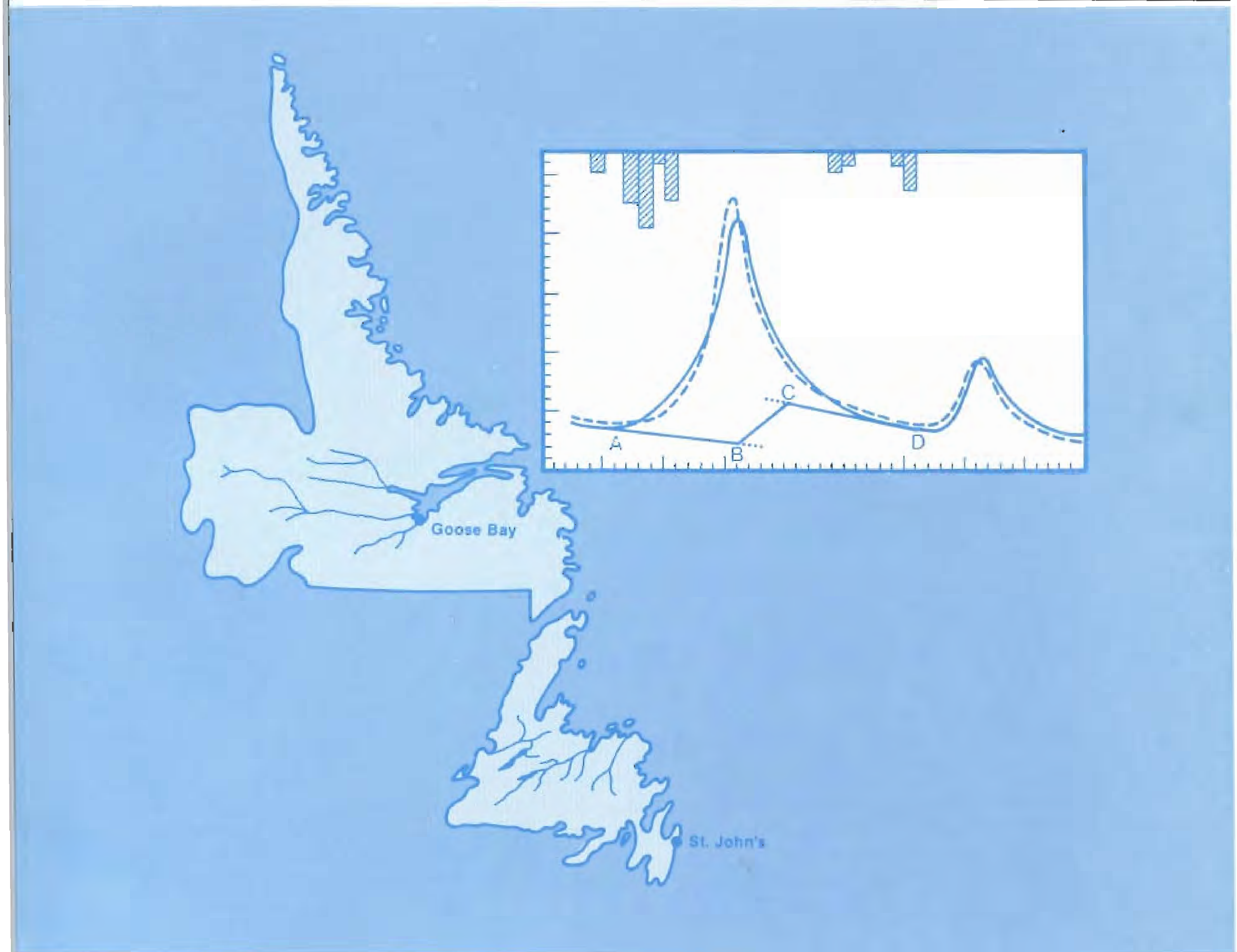
Estimation of Low Flows for the Island of Newfoundland

A User's Guide



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

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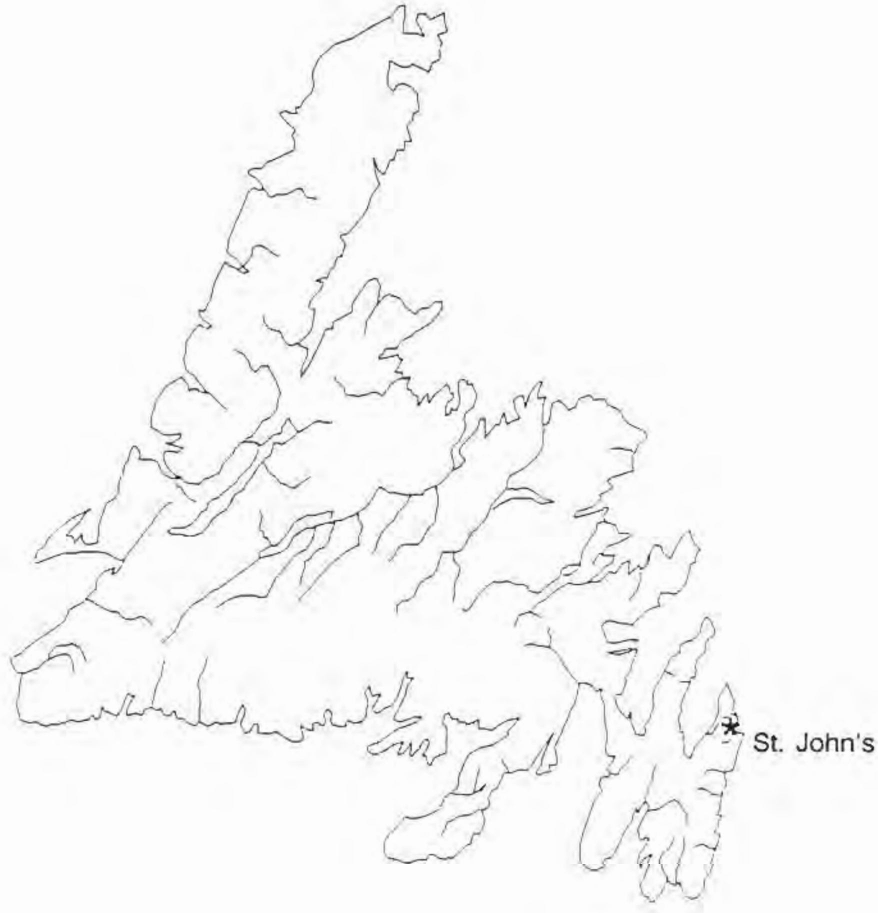

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SUMMARY

The objective of this guide is to provide users with a computer-based method of estimating 1-day, 7-day, 15-day and 30-day low stream flows with return period of 2, 10, 20 and 50 years for the Island of Newfoundland. The significant results of a study on which the estimation technique is based are presented. The computer-based version of the estimation technique is then described followed by an example to illustrate its application.

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1 INTRODUCTION

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.

An annual low flow condition is defined as a period during which the average streamflow is a minimum for the year. 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 the continuous N-day period. For design purposes, low flows are usually expressed in terms of return periods in years. For example, a low flow with duration N-day, magnitude x m^3/s and return period T years is the average flow 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.

A report entitled "***Characteristics and Estimation of Minimum Streamflows for the Island of Newfoundland***" [1], describing the methodology and results of a frequency analysis of low flows at thirty-nine gauging stations on streams in Newfoundland was completed in June 1991. A series of regional regression equations for estimating low flows of several durations and return periods at ungauged sections of streams were derived from the results of the analysis. This guide summarizes the results of the study and presents the regional regression equations. A computer-based approach to using the equations and an example to illustrate their application are then given.

2 DATA ON GAUGED WATERSHEDS

The analysis of low flows was based on unregulated daily stream flows from 39 gauged watersheds in Newfoundland [2]. Figure 1 shows the location of the watersheds and gauging stations. Table 1 lists these watersheds together with the locations of the gauges, the watersheds' drainage areas and the record length available for each station. A partial listing of the physiographic database on the 39 gauged watersheds with natural flows is shown in Table 2 [3].

Figure 1 Locations of Watersheds and Gauging Stations for Low Flow Study

Table 1 List of 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

Table 2 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	28.9	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

3 REGIONAL CHARACTERISTICS OF RUNOFF

The unit mean monthly flows and the mean annual runoff at the 39 gauging stations are shown in Table 3. The mean annual runoff is highest in the southwestern region of the Island where it ranges from 1300 mm to 2100 mm. The lowest mean annual runoff, between 700 mm and 900 mm, occurs in the north-central area of the Island. On the Avalon and Burin Peninsulas, the range of the mean annual runoff is 1000 mm to 1900 mm. On the Northern Peninsula, mean annual runoff is between 1100 mm and 1400 mm.

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.

Table 3 Unit Mean Monthly and Annual Flows at Gauging Stations

Station Number	Drainage Area (km^2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Unit Mean Annual Flow (m^3/s/km^2)	Mean Annual Runoff (mm)
		Unit Mean Monthly Flow (m^3/s/km^2)													
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

4 REGIONAL CHARACTERISTICS OF N-DAY LOW FLOWS

For the study on minimum stream flows [1], the N-day low flows were calculated both for the summer season, which was defined as the period between and including July and December and for the winter season, which was defined as the period between and including January and June. Four durations of low flows were investigated: 1-day, 7-day, 15-day and 30-day.

The average unit mean low flows during the winter and summer seasons for four geographical regions of the Island are shown in Table 4.

Table 4 Average Regional Mean N-Day 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 lower 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. For the purposes of this guide only the results pertaining to the summer low flows will be presented, however, the frequency estimates of winter low flows are provided in the main report [1].

5 FREQUENCY ESTIMATES OF N-DAY LOW FLOWS

Calculated summer low flows of four durations (1-day, 7-day, 15-day and 30-day) and for the period of record were used as input data into the Low Flow Frequency Analysis (LFA) computer program [4] to obtain estimates of low flows with various return periods. The LFA program uses the Gumbel Type III probability density function to statistically model low flows. The summer low flow estimates with return periods 2, 5, 10, 20 and 50 years are shown in Table 5 (1-day), Table 6 (7-day), Table 7 (15-day) and Table 8 (30-day).

Table 5 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 6 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 7 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 8 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

6 REGRESSION EQUATIONS FOR ESTIMATING N-DAY LOW FLOWS

Regression analysis is a multi-variate analysis in which the low flow frequency estimates from gauged watersheds are related quantitatively to independent physiographic characteristics of the watersheds. The resulting equations can be used to estimate low flow characteristics at sites with inadequate hydrologic information.

The "best" regression equations were obtained when the Island was divided into three (3) regions and the regression analysis performed in each region separately. The regions are shown in Figure 2. The division of the Island was the outcome of an iterative process of identifying regions with distinct hydrological, climatic and physiographic characteristics, performing regression analyses for each identified region, evaluating the resulting regression equations and re-defining the regions' boundaries if necessary. The three regions are:

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

The south coast of the Island was not identified as a region in Figure 2 because of insufficient hydrologic data in the area.

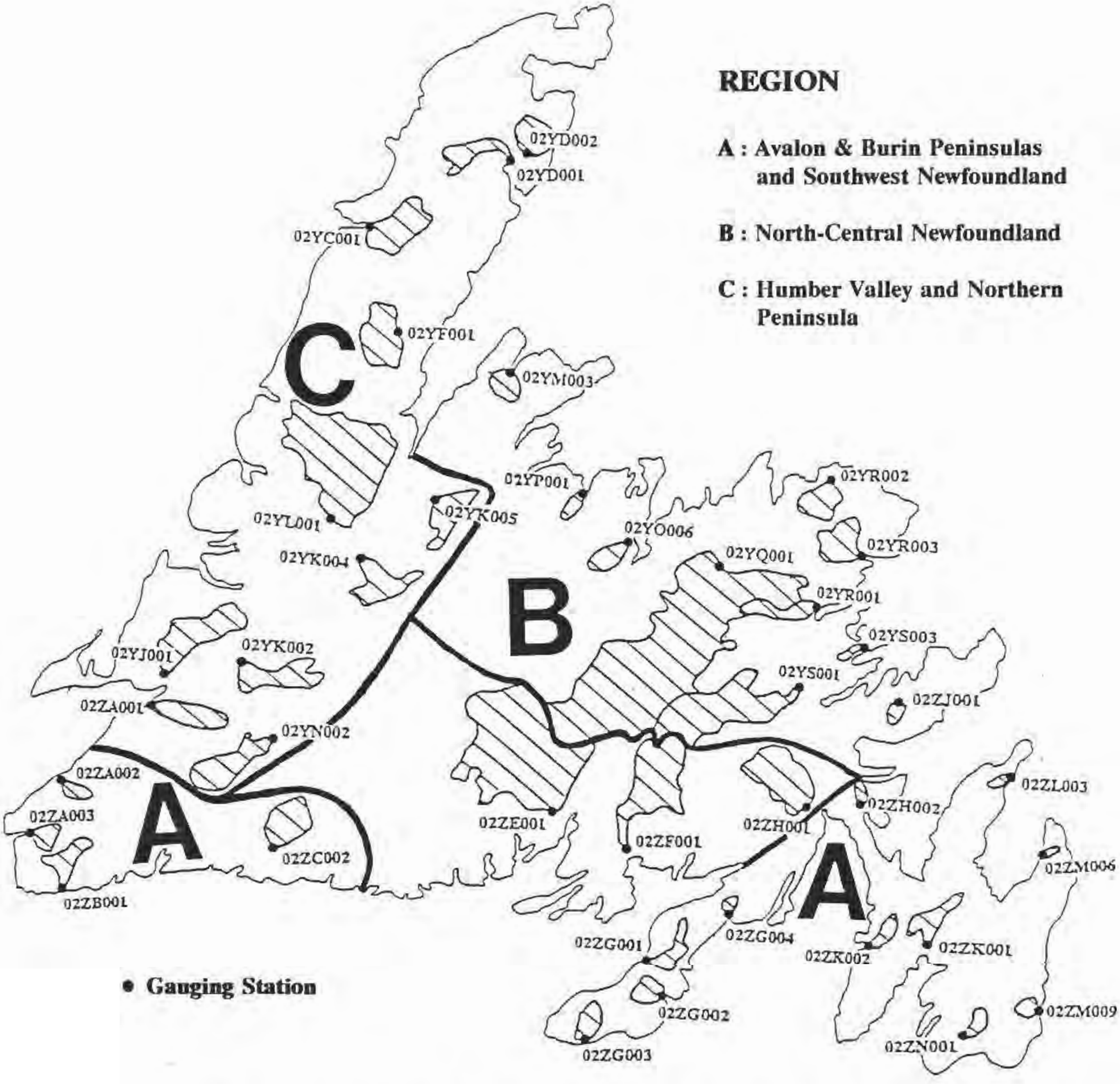

Figure 2 Division of Island into Three Regions for Low Flow Analysis

The regression analysis for each region consisted of the following steps:

(1) Regression analysis between the Beta@30 and watershed characteristics. Beta@30 were the beta parameters of the 30-day low flow series as calculated by LFA [4]. One regression equation was derived for each region.

(2) Regression analysis between Beta@30 and Beta@N, where N = 1, 7 and 15. Beta@N were the beta parameters of the N-day low flow series as calculated by LFA. Three regression equations (N = 1,7,15) were obtained for each region.

(3) Regression analysis between Beta@N and Q2@N, Q2@N and Q5@N, Q5@N and Q10@N, Q10@N and Q20@N, and Q20@N and Q50@N. QT@N was the T-year, N-day low flow estimate, as calculated by LFA. The analysis was done for each region and low flow duration.

The equations resulting from regression analyses are given in Tables 9, 10 and 11 for regions A, B and C, respectively. The equations for Beta@30 for the three regions show that Beta@30 is primarily dependent on drainage area; in region A, Beta@30 depends slightly 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 9. This equation can be used for estimating low flows in region A when only the drainage area is available as the predictive parameter.

A comparison of the low flow frequency estimates with the estimates obtained from applying the regression equations on the gauged watersheds indicates that the percentage difference between the frequency and regression estimates in most cases ranged from +50% to -50%, although some were much higher. The high values occurred most often for low flows with high return periods, that is, when the frequency estimates were close to zero. The high percentage differences were due to the fact that for very low flow estimates the differences between the regression and frequency estimates became very close to the frequency estimates themselves.

Table 9 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 [QT@N, $\log_{10}$(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 10 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 [QT@N, $\log_{10}$(BETA@N)]
DA: Drainage Area (km^2)
FAR: Percentage of drainage area covered by forests

Table 11 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 [QT@N, $\log_{10}$(BETA@N)]
DA:	Drainage Area (km^2)
FAR:	Percentage of drainage area covered by forests

It is recommended that the regression equations given in Tables 9, 10 and 11 be applied under the following conditions:

Equations for Region A:

1. The drainage area of the watershed must be less than 200 km^2.
2. The percentage of barren area in the watershed must be between 25% and 75%. (The percentage of forested area must be between 10% and 70%. The percentage of watershed area occupied by lakes and swamps must between 10% and 20%.)

Equations for Region B:

1. The drainage area of the watershed must be between 40 km^2 and 400 km^2.
2. The percentage of barren area in the watershed must be less than 5%. (The percentage of forested area must be greater than 80%, with the rest of the watershed occupied by lakes and swamps.)

Equations for Region C:

1. The drainage area of the watershed must be between 240 km^2 and 600 km^2.
2. The percentage of barren area in the watershed must be between 10% and 40%. (The percentage of forested area must be between 40% and 65%. The percentage of the watershed occupied by lakes and swamps should be between 10% and 20%.)

7 COMPUTER-BASED USE OF REGRESSION EQUATIONS

Manual calculations of low flow estimates using the regression equations in Tables 9, 10 and 11 require tedious substitutions of watershed characteristics and regression coefficients. This increases the chances of errors. To eliminate this source of errors, a Lotus 1-2-3[1] worksheet, **LFFE-91.WK1** [5], has been developed to perform the calculations automatically once the watershed's name, geographical location and physiographic parameters are input. The results are displayed instantly on the screen. A copy of the package is available from: Director, Water Resources Division, Department of Environment and Lands, P.O. Box 8700, St. John's, Newfoundland, A1B 4J6.

A typical spreadsheet as displayed when the Lotus worksheet **LFFE-91.WK1** is loaded is illustrated in Table 12. The entry cells are unprotected cells and are differentiated on the screen. Any attempt to enter characters in protected cells will result in a "beep" indicating an illegal entry. Pressing the "Esc" key will abort the attempted change in a protected cell. Messages will appear on the screen whenever the user is to be made aware of certain information. For example, whenever watershed parameters are outside their applicable range or area of watershed is less than other entered areas or an unacceptable input for watershed location has been entered, a message will appear in the lower left-hand corner of the screen indicating the error.

Whenever the message "(Not Used)" appears by an entry cell, it means that this particular parameter is not used in calculating the low flow estimates and entering numbers for this parameter will not change the results. However, it is recommended that such parameters be evaluated and input so that the program can indicate whether they are within the applicable range. This will give the user more information on which to assess the validity of the results.

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[1]Lotus 1-2-3 is a U.S. registered trademark of Lotus Development Corporation.

Table 12 Example of Spreadsheet as Displayed on Computer Screen

Regional Frequency Estimates of Low Flows for the Island of Newfoundland.

Name of watershed............... **Northeast River @ Gauged Site 02ZK002**
Location of watershed........... **1 Eastern & Southwestern**
(Eastern-Southwestern=1, North-Central=2, Humber & Northern Peninsula=3)
Range of Mean Annual Runoff for Region 1 = 1100 mm to 2100 mm

..... Physiographic Parameters			Parameter Range	
DA Area of watershed	**89.6**	km²	4.0	200.0
FAR Forested Area (X if Unavail.)	**42.1**	km²	9.0	62.7
BAR Barren Area (Not Used)	**20.6**	km² **	22.4	67.2
ALS Lakes+Swamps Area (Not Used)	**26.9**	km² **	9.0	17.9

... WARNINGS & ERROR DIAGNOSIS ...	T	Low Flows (l/s)			
	(year)	1-day	7-day	15-day	30-day
	2	**368**	**443**	**553**	**791**
** Use results with caution:	10	**171**	**211**	**255**	**373**
These parameters are outside	20	**141**	**177**	**212**	**309**
the range for reliable results.	50	**95**	**154**	**181**	**264**

Data Input into LFFE-91.WK1

[1] **Name of Watershed**

Enter the name of the watershed for which low flows are being estimated.

[2] **Location of Watershed**

Three (3) hydrological regions have been identified during the low flow study and are shown in Figure 2. Refer to this figure to determine the region within which the watershed lies. **Note that Regions A, B and C in Figure 2 must be input as 1, 2 and 3 in LFFE-91.WK1.**

[3] **DA Area of Watershed**

This is the drainage area (in **km^2**) of the watershed at the section where low flows need to be estimated. It is recommended that the drainage area be determined using a planimeter or digitizer from 1:50,000 topographic maps.

[4] **FAR Forested Area**

This is the area (in **km^2**) of the watershed covered by forests. It is recommended that the forested area be determined using a planimeter or digitizer from 1:50,000 topographic maps.

The forested area is used as a predictive parameter in the regression equations for calculating low flows for watersheds in region A only. If, however, the forested area is not available, then an "x" can be entered. The alternate regression equation will be used to calculate low flows for region A and a message will appear at the bottom of the screen indicating this case. For watersheds in regions B and C, the forested area is not used in the regression equations and a message "(Not Used)" will appear by the entry cell. Nevertheless, it is preferable that the forested area be calculated and entered. The program will indicate whether this calculated area is within the range used in deriving the equations. Hence, the user will be able to evaluate the results.

[5] **BAR Barren Area** and [6] **ALS Lakes+Swamps Area**

The area (in **km²**) covered by barrens and the area (in **km²**) covered by lakes and swamps are **not required** for calculating low flow estimates. However, it is recommended that these areas be extracted and entered so that it can be determined whether they are within the applicable range. This is especially important for watersheds located in region B. In this region, all but one of the watersheds used in the analysis were less than 3% barren. Hence, if the ungauged watershed has a much higher proportion of barren area, the low flow estimates could be seriously in error.

OUTPUT OF PROGRAM

The program outputs the **2-, 10-, 20-** and **50-year** expected low flows of durations **1-, 7-, 15-** and **30-day** in **litres per sec (l/s)**.

The program also outputs the range of the **mean annual runoff** (in mm) expected for the particular region within which the watershed is located.

A copy of the worksheet as illustrated in Table 12 can be obtained by pressing the "Print Screen" or by using Lotus 1-2-3 print commands.

8 ESTIMATION PROCEDURE

The procedural steps given below for estimating low flows using the regression equations should be treated as guidelines. Specific situations warrant that professional engineering judgement, as appropriate to site/watershed conditions, be exercised in the application of the procedure. For example, large-scale logging, groundwater contribution from outside the watershed's topographic divide, and artificial regulations and diversions can severely affect the applicability of the procedure.

A detailed description on the application of the regional regression equations using LFFE-91.WK1 to estimate low flows at ungauged sections of streams is given below as **Case A**.

Occasionally, a hydrometric station will be located on the subject stream. If the watershed area at the ungauged site is less than 15% smaller or larger than the watershed area at the gauged site and the number of years of daily flow data at the gauged section is equal to or greater than 8, then a method to estimate low flows at the ungauged site using the information at the gauged section is given as **Case B**.

An example to illustrate the procedural steps is given.

CASE A .. Estimating Low Flows at an Ungauged Site

[A.1] Plot site on a topographic map and delineate the drainage divide.
It is recommended that 1:50,000 National Topographic Series maps be used for delineating the watershed boundary.

[A.2] Refer to Figure 2 and determine the hydrologic region within which the subject basin is located.

[A.3] Estimate Physiographic Parameters .. DA, FAR, BAR, ALS

Determine watershed area (DA), forest area (FAR), barren area (BAR) and area of lakes and swamps (ALS), all in km^2, using a planimeter or a digitizer and 1:50,000 topographic maps.

[A.4] Input Name of Watershed (Step A.1), Location of Watershed (Step A.2) and physiographic parameters (Step A.3) into worksheet.

[A.5] Check whether or not the parameters fall within the specified ranges for which the equations are considered to be applicable.

These ranges are automatically displayed on the computer screen besides the entry cells. If any parameter value used in the regression equation falls well outside the specified range, it is suggested that other methods of obtaining low flows be investigated. If the parameter value is only slightly outside the specified range or if it is not a parameter used in estimating low flows, the equations can be used to obtain first estimates of the low flows. It may still be necessary to investigate other methods of obtaining the low flows.

[A.6] Select the appropriate constants and coefficients from Tables 9, 10 and 11 to calculate low flows of the desired return period and region.

This step is performed automatically by LFFE-91.WK1 and the low flow estimates with return periods of 2, 10, 20 and 50 years and durations 1, 7, 15 and 30 days are displayed on the computer screen.

<u>CASE B .. Estimating Low Flows at an Ungauged Site Located on a Gauged Stream</u>

[B.1] Plot ungauged site on a topographic map, delineate the drainage divide and determine drainage area.
Let area = DA[u] km^2.

[B.2] Plot gauged site on a topographic map, delineate the drainage divide and determine drainage area.
Let area = DA[g] km^2.

Obtain the number of years of daily flow data available at gauged site.
Let n = n[g].

[B.3] If (0.85*DA[g] < DA[u] < 1.15*DA[g]) <u>and</u> n[g] > 7 then goto Step B.4, otherwise goto Step A.1 (case A).

[B.4] Perform Steps A.1 to A.6 for ungauged site.
Extract low flow estimates of required return period and duration from computer results.

[B.5] Perform Steps A.1 to A.6 for gauged site.
If the gauged site is included in Table 2, then, the physiographic parameters DA, FAR, BAR and ALS listed therein can used. Note that FAR, BAR and ALS are given as percentages in Table 2, but must be entered as <u>km^2</u> in LFFE-91.WK1. Extract low flow estimates of required return period and duration from computer results.

[B.6] Conduct a single station flood frequency analysis on data at gauged site.
A method for conducting single station frequency analyses is given in the report [1]. If the gauged site has been included in Tables 5, 6, 7 and 8 then

use the results given in the Tables. Abstract the low flows for the required return periods and durations.

[B.7] Adjust low flow estimates at ungauged site (results of Step B.4) with low flow estimates at gauged site (results of Steps B.5 and B.6).

The adjustment includes the effects arising due to differences in drainage areas (DA) and, if the watershed is in region A, forested area (FAR). The equation used to adjust the low flow estimates is as follows:

$$QT@N[Site,Adjusted] = \frac{QT@N[Site,Regression]}{QT@N[Gauge,Regression]} \times QT@N[Gauge,Frequency]$$

where,

QT@N(Site,Adjusted) is the adjusted T-year and N-day low flow estimate at the site,

QT@N(Site,Regression) is the T-year and N-day low flow estimate at the site obtained by using the regression equations (Step B.4),

QT@N(Gauge,Regression) is the T-year and N-day low flow estimate at the gauging station obtained from the regression equations (Step B.5),

QT@N(Gauge,Frequency) is the T-year and N-day low flow estimate at the gauging station obtained from a frequency analysis of recorded flows or from Tables 5, 6, 7, and 8 if the gauging station was included in the study.

9 ILLUSTRATIVE EXAMPLE

The illustrative example has been designed in such a way that **Case A** of an ungauged site on an ungauged stream and **Case B** of an ungauged site on a gauged stream can be described for the same ungauged site.

Problem Definition

Low flow estimates of return periods 2, 10, 20 and 50 years and durations 1, 7, 15 and 30 days are required at an ungauged site on the Northeast River near Placentia. This site is about 3 km above an existing gauging station (02ZK002). In the first instance, in Case A, it will be assumed that the gauging station does not exist on the stream and only the regression equations will be used to determine the low flow estimates. Then, in Case B, using the known frequency estimates of low flows at the gauging station, the low flows at the site will be re-estimated to illustrate the adjustment process.

Case A .. ASSUME GAUGING STATION DOES NOT EXIST ON STREAM

[A.1] The topographic divide of the watershed to the ungauged site was delineated on a 1:50,000 topographic map. The forest, barren, lakes and swamps areas were identified and marked.

[A.2] Referring to Figure 2, it was determined that the watershed is located in the Burin Peninsula, i.e, **Region A**. In LFFE-91.WK1 this information is entered as Region **1**.

[A.3] All the required areas were determined using a digitizer.

The drainage area, **DA**, was determined to be **82.6** km^2.

The forested area, **FAR**, was determined to be **37.5** km^2.

The barren area, **BAR**, was determined to be **19.5** km^2.

The area of lakes + swamps, **ALS**, was determined to be **25.6** km^2.

[A.4] The values from Steps A.2 and A.3 were input into LFFE-91.WK1.

[A.5] The parameters **BAR** and **ALS** were outside their applicable ranges. ALS was significantly higher than its upper limit. Since neither parameter is used in estimating low flows, the regression equations can still be used, but some caution is necessary in using the results.

[A.6] The required low flow estimates at the ungauged site together with the input parameters are shown in Table 13, which is a copy of the worksheet as displayed on the computer screen.

Table 13 Low Flow Estimates at Ungauged Site

Regional Frequency Estimates of Low Flows for the Island of Newfoundland.

Name of watershed............... Northeast River @ Ungauged Site
Location of watershed........... 1 Eastern & Southwestern
(Eastern–Southwestern=1, North–Central=2, Humber & Northern Peninsula=3)
Range of Mean Annual Runoff for Region 1 = 1100 mm to 2100 mm

..... Physiographic Parameters			Parameter Range	
DA Area of watershed	82.6	km^2	4.0	200.0
FAR Forested Area (X if Unavail.)	37.5	km^2	8.3	57.8
BAR Barren Area (Not Used)	19.5	km^2 **	20.7	61.9
ALS Lakes+Swamps Area (Not Used)	25.6	km^2 **	8.3	16.5

... WARNINGS & ERROR DIAGNOSIS ...	T	Low Flows (l/s)			
	(year)	1-day	7-day	15-day	30-day
	2	337	407	508	727
** Use results with caution:	10	157	194	235	343
These parameters are outside	20	129	163	195	284
the range for reliable results.	50	87	141	166	242

<u>Case B .. GAUGING STATION EXISTS ON STREAM</u>

[B.1] The drainage area at the ungauged site, DA[u] = 82.6 km^2.

[B.2] The gauged site on Northeast River is 02ZK002 and is included in Table 2. From Table 2, the drainage area at the gauged site, DA[g], is 89.6 km^2. From Table 1, the number of years of daily flow data, n[g], is 11.

[B.3] 0.85*DA[g] (=76.2) < DA[u] (=82.6) < 1.15*DA[g] (=103)
<u>and</u> n[g] (=11) > 7, therefore, proceed to Step B.4.

[B.4] Go through Steps A.1 to A.6 for ungauged site. These have already been done for Case A above and the regression low flow estimates are given in Table 13.

[B.5] Go through Steps A.1 to A.6 for the gauged site, 02ZK002. Since this site is included in Table 2, the physiographic parameters are read as **DA = 89.6 km^2**, **FAR = 42.1 km^2**, **BAR = 20.6 km^2** and **ALS = 26.9 km^2**. The regression low flow estimates are shown in Table 14.

[B.6] The gauged site is included in Tables 5, 6, 7 and 8. The low flow frequency estimates, obtained therein, are shown in Table 15.

[B.7] The adjusted low flow estimates at the ungauged site, together with the estimates obtained in Steps B.4, B.5 and B.6, are shown in Table 15.

Table 14 Low Flow Estimates at Gauged Site 02ZK002

Regional Frequency Estimates of Low Flows for the Island of Newfoundland.

Name of watershed............... Northeast River @ Gauged Site 02ZK002
Location of watershed........... 1 Eastern & Southwestern
(Eastern-Southwestern=1, North-Central=2, Humber & Northern Peninsula=3)
Range of Mean Annual Runoff for Region 1 = 1100 mm to 2100 mm

..... Physiographic Parameters				Parameter Range	
DA Area of watershed	89.6	km^2		4.0	200.0
FAR Forested Area (X if Unavail.)	42.1	km^2		9.0	62.7
BAR Barren Area (Not Used)	20.6	km^2	**	22.4	67.2
ALS Lakes+Swamps Area (Not Used)	26.9	km^2	**	9.0	17.9

... WARNINGS & ERROR DIAGNOSIS ...	T	Low Flows (l/s)			
	(year)	1-day	7-day	15-day	30-day
	2	368	443	553	791
** Use results with caution:	10	171	211	255	373
These parameters are outside	20	141	177	212	309
the range for reliable results.	50	95	154	181	264

Table 15 Adjusted Low Flow Estimates at Ungauged Site

A: Low Flow Estimates at Ungauged Site using Regression Equations (l/s)

T (Year)	1-day	7-day	15-day	30-day
2	337	407	508	727
10	157	194	235	343
20	129	163	195	284
50	87	141	166	242

B: Low Flow Estimates at Gauged Site using Regression Equations (l/s)

T (Year)	1-day	7-day	15-day	30-day
2	368	443	553	791
10	171	211	255	373
20	141	177	212	309
50	95	154	181	264

C: Low Flow Estimates at Gauged Site from Frequency Analysis (l/s)

T (Year)	1-day	7-day	15-day	30-day
2	523	641	800	1047
10	230	268	325	468
20	180	205	252	388
50	141	154	198	330

Adjusted Low Flow Estimates at Ungauged Site (l/s) = [A/B]*C

T (Year)	1-day	7-day	15-day	30-day
2	479	589	735	962
10	211	246	300	430
20	165	189	232	357
50	129	141	182	303

Neither the illustration of the procedure in the above example nor the suggested procedural steps given for estimation of low flows are intended to be exhaustive. Rather, the intent has been to merely demonstrate the application of the procedure through worked examples. Therefore, it is recommended that professional engineering judgement should be exercised in specific applications.

10 REFERENCES

[1] **Characteristics and Estimation of Minimum Streamflows for the Island of Newfoundland**, Newfoundland Department of Environment and Lands, Water Resources Division, 1991.

[2] **HYDAT, Surface Water Data, Volume 2.0, 1988**, Environment Canada, Water Resources Branch, 1990.

[3] **Compilation of Physiographic Data for Flood Frequency Analysis, 1982; Hydrometeorologic and Physiographic Data Abstraction for the Island of Newfoundland: An Update, 1989**, Newfoundland Department of Environment and Lands, Water Resources Division.

[4] **Low Flow Frequency Analysis, Program LFA,** Condie, R. and Cheng, L.C., Environment Canada, Water Resources Branch, 1977.

[5] **LFFE-91.WK1, Regional Frequency Estimates of Low Flows for the Island of Newfoundland using Lotus 1-2-3**, Newfoundland Department of Environment and Lands, Water Resources Division, 1991.