RELATIONS BETWEEN GEOMORPHOLOGY AND STREAM FLOW IN SELECTED NEW ZEALAND RIVER CATCHMENTS

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ABSTRACT

The interrelations of discharge and various morphometric variables are tested by multiple correlation and regression analysis for 12 New Zealand rivers. Catchment area, total range of relief, maximum basin length and perimeter can be used to explain 85% of mean annual discharge and 97% of a run-off/rainfall ratio. The effect of catchment size appears to be much more significant in determining discharge than are climatic or other factors. Multiple regression equations, which could be useful in predicting discharge from ungauged rivers, are calculated.

INTRODUCTION

River flow is widely known to be affected by a number of interrelated factors, including size of catchment, climate (especially precipitation), geology, soils, vegetation, and geomorphology. It is possible to relate any one of these factors individually to discharge and at the same time to incorporate indirectly the effects of the others. Geomorphology is a convenient factor to examine because it is easily quantified using morphometric techniques. By combining those geomorphic variables which show the strongest relationships with discharge variables by multiple correlation and regression analysis, it is possible to derive equations which could be used to predict run-off from ungauged New Zealand river catchments.

Many such studies have been made in the United States. Their development can be traced back to Horton (1945) who developed the basic aspects of morphometric analysis. Strahler's modifications of these techniques (1952) have generally been adopted for use in hydrological studies.

Sherman (1932) concluded that there was a definite relationship between basin outline and the unit hydrograph. Potter (1953) related peak discharge to area, a topographical factor, a rainfall-intensity factor, and a rainfall-frequency factor. Benson (1962)

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correlated peak discharge with similar factors. Morisawa (1962) used similar variables in her work in the Appalachian Plateau, with very good results. Hely and Olmsted (1963), Riggs (1964), and Farvolden (1965) have also made contributions.

Sediment delivery rates and volumes can be used as an alternative to discharge for the dependent variable. Maner (1958) and Roehl (1962) are two who have found strong correlations of these with geomorphology. In New Zealand few sediment-delivery data are available and discharge was therefore used in this study.

AREA OF STUDY

The 12 smallest river basins for which there were gauging records and map and aerial-photograph coverage were selected for study.

TABLE 1 — List of Catchments Studied

River	*Area (sq. miles)*	*Map reference of gauging point (NZMS 1)*
Waiarohia	5.6	N20:827982
Mangatawhiri	16.7	N48:676263
Pokaiwhenua	24.0	N75:411952
Wanganui	31.3	N112:089990
Otane	9.2	N141:015921
Omakere	20.8	N146:141751
Moutere	24.1	S14:377347
Collins	6.8	S15:866428
Roding	15.2	S20:615194
Taylor	26.5	S28:220890
Sawyer's Creek	6.4	S44:735871
Selwyn	64.4	S74:347651

All these catchments are designated "representative" by the Water and Soil Division, Ministry of Works. Each is gauged for discharge and is covered by a network of rain gauges. Since each is supposedly representative of a distinct physiographical region, they exhibit contrasts in terms of climate, geology, soils, vegetation, and land use. This is in contrast to most previous investigations which were confined to basins within one physiographical area. In them, discharge could be related directly to geomorphology while the effects of differing climate, geology and soils were minimized. However, such an areal concentration is not possible in New Zealand at present; in any case it is interesting to consider the influence of regional contrasts in physical environment. The size range, from 5.6 to 64.4 square miles, also ensures considerable range in hydrological and morphometric values.

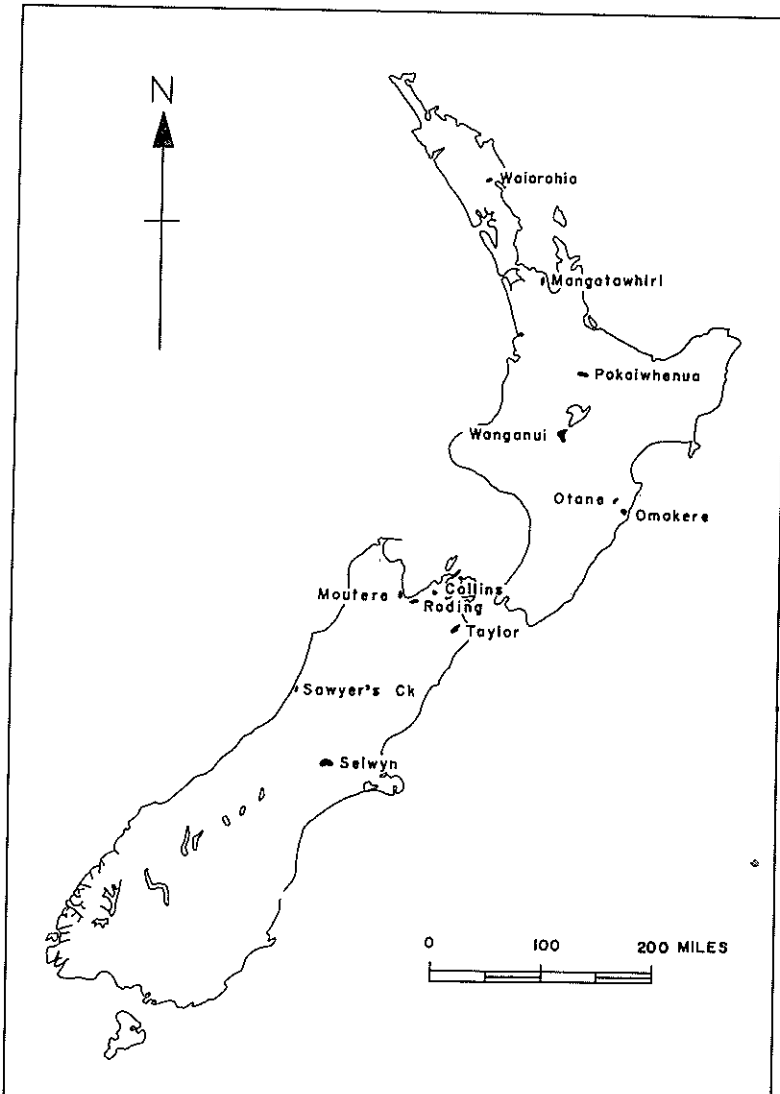

Fig. 1 — Location of catchments.

HYDROLOGY

Mean annual discharge, mean annual flood, and minimum daily discharge values for the catchments were obtained from the Ministry of Works. To incorporate the effects of rainfall, a run-off/rainfall ratio was calculated by dividing the mean annual run-off by the mean annual rainfall for each river. A run-off/area ratio was also used to help illuminate the relations of discharge to variables other than those expressing catchment size.

A limiting factor is the relatively short gauging period of some rivers. For the Otane and Sawyer's Creek the discharge figures are derived from only one year's records. An examination of discharge values for any river shows that there can be considerable variation from one year to the next, so the figures in some cases may not indicate precise mean values.

Another point which must be considered is that ground-water flow will not be recorded as discharge. The importance of this will differ between catchments, depending on geology and soils.

MORPHOMETRY

Base maps for each catchment were prepared on a scale of 20 chains to the inch. Detail of the stream pattern was filled in with the aid of a stereoscope and proportional dividers. Any channel which was discernible on the 20-chain aerial photographs was included. The stream segments were numbered according to Strahler's method of stream ordering (1952). All finger-tip tributaries were designated first-order streams; where two first orders met they formed a second-order stream; where two second orders met they formed a third-order stream, and so on.

Areal measurements were made with a planimeter. Linear measurements (lengths of stream segments, total stream length, length of main channel, perimeter) were made with an opisometer. Range of relief was determined from contour lines.

From such basic calculations 26 different morphometric variables were computed for each basin. Methods are outlined in Morisawa (1962). Together with mean annual rainfall and a measure of the percentage of each basin covered by forest, this gave 28 independent variables to correlate with the discharge parameters.

HYDROLOGY AND MORPHOMETRY RELATIONS

The data were analysed on the University of Canterbury's IBM 1620 computer with a multiple correlation and regression programme. Correlation coefficients which demonstrated statistically significant relationships between discharge and the independent variables are listed in Table 2.

TABLE 2 — Significant Correlation Coefficients

	Mean annual discharge (cusecs)	*Mean annual flood (cusecs)*	*Minimum daily discharge (cusecs)*	*Run-off / rainfall*	*Run-off / area*
Area	.755	.645	—	.949	—
Relief	.889	.701	.646	.868	—
Perimeter	.756	—	—	.888	—
Max. basin length	.732*	.733	—	.903*	—
Length main channel ..	.729	—	—	.901	—
Total stm length	—	—	—	.765	—
Av. total stm length	—	—	—	.735	—
Relief ratio	—	.623*	—	—	—
Mean ann. rainfall	—	—	—	—	.914*
Percentage forest	—	—	.767*	—	.747*

* Logarithmic relationship.

All of the morphometric variables listed in Table 2 are to some extent expressions of basin size, being significantly correlated with catchment area. Thus it is apparent that run-off is greatly increased by catchment dimensions. The larger the catchment area, and the greater its range of relief, the higher its discharge. Rainfall emerges as a significant factor only when the effect of area is incorporated in the dependent variable as a run-off/area ratio; the mean annual rainfall then becomes of prime importance. To a large extent, however, the effects of catchment size over-rule the effects of local climatic variations. Other climatic parameters such as rainfall-intensity and rainfall-frequency measures would probably be important, especially with regard to mean annual flood. A large amount of precipitation occurring in a short time will greatly increase the peak discharge, particularly if run-off is rapid. Catchment characteristics such as relief and drainage density are important in influencing rates of run-off. In a catchment of relatively low channel gradient and high drainage density (length of channel per unit area) the run-off will tend to be retarded, while a steep gradient and a low drainage density will ensure rapid run-off and a higher peak discharge.

The importance of vegetation is also apparent from Table 2, even though percentage of forest cover is rather a crude measure. Vegetation has an important control over minimum discharge. Catchments with a large proportion of their area in forest have higher minimum flows than those that are unforested. This is probably because the dense vegetation retards the run-off and tends to smooth out the hydrograph. During periods of low rainfall there is still run-off available because of this storage effect. A measure of soil characteristics would also be helpful. Infiltration rates in particular are important in influencing rates of run-off. This, however, would have required considerable fieldwork in soil sampling and was beyond the scope of this study.

The independent variables which demonstrate the strongest relations with the discharge variables can be combined in multiple regression equations. Mean annual discharge (Qm) can be seen as a function of area (A), maximum basin length (Lb), total relief (H), and perimeter (P). The regression equation for this is:

$$Qm = -11.398 + 0.741\ A - 3.42\ Lb + 0.028\ H + 0.363\ P \quad (1)$$

The explanation of this equation is 85.28%, and the multiple correlation coefficient is 0.923. Analysis of variance shows this coefficient to be significant at the 0.01 level.

The run-off/rainfall ratio (Qm/Pr) may be correlated with the same independent variables in the equation:

$$Qm/Pr = -95.604 + 29.238\ A - 15.36\ Lb + 0.184\ H - 9.377\ P \quad (2)$$

Equation (2) has an explanation of 97.31% and a multiple correlation coefficient of 0.987. This is significant at the 0.001 level.

The improvement in the correlation through including mean annual rainfall in the equation is immediately apparent. Although rainfall does not correlate strongly with discharge as an independent variable, it is obviously significant. An explanation of better than 85% by morphometric variables alone emphasizes the importance of geomorphology as a factor influencing discharge. Even when considering catchments covering a wide variety of climatic and geological environments it is the size of the catchment which is of prime significance. Within basins of similar dimensions other factors would assume more control over the stream flow.

CONCLUSIONS

The importance of geomorphology as a factor influencing stream flow is apparent from this study. Catchment dimensions — when considering a range of different-sized basins — are critical, overriding the effects of climatic variations. However, when the influence of size is precluded by expressing run-off in terms of unit area, the effect of rainfall and vegetation (and probably soil characteristics) becomes apparent.

Techniques which have been used overseas have validity in a study of New Zealand rivers. It is not suggested that the regression equations given in this paper would provide a totally reliable tool for predicting run-off from ungauged catchments. A considerably larger sample than 12 would have to be employed to confirm the accuracy of the method. However, the technique is easily used and could be of some benefit.

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