Q2, Q5, Q10, Q20, Q50 = Low Flows for Return Periods of 2, 5, 10, 20, 50 Years, Respectively

Probability Density Function = G III : Gumbel Type III

Table 3.14 Frequency Estimates of Summer 15-day Low Flows

Station Number	Drainage Area (km^2)	Probability Density Function*	MEAN (m^3/s)	Q2* (m^3/s)	Q5* (m^3/s)	Q10* (m^3/s)	Q20* (m^3/s)	Q50* (m^3/s)
02ZM006	3.9	G III	0.01	0.011	0.005	0.003	0.001	0.000
02ZL003	10.8	G III	0.06	0.037	0.017	0.014	0.013	0.012
02ZG004	42.7	G III	0.25	0.260	0.163	0.107	0.059	0.003
02ZH002	43.3	G III	0.23	0.178	0.076	0.048	0.034	0.026
02ZN001	53.3	G III	0.74	0.728	0.502	0.395	0.317	0.242
02ZM009	53.6	G III	0.64	0.640	0.405	0.289	0.200	0.111
02ZK002	89.6	G III	0.90	0.800	0.448	0.325	0.252	0.198
02ZG003	115	G III	0.62	0.629	0.401	0.276	0.173	0.061
02ZG002	166	G III	1.53	1.431	0.858	0.627	0.477	0.349
02ZG001	205	G III	1.87	1.745	0.932	0.596	0.372	0.179
02ZK001	285	G III	1.87	1.597	0.834	0.585	0.447	0.349
02ZH001	764	G III	3.55	2.985	1.346	0.811	0.511	0.298
02YS003	36.7	G III	0.15	0.126	0.070	0.052	0.043	0.036
02YP001	63.8	G III	0.22	0.230	0.123	0.064	0.016	0.000
02ZJ001	67.4	G III	0.19	0.113	0.033	0.017	0.010	0.007
02YO006	177	G III	0.48	0.479	0.327	0.250	0.190	0.127
02YR001	267	G III	1.17	0.990	0.480	0.314	0.222	0.157
02YR002	399	G III	0.79	0.464	0.133	0.066	0.040	0.027
02YN002	469	G III	3.24	2.913	2.277	2.099	2.010	1.955
02YR003	554	G III	2.67	2.833	1.589	0.830	0.146	0.000
02ZF001	1170	G III	10.99	10.840	7.026	5.202	3.840	2.507
02YS001	1290	G III	9.16	8.027	4.502	3.307	2.620	2.115
02ZE001	2640	G III	19.96	18.080	10.090	7.103	5.255	3.785
02YQ001	4400	G III	25.36	22.710	12.400	8.657	6.396	4.641
02YM003	93.2	G III	0.17	0.087	0.019	0.007	0.003	0.001
02YD002	200	G III	0.83	0.514	0.163	0.088	0.058	0.042
02YD001	237	G III	1.40	1.377	0.944	0.739	0.588	0.440
02YK005	391	G III	2.59	2.398	1.474	1.118	0.892	0.708
02YK002	470	G III	3.98	3.746	2.428	1.900	1.556	1.266
02YK004	529	G III	4.50	4.236	2.845	2.300	1.951	1.662
02YF001	611	G III	3.74	3.382	1.852	1.284	0.934	0.658
02YC001	624	G III	8.24	7.889	6.048	5.330	4.872	4.494
02YL001	2110	G III	12.68	10.920	6.422	5.002	4.230	3.696
02ZA002	72	G III	0.34	0.350	0.242	0.183	0.135	0.083
02ZA003	139	G III	1.35	1.168	0.915	0.855	0.828	0.813
02ZB001	205	G III	1.70	1.485	0.907	0.722	0.620	0.548
02ZC002	230	G III	1.90	1.779	1.151	0.908	0.753	0.627
02ZA001	343	G III	1.85	1.727	1.264	1.096	0.994	0.915
02YJ001	640	G III	7.21	6.325	4.513	3.988	3.719	3.546

* Notes

Q2, Q5, Q10, Q20, Q50 = Low Flows for Return Periods of 2, 5, 10, 20, 50 Years, Respectively.

Probability Density Function = G III Gumbel Type III

Table 3.15 Frequency Estimates of Summer 30-day Low Flows

Station Number	Drainage Area (km^2)	Probability Density Function*	MEAN (m^3/s)	Q2* (m^3/s)	Q5* (m^3/s)	Q10* (m^3/s)	Q20* (m^3/s)	Q50* (m^3/s)
02ZM006	3.9	G III	0.02	0.015	0.006	0.003	0.001	0.000
02ZL003	10.8	G III	0.09	0.053	0.033	0.030	0.029	0.029
02ZG004	42.7	G III	0.41	0.436	0.271	0.165	0.064	0.000
02ZH002	43.3	G III	0.39	0.299	0.122	0.073	0.049	0.034
02ZN001	53.3	G III	0.94	0.907	0.605	0.472	0.378	0.292
02ZM009	53.6	G III	0.85	0.859	0.559	0.403	0.280	0.151
02ZK002	89.6	G III	1.20	1.047	0.611	0.468	0.388	0.330
02ZG003	115	G III	1.13	1.108	0.642	0.420	0.254	0.093
02ZG002	166	G III	1.94	1.821	1.071	0.768	0.569	0.401
02ZG001	205	G III	2.33	2.278	1.314	0.864	0.534	0.219
02ZK001	285	G III	2.64	2.234	1.153	0.805	0.613	0.478
02ZH001	764	G III	4.54	3.685	1.577	0.927	0.578	0.342
02YS003	36.7	G III	0.22	0.175	0.095	0.074	0.063	0.057
02YP001	63.8	G III	0.29	0.305	0.164	0.078	0.000	0.000
02ZJ001	67.4	G III	0.28	0.129	0.034	0.020	0.015	0.014
02YO006	177	G III	0.66	0.683	0.464	0.338	0.230	0.107
02YR001	267	G III	1.37	1.128	0.530	0.343	0.242	0.173
02YR002	399	G III	0.94	0.550	0.155	0.077	0.046	0.031
02YN002	469	G III	4.16	3.942	2.976	2.614	2.391	2.213
02YR003	554	G III	2.91	3.088	1.841	1.062	0.348	0.000
02ZF001	1170	G III	12.50	12.490	8.167	6.008	4.343	2.653
02YS001	1290	G III	10.71	9.261	5.048	3.650	2.859	2.288
02ZE001	2640	G III	22.45	20.060	11.000	7.726	5.750	4.219
02YQ001	4400	G III	29.13	25.770	13.840	9.625	7.132	5.242
02YM003	93.2	G III	0.27	0.156	0.035	0.010	0.001	0.000
02YD002	200	G III	0.99	0.717	0.239	0.113	0.052	0.016
02YD001	237	G III	1.91	1.754	1.057	0.796	0.634	0.504
02YK005	391	G III	2.95	2.728	1.670	1.263	1.006	0.796
02YK002	470	G III	5.12	4.640	2.836	2.186	1.794	1.492
02YK004	529	G III	5.00	4.619	3.104	2.549	2.212	1.949
02YF001	611	G III	5.78	4.553	2.254	1.621	1.309	1.116
02YC001	624	G III	10.44	9.750	7.455	6.658	6.192	5.843
02YL001	2110	G III	17.73	15.620	9.344	7.258	6.075	5.221
02ZA002	72	G III	0.44	0.452	0.332	0.265	0.208	0.145
02ZA003	139	G III	1.73	1.562	1.134	0.999	0.925	0.874
02ZB001	205	G III	3.02	2.648	1.555	1.192	0.987	0.839
02ZC002	230	G III	2.89	2.507	1.753	1.539	1.432	1.363
02ZA001	343	G III	2.29	2.071	1.357	1.112	0.969	0.863
02YJ001	640	G III	8.74	7.849	5.632	4.946	4.577	4.326

* Notes

Q2, Q5, Q10, Q20, Q50 = Low Flows for Return Periods of 2, 5, 10, 20, 50 Years, Respectively

Probability Density Function = G III Gumbel Type III

3.3.1 Mean of Low Flow Series

As expected, the means of the low flows, both for the winter and summer series, increase with the duration of the low flow series. In general, the ratio of the 30-day mean low flow per unit area to the 1-day mean low flow per unit area was about 2.2 on the Avalon and Burin Peninsulas and the southwest region of the Island. In the rest of the Island the ratio was about 1.6. This indicates that there is greater tendency for low flows to persist for relatively longer periods in the central region of the Island and on the Northern Peninsula than on the rest of the Island.

In general, the means of the summer low flow series were lower than the corresponding winter low flow series. There were exceptions, however. For the 1-day low flow series, at seven gauging stations, the winter mean low flows were lower than the corresponding summer mean low flows. These stations were located in the Humber Valley - Northern Peninsula region and the southwest corner of the Island. There were also seven gauging stations at which the winter mean 30-day low flows were lower than the corresponding summer mean low flows, however, only three of these stations also had lower winter mean 1-day low flows.

The average unit mean low flows during the winter and summer seasons for four regions of the Island were as shown in Table 3.16.

Table 3.16 Average Regional Mean Low Flows per Unit Area

	Winter 1-day $l/s/km^2$	Winter 30-day $l/s/km^2$	Summer 1-day $l/s/km^2$	Summer 30-day $l/s/km^2$
Avalon & Burin	8.4	20.0	5.4	11.0
Central	6.5	11.5	3.1	5
Northern Pen.	4.8	6.8	4.7	7.3
Southwest Region	5.4	12.6	5.1	10.5

It is apparent that in most areas summer unit mean low flows are more critical than winter unit mean low flows. Also, the summer unit mean low flows are lowest in the central region of the Island and highest in the eastern part of the Island.

3.3.2 Coefficients of Skewness and Variation of Low Flow Series

The coefficient of variation of the low flow series ranged from 0.3 to 0.8 for the winter series and from 0.3 to 1.3 for the summer series. There was no general trend in the coefficient of variation from 1-day low flow series to 30-day low flow series for either the winter or summer low flow series. There was also no significant difference in coefficient of variation between the different regions of the Island.

The coefficient of skewness ranged from -0.56 to 2.5. For the summer low flow series, the range was from -1.0 to 2.9. Of the 156 winter low flow series, 10 had a negative coefficient of skewness with only one station having series of all four durations negatively skewed. Of the 156 summer low flow series, 27 had a negative coefficient of skewness with 6 stations having series of all four durations negatively skewed. Of these 6 stations, at 5 stations the drainage areas were less than 100 km^2.

There was no noticeable trend in the coefficient of skewness from the 1-day series to the 30-day series and also from one region of the Island to another.

3.3.3 Parameters Beta, Alpha and Epsilon of Gumbel Type III PDF

In the definition of the Gumbel III type distribution, beta is a location parameter, alpha is a scale parameter and epsilon is a displacement parameter. The displacement parameter, epsilon, is necessary when the lower bound of the distribution is not zero.

Beta is closely related to the mean and both exhibit similar variations. The variations in the mean have been described in Section 3.3.1.

Out of the 156 winter low flow series, 16 have negative values for epsilon. At one station, 02ZE001, epsilon was negative for the low flow series of all four durations. Of the 156 summer low flow series, 50 have negative values for epsilon. At 12 stations, the low flow series for all four durations had negative values for epsilon. Negative low flows are physically impossible. The negative values for epsilon suggest a finite probability that the discharge can reach zero. It, therefore, follows that the summer low flows have a higher tendency to be very close to zero at a number of stations on the Island.

The frequency analysis of low flow series by LFA gives the return period (up to 500 years) for zero flow whenever there is a finite probability for such an event. Table 3.17 shows the stations which had zero flows and the return periods thereof.

Table 3.17 Series with Expected Zero Flows and Return Periods Thereof

	W_01D	W_07D	W_15D	W_30D	S_01D	S_07D	S_15D	S_30D
ZM6	223	***	***	***	48	49	46	43
ZG4	***	***	***	***	54	47	52	32
ZH2	271	232	***	***	***	***	***	***
ZM9	***	***	***	***	***	123	282	221
ZG3	***	***	***	358	***	106	90	101
ZG1	***	***	***	***	182	336	240	123
YP1	***	***	***	***	18	22	26	20
YO6	***	***	***	***	***	***	***	127
YR3	***	***	***	***	23	23	23	29
ZE1	***	338	381	***	***	***	***	***
YM3	***	***	***	***	13	19	***	22
YD2	***	***	***	***	25	***	***	131
ZA2	***	***	***	***	58	107	368	***
ZC2	29	29	38	***	***	***	***	***

ZM6 Abbreviated Station Number.
W Winter Low Flow Series.
S Summer Low Flow Series.
01D Duration of Low Series is 1 Day.
*** Return Period of Zero Flow is > 500 Years.

As can be seen from Table 3.17, 9 winter low flow series had a finite probability for zero flow, whereas, for the summer low flow series the number is 35. Among the latter series, there is a finite probability for zero flow for all four durations of low flow periods at 5 stations.

The return period for zero flow, in general, increases as the duration of the low flow period increases, but, there are some exceptions. In certain instances, the return period for a 30-day low flow is smaller than the return period of a 1-day low flow. Physically, a 30-day low flow estimate of zero automatically means that the flows should be zero over the entire duration and, logically, the 1-day flow series should then have at least the same or smaller return period for zero flow. All low flow series are fitted independently of one another by the Gumbel III PDF and, therefore, the occurrence of the events mentioned above is possible. The anomaly is of a purely mathematical nature.

3.3.4 Frequency Estimates of Low Flows on the Island

In general, the frequency estimates of summer low flows are lower than the frequency estimates of the winter low flows. The exceptions are low flow series at stations 02YD001, 02YF001 and 02YC001 located on the northern tip of the Northern Peninsula and 02ZA003, 02ZB001 and 02ZC002 located in the southwestern region of the Island. On the Northern Peninsula, the winter low flows are lower because the relatively lower mean winter temperatures at these locations means that very little precipitation as rainfall occurs during the winter and the period of below freezing temperatures lasts relatively longer. In the other regions of the Island, the summer low flows are lower because of the higher losses due to higher evapotranspiration caused by relatively higher summer mean temperatures.

The 2-year low flows, Q2, exhibit similar variations as the means of the series and beta parameters of the fitted distribution. The characteristics of the latter two parameters have been discussed in sections 3.3.1 and 3.3.3.

The magnitude of Q2 relative to Q50 (50-year low flow) gives a qualitative indication of the rate at which extreme low flows tend towards the zero value. The rate can be quantified by the ratio of Q2 to Q50. For all stations (except where the ratio goes to infinity because Q50 is zero) the mean and standard deviation of the ratio for each low flow duration and for each season are shown in Table 3.18.

Table 3.18 Ratio of 2-year Low Flow to 50-year Low Flow

	W_01D	W_07D	W_15D	W_30D
MEAN	3.1	2.8	2.7	2.7
STDV	2.3	1.5	1.2	0.9
	S_01D	S_07D	S_15D	S_30D
MEAN	7.3	5.2	5.0	5.0
STDV	10.1	4.3	3.8	3.6

W Winter Low Flow Series.
S Summer Low Flow Series.
01D Duration of Low Flow Series is 1 Day.

As can be seen from Table 3.18, the ratio decreases for increasing duration of low flow periods. This is due to the fact that 1-day low flows are much more variable than the 30-day low flows. This is also demonstrated by the values of the standard deviations given in Table 3.18. However, the ratio of the summer low flow series are always higher than those of the winter low flow series. This indicates that summer low flows decrease much more rapidly with increasing return period than winter low flows.

3.4 Accuracy of Low Flow Frequency Estimates

The accuracy of the low flow frequency estimates depends upon (1) the length of the low flow series and (2) the errors inherent in the measurement and estimation of low flows.

The lengths of the 39 low flow series range from 8 years to 40 years, the average record length being 19 years. The standard error of estimate for the Gumbel III distribution is a function of, among other statistics, the reciprocal of the square root of the record length [6]. For the same size data set, the standard error in the 50-year estimate is between 1.2 and 3 times the standard error in the 2-year estimate [6]. It is therefore expected that errors in the frequency estimates of higher return periods and from the shorter duration series will be much higher than those from the longer duration series.

Discharges for a stream at a gauging station are obtained by continuously measuring the stage in the stream and extracting the corresponding discharge from a stage-discharge curve. The latter is developed from actual measurements of discharges and observed stages. This method of obtaining discharges yields good results for moderate flows, but, low flows and high flows cannot be obtained as accurately. At the lower end of the stage-discharge curve an error in the flow rate can be of the same order as the value of the flow itself. Frequency estimates of low flows may therefore be biased by such inaccuracies. These errors can be quite significant for flows with the higher return periods when the expected low flows are converging fast to zero values.

The frequency estimates of low flows given in this report, while the best that can be obtained from available data, must be used with caution because of errors which are unique to the estimation and analysis of low flows.

Chapter 4

DEVELOPMENT OF REGRESSION EQUATIONS FOR ESTIMATING LOW FLOWS

4.1 Introduction

Obtaining reliable frequency estimates of low flows at a given location on a river depends on the availability of a "long" period of daily flow record at or close to the site. Very often, this is not the case. A relatively straightforward method of obtaining low flow estimates at ungauged sections of rivers is by proration. Frequency estimates of low flows at a nearby gauging station with a "long" period of record are used together with the area of the watershed at the gauged section to obtain the required flow estimates at the ungauged section. This method assumes that there is a gauging station nearby, either on the same river or on an adjacent river with a long period of record. However, even if a gauging station exists close-by, the estimates at the ungauged section will only be as accurate as those at the gauged section. Frequency estimates of low flows can have relatively high standard errors and it may be necessary to use the recorded low flows from several nearby stations to obtain reliable estimates. The method of regression analysis uses this approach. Regression analysis is a multi-variate analysis in which the dependent low flow frequency estimates from gauged watersheds are related quantitatively to independent climatic and/or physiographic variables of the watersheds. The resulting equations can be used to estimate low flow characteristics at sites with inadequate hydrologic information.

4.2 Application of Regression Analysis to Estimating Low Flows

Many examples on regression analysis of low flows are available in the literature. Osborn [7], cited in [8], developed regional correlation graphs for gauged streams between the 2-year and 20-year 7-day low flows and basin characteristics such as drainage area, basin relief and stream lengths. The ungauged basin characteristics were measured from maps, entered into the correlation graphs and the low flows were then estimated for the desired location. One of the most extensive regression analysis is that done by Thomas and Benson [9] (cited in [8]). He used multiple regression analysis to relate, among other things, the 2-year 7-day and 20-year 7-day low flows to 30 meteorologic and topographic characteristics of watersheds. The results indicated that low flow characteristics could be more accurately defined for humid regions than for the more arid regions. Also, compared with high flows, low flows could only be weakly defined. Percentage differences of the order of 100% between frequency and regression estimates were not uncommon. Thomas and Benson concluded that "... *low flow relations ... can provide only rough estimates of low flow characteristics at ungauged sites*."

4.3 Outline of Methodology

For this report, the methodology for developing regression equations between frequency estimates of low flows and climate and watershed characteristics consisted of the following steps:

1. Compilation of low flow frequency estimates, physiographic, climatic and hydrologic characteristics of gauged watersheds.
2. Identification of regions with distinct hydrological, climatic and physiographic characteristics.
3. Regression analysis between frequency estimates of low flows and physiographic and climatic characteristics on watersheds within each region identified in Step 2.
4. Sensitivity analysis on regression equations.

The details of each step are given in the following sections.

4.4 Compilation of Data on Watersheds

4.4.1 Low Flow Frequency Estimates

Tables 3.8 to 3.15 give the frequency estimates of low flows of four durations and for two seasons at 39 gauging stations. For a regression analysis only the lower low flow frequency estimates of the two seasons need to be considered because these are the values used in designing water supply systems, estimating minimum effluent dilution capacity of streams, etc. Winter and summer low flows are, from a hydrological point of view, caused by different hydrometeorologic processes. The summer low flows are caused by increased evapotranspiration losses and the winter low flows are the result of frozen soils and precipitation as snow. Ignoring the physical basis of the low flows would turn the regression analysis into a complete "black-box" approach. For this reason, it is important that in the regression analysis only the low flow estimates from one or the other season be considered.

As discussed in Section 3.3.4, at 33 gauging stations all summer frequency estimates of low flows are lower than the corresponding winter low flow frequency estimates. At the remaining 6 gauging stations, most of the winter frequency estimates of low flows were lower than the corresponding summer values. Three of the six stations are located on the northern tip of the Northern Peninsula and the other three are located in the southwest corner of the Island. It would not be useful to analyze the flow data from three stations from each region separately because the data would be insufficient for deriving reliable regression equations.

Based on the preceding arguments, the database on low flow frequency estimates was, therefore, the summer low flow frequency values shown in Tables 3.12, 3.13, 3.14 and 3.15.

4.4.2 Physiographic Characteristics

Some of the physiographic characteristics of the 39 gauged watersheds on the Island are shown in Table 4.1. The description and extraction of the physiographic characteristics are outlined in Appendix B. Not all the physiographic characteristics affect the magnitude of low flows directly. Some have only indirect influences and are only proxy variables for complex hydrometeorological processes. The physiographic parameters which may have a significant effect on magnitudes of low flows are, in order of importance, drainage area, forested area, barren area and area of lakes and swamps. However, all of them may not be statistically significant.

The magnitude of low flows can be expected to depend primarily on the drainage area. A larger drainage area collects more precipitation and therefore more water is available to sustain baseflow during periods of zero precipitation. The low flows will be higher from relatively larger watersheds, all other parameters being equal. An increase in the area of forest cover will increase transpiration losses and may lead to a decrease in baseflows. More barren area, at the expense of forest area, will decrease transpiration losses and increase the amount of water available for baseflow. The area of the watershed covered by lakes and swamps has two counteracting effects on baseflow: a larger surface area of lakes and ponds leads to a larger amount of available storage and, therefore, the amount of water available to sustain baseflow is larger. However, a larger surface area of lakes and ponds also implies a larger area of exposed water surface and, therefore, an increase in evaporation losses and, consequently, a decrease in baseflow.

Table 4.1 Physiographic Characteristics of Gauged Watersheds

Station Number	Drainage Area (km^2)	% Forest*	% Barren*	% Lakes and Swamps*	% ACLS*	Drainage Density (1/km)	Shape Factor	Slope (%)	Length of main Channel (km)	Elevation Difference (m)
02ZM006	3.9	75.4	3.6	21.0	100.0	1.04	1.24	2.42	2.63	64
02ZL003	10.8	41.9	48.9	9.2	100.0	1.09	1.36	1.25	7.0	91
02ZG004	42.7	35.0	47.0	18.0	92.0	1.62	1.53	1.10	10.0	107
02ZH002	43.3	40.5	49.7	9.9	92.0	1.11	1.66	0.59	17.0	110
02ZN001	53.3	8.0	78.8	12.6	100.0	1.09	2.06	0.61	14.6	93
02ZM009	53.6	37.0	50.0	13.0	100.0	1.13	1.37	0.62	14.9	133
02ZK002	89.6	47.0	23.0	30.0	81.0	1.11	1.91	0.55	26.9	200
02ZG003	115	15.8	72.0	12.0	92.0	1.55	1.62	0.34	24.5	136
02ZG002	166	38.0	48.6	13.3	92.0	1.35	1.84	1.35	26.7	221
02ZG001	205	26.5	64.0	10.1	96.0	0.55	2.45	0.60	44.7	370
02ZK001	285	50.9	37.1	11.9	55.0	1.01	2.00	0.23	45.2	165
02ZH001	764	10.7	23.4	65.9	91.0	0.71	1.67	0.35	51.0	207
02YS003	36.7	83.6	0.5	15.9	100.0	0.64	1.43	1.11	11.2	143
02YP001	63.8	87.0	0.0	12.8	79.0	0.88	1.62	0.53	20.0	113
02ZJ001	67.4	81.5	3.3	15.0	86.0	1.24	1.43	0.50	16.0	128
02YO006	177	82.5	1.8	16.3	97.0	0.80	1.93	0.45	42.7	190
02YR001	267	74.8	0.8	24.4	98.0	0.26	1.93	0.32	49.3	177
02YR002	399	68.1	0.0	32.0	96.0	0.74	1.68	0.21	42.0	95
02YN002	469	22.0	62.0	16.0	100.0	1.37	2.15	0.22	57.3	166
02YR003	554	69.0	0.0	31.0	97.0	0.68	1.72	0.22	52.4	136
02ZF001	1170	32.2	44.1	23.6	96.0	0.61	2.15	0.29	68.1	282
02YS001	1290	55.4	14.8	29.8	92.0	0.73	2.35	0.12	105.0	207
02ZE001	2640	34.8	49.0	15.7	100.0	0.36	1.75	0.08	100.4	122
02YQ001	4400	76.3	6.9	16.9	91.0	0.45	2.08	0.14	134.0	297
02YM003	93.2	90.0	0.0	10.0	56.0	0.68	1.67	0.57	18.6	107
02YD002	200	82.7	0.1	17.2	99.0	0.93	1.65	0.47	38.3	270
02YD001	237	80.6	11.2	8.2	73.0	0.34	2.23	0.67	40.6	328
02YK005	391	67.6	15.2	17.2	94.0	0.19	1.98	1.07	38.1	378
02YK002	470	54.9	29.0	16.1	100.0	0.63	2.32	0.59	54.9	561
02YK004	529	35.2	29.2	35.5	95.0	0.64	1.78	0.32	49.3	320
02YF001	611	68.8	18.0	13.1	100.0	0.58	1.86	0.73	30.2	250
02YC001	624	33.5	49.8	16.7	99.0	0.78	1.45	1.01	48.3	479
02YL001	2110	74.0	14.5	11.5	75.0	0.79	1.56	0.40	119.0	678
02ZA002	72	81.6	12.9	5.1	43.0	1.15	1.72	2.19	20.4	460
02ZA003	139	68.0	19.0	13.0	73.0	1.46	1.67	1.46	25.2	450
02ZB001	205	9.0	78.2	13.4	60.0	0.72	2.09	0.84	33.3	444
02ZC002	230	17.0	79.0	4.0	34.0	0.96	1.84	1.06	28.9	360
02ZA001	343	60.2	29.9	10.0	83.0	1.04	2.45	0.68	65.5	463
02YJ001	640	79.0	6.9	14.2	75.0	1.12	1.81	0.35	60.0	509

* Notes

% Forest, % Barren, % Lakes and Swamps: = Percentage of the Drainage Area Covered by Forests, Barrens, and Lakes and Swamps, Respectively

% ACLS - Percent of Drainage Area Controlled by Lakes and Swamps

4.4.3 Hydrologic and Climatic Characteristics

The distribution and characteristics of mean annual runoff and normal annual precipitation have been described in Sections 2.3 and 2.4, respectively. Information on winter precipitation, defined as precipitation between January and June, and summer precipitation, defined as precipitation between July and December is given in Table 4.2. A similar breakdown of mean annual runoff is also shown in Table 4.2.

It can be inferred from Table 4.2 that

(1) Precipitation amounts at two neighbouring climatic stations can be very different.

(2) The ratio of mean annual runoff to normal annual precipitation ranges from 0.65 to 1.57, indicating that in a number of cases, where the ratio exceeds 0.90, the climatic stations are probably not recording the actual amount of precipitation on the watershed. This is most probably due to differences in elevations between the location of the raingauge and the headwaters of the watershed.

(3) Precipitation seems to be evenly distributed between the winter and summer periods on all regions of the Island, except for the Northern Peninsula region where the percentage of summer precipitation is about 58% and the percentage of winter precipitation is about 42% on average.

(4) For the eastern and southwestern regions of the Island winter runoff accounts for between 55% and 60% of the total annual runoff, while, in the central region and Northern Peninsula winter runoff accounts for between 60% and 70% of the total annual runoff.

4.5 Identification of Distinct Regions for Analysis of Low Flows

The rationale for identifying distinct regions for analyzing low flows is as follows. A multiple regression analysis between a dependent variable and several independent parameters will yield reliable regression equations only if the magnitudes of each independent parameter are randomly distributed across the entire region. When values or range of values of some parameters are region-specific, it is better to perform the regression analysis on a regional basis. This is also the case if certain parameters cannot be exactly quantified for each watershed but can be categorised on a regional basis.

Table 4.2 Precipitation and Runoff Patterns at Recording Stations

Station Number	Closest Climatic Station(s)	Precipitation					Runoff					Runoff/Precip Ratio
		Winter	Summer	Total	Percentages (%)		Winter	Summer	Total	Percentages (%)		
		(mm)	(mm)	(mm)	Winter	Summer	(mm)	(mm)	(mm)	Winter	Summer	
O2ZM006	St. John's A.	734.2	782.5	1516.7	48.4	51.6	648.4	442.9	1091.3	59.4	40.6	0.72
	Logy Bay	415.7	472.5	888.2	46.8	53.2						1.23
O2ZL003	New Chelsea	594.6	623.3	1217.9	48.8	51.2	746.5	532.4	1278.9	58.4	41.6	1.05
O2ZG004	W Brook St. Lawrence	690.3	779.9	1470.2	47.0	53.0	942.3	649.1	1591.4	59.2	40.8	1.08
	Arnold's Cove	615.2	666.1	1281.3	48.0	52.0						1.24
O2ZH002	Come-By-Chance	561.2	566.8	1128.0	49.8	50.2	770.2	593.3	1363.5	56.5	43.5	1.21
	Sunnyside	596.8	678.7	1275.5	46.8	53.2						1.07
	Arnold's Cove	615.2	666.1	1281.3	48.0	52.0						1.06
O2ZN001	St. Shotts	721.6	743.4	1465.0	49.3	50.7	1039.9	831.8	1871.7	55.6	44.4	1.28
	Cape Race	645.8	741.0	1386.8	46.6	53.4						1.35
O2ZM009	Cape Broyle	723.3	792.6	1515.9	47.7	52.3	1051.1	766.1	1817.2	57.8	42.2	1.20
	Cape Race	645.8	741.0	1386.8	46.6	53.4						1.31
O2ZK002	Long Harbour	603.6	705.5	1309.1	46.1	53.9	919.7	665.6	1585.2	58.0	42.0	1.21
O2ZG003	W Brook St. Lawrence	690.3	779.9	1470.2	47.0	53.0	797.6	567.2	1364.8	58.4	41.6	0.93
	St. Lawrence	695.2	752.1	1447.3	48.0	52.0						0.94
	Grand Bank	624.7	677.3	1302.0	48.0	52.0						1.05
O2ZG002	St. Lawrence	695.2	752.1	1447.3	48.0	52.0	924.7	619.5	1544.2	59.9	40.1	1.07
	W Brook St. Lawrence	690.3	779.9	1470.2	47.0	53.0						1.05
O2ZG001	St. Lawrence	695.2	752.1	1447.3	48.0	52.0	765.8	598.8	1364.5	56.1	43.9	0.94
	W Brook St. Lawrence	690.3	779.9	1470.2	47.0	53.0						0.93
	Grand Bank	624.7	677.3	1302.0	48.0	52.0						1.05
O2ZK001	Colinet	650.0	780.0	1430.0	45.5	54.5	685.8	548.8	1234.6	55.5	44.5	0.86
	Salmonier	652.7	735.1	1387.8	47.0	53.0						0.89
O2ZH001	Sunnyside	596.8	678.7	1275.5	46.8	53.2	622.3	409.2	1031.4	60.3	39.7	0.81
	Come-By-Chance	561.2	566.8	1128.0	49.8	50.2						0.91
	Arnold's Cove	615.2	666.1	1281.3	48.0	52.0						0.80
O2YS003	Bonavista	456.1	522.2	978.3	46.6	53.4	549.6	353.5	903.1	60.9	39.1	0.92
	Terra Nova Nat Park	536.4	588.3	1124.7	47.7	52.3						0.80
O2YP001	Springdale	425.8	536.6	962.4	44.2	55.8	662.6	243.8	906.3	73.1	26.9	0.94
O2ZJ001	Bonavista	456.1	522.2	978.3	46.6	53.4	644.0	330.2	974.2	66.1	33.9	1.00
	Lockston	579.8	690.5	1270.3	45.6	54.4						0.77
O2YO006	Botwood	486.7	490.0	976.7	49.8	50.2	556.5	228.0	784.5	70.9	29.1	0.80
	Rattl.Bk.Norris Arm	552.1	571.6	1123.7	49.1	50.9						0.70
O2YR001	Gander Int'l A	559.5	567.3	1126.8	49.7	50.3	534.9	252.2	787.0	68.0	32.0	0.70
	Terra Nova Nat Park	536.4	588.3	1124.7	47.7	52.3						0.70
O2YR002	Fogo	335.9	431.1	767.0	43.8	56.2	497.7	216.3	713.9	69.7	30.3	0.93
	Twillingate	450.2	494.0	944.2	47.7	52.3						0.76
O2YN002	Burnt Pond	623.3	681.9	1305.2	47.8	52.2	924.6	504.2	1428.9	64.7	35.3	1.09
	Buchans	464.0	617.8	1081.8	42.9	57.1						1.32
	Buchans A	448.3	578.5	1026.8	43.7	56.3						1.39

Table 4.2 (Cont.) Precipitation and Runoff Patterns at Recording Stations

Station Number	Closest Climatic Station(s)	Precipitation					Runoff					Runoff/Precip Ratio
		Winter (mm)	Summer (mm)	Total (mm)	Percentages (%) Winter	Percentages (%) Summer	Winter (mm)	Summer (mm)	Total (mm)	Percentages (%) Winter	Percentages (%) Summer	
O2YR003	Fogo	335.9	431.1	767.0	43.8	56.2	515.5	218.1	733.6	70.3	29.7	0.96
	Terra Nova Nat Park	536.4	588.3	1124.7	47.7	52.3						0.65
O2ZF001	Bay D'Espoir Gen Stn	674.7	817.5	1492.2	45.2	54.8	643.0	436.9	1079.9	59.5	40.5	0.72
O2YS001	Terra Nova Nat Park	536.4	588.3	1124.7	47.7	52.3	536.3	372.2	908.5	59.0	41.0	0.81
O2ZE001	Burnt Pond	623.3	681.9	1305.2	47.8	52.2	626.1	396.0	1022.1	61.3	38.7	0.78
	Bay D'Espoir Gen Stn	674.7	817.5	1492.2	45.2	54.8						0.68
	Buchans	464.0	617.8	1081.8	42.9	57.1						0.94
O2YQ001	Fogo	335.9	431.1	767.0	43.8	56.2	538.3	307.3	845.6	63.7	36.3	1.10
	Gander Int'l A	559.5	567.3	1126.8	49.7	50.3						0.75
	Terra Nova Nat Park	536.4	588.3	1124.7	47.7	52.3						0.75
O2YM003	Baie Verte	500.3	570.2	1070.5	46.7	53.3	677.3	268.3	945.6	71.6	28.4	0.88
O2YD002	Roddickton	352.8	484.0	836.8	42.2	57.8	604.5	257.1	861.7	70.2	29.8	1.03
O2YD001	Roddickton	352.8	484.0	836.8	42.2	57.8	799.7	391.1	1190.8	67.2	32.8	1.42
O2YK005	Buchans	464.0	617.8	1081.8	42.9	57.1	580.9	300.4	881.3	65.9	34.1	0.81
	Buchans A	448.3	578.5	1026.8	43.7	56.3						0.86
O2YK002	Corner Brook	494.8	638.3	1133.1	43.7	56.3	663.7	489.8	1153.5	57.5	42.5	1.02
	Deer Lake	440.2	594.6	1034.8	42.5	57.5						1.11
O2YK004	Buchans	464.0	617.8	1081.8	42.9	57.1	590.9	381.4	972.3	60.8	39.2	0.90
	Buchans A	448.3	578.5	1026.8	43.7	56.3						0.95
	Deer Lake	440.2	594.6	1034.8	42.5	57.5						0.94
O2YF001	Baie Verte	500.3	570.2	1070.5	46.7	53.3	904.2	514.7	1418.9	63.7	36.3	1.33
	Roddickton	352.8	484.0	836.8	42.2	57.8						1.70
O2YC001	Daniels Harbour	481.1	585.2	1066.3	45.1	54.9	750.9	544.1	1295.1	58.0	42.0	1.21
	Plum Point	469.8	539.3	1009.1	46.6	53.4						1.28
O2YL001	Deer Lake A	461.0	602.3	1063.3	43.4	56.6	789.2	479.2	1268.3	62.2	37.8	1.19
	Deer Lake	440.2	594.6	1034.8	42.5	57.5						1.23
O2ZA002	Port Aux Basques	665.7	778.8	1444.5	46.1	53.9	739.3	399.3	1138.6	64.9	35.1	0.79
O2ZA003	Port Aux Basques	665.7	778.8	1444.5	46.1	53.9	1069.3	736.0	1805.3	59.2	40.8	1.25
O2ZB001	Burgeo	782.3	896.9	1679.2	46.6	53.4	1130.9	962.7	2093.6	54.0	46.0	1.25
	Burgeo 2	708.9	868.4	1577.3	44.9	55.1						1.33
	Port Aux Basques	665.7	778.8	1444.5	46.1	53.9						1.45
O2ZC002	Burnt Pond	623.3	681.9	1305.2	47.8	52.2	1275.9	771.7	2047.6	62.3	37.7	1.57
	Burgeo	782.3	896.9	1679.2	46.6	53.4						1.22
	Burgeo 2	708.9	868.4	1577.3	44.9	55.1						1.30
O2ZA001	Stephenville A	543.1	673.0	1216.1	44.7	55.3	619.0	387.5	1006.5	61.5	38.5	0.83
O2YJ001	Stephenville A	543.1	673.0	1216.1	44.7	55.3	742.7	527.1	1269.7	58.5	41.5	1.04
	Corner Brook	494.8	638.3	1133.1	43.7	56.3						1.12

The division of the Island into distinct regions for low flow analysis was the outcome of an iterative process of identifying regions with distinct characteristics, performing regression analyses for each region identified, evaluating the statistical significance of the resulting regression equations and re-defining the regions' boundaries if necessary.

The Island was analyzed initially as a single region. The resulting regression equations were not reliable for estimating low flows. The final division of the Island consisted of three regions:

A: **Avalon and Burin Peninsulas and Southwest Newfoundland.** The main characteristics of this region are high precipitation, high runoff and significant barren areas.

B: **North-Central Newfoundland.** The main characteristics of this region are low precipitation, low runoff potential and significant forest areas (insignificant barren areas).

C: **Humber Valley and Northern Peninsula.** The main characteristics of this region are moderate precipitation, moderate runoff potential and moderate barren areas.

The division of the Island into the regions for low flow analysis is shown in Figure 4.1. The south coast of the Island is not identified as a region because of insufficient data. The list of watersheds in each region is shown in Table 4.3.

The division was based on the following considerations:

(1) The normal annual precipitation for a watershed could not be used as an independent parameter because (a) the values given in Table 4.2 do not represent the true amounts of precipitation received on the watersheds, (b) in many instances there were sharp differences in precipitation amounts received at two or more neighbouring climatic stations, (c) precipitation amount would be a very difficult parameter to estimate at an ungauged (hydrometric and/or climatic) section of a river and (e) precipitation is not a parameter whose magnitudes are randomly distributed over the Island. In fact, two regions with distinct annual precipitation patterns can be identified: one is the north-central region of the Island (**Region C**) where precipitation is at its lowest and ranges from 800 mm to 1100 mm and the other is the eastern and southwestern regions (**Region A**) where precipitation is at its highest and ranges from 1200 mm and 1700 mm. There is very little overlap between these two

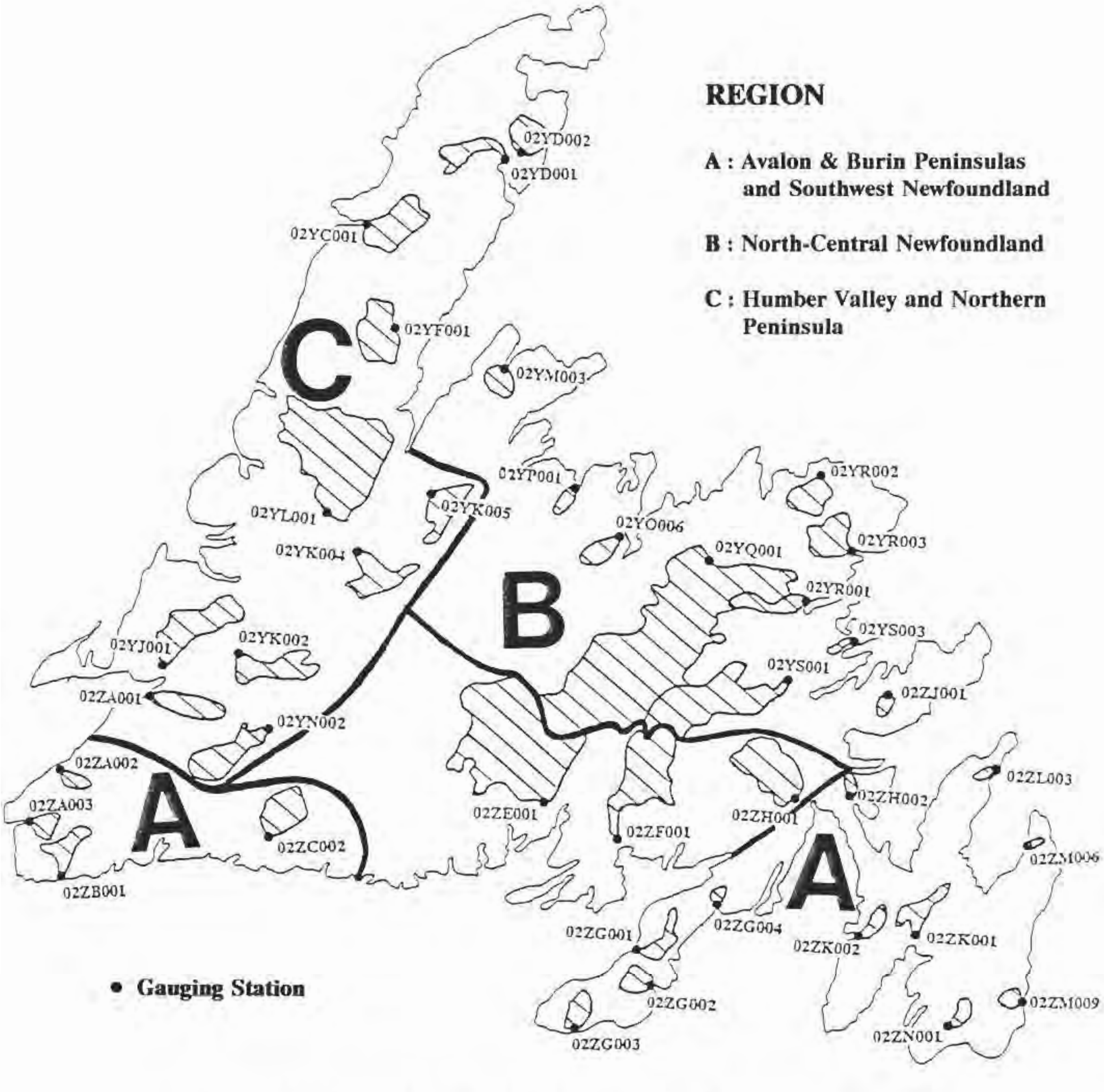

Figure 4.1 Division of Island into Three Regions for Low Flow Analysis

Table 4.3 List of Watersheds for Three Regions of the Island

Region A		Region B		Region C	
Station Number	Drainage Area (km^2)	Station Number	Drainage Area (km^2)	Station Number	Drainage Area (km^2)
02ZM006	3.90	02YS003	36.70	02YD001	237.00
02ZL003	10.80	02YP001	63.80	02ZA001	343.00
02ZG004	42.70	02ZJ001	67.40	02YK005	391.00
02ZH002	43.30	02YM003	93.20	02YN002	469.00
02ZN001	53.30	02YO006	177.00	02YK002	470.00
02ZM009	53.60	02YD002	200.00	02YK004	529.00
02ZA002	72.00	02YR001	267.00	02YF001	611.00
02ZK002	89.60	02YR002	399.00	02YC001	624.00
02ZG003	115.00	02YR003	554.00	02YJ001	640.00
02ZA003	139.00				
02ZG002	166.00				
02ZG001	205.00				
02ZB001	205.01				
02ZC002	230.00				
02ZK001	285.00				

Region A : Avalon and Burin Peninsulas and Southwestern Region of Island

Region B : North – Central Region of Island

Region C : Humber Valley – Northern Peninsula regions. On the remainder of the Island, which is essentially the Humber Valley - Northern Peninsula region (**Region B**), the annual precipitation ranges from 900mm to 1200 mm.

(2) The mean annual runoff, which often is used as a proxy variable to represent precipitation, could not be used as a parameter in the regression analysis because (a) the mean annual runoff at an ungauged section of a river is unknown and extracting the value from a map of mean annual runoff is subject to large errors and (b) mean annual runoff has a distribution pattern similar to annual precipitation and, hence, can be categorised by region.

(3) There are distinct differences in physiographic characteristics, particularly the land cover, between different regions of the Island. The percentage of barren area varies from 4% to 79%, with an average value of 46%, on the eastern region of the Island. In the central part of the Island the range of percentage of barren area is from 0% to 15%, with an average of 3%. On the Northern Peninsula, the range is from 0.1% to 50%, with an average of 20% and on the southwest area the range is from 7 to 79%, with an average of 41%. The differences in barren cover follows, more or less, the same pattern as that of either precipitation or mean annual runoff. The forest cover follows a pattern exactly opposite to barren area, very high percentage in the north-central region and moderate percentage on the east and southwest regions.

(4) For each equation obtained by multiple regression analysis, a plot of residuals versus estimates was examined. The variance of the residuals should be homogeneous across the range of the regression estimates, i.e., the residuals should not have a heteroscedastic distribution. Although a certain amount of heteroscedasticity was present in the final regression equations, the amount was much larger when the Island was considered as a single region.

Exclusion of some Watersheds from Analysis

Low flow series from six gauging stations were left out of the regression analysis. At five of the gauging stations (02ZF001, 02YS001, 02YL001, 02ZE001 and 02YQ001), the drainage areas were greater than 1000 km^2 and it was observed that the coefficients in the regression equations tended to be disproportionately biased by the low flow frequency estimates from these watersheds at the expense of the smaller watersheds. It was reasoned that since most instances where the results of the regression analysis would be used would be those for relatively much smaller watersheds, less than 100 km^2 in many cases, there was, therefore, very little advantage in including the larger watersheds.

The sixth watershed to be left out was Pipers Hole (02ZH001) which was about 66% covered by lakes and swamps (the next highest percentage for area covered by lakes and swamps is 34%). This watershed had much lower low flows than would be expected for a watershed of this size in the region. It is postulated that the large surface area of water bodies caused a considerable amount of water losses by evaporation and therefore resulted in lower than expected low flows.

4.6 Regression Analysis

For each region shown in Figure 4.1, regression equations were developed using multiple regression analysis techniques to correlate frequency estimates of low flows to watershed characteristics. As explained in Section 4.5, precipitation and runoff parameters were excluded as predictive parameters.

4.6.1 Development of Regression Equations

Various ways of relating low flows with several return periods and durations to watershed characteristics were attempted. The methodology which seemed to yield the better regression equations consisted of the following steps:

[1] Regression Equations between Beta@30 and Watershed Characteristics

The beta parameter of the 30-day summer low flows was used as the dependent variable and the independent parameters were the physiographic characteristics of the watersheds. The regression equations, when all dependent and independent variables were expressed as their logarithms to base 10, were assumed to be linear and of the form

$$\log_{10}(\text{Beta@30}) = \log_{10}(k) + a1*\log_{10}(\text{parameter 1}) + a2*\log_{10}(\text{parameter 2}) + ..$$

where,

Beta@30 = beta parameter for the 30-day low flow series in litres/sec (l/s).

k, a1, a2, .. = regression coefficients.

parameter 1, . = independent parameters, i.e., basin characteristics.

For a given region and given low flow duration, a multiple linear regression between the betas of the low flow series and the basin characteristics was carried out to determine the regression coefficients in the equation.

[2] Regression Equations between Beta@30 and Beta@N, where N=1,7,15 Days

Instead of relating beta@N (N=1, 7, 15 days) to the watershed characteristics by multiple regression analysis, these parameters were related for each region to the corresponding beta@30. The equation, when all parameters were expressed in their log-forms (logarithms to base 10), was of the form

$$\log_{10}(Beta@N) = \log_{10}(k) + a1*\log_{10}(Beta@30)$$

where,

Beta@30 = beta parameter for low flow series of 30-day duration,

Beta@N = beta parameter for low flow series of N-day duration,

N = the particular duration being analyzed, N= 1, 7 or 15 days,

a & k = regression coefficients for equation.

For a given region, a linear regression was carried out to obtain equations for the betas of the three flow durations.

[3] Regression Equations between Beta@N (N=1, 7, 15, 30 days) and QT

Because the Gumbel III pdf was used to fit all low flow series and because there is very little correlation between alpha or epsilon with basin characteristics, the low flows of return period T years, QT, should be primarily dependent on beta@N. The effects of alpha and epsilon on QT are indirectly taken into account by obtaining equations correlating Q2 with Beta@N, Q5 with Q10, Q20 with Q10 and Q50 with Q20. The equation was of the form

$$QT = a1*Q[T-1]$$

where,

Q[T-1] = low flow estimate of a return period smaller than T,

a1 = regression coefficient.

A regression analysis was performed between Q[T] and Q[T-1] for each region and each low flow duration.

The optimum regression coefficients in the regression equations were chosen on the basis of the following criteria:

1. The coefficient of correlation for the regression equation was significantly high.
2. The standard error in the predicted estimate was a minimum.
3. The physiographic parameters used in the equation were independent of one another.
4. The regression equation had to be significant at the 5% significance level using the F-ratio. The independent variables in the regression equation had to be significant at the 10% significance level.
5. Plots of residuals were visually examined to verify the homogeneity of variance in the residuals across different values of the estimates.

4.6.2 Results of Regression Analysis

The equations resulting from regression analyses are given in Tables 4.4, 4.5 and 4.6 for regions A, B and C, respectively. It can be observed from the tables that the correlation coefficients for equations relating Beta@30 to basin characteristics were 0.97, 0.83 and 0.85 for regions A, B and C, respectively. The correlation coefficients for equations relating Beta@N (N = 1, 7 and 15 days) to Beta@30 were all above 0.94. The correlation coefficients of equations between low flow estimates of two consecutive return periods (for example, Q2 to Q5) were generally 0.95. However, there were cases, in particular for case T = 20 years in region B, where the correlation coefficients were around 0.2. This is due to the fact that there is a large difference between Q10 low estimates and Q20 low flow estimates.

The plots of residuals for equations relating Beta@30 to basin characteristics for the three regions A, B and C are shown in Figures 4.2, 4.3 and 4.4, respectively. The variance of the residuals appear to be homogeneously distributed over the range of estimates.

The equations for beta@30 for the three regions are primarily dependent on drainage area; the equation for region A is slightly dependent on the percentage of forested area. The equation for region A when percentage of forested area is excluded from the analysis is also shown in Table 4.4. This equation can be used for estimating low flows in region A when only the drainage area is available as the predictive parameter.

Table 4.4 Regression Equations for Region A

Equation			R^2	S.E.E	
BETA@30	=	$14.8594*DA^{1.140}*FAR^{-0.251}$	0.97	0.113	
BETA@30	=	$4.9774*DA^{1.192}$	0.96	0.133	***
Q2@30	=	0.832*BETA@30	0.99	0.049	
Q5@30	=	0.610*Q2@30	0.96	0.104	
Q10@30	=	0.773*Q5@30	0.97	0.081	
Q20@30	=	0.829*Q10@30	0.96	0.081	
Q50@30	=	0.853*Q20@30	0.94	0.099	
BETA@15	=	$0.6699*BETA@30^{1.006}$	0.99	0.059	
Q2@15	=	0.833*BETA@15	0.99	0.036	
Q5@15	=	0.605*Q2@15	0.96	0.080	
Q10@15	=	0.764*Q5@15	0.97	0.057	
Q20@15	=	0.829*Q10@15	0.96	0.052	
Q50@15	=	0.853*Q20@15	0.94	0.062	
BETA@7	=	$0.5236*BETA@30^{1.010}$	0.99	0.077	
Q2@7	=	0.831*BETA@7	0.99	0.029	
Q5@7	=	0.610*Q2@7	0.95	0.072	
Q10@7	=	0.781*Q5@7	0.96	0.053	
Q20@7	=	0.840*Q10@7	0.96	0.048	
Q50@7	=	0.866*Q20@7	0.94	0.057	
BETA@1	=	$0.4198*BETA30^{1.015}$	0.98	0.100	
Q2@1	=	0.831*BETA@1	0.99	0.024	
Q5@1	=	0.606*Q2@1	0.97	0.049	
Q10@1	=	0.769*Q5@1	0.97	0.038	
Q20@1	=	0.822*Q10@1	0.96	0.038	
Q50@1	=	0.676*Q20@1	0.80	0.078	

Notes:

BETA@N:	Beta parameter of Gumbel Type III PDF for N-day low flow series
QT@N:	T-year Low Flow Regression Estimate of duration N days
R^2:	Correlation coefficient
S.E.E.:	Standard error of estimate in [QT@N or $\log_{10}$(BETA@N)]
DA:	Drainage Area (km^2)
FAR:	Percentage of drainage area covered by forests
***	Regression equation with only DA as the predictive parameter

Table 4.5 Regression Equations for Region B

Equation			R^2	S.E.E
BETA@30	=	5.0466*DA$^{0.966}$	0.83	0.184
Q2@30	=	0.844*BETA@30	0.99	0.101
Q5@30	=	0.566*Q2@30	0.97	0.102
Q10@30	=	0.588*Q5@30	0.99	0.032
Q20@30	=	0.393*Q10@30	0.77	0.062
Q50@30	=	0.602*Q20@30	0.88	0.022
BETA@15	=	0.4046*BETA@30$^{1.099}$	0.99	0.047
Q2@15	=	0.841*BETA@15	0.99	0.081
Q5@15	=	0.543*Q2@15	0.98	0.070
Q10@15	=	0.542*Q5@15	0.98	0.034
Q20@15	=	0.287*Q10@15	0.24	0.073
Q50@15	=	0.695*Q20@15	0.99	0.004
BETA@7	=	0.2280*BETA@30$^{1.166}$	0.98	0.075
Q2@7	=	0.834*BETA@7	0.99	0.072
Q5@7	=	0.526*Q2@7	0.98	0.063
Q10@7	=	0.529*Q5@7	0.98	0.033
Q20@7	=	0.280*Q10@7	0.21	0.070
Q50@7	=	0.694*Q20@7	0.99	0.004
BETA@1	=	0.1449*BETA30$^{1.214}$	0.98	0.077
Q2@1	=	0.826*BETA@1	0.99	0.064
Q5@1	=	0.509*Q2@1	0.98	0.057
Q10@1	=	0.518*Q5@1	0.98	0.031
Q20@1	=	0.275*Q10@1	0.19	0.065
Q50@1	=	0.670*Q20@1	0.99	0.004

Notes:

BETA@N:	Beta parameter of Gumbel Type III PDF for N-day low flow series
QT@N:	T-year Low Flow Regression Estimate of duration N days
R^2:	Correlation coefficient
S.E.E.:	Standard error of estimate in [QT@N or $\log_{10}$(BETA@N)]
DA:	Drainage Area (km^2)
FAR:	Percentage of drainage area covered by forests

Table 4.6 Regression Equations for Region C

Equation			R^2	S.E.E
BETA@30	=	$DA^{1.383}$	0.85	0.093
Q2@30	=	0.859*BETA@30	0.99	0.247
Q5@30	=	0.701*Q2@30	0.95	0.449
Q10@30	=	0.862*Q5@30	0.99	0.193
Q20@30	=	0.910*Q10@30	0.99	0.128
Q50@30	=	0.929*Q20@30	0.99	0.108
BETA@15	=	$0.7362*BETA@30^{1.009}$	0.98	0.039
Q2@15	=	0.870*BETA@15	0.99	0.133
Q5@15	=	0.712*Q2@15	0.97	0.291
Q10@15	=	0.858*Q5@15	0.99	0.169
Q20@15	=	0.902*Q10@15	0.99	0.134
Q50@15	=	0.917*Q20@15	0.99	0.130
BETA@7	=	$0.5848*BETA@30^{1.023}$	0.96	0.053
Q2@7	=	0.879*BETA@7	0.99	0.094
Q5@7	=	0.715*Q2@7	0.98	0.229
Q10@7	=	0.847*Q5@7	0.99	0.148
Q20@7	=	0.886*Q10@7	0.99	0.127
Q50@7	=	0.894*Q20@7	0.99	0.134
BETA@1	=	$0.4864*BETA30^{1.034}$	0.94	0.065
Q2@1	=	0.880*BETA@1	0.99	0.086
Q5@1	=	0.708*Q2@1	0.98	0.215
Q10@1	=	0.831*Q5@1	0.99	0.136
Q20@1	=	0.866*Q10@1	0.99	0.114
Q50@1	=	0.867*Q20@1	0.99	0.118

Notes:

BETA@N:	Beta parameter of Gumbel Type III PDF for N-day low flow series
QT@N:	T-year Low Flow Regression Estimate of duration N days
R^2:	Correlation coefficient
S.E.E.:	Standard error of estimate in [QT@N or $\log_{10}$(BETA@N)]
DA:	Drainage Area (km^2)
FAR:	Percentage of drainage area covered by forests

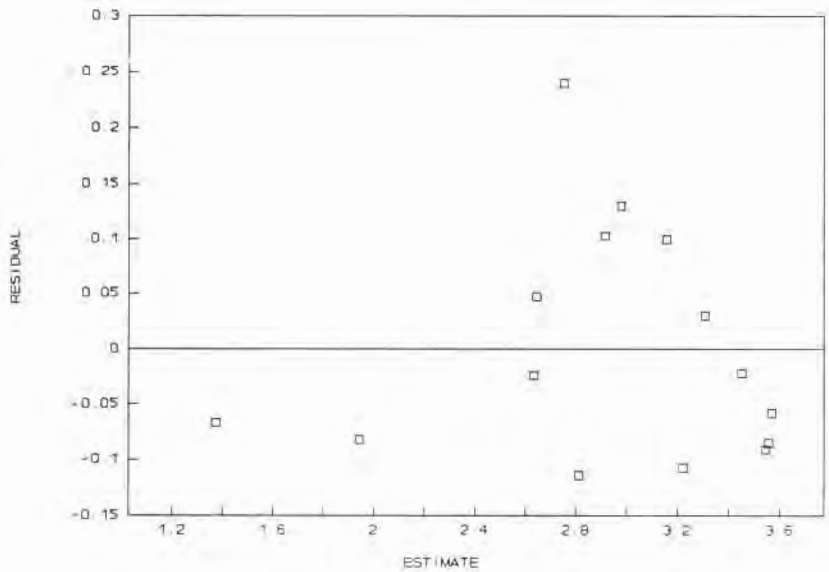

Figure 4.2 Plot of Residuals Against Estimates for Region A.

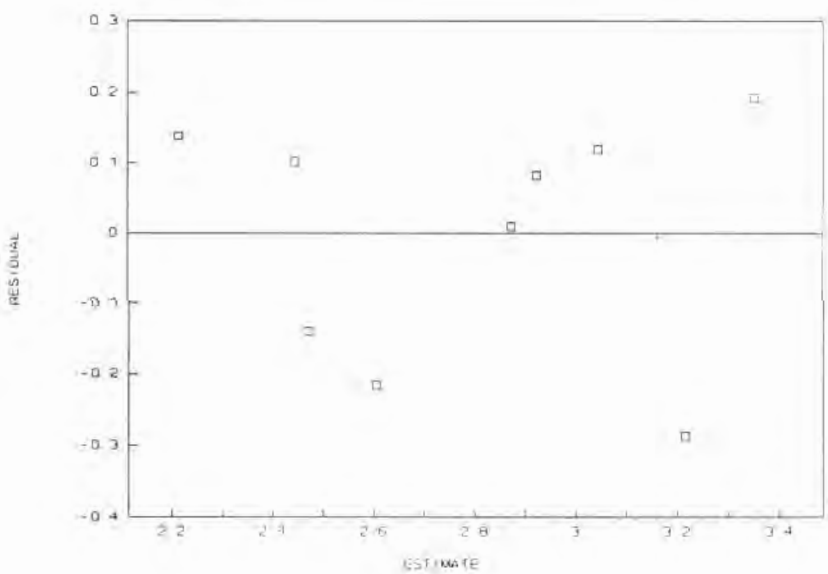

Figure 4.3 Plot of Residuals Against Estimates for Region B.

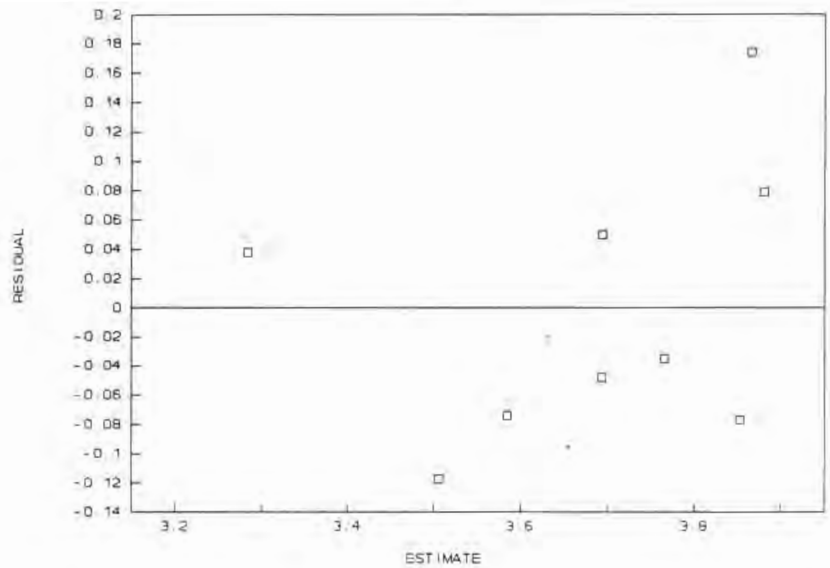

Figure 4.4 Plot of Residuals Against Estimates for Region C.

4.6.3 Applicability of Equations

The equations given in Tables 4.4, 4.5 and 4.6 are applicable under the conditions they were derived, i.e., the parameters of the physiographic characteristics should be within their range in the data set. Recommended ranges for applying the equations are

<u>Equations for Region A:</u>

1. The drainage area is less than 200 km^2.
2. The percentage of barren area is between 15% and 75%. (The percentage of forested area is between 10% and 80%. The percentage of watershed area occupied by lakes and swamps is between 5% and 20%.)

<u>Equations for Region B:</u>

1. The drainage area is between 30 km^2 and 400 km^2.
2. The percentage of barren area is less than 5%. (The percentage of forested area is about 85%, with the rest of the watershed occupied by lakes and swamps.)

<u>Equations for Region C:</u>

1. The drainage area is between 230 km^2 and 600 km^2.
2. The percentage of barren area is between 10% and 50%. (The percentage of forested area is between 30% and 70%. The percentage of the watershed occupied by lakes and swamps is between 10% and 17%.)

4.6.4 Sensitivity of Regression Equations

The independent parameters in the regression equations cannot always be determined exactly and some errors in their extraction from topographic maps may be present. Therefore, it is essential that regression equations be analyzed to determine how sensitive they are to small changes in the magnitudes of the independent parameters.

The equations for determining beta@30 for the three regions are of the form

$$y = a*x^b$$

The change in y, dy, to a small change in x, dx, is determined as follows

$$dy/dx = a*b*x^{b-1}$$

$$100*dy/y = 100*b*dx/x$$

where,

(100*dy/y) is the percentage change in y when x is changed by (100*dx/x) percent.

Since, the equations for beta@30 are primarily dependent on drainage area and the coefficient b is close to 1 in these equations, then a 5% error in the measurement of the drainage area (errors are usually less than 5%) will cause about 5% error in the estimate of Beta@30. Hence, the expected error in Beta@30, due specifically to errors in measurement of drainage area, should not exceed 5%.

4.7 Comparison between Frequency and Regression Estimates

The equations developed during the regression analysis were used to re-estimate the low flow estimates from which they were derived. Tables 4.7, 4.8, 4.9 and 4.10 show the frequency and regression estimates of low flows for durations of 1-day, 7-day, 15-day and 30-day, respectively. The percentage difference between these values, calculated as 100*(regression estimate - frequency estimate)/(frequency estimate) for the 1-, 7-, 15- and 30-day low flow estimates are shown in Tables 4.11, 4.12, 4.13 and 4.14, respectively. Figure 4.5 shows a plot of the regression estimates versus frequency estimates for the 30-day 2-year low flows, Q2@30, at all stations in the three regions. Also shown on the figure are the confidence limits [6] on the frequency estimates of the Q2@30 low flows. An analysis of the above-mentioned tables and figure indicates the following:

1. The percentage errors between the frequency and regression estimates usually range between +50% and -50%, although some are extremely high. These high values occur most often for small watersheds and for high return periods, that is, when the frequency estimates are close to zero. The high percentage differences are due to the fact that for very low flow estimates the difference between the regression and frequency estimates becomes very close to the frequency estimate itself.
2. The errors are relatively lower for the 30-day series and for estimates of beta. This is an expected result because these series and estimates show less variance.
3. The "best" regression estimates are those for region A, that is, the Avalon, Burin and Southwestern regions and "worst" for the central region, region B. The results are worst for region B because it is in this region that the low flow frequency estimates are very close to zero and this causes the percentage differences to be high.

Table 4.7 Frequency and Regression Estimates of 1-day Summer Low Flows

Station Number	DA (km^2)	FAR (%)	BAR (%)	LSAR (%)	ACLS (%)	BETA (m^3/s)	E_BETA1 (m^3/s)	Q2* (m^3/s)	E_Q2*	Q5*	E_Q5*	Q10*	E_Q10*	Q20*	E_Q20*	Q50*	E_Q50*
02ZM006	3.90	75	4	21	100	0.0091	0.0104	0.0074	0.0087	0.0036	0.0053	0.0020	0.0040	0.0009	0.0033	0.0000	0.0022
02ZL003	10.80	42	49	9	100	0.0329	0.0393	0.0223	0.0327	0.0087	0.0198	0.0061	0.0152	0.0051	0.0125	0.0047	0.0085
02ZG004	42.70	35	47	18	92	0.1647	0.2022	0.1440	0.1680	0.0889	0.1018	0.0578	0.0783	0.0315	0.0644	0.0020	0.0435
02ZH002	43.30	40	50	10	92	0.1455	0.1986	0.1030	0.1650	0.0370	0.1000	0.0206	0.0769	0.0132	0.0632	0.0089	0.0427
02ZN001	53.30	8	79	13	100	0.6188	0.3806	0.5550	0.3163	0.3950	0.1917	0.3150	0.1474	0.2530	0.1212	0.1900	0.0819
02ZM009	53.60	37	50	13	100	0.5262	0.2593	0.4500	0.2155	0.2740	0.1306	0.1950	0.1004	0.1390	0.0826	0.0868	0.0558
02ZA002	72.00	82	13	5	43	0.3074	0.2979	0.2770	0.2476	0.1850	0.1500	0.1280	0.1154	0.0751	0.0946	0.0098	0.0641
02ZK002	89.60	47	23	30	81	0.6280	0.4422	0.5230	0.3675	0.3100	0.2227	0.2300	0.1712	0.1800	0.1408	0.1410	0.0952
02ZG003	115.00	16	72	12	92	0.4331	0.7767	0.3650	0.6454	0.2100	0.3911	0.1410	0.3008	0.0920	0.2472	0.0473	0.1671
02ZA003	139.00	68	19	13	73	1.0265	0.6690	0.8880	0.5559	0.6710	0.3369	0.6130	0.2591	0.5860	0.2129	0.5700	0.1440
02ZG002	166.00	38	49	13	92	1.2502	0.9528	1.0170	0.7918	0.5840	0.4798	0.4410	0.3690	0.3600	0.3033	0.3010	0.2050
02ZG001	205.00	26	64	10	96	1.5756	1.3398	1.3230	1.1133	0.7460	0.6747	0.4910	0.5188	0.3100	0.4265	0.1450	0.2883
02ZB001	205.01	9	78	13	60	1.1492	1.7556	0.9800	1.4589	0.6350	0.8841	0.5030	0.6799	0.4200	0.5589	0.3520	0.3778
02ZC002	230.00	17	79	4	34	1.1704	1.7055	0.9330	1.4173	0.5650	0.8589	0.4710	0.6605	0.4270	0.5429	0.4020	0.3670
02ZK001	285.00	51	37	12	55	1.3326	1.6522	1.0680	1.3730	0.5750	0.8320	0.4100	0.6398	0.3160	0.5259	0.2480	0.3555
02YS003	36.70	84	1	16	100	0.1031	0.0707	0.0800	0.0584	0.0411	0.0297	0.0297	0.0154	0.0240	0.0042	0.0202	0.0028
02YP001	63.80	87	1	13	79	0.2100	0.1352	0.1810	0.1117	0.0953	0.0569	0.0410	0.0295	0.0000	0.0081	0.0000	0.0054
02ZJ001	67.40	82	3	15	86	0.1196	0.1442	0.0774	0.1191	0.0203	0.0606	0.0085	0.0314	0.0038	0.0086	0.0015	0.0058
02YM003	93.20	90	1	10	56	0.0830	0.2109	0.0529	0.1742	0.0110	0.0887	0.0019	0.0459	0.0000	0.0126	0.0000	0.0085
02YO006	177.00	82	2	16	97	0.3972	0.4475	0.3500	0.3696	0.2350	0.1881	0.1800	0.0975	0.1380	0.0268	0.0979	0.0180
02YD002	200.00	83	1	17	99	0.6033	0.5164	0.3850	0.4265	0.0894	0.2171	0.0286	0.1125	0.0045	0.0309	0.0000	0.0207
02YR001	267.00	75	1	24	98	1.1008	0.7247	0.8660	0.5986	0.4230	0.3047	0.2720	0.1578	0.1840	0.0434	0.1190	0.0291
02YR002	399.00	68	1	32	96	0.5842	1.1607	0.3680	0.9588	0.0922	0.4880	0.0403	0.2528	0.0210	0.0695	0.0122	0.0466
02YR003	554.00	69	1	31	97	2.8383	1.7056	2.4080	1.4089	1.2570	0.7171	0.6240	0.3715	0.0976	0.1022	0.0000	0.0684
02YD001	237.00	81	11	8	73	1.2232	1.3085	1.1000	1.1515	0.7890	0.8153	0.6310	0.6775	0.5070	0.5867	0.3790	0.5087
02ZA001	343.00	60	30	10	83	1.6310	2.1256	1.4620	1.8706	1.1040	1.3244	0.9610	1.1005	0.8680	0.9531	0.7900	0.8263
02YK005	391.00	68	15	17	94	2.4063	2.5243	2.0530	2.2214	1.2850	1.5728	0.9670	1.3070	0.7530	1.1318	0.5680	0.9813
02YN002	469.00	22	62	16	100	2.6904	3.2050	2.3730	2.8204	1.9220	1.9968	1.8210	1.6594	1.7780	1.4370	1.7560	1.2459
02YK002	470.00	55	29	16	100	3.4747	3.2140	2.9880	2.8283	1.9610	2.0024	1.5520	1.6640	1.2860	1.4410	1.0620	1.2494
02YK004	529.00	35	29	36	95	4.2346	3.7536	3.6880	3.3032	2.5170	2.3386	2.0380	1.9434	1.7210	1.6830	1.4500	1.4591
02YF001	611.00	69	18	13	100	2.9314	4.5351	2.5270	3.9909	1.6040	2.8256	1.1920	2.3480	0.9010	2.0334	0.6320	1.7630
02YC001	624.00	33	50	17	99	7.6934	4.6622	6.9510	4.1027	5.2770	2.9047	4.5430	2.4138	4.0310	2.0904	3.5670	1.8123
02YJ001	640.00	79	7	14	75	6.2758	4.8197	5.4110	4.2413	3.5410	3.0029	2.7670	2.4954	2.2500	2.1610	1.8030	1.8736

* Notes

QT : Frequency Estimates of Low Flow

E_QT : Regression Estimates of Low Flow

Table 4.8 Frequency and Regression Estimates of 7-day Summer Low Flows

Station	DA	FAR	BAR	LSAR	ACLS	BETA	E_BETA7	Q2*	E_Q2*	Q5*	E_Q5*	Q10*	E_Q10*	Q20*	E_Q20*	Q50*	E_Q50*
Number	(km^2)	(%)	(%)	(%)	(%)	(m^3/s)	(m^3/s)	(m^3/s)									
02ZM006	3.90	75	4	21	100	0.0109	0.0128	0.0089	0.0107	0.0044	0.0065	0.0024	0.0051	0.0011	0.0043	0.0000	0.0037
02ZL003	10.80	42	49	9	100	0.0415	0.0480	0.0281	0.0399	0.0125	0.0243	0.0100	0.0190	0.0091	0.0160	0.0088	0.0138
02ZG004	42.70	35	47	18	92	0.2204	0.2447	0.1960	0.2033	0.1240	0.1240	0.0813	0.0969	0.0430	0.0814	0.0000	0.0705
02ZH002	43.30	40	50	10	92	0.1837	0.2403	0.1360	0.1997	0.0581	0.1218	0.0368	0.0952	0.0264	0.0799	0.0199	0.0692
02ZN001	53.30	8	79	13	100	0.6992	0.4591	0.6250	0.3815	0.4410	0.2327	0.3490	0.1818	0.2780	0.1527	0.2050	0.1322
02ZM009	53.60	37	50	13	100	0.6099	0.3134	0.5340	0.2605	0.3380	0.1589	0.2360	0.1241	0.1540	0.1042	0.0671	0.0903
02ZA002	72.00	82	13	5	43	0.3368	0.3598	0.3040	0.2990	0.2110	0.1824	0.1550	0.1425	0.1050	0.1197	0.0449	0.1036
02ZK002	89.60	47	23	30	81	0.7746	0.5330	0.6410	0.4429	0.3700	0.2702	0.2680	0.2110	0.2050	0.1772	0.1540	0.1535
02ZG003	115.00	16	72	12	92	0.5475	0.9336	0.4770	0.7758	0.2960	0.4732	0.2020	0.3696	0.1280	0.3105	0.0506	0.2689
02ZA003	139.00	68	19	13	73	1.1527	0.8047	1.0180	0.6687	0.8300	0.4079	0.7890	0.3186	0.7720	0.2676	0.7630	0.2317
02ZG002	166.00	38	49	13	92	1.4572	1.1441	1.2100	0.9507	0.7110	0.5800	0.5250	0.4529	0.4090	0.3805	0.3170	0.3295
02ZG001	205.00	26	64	10	96	1.7873	1.6061	1.4740	1.3346	0.7960	0.8141	0.5170	0.6358	0.3300	0.5341	0.1690	0.4625
02ZB001	205.01	9	78	13	60	1.4411	2.1018	1.2000	1.7466	0.7490	1.0654	0.5970	0.8321	0.5100	0.6990	0.4460	0.6053
02ZC002	230.00	17	79	4	34	1.4830	2.0421	1.2150	1.6970	0.7770	1.0352	0.6560	0.8085	0.5960	0.6791	0.5590	0.5881
02ZK001	285.00	51	37	12	55	1.6047	1.9785	1.2740	1.6442	0.6760	1.0029	0.4850	0.7833	0.3790	0.6580	0.3050	0.5698
02YS003	36.70	84	1	16	100	0.1315	0.0871	0.1040	0.0726	0.0536	0.0382	0.0378	0.0202	0.0293	0.0057	0.0234	0.0039
02YP001	63.80	87	1	13	79	0.2380	0.1624	0.2010	0.1354	0.1030	0.0712	0.0497	0.0377	0.0059	0.0106	0.0000	0.0073
02ZJ001	67.40	82	3	15	86	0.1460	0.1727	0.0944	0.1441	0.0263	0.0758	0.0127	0.0401	0.0075	0.0112	0.0050	0.0078
02YM003	93.20	90	1	10	56	0.0990	0.2488	0.0631	0.2068	0.0141	0.1088	0.0038	0.0575	0.0000	0.0161	0.0000	0.0112
02YO006	177.00	82	2	16	97	0.4549	0.5124	0.4020	0.4258	0.2740	0.2240	0.2120	0.1185	0.1660	0.0332	0.1200	0.0230
02YD002	200.00	83	1	17	99	0.6887	0.5880	0.4530	0.4887	0.1240	0.2570	0.0535	0.1360	0.0244	0.0381	0.0095	0.0264
02YR001	267.00	75	1	24	98	1.1935	0.8142	0.9350	0.6766	0.4560	0.3559	0.2960	0.1883	0.2050	0.0527	0.1390	0.0366
02YR002	399.00	68	1	32	96	0.6505	1.2801	0.4170	1.0638	0.1130	0.5596	0.0540	0.2960	0.0313	0.0829	0.0206	0.0575
02YR003	554.00	69	1	31	97	3.0772	1.8527	2.6410	1.5396	1.4290	0.8098	0.7270	0.4284	0.1200	0.1200	0.0000	0.0832
02YD001	237.00	81	11	8	73	1.3742	1.4220	1.2200	1.2500	0.8490	0.8937	0.6720	0.7570	0.5390	0.6707	0.4100	0.5996
02ZA001	343.00	60	30	10	83	1.7544	2.3231	1.5690	2.0420	1.1890	1.4600	1.0420	1.2366	0.9500	1.0956	0.8740	0.9795
02YK005	391.00	68	15	17	94	2.6135	2.7643	2.2120	2.4298	1.3690	1.7373	1.0350	1.4715	0.8190	1.3037	0.6390	1.1655
02YN002	469.00	22	62	16	100	2.8884	3.5194	2.5580	3.0935	2.0770	2.2119	1.9640	1.8734	1.9160	1.6599	1.8890	1.4839
02YK002	470.00	55	29	16	100	3.8830	3.5293	3.3230	3.1023	2.1540	2.2181	1.6940	1.8788	1.3990	1.6646	1.1530	1.4881
02YK004	529.00	35	29	36	95	4.5521	4.1293	3.9770	3.6297	2.7190	2.5952	2.1920	2.1981	1.8370	1.9476	1.5250	1.7411
02YF001	611.00	69	18	13	100	3.4679	5.0000	2.9430	4.3950	1.7460	3.1424	1.2130	2.6616	0.8370	2.3582	0.4900	2.1082
02YC001	624.00	33	50	17	99	8.0723	5.1417	7.2800	4.5196	5.5380	3.2315	4.8010	2.7371	4.3020	2.4251	3.8610	2.1680
02YJ001*	640.00	79	7	14	75	6.8188	5.3175	5.9010	4.6741	4.1610	3.3420	3.5630	2.8307	3.2150	2.5080	2.9580	2.2421

* Notes

QT : Frequency Estimates of Low Flow

E_QT : Regression Estimates of Low Flow

Table 4.9 Frequency and Regression Estimates of 15-day Summer Low Flows

Station Number	DA (km^2)	FAR (%)	BAR (%)	LSAR (%)	ACLS (%)	BETA (m^3/s)	E_BETA15 (m^3/s)	Q2*	E_Q2*	Q5*	E_Q5*	Q10*	E_Q10*	Q20*	E_Q20*	Q50*	E_Q50*
								(m^3/s)									
02ZM006	3.90	75	4	21	100	0.0136	0.0162	0.0107	0.0135	0.0047	0.0082	0.0025	0.0062	0.0011	0.0051	0.0000	0.0042
02ZL003	10.80	42	49	9	100	0.0534	0.0603	0.0369	0.0502	0.0173	0.0304	0.0140	0.0232	0.0129	0.0189	0.0124	0.0158
02ZG004	42.70	35	47	18	92	0.2940	0.3055	0.2600	0.2545	0.1630	0.1540	0.1070	0.1176	0.0587	0.0960	0.0025	0.0799
02ZH002	43.30	40	50	10	92	0.2406	0.3001	0.1780	0.2500	0.0758	0.1513	0.0480	0.1156	0.0344	0.0943	0.0261	0.0785
02ZN001	53.30	8	79	13	100	0.8239	0.5719	0.7280	0.4764	0.5020	0.2882	0.3950	0.2202	0.3170	0.1797	0.2420	0.1495
02ZM009	53.60	37	50	13	100	0.7360	0.3910	0.6400	0.3257	0.4050	0.1970	0.2890	0.1505	0.2000	0.1228	0.1110	0.1022
02ZA002	72.00	82	13	5	43	0.3913	0.4486	0.3500	0.3737	0.2420	0.2261	0.1830	0.1727	0.1350	0.1409	0.0828	0.1173
02ZK002	89.60	47	23	30	81	0.9844	0.6635	0.8000	0.5527	0.4480	0.3344	0.3250	0.2555	0.2520	0.2084	0.1980	0.1734
02ZG003	115.00	16	72	12	92	0.7149	1.1595	0.6290	0.9659	0.4010	0.5844	0.2760	0.4465	0.1730	0.3643	0.0612	0.3031
02ZA003	139.00	68	19	13	73	1.3377	1.0000	1.1680	0.8330	0.9150	0.5040	0.8550	0.3850	0.8280	0.3142	0.8130	0.2614
02ZG002	166.00	38	49	13	92	1.7015	1.4199	1.4310	1.1827	0.8580	0.7156	0.6270	0.5467	0.4770	0.4461	0.3490	0.3712
02ZG001	205.00	26	64	10	96	2.1221	1.9905	1.7450	1.6581	0.9320	1.0032	0.5960	0.7664	0.3720	0.6254	0.1790	0.5203
02ZB001	205.01	9	78	13	60	1.8035	2.6021	1.4850	2.1676	0.9070	1.3114	0.7220	1.0019	0.6200	0.8175	0.5480	0.6802
02ZC002	230.00	17	79	4	34	2.0839	2.5285	1.7790	2.1063	1.1510	1.2743	0.9080	0.9736	0.7530	0.7944	0.6270	0.6610
02ZK001	285.00	51	37	12	55	2.0149	2.4501	1.5970	2.0409	0.8340	1.2348	0.5850	0.9434	0.4470	0.7698	0.3490	0.6405
02YS003	36.70	84	1	16	100	0.1574	0.1098	0.1260	0.0924	0.0702	0.0502	0.0524	0.0272	0.0427	0.0078	0.0359	0.0054
02YP001	63.80	87	1	13	79	0.2697	0.1976	0.2300	0.1661	0.1230	0.0902	0.0642	0.0489	0.0155	0.0140	0.0000	0.0098
02ZJ001	67.40	82	3	15	86	0.1722	0.2094	0.1130	0.1761	0.0330	0.0956	0.0165	0.0518	0.0100	0.0149	0.0067	0.0103
02YM003	93.20	90	1	10	56	0.1422	0.2954	0.0873	0.2484	0.0194	0.1349	0.0072	0.0731	0.0029	0.0210	0.0009	0.0146
02YO006	177.00	82	2	16	97	0.5386	0.5836	0.4790	0.4908	0.3270	0.2665	0.2500	0.1445	0.1900	0.0415	0.1270	0.0288
02YD002	200.00	83	1	17	99	0.7694	0.6645	0.5140	0.5588	0.1630	0.3034	0.0881	0.1645	0.0577	0.0472	0.0423	0.0328
02YR001	267.00	75	1	24	98	1.2697	0.9030	0.9900	0.7594	0.4800	0.4124	0.3140	0.2235	0.2220	0.0641	0.1570	0.0446
02YR002	399.00	68	1	32	96	0.7126	1.3833	0.4640	1.1633	0.1330	0.6317	0.0659	0.3424	0.0397	0.0983	0.0270	0.0683
02YR003	554.00	69	1	31	97	3.2622	1.9599	2.8330	1.6482	1.5890	0.8950	0.8300	0.4851	0.1460	0.1392	0.0000	0.0968
02YD001	237.00	81	11	8	73	1.5586	1.5689	1.3770	1.3650	0.9440	0.9719	0.7390	0.8339	0.5880	0.7521	0.4400	0.6897
02ZA001	343.00	60	30	10	83	1.9620	2.5801	1.7270	2.2447	1.2640	1.5982	1.0960	1.3713	0.9940	1.2369	0.9150	1.1342
02YK005	391.00	68	15	17	94	2.8479	3.0774	2.3980	2.6774	1.4740	1.9063	1.1180	1.6356	0.8920	1.4753	0.7080	1.3528
02YN002	469.00	22	62	16	100	3.2980	3.9309	2.9130	3.4198	2.2770	2.4349	2.0990	2.0892	2.0100	1.8844	1.9550	1.7280
02YK002	470.00	55	29	16	100	4.3693	3.9421	3.7460	3.4297	2.4280	2.4419	1.9000	2.0952	1.5560	1.8898	1.2660	1.7330
02YK004	529.00	35	29	36	95	4.9044	4.6221	4.2360	4.0213	2.8450	2.8631	2.3000	2.4566	1.9510	2.2158	1.6620	2.0319
02YF001	611.00	69	18	13	100	4.1463	5.6113	3.3820	4.8818	1.8520	3.4758	1.2840	2.9823	0.9340	2.6900	0.6580	2.4667
02YC001	624.00	33	50	17	99	8.7766	5.7725	7.8890	5.0221	6.0480	3.5757	5.3300	3.0680	4.8720	2.7673	4.4940	2.5376
02YJ001	640.00	79	7	14	75	7.3996	5.9726	6.3250	5.1961	4.5130	3.6996	3.9880	3.1743	3.7190	2.8632	3.5460	2.6256

* Notes

QT : Frequency Estimates of Low Flow

E_QT : Regression Estimates of Low Flow

Table 4.10 Frequency and Regression Estimates of 30-day Summer Low Flows

Station Number	DA (km^2)	FAR (%)	BAR (%)	LSAR (%)	ACLS (%)	BETA (m^3/s)	E_BETA30 (m^3/s)	Q2* (m^3/s)	E_Q2*	Q5*	E_Q5*	Q10*	E_Q10*	Q20*	E_Q20*	Q50*	E_Q50*
02ZM006	3.90	75	4	21	100	0.0203	0.0237	0.0154	0.0197	0.0061	0.0120	0.0030	0.0093	0.0012	0.0077	0.0000	0.0066
02ZL003	10.80	42	49	9	100	0.0726	0.0876	0.0532	0.0729	0.0327	0.0445	0.0298	0.0344	0.0290	0.0285	0.0287	0.0243
02ZG004	42.70	35	47	18	92	0.4898	0.4397	0.4360	0.3658	0.2710	0.2231	0.1650	0.1725	0.0643	0.1430	0.0000	0.1220
02ZH002	43.30	40	50	10	92	0.4075	0.4320	0.2990	0.3594	0.1220	0.2192	0.0733	0.1695	0.0491	0.1405	0.0340	0.1198
02ZN001	53.30	8	79	13	100	1.0400	0.8200	0.9070	0.6822	0.6050	0.4161	0.4720	0.3217	0.3780	0.2667	0.2920	0.2275
02ZM009	53.60	37	50	13	100	0.9764	0.5619	0.8590	0.4675	0.5590	0.2852	0.4030	0.2204	0.2800	0.1827	0.1510	0.1559
02ZA002	72.00	82	13	5	43	0.4962	0.6442	0.4520	0.5359	0.3320	0.3269	0.2650	0.2527	0.2080	0.2095	0.1450	0.1787
02ZK002	89.60	47	23	30	81	1.2845	0.9505	1.0470	0.7908	0.6110	0.4824	0.4680	0.3729	0.3880	0.3091	0.3300	0.2637
02ZG003	115.00	16	72	12	92	1.3021	1.6556	1.1080	1.3775	0.6420	0.8403	0.4200	0.6495	0.2540	0.5385	0.0928	0.4593
02ZA003	139.00	68	19	13	73	1.8008	1.4292	1.5620	1.1891	1.1340	0.7253	0.9990	0.5607	0.9250	0.4648	0.8740	0.3965
02ZG002	166.00	38	49	13	92	2.1729	2.0249	1.8210	1.6847	1.0710	1.0277	0.7680	0.7944	0.5690	0.6585	0.4010	0.5617
02ZG001	205.00	26	64	10	96	2.6854	2.8330	2.2780	2.3570	1.3140	1.4378	0.8640	1.1114	0.5340	0.9214	0.2190	0.7859
02ZB001	205.01	9	78	13	60	3.2388	3.6975	2.6480	3.0763	1.5550	1.8766	1.1920	1.4506	0.9870	1.2025	0.8390	1.0258
02ZC002	230.00	17	79	4	34	2.9615	3.5936	2.5070	2.9899	1.7530	1.8238	1.5390	1.4098	1.4320	1.1687	1.3630	0.9969
02ZK001	285.00	51	37	12	55	2.8315	3.4828	2.2340	2.8977	1.1530	1.7676	0.8050	1.3663	0.6130	1.1327	0.4780	0.9662
02YS003	36.70	84	1	16	100	0.2248	0.1639	0.1750	0.1383	0.0952	0.0783	0.0738	0.0460	0.0634	0.0181	0.0571	0.0109
02YP001	63.80	87	1	13	79	0.3529	0.2795	0.3050	0.2359	0.1640	0.1335	0.0778	0.0785	0.0000	0.0309	0.0000	0.0186
02ZJ001	67.40	82	3	15	86	0.2131	0.2948	0.1290	0.2488	0.0341	0.1408	0.0198	0.0828	0.0152	0.0325	0.0135	0.0196
02YM003	93.20	90	1	10	56	0.2451	0.4031	0.1560	0.3402	0.0351	0.1926	0.0104	0.1132	0.0006	0.0445	0.0000	0.0268
02YO006	177.00	82	2	16	97	0.7628	0.7491	0.6830	0.6322	0.4640	0.3578	0.3380	0.2104	0.2300	0.0827	0.1070	0.0498
02YD002	200.00	83	1	17	99	1.0179	0.8429	0.7170	0.7114	0.2390	0.4027	0.1130	0.2368	0.0519	0.0931	0.0155	0.0560
02YR001	267.00	75	1	24	98	1.4646	1.1143	1.1280	0.9405	0.5300	0.5323	0.3430	0.3130	0.2420	0.1230	0.1730	0.0741
02YR002	399.00	68	1	32	96	0.8472	1.6426	0.5500	1.3864	0.1550	0.7847	0.0766	0.4614	0.0459	0.1813	0.0312	0.1092
02YR003	554.00	69	1	31	97	3.5106	2.2554	3.0880	1.9036	1.8410	1.0774	1.0620	0.6335	0.3480	0.2490	0.0000	0.1499
02YD001	237.00	81	11	8	73	2.0988	1.9243	1.7540	1.6530	1.0570	1.1587	0.7960	0.9988	0.6340	0.9089	0.5040	0.8444
02ZA001	343.00	60	30	10	83	2.4473	3.2086	2.0710	2.7562	1.3570	1.9321	1.1120	1.6654	0.9690	1.5156	0.8630	1.4080
02YK005	391.00	68	15	17	94	3.2434	3.8457	2.7280	3.3035	1.6700	2.3157	1.2630	1.9962	1.0060	1.8165	0.7960	1.6875
02YN002	469.00	22	62	16	100	4.4228	4.9457	3.9420	4.2484	2.9760	2.9781	2.6140	2.5671	2.3910	2.3361	2.2130	2.1702
02YK002	470.00	55	29	16	100	5.5603	4.9603	4.6400	4.2609	2.8360	2.9869	2.1860	2.5747	1.7940	2.3430	1.4920	2.1766
02YK004	529.00	35	29	36	95	5.3839	5.8417	4.6190	5.0180	3.1040	3.5176	2.5490	3.0322	2.2120	2.7593	1.9490	2.5634
02YF001	611.00	69	18	13	100	5.9632	7.1301	4.5530	6.1247	2.2540	4.2934	1.6210	3.7010	1.3090	3.3679	1.1160	3.1287
02YC001	624.00	33	50	17	99	10.9525	7.3407	9.7500	6.3057	7.4550	4.4203	6.6580	3.8103	6.1920	3.4674	5.8430	3.2212
02YJ001	640.00	79	7	14	75	9.1051	7.6023	7.8490	6.5304	5.6320	4.5778	4.9460	3.9461	4.5770	3.5909	4.3260	3.3360

* Notes

QT : Frequency Estimates of Low Flow

E_QT : Regression Estimates of Low Flow

Table 4.11 Percentage Difference Between Frequency and Regression Estimates of 1-day Low Flows

Station Number	DA (km^2)	FAR (%)	BAR (%)	LSAR (%)	ACLS (%)	Delta Beta (%)	Delta Q2 (%)	Delta Q5 (%)	Delta Q10 (%)	Delta Q20 (%)
02ZM006	3.90	75	4	21	100	14.8	17.3	46.1	102.2	269.3
02ZL003	10.80	42	49	9	100	19.6	46.6	127.7	149.7	145.5
02ZG004	42.70	35	47	18	92	22.8	16.7	14.5	35.5	104.3
02ZH002	43.30	40	50	10	92	36.5	60.2	170.3	273.4	379.0
02ZN001	53.30	8	79	13	100	-38.5	-43.0	-51.5	-53.2	-52.1
02ZM009	53.60	37	50	13	100	-50.7	-52.1	-52.3	-48.5	-40.6
02ZA002	72.00	82	13	5	43	-3.1	-10.6	-18.9	-9.9	26.3
02ZK002	89.60	47	23	30	81	-29.6	-29.7	-28.2	-25.5	-21.8
02ZG003	115.00	16	72	12	92	79.3	76.8	86.3	113.3	168.7
02ZA003	139.00	68	19	13	73	-34.8	-37.4	-49.8	-57.7	-63.7
02ZG002	166.00	38	49	13	92	-23.8	-22.1	-17.8	-16.3	-15.8
02ZG001	205.00	26	64	10	96	-15.0	-15.8	-9.6	5.7	37.6
02ZB001	205.01	9	78	13	60	52.8	48.9	39.2	35.2	33.1
02ZC002	230.00	17	79	4	34	45.7	51.9	52.0	40.2	27.1
02ZK001	285.00	51	37	12	55	24.0	28.6	44.7	56.1	66.4
02YS003	36.70	84	1	16	100	-31.4	-27.0	-27.7	-48.2	-82.4
02YP001	63.80	87	1	13	79	-35.6	-38.3	-40.3	-28.2	ERR
02ZJ001	67.40	82	3	15	86	20.6	53.9	198.7	269.5	127.3
02YM003	93.20	90	1	10	56	154.1	229.3	706.1	2317.5	ERR
02YO006	177.00	82	2	16	97	12.7	5.6	-19.9	-45.9	-80.6
02YD002	200.00	83	1	17	99	-14.4	10.8	142.9	293.2	587.3
02YR001	267.00	75	1	24	98	-34.2	-30.9	-28.0	-42.0	-76.4
02YR002	399.00	68	1	32	96	98.7	160.5	429.3	527.3	231.0
02YR003	554.00	69	1	31	97	-39.9	-41.5	-43.0	-40.5	4.7
02YD001	237.00	81	11	8	73	7.0	4.7	3.3	7.4	15.7
02ZA001	343.00	60	30	10	83	30.3	27.9	20.0	14.5	9.8
02YK005	391.00	68	15	17	94	4.9	8.2	22.4	35.2	50.3
02YN002	469.00	22	62	16	100	19.1	18.9	3.9	-8.9	-19.2
02YK002	470.00	55	29	16	100	-7.5	-5.3	2.1	7.2	12.1
02YK004	529.00	35	29	36	95	-11.4	-10.4	-7.1	-4.6	-2.2
02YF001	611.00	69	18	13	100	54.7	57.9	76.2	97.0	125.7
02YC001	624.00	33	50	17	99	-39.4	-41.0	-45.0	-46.9	-48.1
02YJ001	640.00	79	7	14	75	-23.2	-21.6	-15.2	-9.8	-4.0

* Notes:
Delta X (%) = 100 * (Regression Estimates of X – Frequency Estimate of X) / (Frequency Estimate of X)

Table 4.12 Percentage Difference Between Frequency and Regression Estimates of 7-day Low Flows

Station Number	DA (km^2)	FAR (%)	BAR (%)	LSAR (%)	ACLS (%)	Delta Beta (%)	Delta Q2 (%)	Delta Q5 (%)	Delta Q10 (%)	Delta Q20 (%)
02ZM006	3.90	75	4	21	100	17.6	19.7	47.7	111.5	287.6
02ZL003	10.80	42	49	9	100	15.6	41.9	94.6	90.0	75.4
02ZG004	42.70	35	47	18	92	11.0	3.7	0.0	19.1	89.2
02ZH002	43.30	40	50	10	92	30.8	46.9	109.7	158.6	202.8
02ZN001	53.30	8	79	13	100	-34.3	-39.0	-47.2	-47.9	-45.1
02ZM009	53.60	37	50	13	100	-48.6	-51.2	-53.0	-47.4	-32.3
02ZA002	72.00	82	13	5	43	6.8	-1.6	-13.6	-8.1	14.0
02ZK002	89.60	47	23	30	81	-31.2	-30.9	-27.0	-21.3	-13.5
02ZG003	115.00	16	72	12	92	70.5	62.6	59.9	83.0	142.6
02ZA003	139.00	68	19	13	73	-30.2	-34.3	-50.9	-59.6	-65.3
02ZG002	166.00	38	49	13	92	-21.5	-21.4	-18.4	-13.7	-7.0
02ZG001	205.00	26	64	10	96	-10.1	-9.5	2.3	23.0	61.8
02ZB001	205.01	9	78	13	60	45.8	45.5	42.2	39.4	37.1
02ZC002	230.00	17	79	4	34	37.7	39.7	33.2	23.2	13.9
02ZK001	285.00	51	37	12	55	23.3	29.1	48.4	61.5	73.6
02YS003	36.70	84	1	16	100	-33.8	-30.2	-28.7	-46.5	-80.7
02YP001	63.80	87	1	13	79	-31.8	-32.6	-30.8	-24.2	78.8
02ZJ001	67.40	82	3	15	86	18.3	52.6	188.1	215.6	49.6
02YM003	93.20	90	1	10	56	151.3	227.7	671.4	1414.1	ERR
02YO006	177.00	82	2	16	97	12.7	5.9	-18.3	-44.1	-80.0
02YD002	200.00	83	1	17	99	-14.6	7.9	107.3	154.2	56.0
02YR001	267.00	75	1	24	98	-31.8	-27.6	-22.0	-36.4	-74.3
02YR002	399.00	68	1	32	96	96.8	155.1	395.2	448.2	164.8
02YR003	554.00	69	1	31	97	-39.8	-41.7	-43.3	-41.1	-0.0
02YD001	237.00	81	11	8	73	3.5	2.5	5.3	12.6	24.4
02ZA001	343.00	60	30	10	83	32.4	30.1	22.8	18.7	15.3
02YK005	391.00	68	15	17	94	5.8	9.8	26.9	42.2	59.2
02YN002	469.00	22	62	16	100	21.8	20.9	6.5	-4.6	-13.4
02YK002	470.00	55	29	16	100	-9.1	-6.6	3.0	10.9	19.0
02YK004	529.00	35	29	36	95	-9.3	-8.7	-4.6	0.3	6.0
02YF001	611.00	69	18	13	100	44.2	49.3	80.0	119.4	181.7
02YC001	624.00	33	50	17	99	-36.3	-37.9	-41.6	-43.0	-43.6
02YJ001	640.00	79	7	14	75	-22.0	-20.8	-19.7	-20.6	-22.0

* Notes

Delta X (%) = 100 * (Regression Estimates of X - Frequency Estimate of X) / (Frequency Estimate of X)

Table 4.13 Percentage Difference Between Frequency and Regression Estimates of 15–day Low Flows

Station Number	DA (km^2)	FAR (%)	BAR (%)	LSAR (%)	ACLS (%)	Delta Beta (%)	Delta Q2 (%)	Delta Q5 (%)	Delta Q10 (%)	Delta Q20 (%)
02ZM006	3.90	75	4	21	100	19.1	26.1	73.7	149.5	362.6
02ZL003	10.80	42	49	9	100	12.9	36.1	75.7	65.8	46.9
02ZG004	42.70	35	47	18	92	3.9	-2.1	-5.5	9.9	63.5
02ZH002	43.30	40	50	10	92	24.7	40.5	99.5	140.7	174.1
02ZN001	53.30	8	79	13	100	-30.6	-34.6	-42.6	-44.3	-43.3
02ZM009	53.60	37	50	13	100	-46.9	-49.1	-51.3	-47.9	-38.6
02ZA002	72.00	82	13	5	43	14.6	6.8	-6.6	-5.6	4.4
02ZK002	89.60	47	23	30	81	-32.6	-30.9	-25.4	-21.4	-17.3
02ZG003	115.00	16	72	12	92	62.2	53.6	45.7	61.8	110.6
02ZA003	139.00	68	19	13	73	-25.2	-28.7	-44.9	-55.0	-62.1
02ZG002	166.00	38	49	13	92	-16.6	-17.3	-16.6	-12.8	-6.5
02ZG001	205.00	26	64	10	96	-6.2	-5.0	7.6	28.6	68.1
02ZB001	205.01	9	78	13	60	44.3	46.0	44.6	38.8	31.9
02ZC002	230.00	17	79	4	34	21.3	18.4	10.7	7.2	5.5
02ZK001	285.00	51	37	12	55	21.6	27.8	48.1	61.3	72.2
02YS003	36.70	84	1	16	100	-30.2	-26.7	-28.6	-48.1	-81.7
02YP001	63.80	87	1	13	79	-26.8	-27.8	-26.7	-23.8	-9.5
02ZJ001	67.40	82	3	15	86	21.6	55.8	189.8	214.1	48.8
02YM003	93.20	90	1	10	56	107.7	184.6	595.4	915.5	623.6
02YO006	177.00	82	2	16	97	8.4	2.5	-18.5	-42.2	-78.2
02YD002	200.00	83	1	17	99	-13.6	8.7	86.2	86.7	-18.2
02YR001	267.00	75	1	24	98	-28.9	-23.3	-14.1	-28.8	-71.1
02YR002	399.00	68	1	32	96	94.1	150.7	374.9	419.5	147.5
02YR003	554.00	69	1	31	97	-39.9	-41.8	-43.7	-41.6	-4.6
02YD001	237.00	81	11	8	73	0.7	-0.9	3.0	12.8	27.9
02ZA001	343.00	60	30	10	83	31.5	30.0	26.4	25.1	24.4
02YK005	391.00	68	15	17	94	8.1	11.6	29.3	46.3	65.4
02YN002	469.00	22	62	16	100	19.2	17.4	6.9	-0.5	-6.2
02YK002	470.00	55	29	16	100	-9.8	-8.4	0.6	10.3	21.5
02YK004	529.00	35	29	36	95	-5.8	-5.1	0.6	6.8	13.6
02YF001	611.00	69	18	13	100	35.3	44.3	87.7	132.3	188.0
02YC001	624.00	33	50	17	99	-34.2	-36.3	-40.9	-42.4	-43.2
02YJ001	640.00	79	7	14	75	-19.3	-17.8	-18.0	-20.4	-23.0

* Notes

Delta X (%) = 100 * (Regression Estimates of X – Frequency Estimate of X) / (Frequency Estimate of X)

Table 4.14 Percentage Difference Between Frequency and Regression Estimates of 30-day Low Flows

Station Number	DA (km^2)	FAR (%)	BAR (%)	LSAR (%)	ACLS (%)	Delta Beta (%)	Delta Q2 (%)	Delta Q5 (%)	Delta Q10 (%)	Delta Q20 (%)
02ZM006	3.90	75	4	21	100	16.9	28.2	97.4	210.2	543.0
02ZL003	10.80	42	49	9	100	20.7	37.1	36.0	15.4	-1.7
02ZG004	42.70	35	47	18	92	-10.2	-16.1	-17.7	4.5	122.4
02ZH002	43.30	40	50	10	92	6.0	20.2	79.7	131.2	186.1
02ZN001	53.30	8	79	13	100	-21.2	-24.8	-31.2	-31.8	-29.5
02ZM009	53.60	37	50	13	100	-42.5	-45.6	-49.0	-45.3	-34.7
02ZA002	72.00	82	13	5	43	29.8	18.6	-1.5	-4.6	0.7
02ZK002	89.60	47	23	30	81	-26.0	-24.5	-21.1	-20.3	-20.3
02ZG003	115.00	16	72	12	92	27.2	24.3	30.9	54.6	112.0
02ZA003	139.00	68	19	13	73	-20.6	-23.9	-36.0	-43.9	-49.8
02ZG002	166.00	38	49	13	92	-6.8	-7.5	-4.0	3.4	15.7
02ZG001	205.00	26	64	10	96	5.5	3.5	9.4	28.6	72.5
02ZB001	205.01	9	78	13	60	14.2	16.2	20.7	21.7	21.8
02ZC002	230.00	17	79	4	34	21.3	19.3	4.0	-8.4	-18.4
02ZK001	285.00	51	37	12	55	23.0	29.7	53.3	69.7	84.8
02YS003	36.70	84	1	16	100	-27.1	-21.0	-17.8	-37.6	-71.5
02YP001	63.80	87	1	13	79	-20.8	-22.6	-18.6	0.9	ERR
02ZJ001	67.40	82	3	15	86	38.3	92.9	312.9	318.2	114.1
02YM003	93.20	90	1	10	56	64.5	118.1	448.7	988.8	7317.1
02YO006	177.00	82	2	16	97	-1.8	-7.4	-22.9	-37.7	-64.0
02YD002	200.00	83	1	17	99	-17.2	-0.8	68.5	109.5	79.3
02YR001	267.00	75	1	24	98	-23.9	-16.6	0.4	-8.7	-49.2
02YR002	399.00	68	1	32	96	93.9	152.1	406.3	502.3	295.1
02YR003	554.00	69	1	31	97	-35.8	-38.4	-41.5	-40.3	-28.5
02YD001	237.00	81	11	8	73	-8.3	-5.8	9.6	25.5	43.4
02ZA001	343.00	60	30	10	83	31.1	33.1	42.4	49.8	56.4
02YK005	391.00	68	15	17	94	18.6	21.1	38.7	58.1	80.6
02YN002	469.00	22	62	16	100	11.8	7.8	0.1	-1.8	-2.3
02YK002	470.00	55	29	16	100	-10.8	-8.2	5.3	17.8	30.6
02YK004	529.00	35	29	36	95	8.5	8.6	13.3	19.0	24.7
02YF001	611.00	69	18	13	100	19.6	34.5	90.5	128.3	157.3
02YC001	624.00	33	50	17	99	-33.0	-35.3	-40.7	-42.8	-44.0
02YJ001	640.00	79	7	14	75	-16.5	-16.8	-18.7	-20.2	-21.5

* Notes

Delta X (%) = 100 * (Regression Estimates of X - Frequency Estimate of X) / (Frequency Estimate of X)

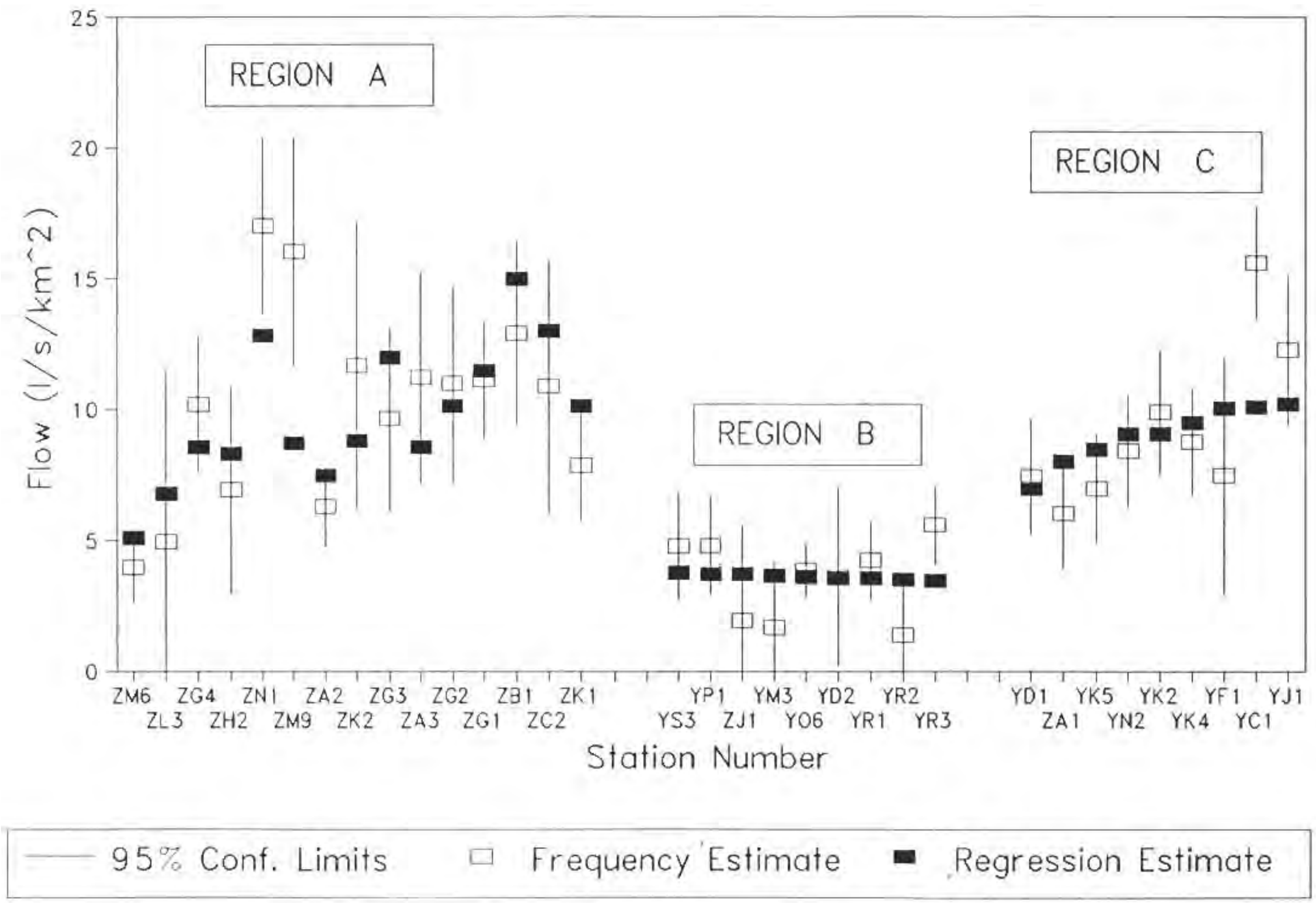

Figure 4.5 Comparison Between Frequency and Regression Estimates of the Two-Year 30-day Low Flows.

4. Most of the regression estimates fall between the 95% confidence limits of the frequency estimates. The exceptions are those for stations 02ZN001, 02ZM009, 02YR003 and 02YC001. At the first two stations, the mean annual runoff is in excess of 1800 mm. The average for the region (Region A) is about 1400 mm. Since mean annual runoff is not used as a predictive parameter, only as a parameter which defines a region and is implicitly constant at the average value for that region, therefore, the regression equations will underestimate the low flows. At station 02YR003, there is a discontinuity in the flow duration curve (see Figure A.20) at very low flows. It is postulated that the low flows used in the frequency analysis were probably not good estimates. At station 02YC001, the frequency estimates used in the regression analysis were those from summer low flow series, which were higher than the winter low flow frequency estimates (see Section 4.4.1). At most of the other stations in the region (Region C), the summer low flow estimates were lower than the winter low flow estimates. Hence, regression equations derived for this region will underestimate the summer low flow estimates at 02YC001, which is the case as shown in Figure 4.5.

4.8 Comment on Results of Regression Analysis

The objective of the regression analysis was to derive equations which could be used to estimate low flows of various durations and return periods at ungauged sections of rivers. A review of the literature on regression analysis of low flows indicates that very often the results have been disappointing. While the results obtained during this study are not very good, they may, if used with some care, be useful for estimating low flow estimates. In the analysis of low flows, the estimates of low flows are very close in magnitude to the errors possible in estimating them. Hence, the percentage differences between frequency estimates and regression estimates are large.

Chapter 5

APPLICATION OF REGRESSION EQUATIONS ON TEST WATERSHEDS

5.1 Introduction

In the preceding chapter, the regression equations were used to estimate low flows from watersheds whose data had been used in the derivation of the regression equations. While the comparison between the frequency and regression estimates was useful, a more objective test of the regression equations is to apply them on watersheds for which low flow frequency estimates are available but which were not used in the derivation of the equations.

5.2 Description of Test Watersheds

Since all the watersheds with relatively long periods of flow data were used in the derivation of the equations, therefore, the gauged watersheds chosen as test watersheds had relatively short periods of daily flow record. Twenty-one such basins were identified on the Island. Except for one watershed on which eleven years of daily flow data were available, on the others the daily flow record lengths were between four years and seven years. At five stations, only four years of data were available. Table 5.1 lists the watersheds, lengths of flow record, drainage areas and percentage of forest area where applicable. The locations of the watersheds are shown in Figure 5.1.

5.3 N-day Low Flows and their Frequency Estimates

5.3.1 N-day Low Flows

The 1-day and 30-day low flows for the summer and winter seasons for the period of stream flow record were determined for each test watershed. Out of the 21 watersheds, 3 watersheds had their winter low flows more critical than the summer low flows. These series were at stations 02YA002, 02YJ002 and 02YE001, all of them located in the Northern Peninsula - Humber Valley region. Since the regression equations are based on the summer frequency estimates of low flows for all regions, therefore, the summer frequency estimates of low flows from these stations were used for comparison with the estimates from the regression equations.

Table 5.1 Characteristics of Test Watersheds

Station Number	Station Name	Drainage Area (km^2)	Forested Area (%)	Record Length (Years)
02ZL005	Big Brook at Lead Cove	11.20		4
02ZN002	St. Shotts River Near Trepassey	15.50		5
02ZM016	South River Near Holyrood	17.30	8	7
02ZL004	Shearstown Brook at Sherastown	28.90	52	7
02ZK003	Little Barachois River Near Placentia	37.20	84	7
02ZK005	Trout Brook Near Bellevue	50.30		4
02ZK004	Little Salmonier River Near North Harbour	106.70	24	7
02YO010	Junction Brook Near Badger	61.60		5
02ZJ002	Salmon Cove River Near Champneys	73.60		7
02YO007	Leech Brook Near Grand Falls	88.30		6
02ZJ003	Shoal Harbour River Near Clarenville	106.00		5
02YO008	Great Rattling Brook Above Tote River Confluence	823.00		6
02YL005	Rattler Brook Near McIvers	17.00		5
02YK008	Boot Brook at Trans-Canada Highway	20.40		4
02YH001	Bottom Creek Near Rocky Harbour	33.40		4
02YA002	Bartletts River Near St. Anthony	33.60		4
02YL004	South Brook at Pasadena	58.50		7
02YE001	Greavett Brook Above Portland Creek Pond	95.70		6
02YK007	Glide Brook Below Glide Lake	112.00		6
02YJ003	Pinchgut Brook at Outlet of Pinchgut Lake	119.00		4
02YJ002	Blanche Brook Near Stephenville	120.00		11

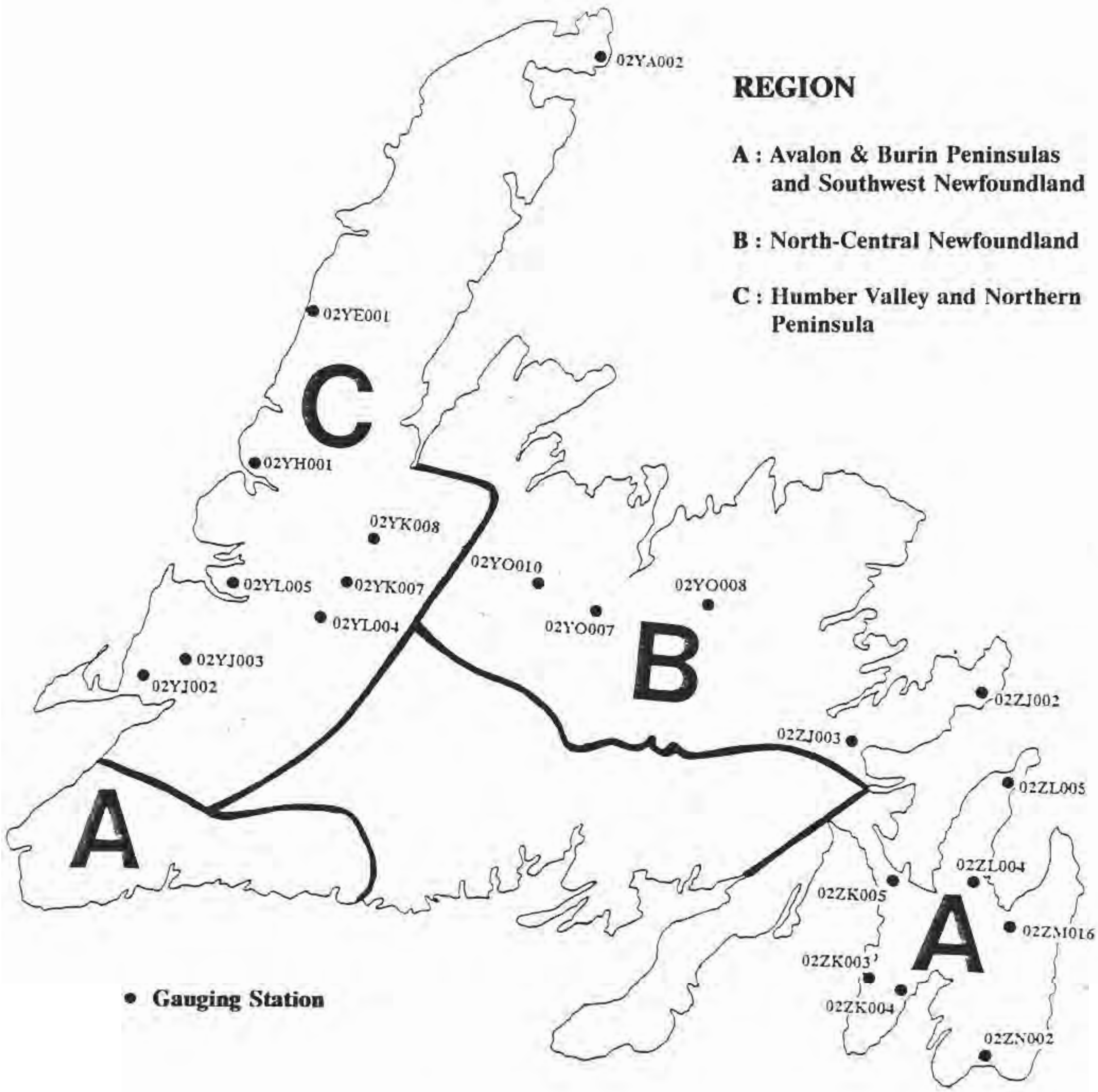

Figure 5.1 Locations of Test Watersheds

5.3.2 Frequency Analysis

The frequency analysis of the summer 1-day and 30-day low flow series for each station was carried out in a similar fashion to that described in section 3.2, that is, the LFA program was used to fit the Gumbel Type III distribution to the low flow series. Since most of the low flow series had less than 7 members, only the 2-year and 10-year frequency estimates of low flows were determined. The 2-year and 10-year frequency estimates for the summer 1-day and 30-day low flow series at the 21 test watersheds are shown in Table 5.2.

5.4 Application of Regression Equations

5.4.1 Application Criteria

The application of the regression equations was subject to the conditions described in Section 4.6.3.

The first step was to choose the appropriate regional equations to use. According to Figure 5.1, seven of the basins were in region A, five in region B and nine in region C.

The second step was to determine if the area of each watershed was within the limits set for its region. Based on this second criterion, all seven watersheds in region A satisfied the drainage area limits requirement, one watershed (02YO008) with an area of 823 km^2 out of five watersheds in region B was outside the drainage area limits for the region and all nine watersheds in region C had drainage areas which were less than the lower limit for the region. The equations of region B were still applied to watershed 02YO008 to determine the regression estimates of low flows even if its drainage was outside the limits for application. Similarly, for region C, the regional regression equations were still applied even though all areas of watersheds were below the lower limit.

The third criterion for applying the regional equations was the percentage of forested area, or alternatively, the percentage of barren area. Data on percentage of forested areas were not available for most watersheds in Region A and all watersheds in regions B and C. Visual inspection of the watersheds on 1:50,000 topographic maps indicated that the forest area criterion on each watershed in each region was satisfied.

For watersheds in region A the regression equations which did not use "percentage of forest area" were used for estimating low flows. For watersheds in regions B and C, the corresponding regional regression equations were used.

Table 5.2 Frequency Estimates of Low Flows on Test Watersheds

Station Number	Drainage Area	1-day			30-day		
		Mean	Q2	Q10	Mean	Q2	Q10
	(km^2)	(m^3/s)			(m^3/s)		
02ZL005	11.20	0.03	0.0306	0.0025	0.04	0.0457	0.0147
02ZN002	15.50	0.12	0.1340	0.0612	0.28	0.2940	0.0967
02ZM016	17.30	0.11	0.1180	0.0553	0.20	0.1950	0.1110
02ZL004	28.90	0.11	0.1090	0.0406	0.18	0.1830	0.0684
02ZK003	37.20	0.25	0.2490	0.1630	0.42	0.4080	0.2850
02ZK005	50.30	0.14	0.1390	0.0257	0.26	0.2240	0.1050
02ZK004	106.70	0.50	0.5410	0.2180	1.13	1.0740	0.4820
02YO010	61.60	0.05	0.0377	0.0000	0.12	0.1290	0.0268
02ZJ002	73.60	0.18	0.1420	0.0125	0.32	0.2960	0.0485
02YO007	88.30	0.06	0.0613	0.0164	0.23	0.2550	0.0640
02ZJ003	106.00	0.12	0.0907	0.0280	0.23	0.2030	0.0522
02YO008	823.00	1.35	1.3990	0.2060	2.56	2.6270	0.5910
02YL005	17.00	0.01	0.0074	0.0046	0.04	0.0453	0.0112
02YK008	20.40	0.01	0.0116	0.0023	0.04	0.0436	0.0084
02YH001	33.40	0.08	0.0662	0.0394	0.16	0.1600	0.0610
02YA002	33.60	0.09	0.0856	0.0535	0.23	0.2340	0.0920
02YL004	58.50	0.22	0.2110	0.1400	0.33	0.3210	0.2030
02YE001	95.70	0.66	0.6450	0.4040	1.26	1.1610	0.9620
02YK007	112.00	0.16	0.1690	0.0401	0.29	0.3160	0.1220
02YJ003	119.00	0.43	0.4260	0.1300	0.69	0.7130	0.2090
02YJ002	120.00	0.62	0.5770	0.3380	1.26	1.1080	0.5590

5.4.2 Results

The results of applying the regression equations to the test watersheds together with the frequency estimates of the 2-year and 10-year 30-day low flows are shown in Table 5.3. Also included in Table 5.3 are the percentage differences between the frequency and regression estimates. Figure 5.2 shows a plot of regression and frequency estimates together with the confidence limits for the 2-year frequency estimates for the 30-day low flow series.

5.5 Discussion of Results

Region A

The results indicate that for region A the regression estimates were outside the 95% confidence limits of the frequency estimates in two cases: at gauging stations 02ZN002 and 02ZK005. These two cases illustrate the effect of ignoring precipitation patterns. At gauging station 02ZN002, the mean annual runoff is about 1800 mm, while, at gauging station 02ZK005 the mean annual runoff is about 1000 mm. These values represent the upper and lower limits of the range of mean annual runoff in region A. The precipitations at these two stations follow the same patterns. Since precipitation and runoff were not included in the development of the regression equations, therefore, they were implicitly assumed to be constants for the region. Whenever watersheds are located in these subareas at the extreme ranges of precipitation patterns, large discrepancies between regression and frequency estimates can be expected.

Region B

The results in Table 5.3 show that whenever the frequency estimates are very low, the percentage difference between frequency and regression estimates is very large. In such cases, the difference between frequency and regression estimates is almost equal to the frequency estimate itself.

Region C

All the test watersheds were smaller than the lower limit on drainage area for this region. Figure 5.2 shows that there were two cases when the regression estimates were outside the 95% confidence limits of the frequency estimates: stations 02YE001 and 02YJ002. In both cases the regression estimates were underestimates.

Table 5.3 Performance of Regression Equations on Test Watersheds

Station Number	Region	Drainage Area	1-DAY				30-DAY				1 - Day		30 - Day	
			Q2	E_Q2	Q10	E_Q10	Q2	E_Q2	Q10	E_Q10	Delta Q2	Delta Q10	Delta Q2	Delta Q10
		(km^2)	(m^3/s)								%			
02ZL005	A*	11.20	0.031	0.033	0.003	0.015	0.046	0.074	0.015	0.035	8	517	61	137
02ZN002	A*	15.50	0.134	0.049	0.061	0.023	0.294	0.109	0.097	0.051	-63	-63	-63	-47
02ZM016	A*	17.30	0.118	0.056	0.055	0.026	0.195	0.124	0.111	0.058	-53	-53	-36	-47
02ZL004	A*	28.90	0.109	0.104	0.041	0.049	0.183	0.228	0.068	0.108	-4	20	25	57
02ZK003	A*	37.20	0.249	0.141	0.163	0.066	0.408	0.308	0.285	0.145	-43	-60	-24	-49
02ZK005	A*	50.30	0.139	0.204	0.026	0.095	0.224	0.442	0.105	0.208	46	269	97	98
02ZK004	A*	106.70	0.541	0.506	0.218	0.236	1.074	1.083	0.482	0.511	-7	8	1	6
02YO010	B	61.60	0.038	0.107	0.000	0.028	0.129	0.228	0.027	0.076	184	ERR	77	183
02ZJ002	B	73.60	0.142	0.200	0.013	0.118	0.296	0.328	0.049	0.198	41	842	11	309
02YO007	B	88.30	0.061	0.164	0.016	0.043	0.255	0.323	0.064	0.107	167	163	27	68
02ZJ003	B	106.00	0.091	0.337	0.028	0.198	0.203	0.543	0.052	0.328	272	608	168	529
02YO008	B	823.00	1.399	2.241	0.206	0.591	2.627	2.790	0.591	0.929	60	187	6	57
02YL005	C	17.00	0.007	0.025	0.005	0.014	0.045	0.043	0.011	0.026	233	215	-5	133
02YK008	C	20.40	0.012	0.032	0.002	0.019	0.044	0.056	0.008	0.034	175	717	28	300
02YH001	C	33.40	0.066	0.065	0.039	0.038	0.160	0.110	0.061	0.066	-2	-3	-31	9
02YA002	C	33.60	0.086	0.065	0.054	0.038	0.234	0.111	0.092	0.067	-24	-28	-53	-27
02YL004	C	58.50	0.211	0.144	0.140	0.085	0.321	0.239	0.203	0.144	-32	-39	-26	-29
02YE001	C	95.70	0.645	0.291	0.404	0.171	1.161	0.472	0.962	0.285	-55	-58	-59	-70
02YK007	C	112.00	0.169	0.365	0.040	0.215	0.316	0.586	0.122	0.354	116	435	86	190
02YJ003	C	119.00	0.426	0.398	0.130	0.234	0.713	0.637	0.209	0.385	-7	80	-11	84
02YJ002	C	120.00	0.577	0.402	0.338	0.237	1.108	0.645	0.559	0.390	-30	-30	-42	-30

* Notes

Regression Equations for Region A had Only the Drainage Area as the Independent Variable

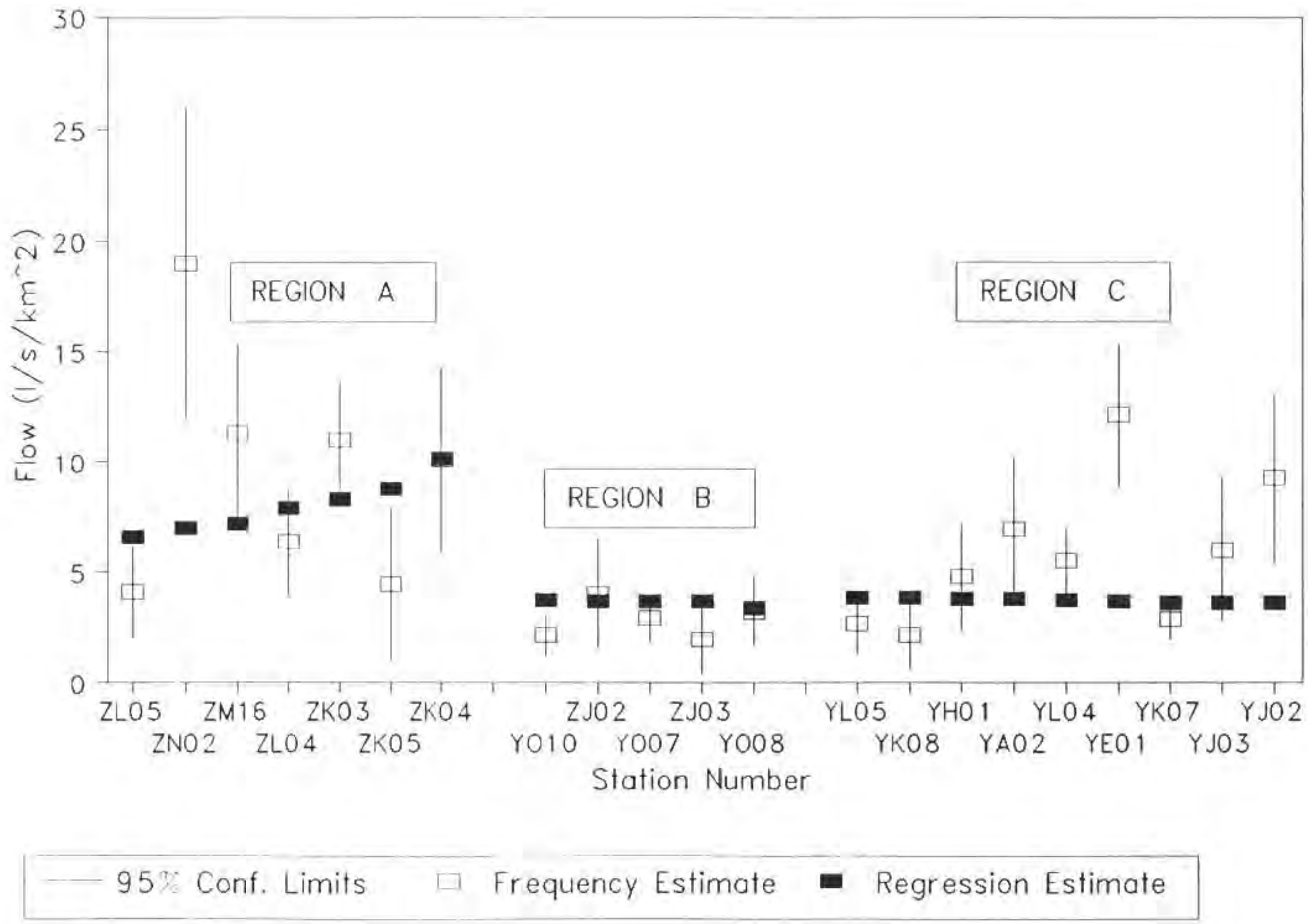

Figure 5.2 Comparison Between Frequency and Regression Estimates of the Two-Year 30-day Low Flows on the Test Watersheds.

The following hypotheses are offered as explanations for the large discrepancy between the frequency and regression estimates. Station 02YJ002 is located downstream of a lake on which there is an uncontrolled weir. Since the lake is of a significant size, it regulates the flow by dampening high flows and increasing low flows. Hence, the frequency estimates at 02YJ002 may be artificially high. Station 02YE001 is located just upstream of a lake which is also fed by another stream with a larger and steeper drainage area than at 02YE001. It is possible that the changes in level of water in the lake caused by inflow from the other stream affects the water level readings at 02YE001. The effect will be to give a higher than natural level. Hence, in this case also, the frequency estimates will be higher than naturally expected.

5.6 Comment on Tests of Regression Equations

The regression estimates on the test watersheds were not very satisfactory, but can be considered reasonable, given that the frequency estimates were based on four years of data in some cases and that in region C the areas of all the test watersheds were outside the limits for applying the equations for region C. The conclusion is that the regression equations can be used to obtain estimates of low flows of various durations. However, the results obtained should always be compared with low flow frequency estimates from nearby gauged watersheds, and "large" discrepancies investigated.

Chapter 6

SUMMARY AND RECOMMENDATIONS

6.1 Summary

The objectives of the low flow analysis were to: (1) characterise low flows in streams across the Island and (2) develop equations which could be used to calculate low flows of various return periods at ungauged sections of rivers.

The unit mean annual river flows on the Island vary between 0.023 $m^3/s/km^2$ and 0.066 $m^3/s/km^2$, the lower values of the range occurring on the north - central region and the higher values of the range occurring on the southwestern corner of the Island.

Unit mean monthly flows show large variations, both temporally and spatially. They range from 0.005 $m^3/s/km^2$ to 0.158 $m^3/s/km^2$ depending on month of year and region. Watersheds on the Avalon and Burin Peninsulas and on the southwestern region of the Island have the highest yields and those on the north - central region of the Island have the lowest yields. Two low flow periods were selected for analytical purposes: one during the winter season between January and March and the other during the summer season between July and September.

At each of the 39 gauging stations selected for the study, daily flows over the period of record were analyzed to obtain the minimum N-day low flows during the winter and summer seasons. The durations, N, of the low flow periods were 1, 7, 15 and 30 days. The minimum low flows ranged between 0 $l/s/km^2$ and 11 $l/s/km^2$. On the eastern and north - central regions of the Island, summer minimum low flows were smaller than winter minimum low flows.

The Gumbel Type III distribution was fitted to the summer and winter low flow series. At 6 of the 39 gauging stations, the winter frequency estimates of low flows were smaller than the corresponding summer estimates: three were located on the northern tip of the Northern Peninsula and the other three were on the southwestern corner of the Island. The average mean per unit area of the summer 1-day low flow series was 5.4 $l/s/km^2$ on the Avalon and

Burin Peninsulas, 3.1 $l/s/km^2$ on the north - central part of the Island, 4.7 $l/s/km^2$ on the Northern Peninsula and 5.1 $l/s/km^2$ on the southwestern corner of the Island. The corresponding values for the summer 30-day low flow series were 11 $l/s/km^2$, 7.3 $l/s/km^2$, 5 $l/s/km^2$ and 10.5 $l/s/km^2$.

The coefficients of skewness ranged from -0.56 to 2.5 for the winter low flow series. For the summer low flow series the range was from -1.0 to 2.9. Of the 156 winter low flow series, 10 had a negative coefficient of skewness. Of the 156 summer low flow series, 27 had a negative coefficient of skewness. Most of the latter series were for watersheds less than 100 km^2 in area.

Of the 156 winter series, 9 had a finite probability of zero flows; for the summer low flow series the number was 35. The average ratio of the 2-year low flow to the 50-year low flow was 3.1 for the winter 1-day low flow series, 2.7 for the winter 30-day low flow series, 7.3 for the summer 1-day low flow series and 5.0 for the summer 30-day low flow series.

Summer low flows, therefore, are generally lower than the winter low flows and are more likely to reach zero values and exhibit relative high variance.

Regression analysis between frequency estimates of low flows and watershed parameters was carried out separately in three regions of the Island. These regions were hydrologically, climatically and physiographically distinct from one another. They were: [1] Region A comprised the Avalon and Burin Peninsulas and the southwestern region of the Island. The main characteristics of the region were: drainage areas were less than 285 km^2, average percentage of watershed covered by barrens was about 45% and the mean annual runoff ranged from 1000 mm to 2100 mm. [2] Region B was the north - central region of the Island. Its main characteristics were: drainage areas ranged from 30 km^2 and 600 km^2, average percentage of watershed covered by barren area was about 3% and mean annual runoff was between 700 mm and 900 mm. [3] Region C was the Humber Valley - Northern Peninsula area. The main characteristics in this region were: drainage areas were between 230 km^2 and 700 km^2, average percentage of watershed covered by barrens was about 20% and the mean annual runoff ranged from 1100 mm to 1400 mm.

The regression equations were developed in three stages: [1] For each of the three regions, the beta parameters of all the 30-day summer low series were correlated with the basin characteristics. In region A, the significant independent basin characteristics were drainage area and percentage of drainage area covered by forests. In regions B and C, drainage area was the only significant parameter in the regression equations. [2] For each region, the 30-day beta parameters were correlated with (a) the 1-day beta parameters, (b) the 7-day beta parameters and (c) the 15-day beta parameters. [3] Finally, for each region and for each low flow duration, the frequency estimates of successive return periods were correlated with the estimates of the previous return period, starting by correlating beta of a given duration with Q2, Q5 with Q2, etc. In this way, low flow estimates can be obtained for any region, any duration and return periods between 2 and 50 years.

The correlation coefficients for most of the equations were above 0.9. The percentage difference between frequency and regression estimates ranged between -50% and +50%, on the average. Some percentage differences were very high, over 100%; these occurred mostly when the frequency estimate was very close to zero, so that, the difference between the frequency and regression estimates was almost equal to the frequency estimate itself and hence the percentage difference between the two estimates was high.

The regression equations were tested on 21 watersheds for which some data were available but which were not used in the derivation of the equations. Results indicate that relatively high percentage differences between frequency and regression estimates can be expected, particularly, when the frequency estimates are close to zero.

6.2 Recommendations

These recommendations are primarily meant to address the twin problems of inadequacy of database on low flows and lack of information on effects of various physiographic and hydrometeorological components on the magnitudes of low flows in streams.

(1) The regression equations developed during this study give reasonable estimates of low flows at ungauged sections of streams in most cases. However, there are instances

when the regression estimates are either too high or too low. A prudent approach to estimating low flows is to compare the regression estimates with frequency estimates of low flows on similar watersheds in the vicinity of the ungauged watershed. The study has provided these estimates at 39 gauging stations where the data record exceed 8 years. It is recommended that every year this data base be updated and expanded. The growing database will provide a valuable reference for checking regression estimates.

(2) Winter low flows on watersheds in the northern half of the Northern Peninsula are lower than summer low flows. If recently added gauging stations, when sufficient data have been collected, support this observation, then, it is recommended that this area of the Island be designated as a distinct region. The regression analysis should then be repeated using only winter low flows.

(3) Winter low flows are also more critical on some of the watersheds in the southwestern corner of the Island. If this observation is supported by data from an expanded hydrometric network in the region, then, winter low flows in this region should be analyzed separately.

(4) In the Humber Valley - Northern Peninsula region, region C, all the watersheds included in the analysis of low flows were greater than 200 km^2 in area. Several gauging stations with drainage areas less than 100 km^2 have been set up recently. Within five years, these stations should have at least ten years of daily flow data. It is recommended that, at such time, the regression analysis be repeated to include a wider range of drainage areas.

(5) The results of the analysis indicate that magnitudes of low flows across the Island are very highly correlated with drainage area, precipitation amounts and type and extent of land cover. At present there have not been studies to physically model the interrelationship between the above-mentioned variables. It is recommended that experimental watersheds be set up in each of the three regions identified in this study. Precipitation-runoff modelling on these watersheds should give valuable information

on characteristics of flows during low flows periods. The information could also be used to improve on the regression equations.

(6) The accuracy of the frequency estimates depends very much on the amount of data available. On the other hand, the reliability of the regression analysis depends not only on the accuracy of the frequency estimates, but also, on the range of all parameters included in the analysis. Hence, estimates of low flows by regression analysis depends on amount and range of data. It is recommended that an analysis of the hydrometric network presently in existence be analyzed to identify gaps, both in terms inadequate record length and in coverage of parameters. The results of the analysis should provide the Division with a clearer view on where and by how much the network need to be improved.

APPENDIX A

DAILY FLOW DURATION CURVES AT GAUGING STATIONS

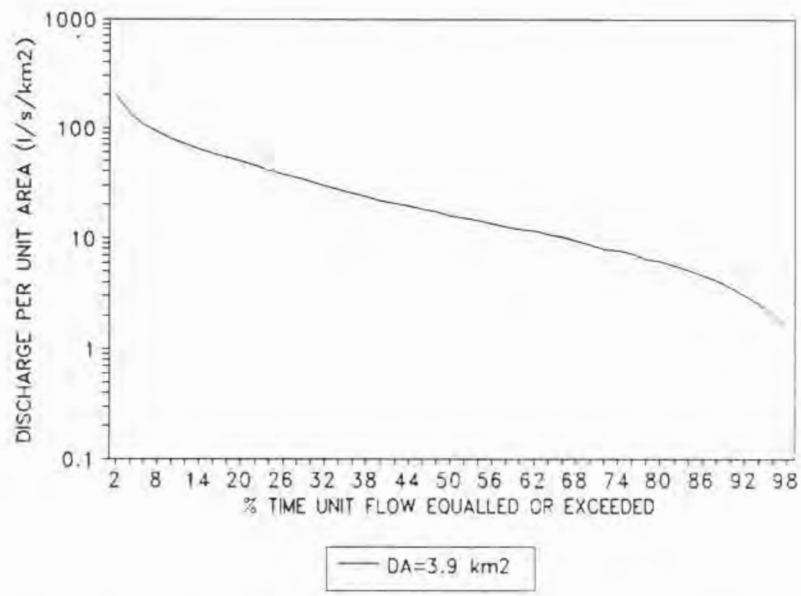

Figure A.1 Daily Flow Duration Curve at Gauging Station 02ZM006.

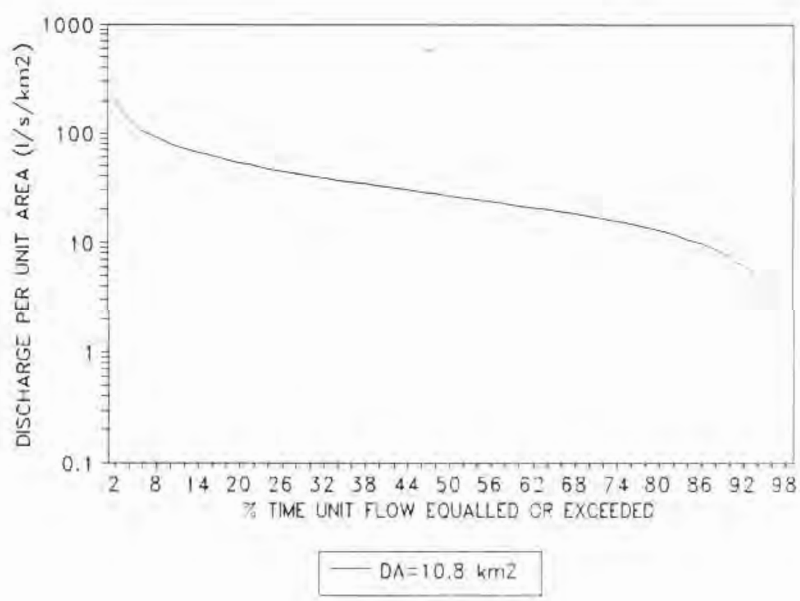

Figure A.2 Daily Flow Duration Curve at Gauging Station 02ZL003.

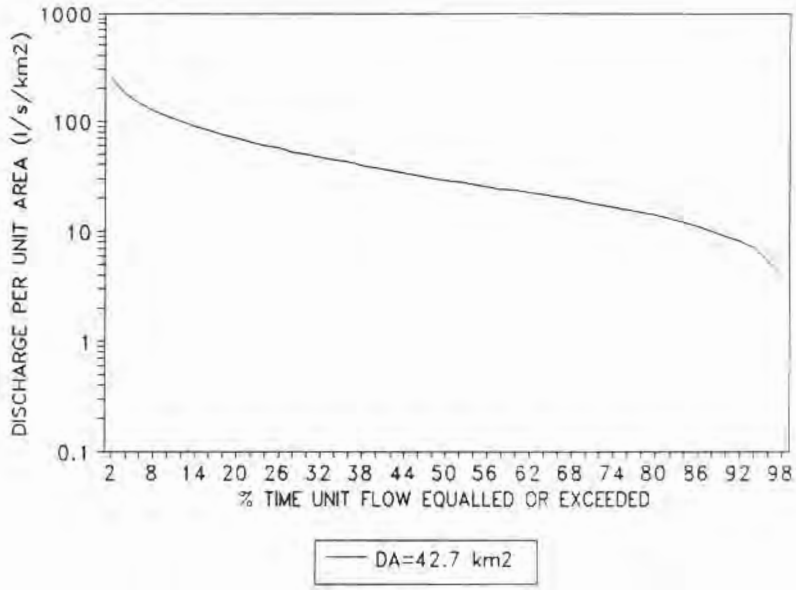

Figure A.3 Daily Flow Duration Curve at Gauging Station 02ZG004.

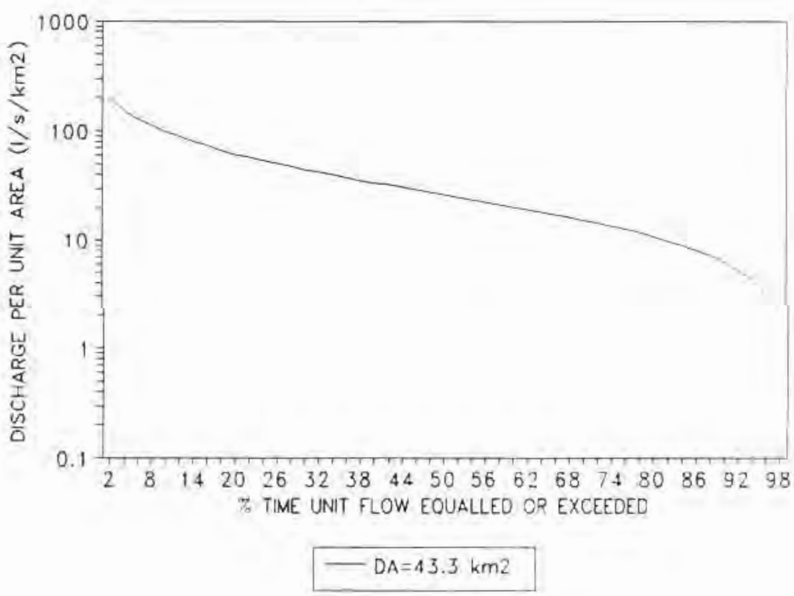

Figure A.4 Daily Flow Duration Curve at Gauging Station 02ZH002.

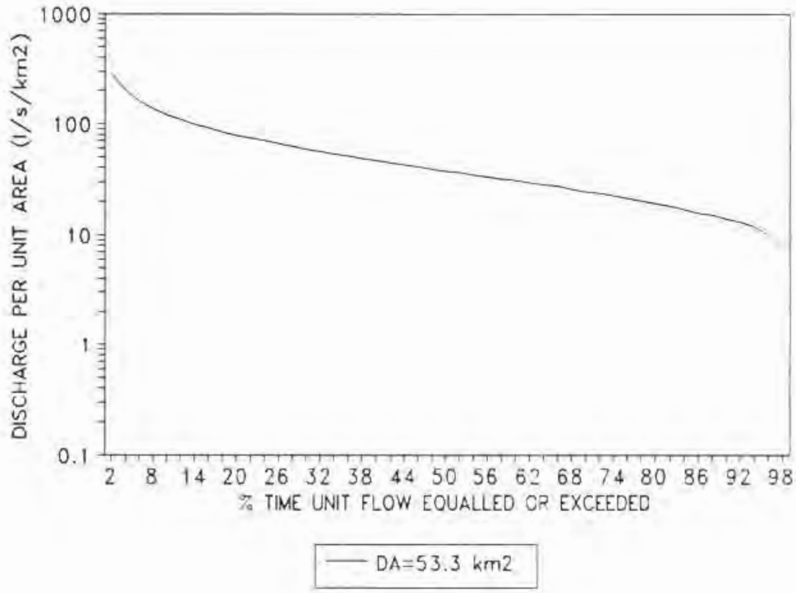

Figure A.5 Daily Flow Duration Curve at Gauging Station 02ZN001.

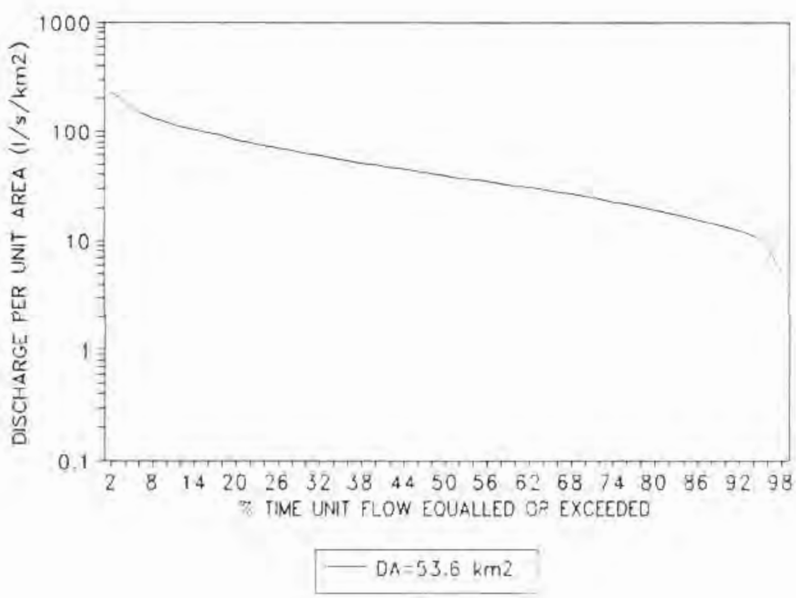

Figure A.6 Daily Flow Duration Curve at Gauging Station 02ZM009.

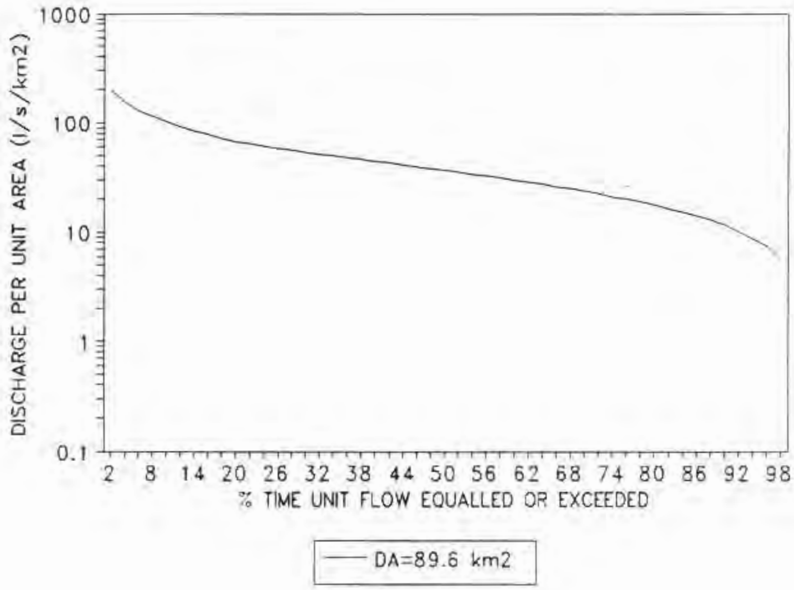

Figure A.7 Daily Flow Duration Curve at Gauging Station 02ZK002.

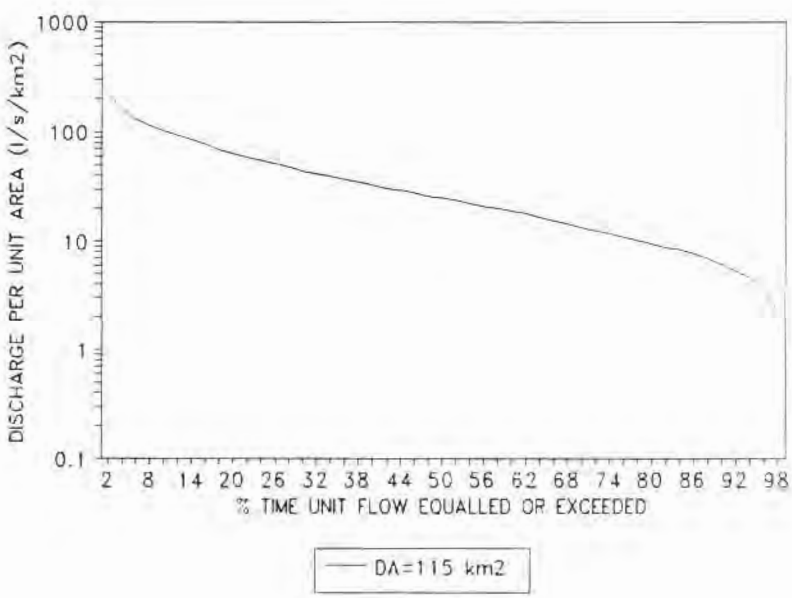

Figure A.8 Daily Flow Duration Curve at Gauging Station 02ZG003.

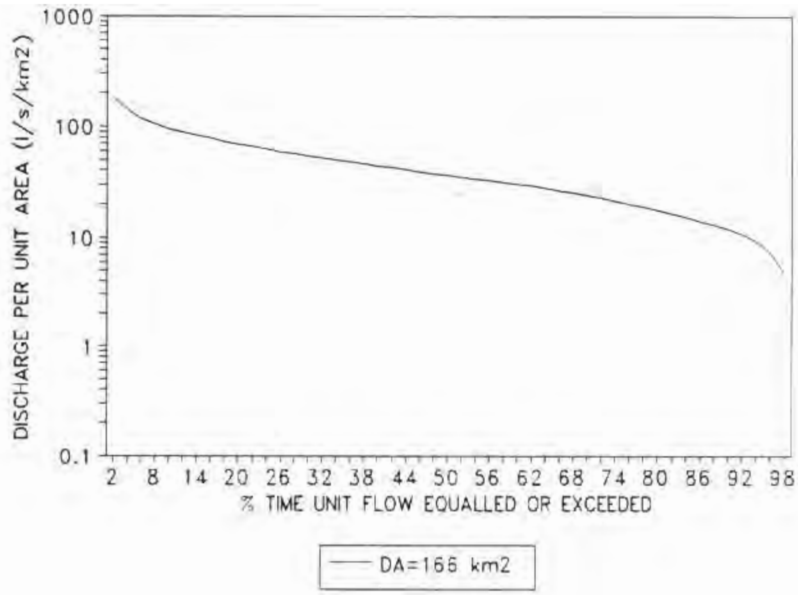

Figure A.9 Daily Flow Duration Curve at Gauging Station 02ZG002.

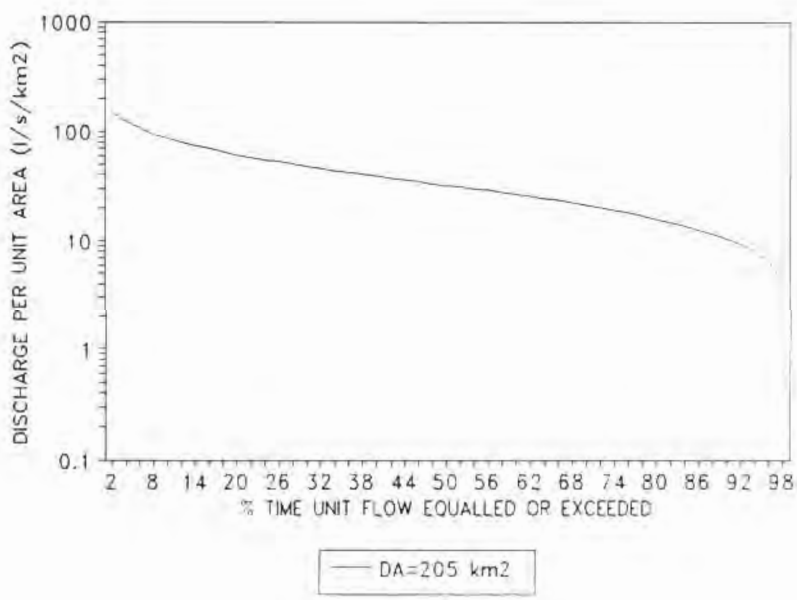

Figure A.10 Daily Flow Duration Curve at Gauging Station 02ZG001.

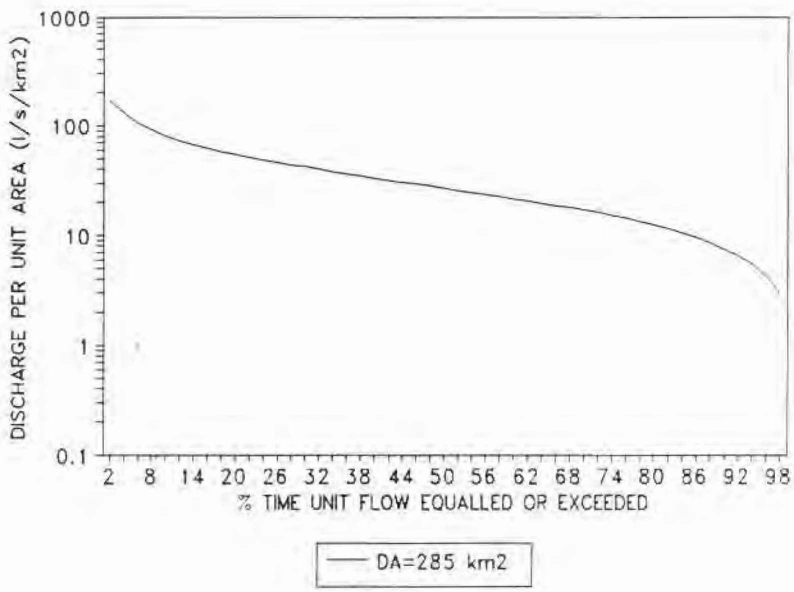

Figure A.11 Daily Flow Duration Curve at Gauging Station 02ZK001.

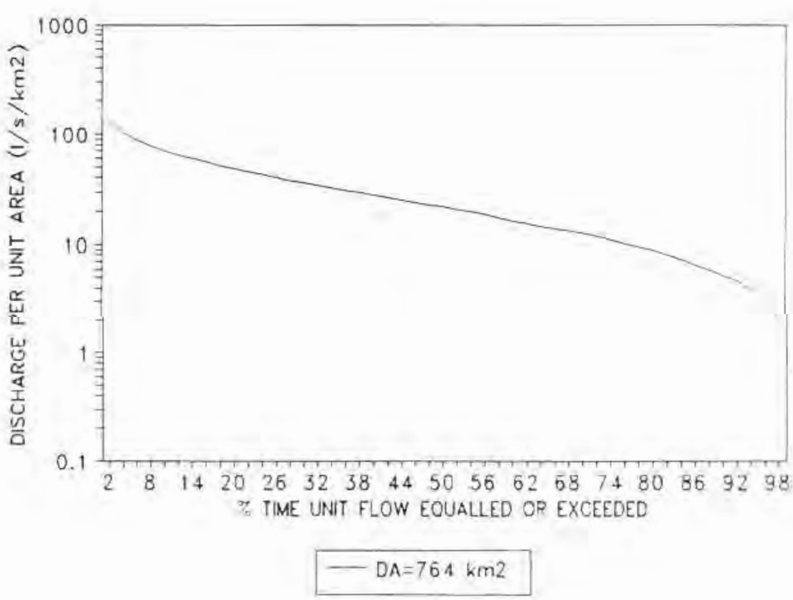

Figure A.12 Daily Flow Duration Curve at Gauging Station 02ZH001.

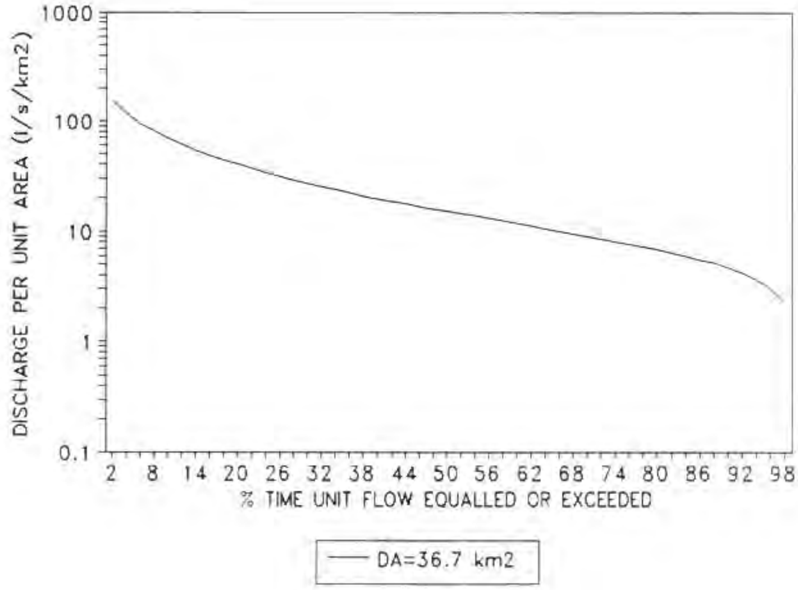

Figure A.13 Daily Flow Duration Curve at Gauging Station 02YS003.

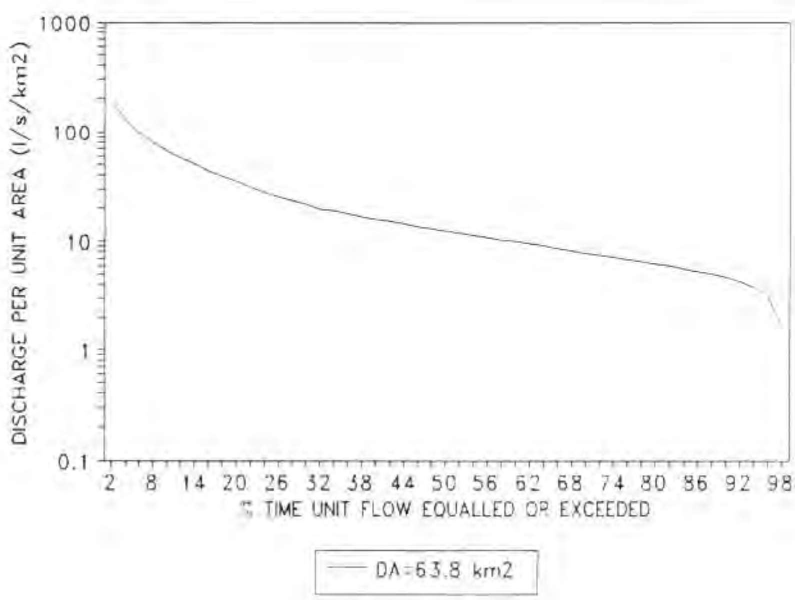

Figure A.14 Daily Flow Duration Curve at Gauging Station 02YP001.

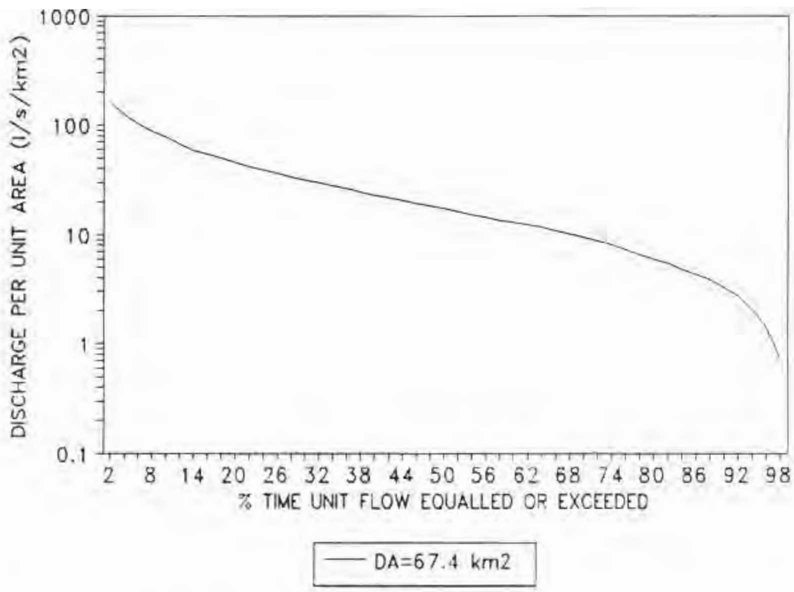

Figure A.15 Daily Flow Duration Curve at Gauging Station 02ZJ001.

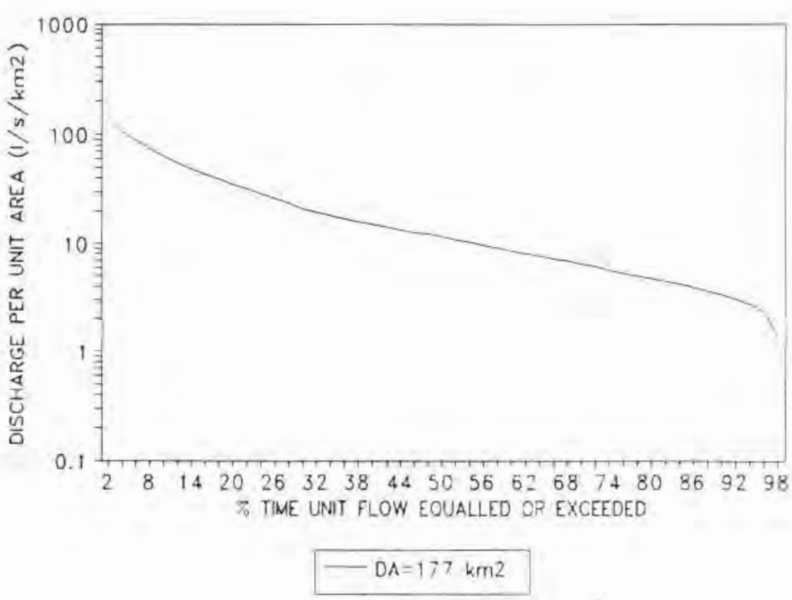

Figure A.16 Daily Flow Duration Curve at Gauging Station 02YO006.

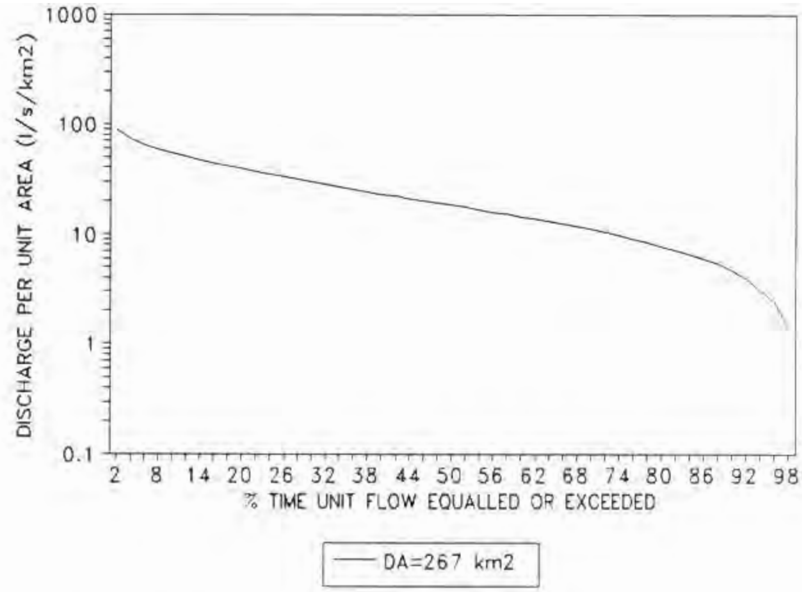

Figure A.17 Daily Flow Duration Curve at Gauging Station 02YR001.

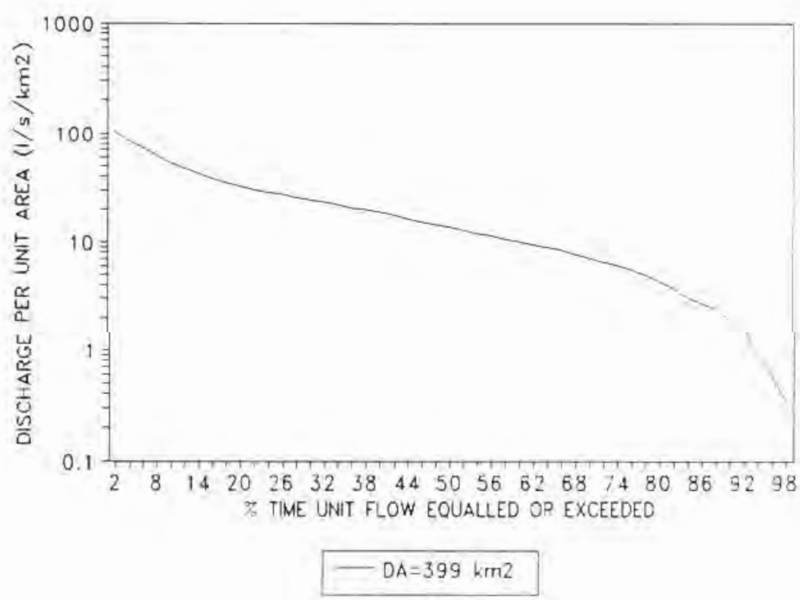

Figure A.18 Daily Flow Duration Curve at Gauging Station 02YR002.

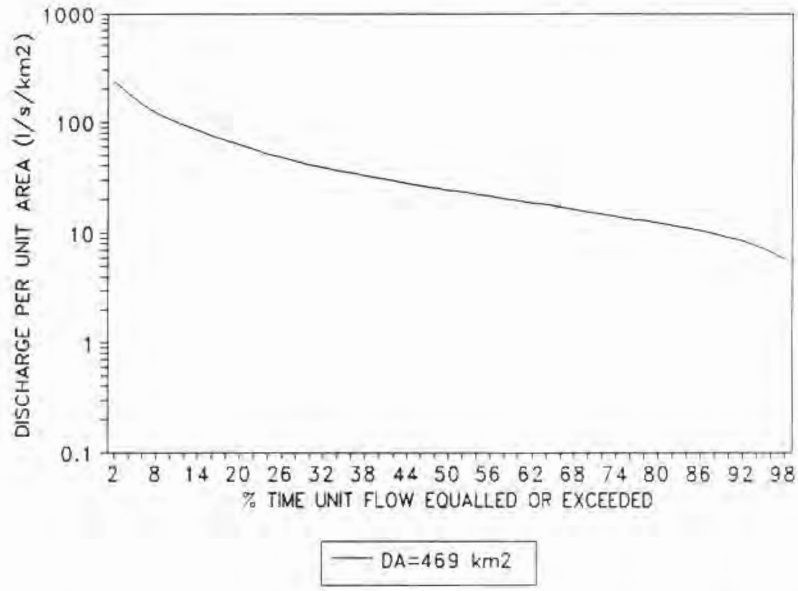

Figure A.19 Daily Flow Duration Curve at Gauging Station 02YN002.

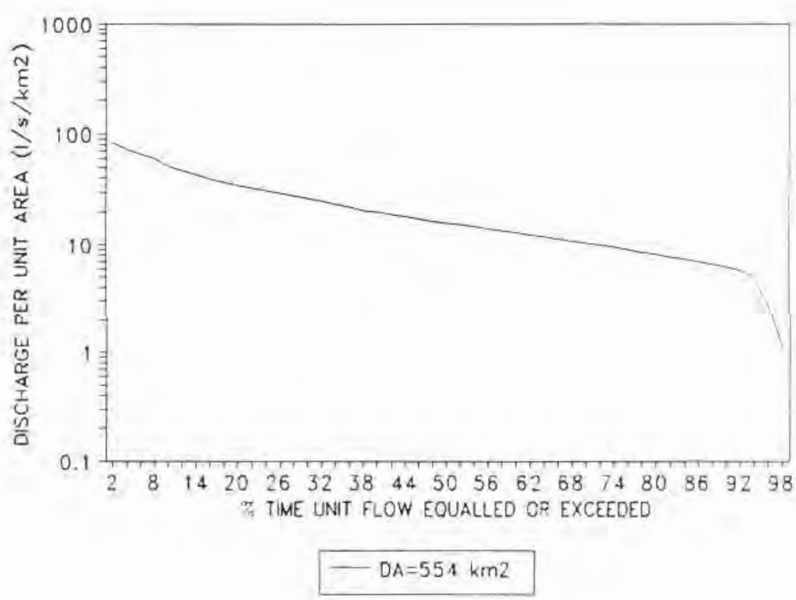

Figure A.20 Daily Flow Duration Curve at Gauging Station 02YR003.

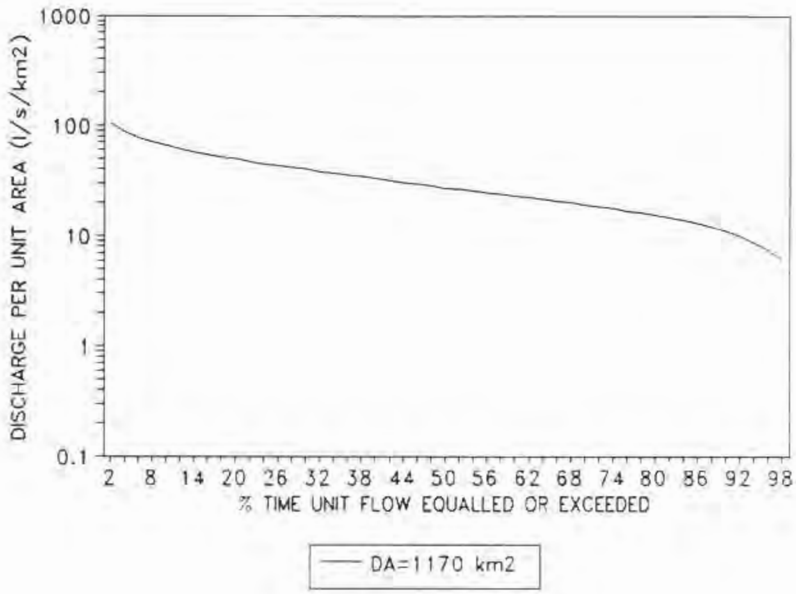

Figure A.21 Daily Flow Duration Curve at Gauging Station 02ZF001.

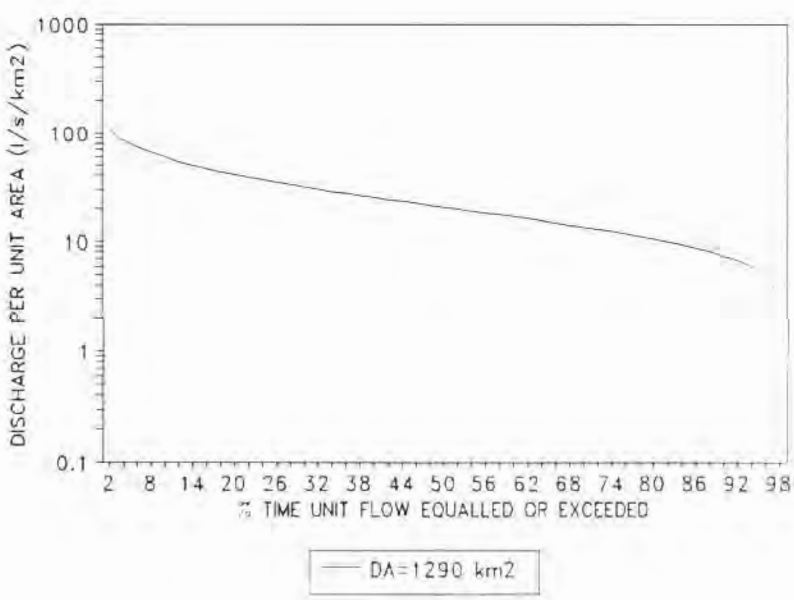

Figure A.22 Daily Flow Duration Curve at Gauging Station 02YS001.

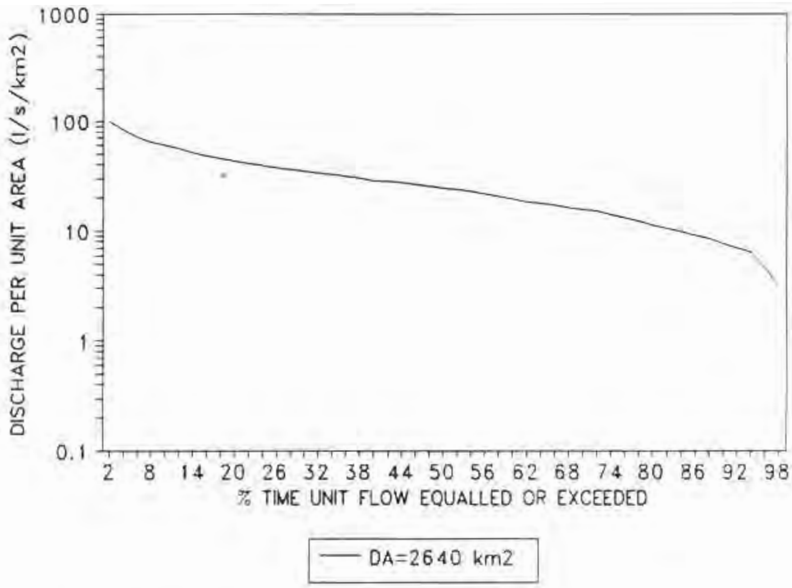

Figure A.23 Daily Flow Duration Curve at Gauging Station 02ZE001.

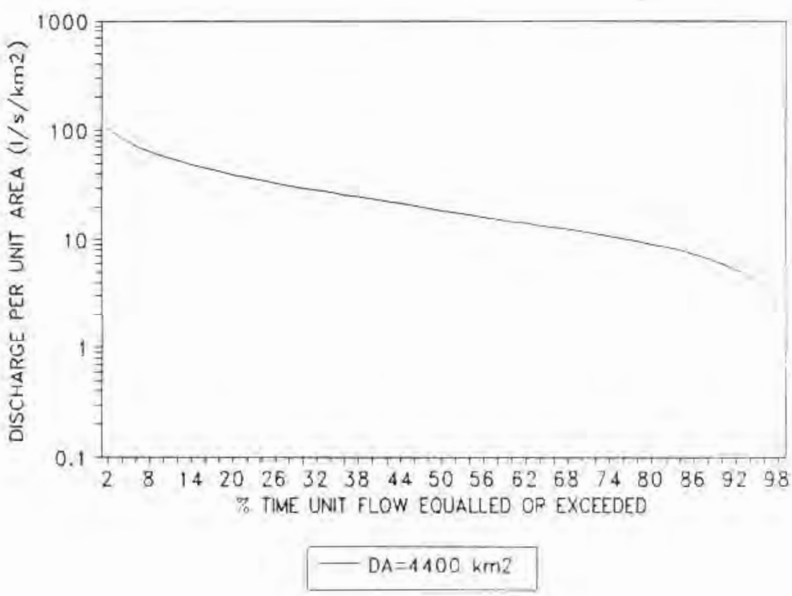

Figure A.24 Daily Flow Duration Curve at Gauging Station 02YQ001.

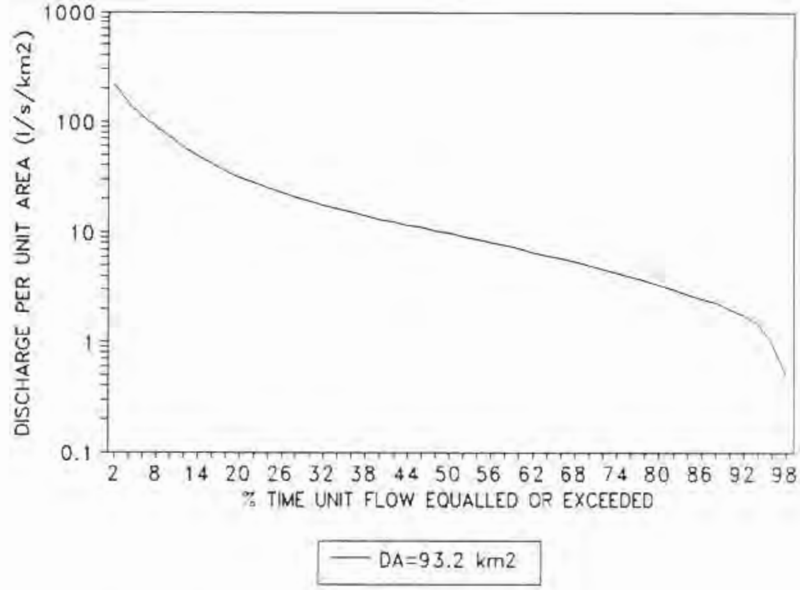

Figure A.25 Daily Flow Duration Curve at Gauging Station 02YM003.

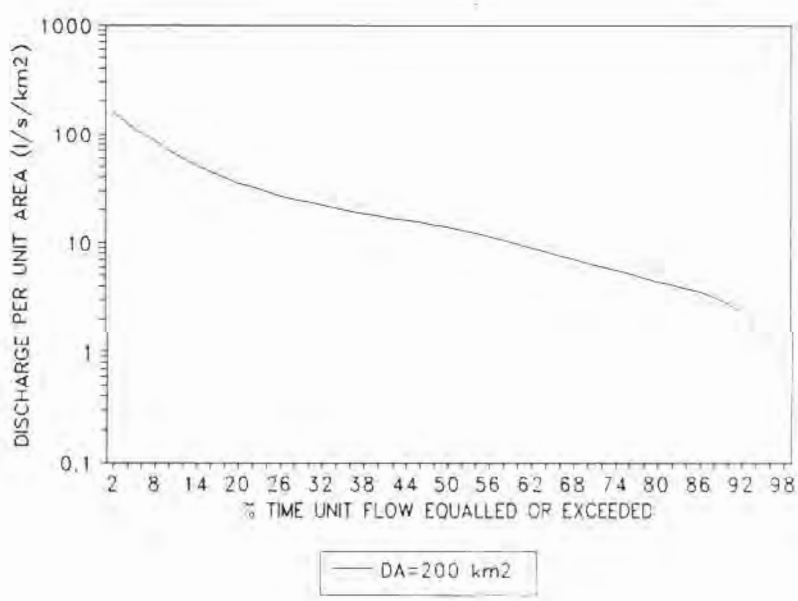

Figure A.26 Daily Flow Duration Curve at Gauging Station 02YD002.

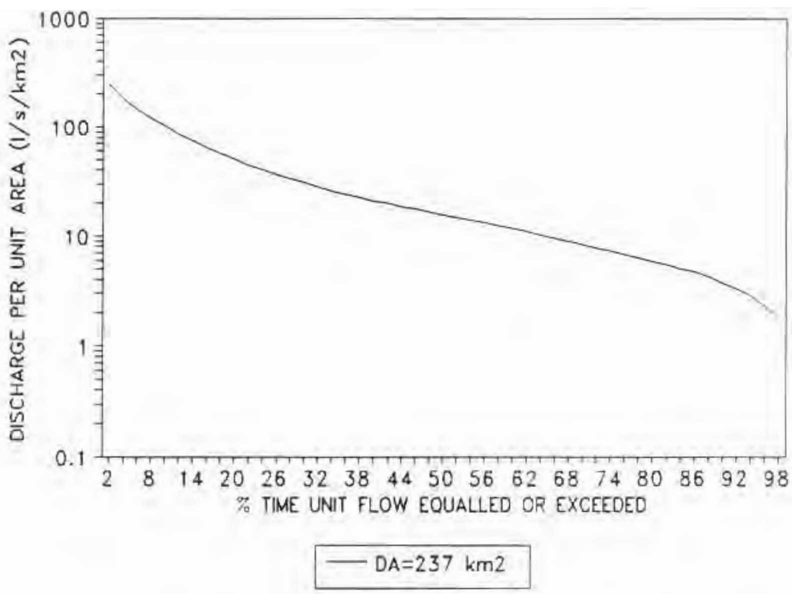

Figure A.27 Daily Flow Duration Curve at Gauging Station 02YD001.

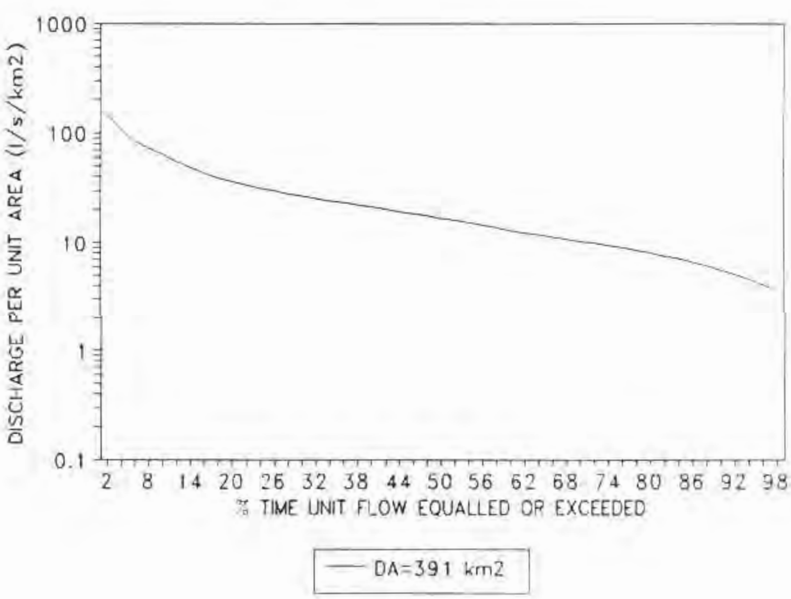

Figure A.28 Daily Flow Duration Curve at Gauging Station 02YK005.

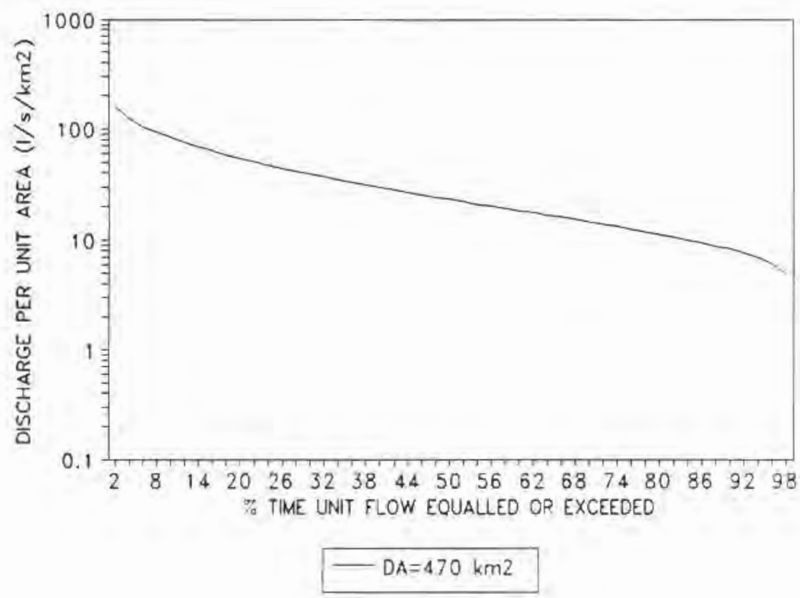

Figure A.29 Daily Flow Duration Curve at Gauging Station 02YK002.

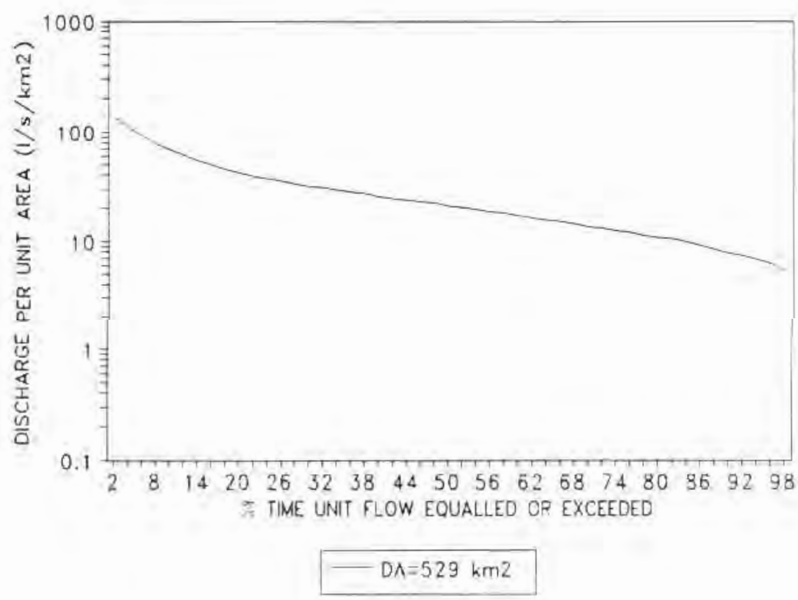

Figure A.30 Daily Flow Duration Curve at Gauging Station 02YK004.

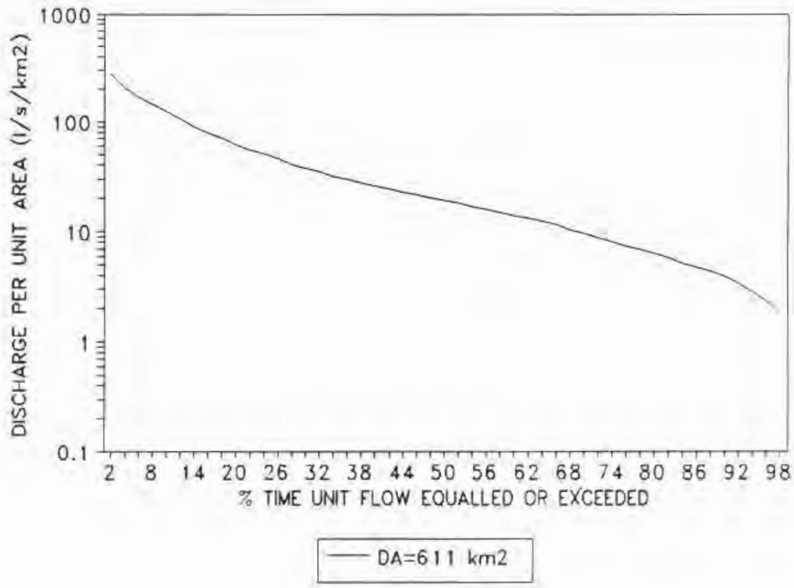

Figure A.31 Daily Flow Duration Curve at Gauging Station 02YF001.

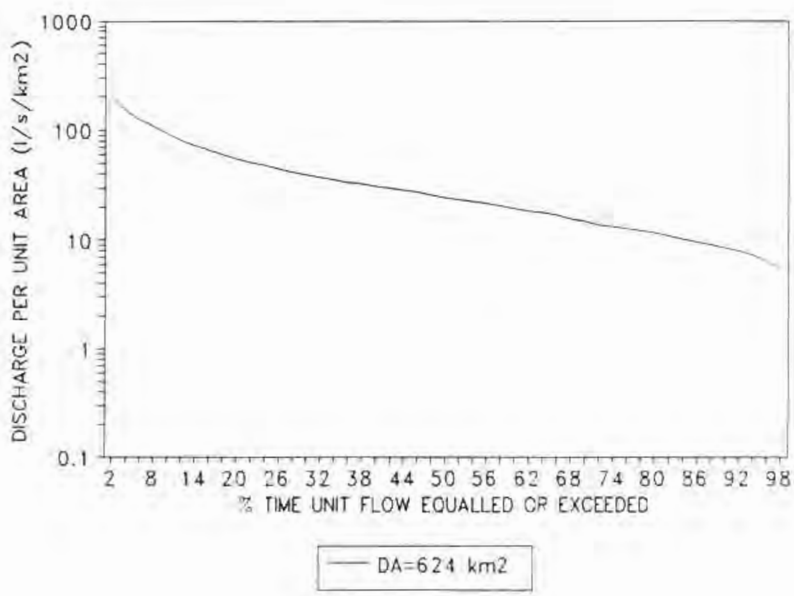

Figure A.32 Daily Flow Duration Curve at Gauging Station 02YC001.

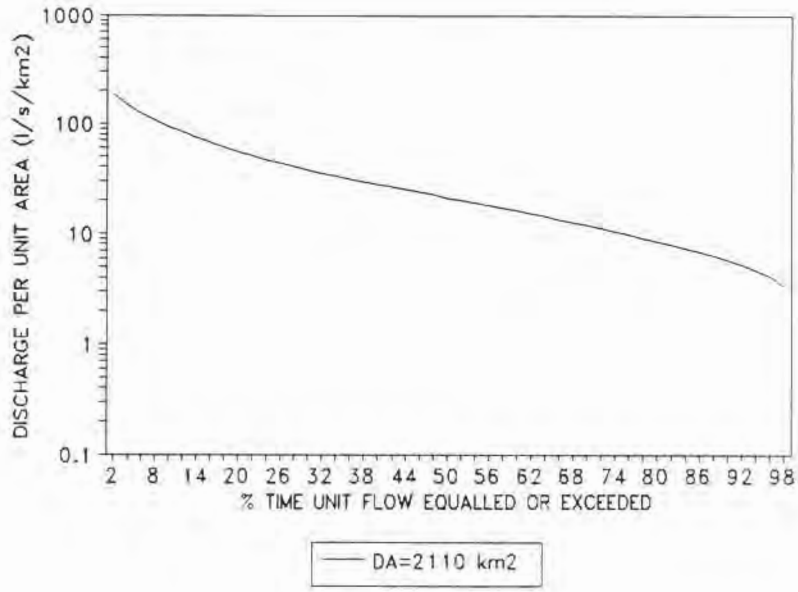

Figure A.33 Daily Flow Duration Curve at Gauging Station 02YL001.

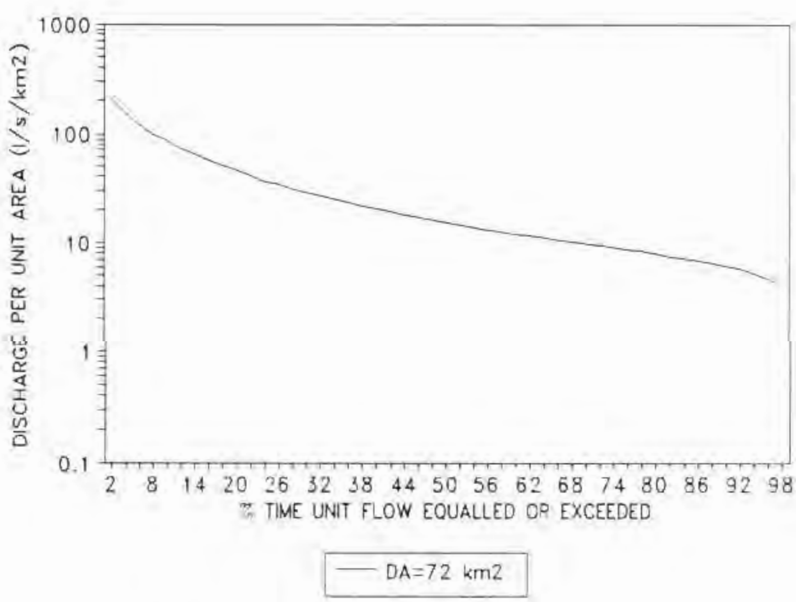

Figure A.34 Daily Flow Duration Curve at Gauging Station 02ZA002.

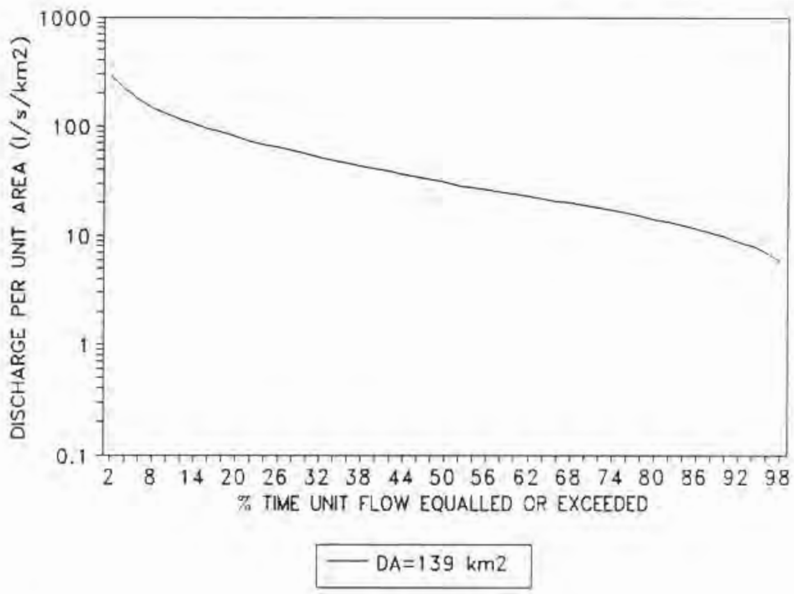

Figure A.35 Daily Flow Duration Curve at Gauging Station 02ZA003.

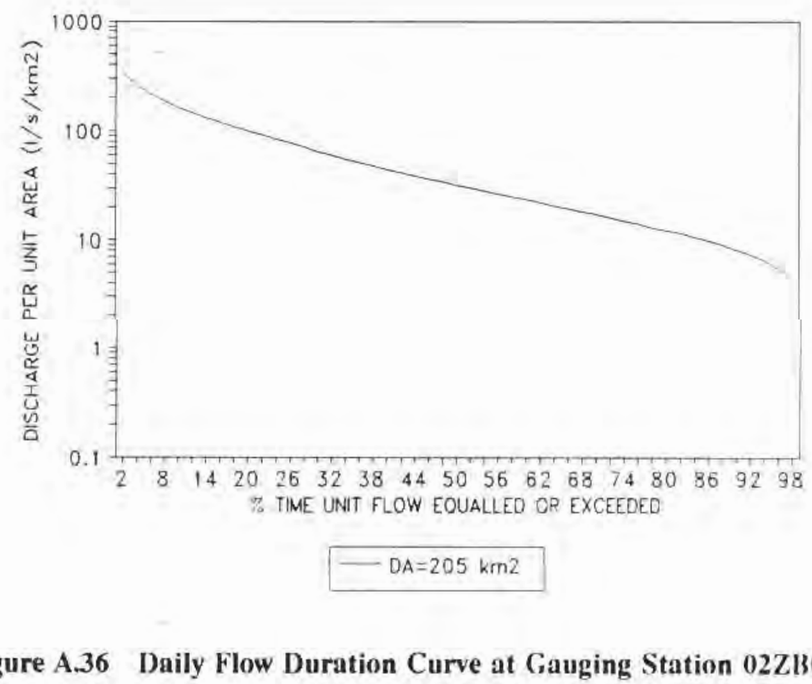

Figure A.36 Daily Flow Duration Curve at Gauging Station 02ZB001.

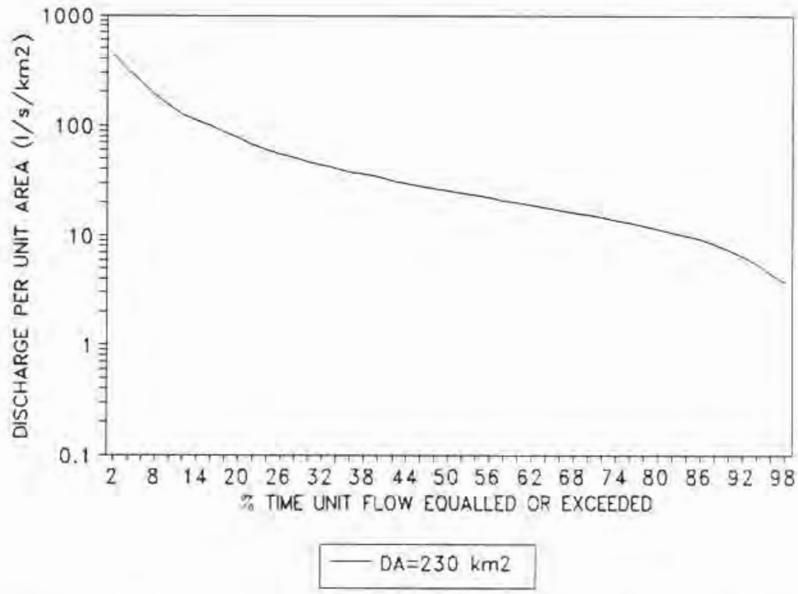

Figure A.37 Daily Flow Duration Curve at Gauging Station 02ZC002.

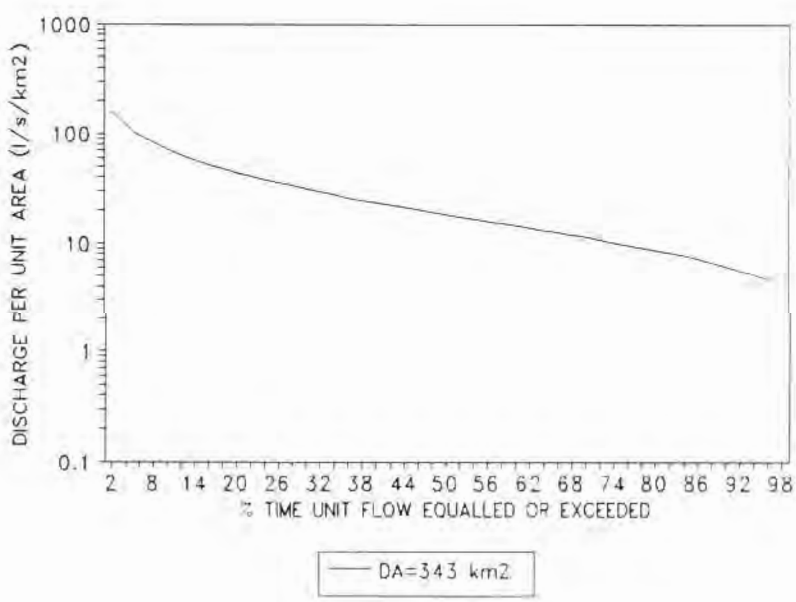

Figure A.38 Daily Flow Duration Curve at Gauging Station 02ZA001.

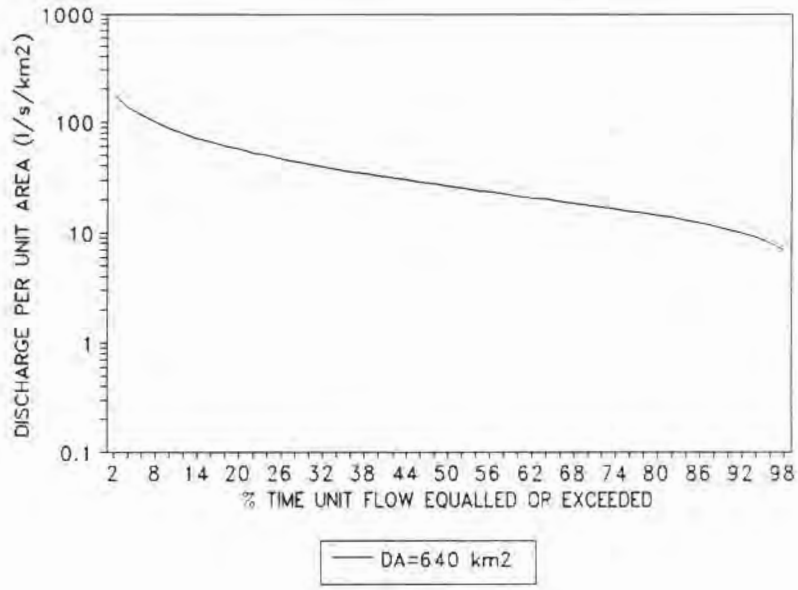

Figure A.39 Daily Flow Duration Curve at Gauging Station 02YJ001.

APPENDIX B

PHYSIOGRAPHIC PARAMETERS: DESCRIPTION AND EXTRACTION

A number of physiographic parameters were selected for use in the study. This Appendix describes these parameters and indicates how they were determined.

The parameters selected were:

1.	Drainage Area (DA)	(km^2)
2.	Lake Area	(km^2)
3.	Forest Area	(km^2)
4.	Swamp Area	(km^2)
5.	Barren Area	(km^2)
6.	Fraction of Drainage Area Controlled by Lakes and Swamps (FACLS)	
7.	Length of the Main Channel	(km)
8.	Slope of the Main Channel	(%)
9.	Drainage Density	(km/km^2)
10.	Shape Factor (SHAPE)	(-)
11.	Elevation Difference between the Basin Divide near the Origin of the Main Channel and the Hydrometric Station or Point at which Discharges are to be Estimated	(m)

Drainage area, lake area, forest area and swamp area were determined from 1:50,000 NTS (National Topographic Series) maps using either a planimeter or digitizer. Barren area was determined by subtracting lake area, forest area and swamp area from the drainage area. For basins with drainage areas greater than 2000 km^2, 1:250,000 scale NTS maps were used. Since less lakes and swamps are shown on 1:250,000 scale maps than on 1:50,000 scale maps, the values were adjusted upward based on comparisons of "representative" sample portions of each basin at each of the two scales. The area of forest and barren were then adjusted downward proportionally.

The fraction of the drainage area controlled by lakes and swamps (FACLS) was determined using 1:50,000 scale NTS mapping for all basins. A lake or swamp had to have a surface area equal to at least one percent of the drainage area to the outlet of the lake or swamp in order to be considered to control high flows. Figure B.1 [10] provides the definition of the parameter "area controlled by lakes and swamps".

The length of the main channel was determined using a map meter and 1:50,000 scale NTS mapping. For basins larger than 2000 km^2, a 1:250,000 scale mapping was used. The slope of the main channel was calculated over only 75% of its length. The elevation difference was found between the point 10% of the main channel from the hydrometric station and the point 85% from the station. Thus, the run consisted of 75% of the main channel. The effects of rapids and waterfalls were excluded by subtracting their heights and lengths from the run and rise, respectively.

Drainage density was determined by dividing the total length of stream by the drainage area. For all but the three largest basins, 1:50,000 scale mapping was used to measure the stream length. For the three basins with drainage areas greater than 2000 km^2, 1:250,000 scale maps were used and adjustment factors, based on the comparison between the length of streams on "representative" portions of the basins at each map scale, were applied.

A dimensionless shape factor (SHAPE) was adopted for use in this study. The formula is:

$$SHAPE = \frac{0.28\,P}{\sqrt{DA}}$$

where P is the perimeter of the drainage basin, and DA is the drainage area.

Basin perimeters were measured using a map meter and 1:50,000 scale NTS maps. For basins larger than 2000 km^2, 1:250,000 scale maps were used. Adjustment factors, based on a comparison between perimeters measured on selected portions of the watershed divide at each map scale, were then applied.

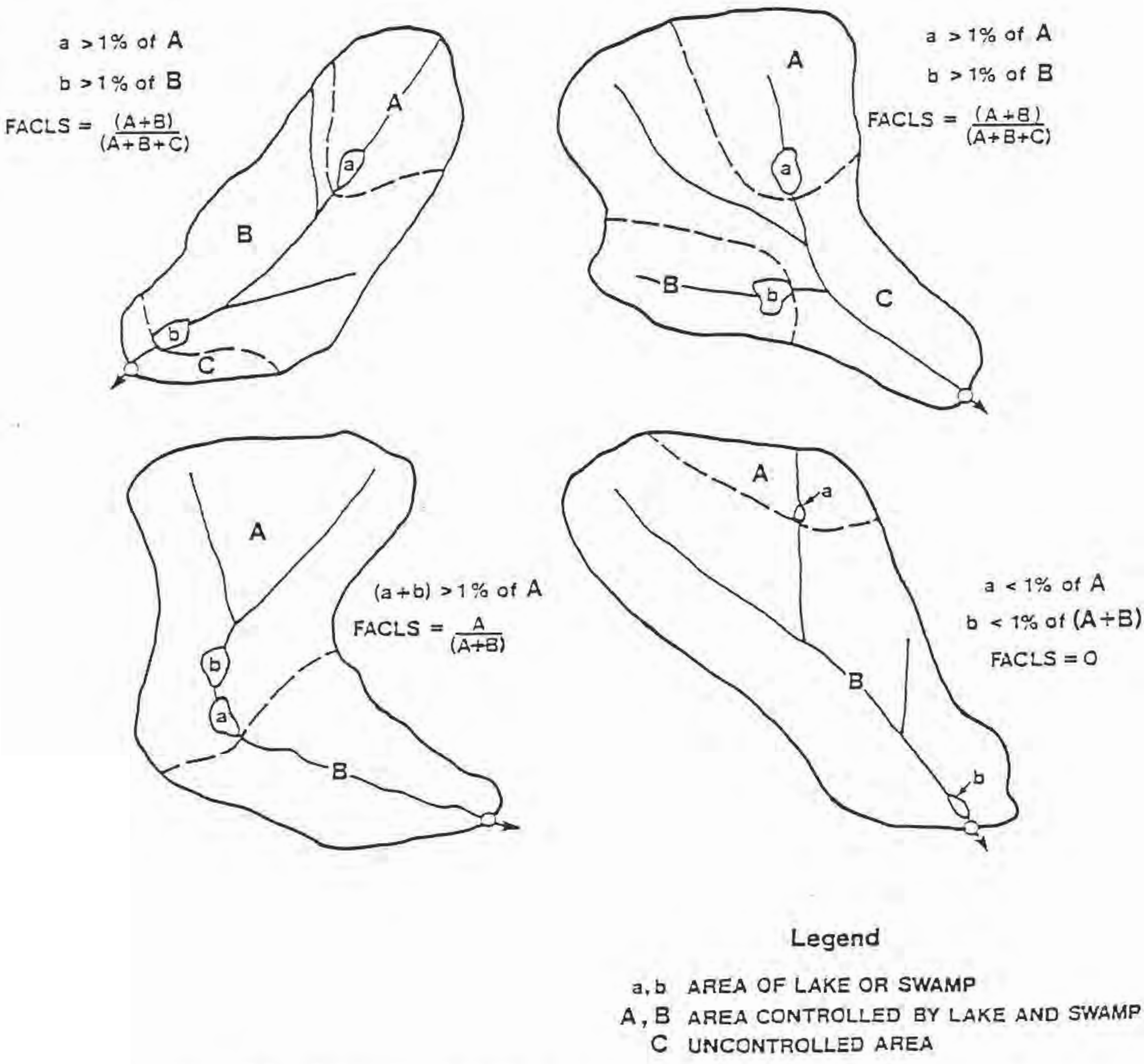

Figure B.1 Schematic Definition of Fraction of Drainage Area Controlled by Lakes and Swamps [FACLS]

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