Physiographic Parameters: Estimation and Application to Hydrologic Regionalization

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CONTENTS

ABSTRACT

Mean basin physiographic quantities have been estimated from various sampling schemes. The major schemes are a 2 kilometre by 2 kilometre grid on a 1:50,000 scale topographic map and a 10 kilometre by 10 kilometre grid on a 1:250,000 map. Basin estimates have been compared and have been used as predictors (independent variables) in regional regression equations for mean annual flow. Results indicate that the 2 X 2 data provide estimates closer to fine sampling estimates of basin quantities than 10 X 10 data and that 2 X 2 data provide better predictors in that the regression equations developed using them have lower standard errors than do equations using 10 X 10 data.

perhaps clarify here

RESUME

PHYSIOGRAPHIC PARAMETERS: ESTIMATION AND APPLICATION TO HYDROLOGIC REGIONALIZATION

1. INTRODUCTION

1.1 Preface

The 1971 Shawinigan Engineering Company report "Hydrometric Planning Study for Western and Northern Canada" pointed to the need for a data bank and an analysis system in order to increase the usefulness of hydrometric data and to analyze the efficiency of data gathering. Such a data bank should contain not only hydrometric data but also other data that could be correlated with hydrometric data. These correlations would allow the hydrometric data to be extrapolated to ungauged basins, thus increasing its usefulness. The correlations and extrapolations as functions of the number of hydrometric stations used in their development provide accuracy measures for the assessment of hydrologic data gathering.

The data bank developed by Shawinigan Engineering Company contained physiographic parameters extracted using a 10 kilometre by 10 kilometre grid on 1:250,000 topographic maps. In this report this grid is referred to as the 10 X 10 grid. One of the recommendations of the Shawinigan report was that, in areas of complex hydrologic response, the analysis be expanded with physiographic data extracted on a finer grid. In British Columbia, an area of complex, highly varied hydrology, a 2 kilometre by 2 kilometre grid (2 X 2) was chosen and the extraction of physiographic data from 1:50,000 scale maps was undertaken. In this report this grid is referred to as the 2 X 2 grid and data extracted from this grid is referred to as 2 X 2 data. The title for this report refers to estimation of physiographic quantities from 2 X 2 and 10 X 10 grids for southern British Columbia. The application of physiographic parameters to hydrologic regionalization refers to their use as predictors in regression equations for mean annual flow.

As of October 1985 the extraction of data for the province of British Columbia was complete south of Latitude 55 degrees north. To the north of 55 degrees the extraction is approximately 65% complete. However, only 80% of the extracted data has been transferred onto magnetic tape. Figure 1 indicates the availability of the physiographic data extracted from the 2 X 2 grid for the Province (Note: The figures and tables are in separate sections at the end of the report).

As the computer programs for storing and accessing the 2 X 2 data are now being tested, this time appears propitious to compare physiographic estimates made from the two grids and to examine the effects of these physiographic estimates upon hydrologic regionalization by the use of regression. An outline of objectives for this report showing the development of the two main objectives is as follows:

Objectives

1. Comparison of Basin Quantities Estimated From Various Spatial Sampling Schemes

   Basin Quantities
   - Drainage Area
   - Elevation
   - Slope
   - Aspect
   - Area of Lakes

2. Examination of Contribution of Various Physiographic Quantities to Regional Hydrologic Equations

   Regression Equations Developed for
   - 2 X 2 Descriptors
   - 10 X 10 Descriptors
   - 10 X 10 Locators

   Compare standard errors

1.2 Effects of Sampling Different Grids

In this study basin mean quantities are estimated from physiographic data extracted from different grids. The basin mean quantites compared are: elevation, slope, aspect and areas of lakes and swamps. Estimates of basin drainage area by various methods related to sampling grids are also compared. The question of accuracy of the estimates has considerable importance to both present and future hydrologic studies. The question is raised: does physiographic data extracted from a finer grid (higher sampling density) provide better estimates than those produced from a coarser grid? In this context, "better" implies producing regional regression equations with lower standard errors given a similar number of independent variables.

Physiographic data have been sampled on 10 X 10 and 2 X 2 grids. Other sampling schemes such as sampling at corner points and centre point of 2 X 2 squares and taking one sample elevation at the centre of a 6 km X 6 km square are used to fill in the range of sampling densities. In addition, elevations for the basin gauged by 08LG016 Pennask Creek near Quilchena have been sampled on a 100 metre by 100 metre grid. Several basins have had elevations sampled on a 1 kilometre by 1 kilometre grid. This allows comparison of mean physiographic quantities based on a range of spatial sampling.

1.3 Classification of Physiographic Parameters

In addition to the grid from which they are extracted, physiographic parameters can be further classified. In this report physiographic quantities such as elevation, land use, or slope are called descriptor parameters in that they describe a basin. Descriptor parameters can be classified as primary - those which are extracted directly from maps or derived - those which are derived from primary descriptors.

Elevation is a primary descriptor while slope and aspect are derived descriptors.

Physiographic quantities such as distance to the sea or barrier height in specified directions are termed locator parameters. As complete coverage is necessary to produce locator parameters, basin locator parameters are currently available only from the 10 X 10 grid. Complete coverage is the condition that there must be no missing data from the given square to the sea or other boundary of data coverage (such as the border between Canada and the United States).

1.4 Purposes of Study

This investigation has two purposes. The first is a comparison of basin quantities estimated from various sampling schemes. These schemes are primarily the 10 X 10 and 2 X 2 grids, but variations on the 2 X 2 grid and limited use of smaller resolution sampling schemes are employed in order to assess the variation in estimates of basin quantities in relation to the sampling densities. The second purpose is to assess the contribution of various physiographic quantities to regional hydrologic regression equations. Various physiographic quantities refer to physiographic quantities extracted from the 2 X 2 and 10 X 10 grids as well as basin descriptor and basin locator quantities. The effects of spatial resolution and type of physiographic quantity are investigated to try to provide answers to the following questions:

i) do 2 X 2 descriptors provide better equations than 10 X 10 descriptors?

ii) do derived basin descriptors provide improvement to equations?

iii) do basin locator variables make a significant contribution to regression equations?

iv) what are the results when parameters of different types and different resolutions are entered into regression studies?

2. PROCEDURE

2.1 Study Area

The study area chosen was southern British Columbia, which is densely gauged relative to other parts of the province, with approximately one station per 1200 square kilometres. Mean annual runoff ranges from less than 100 mm on the dry interior plateau to 4000 mm on the exposed west coast of Vancouver Island. In the study area, 71 stations operated by the Water Survey of Canada were selected. These stations record flow regimes classified as natural; that is, no significant man induced intervention to the flow regime is known. Drainage areas range from 20 square kilometres to 3000 square kilometres and are represented in heavy black silhouettes on Figure 2. Also shown on Figure 2 are three hydrologic regions which were identified in previous work by Leith (1983).

The three regions - coastal, wet interior and dry interior - were identified from a typicality-diversity plot, Wong and Liu (1975) and a bivariate plot of runoff versus mean basin response in Geostationary Operational Environmental Satellite (GOES) visible band. Further details on these procedures and results will be provided in a forthcoming publication. These methods produce objective delineation of regions which generally agree with experience. The boundaries of the regions are blurred, particularly from coastal to wet interior.

2.2 Basin Drainage Area

In this report basin drainage area is the area of the surface drainage system and it is assumed that the surface and subsurface drainage systems coincide. Thus, the runoff recorded at hydrometric gauging stations is the response of both surface and subsurface drainage and can be ascribed to the surface drainage area. Note that the Water Survey of Canada number and name identifiers for a hydrometric station are used to identify a basin. Drainage areas estimated by three methods were compared.

The published Water Survey drainage areas are determined from a continuous delineation of drainage area on a topographic map. The basin boundary is delineated by joining the points of high ground around the basin with a continuous smooth curve as discussed in Linsley et al. (1949). Maps of both 1:50,000 and 1:250,000 scales are used for the delineation. The area enclosed by the curve is estimated by a program PAL (Point Area Length) which uses a digitized input of the basin boundary. Before the program became available, drainage areas were estimated by planimeter. The drainage area determined using this method will depend upon the skill of the person delineating the boundary and to some extent upon the relation between the size of the basin and the scale of the mapsheet. Basins with drainage areas between 200 and 400 square kilometres are usually considered to be estimated to within 2%.

The 2 X 2 delineation of the basin depends upon the continuous basin outline and the 2 X 2 grid on 1:50,000 mapsheets. Each square through which the continuous outline passes is included in the basin if the square contains 50% or more of the basin. Figure 3 provides an example of the continous curve in heavy black and the resulting 2 X 2 approximation to the boundary appears as the polygon figure. Figure 3 also provides an example of the coding of 2 X 2 physiographic data on a mapsheet. Kreuder (1979) provides a description of the development of the 2 X 2 data bank.

The drainage areas extracted from the 10 X 10 square grid were accepted as provided by Water Resources Branch in Ottawa.

2.3 Mean Basin Elevation

Elevations were taken at the centre point of each 2 X 2 square. To examine the effects of more frequently sampled data, elevations were extracted at the corner points of each square. This sampling scheme produced a slightly higher sampling density than the centre point sampling scheme, the increase depending upon the number of basin boundary squares. Basins were initially chosen to cover a range of drainage basin areas from 20 square kilometres to 600 square kilometres and a range of steepness from relatively flat to very steep basins. Relatively flat basins had a range of elevations less than 500 feet while the relatively steep basins had elevation ranges of 5000 feet. Several basins showed large differences in mean basin elevation estimated from 10 X 10 and 2 X 2 data. For these basins elevation was extracted on a 1 km X 1 km grid, the elevation being extracted at the centre point, thus providing four samples of elevation in each 2 km X 2 km square or a sampling density of 1 sample per square kilometre. For the basin gauged by station 08LG016 Pennask Creek near Quilchena, the mean basin elevation was estimated from elevations taken to produce a digital elevation model (DEM). Elevations were sampled on a 100 metre by 100 metre grid from stereoscopic air photos. Accuracy of elevations estimated using this technique depends upon ground reference points; for the Pennask basin which is relatively open (not heavily treed) each elevation is expected to be be accurate to ± 5%. The digital elevation model work was done by Pacific Survey (Spar Aerospace) on contract to the Water Survey of Canada.

10 km by 10 km elevation is established by sampling the elevation at each corner point and the centre point of the

10 km by 10 km square. The usual contour interval on 1:250,000 maps in British Columbia is 500 feet, while on the 1:50,000 maps the contour interval is usually 100 feet although it can be less. These differences in scale and resolution should be kept in mind in the comparison.

2.4 Mean Basin Slope

Previous studies on hydrologic regionalization (Leith, 1978) have shown that basin slope is a statistically important parameter, particularly for low flows. Ragan (1985) has pointed to the importance of basin slope to the timing of hydrologic response and to the sensitivity of slope to the sampled elevations which go into its estimation.

On a square by square basis slope is estimated in two ways from the 2 X 2 data: first from contour crossing data, reference National Handbook of Recommended Methods for Water Data Acquisition, and second from the largest gradient between the centre point elevation of the square under consideration and the nearest neighbour elevations. For the first method the slope (s) for a square is found from

$$s = \frac{N\ h\ \sec\ (cc)}{l}$$

where N is the number of contour crossings both east-west and north-south, h is the contour interval, for example, 100 feet, cc is the angle between the contour lines on the map and the grid line, l is the length of the grid, in this case 4 kilometres.

Linsley et al.(page 250) suggest that any attempt to determine an average secant is at best uncertain, but Horton's value of 1.571 has been accepted for the estimation of slope.

The second method for slope estimation from 2 X 2 data is illustrated in Figure 4; the data are elevations in metres taken for 08NH084 Arrow Creek near Erickson. The slope for a square is found by scanning for the greatest change in elevation from the centre point of the square to the centre point of the nearest neighbours. For an interior square there are 8 nearest neighbours. For a boundary square only squares within the basin are scanned. The slope is the greatest change in elevation divided by 2 km.

The procedure for estimating slope for each 10 X 10 square is shown in Figure 4. The slope in the north-south direction is estimated from the difference between the elevation in the northwest corner and the elevation in the southwest corner divided by 10 km. The slope in east-west direction is estimated from the difference between the elevation in the southwest corner and the elevation in the southeast corner divided by 10 km. The slope for the square is found by taking the square root of the sum of the slope squared in the north-south direction and the slope squared in the east-west direction.

An estimate of slope is also provided by the Digital Elevation Model for Pennask Creek basin. This estimate is based upon greatest rate of change from an observation elevation to its nearest neighbours.

2.5 Relative Area of Lakes and Swamps

For the 2 X 2 grid, the area of lakes and swamps is estimated by overlaying each square with a transparency having a random array of dots. The number of dots covering lakes and swamps were counted, no distinction being made between lakes and swamps. With reference to Figure 3, the dot count is the number in the lower left quadrant. The area in square inches is the number of dots divided by 100. For mapsheets with a scale of 1:50,000, the area of lakes and swamps in square miles is found by dividing the dot count by 100 and multiplying by 0.62. The derivation of the 0.62 factor is developed in Appendix 2.

The dot overlay claims a precision of 97% if a map area of at least 12 square inches is estimated. The error for smaller areas could be large, small areas of lakes and swamps could be missed. For dot counts of the order of 25 the error should be less than 15%. This error estimate depends upon the accuracy of the map.

2.6 Basin Orientation or Aspect

The measure of basin orientation or basin aspect is provided by taking the most frequently occurring orientation for the 2 km by 2 km squares. The orientation of each square is taken to be the direction of greatest rate of change of elevation from the slope of the square (see Figure 4 previous section for an example). If the gradient from the centre point of a square is positive, i.e. the neighbouring square is lower, then the aspect is taken to be the direction to the neighbouring square. If the gradient is negative, i.e. the neighbouring square is higher, then the aspect is taken as gradient direction plus 180. The directions for the aspect of a square are quantized to every 45 degrees. An aspect of zero degrees is north. An example of the aspects of the squares of the Arrow Creek near Erickson basin together with their distribution is shown in Figure 5. From this distribution the basin was assigned an aspect of 180 degrees, i.e. south.

For each 10 km by 10 km square a plane is fitted through the elevations of the northwest, northeast and southwest corner points of the square, then the projection of the orienation of this fitted plane on the horizontal plane is found and the azimuth is taken to be the angle clockwise from north to the projection. The basin aspect is the mean value for the squares belonging to the basin.

2.7 Annual Runoff

The response (dependent) variable for the regression studies was mean runoff over the 48 month period from November 1978 to October 1982. In this case, mean is determined by dividing by four, as if there were four years of data. The runoff in millimetres (mm) is obtained by dividing the flow volume in cubic decametres by the drainage areas in square kilometres.

In order to see if the results were applicable to longer term runoff, mean runoff from 1950 or when the station opened until 1984 was computed and compared with the 48 month mean runoff.

The use of the 48 month mean runoff makes the results capable of comparison with previous studies (Leith, 1983).

Only 66 of the 71 basins had sufficient flow records to be used in the regression portion of the study. The other five were missing too much record, that is, 20% or more, or were missing high flow records.

2.8 Regression Equations

Regression equations for runoff (response) were developed in terms of physiographic parameters (predictors) using the Triangular Regression Package (TRP) at the University of British Columbia. The equations were developed using backward elimination. Equation building calibration-validation exercises were undertaken in the wet interior region in order to assess the variability in standard error and to get an indication of importance of various physiographic parameters in terms of the frequency with which they occurred.

3. RESULTS

3.1 Drainage Area

For drainage basins with published drainage areas greater than 40 square kilometres the 2 X 2 drainage area estimates agree with published drainage areas to within 4%. The 10 X 10 drainage area estimates are within 4% of published areas for basins greater than 100 square kilometres. The results are summarized in Table 1. In this table the mean absolute difference refers to the mean value of the absolute differences, that is, there is no consideration given to whether the difference is positive or negative. For example, for 2 X 2 estimates of drainage areas for basins with areas between 41 and 100 square kilometres, the mean of the signed differences is -0.1%, while the mean of the absolute differences is 4%. The mean of the absolute differences is assumed to be useful for developing an envelope curve.

With reference to Table 1, for the six basins with published drainage areas less than 40 square kilometres, five have had their drainage areas overestimated by 2 X 2. Overestimation yields a positive difference between published and estimated drainage areas. The mean signed difference is 9%. This indicates a significant overestimation of drainage area. For other drainage area ranges, the number of overestimates and underestimates are nearly equal and there is no indication of bias.

A noticeably large difference of 28% between the 2 X 2 estimate of drainage area and the published area is provided by station 08NH130 Fry Creek below Carney Creek. For this basin the basin boundary input to PAL has been questioned and a larger basin thought to be more realistic was used for the 2 X 2 delineation.

3.2 Mean Basin Elevation

The differences in mean basin elevation estimated from 2 X 2 and 10 X 10 data are summarized in Table 2 and plotted in Figure 6. The percentage differences are taken relative to the 2 X 2 estimate. It is interesting to observe that for basins with drainage areas between 40 and 1000 square kilometres the mean unsigned difference is relatively constant - between 10 and 13%. This mean is largely controlled by a small number of large differences. Even for the San Juan River basin (08HA010), a relatively large area of 580 square kilometres, the difference is 25%.

In Figure 6 a positive difference indicates that the 2 X 2 estimate of mean basin elevation is greater than that for the 10 X 10. For 69% (49 of 71) of the basins the 2 X 2 data produce higher estimates of mean basin elevation. While the largest differences and greatest spread are observed for small basins, the size of differences and spread has not reduced much for basins of 200 to 300 square kilometres. Differences, both positive and negative, greater than 20% occur in 15 out of 62 basins with drainage areas of less than 500 square kilometres and for 1 out of 9 basins with drainage areas greater than 500 square kilometres. Figure 7 shows the plot of the difference between the estimates of 2 X 2 and 10 X 10 mean basin elevations against the range in elevations in the basins. The range in elevations is the difference between the maximum and minimum 2 X 2 centre point elevations. There may be a suggestion of narrowing in the difference in mean basin elevation with range of elevation but there is no strong relation.

The sixteen basins with largest differences in mean basin elevation estimates are listed in Table 3. The differences are not surprising for basins smaller than 200 square kilometres but are surprising for larger basins. It is worth noting that all of the sixteen basins except for 08NN016 Sutherland Creek near Fife are in the Vancouver Island and Coastal Mountain area of British Columbia.

Table 4 provides a summary of the consistency of mean basin elevation estimates. In this study the best estimate for the mean basin elevation is taken to be that provided by 1 km X 1 km data. In general, the 2 X 2 centre point estimate of mean basin elevation is found to be closer to the 1 X 1 estimate that is the 10 X 10 estimate and is therefore termed more consistent.

The 2 X 2 centre point and 2 X 2 four corner point estimates are generally close, that is within one standard error of the mean. For example, for Shawnigan basin (08HA033), the standard error for the 2 X 2 centre point is 61 feet based on 22 observations. The four corner point estimates of mean basin elevation are based on more observations than the centre point estimates, for the Koksilah basin (08HA003) 80 four corner point observations, to 55 centre point observations. In this case the 80 observations are independent, that is allowance has been made for a corner point belonging to more than one square. For one basin, gauged by 08HA010 San Juan near Port Renfrew, the 10 km by 10 km sampling of elevation was checked by taking six squares which partially covered the basin. Mean basin elevation was estimated to be 1600 feet. The 10 X 10 estimate supplied by Ottawa was 1366 feet.

3.3 Mean Basin Slope

The mean basin slope has been estimated for each basin by the three methods detailed in Section 3.2.4. Figure 8 shows that estimates made from 2 X 2 elevation data are generally about 1/2 of the estimates made from contour crossings. The distributions about the 1:2 line is amazingly narrow for physiographic quantities, the exception being basin 22, station 08HA034 Craigflower Creek below Burnside Road (drainage area 13.5 square kilometres).

The contour crossing method was assumed to produce more reliable estimates of slope, although estimates are probably going to be high as some contours cross a grid line more than once. The assumption was supported by estimates of basin slope for station 08LG016 Pennask Creek above Quilchena. These estimates are summarized in Table 5 and show that the 2 X 2 contour crossings estimate was the closest to the DEM estimate.

Table 6 lists basins with large differences between 2 X 2 contour crossing estimates and 10 X 10 estimates. The last column of the table suggests factors which may have produced the differences. Most of the basins have shown large differences in either drainage area or mean basin elevation beween 2 X 2 and 10 X 10 estimates. Basin 08MG005 Lillooet River at Pemberton contains extensive glaciers which may affect the estimation of elevations and contour crossings.

3.4 Relative Area of Lakes and Swamps

In general, the area of lakes and swamps estimated for basins on 2 X 2 and 10 X 10 grids agreed. The 10 x 10 estimates seemed quantized in units of 2.0 for lakes and 1.0 for swamps, so basins with relative areas less than 1% as estimated from 2 X 2 registered as 0% from 10 X 10 data. Several smaller basins showed large differences in estimates made from 2 X 2 and 10X 10 data. From Table 7 08NN023 Burrel Creek showed a large discrepancy which was possibly brought about by the inclusion of the Lower Arrow Lake in the basin on the 10 X 10 grid.

3.5 Mean Basin Aspect

The mean basin aspect might better be termed the mode for the 2 X 2. In general, the orientation of the basin estimated from basin aspect 2 X 2 agrees with the 10 X 10 estimates given that there is a 45 degree quantization in the 2 x 2 (Table 8). Notable exceptions are small basins (less than 100 square kilometres) and several basins with large differences (greater than 10%) in estimated drainage area from between 10 X 10 or 2 X 2 and the published source. The basins are identified in Table 8.

The discrepancies may be due to inclusion in the basin of 10 X 10 squares which do not cover a large percentage of the basin and those not representative of the basin. The difference observed for station 08MG005 Lillooet River near Pemberton may be associated with the difference in slope (see Section 3.3).

3.6 Annual Runoff

Figure 9 shows the close association between the 48 month mean runoff and the long term mean annual runoff. The majority of stations are within 10%, suggesting that the regression results of this study are not limited to the period November 1978 to October 1982 but have wider applicability.

3.7 Contribution of Various Physiographic Quantities to Regional Equations

Tables 9, 10, and 11 summarize the regression equations for the Wet Interior, Dry Interior and Coastal Regions. These regions are outlined in Figure 2. Assuming that a reduction in standard error of estimate provides an improved equation in terms of lower errors in prediction, then in Table 9 the equation developed from 2 X 2 basin descriptor parameters is superior to the equation from 10 X 10 descriptors. The introduction of 10 X 10 locators produced an equation with lower standard error than that developed from basin descriptors either 2 X 2 or 10 X 10.

Figure 10 shows the results of an equation building calibration-validation exercise for Wet Interior Region basins. The horizontal axis shows the number of basins used in developing the calibration equation. These basins were random samples. The equation developed from each random sample was then applied to the remaining basins. With calibration samples of twenty basins the range of calibration errors has narrowed from that for 10 basins. This provides an indication of the range of calibration error to be expected for 26 basins. Using the equation for prediction in the Wet Interior Region will probably involve larger errors than those suggested by calibration standard error. The magnitude of this error is indicated by the range of validation errors for 20 basins. All the above results are for regression equations developed by ordinary least squares.

In the buildup procedure the occurrence in various physiographic parameters in the equations was noted and is summarized in Table 12. The basin slope estimated from contour crossings on the 2 X 2 grid (SLPCC2) occurred six times in the nine equations developed.

From Table 10, in the Dry Interior Region, basin descriptors from either grid were statistically insignificant. 2 X 2 descriptors combined with basin locators produced an equation with a slightly lower standard error than that for the equation developed from locator parameters.

From Table 11, in the coastal region 2 X 2 descriptors were superior to 10 X 10 descriptors and basin locators were required to produce the best equation.

4.0 CONCLUSIONS AND RECOMMENDATIONS

With reference to Section 1.4 Purposes of Study, the comparison of sampling on estimating physiogaphic parameters indicates that, in general, 2 X 2 data do provide more reliable estimates of basin properties than do 10 X 10 data. "Reliable" here refers to the evidence that the 2 X 2 estimates are closer to those made with more densely sampled data than are estimates made with 10 X 10. This consistency is particularly evident in basins between 40 and 100 square kilometres and for derived parameters such as basin slope. Drainage area estimates made from the 2 X 2 grid are generally closer to the published values, indicating that 10 X 10 estimates of the basins may be either including or excluding significant areas of the basin, hence producing unrepresentative basin average estimates. The 2 X 2 data also appears to provide more realistic estimates of area of lakes and swamps which, considering the larger scale of the maps from which 2 X 2 are extracted, is as would be expected.

As to the comparison of effects on regression equations of various physiographic parameters, the results do appear to depend upon hydrologic region. Except for the Dry Interior Region, 2 X 2 descriptors explain more of the variance, i.e. they provide better predictors than do 10 X 10 descriptors. 10 X 10 locators improve regression equations in terms of reducing the standard errors. In the Dry Interior Region only the 10 X 10 basin locators were significant. These results clearly show the value of the 2 X 2 descriptors and the 10 X 10 locators to hydrologic regionalization by regression equations.

Recommendations arising from this study are:

1) That the importance of slope be further investigated, particularly with emphasis on the estimation of slope by

contour crossings. It may be that contour crossings do not have to be extracted from the unprocessed mapsheets since estimates from 2 X 2 elevations are very close to 1/2 estimates by contour crossing.

2) That the development of location parameters from 2 X 2 data be examined since location parameters do make a contribution to regional equations.

3) That Digital Elevation Models be prepared for several basins, particularly the ones with large differences between 2 x 2 and 10 X 10 estimates. This would allow a more extensive examination of the assumption that closely sampled data provide better basin estimates.

4) That air photos used to develop the DEMs in Recommmendation 3 be used to estimate areas of lakes and swamps and forest cover for the basins.

5) That the addition of land cover data such as forest be considered for the 2 X 2 data bank.

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FIGURES

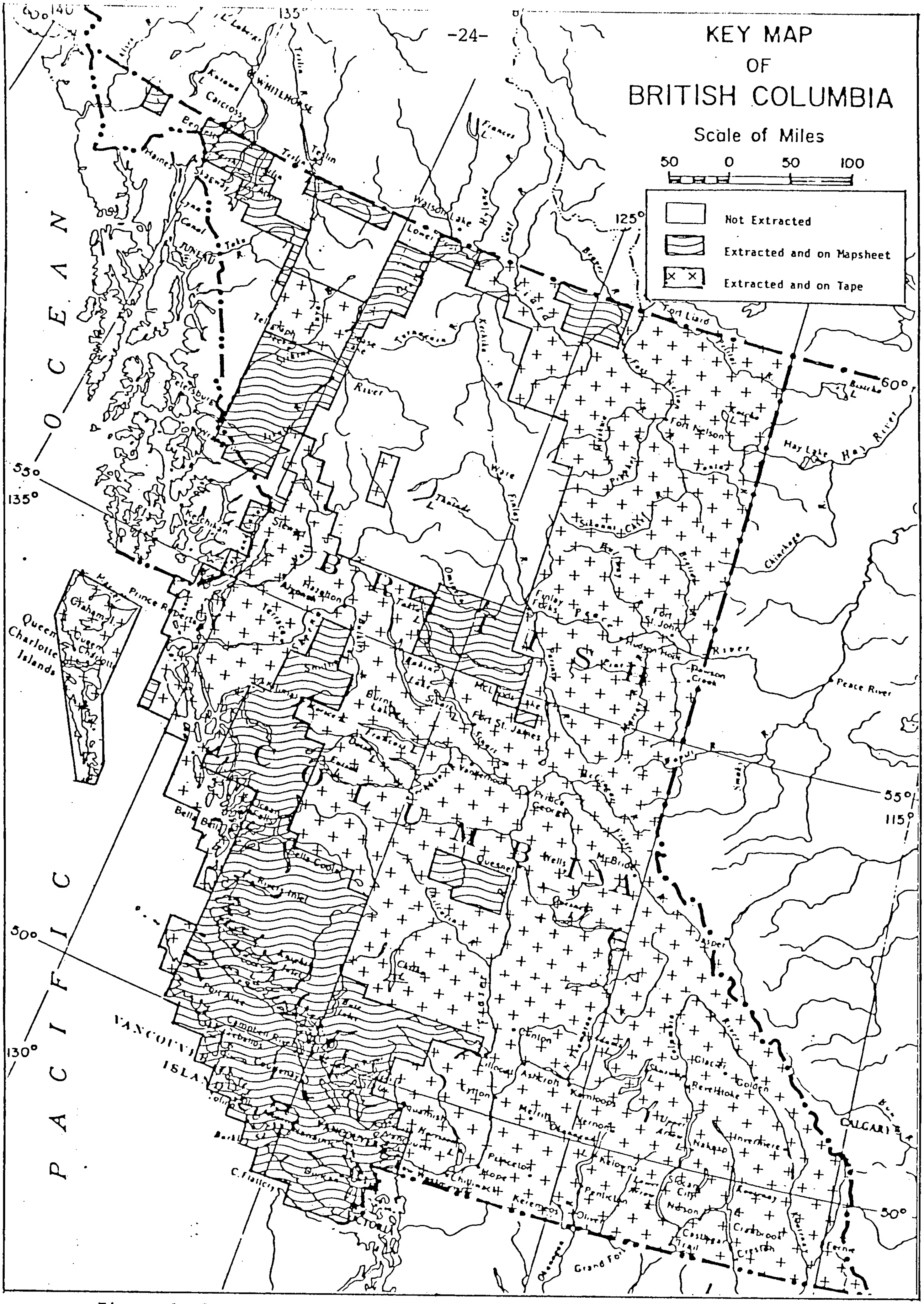


Figure 1 State of the 2 X 2 Physiographic Data for British Columbia

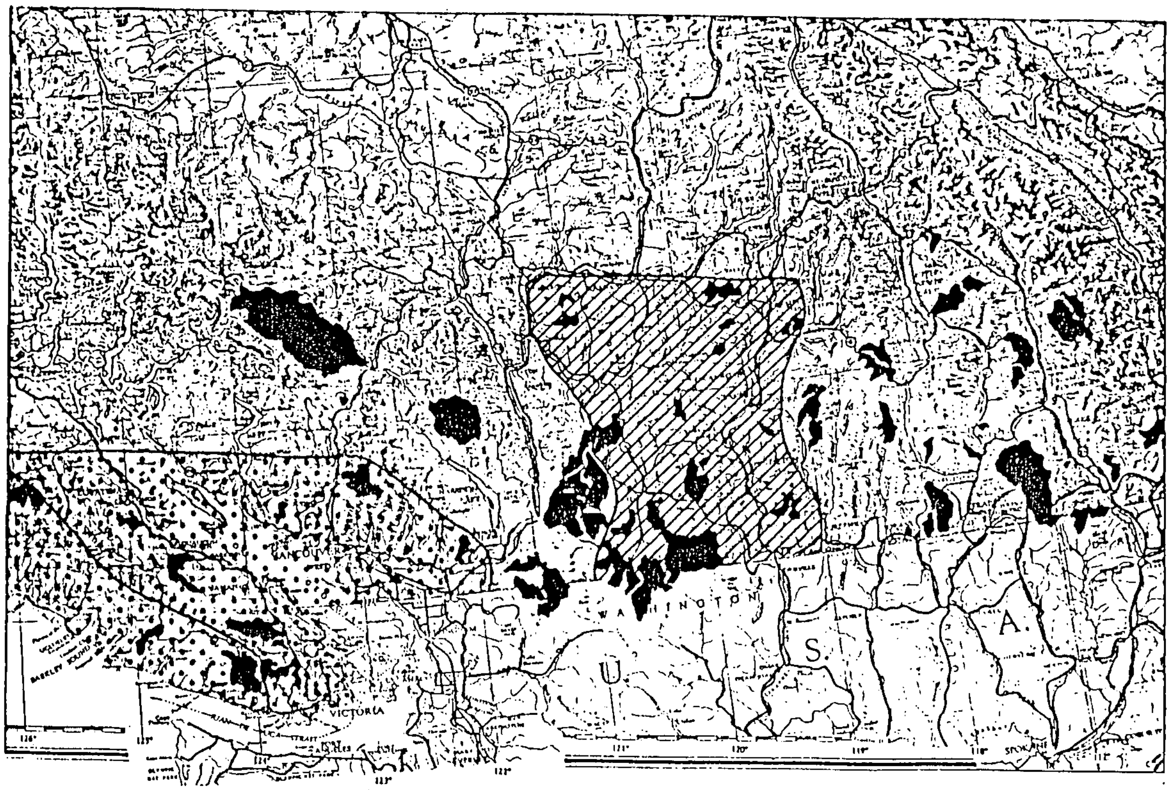


Figure 2 Location of Basins (black silhouettes) and Delineation of Hydrologic Regions

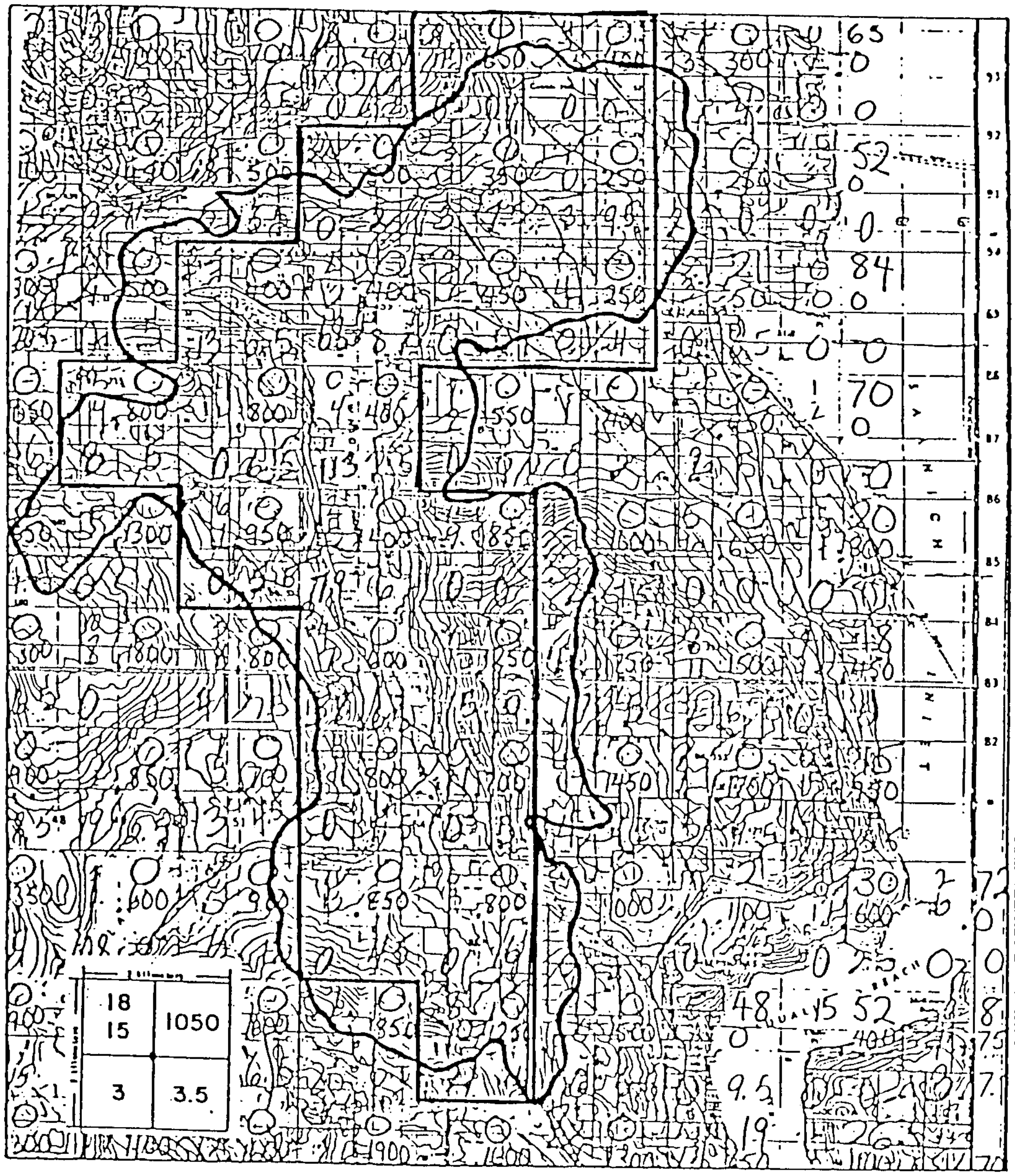
Basins are indicated in black.

Dry Interior Region

Vancouver Island and Lower Mainland

Wet Interior Region - remaining study region

Figure 3 Shawnigan Creek Basin on Vancouver Island and Sample of Coded Grid Square



Upper Right	Elevation in Feet
Upper Left	Number of Contour Crossings
Lower Left	Number of Dots for Area of Lakes and Swamps
Lower Right	Number of Divider Intervals for Measuring Channel Length

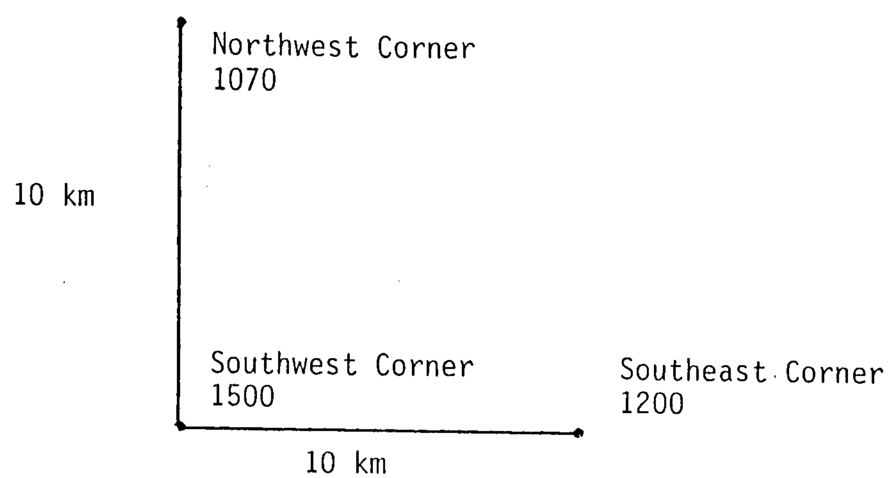
Figure 4 Estimation of Basin Slope From 2 X 2 Elevations
Arrow Creek near Erickson

2103	1829			
1646	1875			
	1676	1737		
	1768	1524	1341	
		1600	1189	1692
		1433	1097	1737
		1509	975	1798
		1463	975	

Slope in upper corner is $\frac{(2103 - 1646)}{2 \text{ km}} = 229$ m/km.

The direction is toward the square with elevation 1646 m, i.e., south or 180°.

From 10 X 10 Elevation Data



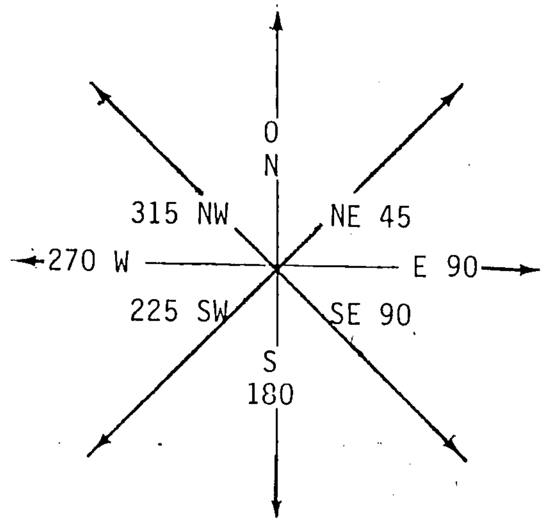
$$\text{Slope} = \sqrt{\left(\frac{1500-1070}{10}\right)^2 + \left(\frac{1500-1200}{10}\right)^2}$$

$= 52$ m/km

Figure 5 Square by Square Aspect Values for Arrow Creek near Erickson Basin

Physiographic parameter number 8 Aspect (degrees clockwise from North)

180	225			
180	270			
	135	135		
	90	135	180	
		135	180	225
		135	180	225
		90	180	270
		45	0	

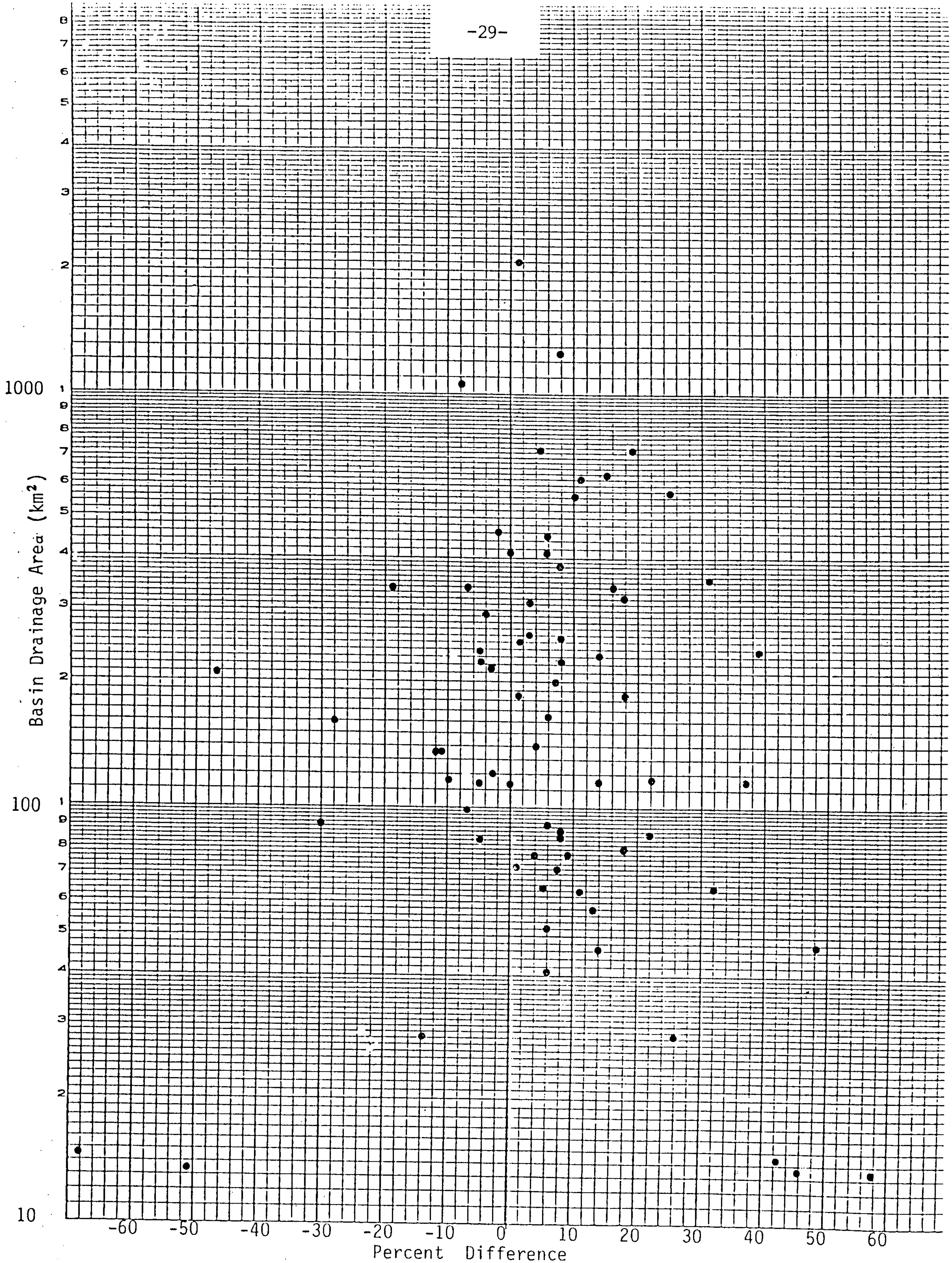


Distribution of aspects found in the basin

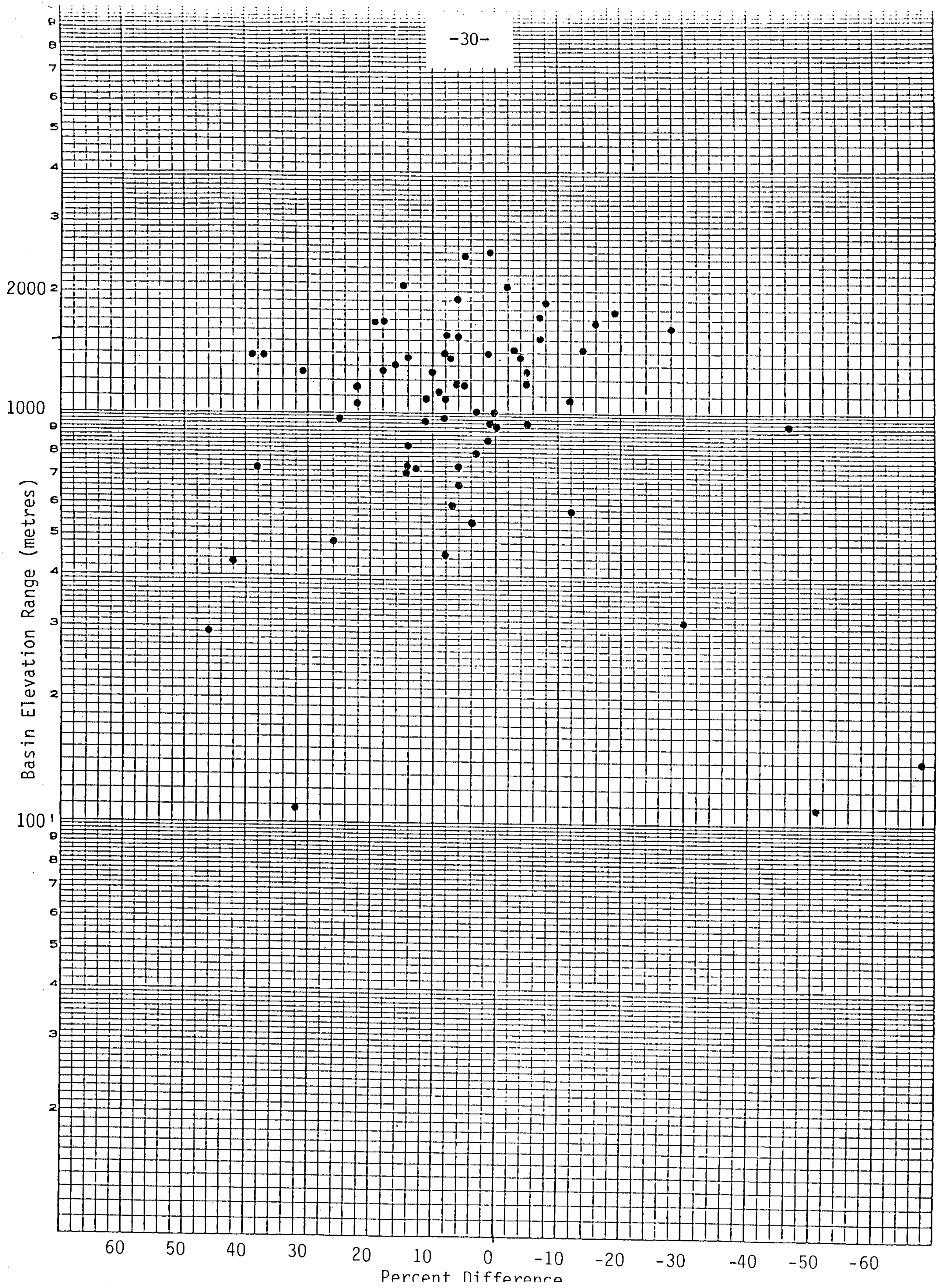
Direction	Tally of 2 km x 2 km squares
N	X
NE	X
E	XX
SE	XXXXX
S	XXXXXX
SW	XXX
W	XX
NW	

```
====|====|====|====|====|====|
        10        20        30
```

Mode of physiographic parameters over basin



Basin Drainage Area (km²)
1000
100
10
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
Percent Difference



Basin Elevation Range (metres)
2000
1000
100
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
Percent Difference

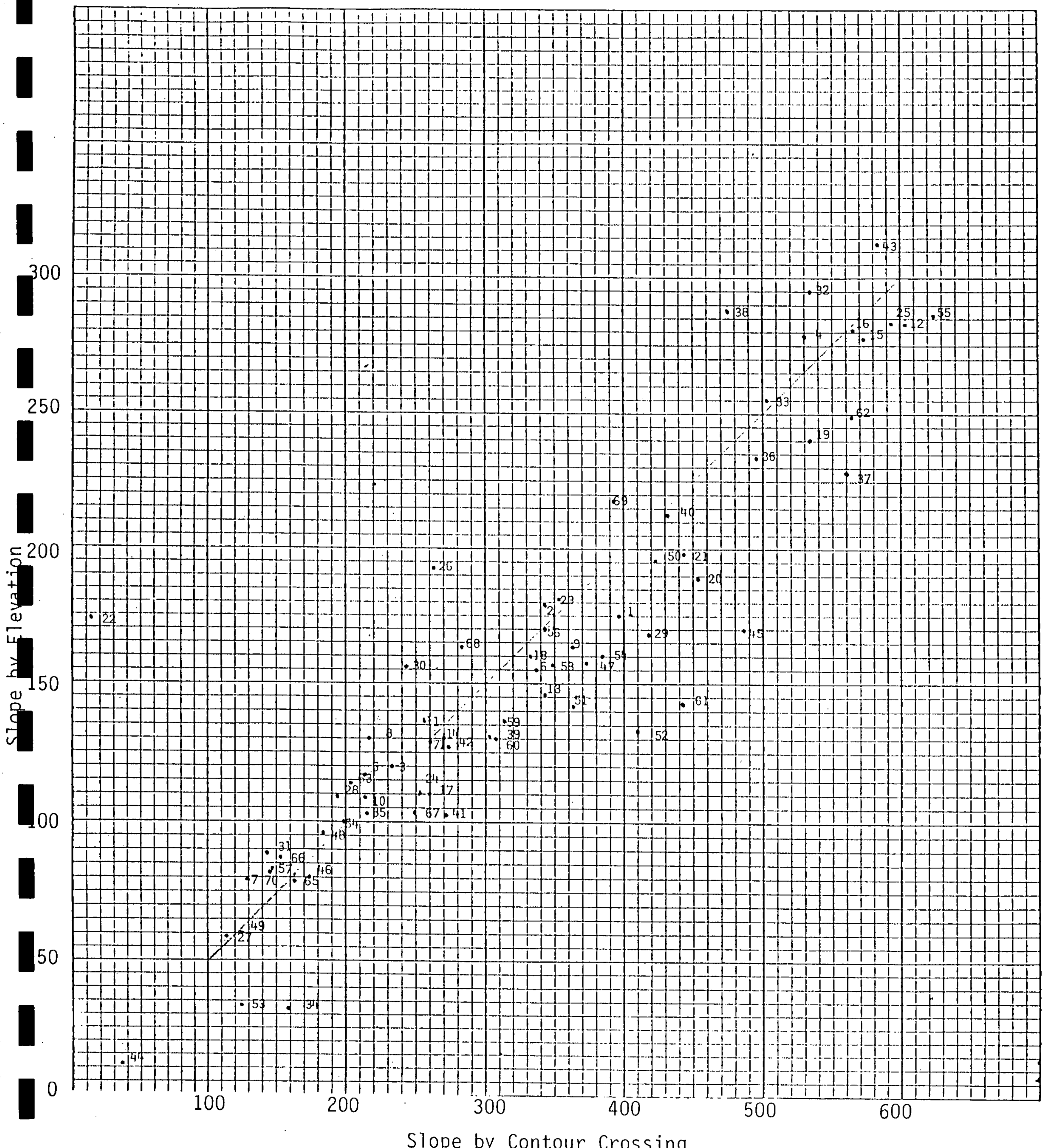


Figure 8 2 km x 2 km Mean Basin Slope in m/km
Numbers identify basins. See Table 7.

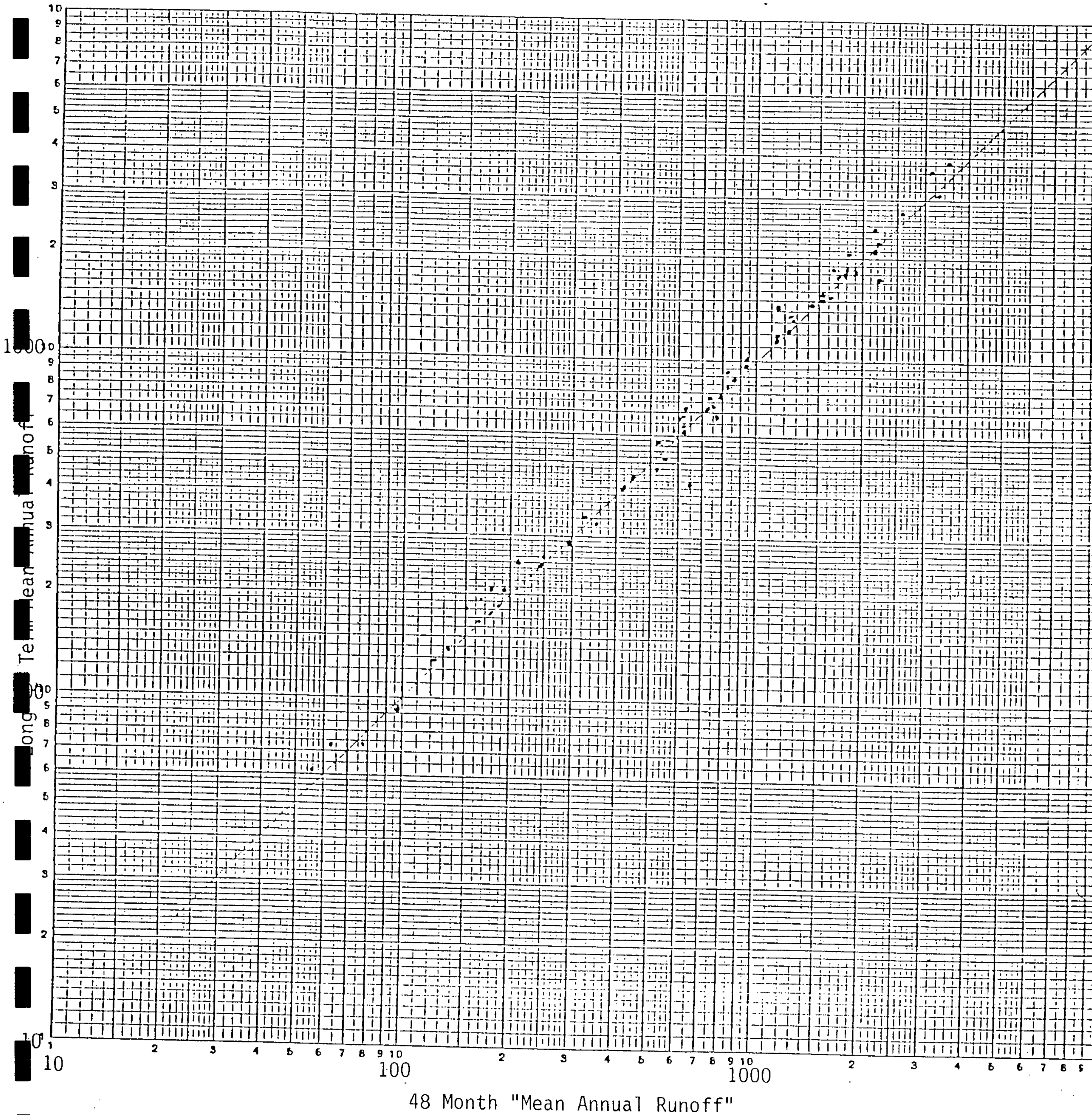


Figure 9 Long Term Mean Annual Runoff Plotted Against 48 Month Mean Annual Runoff in Millimetres.

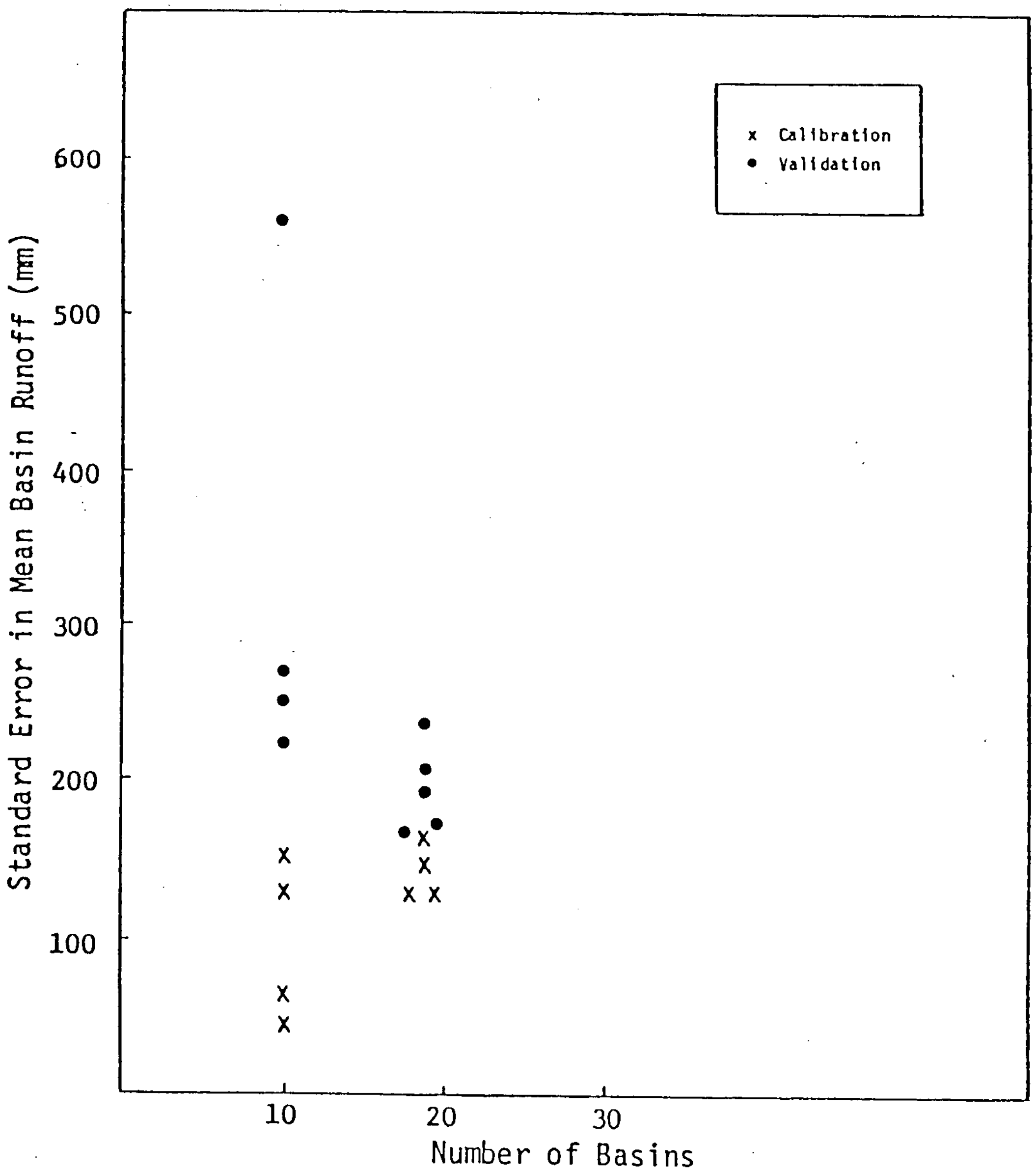


Figure 10 Standard Errors versus Number of Basins in Wet Interior Equation Building

TABLES

Table 1 Summary of Comparison of Drainage Areas

Range of Published Drainage Areas Square Kilometres	Number of Basins	2 km X 2 km Mean Absolute Difference	2 km X 2 km Range of Differences	10 km x 10 km Mean Absolute Difference	10 km x 10 km Range of Differences
0 - 40	6	13%	-11 to 28		
41 - 100	20	4%	-8 to 9	18%	-62 to 20
101 - 200	13	5%	-4 to 12	3%	-4 to 8
201 - 400	19	2%	-7 to 4	8%	-5 to 46
401 - 1000	10	4%	-4 to 28	8%	-3 to 18
Over 1000	3	3%	-5 to 2	3%	-4 to -1

Table 2 Summary of Differences in Mean Basin Elevation Estimates

Drainage Area Square Kilometres	Number of Basins	Mean Unsigned Difference 2 km by 2 km 10 km by 10 km	Range of Differences
0 - 40	6	41%	14% - 68%
40 - 100	20	13%	1% - 48%
101 - 200	13	12%	0% - 37%
201 - 400	19	13%	3% - 47%
401 - 1000	10	10%	0% - 25%
Over 1000	3	6%	1% - 8%

Table 3 Basins with Large Differences between Estimates of Mean Basin Elevation from 2 X 2 and 10 X 10 Data

Water Survey Station Number	Basin Name	Drainage Area (km^2)	Difference in Percent
08HA016	Bings Creek near the Mouth	15.5	42
08HA001	Chemainus River near Westholme	355	31
08HA034	Craigflower Creek below Burnside Road, Vict.	13.5	34
08MH076	Kanaka Creek near Webster Corners	47.7	48
08HB063	Kitsucksus Creek above Cherry Creek	15.5	68
08HA003	Koksilah River at Cowichan Station	209	47
08HB029	Little Qualicum River near Qualicum Beach	237	39
08NN021	Moody Creek near Christina	13.5	46
08MH105	Nicomekl River below Murray Creek	64.5	32
08MH058	Norrish Creek near Dewdney	117	22
08HA010	San Juan River near Port Renfrew	580	25
08HA033	Shawnigan Creek near Mill Bay	91.9	30
08MH056	Slesse Creek near Vedder Crossing	162	28
08NN016	Sutherland Creek near Fife	88.1	22
08HB024	Tsable River near Fanny Bay	113	37
08MG021	Twenty-One Mile Creek at 670 m Contour	28	26

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Table 4 Summary of Mean Basin Elevation Estimates

Water Survey Station Number	Drainage Area Sq. Km.	Mean Basin Elevation Estimate in Feet: 1 X 1	2 X 2 4 corner points (ft.)	2 X 2 centre point	10 X 10
08HA016	15.5	828	797	825	480
08HA001	355		2013	1995	1371
08HA034	13.5	316	344	313	435
08MH076	47.7	1069	1014	1091	563
08HB063	15.5	600	697	475	795
08HA003	209	1516	1504	1544	2272
08HB029	237	1907	1995	1885	1150
08MH105	64.5	189	185	187	128
08MH058	117	na	2494	2589	2030
08HA010	580	na	1748	1826	1366
08HA033	91.9	649	684	641	832
08MH056	162	na	4292	4257	5439
08HB024	113	2427	2387	2491	1629

Table 5 Basin Slope Estimates for 08LG016
Pennask Creek above Quilchena

Method	Slope (m/km)
2 km x 2 km Contour Crossings	126
2 km x 2 km Centre Point Elevations (max. gradient)	51
2 km x 2 km Four Corner Point Elevation (max. gradient)	80
10 km x 10 km	22
Digital Elevation Model 100 m x 100 m grid (max. gradient)	186

Table 6 Basins with Large Differences between the Estimates of Mean Basin Slope (2 km x 2 km contour crossings and 10 km x 10 km contour crossings)

Basin otting lumber	Water Survey Station Number	Basin Name	Drainage Area (km^2)	Difference in Mean Basin Elevation 2X2 10X10	Difference in Drainage Area
4	08NE008	Beaton Creek near Beaton	99.5	7%	60%
5	08NM035	Bellevue Creek near Okanagan Mission	73.3	7%	23%
13	08GA060	Chapman Creek above Sechelt Diversion	64.5	5%	NA
15	08MH103	Chilliwack River above Slesse Creek	645	15%	50% USA
16	08MH016	Chilliwack River at Outlet of Chilliwack Lake	329	18%	part of basin USA
17	08NM142	Coldstream River above Municipal Intake	58.5	13%	NA
18	08LG048	Coldwater River near Brookmere	316	3%	2%
23	08NE087	Deer Creek at Deer Park	80.5	18%	4%
29	08NE120	Hill Creek at Mill Road Bridge	28.2	14%	NA
38	08MG005	Lillooet River near Pemberton	2160	1%	glaciers
51	08HA020	San Juan River near Port Renfrew	580	25%	NA
54	08NL070	Similkameen River above Goodfellow Creek	407	6%	USA
55	08MH056	Slesse Creek near Vedder Crossing	162	28%	USA
57	08NN019	Trapping Creek near the Mouth	144	4%	4%
62	08HC002	Ucona River at the Mouth	185	18%	3%

Table 7 Relative Area of Lakes and Swamps Expressed as Percent of Basin Area

Identifier on plot (Fig. 8)	Water Survey Number	Basin Name	2 X 2	10 X 10 Lakes	10 X 10 Swamps
1	08NH084	Arrow Creek near Erickson	0.0	0.0	0.0
2	08NL004	Ashnola River near Keremeos	0.475	0.0	0.0
3	08NE077	Barnes Creek near Needles	0.160	0.0	0.0
4	08NE008	Beaton Creek near Beaton	1.63	2.0	0.0
5	08NM035	Bellevue Creek near Okanagan Mission	0.0	0.0	0.0
6	08NE039	Big Sheep Creek near Rossland	0.023	0.0	0.0
7	08HA016	Bings Creek near the Mouth	0.0	2.0	0.0
8	08LE094	Bolean Creek near the Mouth	1.174	1.0	0.0
9	08NH032	Boundary Creek near Porthill	0.308	0.0	0.0
10	08NM133	Bull Creek near Crump	0.269	0.0	0.0
11	08NN023	Burrell Creek near Gloucester Creek	0.161	6.0	0.0
12	08NH131	Carney Creek below Pambrun Creek	0.428	1.0	0.0
13	08GA060	Chapman Creek above Sechelt Diversion	1.512	1.0	0.0
14	08HA001	Chemainus River near Westholme	0.241	0.0	0.0
15	08MH103	Chilliwack River above Slesse Creek	2.164	2.0	0.0
16	08MH016	Chilliwack River at Outlet of Chilliwack Lake	3.886	2.0	0.0
17	08NM142	Coldstream Creek above Municipal Intake	0.317	0.0	0.0
18	08LG048	Coldwater River near Brookmere	0.459	0.0	0.0
19	08MF003	Coquihalla River near Hope	0.154	0.0	0.0
20	08MF062	Coquihalla River below Needle Creek	0.543	0.0	0.0
21	08NH068	Corn Creek near Creston	0.0	0.0	1.0
22	08HA034	Craigflower Creek below Burnside Road, Vict.	3.73	2.0	0.0
23	08NE087	Deer Creek at Deer Park	0.0	2.0	0.0
24	08NM176	Ewer Creek near the Mouth	0.403	2.0	0.0
25	08NH130	Fry Creek below Carney Creek	0.219	0.0	0.0
26	08NJ112	Goose Creek near Crescent Valley	0.018	2.0	0.0
27	08LG056	Guichon Creek above Tunkwa Lake Diversion	0.220	0.0	0.0
28	08NL050	Hedley Creek near the Mouth	0.584	0.0	1.0
29	08NE120	Hill Creek at Mill Road Bridge	0.224	4.0	0.0
30	08NE110	Inonoaklin Creek above Valley Creek	0.281	0.0	0.0
31	08MH076	Kanaka Creek near Websters Corners	0.134	9.0	0.0
32	08NH005	Kaslo River below Kemp Creek	0.355	4.0	0.0
33	08NH132	Keen Creek below Kyawats Creek	0.719	0.0	0.0
34	08HB063	Kitsucksus Creek above Cherry Creek	0.101	3.0	0.0
35	08HA003	Koksilah River at Cowichan Station	0.909	0.0	0.0
36	08NE006	Kuskanax Creek near Nakusp	0.291	0.0	0.0
37	08NE117	Kuskanax Creek at 1040 m Contour	0.149	0.0	0.0
38	08MG005	Lillooet River near Pemberton	0.272	0.0	0.0
39	08HB029	Little Qualicum River near Qualicum Beach	2.259	2.0	0.0
40	08GA054	Mamquam River above Mashiter Creek	0.321	0.0	0.0

Continued.......

Table 7 (cont'd)

	Water Survey Station Number	Basin Number	2 X 2	10 X 10 Lakes	10 X 10 Swamps
41	08NN021	Moody Creek near Christina	0.0	2.0	0.0
42	08NH120	Moyie Creek above Negro Creek	0.451	0.0	0.0
43	08MF065	Nahatlatch River below Tachewana	0.667	1.0	0.0
44	08MH105	Nicomekl River below Murray Creek	0.202	4.0	1.0
45	08MH058	Norrish Creek near Dewdney	0.848	0.0	0.0
46	08NL060	Otter Creek below Spearing Creek	1.613	1.0	0.0
47	08NL069	Pasayten River above Calcite Creek	0.192	0.0	0.0
48	08NM172	Pearson Creek near the Mouth	1.565	1.0	0.0
49	08LG016	Pennask Creek near Quilchena	2.364	1.0	2.0
50	08NE074	Salmo River near Salmo	0.110	0.0	0.0
51	08HA010	San Juan River near Port Renfrew	0.450	0.0	0.0
52	08HB014	Sarita River near Bamfield	0.767	2.0	0.0
53	08HA033	Shawnigan Creek near Mill Bay	6.250	5.0	0.0
54	08NL070	Similkameen River above Goodfellow Creek	0.224	339.0	0.0
55	08MH056	Slesse Creek at Vedder Crossing	0.182	0.0	0.0
56	08NN016	Sutherland Creek near Fife	0.017	2.0	0.0
57	08NN019	Trapping Creek near the Mouth	0.520	-1.0	0.0
58	08HB024	Tsable River near Fanny Bay	1.584	1.0	0.0
59	08NL067	Tulameen River near Tulameen	0.297	0.0	0.0
60	08NL071	Tulameen River near Vuich Creek	0.521	0.0	1.0
61	08MG021	Twenty-One Mile Creek at 670 m Contour	0.857	2.0	0.0
62	08HC002	Ucona River at the Mouth	3.432	2.0	0.0
63	08LC040	Vance Creek below Deafies Creek	0.224	0.0	0.0
64	08NM015	Vaseux Creek above Dutton	0.583	0.0	0.0
65	08NM171	Vaseux Creek above Solco Creek	0.441	0.0	0.0
66	08NN015	West Kettle River near McCulloch	0.987	1.0	0.0
67	08NL036	Whipsaw Creek below Lamont Creek	0.151	1.0	1.0
68	08NM174	Whiteman Creek above Bouleau Creek	0.403	0.0	0.0
69	08NJ120	Winlaw Creek near Winlaw	0.040	2.0	0.0
70	08LG009	Witches Brook near Merritt	1.251	1.0	0.0
71	08NL041	Wolfe Creek at Outlet of Issitz Lake	0.560	1.0	0.0

Table 8 Mode of Basin Aspect in Degrees Clockwise from North

	Water Survey Station Number	Basin Name	From 2 X 2	From 10 X 10
1	08NH084	Arrow Creek near Erickson	180	208
2	08NL004	Ashnola River near Keremeos	315	351
3	08NE077	Barnes Creek near Needles	135	156
4	08NE008	Beaton Creek near Beaton	45	28
5	08NM035	Bellevue Creek near Okanagan Mission	315	319
6	08NE039	Big Sheep Creek near Rossland	135	164
7	08HA016	Bings Creek near the Mouth	135	164
8	08LE094	Bolean Creek near the Mouth	225	216
9	08NH032	Boundary Creek near Porthill	45	147
10	08NM133	Bull Creek near Crump	45	83
11	08NN023	Burrell Creek above Gloucester Creek	135	118
12	08NH131	Carney Creek below Pambrun Creek	45	180
13	08GA060	Chapman Creek above Sechelt Diversion	180	250
14	08HA001	Chemainus River near Westholme	90	119
15	08MH103	Chilliwack River above Slesse Creek	315	337
16	08MH016	Chilliwack River at Outlet of Chilliwack Lake	315	337
17	08NM142	Coldstream Creek above Municipal Intake	180	190
18	08LG048	Coldwater River near Brookmere	45	18
19	08MF003	Coquihalla River near Hope	315	279
20	08MF062	Coquihalla River below Needle Creek	315	199
21	08NH068	Corn Creek near Creston	135	321
22	08HA034	Craigflower Creek below Burnside Road, Victoria	180	124
23	08NE087	Deer Creek at Deer Park	225	252
24	08NM176	Ewer Creek near the Mouth	90	164
25	08NH130	Fry Creek below Carney Creek	315	191
26	08NJ112	Goose Creek near Crescent Valley	135	141
27	08LG056	Guichon Creek above Tunkwa Lake Diversion	45	81
28	08NL050	* Hedley Creek near the Mouth	225	174
29	08NE120	Hill Creek at Mill Road Bridge	315	208
30	08NE110	* Inonoaklin Creek above Valley Creek	45	155
31	08MH076	Kanaka Creek near Websters Corners	225	172
32	08NH005	Kaslo River below Kemp Creek	135	89
33	08NH132	Keen Creek below Kyawats Creek	270	185
34	08HB063	Kitsucksus Creek above Cherry Creek	180	320
35	08HA003	Koksilah River at Cowichan Station	45	32
36	08NE006	Kuskanax Creek near Nakusp	225	190
37	08NE117	Kuskanax Creek at 1040 m Contour	225	186
38	08MG005	* Lillooet River near Pemberton	45	141
39	08HB029	Little Qualicum River near Qualicum Beach	45	25
40	08GA054	Mamquam River above Mashiter Creek	225	223

* large differences in results

Continued.........

Table 8 (cont'd)

	Water Survey Station Number		Basin Name	From 2 X 2	From 10 X 10
41	08NN021		Moody Creek near Christina	135	133
42	08NH120	*	Moyie River above Negro Creek	135	65
43	08MF065	*	Nahatlatch River below Tachewana	45	176
44	08MH105		Nicomekl River below Murray Creek	315	260
45	08MH058		Norrish Creek near Dewdney	135	153
46	08NL060	*	Otter Creek below Spearing Creek	45	189
47	08NL069		Pasayten River above Calcite Creek	315	203
48	08NM172		Pearson Creek near the Mouth	225	250
49	08LG016		Pennask Creek near Quilchena	0	352
50	08NE074		Salmo River near Salmo	225	284
51	08HA010		San Juan River near Port Renfrew	225	208
52	08HB014		Sarita River near Bamfield	315	242
53	08HA033		Shawnigan Creek near Mill Bay	0	142
54	08NL070		Similkameen River above Goodfellow Creek	135	203
55	08MH056		Slesse Creek at Vedder Crossing	45	12
56	08NN016		Sutherland Creek near Fife	225	185
57	08NN019		Trapping Creek near the Mouth	180	195
58	08HB024		Tsable River near Fanny Bay	45	330
59	08NL067	*	Tulameen River near Tulameen	315	151
60	08NL071		Tulameen River below Vuich Creek	315	207
61	08MG021		Twenty-One Mile Creek at 670 m Contour	135	219
62	08HC002		Ucona River at the Mouth	0	250
63	08LC040		Vance Creek below Deafies Creek	135	94
64	08NM015		Vaseux Creek above Dutton	225	280
65	08NM171		Vaseux Creek above Solco Creek	315	201
66	08NN015		West Kettle River near McCulloch	225	285
67	08NL036		Whipsaw Creek below Lamont Creek	135	111
68	08NM174	*	Whiteman Creek above Bouleau Creek	0	184
69	08NJ120		Winlaw Creek near Winlaw	270	239
70	08LG009		Witches Brook near Merritt	45	95
71	08NL041		Wolfe Creek at Outlet of Issitz Lake	315	229

* large differences in results

Table 9 Regional Regression Equations for Wet Interior Region
26 Basins Mean Basin Runoff: 846 mm

	R^2	SE mm	Significant Variables
2 x 2 Descriptors	0.71	181	SLPCC2
10 x 10 Descriptors	0.66	221	ELEV10, RALKE, RAFOR
10 x 10 Locators	0.72	208	DISSW, BHN, BHSW, SEW
10 x 10 Descriptors & Locators	0.74	188	DISSW, BHN, BHW, SEW
All Descriptors & Locators	0.85	145	SLPCC2, ELEV10, RAFOR, BHN
Previous Study	0.85	150	SLPCC2, DISNW, DISSW, BHW

Explanation:	R^2	Coefficient of determination
	SE	Standard error
Locators:	BHN	Barrier height to north
	BHSW	Barrier height to southwest
	BHW	Barrier height to west
	DISNW	Distance to sea in northwest direction
	DISSW	Distance to sea in southwest direction
Descriptors:	ELEV10	Elevation at centre point for 10 km grid
	RAFOR	Relative area of forest
	RALKE	Relative area of lake
	SEW	Shield effect to west
	SLPCC2	Slope from contour crossings for 2 km grid

Table 11 Regional Regression Equations for Coastal Region: Vancouver Island and Lower Mainland

19 Basins Mean Basin Runoff : 1912 mm

	R^2	SE mm	Significant Variables
2 x 2 Descriptors	0.45	614	DRNGD2, SLPCC2
10 x 10 Descriptors	0.14	769	RAFOR
10 x 10 Locators	0.60	588	DISN, DISNW, DISW, DISSW, BHW, SEW
10 x 10 Descriptors & Locators	0.62	584	DISN, DISNW, DISW, RAFOR, BHW, SEW
All Descriptors & Locators	0.74	474	DRNGD2, DISN, DISNW, DISW, BHW, SEW
Previous Study	0.63	480	ELEV2, DISW, BHW

Explanation:

R^2	Coefficient of determination
SE	Standard error
BHW	Barrier height to west
DISN	Distance to sea in north direction
DISNW	Distance to sea in northwest direction
DISW	Distance to sea in west direction
DRNGD2	Drainage density on 2 km grid
ELEV2	Elevation at centre point for 2 km grid
RAFOR	Relative area of forest
SEW	Shield effect to west

Table 12 Frequency of Occurrence of Variables in Equation Building for Wet Interior Region

Variable		Total
ELEV.2	X	1
RALS.2	XX	2
DRNGD2		
SLPCC2	XXXXXX	6
SLPEL2		
ASPCT2		
DIS.NW	XXXX	4
DIS.N		
DIS.SW	XXXX	4
RALK10		
RAFOR	XXXXX	5
RASWMP		
RAGLAC		
BH.N	XX	2
BH.NW		
BH.W	X	1
BH.SW	X	1
SE.N		
SE.NW		
SE.W		
SE.SW		

APPENDIX 1.

DESCRIPTION OF 10 X 10 PHYSIOGRAPHIC DATA

ABBREVIATIONS

AREA10	The 10 km by 10 km basin area
ELEV10	The 10 km by 10 km mean basin elevation
SLP.10	The 10 km by 10 km mean basin slope
ASPT10	The 10 km by 10 km mean basin aspect
DIS.N	Distance to sea to North
DIS.NW	Distance to sea to North-West
DIS.SW	Distance to sea to South-West
RALK10	The 10 km by 10 km relative area of lakes
RAFOR	Relative area of forest
RASWP	Relative area of swamps
RAGLC	Relative area of glaciers
RAURB	Relative area of urbanization
BH.N	Barrier height to North
BH.NW	Barrier height to North-West
BH.W	Barrier height to West
BH.SW	Barrier height to South-West
SE.N	Shield effect to North
SE.NW	Shield effect to North-West
SE.W	Shield effect to West
SE.SW	Shield effect to South-West

The 10 km by 10 km grid was overlaid on 1:250,000 scale topographic maps. Elevation sampling consisted of extracting elevations at the four corner points and at the centre of each 10 X 10 square. The calculation of slope for each square is described in Section 3.2.4. The basin slope is the average value for the squares included in the basin.

The aspect of a basin is described in Section 2.6.

Distance to Sea			Distance from centre of gravity of basin to the sea in the north, the northwest, west, and southwest directions
North	DSN		
Northwest	DSNW		
West	DSW	Kms.	
Southwest	DSSW		

The relative areas of lakes, forest, glacier and urban land cover were taken from the maps by counting the number of dots on a random array which covered the appropriate classification.

Relative Area			Percentage of the area of the basin occupied by lakes, forests, swamp, glaciers, and built-up areas Note: .RA does not always equal 100 for a basin
Lake	RALKE		
Forest	RAFOR		
Swamp	RASWP		
Glacier	RAGLC	Dimension-	
Urban	RAURB	less	

Barrier Height			Difference between average elevation of the square and highest elevation encountered in the north, northwest, west and southwest directions until the ocean is reached.
North	BHN		
Northwest	BHNW		
West	BHW	Feet	
Southwest	BHSW		

For each 10 X 10 square the value of barrier height is weighted by barrier heights of 5 squares to the north and 5 squares to the south.

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		

APPENDIX 2. DESCRIPTION OF 2 X 2 PHYSIOGRAPHIC DATA

The 2 X 2 data were extracted from 1:50,000 scale Universal Transverse Mercator Projection maps. A one kilometre square grid with northing and easting coordinates is printed on the maps.

AREA.2	The 2 km by 2 km basin area
ELEV.2	The 2 km by 2 km mean basin elevation
RALS.2	The 2 km by 2 km relative area of lakes and swamps
DRNGD2	The 2 km by 2 km drainage density
SLPCC2	The 2 km by 2 km mean basin slope by contour crossings
SLPEL2	The 2 km by 2 km mean basin slope by elevation differences
ASPT.2	The 2 km by 2 km mode of the aspect of the squares

Mean Elevation

This is the elevation at the centre of the 2 X 2 square which is assumed to represent the average elevation of the square.

Average Land Slope

The contour lines on the maps provide a basis for determining the slope of the land by the intersection-line method as outlined by Horton and described in the U.S. Geological Survey [1947] Water Supply Paper. The number of contour lines crossing the north-south and east-west centre lines of the square are counted and recorded. By the use of the following formula the mean slope of the area can be determined: $\text{slope} = \frac{Nh \sec(cc)}{1}$, $\sec(cc) = 1.571$,

the constant for averaging the angle at which contours cross the intersection line, h is the contour interval or difference in elevation in feet, N is the number of contours crossed, and l is the sum of lengths of the centre lines.

Stream Density

This is defined as the total length of the streams divided by the area. Thus the total length of streams in the square is the desired parameter to be identified. This is accomplished by setting a pair of dividers a specified distance (in this study scaled at 0.2 miles before metric conversion) and recording the number of intervals required to trace the length of the streams in the square.

Area of Lakes and Swamps

This area is determined with the aid of a random dot overlay, then counting and recording the number of dots found within the lake or swamp boundaries in each square. By a suitable conversion, the area of lakes and swamps may then be computed.

To estimate the area of lakes and swamps from 1:50,000 maps:

$$\frac{\text{number of dots}}{100} = \text{area in square inches}$$

Maps are 1:50,000 or 1 inch on map = 50,000 inches on the ground. There are 5,280 X 12 = 63,360 inches in one mile. One inch on mapsheet $= \frac{50,000}{63,360} = 0.7891$ miles on the ground

or 1 square inch on mapsheet equals (0.7891) = 0.62 miles on the ground.