7. CORRELATION OF HYDROLOGICAL AND PHYSIOGRAPHIC DATA

7.1 Selection of Watersheds

On the island of Newfoundland, regional flow frequency equations were developed for the prediction of instantaneous maximum flows and "n"-day low flows for various return periods based on the following physiographic parameters: drainage area, lakes and swamps factor, drainage density, slope of the main stream, and the percentage of the drainage area covered by forests. A previous regional flood frequency analysis used the following independent variables: drainage area, mean annual runoff (mm), percentage of drainage area controlled by lakes and swamps, a basin shape factor, and the latitude of the watershed centroid. Drainage area was the most important parameter in all equations. The inadequacies of the hydrometric and climatic networks, and the lack of watershed specific physiographic data, preclude detailed regional flow frequency analysis for Labrador. Despite the inadequacies of the data, a methodology is needed for the prediction of instantaneous maximum flows for various return periods on small to medium sized watersheds (50 - 1000 km^2).

The primary criterion for selecting watersheds was that the watersheds have at least 10 years of unregulated annual maximum instantaneous discharge data. At least 10 years of data were required to get a good estimate of the mean peak flow. Very large watersheds ($>$ 20,000 km^2 in area) were not expected to assist in the development of methodologies for transferring hydrologic information from large gauged watersheds to small ungauged watersheds (< 1000 km^2) and thus were removed from the analysis. Nine (9) watersheds remained in Labrador after the initial screening. To augment the database, annual maximum instantaneous discharges were extracted from 9 watersheds in Quebec. In all cases, these watersheds receive precipitation from inside Labrador and/or some portion of their divide coincides with the Labrador-Quebec border. All selected watersheds in Labrador and Quebec were greater than 1000 km^2 in area.

Mean peak flow data on small to medium sized drainage areas (50 to 1000 km^2) was non-existent. In an attempt to model peak flows in this range of drainage areas, a number of watersheds in Newfoundland were selected for analysis. Watersheds were selected based on drainage area and hydrology. The minimum drainage area was selected to be 50 km^2. The hydrologic criteria was that the watersheds have peak flows in the spring, and that the watersheds have similar mean annual runoff (600 - 800 mm). Almost all of these watersheds were located in north-central and north-eastern Newfoundland.

A very limited amount of peak flow data was available for small watersheds in Labrador. In 1994 and 1995, a total of three streamflow gauging stations, with relatively small drainage areas, were installed on three brooks in Labrador. Big Pond Brook below Big Pond (03OE010) was installed in 1994 near Goose Bay and had a drainage area of 71.4 km^2. Reid Brook at outlet of Reid Pond (03NE001) and Camp Pond Brook below Camp Pond (03NE002) were installed in 1995 near Voisey’s Bay and had drainage areas of 75.7

km^2 and 23.8 km^2 respectively. While these data were insufficient for the calculation of mean peak flows, estimates of mean peak flows were calculated from the annual maximum instantaneous discharges on the small watersheds, annual maximum instantaneous discharges on the nearby larger watersheds, and the mean peak flow on the nearby larger watersheds. The larger watersheds were selected as those that were geographically close to the smaller watersheds and had at least 10 years of data available for the calculation of the mean peak flow. Big Pond Brook was paired with Naskaupi River (03PB002) and Minipi River (03OE003). Reid Brook and Camp Pond Brook were paired with Ugjoktok River (03NF001).

All selected watersheds are listed in Table 7.1 along with their mean annual maximum instantaneous discharge where available. Outlet control, as defined in Section 3.2, is also listed because it has an effect on peak flows and will be utilized in the analysis.

Table 7.1 Watersheds Selected for Correlation

Station Number	Region	Controlled Outlet? (Yes/No)	Drainage Area (km^2)	Mean Annual Peak Flow (m^3/s)
03NE002	Lab	Yes	23.8	na
03OE010	Lab	Yes	71.4	na
03NE001	Lab	Yes	75.7	na
03OE003	Lab	Yes	2330	241
03PB002	Lab	Yes	4480	496
03NG001	Lab	Yes	8930	1218
03OC003	Lab	Yes	15100	1471
02XA004	Lab	No	2060	331
03QC002	Lab	No	2310	508
02XA003	Lab	No	4540	637
03NF001	Lab	No	7570	1072
03QC001	Lab	No	10900	1840
02XB002	Que	Yes	1060	125
02VC002	Que	Yes	6550	834
02VB004	Que	Yes	7230	844
03LD004	Que	Yes	8990	875
02XA007	Que	Yes	12100	1677
02UC003	Que	No	3390	455
02XB001	Que	No	5750	1238
02XC001	Que	No	6630	1217
02WB002	Que	No	11600	1803
02YO010	NF	Yes	61.6	12.0
02YK007	NF	Yes	112	23.9
02YO006	NF	Yes	177	52.8
02YD002	NF	Yes	200	40.5
02YG002	NF	Yes	224	52.8
02YR001	NF	Yes	275	36.0
02YK003	NF	Yes	362	60.9
02YK005	NF	Yes	391	78.3
02YR002	NF	Yes	399	72.0
02YK004	NF	Yes	529	94.1
02YR003	NF	Yes	554	57.8
02YS001	NF	Yes	1290	183
02YS005	NF	Yes	2000	243
02YQ001	NF	Yes	4400	604
02YP001	NF	No	63.8	25.8
02YQ005	NF	No	80.8	39.0
02YO007	NF	No	88.3	29.7
02YM003	NF	No	93.2	42.9
02YQ006	NF	No	531	150
02YO008	NF	No	823	239
02YL001	NF	No	2110	652
02YQ004	NF	No	2150	673

na - not available

7.2 Data Analysis

Due to the lack of data, Labrador was treated as one hydrological region for the purpose of estimating mean peak flows on small to medium sized watersheds. Correlations were developed between mean peak flow and drainage area. Estimates of mean peak flows can be used to estimate flood flows of higher return periods as shown later in this section.

One low outlier was removed from the data set: 03PB001 - Naskaupi River at Freemont Lake (1955-70). Before this watershed was diverted to the Churchill River Basin in 1971, more than 25% of its area was lakes. This undoubtably had a very significant influence on peak flows. No screening was done on the Newfoundland data set.

Watersheds were grouped as “controlled” or “not controlled”. This grouping accounted for the attenuating effect of lakes (near the outlet of a watershed) on peak flows. Watersheds were also grouped by region.

For comparison purposes, a linear regression with and without a constant was performed on the Labrador-Quebec (Lab-Que) data set despite a high level of skewness in the data set. Mean peak flow versus drainage area by region and control is shown in Figure 7.1.

The Lab-Que data was log transformed to reduce skewness prior to another linear regression of the Lab-Que data set. A linear regression was also performed on the Labrador-Quebec-Newfoundland (Lab-Que-NF) log transformed data set and also on the Newfoundland (NF) log transformed data set. Mean peak flow versus drainage area is shown by region and lake control condition on log scaled axis in Figure 7.2.

Preliminary annual maximum instantaneous discharges were available, or were estimated from the daily discharge data on the recently gauged small watersheds: Big Pond Brook (1994-96), Reid Pond Brook (1995-96), and Camp Pond Brook (1995-96). These discharges were used to estimate the mean peak flow for 100 km^2 watersheds. The procedure is as follows. For each year, it was assumed that the return period of maximum instantaneous discharges was a constant across all drainage areas in a given region. Further, it was assumed that the ratio of the maximum instantaneous discharge to the mean peak flow was a constant across all drainage areas in a given region and year. An estimate of the mean peak flow for Big Pond Brook, Reid Brook and Camp Pond Brook, for each year was calculated based on the product of the maximum instantaneous discharge for that year and the ratio of the mean peak flow to the maximum instantaneous discharge on the nearby data rich larger watersheds: Naskaupi River, Minipi River and Ugjoktok River. Three (3) estimates of the mean peak flow were obtained for Big Pond Brook, 2 estimates were obtained for Reid Brook, and 2 estimates were obtained for Camp Pond Brook. The calculated mean peak flows for the small watersheds were subsequently prorated to 100 km^2 watersheds. These estimates of mean peak flow on 100 km^2 watersheds were then

Figure 7.1

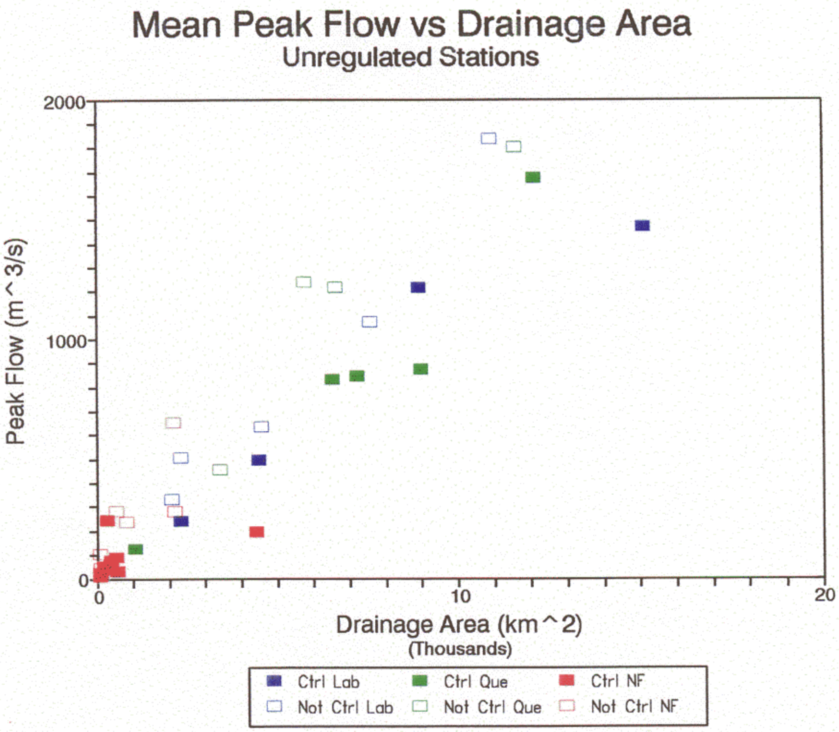
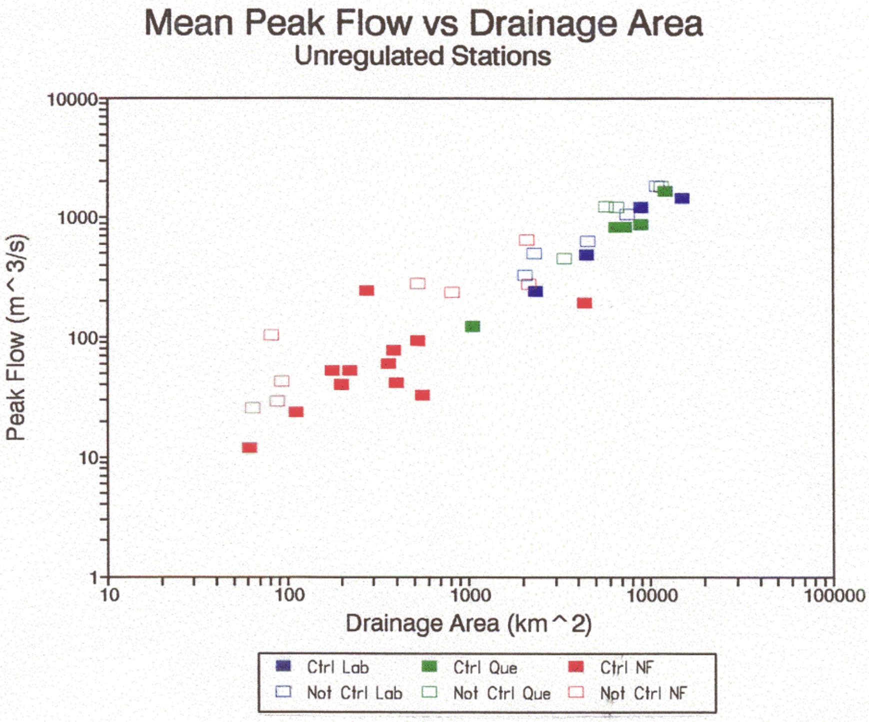


Figure 7.2



compared the mean peak flows calculated from the regression equations.

Finally, the ratios of return period flows to mean peak flows for watersheds which have undergone single station frequency analysis were calculated. These ratios, which are approximately constant, are shown in Table 7.2. The ratios can be multiplied by the mean peak flow of a small to medium sized watershed to arrive at higher return period flood flows for the given drainage area. Mean peak flows on small to medium sized watersheds can be calculated from regression equations developed in this section.

Table 7.2 Ratio of Return Period Flows to the Mean Peak Flow

Station Number	Number of Observations	Q_{10}/Q_m	Q_{25}/Q_m	Q_{50}/Q_m	Q_{100}/Q_m
02XA004	14	1.43	1.65	1.82	1.98
03QC002	15	1.38	1.58	1.73	1.88
02XA003	14	1.42	1.65	1.82	2.00
03NF001	15	1.33	1.49	1.61	1.72
03QC001	25	1.47	1.73	1.92	2.11
03OE001a	17	1.34	1.53	1.67	1.81
Uncontrolled Watersheds:	Maximum	1.47	1.73	1.92	2.11
	Minimum	1.33	1.49	1.61	1.72
	Mean	1.40	1.60	1.76	1.92
	Std. Dev.	0.05	0.09	0.11	0.14
03OE003	14	1.35	1.53	1.65	1.77
03PB002	16	1.32	1.43	1.51	1.58
03NG001	16	1.44	1.67	1.84	2.00
03PB001	16	1.26	1.37	1.45	1.53
03OB002	25	1.27	1.40	1.48	1.57
Controlled Watersheds:	Maximum	1.44	1.67	1.84	2.00
	Minimum	1.26	1.37	1.45	1.53
	Mean	1.33	1.48	1.59	1.69
	Std. Dev.	0.07	0.12	0.16	0.20
All Watersheds:	Maximum	1.47	1.73	1.92	2.11
	Minimum	1.26	1.37	1.45	1.53
	Mean	1.36	1.55	1.68	1.81
	Std. Dev.	0.07	0.12	0.16	0.20

notes: Q_x/Q_m - ratio of X year return period peak flow to the mean annual peak flow
Std. Dev. - standard deviation

7.3 Results

The results of the linear regressions are summarized in Tables 7.3 to 7.5. Regression lines of log-transformed data for the Lab-Que and the Lab-Que-NF regions are

Table 7.3 Linear Regression of Untransformed Data

Region	Ctrl	X Coef	SE X Coef	Const	SEE	R^2	n
Lab-Que	Yes	0.112	0.0139	37.2	177	0.90	9
	No	0.158	0.0162	51.3	160	0.93	9
	All Stations	0.122	0.0151	116.9	246	0.80	18

Table 7.4 Linear Regression of Untransformed Data with Constant=0

Region	Ctrl	X Coef	SE X Coef	Const	SEE	R^2	n
Lab-Que	Yes	0.115	0.0065	0	166	0.90	9
	No	0.164	0.0073	0	152	0.93	9
	All Stations	0.135	0.0075	0	246	0.79	18

Table 7.5 Linear Regression of Log-transformed Data

Region	Ctrl	X Coef	SE X Coef	Const	SEE	R^2	n
Lab-Que	Yes	1.010	0.0599	-0.977	0.0620	0.98	9
	No	0.957	0.1082	-0.620	0.0830	0.92	9
	All Stations	0.970	0.0840	-0.745	0.1087	0.89	18
NF	Yes	0.842	0.0564	-0.352	0.1000	0.95	14
	No	0.894	0.0368	-0.189	0.0639	0.99	8
Lab-Que-NF	Yes	0.862	0.0266	-0.410	0.0907	0.98	23
	No	0.795	0.0309	0.017	0.0973	0.98	17
	All Stations	0.839	0.0314	-0.247	0.1460	0.95	40

Notes: **Ctrl** - Are the watersheds controlled by a large lake near the outlet?
X Coef - X coefficient of the linear equation
SE X Coef - standard error of the X coefficient
Const - constant in the linear equation
SEE - standard error of the Y estimate
R^2 - correlation coefficient
n - number of observations

Figure 7.3

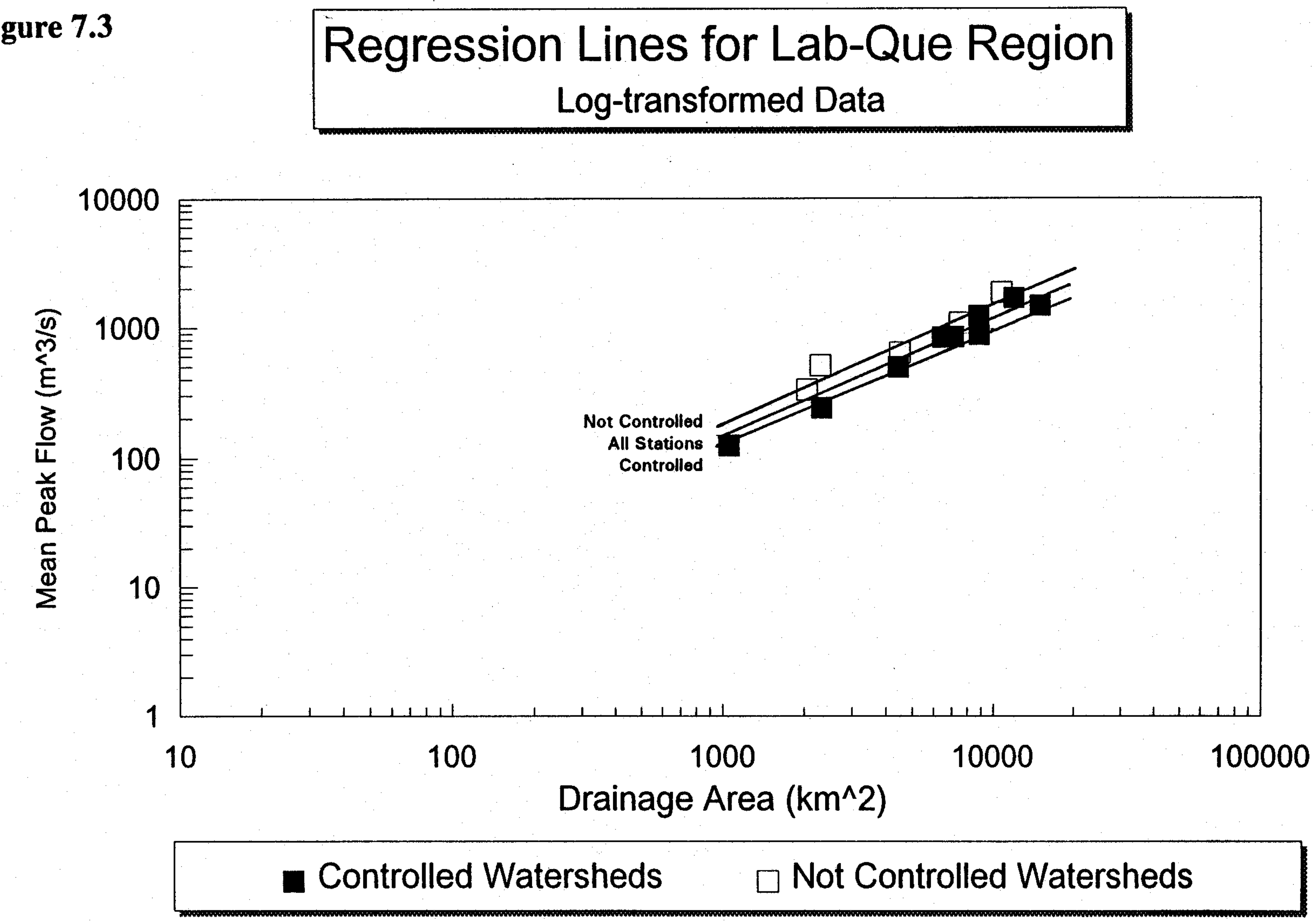
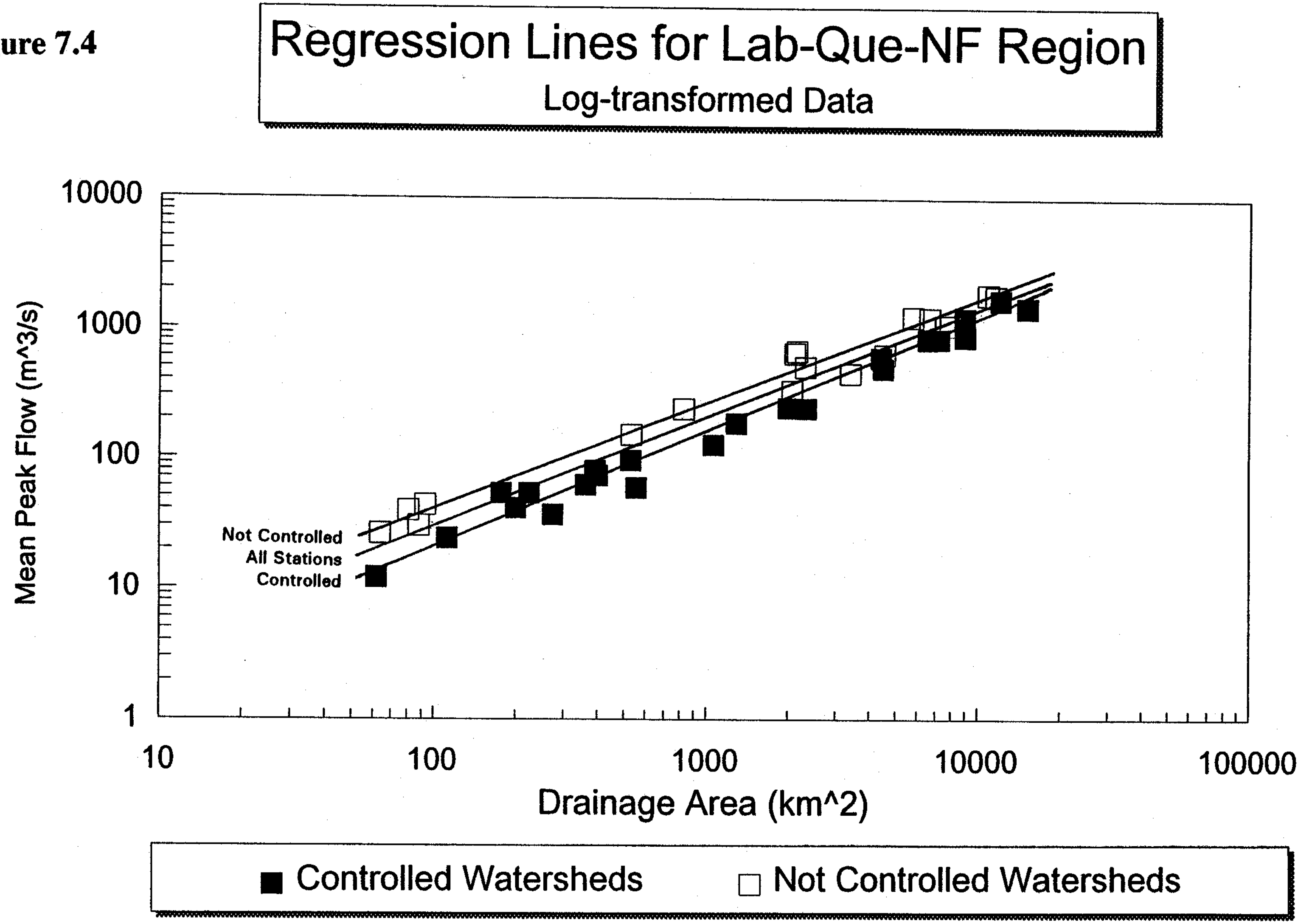

Regression Lines for Lab-Que Region
Log-transformed Data
Mean Peak Flow (m^3/s)
10000
1000
100
10
1
Drainage Area (km^2)
10
100
1000
10000
100000
Not Controlled
All Stations
Controlled
■ Controlled Watersheds
□ Not Controlled Watersheds

Figure 7.4


Regression Lines for Lab-Que-NF Region
Log-transformed Data
Mean Peak Flow (m^3/s)
10000
1000
100
10
1
10
100
1000
10000
100000
Drainage Area (km^2)
Not Controlled
All Stations
Controlled
■ Controlled Watersheds
□ Not Controlled Watersheds

shown in Figures 7.3 and 7.4.

The linear regression of the untransformed data did not work well. This was probably due to the high skewness of the data set. The constant for the controlled and uncontrolled stations combined was unrealistically high, and the standard error of the estimate for the combined data set was large, especially for the prediction of mean peak flows on small watersheds. The constant was forced to zero in a second attempt at linear regression. The standard error of the estimate remained large at 26.2% (246/937.89) of the mean. Data were subsequently log (to base 10) transformed to remove skewness prior to a third linear regression which in one case included and in the other excluded data from a hydrologically similar region on the island of Newfoundland. The correlation coefficient improved dramatically for the controlled data set and also for the combined data set. The standard error of the estimate in log units was 3.8% (0.1087/2.881) of the mean in log units for the combined data set.

For the log-transformed data, the X Coefficients for the Lab-Que Region seem to be high and the constants seem to be low when compared to regression equations which were developed by Gingras, Adamouski, and Pilon (1994) for Quebec and by Beersing (1990) for Newfoundland. X Coefficients greater than 1.0 imply that a doubling of the drainage area would more than double the mean peak flow. While this is not theoretically realistic over the full range of drainage areas it is possible given the small data set and can be explained physically as follows. If the distribution of lake size is uniform throughout

Labrador, then larger watersheds would be less controlled and have higher peak flows per unit area, because the degree of flood attenuation would be smaller due to the fact that the area of the outlet lake, as a proportion of the total drainage area, would be smaller on a larger watershed than on a smaller watershed.

Extrapolating regression equations to drainage areas far below the smallest drainage area in the region (1060 km^2) may be unwise. Data from Newfoundland was utilized to provide a basis for extending the regression line below 1000 km^2. The X Coefficient and the Constant for the Lab-Que-NF regression appear to be more in line with the previous studies done in Quebec and Newfoundland.

Analysis of 3 years of annual maximum instantaneous discharge data on small watersheds in Labrador indicate a mean peak flow of about 20 m^3/s $\pm$ about 5 m^3/s for a 100 km^2 outlet controlled basin. The regression equation which best supports this result is the regression equation which was developed for the outlet controlled log-transformed data in the Lab-Que-NF Region.

Since data for hydrologic design in Labrador is desperately lacking, it is suggested that the most up-to-date data be used at all times. For the estimation of mean peak flows on small to medium sized watersheds, consideration should first be given to the regression equations developed for the log-transformed data in the Lab-Que-NF Region, then to the regression equations developed for the log-transformed data in the Lab-Que Region, and finally the regression equation developed for the linear data in the Lab-Que Region. Due to a general lack of data, estimates of the mean peak flow should be calculated from the equations which typifies the type of outlet control and the equations developed for the combined case. Increasing the X Coefficient and the Constant by a multiple of the % standard error of the estimate should be considered for peak flow design since the regression equations only "estimate" mean peak flows. Consideration should also be given to any new peak flow data on the small watersheds which have been recently established.

To arrive at higher return period flows for small to medium sized watersheds an estimate of the mean peak flow needs to be multiplied by a factor which was calculated from the ratio of higher return period flows to the mean peak flows on watersheds which have undergone single station flood frequency analysis. The ratios are approximately constant with a coefficient of variation between 3.6% and 11.8%. Extreme care should be taken when estimating large return period flows on small watersheds because the higher return period flow to mean peak flow ratio can deviate significantly from the assumed constant value.