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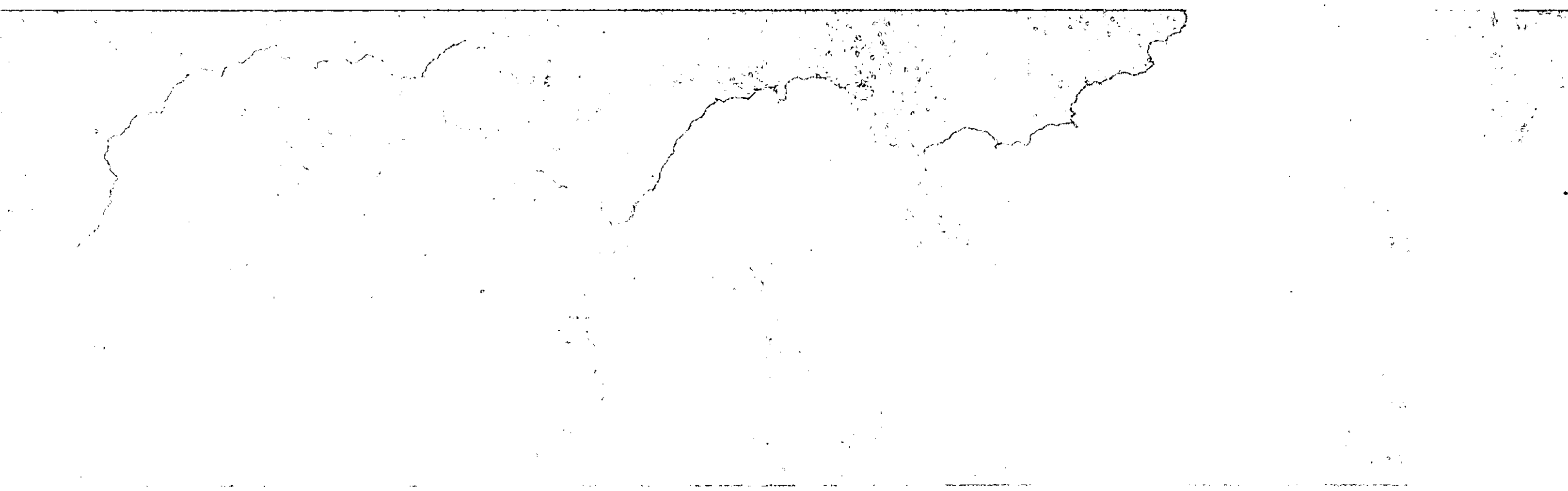
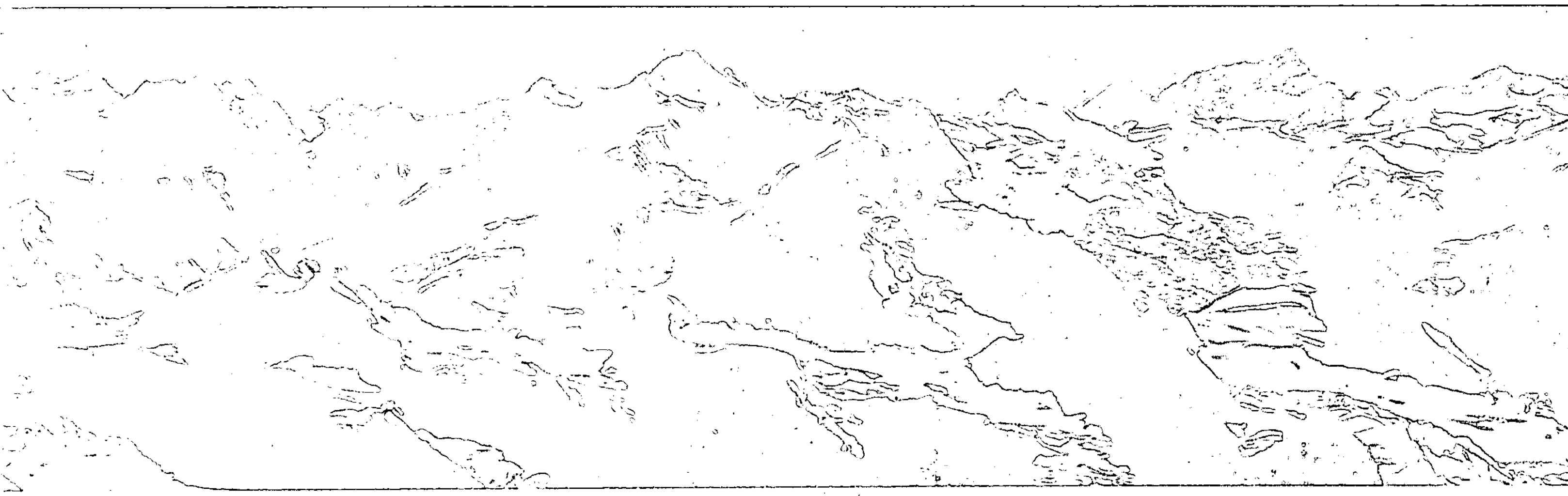
Environment Canada — Environnement Canada

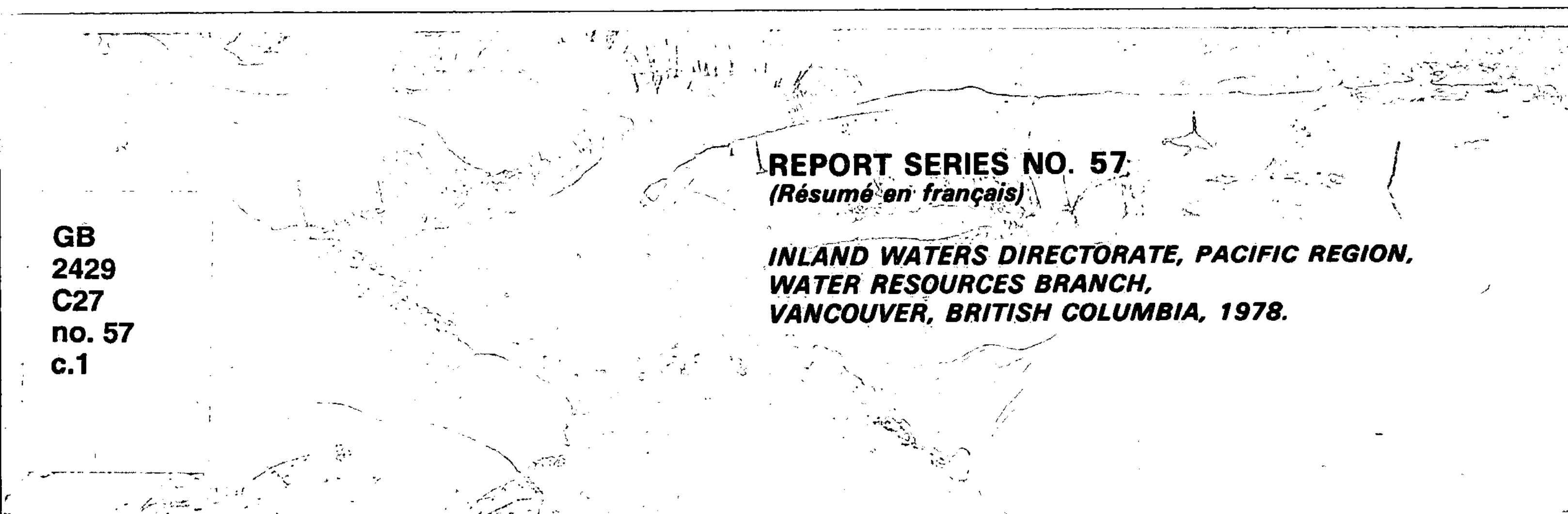
Streamflow Regionalization in British Columbia, No.

Regression of Low Flows on Physiographic Parameters

R.M. Leith







REPORT SERIES NO. 57
(Résumé en français)

INLAND WATERS DIRECTORATE, PACIFIC REGION,
WATER RESOURCES BRANCH,
VANCOUVER, BRITISH COLUMBIA, 1978.

Environment Canada Environnement Canada

Streamflow Regionalization in British Columbia, No. 4

Regression of Low Flows on Physiographic Parameters

R.M. Leith

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ABSTRACT

Mean annual seven-day low flows have been regressed on basin-averaged physiographic parameters for 85 hydrometric stations in British Columbia. To examine the effect of number of stations used in the analysis several sets of random samples were selected from the 85 stations and equations developed for each sample. Finally, for the complete 85-station sample, the following equation was developed for unit mean low flow (UMLF), in cfs per square mile:

$$\begin{aligned} UMLF = {} & 0.6689 + 0.0130\ NPOSI - 0.0001170\ ELEV \\ & + 0.005350\ SLP\% - 0.0007083\ DSN \\ & - 0.0008782\ DSNW + 0.02073\ RALKE \\ & - 0.00009903\ BHW + 0.000008956\ SENW \\ & + 0.00001215\ SEW - 0.000003755\ SESW \end{aligned}$$

This equation explained 65% of the variance and had a standard error of estimate of 0.204 or 52% of the response mean.

Examination of the residuals for the preceding equation provided evidence for the geographical division of the original sample into three regions. Equations were developed for each region.

The regionalization procedure was tested by a split sample which indicated that better estimates were made with the regional equations than with the overall equation.

RÉSUMÉ

On a fait la régression de la moyenne annuelle des débits d'étiage de sept jours, à partir des paramètres physiographiques moyens par bassin, pour 85 stations hydrométriques de la Colombie-Britannique. Afin d'examiner l'effet du nombre de stations utilisées dans l'analyse, on a choisi plusieurs ensembles d'échantillons aléatoires à partir des 85 stations et on a élaboré des équations pour chacun des échantillons. Finalement, pour l'ensemble de l'échantillonnage des 85 stations, on a mis au point l'équation suivante qui porte sur la moyenne unitaire du débit d'étiage (UMLF), en pi^3/s par mille carré:

$$\begin{aligned} UMLF = {} & 0{,}6689 + 0{,}0130\ NPOSI - 0{,}0001170\ ELEV \\ & + 0{,}005350\ SLP\% - 0{,}0007083\ DSN \\ & - 0{,}0008782\ DSNW + 0{,}02073\ RALKE \\ & - 0{,}00009903\ BHW + 0{,}000008956\ SENW \\ & + 0{,}00001215\ SEW - 0{,}000003755\ SESW \end{aligned}$$

L'équation a pu expliquer 65% de la variation et comporte une erreur type d'estimation de 0,204 ou 52% de la moyenne de réaction.

L'examen des résidus de l'équation qui précède a démontré l'utilité de répartir l'échantillon original en trois régions géographiques. Des équations ont porté sur chacune des régions.

Le procédé de régionalisation a pu être vérifié au moyen d'un échantillon fractionnaire qui a révélé que les équations régionales donnent de meilleures estimations que l'équation générale.

STREAMFLOW REGIONALIZATION IN BRITISH COLUMBIA, NO. 4
REGRESSION OF LOW FLOWS ON PHYSIOGRAPHIC PARAMETERS

R.M. Leith

1. INTRODUCTION

This report summarizes the fourth in a series of hydrometric regionalization studies in British Columbia. Regionalization is grouping and analyzing data so inferences may be made concerning data collection and estimates made at ungauged sites. In this study regression is the means of analysis, while grouping is by regions wherein a particular regression equation applies. The hydrometric quantity of concern is mean annual seven-day low flow for 85 basins. These data are taken from Low Flows in British Columbia, Reference 1, which contains a brief description of the data extraction.

2. DISCUSSION

A data-gathering activity requires analysis so that its efficiency may be examined. A part of this analysis should be a means of extending data either in time or space. One means of examination and extension is regression, whereby a response variable is related to predictor variables in a regression equation.

The response variable, unit mean annual seven-day low flow (UMLF), in cfs per square mile, was taken for hydrometric stations which met four conditions:

i) recorded natural or near natural flow;
ii) at least five complete years of record;
iii) recorded flows from basins with drainage areas between 80 and 800 square miles (200 to 2000 square kilometres);
iv) recorded flows from basins for which basin-averaged physiographic parameters are available.

With regard to requirement i), near natural flow refers to flow which suffers mild artificial modification, for example the flow gauged at Station 08NA011, Spillimacheen River near Spillimacheen. This stream has had pondage since 1955. A list of stations used in the study, Appendix 1, notes the known flow modifications.

Five years were considered to be the minimum necessary to define UMLF. The station records are not on a common time base nor are they necessarily continuous.

Because the predictor variables were basin-averaged physiographic parameters extracted from a 10 km x 10 km grid, the lower drainage area limit was imposed so that the average would be taken over at least three squares. The upper limit restricts the station to sampling flow from primarily one region.

Geophysical data, such as basin-averaged physiographic parameters are usually intercorrelated and do not have uniform variance. Therefore, strictly speaking, an F-test cannot be used for determining the significance of terms in a regression equation, so backward elimination and forward selection would be ruled out in development of the best equation. However, an operational assumption is made that F-tests can be used, but validation tests and examining residuals for bias and normalcy become important in selecting the best equation.

The best equation is the one with the lowest standard error, the most nearly normal residuals, and no bias for both calibration and validation samples. The equation may contain an unexpected variable or an unexpected sign. This unexpected result is usually due to the finite sample used in developing the equation. The region of applicability of a multiple regression equation is difficult to specify. A simple example is given in Reference 2, page 7. As a rule of thumb the regression equation should not be used for data outside the range of data used in developing the equation.

The reliability of a regression equation applied to any single basin is impossible to estimate; only when the equation is applied to a set of 30 or more basins can the standard error of estimate be used as a reliability criterion and then only if the set comes from the same population as was used in the development of the equation.

3. PROCEDURE

To examine changes in standard errors of calibration and validation with size of calibration sample, sets of random samples of 16, 32, 48 and 64 stations were taken without replacement from the 85 stations. For each sample a regression equation was developed for the unit mean annual seven-day low flow (UMLF). UMLF was chosen to remove the effect of drainage area. No other variable transformations were considered for this part of the study.

Equations were developed by selecting those physiographic parameters most highly correlated with UMLF. If parameters were highly correlated, the parameter with the highest F-value was selected as a possible regression variable. The equations were developed by backward elimination procedure of TRIP, Triangular Regression Package of the University of British Columbia. For the smaller samples the number of observations limited the maximum number of variables in an equation.

For each equation the standard error of estimate was taken as the standard error of calibration. When the equation was applied to the stations not used in its development, the mean square of the residuals so produced was the standard error of validation. For each equation the significant physiographic parameters were noted so that overall important parameters could be identified.

Equations for all 85 stations were developed by considering all variables as possible and using backward elimination. Scatter plots were examined for indication of transformation.

Equations were tested by probability plots of residuals, geographical plots of residuals, plots of residuals versus predicted UMLF, and by calculation of skew and kurtosis for the residuals. Procedures are described in Reference 3.

A geographical plot of residuals provided evidence for subdividing the study area into three regions: Southeastern British Columbia, Coast and Vancouver Island, and Interior. For the Coast and Island region, scatter plots suggested transformation of the predictor variables. With these transformations equations were developed and tested. The value of regionalization was tested by examining standard errors and residuals before and after subdivision.

To assess the effect of a more nearly common time base, a subsample of 69 stations with records between 1950 and 1972 was analyzed. Stations do not necessarily have records over the complete period, for example, there may be records from 1962 to 1970.

The effect of time of occurrence of low flow was examined by establishing two categories. Basins in Category 1 had low flows primarily in the summer or fall and basins in Category 2 had low flows primarily in the winter. Stations having lows equally distributed between fall and winter were excluded from analysis.

4. RESULTS AND OBSERVATIONS

Standard errors and standard deviations for random samples of 32 stations are displayed in Figure 1. The distributions of the standard errors appear symmetrical, while that of the standard deviation is skewed to the left, indicating that some of the samples used in developing the equations may have had unrepresentative small standard deviations so that the validation errors could be large.

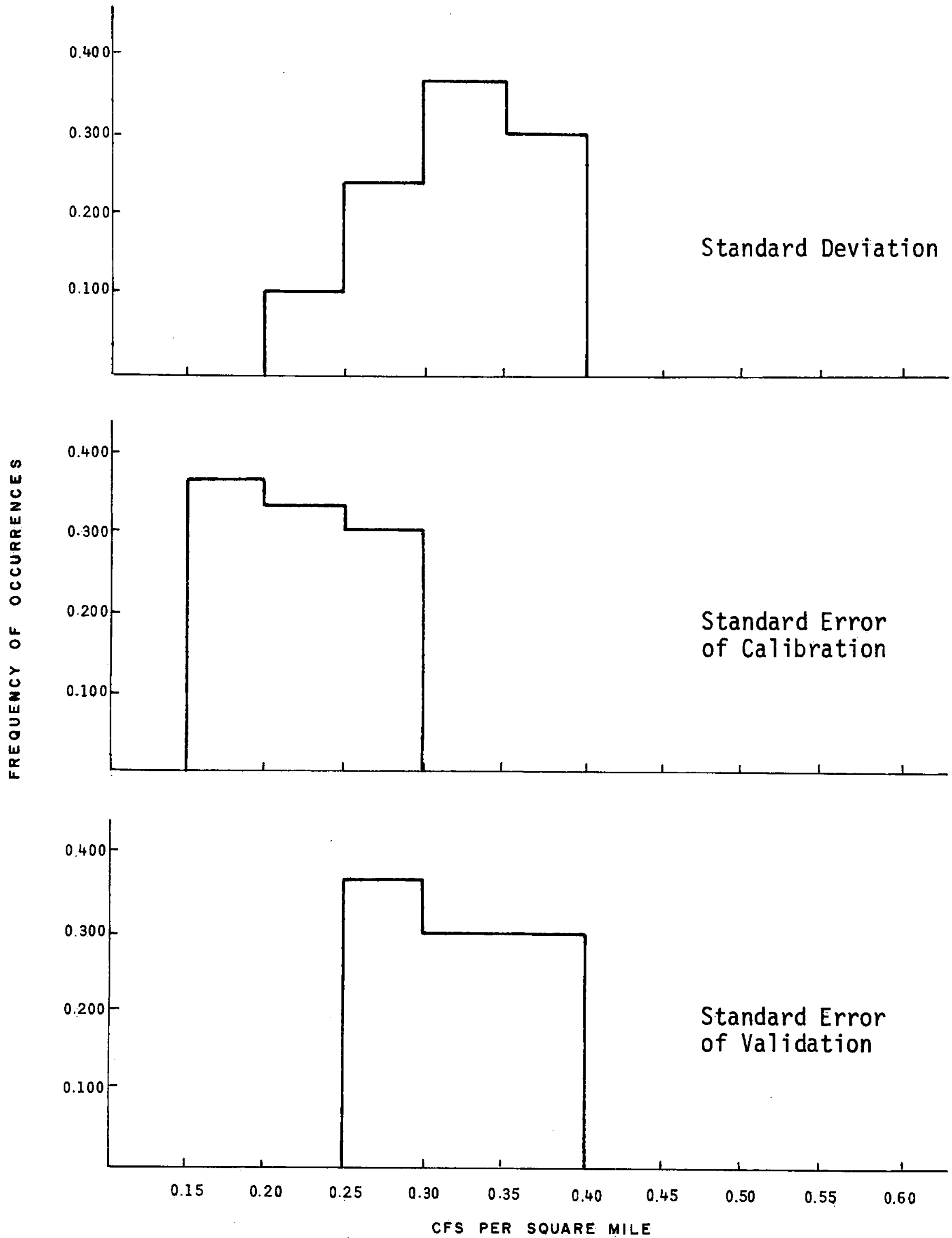

Figure 1. Frequency distributions of standard deviation, standard error of calibration and standard error of validation for 30 random samples of 32 stations.

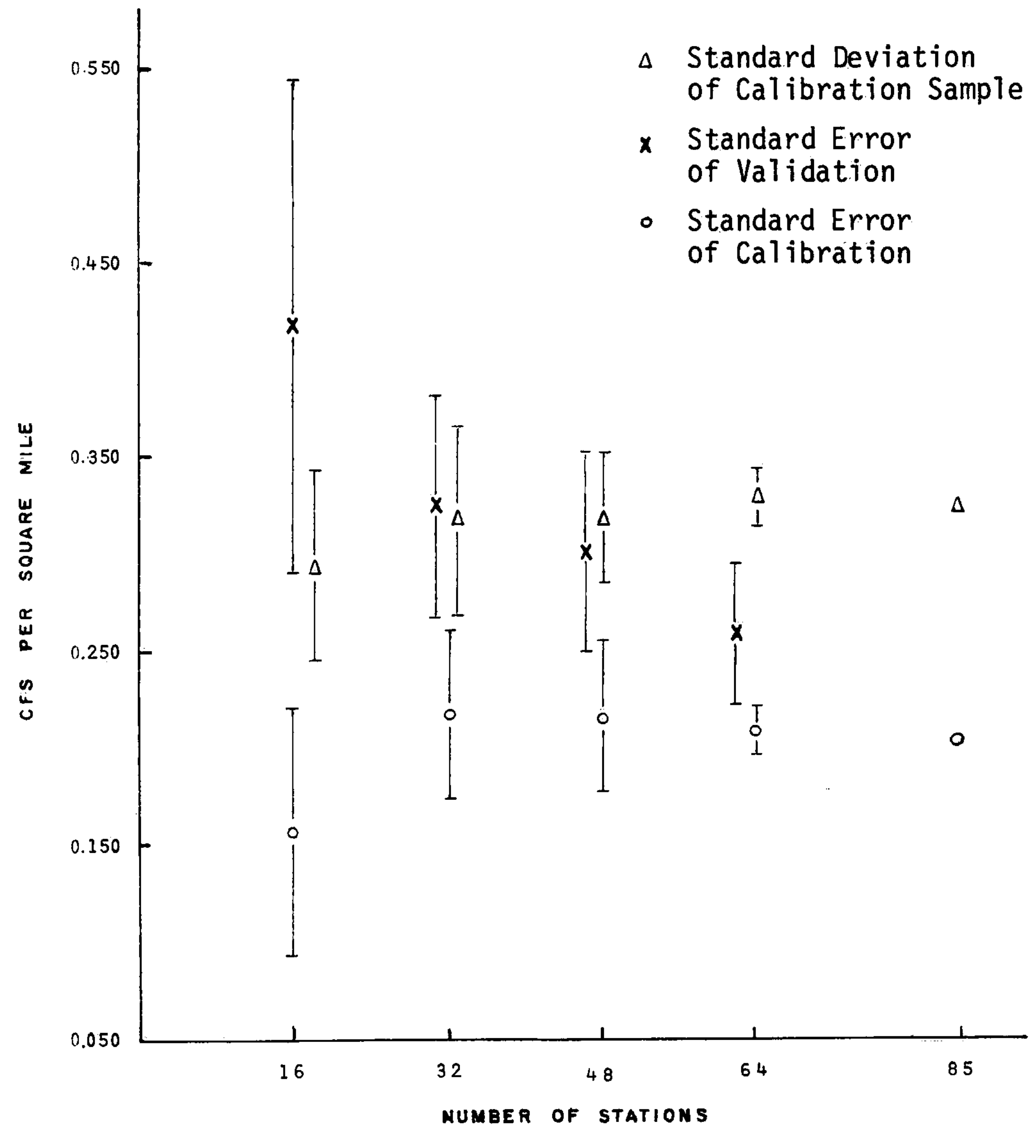

Figure 2. Results of random sampling on standard deviation, standard error of calibration and standard error of validation.

Results of the random sampling equation development are summarized in Figure 2. Mean values and mean values plus and minus one standard deviation have been plotted to indicate the spread in standard errors and standard deviations for each size of random sample.

Figure 2 suggests that for the 85-station equation the standard error of validation would fall between 0.200 and 0.250. With the mean of UMLF for the 85-station sample being 0.394, the percent of response mean is between 51 and 64. The final 85-station equation has a standard error of calibration of 0.204, well below the standard deviation of 0.325. The variability of the 64-station samples is probably underestimated because of the number of common stations appearing in the samples.

Because of the difficulty in determining the best equation by an F-test, two 85-station equations were developed: a 10-variable equation for analysis and a 7-variable equation for quick estimates.

<u>85-Station Equation (10 variables)</u>

R^2 = 0.6524 FPROB = 0.0000

S.E. = 0.2040 52% of response mean

$$\begin{aligned} UMLF = {} & 0.6689 + 0.0130\ NPOSI - 0.0001170\ ELEV \\ & + 0.005350\ SLP\% - 0.0007083\ DSN \\ & - 0.0008782\ DSNW + 0.02073\ RALKE \\ & - 0.00009903\ BHW + 0.000008956\ SENW \\ & + 0.00001215\ SEW - 0.000003755\ SESW \end{aligned}$$

<u>85-Station Equation (7 variables)</u>

R^2 = 0.6015 FPROB = 0.0000

S.E. = 0.2141 54% of response mean

$$\begin{aligned} UMLF = {} & 0.4998 + 0.0111\ NPOSI - 0.00006876\ ELEV \\ & + 0.006429\ SLP\% - 0.0006558\ DSN \\ & - 0.0005961\ DSNW + 0.0307\ RALKE \\ & + 0.000004838\ SENW \end{aligned}$$

The abbreviations for the physiographic parameters are explained in Appendix 2. Appendix 3 provides an example of estimating basin-averaged physiographic parameters and their application in a regression equation. A list of basins in British Columbia for which 10 km x 10 km basin-averaged physiographic parameters are available can be provided from the Planning and Studies Section of the Water Survey of Canada, Vancouver.

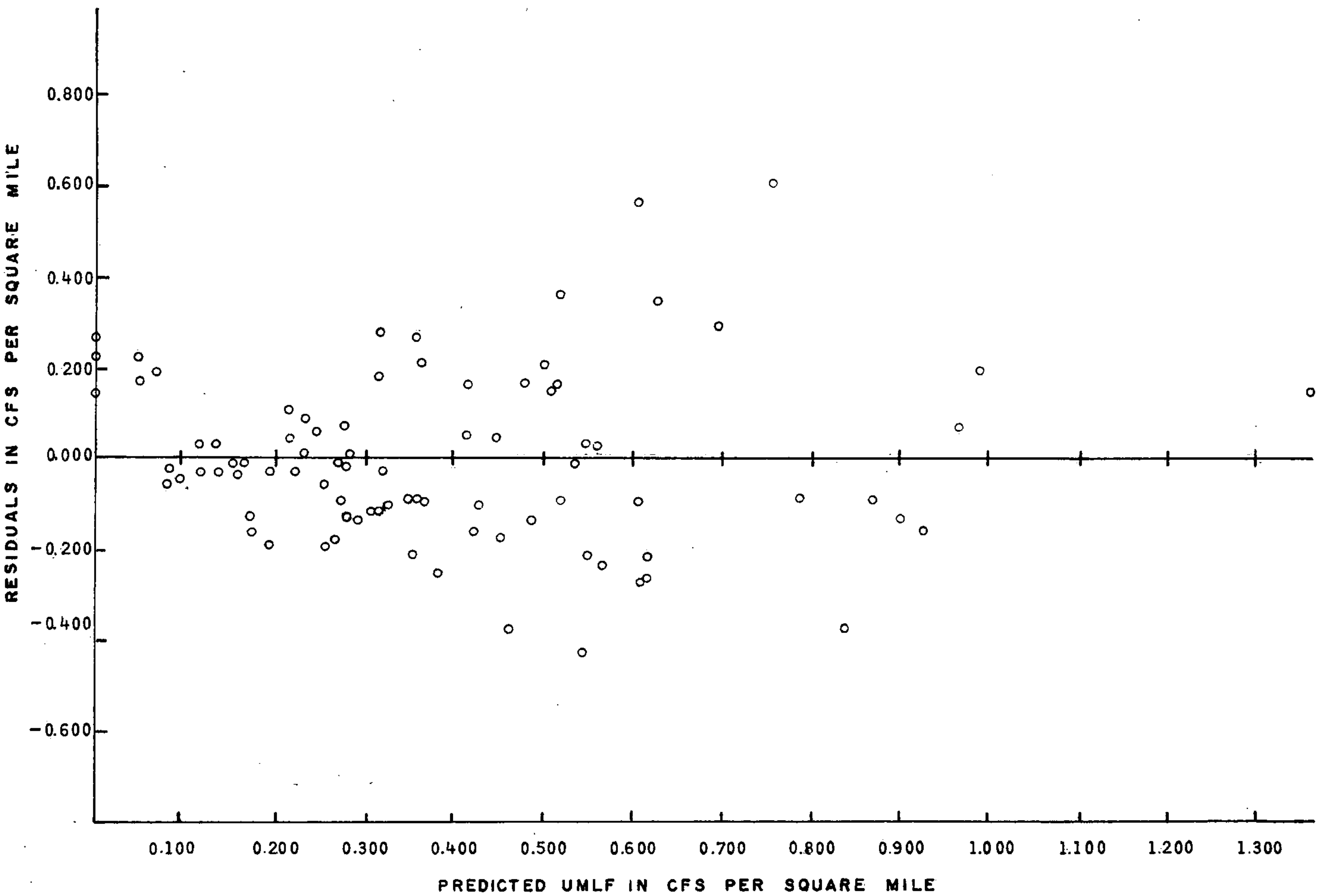

Figure 3. Residuals for the 10-variable 85-station equation plotted against predicted unit mean annual seven-day low flows.

Figure 3 is a plot of residuals from the 10-variable equation against predicted UMLF. There is a suggestion of more large positive residuals than large negative residuals, which suggests the equation may underestimate. The probability plot, Figure 4, reinforces this observation with the residuals behaving normally except for the large positive residuals. For normally distributed residuals skew equals 0.0 and kurtosis equals 3.0.

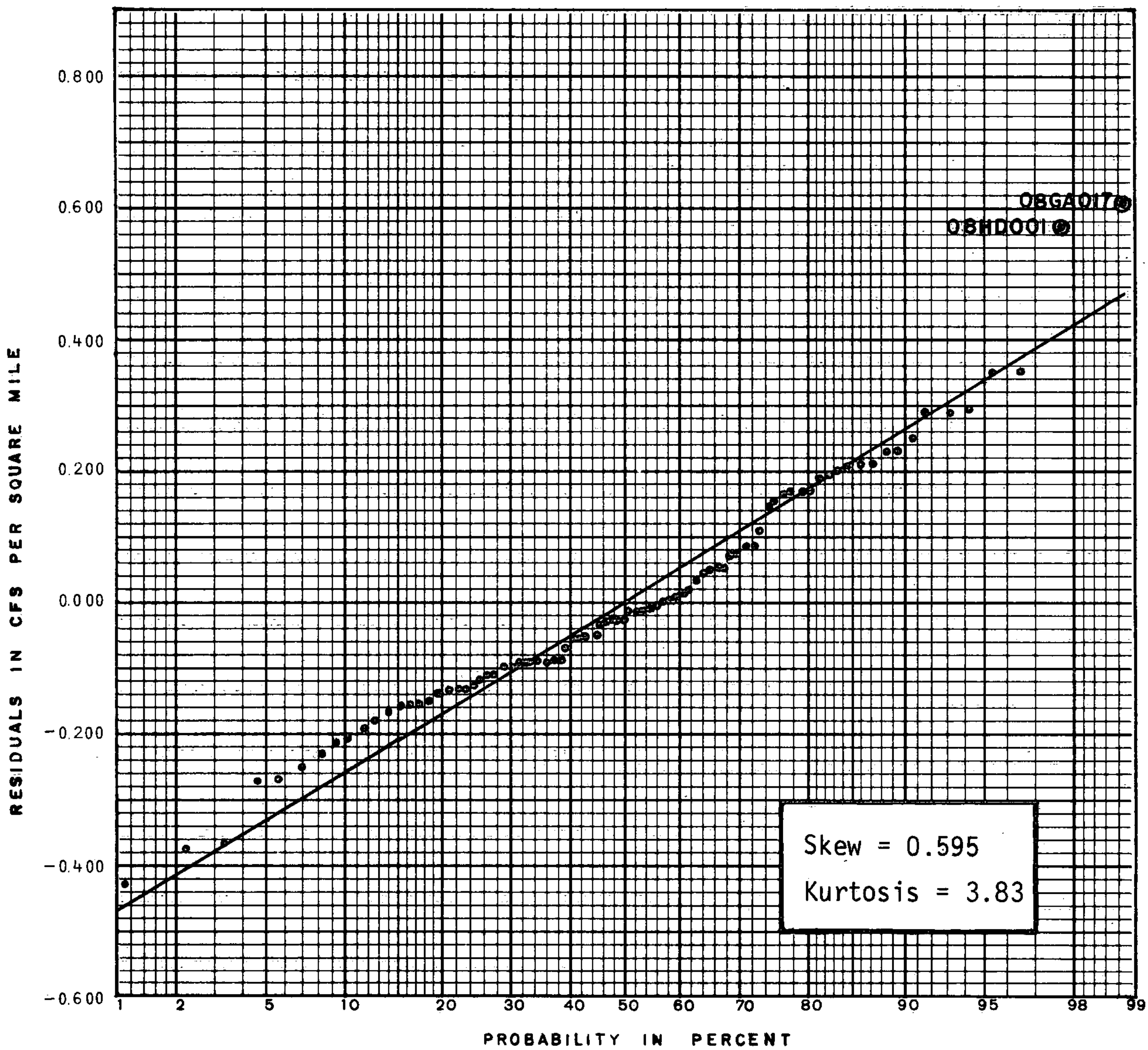

Figure 4. Probability plot of residuals for 10-variable 85-station equation.

A geographical plot of residuals from the 10-variable equation indicated several large residuals in the Coastal and Vancouver Island area while in Southeastern British Columbia there is a concentration of positive residuals. Stations in these regions were used in developing separate regional equations. The remaining stations were grouped in the Interior region.

Equation for Southeastern British Columbia with 31 Stations

$R^2 = 0.8680$ FPROB = 0.0000

S.E. = 0.0796 22% of response mean

$$UMLF = 4.5774 - 0.0254\ NPOSI - 0.001135\ DSN + 0.001533\ DSW - 0.0001007\ BHN + 0.00001231\ SENW - 0.009276\ SSSE$$

Equation for Coast and Vancouver Island with 21 Stations

$R^2 = 0.8466$ FPROB = 0.0001

S.E. = 0.2085 32% of response mean

$$UMLF = 4.0151 - 0.00006356\ (NPOSI)^2 - 0.0001874\ (NPOSJ)^2 - 0.00000005229\ (ELEV)^2 - 0.00000005452\ (BHN)^2 + 0.0000001737\ (BHW)^2 - 0.0000002577\ (BHSW)^2$$

Equation for Interior with 33 Stations

$R^2 = 0.8403$ FPROB = 0.0000

S.E. = 0.1113 44% of response mean

$$UMLF = 0.2869 + 0.001322\ NPOSI + 0.002986\ SLP\% + 0.0413\ RALKE - 0.0001325\ BHW - 0.000006038\ SESW - 0.009456\ SSNE + 0.004374\ SSE$$

The value of regionalization could be assessed by the reduction in standard error of calibration. However, the number of stations in each region is low, particularly in the Coast and Island region, and by Figure 2 the error of validation when the equations are applied to a split sample may be much larger than the standard error of calibration.

Table 1 shows the results for a split sample of 18 stations. The lumped standard error of validation for the regional equations is lower than that of the 10-variable equation, however, an F-test indicates the difference is not statistically significant. The residuals are not normally distributed for either the 10-variable equation or the regional equations.

TABLE 1. Split Sample Test

Station Number	Residuals for: 10-Variable 85-Station Equation	Southeast British Columbia	Coast and Vancouver Island	Interior	Observed UMLF
08GA024	0.181		0.099		0.918
08NH120	-0.188	-0.076			0.099
08DC006	0.147		0.097		0.425
07FC003	-0.597			-0.047	0.003
08LG048	-0.412			-0.144	0.159
08KA001	0.081			-0.070	0.280
08NG004	0.112	0.169			0.121
08ND014	0.232	0.222			0.649
08EB004	-0.067			-0.023	0.236
08HF001	-0.334		-0.964		0.292
08KH008	-0.241			-0.408	0.312
08GA054	1.71		0.908		1.89
08KH019	0.054			0.015	0.060
08HF002	0.251		-0.186		0.964
08ME015	-0.511		-0.170		0.496
08FA001	0.315		-0.576		0.781
08MF009	0.043		0.266		0.843
08DD001	0.261		0.074		0.604
Sum of Squares	2.72	0.084	2.24	0.195	
Number of Variables	10	6	6	7	
Mean Square or Standard Error of Validation	0.623	0.501 (combined)			

	85-Station Sample	18-Station Sample
Mean	0.394	0.507
Standard Deviation	0.325	0.475

For the residuals in Table 1, the ratio of the sum of mean squares for the 10-variable equation to that for the regional equations is:

$$FCAL = \frac{2.72/(18-10-1)}{2.52/(18-7-1)} = 1.54$$

The tabulated F-ratio for 7 and 10 degrees of freedom is 3.14 at 5% confidence level, so the difference in mean square of the standard error of validation is not statistically significant.

For the 69 stations with records between 1950 and 1972 the following equation was developed:

$$R^2 = 0.7131 \qquad FPROB = 0.0000$$

$$S.E. = 0.174 \qquad 49\% \text{ of response mean}$$

$$\begin{aligned} UMLF = {} & 0.8306 + 0.0110\ NPOSI - 0.00008874\ ELEV \\ & + 0.007203\ SLP\% - 0.0007726\ DSN \\ & - 0.0005977\ DSNW - 0.00005684\ BHW \\ & + 0.000005645\ SENW \end{aligned}$$

The standard error of calibration is lower than the mean standard error of calibration minus one standard deviation for 69 stations in Figure 2. This indicated that bringing the data to a common time base could increase accuracy. The equation would then be applicable to the chosen time period only, so a long period would be desirable. The equation is similar to the short 85-station equation except for BHW instead of RALKE. The standard errors of the coefficients are listed in Table 2.

TABLE 2. Comparison of Regression Coefficients and Their Standard Errors of Estimate

	69-Station Equation		Short 85-Station Equation	
	Coefficient	Standard Error	Coefficient	Standard Error
Constant	0.8306	0.1987	0.4998	0.2304
NPOSI	0.0110	0.001799	0.0111	0.002076
ELEV	-0.00008874	0.00002726	-0.00006876	0.00002498
SLP%	0.007203	0.001011	0.006429	0.001127
DSN	-0.0007726	0.0001389	-0.0006558	0.0001603
DSNW	-0.0005977	0.0001381	-0.0005961	0.0001548
SENW	0.000005645	0.000001763	0.000004838	0.000002061

The plots of probability and residuals versus predicted UMLF indicated no unusual behaviour; only two stations, 08GA010 Capilano River above Intake (0.494) and 08NH006 Moyie River at Eastport (-0.450), stood out with unusual residuals.

After the stations had been separated according to season of low flow occurrence, only 16 had lows in summer and fall. No reliable equation with less than six variables could be developed, but for the 59 stations with low flows in winter,

R^2 = 0.7108 FPROB = 0.0000

S.E. = 0.1529 37% of response mean

$$\text{UMLF} = 1.3125 + 0.006537\ \text{NPOSI} - 0.0001755\ \text{ELEV} - 0.0009850\ \text{DSSW} - 0.00008697\ \text{BHW} - 0.0001731\ \text{BHSW}$$

The standard error of calibration is lower than the mean minus one standard deviation for 59 stations, Figure 2, indicating that different equations could pertain to the seasons of occurrence of low flows.

5. CONCLUSIONS AND RECOMMENDATIONS

Grouping and analyzing mean low flows by regression suggests that Interior and Coastal British Columbia are undergauged, and if additional gauges are installed, consideration should be given to sampling physiographic parameters such as elevation, basin slope, distances to the sea, relative areas of lakes and shield effects.

No conclusions could be drawn about the low flow data in Northern British Columbia because of the scarcity of available stations.

For developing regional regression equations a common time period for records appears to reduce the standard error of calibration. As long records are required for good definition of mean low flow and to expand the usefulness of the regional estimates, then stations should be operated for long periods or reliable methods developed for extending records.

Regionalization or dividing the total sample into regions of similar response appears to improve the accuracy of validation of a split sample, although the improvement is not statistically distinct.

Regression is a statistical technique that provides the most reliable results in the centre region of the ranges of values of the predictor variables used in the development of the equation. Appendix 4 provides a guide to what should be the best ranges of values for use in the equations for mean annual seven-day low flow.

REFERENCES

1. Water Survey of Canada. Low Flows in British Columbia, Annual 7-Day Averages. Inland Waters Directorate, Pacific Region, Water Resources Branch, Vancouver, B.C., 1974.

2. Draper, N.R., and Smith, H. Applied Regression Analysis. John Wiley and Sons Inc., 1966.

3. Leith, R.M. Streamflow Regionalization in British Columbia, No. 2. Regression of Mean Annual Flows on Physiographic Parameters. Report Series No. 46. Inland Waters Directorate, Pacific Region, Water Resources Branch, Vancouver, B.C., 1976.

APPENDIX 1. List of Stations Used in Study

Coast Region

Station Number	and Name			Comments
08MH014	Alouette River	S		
08MG008	Birkenhead River	W	*	
08ME004	Bridge River	W		
08ME005	Bridge River	W		
08HD001	Campbell River	S		
08GA010	Capilano River	S	*	
08GA017	Cheakamus River	W		Mean 1917-1956
08HA001	Chemainus River	S	*	
08MB004	Chilanko River	W	*	
08MA002	Chilko River	W	*	
08MH001	Chilliwack River		*	
08MF003	Coquihalla River	S	*	
08HA002	Cowichan River	S	*	Mean 1913-1957
08EG012	Exchamsiks River	W	*	
08MG003	Green River	W		
08CG003	Iskut River	W	*	
08EF004	Kitsequecla River	W	*	
08HA010	San Juan River	S	*	
08MG007	Soo River	W		
08HB011	Tsolum River	S	*	
08EG011	Zymagotitz River	W	*	

W Lows occurred predominantly in winter months

S Lows occurred predominantly in summer and fall months

* Stations used in developing the 69-station equation on page 12

Appendix 1. (cont'd)

Interior Region

Station Number and Name				Comments
08KE016	Baker Creek		*	
08LB069	Barriere River	W		
10AC004	Blue River	W	*	
08LF062	Bonaparte River	W	*	Regulated
08KD001	Bowron River	W	*	
08KE015	Cale Creek	S	*	
08LA013	Clearwater River	W	*	
10AC005	Cottonwood River	W	*	
08KE009	Cottonwood River	W	*	
08LF007	Criss Creek	S	*	
10AC003	Dease River	W	*	
09AA014	Fantail River	W	*	
08KA007	Fraser River	W	*	
09AE004	Gladys River	W	*	
08KH010	Horsefly River	W	*	
09AA010	Lindeman Creek	W	*	
08LB050	Mann Creek		*	
08KA008	Moose River	W	*	
08ED002	Morice River	W	*	
08LA004	Murtle River	W	*	
08KE014	Naver Creek	S	*	
09AA008	Pine Creek	W	*	
08LB017	Raft River	W	*	
10CB001	Sikanni Chief River	W	*	
08PA001	Skagit River		*	
08BB002	Sloko River	W	*	
08NL008	Tulameen River	S		Regulated since 1951
09AA013	Tutshi River	W	*	
08NM015	Vaseux Creek		*	

APPENDIX 1. (cont'd)

Interior Region

Station Number and Name				Comments
09AA015	Wann River	W	*	
08NN015	West Kettle River	W	*	
08JA003	Whitesail River	W		
08NC001	Wood River	W	*	

Southeastern Region

08ND001	Akolkolex River	W		
08NE077	Barnes Creek	W	*	
08NE039	Big Sheep Creek	S	*	
08NA001	Bugaboo Creek	W	*	
08NA045	Columbia River	W	*	
08ND009	Downie Creek	W	*	
08NH119	Duncan River	W	*	
08LE024	Eagle River	W	*	
08NK016	Elk River	W	*	
08NG001	Findlay Creek	W	*	
08NP001	Flathead River	W	*	
08NH004	Goat River	W	*	Regulated 1934-52
08ND012	Goldstream River	W	*	
08NA005	Horsethief River	W		
08NE001	Incomappleux River	W	*	
08NH005	Kaslo River	W	*	
08NF001	Kootenay River	W	*	
08NE006	Kuskanax River	W	*	
08NH066	Lardeau River	W	*	
08NH007	Lardeau River	W	*	
08NH006	Moyie River	S	*	
08NH034	Moyie River	S	*	

APPENDIX 1. (cont'd)

Southeastern Region

Station Number and Name				Comments
08NG046	St. Mary River	W	*	
08NE074	Salmo River		*	
08NE044	Salmo River			
08LE027	Seymour River	W		
08NG051	Skookumchuck Creek	W	*	
08NJ014	Slocan River	W	*	
08NA011	Spillimacheen River	W		Pondage since 1955
08NA012	Toby Creek	W		
08NF004	Vermilion River	W	*	

APPENDIX 1. (cont'd)

Split Sample Test

Station Number and Name		Region
08GA024	Cheakamus River near Mons	C
08NH120	Moyie River above Negro Creek	SE
08DC006	Bear River above Bitter Creek	C
07FC003	Blueberry River below Aitken Creek	INT
08LG048	Coldwater River near Brookmere	INT
08KA001	Dore River near McBride	INT
08NG004	Gold River near Newgate	SE
08ND014	Jordan River above Kirkup Creek	SE
08EB004	Kispiox River near Hazelton	INT
08HF001	Kokish River at Beaver Cove	C
08KH008	Little Horsefly River near Horsefly	INT
08GA054	Mamquam River above Mashiter Creek	C
08KH019	Moffat Creek near Horsefly	INT
08HF002	Nimpkish River near Englewood	C
08ME015	Portage River near Seton Lake P.O.	C
08FA001	Sandell River near Wadhams	C
08MF009	Silverhope Creek near Hope	C
08DD001	Unuk River near Stewart	C

C Coast and Vancouver Island Region
INT Interior Region
SE Southeastern British Columbia Region

APPENDIX 2. Definition of Physiographic Parameters

Parameters	Symbols	Units	Explanation
Drainage Area	AREA	Square Miles	Total drainage area for basin
Grid Coordinates	NPOSI NPOSJ	Dimensionless	Coordinates for the centre of gravity of basin, see Appendix 3 for conversion to latitude and longitude
Elevation	ELEV	Feet	Average elevation of basin
Percent Slope x 10	SLP%		Basin slope average over the squares included in basin
Azimuth	SLPAZ	Degrees	Angle between the west-east direction and the horizontal projection of the line of steepest descent of the local slope plane
Distance to Sea			
North Northwest West Southwest	DSN DSNW DSW DSSW	Kilometres	Distance from centre of gravity of basin to the sea in the north, the northwest, west, and southwest directions
Relative Area			
Lake Forest Swamp Glacier Urban	RALKE RAFOR RASWP RAGLC RAURB	Dimensionless	Percentage of the area of basin occupied by lakes, forests, swamp, glaciers and built-up areas Note: ΣRA does not always equal 100
Barrier Height			
North Northwest West Southwest	BHN BHNW BHW BHSW	Feet	Difference between average elevation of basin and highest elevation encountered in the north, northwest, west and southwest directions until the ocean is reached

APPENDIX 2. (cont'd)

Parameters	Symbols	Units	Explanation
Shield Effect			
North	SEN	Feet	Sum of elevation differential of all ascending stretches of terrain encountered when travelling from ocean shore at north, northwest, west, southwest directions to corresponding point
Northwest	SENW		
West	SEW		
Southwest	SESW		
Signed Slope			
Northeast	SSNE	Feet/Kilometres	Takes into account general configuration of the terrain
East	SSE		
Southeast	SSSE		

Note:

Further information and references on these parameters may be found in Hydrometric Network Planning Study for Western and Northern Canada Report 5019-70, November 1970, by the Shawinigan Engineering Company Limited, Section 4.2.1, page 33.

APPENDIX 3. Estimating Basin-averaged Physiographic Parameters

Physiographic parameters are estimated for 08NH032 Boundary Creek near Porthill (97 square miles) and 08NH084 Arrow Creek near Erickson (30.1 square miles). The parameters are available for 08NH084 for comparison, but part of Boundary Creek basin is in the United States and parameters are not available.

The parameters are estimated by comparison with nearby basins:

	08NH004 Goat River near Erickson	08NE044 Salmo River near Waneta	08NE074 Salmo River near Salmo
NPOSI	199	193	192
ELEV	5470	4320	4416
DSN	2190	1980	1978
DSW	730	600	594
BHN	4130	3940	3925
SENW	205400	184900	184660
SSSE	4	-13	-14

Boundary Creek is between 08NH004 and 08NE044, so that NPOSI is estimated to be 194, which agrees with the value from the graph of NPOSI as a function of longitude.

The basin is to the south of the others, so DSN is estimated as 2200. The distance to the sea to the west is less than that for 08NH004 and greater than that for 08NE044, so is about 650.

The basin's mean elevation is 4100 feet, similar to 08NE044, so the barrier height to the north is approximately 4000 feet.

The shield effect to the northwest would be slightly greater than 08NH004 as the basin is lower, but 08NH004 is to

APPENDIX 3. (cont'd)

the east, so estimate 204000.

Boundary Creek is a moderately steep east-facing basin, so estimate a positive signed slope to the southeast, approximately 12.

Using the same estimating procedure:

08NH084	Estimated	From Data Bank
AREA	-	28
NPOSI	198	199
DSN	2100	2200
DSW	710	710
BHN	4100	5040
SENW	205000	206200
SSSE	2	2

Using these data in the regional equation for South-eastern British Columbia:

	Estimated Parameters Prediction	Data Bank Prediction	Recorded UMLF
08NH084	0.345	0.1264	0.372
08NH032	0.173	-	0.209

$NPOSJ = -537 + 11.2\ \text{Latitude}$

Equation valid for, $48°N < \text{Latitude} < 61°N$

Latitude in degrees as $59° 30' = 59.5°$

$NPOSI = 1075 - 7.5\ \text{Longitude}$

Equation valid for, $116°W < \text{Longitude} < 143°W$

APPENDIX 4. Statistics for Physiographic Parameters Used in Study. Units as noted in Appendix 2.

	Mean	Standard Deviation	Maximum	Minimum
AREA	349	198	800	62
NPOSI	157	42	212	55
NPOSJ	47	36	132	11
ELEV	4603	1328	7017	1136
SLP%	61	23	115	5
SLPAZ	183	98	350	14
DSN	1926	345	2395	958
DSNW	2278	1075	3393	226
DSW	581	250	990	64
DSSW	489	252	989	52
RALKE	1.78	2.82	9	0
RAFOR	70.3	22.7	99	11
RASWP	0.29	1.11	9	0
RAGLC	2.98	6.66	48	0
RAURB	0.0	0.0	0	0
BHN	3135	1235	6733	1160
BHNW	2457	868	5886	690
BHW	2195	841	3920	47
BHSW	1715	939	4490	400
SEN	42800	14500	88490	18300
SENW	132000	63100	200000	7910
SEW	35000	18600	71300	2070
SESW	48300	41800	128200	1850
SSNE	1.14	13.2	32	-26
SSE	1.06	24.4	65	-64
SSSE	0.376	12.5	38	-38

APPENDIX 4. (cont'd)

Frequency of Occurrence of Physiographic Parameters in Random Sample Equations

	16-Station	32-Station	48-Station	64-Station
NPOSI	2			8
NPOSJ	1	3	17	4
ELEV	4	9	14	13
SLP%	15	24	24	15
SLPAZ	1		1	
DSN	5	3		11
DSNW	7	11	17	15
DSW	6	5	5	8
DSSW	4	4	1	
RALKE	3	7	9	10
RAFOR	1			2
RASWP	1			
RAGLC	3	1		
RAURB				
BHN	4	4	3	
BHNW	2		3	
BHW	8	5	3	4
BHSW	7	6	5	4
SEN	6	4	7	
SENW	10	9	5	7
SEW	2		4	5
SESW	2		1	5
SSNE	2	1	1	
SSE	5	3	2	1
SSSE	5	1		