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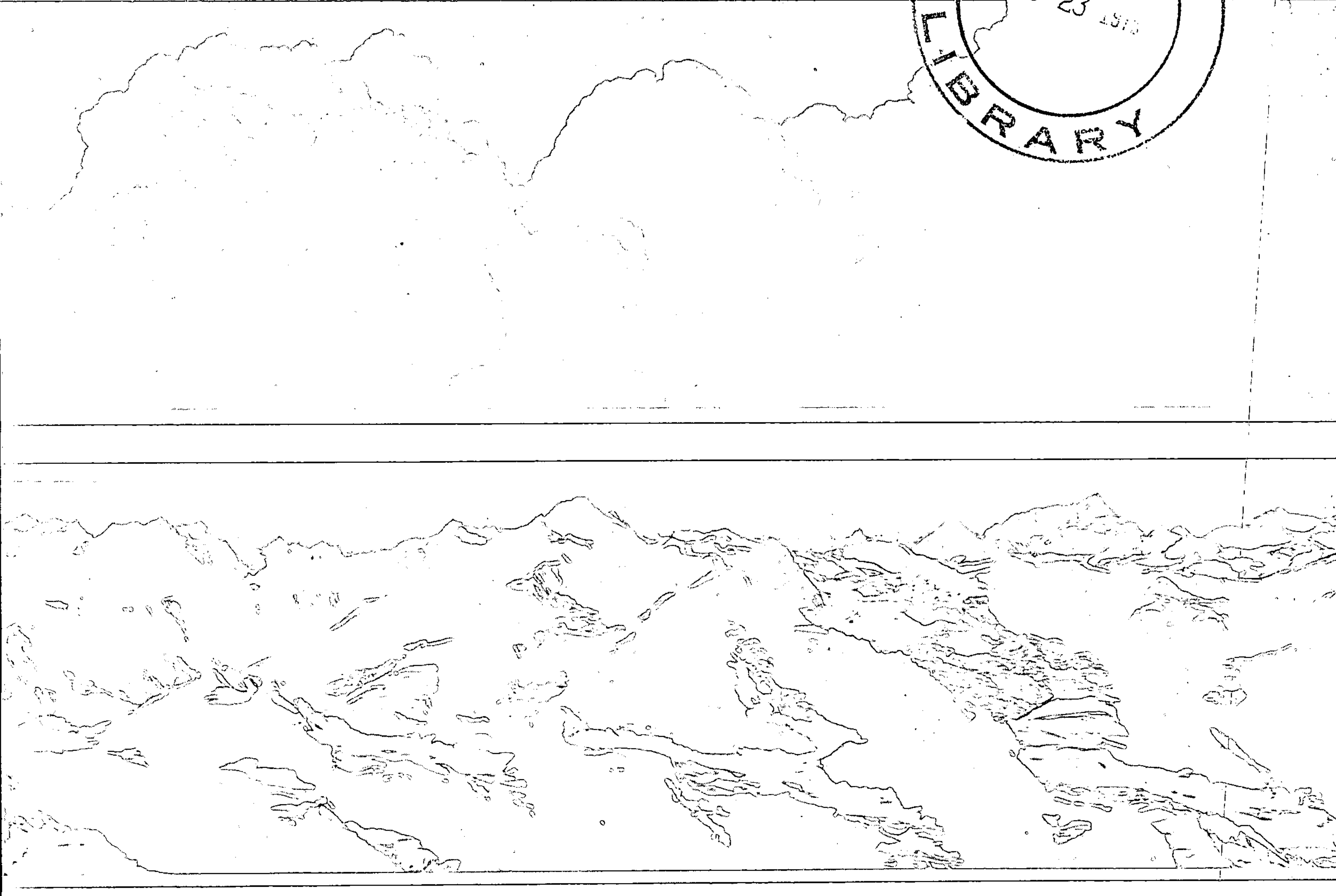
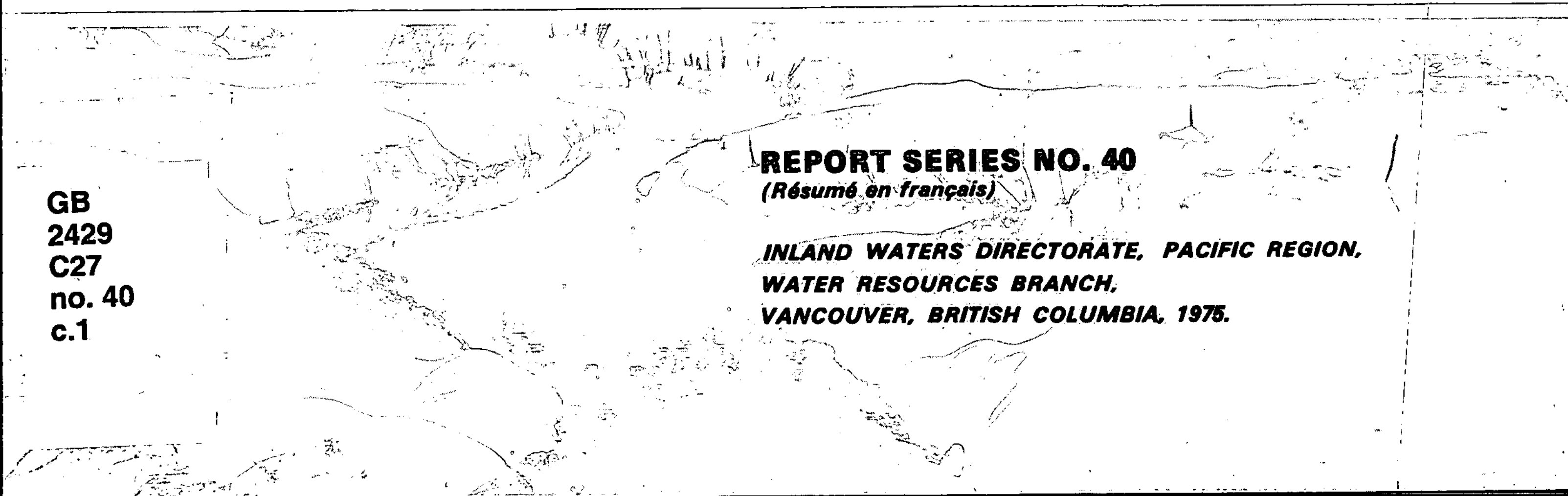
Streamflow Regionalization in British Columbia, No. 1

Regression of Mean Annual Floods on Physiographic Parameters

R. M. Leith





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(Résumé en français)

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ABSTRACT

The mean annual flood has been regressed on certain physiographic parameters and climatological variables for 144 stations in seven regions of British Columbia. The prime objective of this study was to examine regression as a tool for regionalization. If distinct regression equations could be produced for each region then regionalization would be considered effective and three results could be achieved:

1. a means of evaluating the present network,
2. identification of important physiographic parameters,
3. a means of estimating mean annual flood for ungauged basins.

Distinct equations were developed. The best equations for Mean Annual Flood, M.A.F., for each region are listed below. In this context, best equation means the last equation produced by backward elimination of variables. The units of Mean Annual Flood are cubic feet per second, cfs.

Cranbrook Region

$$\text{M.A.F.} = 0.1448 \times 10^5 - 144.0 \times \text{RA FOR} + 0.2131 \times \text{TB PRE}$$

Kamloops-Merritt Region

$$\text{M.A.F.} = 2890. - 1.425 \times \text{AREA} - 0.1434 \times \text{ELEV} - 1.601 \times \text{DS W} - 13.19 \times \text{RA FOR} + 0.1313 \times \text{TB PRE}$$

Prince George Region

$$\text{M.A.F.} = 584.2 + 166.4 \times \text{RA GLC} + 0.2047 \times \text{TB PRE}$$

Princeton-Penticton Region

$$\text{M.A.F.} = 5983. - 6.090 \times \text{DS N} + 0.1606 \times \text{SE N} - 33.48 \times \text{MA PRE} + 0.1697 \times \text{TB PRE}$$

Revelstoke Region

$$\text{M.A.F.} = 4516. + 16.94 \times \text{AREA} + 139.4 \times \text{RA FOR} - 0.5191 \times 10^5 \times \text{RA SWP} - 0.3522 \times \text{SE N}$$

Vancouver Region

$$\text{M.A.F.} = 572.3 + 13.67 \times \text{AREA} + 36.19 \times \text{SLP \%}$$

Windermere Region

$$\text{LOG (M.A.F.)} = 9.490 + 1.019 \times \text{LAREA} - 1.086 \times \text{LELEV} - 1.544 \times \text{LBH W} + 0.4822 \times \text{LSS NE} - 0.4342 \times \text{LSS E} + 0.4750 \times \text{LMA PRE}$$

The equations were developed by backward elimination of variables and were tested by plotting residuals and with split samples.

RÉSUMÉ

On a fait la régression des crues annuelles moyennes à partir de certains paramètres physiographiques et de certaines variables climatologiques, pour 144 stations réparties dans sept régions de la Colombie-Britannique. Le but principal de cette étude consistait à analyser la régression en tant qu'instrument de généralisation régionale. Si, pour chacune des régions, on pouvait établir des équations de régression distinctes, la généralisation régionale semblerait alors un outil efficace et permettrait d'arriver aux trois résultats suivants:

1. l'évaluation du réseau actuel de stations;
2. l'identification des paramètres physiographiques importants; et
3. l'estimation des crues annuelles moyennes dans le cas des bassins non mesurés.

On a établi des équations distinctes. On donne ci-dessous la liste des équations les meilleures en ce qui a trait aux crues annuelles moyennes (M.A.F.) pour chaque région. Dans cette étude, l'expression «meilleure équation» est synonyme de la dernière équation produite par élimination ultérieure de variables non significatives. Les crues annuelles moyennes sont données en pieds cubes par seconde (cfs).

Cranbrook

$$\text{M.A.F.} = 0.1448 \times 10^{5} - 144.0 \times \text{RA FOR} + 0.2131 \times \text{TB PPE}$$

Kamloops-Merritt

$$\text{M.A.F.} = 2890. - 1.425 \times \text{AREA} - 0.1434 \times \text{ELEV} - 1.601 \times \text{DS W} - 13.19 \times \text{RA FOR} + 0.1313 \times \text{TB PRE}$$

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$$\text{M.A.F.} = 584.2 + 166.4 \times \text{RA GLC} + 0.2047 \times \text{TB PRE}$$

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$$\text{M.A.F.} = 5983. - 6.090 \times \text{DS N} + 0.1606 \times \text{SE N} - 33.48 \times \text{MA PRE} - 0.1697 \times \text{TB PRE}$$

Revelstoke

$$\text{M.A.F.} = 4516 + 16.94 \times \text{AREA} + 139.4 \times \text{RA FOR} - 0.5191 \times 10^{5} \times \text{RA SWP} - 0.3522 \times \text{SE N}$$

Vancouver

$$\text{M.A.F.} = 572.3 + 13.67 \times \text{AREA} + 36.19 \times \text{SLP \%}$$

Windermere

$$\text{LOG (M.A.F.)} = 9.490 + 1.019 \times \text{LAREA} - 1.086 \times \text{LELEV} - 1.544 \times \text{LBH W} + 0.4822 \times \text{LSS NE} - 0.4342 \times \text{LSS E} + 0.4750 \times \text{LMA PRE}$$

On a établi les équations par élimination ultérieure de variables non significatives et on les a vérifiées en traçant un graphique des résidus et par la méthode moitié-moitié.

Streamflow Regionalization in British Columbia, No. 1

Regression of Mean Annual Floods on Physiographic Parameters

R. M. Leith

1. INTRODUCTION

This report describes a study on regression of mean annual floods on annual precipitations and certain physiographic parameters. Mean annual flood is the arithmetic average of annual maximum mean daily flows. The annual precipitation data are taken from the Shawinigan Engineering Company's Report for Western and Northern Canada, Reference 1. The physiographic parameters are those used in the above report and are listed in Appendix 1.

The objective of this study is to examine regression as a tool for regionalization of mean annual floods in British Columbia's diverse terrain. If regionalization by regression is practical then the capability of the existing network of stations to estimate mean annual flood values at ungauged sites can be assessed in terms of standard errors. As well, important physiographic parameters may be identified.

The motivation for this study is provided in a recommendation of Shawinigan Engineering Company, Reference 1:

> "Comparative investigations be carried out using other hydrologic characteristics than mean annual flow as basin parameter so that the present conclusions based on mean annual flow may be explored."

At first, a pilot study was conducted with regression of mean annual floods on physiographic parameters for five regions of British Columbia (Figure 1). This pilot study produced encouraging results so a preliminary report was circulated for comments. With suggestions from several reviewers an expanded study with basin precipitations and an additional 41 stations in two regions was undertaken.

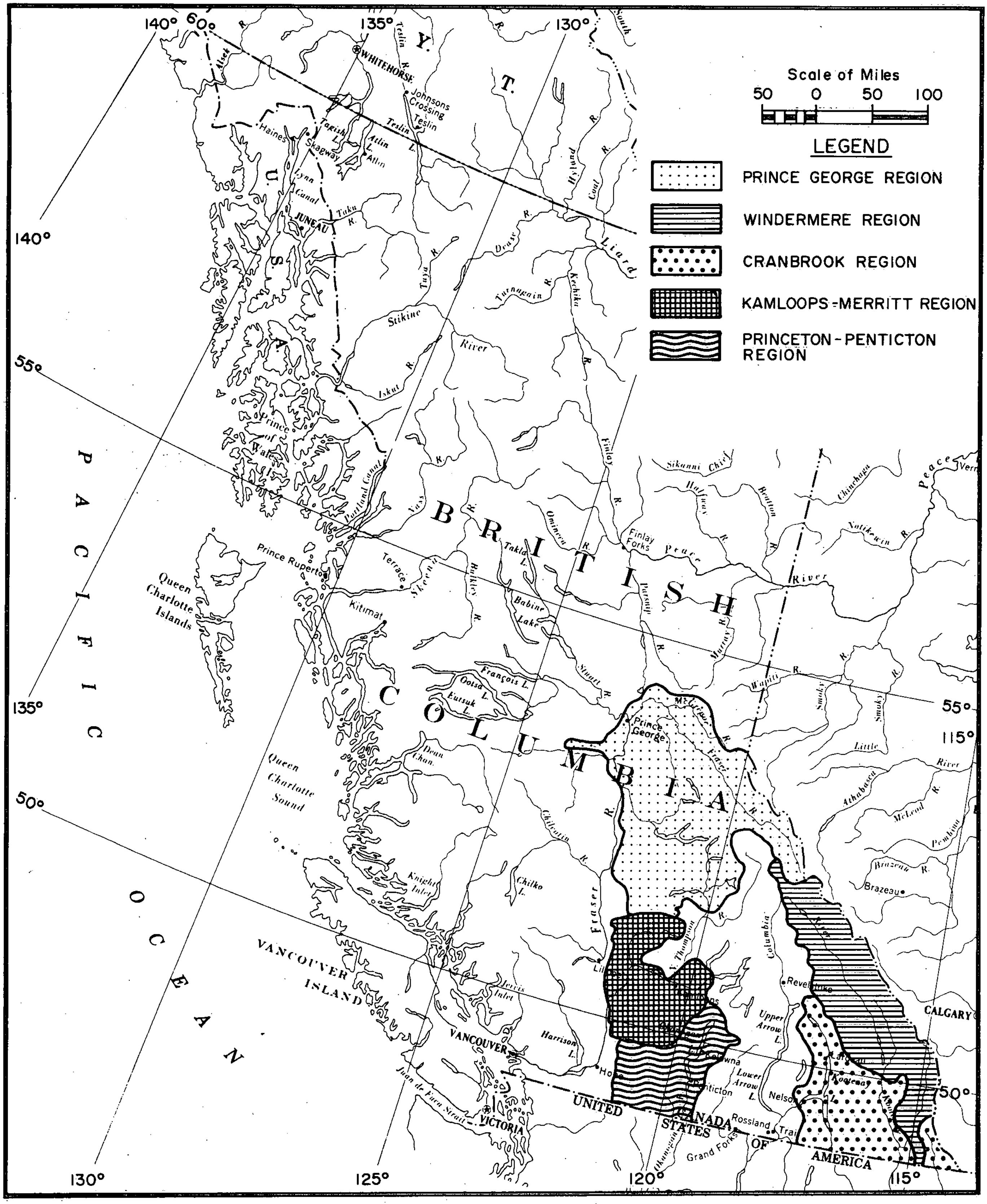


Figure 1. Map of British Columbia showing the five regions of the pilot study.

2. DISCUSSION

2.1 Regionalization

Regionalization refers to grouping data in such a way that analysis benefits in increased accuracy. In this study the stations are grouped into geographically similar areas so that the response of streams to physiographic variables should be similar. Because of this similarity of response, streamflow records may be transferred from gauged basins to ungauged basins within a region. Thus, regionalization provides a structure for data transfer.

At first, regions were selected on the basis of geographical and climatological similarity. For example, Kamloops - Merritt region is a lightly forested plateau with low annual precipitation. However, as each region should have thirty or more stations to provide sufficient degrees of freedom for a representative estimate of mean square residual, each original region had to be expanded. An example of this enlargement is Vancouver Region where stations in the Fraser Valley were combined with stations in the mountainous area north of Vancouver.

Within a region, variability of a hydrologic quantity, such as mean annual flood, consists of two parts; chance variation due to sampling and variation due to differences in basin characteristics. The method of regional analysis, in this study, regression, should average the chance variation but maintain variation due to basin characteristics. In order to keep the chance variation to a minimum, dependable records of natural streamflow are required for the analysis.

2.2 Regression

Regression is a useful regionalization tool, because a hydrologic quantity may be related to basin characteristics, leaving residuals that may theoretically be considered due to chance; theoretically, that is, because this will be true only if the model is correct. The residuals from a regression equation such that the sum of squares of residuals is a minimum with respect to regression parameters may be operationally considered due to chance within the sample space of the variables considered in the regression. However, the equations should be tested for bias.

In practice residuals contain both chance variation and variation due to basin characteristics, with no measure of the relative amounts. If records are independent and chance variation is large, regression analysis should produce an unbiased result but the standard error of estimate will be large. Thus success of regionalization by regression cannot be measured by standard error of estimate alone.

In the above, independent means no statistically significant cross correlation among the records.

To use the F-test for significance of a regression equation, four conditions must be met:

(1) A linear model of the form $Y_i = B_o + B_1 X_{1i} + \ldots E_i$ must be chosen.

(2) E_i is normally distributed with zero mean and σ^2 variance and covariance $(E_i, E_j) = 0$; that is, the residuals must be independent.

(3) Y_i is normally distributed $N (B_o + B_1 X_{1i} + \ldots, \sigma^2)$, covariance $(Y_i, Y_j) = 0$.

(4) X_{ji} is measured without error.

With regard to the requirement for a linear model, an equation of the form, $Y = aX_1^{b1} X_2^{b2} \ldots X_n^{bn}$, is intrinsically linear, as taking logarithms of both sides produces a linear equation.

Certain expressions used with regression such as standard error of estimate are explained in Appendix 6.

Some practical considerations in the design of multiple regression analysis include:

(1) For independent variables, measure pertinent variables and as a rule of thumb keep the number of independent variables (m) below twenty, to reduce chance correlation.

(2) Avoid highly correlated independent variables; but in case of high correlation, use the easiest and least expensive to measure.

(3) Try to have sufficient observations (n) so that the degrees of freedom of the mean square residual, (n-m-1), is greater than thirty. This generally will allow a closer estimate of population standard error and R^2.

2.2.1. Criteria

There are two conflicting criteria for selecting a regression equation:

(1) to include as many independent variables as possible so that reliable values of the dependent variable may be determined.

(2) to include as few independent variables as possible to reduce costs of obtaining information.

The compromise is usually called selecting the best equation. There is no unique statistical procedure for this selection. The following procedures are available: all possible equations, backward elimination, forward selection, stepwise regression, and stagewise regression. They do not all necessarily lead to the same equation when applied to the same problem.

In this study backward elimination was used. By this method, variables are eliminated by F-ratio until only significant variables remain; that is, no variable has an F-ratio lower than a predetermined value.

2.3 Physiographic Parameters

The physiographic parameters used in this study are listed in Appendix 1. They were extracted from 1:250,000 topographic maps on a 10 km x 10 km grid and then averaged over each basin by the Hydrometric Network Planning and Forecasting Section of the Applied Hydrology Division in Ottawa. In addition, several sets of basin parameters are taken from the Shawinigan report.

2.4 Mean Annual Precipitation

Mean annual precipitations were obtained from a computer-produced map of mean annual precipitation for each 10 km x 10 km square, in British Columbia, Reference 1. Precipitation values on this map were produced by regression on physiographic parameters.

Basins were outlined on an enlargement of the map and basin averages were found. These basin averages are identified by MA PRE in the equations. A second precipitation value, total basin precipitation, TB PRE, was also used. Total basin precipitation equals mean annual basin precipitation multiplied by area of drainage basin.

The units of MA PRE are inches; the units of TB PRE are inches x square miles.

3. PROCEDURE

3.1 Selection of Regions

Seven regions were selected on the basis of geography and extended to increase the number of stations (Figure 2). These regions were named for cities; Cranbrook, Kamloops-Merritt, Prince George, Princeton-Penticton, Revelstoke, Vancouver, and Windermere. The assignment of individual stations to a region is not unique. Station 08NP001, Flathead River at Flathead, could be assigned to either Windermere or Cranbrook regions. The data on mean annual floods were taken from the publication, "Magnitude of Floods in British Columbia". These records are for periods of 10 years or longer, not necessarily consecutive,

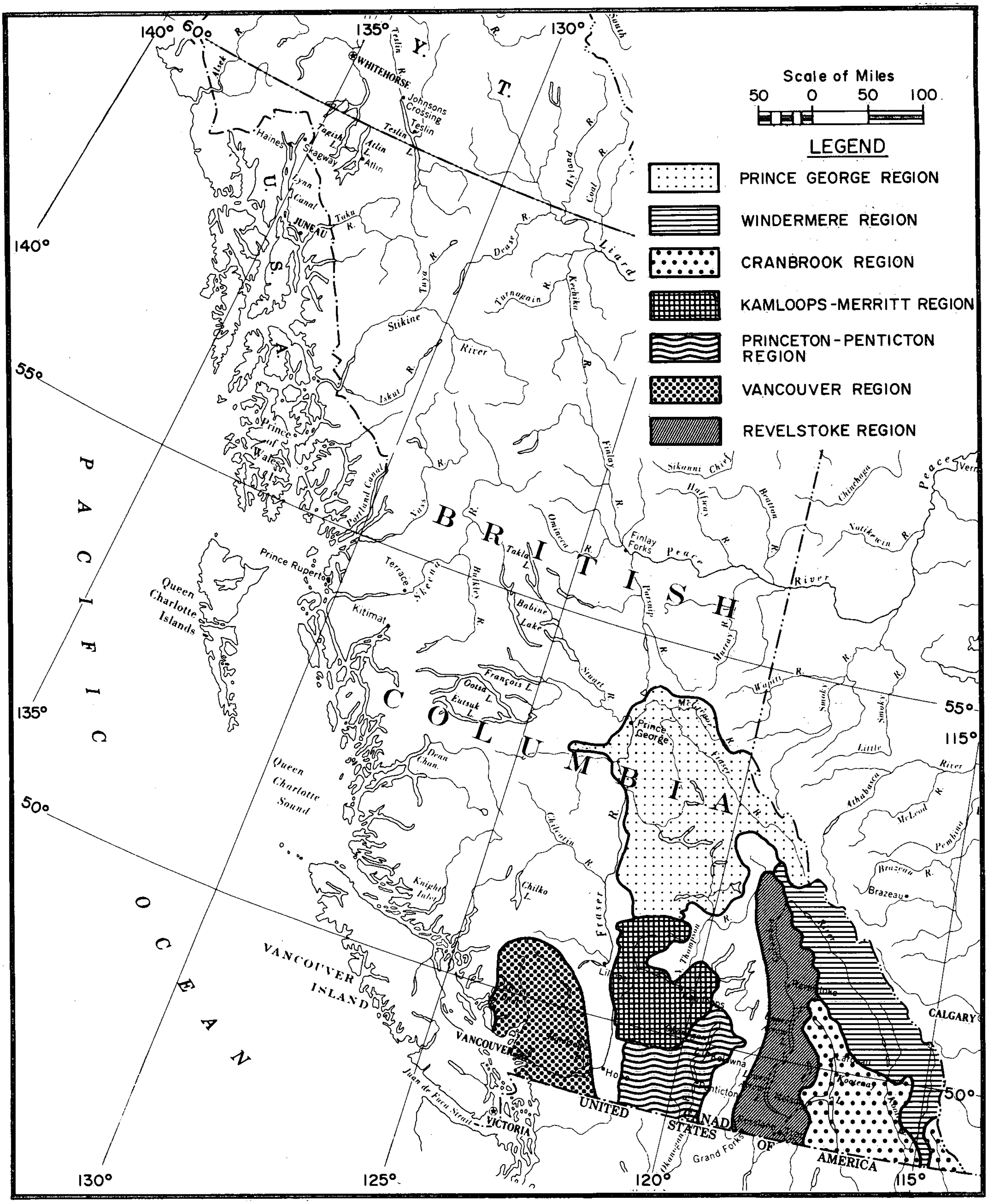


Figure 2. Map of British Columbia showing the seven regions of the expanded study.

and with no common base period. The lack of a base period reduces the chance of bias from working in either a high or low flood period.

At first, only stations recording natural flow from basins of less than 500 square miles were selected, but these restrictions allowed for too few stations. Therefore streams with diversions and drainage areas over 500 square miles were considered. The diversions, mainly for irrigation, were assumed to have a negligible effect on floods.

3.2 Development of Equations

Once a region had been selected and stations assigned to that region, a correlation matrix was developed for physiographic parameters, climatological variables and mean annual flood. Physiographic parameters were screened by grouping and backward elimination. For example, all relative area parameters, that is, relative area of lakes, relative area of forests, relative area of swamps, relative area of glaciers, and relative area of urbanization were regressed against mean annual flood. The non-significant relative areas were eliminated one by one until only significant relative area parameters remained. When all the significant physiographic parameters were determined, they were combined with climatological variables and regressed until an equation was developed where all the variables were significant at a 0.05 level.

3.3 Testing Regression Equations

As standard error alone cannot be a test of validity of regression equation, the equations were tested by plots of residuals and by split sample tests. Examples of the plots of residuals are provided in Appendix 2. The general results of the tests are discussed in Section 4.

As a test for the sensitivity of the Prince George regional equation, stations in the Prince George region were divided into four categories on the basis of area and elevation. Regression equations were developed for each category and the results are listed in Table 5.

3.4 Regression of Standard Deviations

Linear regression equations for the standard deviation of mean annual flood were developed in all regions except Vancouver. The results may be useful in flood frequency analysis but did not appear to warrant time to develop logarithmic equations.

4. RESULTS AND OBSERVATIONS

4.1 Regression Equations for Mean Annual Flood

Regional Equations are listed in Table 1. Abbreviations for physiographic parameters are tabulated in Appendix 1. A capital "L" before an abbreviation indicates logarithm to base 10, example, LAREA is $\log_{10}$ (AREA). The standard errors of estimate for the full logarithms equations have been converted to linear units, cfs, to allow direct comparison with standard errors of the linear equations.

<u>TABLE 1.</u> <u>Regional Regression Equations for Mean Annual Flood (cfs)</u>

(a) <u>Linear Equations</u>

Cranbrook Region 20 Stations $R^2 = 0.966$ S.E.E. = 2020 cfs

$$\text{M.A.F.} = 0.1448 \times 10^5 - 144.0 \times \text{RA FOR} + 0.2131 \times \text{TB PRE}$$

Kamloops-Merritt Region 25 Stations $R^2 = 0.918$ S.E.E.=160 cfs

$$\text{M.A.F.} = 2890 - 1.425 \times \text{AREA} - 0.1434 \times \text{ELEV} - 1.601 \times \text{DS W} - 13.19 \times \text{RA FOR} + 0.1313 \times \text{TB PRE}$$

Prince George Region 21 Stations $R^2 = 0.979$ S.E.E. = 4226 cfs

$$\text{M.A.F.} = 584.2 + 1664. \times \text{RA GLC} + 0.2047 \times \text{TB PRE}$$

Princeton-Penticton Region 18 Stations $R^2 = .973$ S.E.E.=230 cfs

$$\text{M.A.F.} = 5983. - 6.090 \times \text{DS N} + 0.1606 \times \text{SE N} - 33.48 \times \text{MA PRE} + 0.1697 \times \text{TB PRE}$$

Revelstoke Region 16 Stations $R^2 = .999$ S.E.E.=2120 cfs

$$\text{M.A.F.} = 4516. + 16.94 \times \text{AREA} + 139.4 \times \text{RA FOR} - 0.5191 \times 10^5 \times \text{RA SWP} - 0.3522 \times \text{SE N}$$

TABLE 1 (cont'd) Regional Regression Equations for Mean Annual Flood (cfs)

(a) Linear Equations (continued)

Vancouver Region 25 Stations R^2 = .940 S.E.E. = 2396 cfs

M.A.F. = 572.3 + 13.67 x AREA + 36.19 x SLP %

Windermere Region 19 Stations R^2 = .960 S.E.E. = 3620 cfs

M.A.F. = 0.5868 x 10^5 + 8.486 x AREA - 28.16 x DS N - 1919. x RA SWP

(b) Logarithmic Equations (Logarithms are to base 10)

Cranbrook Region 20 Stations R^2 = .939 S.E.E. = 4120 cfs

L.M.A.F. = -1.440 + 0.9945 x LAREA + 1.593 x LMA PRE

Kamloops-Merritt Region 25 Stations R^2 = .863 S.E.E.=216 cfs

L.M.A.F. = 9.774 + 0.7358 x LAREA + 2.559 x LBH N - 5.454 x LBH W + 1.617 x LBH SW - 0.9018 x LSE SW

Prince George Area 21 Stations R^2 = .977 S.E.E. = 5120 cfs

L.M.A.F. = 23.13 + 0.8277 x LAREA - 1.416 x LELEV + 2.062 x LSLP % - 5.758 x LDS NW

Princeton-Penticton Region 18 Stations R^2 = .909 S.E.E.=433 cfs

L.M.A.F. = -7.454 + 0.8758 x LAREA + 1.935 x LELEV + 0.5388 x LSLPAZ

Revelstoke Region 16 Stations R^2 = .996 S.E.E. = 3200 cfs

L.M.A.F. = -34.54 + 0.8609 x LAREA + 5.018 x LELEV + 0.8317x LSLPAZ + 4.956 x LRA FOR + 1.883 x LBH W - 0.3590 x LSS SE

Vancouver Region 25 Stations R^2 = .862 S.E.E. = 3100 cfs

L.M.A.F. = -0.1206 + 0.6694 x LAREA + 1.322 x LRA FOR

Windermere Region 19 Stations R^2 = .955 S.E.E. = 2460 cfs

L.M.A.F. = 9.490 + 1.019 x LAREA - 1.086 x LELEV - 1.544 x LBH W + 0.4822 x LSS NE - 0.4342 x LSS E + 0.4750 x LMA PRE

TABLE 1 Regional Regression Equations for Mean Annual Flood (cfs) (cont'd)

(c) Logarithmic Equations - Total Annual Basin Precipitation Only

Cranbrook Region R^2 = .933 S.E.E. = 0.2258
L.M.A.F. = -0.7356 + 1.050 x LTB PRE

Kamloops-Merritt Region R^2 = .672 S.E.E. = 0.3482
L.M.A.F. = -0.6703 + 0.8824 x LTB PRE

Prince George Region R^2 = .926 S.E.E. = 0.1547
L.M.A.F. = -0.0458 + 0.8868 x LTB PRE

Princeton-Penticton Region R^2 = .663 S.E.E. = 0.3301
L.M.A.F. = -0.4659 + 0.8392 x LTB PRE

Revelstoke Region R^2 = .983 S.E.E. = 0.1185
L.M.A.F. = 0.0204 + 0.8756 x LTB PRE

Vancouver Region R^2 = .763 S.E.E. = 0.3085
L.M.A.F. = 0.7788 + 0.7208 x LTB PRE

Windermere Region R^2 = .939 S.E.E. = 0.1908
L.M.A.F. = -0.9537 + 1.078 x LTB PRE

(d) Logarithmic Equations - Drainage Area Only

Cranbrook Region R^2 = .893 S.E.E. = 0.2863
L.M.A.F. = 0.7240 + 1.121 x LAREA

Kamloops-Merritt Region R^2 = .638 S.E.E. = 0.3665
L.M.A.F. = 0.2320 + 0.9858 x LAREA

Prince George Region R^2 = .742 S.E.E. = 0.2891
L.M.A.F. = 1.198 + 0.9237 x LAREA

Princeton-Penticton Region R^2 = .634 S.E.E. = 0.3975
L.M.A.F. = 0.03994 + 1.198 x LAREA

Revelstoke Region R^2 = .973 S.E.E. = 0.1508
L.M.A.F. = 1.203 + 0.9817 x LAREA

TABLE 1 Regional Regression Equations for Mean Annual Flood (cfs) (cont'd)

(d) Logarithmic Equations - Drainage Area Only (continued)

Vancouver Region R^2 = .741 S.E.E. = 0.3244
L.M.A.F. = 2.202 + 0.6944 x LAREA

Windermere Region R^2 = .904 S.E.E. = 0.2393
L.M.A.F. = 0.5132 + 1.156 x LAREA

The significance of the regression coefficients for the Princeton-Penticton Region is examined in Appendix 3. The regression coefficients are given to four significant figures although input mean annual floods are three figures, precipitations are two figures, and some of the physiographic parameters, such as relative area of glaciers, are one figure. Therefore, for some regions, the calculated mean annual floods will have one significant figure.

As has been mentioned in Section 3.3, the equations should be examined with respect to residuals, Appendix 2. These residual analyses indicate the logarithmic equations produce better results, that is, smaller residuals for small streams with drainage areas of less than 200 square miles. For larger streams the linear equations are better as they show less bias against high observed floods.

In particular, in Appendix 2, a plot of residuals for Cranbrook linear equation shows an unusual pattern. Without the two high floods there would be a strong suggestion of a straight-line tendency indicating that a significant term had been omitted from the equation. With the two high flood values there is a suggestion of a non-linear term being required. More floods in the range 16,000 to 40,000 cfs would be required to substantiate this suggestion.

As there is no quantitative description of floods in terms of physiographic parameters, no critical examination was made of the equations, other than statistical testing. For example, no explanation was sought as to the negative coefficient TBPRE in the Princeton-Penticton linear equation.

When the expanded study began, it was hoped that the inclusion of precipitation would remove the barrier heights, shield effects and distances to the sea from the equations. This was not the case. Table 2 shows the effects on linear equations of the addition of precipitation values. In four of the seven regions the standard error for linear equations was decreased and residuals were improved but shield effects and distances to the sea were not removed. In the Revelstoke, Vancouver, and Windermere regions precipitation was not significant.

TABLE 2 Linear Regression Equations Showing Effect of Adding Precipitation to Analysis

Cranbrook Region

Without precipitation $R^2 = 0.930$ S.E.E. = 2230 cfs

M.A.F. = -2912. + 8.888 x AREA + 0.9492 x ELEV

With precipitation $R^2 = 0.966$ S.E.E. = 2020 cfs

M.A.F. = 0.1448×10^5 - 144.0 x RA FOR + 0.2131 x TBPRE

Kamloops-Merritt Region

Without precipitation $R^2 = 0.619$ S.E.E. = 366 cfs

M.A.F. = 3808. + 1.107 x AREA - 0.2521 x ELEV - 3.732 x RA FOR - 0.0515 x SE W

With precipitation $R^2 = 0.918$ S.E.E. = 160 cfs

M.A.F. = 2890. - 1.425 x AREA - 0.1434 x ELEV - 1.601 x DS W - 13.19 x RA FOR + 0.1313 x TBPRE

Prince George Region

Without precipitation $R^2 = 0.968$ S.E.E. = 5380 cfs

M.A.F. = 0.5125×10^5 + 8.462 x AREA + 172.5 x SLP% - 0.3568 x SE NW

With precipitation $R^2 = 0.979$ S.E.E. = 4226 cfs

M.A.F. = 584.2 + 1664. x RAGLC + 0.2047 x TBPRE

Princeton-Penticton Region

Without precipitation $R^2 = 0.889$ S.E.E. = 298 cfs

M.A.F. = 5176. + 3.946 x AREA + 1.427 x SLPAZ - 2.082 x DS N - 0.2495 x BH NW

With precipitation $R^2 = 0.937$ S.E.E. = 230 cfs

M.A.F. = 5983. - 6.090 x DS N + 0.1606 x SE N - 33.43 x MAPRE + 0.1697 x TBPRE

4.2 Regression Equations for Standard Deviation of Mean Annual Flood

Regression equations for the standard deviation of the mean annual flood are shown in Table 3 for six regions. These equations produce reasonable estimates except in Cranbrook and Kamloops-Merritt regions where the standard errors are high. No examination of these equations has been undertaken as their applications have not been defined.

TABLE 3 Regional Regression Equations for Standard Deviations of Mean Annual Flood

Cranbrook Region 20 Stations $R^2 = 0.624$ S.E.E. = 4006 cfs
S.D. (M.A.F.) = -6849. - 2.844 x BH N + 0.1975 x SE SW - 219.4 x SS SE

Kamloops-Merritt Region 25 Stations $R^2 = 0.769$ S.E.E.=78.8 cfs
S.D. (M.A.F.) = 464.2 - 4.518 x RA FOR + 0.0291 x TB PRE

Prince George Region 21 Stations $R^2 = 0.919$ S.E.E.=1003 cfs
S.D. (M.A.F.) = 1092. + 0.0261 x TBPRE

Princeton-Penticton Region 18 Stations $R^2 = 0.935$ S.E.E.=95.4 cfs
S.D. (M.A.F.) = 3605. + 1.796 x AREA - 1.426 x DS N - 0.1286 x BH N

Revelstoke Region 16 Stations $R^2 = 0.970$ S.E.E. = 1306 cfs
S.D. (M.A.F.) = 260.2 + 3.244 x AREA - 0.1286 x 10^5 x RA SWP

Windermere Region 19 Stations $R^2 = 0.851$ S.E.E. = 1017 cfs
S.D. (M.A.F.) = 5989. + 5.893 x AREA - 0.0810 x SE W - 0.1139 x TBPRE

4.3 Important Physiographic Parameters

The important physiographic parameters for all equations for each region are shown in Table 4. The parameters themselves are explained in Appendix 1. A detailed list of values of parameters, showing maximum and minimum values in each region are in Appendix 4. This appendix provides an indication of the range of applicability of the equations as well as the sampling range of the present network.

TABLE 4 Important Physiographic Parameters

	CRANBROOK	KAMLOOPS-MERRITT	PRINCE GEORGE	PRINCETON-PENTICTON	REVELSTOKE	VANCOUVER	WINDERMERE
AREA	L	SL	L	L	SL	SL	SL
ELEV		S	L	L	L		L
SLP %			L			S	
SLP AZ				L	L		
DS N				S			S
DS NW			L				
DS W		S					
RA FOR	S	S			LS	L	
RA SWP					S		S
RA GLC			S				
BH N		L					
BH W		L			L		L
BH SW		L					
SE N				S	S		
SE NE							L
SS E							L
SS SE					L		
MAPRE	L			S			L
TBPRE	S	S	S	S			

S - Linear equation
L - Logarithmic equation
SL- Linear and logarithmic equations

The most important parameter is drainage area. This must be widely sampled by the stations of the network. Also important are elevation and precipitation. An improved method of specifying precipitation is desirable; i.e. more measurements. Parameters which occur only once or twice such as DS NW and RA GLC should not be considered as important to the network. In light of the results in the next section, care must be exercised in specifying important parameters on the basis of regression.

4.4 Tests of Regression Equations

4.4.1 Sensitivity of Regression

Stations in the Prince George Region were divided into four categories; large drainage area, small drainage area, high basin elevation and low basin elevation. There was overlap in the categories, for example, the lowest of the high elevation stations had to be included in the low elevation category in order to keep the number of stations as high as possible. The details on stations used in each category is included in Appendix 5.

Table 5 summarizes the regression equations. Significant Variables appear to depend upon stations used in developing equations. The high elevation equation contains too many variables for the number of stations. This number of variables does indicate variability of high elevation stations and the need for a dense network if regression is used as a tool for regionalization.

TABLE 5 Sensitivity of Linear Regression Equations for Prince George Region

AREA			ELEVATION	
17 Small Basins	16 Large Basins		14 Low Basins	15 High Basins
0.942	0.975	R^2	0.986	0.995
1662	5072	S.E.E.(cfs)	3750	2756
8153	27400	$\overline{\text{M.A.F.}}$(cfs)	17300	27911
805	2924	$\overline{\text{AREA}}$ (sq.mi.)	2334	2610
4415	4377	$\overline{\text{ELEV}}$ (ft.)	3741	5049

CONST.	3385	CONST.	50570	REGRESSION	CONST. 11.13	CONST.	-425600
ELEV.	-2.699	SE NW	-0.2857	COEFFICIENTS	TBPRE 0.2123	DS SW	515.4
SLP %	200.2	TB PRE	0.1913			RA LKE	-3154
TB PRE	0.2769					BH NW	14.49
						SE N	5.858
						SE SW	-2.020
						TB PRE	0.1648

4.4.2 Split Sample Tests

Stations not used in the development of equations in the Cranbrook, Kamloops-Merritt, and Princeton-Penticton regions were used in split sample tests. The results are presented below. The calculated mean annual floods were produced from appropriate regional equations in Sections (a)-linear equations and,(b)-logarithmic equations of Table 1.

TABLE 6 Split Sample Test Results

		Mean Annual Flood (cfs)		
		Observed	Calculated	
Cranbrook Region			Log	Linear
08NH004	Goat River	7690	8190	5280
08NH005	Kaslo River	3510	2610	5010
08NG042	Kootenay River	58100	76500	59700
Kamloops-Merritt Region				
08LE001	Bolean Creek	285	43.3	143
08LE008	Ingram Creek	86.8	37.2	-48.2
08LE019	Salmon River	488	240	592
08LG006	Nicola River	6250	3310	6340
08LG007	Nicola River	3220	2470	3370
08LG008	Spius Creek	1960	937	1540
08LG020	Spahomin Creek	152	346	281
Princeton-Penticton Region				
08NL006	Similkameen River	16100	12100	35000
08NL008	Tulameen River	6280	496	5601
08NL015	Asp River	151	65	-2030
08NL024	Tulameen River	7170	781	7600
08NM015	Vaseux Creek	531	529	364
08NM020	B.X. Creek	79	45	330
08NM021	Vernon Creek	94	475	718
08NM065	Vernon Creek	79.5	462	703

In general the results indicate that these regional equations are not satisfactory for small basins. With a 10 kilometre square grid the estimates of physiographic parameters are probably poor and the equations, especially the linear ones, are better for larger basins.

Vernon Creek is not a good subject for split sample tests as it is diverted and regulated so measured floods are probably low.

5. CONCLUSIONS

The prime object of this study was to examine regression as a tool for regionalization of mean annual floods in British Columbia. As well as an examination of the strengths and weaknesses of regression as applied to regionalization, this study was to provide: an evaluation of the present network; identification of important physiographic parameters; and a means of estimating mean annual flood for ungauged basins.

Regionalization by regression appears to be effective as different regions had significantly different equations and in each region the standard error was lower than the standard deviation of the mean annual floods. As regression is a statistical technique, regional equations would have been more satisfying if there had been a physical theory to guide the development of the equations. This need for physical theory or background would probably have been more acute if the hydrologic variable being modeled had been less general than mean annual flood.

One particular weakness of regression is the lack of uniqueness of the equation, as in the Prince George Region. This lack of uniqueness may be due to scarcity of stations and diversity of terrain in British Columbia. Regions had to be expanded beyond originally selected areas in order to increase the number of stations and even then none of the regions reached the rule of thumb 30 stations, the approximate number at which the estimate of the mean square residual could be considered reliable.

Another difficulty was the size of grid with which physiographic and precipitation parameters were determined. Estimates of parameters for basins with areas less than 200 square miles are probably not reliable.

However, regionalization by regression does provide, through standard error, a means of evaluating the effectiveness of transferring information gathered by the existing network. This then provides an estimate of the effectiveness of the network and a strong indication that the network requires more stations sampling natural flow from basins of under 500 square miles.

Identification of important physiographic parameters is not satisfactory by regression, due to the lack of uniqueness of the equations.

Regression equations do provide a means of estimating mean annual floods at an ungauged site and an indication of the accuracy of the estimate. This was shown by the split sample tests.

If regression equations developed in this study are used on an ungauged basin, four considerations must be borne in mind:

1. The values of physiographic parameters of the basin are within the ranges of those used in developing the equations.

2. Consider the possible bias of the equations; that is, for a small stream, the logarithmic equation will probably provide the best result.

3. The standard error indicates the accuracy of the result.

4. The results for basins of under 200 square miles must be treated with care.

The overall result of this study indicates that in British Columbia scarcity of streamflow and precipitation data combined with diversity of physiographic conditions makes regression a not completely satisfying tool for regionalization. However regional equations can be produced which yield reasonable estimates of mean annual floods for basins not included in the development of the equations.

6. RECOMMENDATIONS

1. To examine by regression another hydrologic quantity such as annual runoff volume, to see if regional equations can be developed.

2. To try a finer grid; that is, a 2 kilometre by 2 kilometre grid, for extracting physiographic parameters.

3. To examine regionalization with other means, such as grid square parametric modeling.

REFERENCES

1. Shawinigan Engineering Co. Ltd. Hydrometric Network Planning Study for Western and Northern Canada. Report 5019-1-70, November 1970.

2. Kite, G.W. Flood Frequency for MacKenzie Highway Culverts. Inland Waters Directorate, Ottawa, April, 1973.

3. Thomas, D.M. and M.A. Benson. Streamflow Generalization in the Potomac River Basin. Administrative Report, U.S. Geological Survey, November, 1965.

4. Magnitude of Floods in British Columbia. Inland Waters Directorate, Pacific Region, Water Survey of Canada, Vancouver, May, 1972.

APPENDIX 1

Physiographic Parameters

Parameters	Abbreviation	Units	Explanation
Drainage Area	AREA	Square Miles	Total drainage area for the basin
Grid Coordinate	I	Dimensionless	Coordinates for the centre of gravity of the basin
Grid Coordinate	J	Dimensionless	
Elevation	ELEV	Feet	Average elevation of the basin
Slope % x 10	SLP %		Basin slope averaged over the squares included in the basin
Azimuth	SLP AZ	Degrees	Angle between the west-east direction and the horizontal projection of the line of steepest descent of the local slope plain
Distance to Sea North	DS N	Kilometres	Distance from centre of gravity of basin to the sea in the north, the northwest, west and southwest directions
Northwest	DS NW	Kilometres	
West	DS W	Kilometres	
Southwest	DS SW	Kilometres	
Relative Area of Lake	RA LKE	Dimensionless	Percentage of the area of the basin occupied by lakes, forests, swamp, glaciers and built-up areas
Forest	RA FOR	Dimensionless	
Swamp	RA SWP	Dimensionless	
Glacier	RA GLC	Dimensionless	
Urban	RA URB	Dimensionless	

(Note: RA does not always equal 100)

Parameters	Abbreviation	Units	Explanation
Barrier Height to North	BH N	Feet	Difference between average elevation of the basin and highest elevation encountered in the north, northwest, west, southwest directions until the ocean is reached
Northwest	BH NW	Feet	
West	BH W	Feet	
Southwest	BH SW	Feet	
Shield Effect North	SE N	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	SE NW	Feet	
West	SE W	Feet	
Southwest	SE SW	Feet	
Signed Slope Northeast	SS NE	Feet/Kilometre	Takes into account general configuration of the terrain
East	SS E	Feet/Kilometre	
Southeast	SS SE	Feet/Kilometre	

Further information and references on these parameters may be found in Hydrometric Network Planning Study for Western and Northern Canada Report 5019-1-70 November 1970 by the Shawinigan Engineering Company Limited, Section 4.2.1. page 33.

APPENDIX 2

Comparison of Observed Mean Annual Floods with Calculated Mean Annual Floods

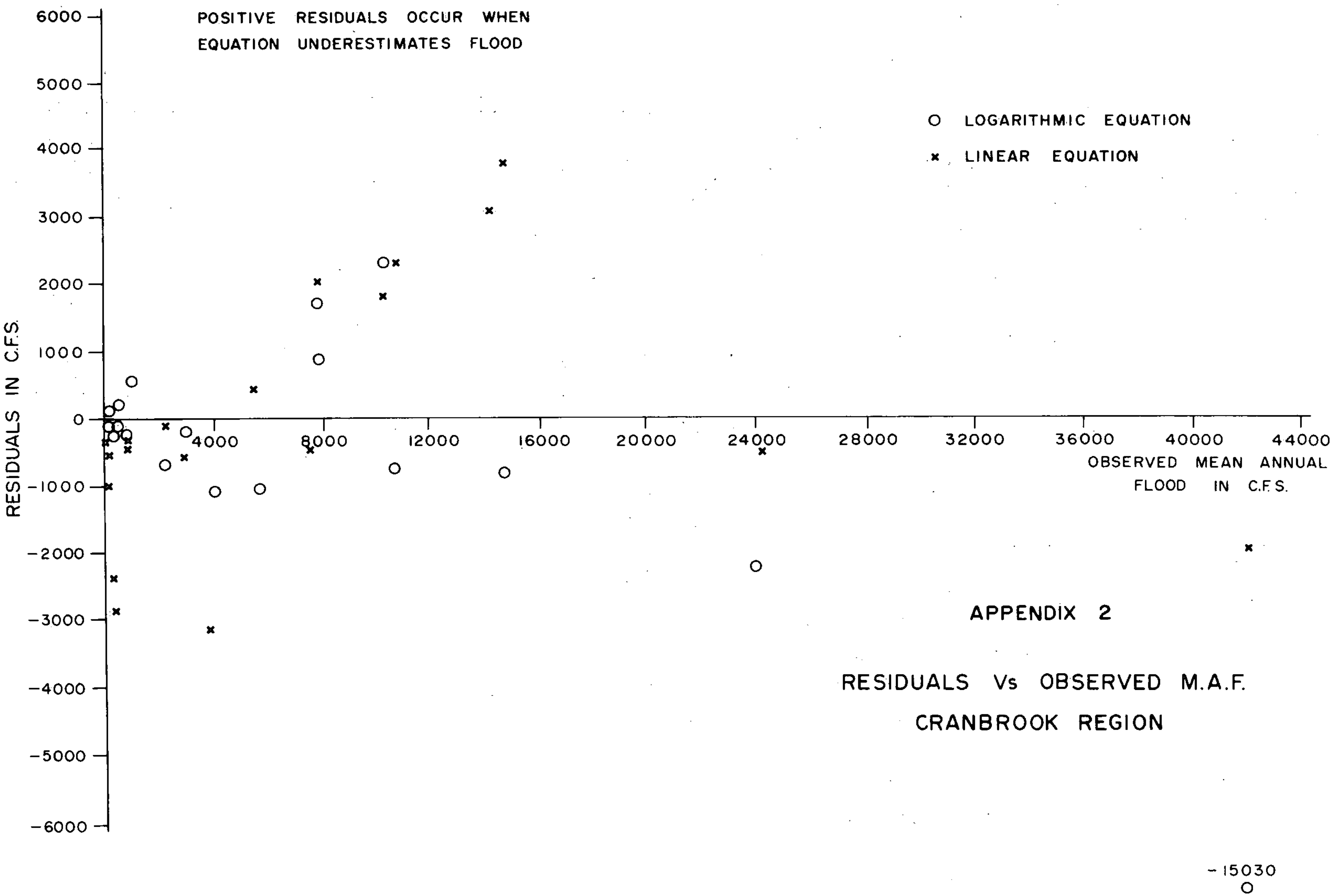
Appendix 2 provides comparisons of observed mean annual floods with values calculated by regional regression equations for Cranbrook and Princeton - Penticton Regions. These comparisons are typical of tests performed on residuals from regression equations. Residual is the difference between observed and calculated floods.

Plots of residuals against observed floods indicate bias in logarithmic equations, that is, residuals for large floods are larger than residuals for small floods. A geographical plot of residuals for linear equation in the Princeton - Penticton Region shows no bias. The residuals scatter in sign and magnitude throughout the region.

APPENDIX 2 (cont'd)

Cranbrook Region

Station Number	Observed	Log Equation		Linear Equation		Log (AREA) Equation	
		Mean Annual Floods and (Residuals)					
08NG002	7400.0	6452.3	(947.8)	7708.7	(-308.7)	2263.1	(5136.9)
08NG005	41800.0	56787.0	(-14987.0)	43816.4	(-2016.4)	31082.8	(10717.2)
08NG010	920.0	363.5	(556.5)	1259.8	(-339.8)	139.3	(780.7)
08NG011	183.0	149.3	(33.7)	1249.1	(-1066.1)	96.6	(86.4)
08NG012	14900.0	15682.3	(-782.3)	11279.1	(3620.9)	4003.1	(10896.9)
08NG046	10800.0	11502.7	(-702.7)	8367.2	(2432.8)	2198.3	(8601.7)
08NG047	146.0	287.3	(-141.3)	3065.3	(-2919.3)	104.9	(41.1)
08NG048	197.0	98.3	(98.7)	749.8	(-552.8)	39.7	(157.3)
08NG051	3010.0	3166.5	(-156.5)	3524.0	(-514.0)	826.7	(2183.3)
08NG053	24000.0	26326.4	(-2326.4)	23597.6	(402.4)	14481.7	(9518.3)
08NG058	60.0	220.2	(-160.2)	2739.0	(-2679.0)	104.9	(- 44.9)
08NH001	14400.0	7884.4	(6515.6)	11334.7	(3065.3)	3388.8	(11011.1)
08NH006	5280.0	6298.4	(-1018.4)	4862.3	(417.7)	2198.3	(3081.7)
08NH007	10100.0	7629.0	(2471.0)	8303.6	(1796.4)	2384.4	(7715.6)
08NH016	186.0	258.1	(-72.1)	258.2	(-72.2)	44.5	(141.5)
08NH034	2620.0	3377.4	(-757.4)	2695.1	(-75.1)	937.9	(1682.1)
08NH066	3920.0	5017.4	(-1097.4)	7104.8	(-3184.8)	1100.7	(2819.3)
08NH068	930.0	823.2	(106.8)	1309.7	(-379.7)	124.8	(805.2)
08NH084	490.0	444.7	(45.3)	498.5	(-8.5)	59.4	(430.6)
08NP001	7400.0	5637.1	(1762.9)	5067.8	(2332.2)	1656.0	(5744.0)



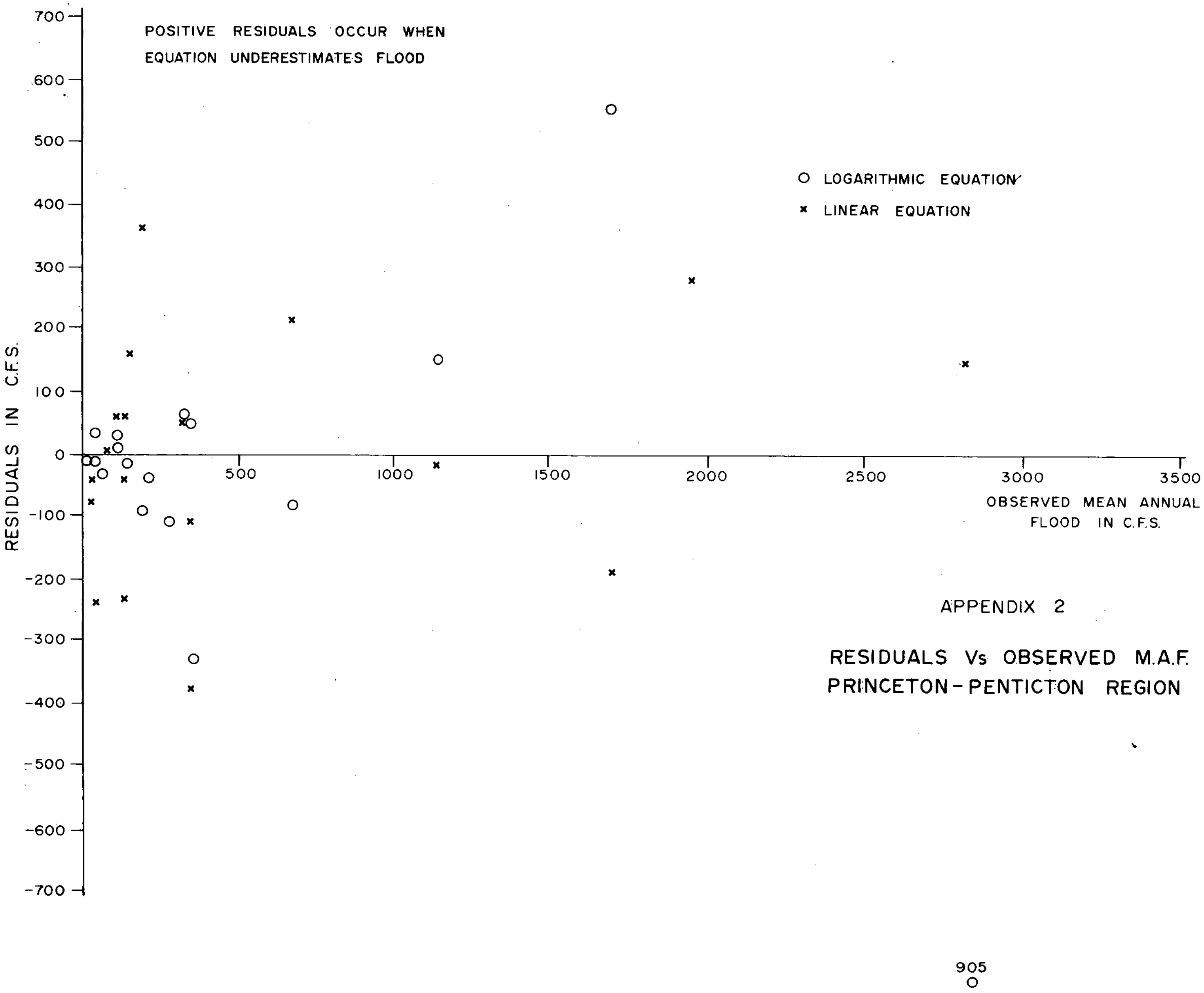
APPENDIX 2

RESIDUALS Vs OBSERVED M.A.F.
CRANBROOK REGION

APPENDIX 2 (cont'd)

Princeton-Penticton Region

			Mean Annual Floods	
Station Number	Observed	Log Equation	Linear Equation	Log (AREA) Equation
08NL004	2830.0	3735.4	2680.1	1416.5
08NL010	201.0	298.7	-157.0	205.9
08NL012	363.0	705.1	761.5	760.3
08NL023	1160.0	1006.1	1187.9	946.0
08NM006	93.0	127.3	87.0	72.4
08NM012	141.0	169.0	382.6	172.1
08NM016	1960.0	805.1	1675.0	838.5
08NM022	66.3	44.3	155.1	46.9
08NM035	185.0	209.0	28.8	75.0
08NM037	135.0	177.7	71.0	85.7
08NM038	112.0	76.0	42.1	30.4
08NM041	330.0	260.7	263.1	190.4
08NM046	355.0	305.2	457.7	199.7
08NM053	127.0	97.2	176.8	215.3
08NM054	690.0	780.7	418.1	878.0
08NM075	58.5	78.3	300.2	250.4
08NM116	1700.0	1153.5	1899.9	1108.9
08NM119	40.2	53.7	105.8	130.5

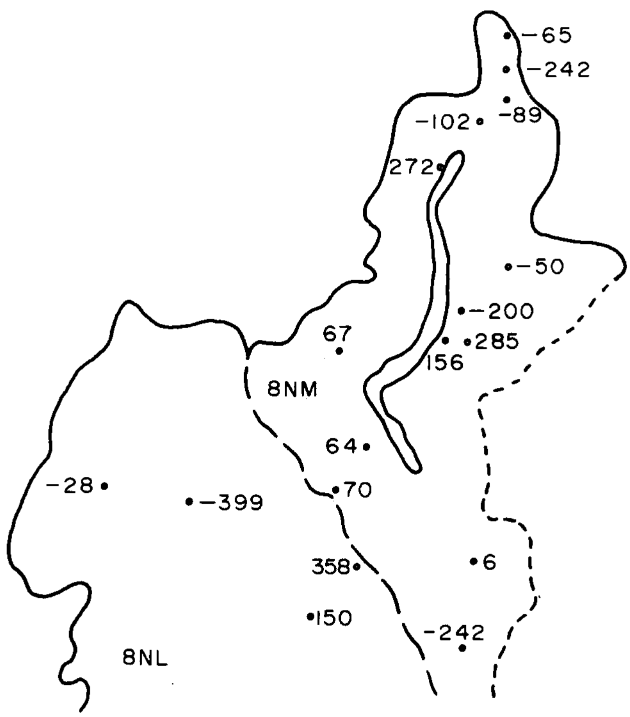


APPENDIX 2

RESIDUALS Vs OBSERVED M.A.F.
PRINCETON - PENTICTON REGION

APPENDIX 2

GEOGRAPHICAL PLOT OF RESIDUALS FOR THE PRINCETON - PENTICTON LINEAR EQUATION



APPENDIX 3

Significance of Regression Coefficients for Equations in Princeton-Penticton Region

	Coefficient	Standard Error	F-Ratio	F-Prob.
1. Linear Equation				
Constant	5983.	2639.		
DS N	-6.090	1.465	17.27	0.0012
SE N	0.1606	0.0264	36.93	0.0001
MAPRE	-33.48	8.634	15.04	0.0020
TBPRE	0.1697	0.0215	62.15	0.0000
2. Logarithmic Equation				
Constant	-7.454	1.324		
LAREA	0.8758	0.1301	45.32	0.0000
LELEV	1.935	0.3319	33.98	0.0001
LSLPAZ	0.5388	0.2108	6.533	0.0219
3. Logarithmic Equation: Area only				
Constant	0.03994	0.4353		
LAREA	1.198	0.2210	29.39	0.0001
4. Logarithmic Equation: TBPRE only				
Constant	-0.4659	0.5209		
LTBPRE	0.8392	0.1495	31.53	0.0000

APPENDIX 4

Values of Significant Variables

Cranbrook Region

Station Number	Station Name	M.A.F.	Physiographic Parameters: AREA	RA FOR	MAPRE
08NH084	Arrow Creek	490	28	99	46
08NG002	Bull River	7400	584	79	37
08NH068	Corn Creek	930	52	95	46
08NH016	Duck Creek	186	22	100	38
08NH001	Duncan River	14400	818	63	34
08NP001	Flathead River	7400	450	92	40
08NG005	Kootenay River	41800	5200	81	37
08NG053	Kootenay River	24000	2749	75	34
08NH066	Lardeau River	3920	320	73	46
08NH007	Lardeau River	10100	610	79	40
08NG011	Little Sand Creek	183	42	93	18
08NH006	Moyie River	5280	570	98	37
08NH034	Moyie River	2620	280	98	39
08NG058	Norbury Creek	60	45	83	22
08NG047	Phillips Creek	146	45	81	26
08NG048	Phillips Creek	197	20	96	22
08NG010	Sand Creek	910	57	94	26
08NG051	Skookumchuck River	3010	252	91	40
08NG046	St. Mary River	10800	570	88	54
08NG012	St. Mary River	14900	940	89	48
	Max.	41800	5200	100	54
	Avg.	7437	683	87	36.5
	Min.	60	20	63	18
08NH004	Goat River	7690	430	97	52
08NH005	Kaslo River	3510	207	78	40
08NG042	Kootenay River	58100	7660	83	35

APPENDIX 4 (cont'd)

Values of Significant Variables
Kamloops-Merritt Region

Number	Station Name	M.A.F.	AREA	ELEV	DS W	RA FOR	BH N	BH W	BH SW	SE SW	MAPRE
08LF001	Barnes Creek	49.2	41	5745	549	97	2190	3507	2207	20120	18
08LF062	Boneparte River	476	286	4441	539	91	3371	3479	2856	23140	19
08LF005	Cherry Creek	48	28	5200	576	98	3460	3753	1420	15900	14
08LF038	Clinton Creek	14.1	29	5918	466	95	1404	3335	2789	22050	10
08LG010	Coldwater River	2330	359	3827	487	86	3349	2736	1892	15140	50
08LF007	Criss Creek	806	197	3990	589	97	3264	3975	2703	21520	19
08LF037	Cutoff Valley Creek	24.9	20	5382	472	95	1495	3274	2545	21190	6
08LF027	Deadman River	477	322	4157	526	97	3092	4005	3110	22440	20
08LG003	Guichon Creek	210	331	4780	560	95	2761	3372	1899	16260	18
08LG032	Guichon Creek	222	321	4801	560	94	2750	3413	1458	16450	21
08LF013	Hat Creek	67	29	5856	510	98	2190	3390	2237	18790	18
08LF015	Hat Creek	260	266	4552	506	88	2505	3767	3104	19650	8
08LF061	Hat Creek	252	120	4888	508	84	2176	3379	2572	18780	17
08LE013	Monte Creek	37	68	4522	641	96	4342	4661	1839	23600	24
08LE012	Monte Creek	67	23	4500	640	97	4070	4190	1590	30700	22
08LF017	Murray Creek	103	55	5120	505	88	2693	3484	2514	16700	30
08LG049	Nicola River	1080	570	4127	593	58	3536	2957	1510	41370	16
08LG016	Pennask Creek	300	34	5114	543	86	2453	1606	902	55350	32
08LG033	Quenville Creek	33.3	15	4100	560	98	3290	3090	1010	13900	18
08LF021	Scottie Creek	68.9	78	3906	501	99	2700	4059	3305	21980	6
08LE041	Tappen Creek	11	42	4271	670	93	3964	4265	1641	30220	30
08LF024	Tranquille River	463	177	3497	566	92	3741	3920	2397	19690	18
08LF049	Watching Creek	168	33	5000	560	99	2920	3130	1530	20000	18
08LE039	White Creek	43	33	3654	677	88	5010	5236	2692	32490	18
08LG009	Witches Brook	100	58	5175	546	97	1996	2978	1296	16420	18
	Max.	2330	570	5918	670	99	5010	5236	3305	55350	50
	Avg.	308	141	4660	552	92	2980	3558	2080	22953	19.5
	Min.	11	15	3497	466	58	1404	1606	902	13900	6

APPENDIX 4 (cont'd)

Values of Significant Variables
Prince George Region

Number	Station Name	M.A.F.	AREA	ELEV	SLP% *10	DS NW	RA GLC	TB PRE
08KD004	Bowron River	12900	1390	3940	36	2771	0	50,000
08KD001	Bowron River	1360	170	4470	41	2813	0	7,640
08KE015	Cale Creek	567	62	2680	22	2714	0	866
08LA006	Canim River	3710	1470	3830	25	2983	0	20,600
08KH003	Cariboo River	13600	1310	4770	46	2842	1	43,300
08KH013	Cariboo River	13000	1160	4840	46	2842	1	56,900
08JC005	Chilako River	2460	1320	2990	16	2714	0	17,200
08LA009	Clearwater River	17000	900	5330	78	2926	5	49,500
08LA007	Clearwater River	23800	1180	5070	75	2926	4	59,000
08LA013	Clearwater River	6800	387	5500	75	2898	3	22,800
08LA001	Clearwater River	34900	3950	4390	51	2969	1	139,000
08KE009	Cottonwood River	7050	710	3343	33	2828	0	18,500
08KA004	Fraser River	73600	7060	4740	60	2813	2	353,000
08KA005	Fraser River	32300	2690	5690	77	2884	6	129,000
08KA007	Fraser River	9040	615	6320	68	2912	3	27,600
08KB001	Fraser River	116000	12500	4200	47	2757	2	53,700
08LA008	Mahood River	5890	1780	3890	32	2983	0	32,000
08KB003	McGregor River	40700	1840	4610	64	2714	4	110,000
08LA004	Murtle River	6910	505	4980	58	2969	2	14,700
08KH006	Quesnel River	26300	4690	4220	47	2884	1	164,000
08KD003	Willow River	8440	1206	3489	27	2751	0	30,000
	Max.	116000	12500	6320	78	2983	6	537,000
	Avg.	21730	2230	4442	49	2852	1.7	89,760
	Min.	567	62	2680	16	2714	0	866
08KH007	Horsefly River	5690	854	3970	39	2926	0	22,200
08KH001	Quesnel River	13800	2332	4030	55	2898	0	111,000

APPENDIX 4 (cont'd)

Values of Significant Variables
Princeton-Penticton Region

Number	Station Name	M.A.F.	AREA	ELEV	SLP AZ.	DS N	SE N	MAPRE
08NL012	Allison Creek	363	235	4097	196	2217	49090	62
08NL004	Ashnola River	2830	395	6517	351	1977	43960	50
08NM035	Bellevue Creek	185	34	4578	319	2214	49990	18
08NM119	Deep Creek	40.2	54	2362	130	2125	47320	22
08NM075	Deep Creek	58.5	93	2279	123	2131	47410	18
08NM012	Inkaneep Creek	141	68	3248	239	2279	57290	42
08NM053	Kelowna Creek	127	82	2245	238	2188	49500	22
08NL010	Keremeos Creek	201	79	5469	83	2256	53570	50
08NM116	Mission Creek	1700	322	4104	291	2193	53390	33
08NM016	Mission Creek	1960	255	3921	257	2189	53930	37
08NL023	Otter Creek	1160	292	3927	360	2210	49490	61
08NM037	Shatford Creek	135	38	6060	72	2246	53410	30
08NM038	Shingle Creek	112	16	5800	71	2240	53700	30
08NM006	Shuttleworth Creek	93	33	3735	277	2254	55360	38
08NM041	Trepanier Creek	330	74	4351	163	2195	51140	27
08NM054	Trout Creek	690	265	4585	130	2216	46990	35
08NM022	Vernon Creek	66.3	23	4178	47	2175	50990	26
08NM046	Whiteman Creek	355	77	4959	128	2157	49300	15
	Max.	2830	395	6517	360	2279	57290	62
	Avg.	586	129	4100	193	2196	51817	34
	Min.	40.2	16	2245	47	1977	43960	15
08NL015	Asp River	151	21	4307	99	2234	50840	86
08NM020	B.X. Creek	74.8	21.5	2730	249	2150	49700	18
08NL006	Similkameen River	16100	2884	4883	348	2045	44900	75
08NL008	Tulameen River	6280	545	4415	20	2226	48970	90
08NL024	Tulameen River	7170	699	4540	28	2230	49360	85
08NM015	Vaseux Creek	531	97	4780	280	2270	56600	52
08NM065	Vernon Creek	79.5	213	2992	326	2167	49000	18
08NM021	Vernon Creek	94.4	220	2989	328	2166	49220	18

APPENDIX 4 (cont'd)

Values of Significant Variables
Revelstoke Region

Number	Station Name	M.A.F.	AREA	ELEV	SLP AZ.	RA FOR	RA SWP	BH W	SE N	SS EE
08ND001	Akolkolex River	4200	147	5136	206	74	0	2359	38420	-1
08NE077	Barnes Creek	1260	81	4520	156	99	0	2580	51000	23
08NE008	Beaton Creek	493	38	4880	28	86	0	3180	41700	-30
08NE039	Big Sheep Creek	1740	140	3800	164	96	0	3280	55300	12
08NE073	Blueberry Creek	542	59	4070	72	94	0	2640	56500	2
08ND007	Columbia River	88200	8220	5860	215	62	1	2380	30500	0
08ND011	Columbia River	12700	10300	5760	212	66	1	2430	31200	0
08ND006	Columbia River	136000	11000	5720	224	66	1	2470	31600	-1
08ND002	Columbia River	128000	10400	5760	212	66	1	2340	31200	0
08NE087	Deer Creek	282	31	3680	252	96	0	3220	51100	36
08ND009	Downie Creek	5360	250	5450	248	69	0	2690	34100	-3
08NE001	Incomappleux River	10600	387	5370	240	69	0	2790	38600	-23
08NE074	Salmo River	8030	472	4416	284	89	0	1803	49710	-14
08NE044	Salmo River	7080	500	4320	283	90	0	1820	49800	-13
08NJ014	Slocan River	8750	640	5100	261	73	0	2130	48800	-4
08NJ013	Slocan River	15400	1270	5080	189	76	0	2060	51300	0
	Max.	136000	11000	5860	284	99	1	3280	56500	36
	Avg.	33900	2750	4930	202	79	.25	2516	43100	-0.63
	Min.	282	31	3680	28	62	0	1803	30500	-30

APPENDIX 4 (cont'd)

Values of Significant Variables

Vancouver Region

Number	Station Name	M.A.F.	AREA	ELEV	RA FOR
08MH014	Alouette River	7690	78	1149	85
08MG008	Birkenhead River	4550	230	3840	66
08GA010	Capilano River	8080	67	1136	87
08GA031	Capilano River	7770	68	2630	94
08GA046	Chapman Creek	2890	27	1602	82
08MH016	Chilliwack River	2360	133	4200	50
08MH001	Chilliwack River	11400	481	3709	61
08MG003	Green River	7500	330	4590	61
08MG004	Green River	1390	55	5270	65
08MG013	Harrison River	46100	3154	3931	64
08MG005	Lillooet River	18300	800	5030	40
08MH020	Mahood Creek	594	13	50	34
08MH050	Nicomekl River	935	38	48	35
08GA052	Noons Creek	300	1	1	94
08MH058	Norrish Creek	4370	44.1	2030	99
08MH006	North Alouette River	1550	11	690	88
08GA047	Roberts Creek	523	12	262	62
08GA023	Rubble Creek	362	28	3842	60
08MG006	Rutherford Creek	2790	62	4660	50
08GA013	Seymour River	7630	57	2909	91
08GA030	Seymour River	7180	148	2468	88
08MH056	Slesse Creek	1770	62	5439	65
08MG007	Soo River	3650	103	4731	59
08MH029	Sumas River	700	57	101	39
08MH097	Yorkson Creek	108	1	15	23
	Max.	46100	3154	5439	99
	Avg.	6019	239	2576	65
	Min.	108	1	1	23

APPENDIX 4 (cont'd)

Values of Significant Variables
Windermere Region

Number	Station Name	M.A.F.	AREA	ELEV	DS N	RA SWP	BH W	SS NE	SS SE	MAPRE
08NA001	Bugaboo Creek	2250	144	7017	2026	0	1387	26	18	39
08NC002	Canoe River	18200	1281	5273	1892	0	2043	-6	-4	52
08NB005	Columbia River	25400	3700	5850	2010	1	2620	2	3	38
08NA002	Columbia River	15500	2570	5660	2040	2	2880	11	8	36
08NB006	Columbia River	51500	5420	5910	1990	1	2470	2	0	41
08NA045	Columbia River	1710	343	5865	2080	0	3033	9	9	33
08NK012	Elk River	13900	1318	5623	2092	0	2253	-3	-5	34
08NK016	Elk River	6330	760	6240	2060	0	2200	0	2	32
08NK005	Elk River	17300	1719	5470	2053	0	2148	-6	-6	33
08NA005	Horsethief Creek	2490	260	6880	2050	1	2000	32	24	39
08NA006	Kicking Horse River	9680	703	5880	1968	0	2033	-6	-6	50
08NF002	Kootenay River	17800	2062	5672	2031	0	2676	-10	-9	36
08NF001	Kootenay River	1140	162	4891	1998	2	3305	-12	-7	46
08NA018	Sinclair Creek	196	37	3747	2041	2	4313	-16	6	22
08NA011	Spillimacheen River	7380	555	6345	2005	0	2323	18	0	35
08NA012	Toby Creek	2730	255	6710	2072	0	1704	26	17	28
08NF004	Vermilion River	4550	372	6093	1989	0	2027	-10	-9	33
08NA024	Windermere Creek	45	33	4227	2052	0	4077	-17	-6	22
08NC001	Wood River	6470	356	5670	1900	0	1990	-8	-19	63
	Max.	51500	5420	7017	2092	2	4313	32	24	63
	Avg.	10700	1160	5743	2018	0.47	2499	1.68	0.53	37.5
	Min.	45	33	3747	1892	0	1387	-17	-19	22

APPENDIX 5

Station Division in Prince George Region Sensitivity Tests

By Drainage Area (square miles)

Large Streams		Small Streams	
08KB001	12500	08KD004	1390
08KA004	7060	08JC005	1320
08KH006	4690	08KH003	1310
08LA001	3950	08KD003	1260
08KA005	2690	08LA007	1180
08KH001	2332	08KH013	1160
08KB003	1840	08LA009	900
08LA008	1780	08KH007	854
08LA006	1470	08KE009	710
08KD004	1390	08KA007	615
08JC005	1320	08LA004	505
08KH003	1310	08LA013	387
08KD003	1260	08KE014	247
08LA007	1180	08KA008	192
08KH013	1160	08KD001	170
08LA009	900	08KE015	62

APPENDIX 5 (cont'd)

Station Division in Prince George
Region Sensitivity Tests

By Basin Elevation (feet)

16 High Basins		14 Low Basins	
08KA008	6600	08KB003	4610
08KA007	6320	08KD001	4470
08KA005	5690	08LA001	4390
08LA013	5500	08KH006	4220
08LA009	5330	08KB001	4200
08LA007	5070	08KH001	4030
08LA004	4980	08KH007	3970
08KH013	4840	08KD004	3940
08KH003	4770	08LA008	3890
08KA004	4740	08LA006	3830
08KB003	4610	08KD003	3489
08KD001	4470	08KE009	3343
08LA001	4390	08JC005	2990
08KH006	4220	08KE015	2680
08KB001	4200		
08KH001	4030		

APPENDIX 6

Explanation of Statistical Terms

bias

a prejudiced view; for example, if b is a regression coefficient for a postulated model, B is the regression coefficient for the correct model and E(b) is the expected value of b, then for an incorrectly postulated model, $E(b) \neq B$ and the estimates of the model are biased.

Correlation coefficient

r measures the strength of the linear relationship of two quantities, x and y

$$r = \frac{\sum_{i=i}^{n} (x_i - \bar{x}) \times (y_i - \bar{y})}{n s_x s_y}$$

n is the number of samples

$\bar{x}$ is the arithmetic average of (x_i)

s_x is the standard deviation of (x_i)

$\bar{y}$ is the arithmetic average of (y_i)

s_y is the standard deviation of (y_i)

expected value

$$E(x) = \sum_{i=1}^{n} x_i \quad f(x_i), \text{ for discreet } x_i,$$

where $f(x_i)$ is the frequency function of x_i.

F - ratio

tests the significance of a regression coefficient, b_i,

$$F_i \quad (1, M-m-1) \quad = \quad \left[\frac{b_i}{s.e. \quad (b_i)}\right]^2$$

Explanation of Statistical Terms

where s.e. (b_i) is the standard error of b_i, M is the degrees of freedom plus 1, and m is the number of independent variables.

F - probability

the probability of obtaining a value of F_i greater than or equal to the one calculated for b_i, given $B_1 = 0$. If this probability is less than 0.05, b_i is assumed to be significantly different from zero.

R^2

coefficient of multiple correlation - for regression, measures the proportion of the total variation about the mean of the dependent variable explained by the regression.

$$R^2 = \frac{SSREG}{SSTOT}$$

$$SSREG = \sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2, \quad \hat{y}_i \text{ is value generated by regression}$$

$$SSTOT = \sum_{i=1}^{n} (y_i - \bar{y})^2, \quad y_i \text{ is observed value.}$$

residual

the difference between the observed value and the calculated value $(y_i - \hat{y}_i)$

standard error

the standard error of the mean is given by s/ n, where s is the standard deviation and n is the number of samples.

APPENDIX 6 (cont'd)

Explanation of Statistical Terms

standard error of estimate	for the dependent variable, y, is given by

$$\frac{1}{n-m-1}\left[\sum_{i=1}^{n} wi\,(y_i - \hat{y}_i)^2\right]^{1/2},$$

where n is the number of observations,

y_i is the observed value

$\hat{y}_i$ is the generated value

w_i is the weighting factor of the r^{th} observation

m is the number of variables

relative standard error	or relative error is the standard error of estimate (Y) divided by the average value of Y times 100. For the mean annual flood, the relative error is the standard error of estimate divided by the average mean annual flood for the sample times 100.