PREDICTION OF HYDROLOGIC VARIABLES FROM CHANNEL MORPHOLOGY, SOUTH ISLAND RIVERS

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ABSTRACT

Data on the hydrology, sedimentology and morphology of 73 alluvial channels in the South Island are used to develop predictive equations for hydrologic parameters. Of ten indices of magnitude and variability of discharge, prediction equations for only mean annual flood, standard deviation of annual floods and bankfull discharge could be developed which had acceptable precision. An equation for mean annual flood using channel cross-sectional area and aspect ratio (maximum depth/hydraulic radius) as predictive variables has a standard error of estimate lower than an equivalent equation for the whole South Island using other catchment and precipitation characteristics. Its precision is less than that of four regional equations using catchment and precipitation characteristics, but it avoids the problems of defining regions, and could usefully be used in conjunction with these equations.

INTRODUCTION

Prediction of the flood flow characteristics of ungauged catchments is important for planning and design of river channel works and for floodplain development. A wide variety of prediction techniques have been used (Dunne and Leopold, 1978); one of the more common relies on the development of regression equations relating flood variables to measurable characteristics of catchments such as drainage area or stream channel dimensions. Beable and McKerchar (in prep., chapter 4) use this approach to estimate mean annual floods of New Zealand rivers. Using 160 catchments for which reliable hydrologic data are available, they computed equations for both main islands and for nine separate regions, and found that mean annual flood could be predicted from one or more of several catchment and precipitation characteristics.

An alternative approach is to develop regression equations relating flood variables to channel characteristics (Riggs, 1978). Because "the dimension, shape, gradient and pattern of stable alluvial rivers should be controlled by the quantity of water and quantity and type of sediment moved through their channels" (Schumm, 1969), knowledge of morphologic and sediment characteristics of river channels may conversely permit prediction of the quantity of water they are adjusted to convey. It is widely assumed that stable alluvial channels are optimally adjusted to carry the flow with a recurrence interval on the annual series of about 1.5 years (Dunne and Leopold, 1978); this implies that bankfull discharge occurs on average about once a year. It may seem unjustifiable

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to attempt prediction of flood discharges greater than bankfull, but Riggs (1978) for example, demonstrates that prediction of the 50 year flood from channel characteristics is feasible.

This study of the influence of hydrologic regime upon channel morphology in the South Island, New Zealand, evaluates the regression approach to prediction of hydrologic variables from channel morphology.

DATA

Hydrologic data

The rivers selected for study were those with a minimum of ten years of reliable hydrologic data, although in a number of cases this requirement was relaxed. Only channels draining catchment areas in excess of 10 km^2 were used for development of prediction equations, although some smaller catchments were used in preliminary analysis. Only those stations used in chapters 3 and 4 of the report by Beable and McKerchar (in prep.) and in the Catchment Register of New Zealand (Ministry of Works and Development, in prep.), were used, except for a small number of stations with exceptionally long records.

Values of variables describing flood hydrology characteristics were obtained for 73 sites (Fig. 1) from the sources noted above, supplemented

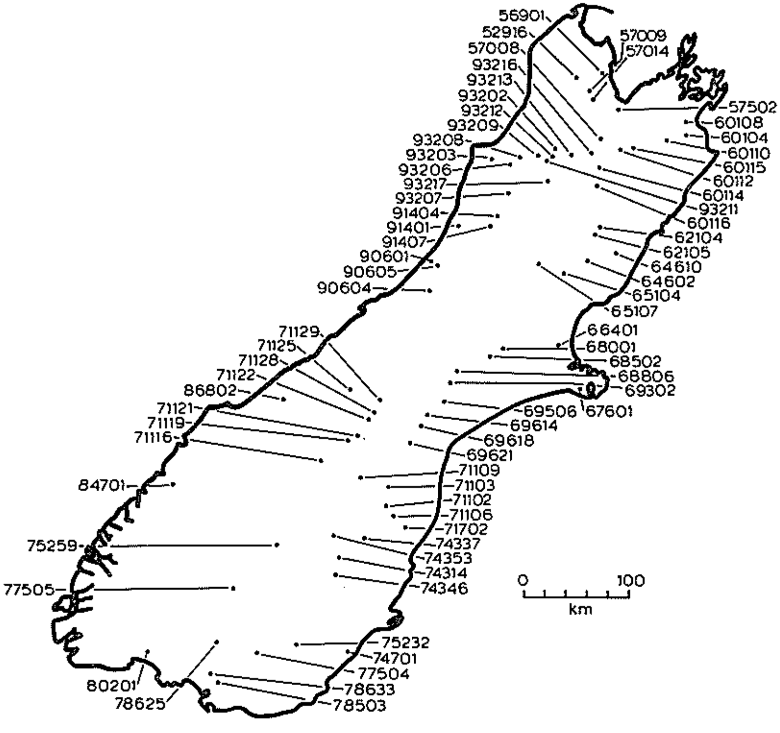

FIG. 1—Locations of sites used in the study.

by updated information from the Ministry of Works and Development (Table 1). For 66 of the sites instantaneous flow data provided six additional hydrologic variables (Table 1); the period 1971-6 was used to derive flow duration curves where data were available, but curves were derived for other periods for certain stations. Computations followed standard procedures, except for the variability index and the range of instantaneous flow, which are indices of flow variability. Variability index (VI) (Lane and Lei, 1950) is similar to a widely used index of the standard deviation of sediment (Folk, 1974, p. 46):

$$VI = \frac{(\ln Q_{16} - \ln Q_{84})}{4} + \frac{(\ln Q_5 - \ln Q_{95})}{6.6},$$

in which Q_{84} is the discharge equalled or exceeded 84% of the time, etc. Range of instantaneous flows QSR were computed by $QSR = (Q_5 - Q_{95}) / Q_{50}$.

Variable Name	Symbol	Units	Range
Flood variables			
Mean annual flood	QMAF	m^3s^{-1}	3.2-4710
Standard deviation of annual floods	QMAFSD	m^3s^{-1}	2.2-1230
Ratio of flood of record QMAX/QMAF	QPKRA	m^3s^{-1}	1.1-60
Bankfull discharge	QBF	m^3s^{-1}	1.7-3110
Instantaneous flow variables			
Mean discharge	QBAR	m^3s^{-1}	0.091-413
Standard deviation of instantaneous flows	QBARSD	m^3s^{-1}	0.17-473
Median flow	Q50	m^3s^{-1}	0.025-260
Variability index	VI	—	0.16-1.8
Range of instantaneous flow	QSR	—	2.2-21
Ratio of QMAF/QBAR	QMAFBAR	—	3.8-136
Morphologic variables—reach			
Sinuosity	SIN	—	1.0-1.8
Channel Slope	SLOPE	—	0.0006-0.058
Meander wavelength	WAVE	m	85-5540
Braiding index	BI	—	1.0-7.2
Morphological variables—cross-section			
Cross-sectional area	A	m^2	1.4-1630
Wetted perimeter	P	m	4.2-1750
Hydraulic radius	R	m	0.33-4.6
Width-depth ratio P/R	POR	—	10-2103
Maximum depth	DMAX	m	0.57-6.2
Aspect ratio (DMAX/R)	ASPRAT	—	1.2-4.0
Relative roughness (R/D75)	ROUGHAN	—	1.6-618
Sediment variables			
Mean diameter of bed sediment	DMEAN	m	0.001-0.17
Median diameter of bed sediment	D50	m	0.001-0.19
Representative diameter, surface layer	D75	m	0.004-0.36
Standard deviation of bed sediment	SIGMA	ø units	8.3-50
Silt-clay percentage, bank sediment	SILT	—	0.2-66

TABLE 1—Variables Used in Study.

Channel Morphology

Eleven variables were used to characterise the channel morphology of each river included in the study (Table 1). Because most flow gauging sites are selected to make use of natural or artificial control, a reach of alluvial channel with no identifiable bedrock or other control was chosen as close as possible to each gauging site. Each reach of channel was selected, with the aid of stereo aerial photographs, to be representative of the waterway within the stretch of channel between confluences up and downstream. Four variables were used to characterise channel morphology at the scale of the reach: channel sinuosity, slope (measured on topographic maps and checked by field survey), dominant meander wavelength, and braiding index (total length of bankfull channels in each reach divided by distance along the main channel). In a number of channels free meandering was constrained by bedrock bluffs, so that sinuosity and meander wavelength could not be defined.

Channel shape of individual cross-sections was characterised by seven variables, obtained from a survey of one or more representative cross-sections (Table 1). All variables refer to the bankfull channel, defined with respect to the active floodplain surface, as indicated by vegetation limits, and other criteria suggested by Riggs (1978). One station, the Kakanui (71702) subsequently had to be deleted because the bankfull channel could not be defined at the surveyed cross-section, as the channel limits are formed by an old terrace surface.

Sediment data

Bed and bank sediments were characterised by five variables (Table 1). The four variables describing bed sediment were obtained from measurement of surficial bed material using sampling procedures outlined by Wolman (1954) and collected from the surveyed cross-section and from traverses across the channel up and downstream. The standard deviation of bed sediment diameter is calculated by $\text{SIGMA} = (D_{84} - D_{16})/2$, where D_{84} is the diameter in ϕ units at which 84% is coarser (Folk, 1974). Silt-clay percentages of bank sediments were obtained from wet-sieve analysis of bulk samples of up to several kilograms of sediment.

PRELIMINARY ANALYSIS

Histograms indicated that most variables were approximately log-normally distributed, so logarithms were taken of all variables. This tended to normalise all variables except braiding index and sinuosity, each of which had large numbers of values of unity and hence highly skewed distributions.

Confirmation that hydrologic variables are strongly related to channel morphology is provided by the matrix of correlation coefficients (Table 2). Mean annual flood, mean discharge and median discharge are all positively related to indices of channel dimension (cross-section area, wetted perimeter, etc.) and negatively related to channel slope, as also are the standard deviations of annual floods and annual flows, both indices of flow range. Correlations between means and standard deviations of annual floods and annual flows are both 0.97, indicating that as

	QMAF	QMAFSD	QMAFCV	QBAR	QBARSD	QBARCV	Q50	VI	QSR	QPKRA	QMFBR	DMEAN	D50	D25	SIGMA	SILT	A	P	DMAX	BI	SLOPE	R	P/R	ASPRAT	ROUGH
QMAF	1.0																								
QMAFSD	0.97	1.0																							
QMAFCV	-0.62	-0.41	1.0																						
QBAR	0.93	0.88	-0.68	1.0																					
QBARSD	0.95	0.90	-0.64	0.97	1.0																				
QBARCV	0.29	–	0.38	-0.47	-0.64	1.0																			
Q50	0.90	0.84	-0.66	0.99	0.95	-0.49	1.0																		
VI	–	–	–	-0.27	–	–	-0.32	1.0																	
QSR	–	–	–	-0.39	-0.30	0.45	-0.50	0.62	1.0																
QPKRA	-0.35	-0.27	0.43	-0.32	-0.31	–	-0.30	–	–	1.0															
QMFBR	–	–	0.41	-0.55	-0.43	0.62	-0.61	0.39	0.69	–	1.0														
DMEAN	–	–	–	–	–	–	–	–	–	–	–	1.0													
D50	–	–	–	–	–	–	–	–	–	–	–	0.92	1.0												
D25	–	–	–	–	–	–	–	–	–	–	–	0.88	0.94	1.0											
SIGMA	–	–	–	–	–	–	–	–	–	–	–	-0.63	-0.41	-0.27	1.0										
SILT	–	–	–	–	–	–	–	–	–	–	–	–	-0.33	-0.29	–	1.0									
A	0.91	0.90	-0.28	0.87	0.87	-0.28	0.84	–	–	–	-0.25	–	–	–	–	–	1.0								
P	0.78	0.79	-0.26	0.75	0.76	-0.26	0.75	-0.27	-0.32	–	-0.24	–	–	–	–	–	0.93	1.0							
DMAX	0.82	0.79	-0.52	0.78	0.79	–	0.74	–	–	–	–	–	–	–	–	–	0.85	0.65	1.0						
BI	0.38	0.39	–	0.38	0.37	–	0.38	-0.32	-0.25	–	–	–	–	–	–	–	0.52	0.68	0.25	1.0					
SLOPE	-0.63	-0.59	0.46	-0.64	-0.65	–	-0.59	–	–	0.36	0.28	0.28	0.43	0.49	–	-0.31	-0.53	-0.35	-0.55	–	1.0				
R	0.65	0.60	-0.48	0.60	0.61	–	0.54	–	–	–	–	–	–	–	-0.26	–	0.54	–	0.79	–	-0.61	1.0			
P/R	0.50	0.53	–	0.50	0.49	–	0.52	-0.34	-0.37	–	–	-0.29	–	–	–	-0.28	0.70	0.91	0.31	0.76	–	–	1.0		
ASPRAT	–	–	–	–	–	–	–	-0.26	-0.31	–	–	-0.28	–	–	0.32	-0.36	0.33	0.60	–	0.65	–	-0.50	0.81	1.0	
ROUGH	0.48	0.48	-0.27	0.46	0.48	–	0.41	–	–	-0.27	–	-0.58	-0.70	-0.74	–	0.36	0.46	0.28	0.53	–	-0.80	0.60	–	–	1.0

Notes: 1. Sample size = 73.
2. Values greater than ±0.239 significantly different from zero, P 0.05; remainder deleted from table.

TABLE 2—Matrix of correlation coefficients of logarithmically transformed variables.

Recurrence Interval	Number of Sites
< 1.01	7
1.01-1.25	22
1.26-1.5	7
1.51-1.75	5
1.76-2.0	5
2.01-3.0	9
3.01-4.0	2
4.01-5.0	2
> 5.0	14

TABLE 3—Recurrence intervals of computed bankfull discharge.

discharge increases, so does the range of discharges. Other indices of flow variability were, however, poorly related to morphologic variables, and no hydrologic parameters were significantly correlated with any sediment variables.

As a check on the data, bankfull discharge at each site was computed, using the measured cross-sections and slopes. Values of Manning n were estimated using tables in Chow (1959) and photographs in Barnes (1967). Table 3 shows the distribution of recurrence intervals of bankfull discharge, estimated from the Gumbel plots of annual flood peaks for each station. As shown by Williams (1978), there is wide variability about an assumed recurrence interval of 1.5 years, with 14 of the 73 sites having estimated bankfull recurrence intervals greater than 5 years. The methods of computation of bankfull discharge and of estimation of its recurrence interval may clearly lead to errors, but it is significant that most of the sites with recurrence intervals exceeding 5 years are braided tributaries of the lower Waitaki. Others are the Hooker and the Hokitika at Kaniere, both with apparently unreliable records; the Wairau at Hell's Gate and at Dip Flat, both sites immediately downstream from bedrock controlled sections which may have excessively influenced the relation between mean annual flood and channel morphology; and the South Ashburton, a braided, heavily-vegetated channel similar in most respects to the lower Waitaki sites which also have braided, gravel-bedded channels and unusually heavily-vegetated bars and islands. It is possible that these sites are presently in a disequilibrium state because of a combination of land use (Evans, 1979) and recent weather conditions (cf. Schumm and Lichty, 1963).

PREDICTION EQUATIONS

A stepwise regression computer programme (BMDP2R (Dixon, 1975)) was used to estimate best-fit prediction equations for the hydrologic variables listed in Table 1. Sinuosity and meander wavelength were omitted from the list of predictor variables; 21 sites had undefined values and values would be difficult to estimate for other channels. Equations to predict flood hydrology included all 73 sites, while equations to predict variables derived from the magnitude-duration curves for instantaneous discharges included only the 65 sites for which these curves were available.

The prediction equations for flow parameters are presented in Table 4. Cross-sectional area was entered first into all equations, and with one exception aspect ratio was entered second. Channel slope also appeared in all but one equation; the only sediment variable to be included by the stepwise procedure in any equation was mean diameter of bed sediment. The equations in Table 4 are of limited value as predictive tools because of the high standard errors of estimate of the logarithms of the dependent variables. For example, for equation 1 68% of the sites would have values in the range −42% to +71% of the predicted value for mean annual flood (antilog of ±0.234).

Equation	R^2	*s.e.*
1. $QMAF = 1.600\ \underset{(0.047)}{A^{0.900}}\ \underset{(0.131)}{ASPRAT^{-0.376}}\ \underset{(0.098)}{SLOPE^{-0.392}}\ \underset{(0.081)}{DMEAN^{0.278}}$	0.903	0.234
2. $QMAFSD = 1.064\ \underset{(0.052)}{A^{0.794}}\ \underset{(0.139)}{ASPRAT^{-0.290}}\ \underset{(0.102)}{SLOPE^{-0.213}}$	0.849	0.257
3. $QBAR = 0.024\ \underset{(0.075)}{A^{0.999}}\ \underset{(0.190)}{ASPRAT^{-0.691}}\ \underset{(0.145)}{SLOPE^{-0.413}}$	0.845	0.347
4. $QBARSD = 0.039\ \underset{(0.064)}{A^{0.827}}\ \underset{(0.126)}{SLOPE^{-0.672}}\ \underset{(0.108)}{DMEAN^{0.392}}$	0.851	0.309
5. $Q50 = 0.064\ \underset{(0.078)}{A^{1.177}}\ \underset{(0.228)}{ASPRAT^{-0.918}}$	0.784	0.443

Note 1. Equations were computed as linear regressions of logarithms, then converted to the power function form.
2. s.e. is standard error of estimate of logarithms
3. values in parentheses under equations are standard errors of coefficients.

TABLE 4—Prediction equations for Hydrologic Variables, Using Whole Data Set

Examination of the residuals gives little indication of a reason for the poor result. Some sites (93202, 93213, 93216—all lake controlled, and 75259—recently affected by a large flood) tend to have large residuals from all equations, but there is no clear pattern. A slight tendency for a geographical pattern is evident, with more negative residuals in the south and more positive residuals in the north, but there seems to be no good reason for this. Recomputation of equations for means and standard deviations of annual floods for braided and nonbraided rivers improved the standard error of estimate for both variables for the nonbraided group but not the braided. This indicates that the poor fits of the equations in Table 4 are caused by inclusion of the braided river sites suggested by computation of the recurrence interval of bankfull discharge to be unstable or in some other way anomalous.

Accordingly, those sites were deleted and prediction equations recomputed (Table 5); sample sizes were 63 for equations 1 and 2 and 56 for equations 3 to 5. Again, cross-sectional area was entered first into all equations. Once the influence of channel cross-section area (A) is removed, the largest proportion of the residual variance in the dependent variables is in all cases 'explained' by aspect ratio, a measure of channel shape or efficiency. That aspect ratio entered into the equations rather than width/depth ratio (P/R) is a function of the high correlation between cross-section area and width/depth ratio. The equations in Table 5 are to be preferred over those in Table 4, not only because of the removal of the aberrant sites from the data set but because of their simplicity and similarity. The improvement in fit is, however, limited for equations 3 to 5, although good for equations 1 and 2. Examination of the residuals from the equations in Table 5 provided no information that could be used to further improve goodness of fit, other than to indicate that large residuals tended to be associated with short lengths of record.

Equation	R^2	*s.e.*
1. $\mathrm{QMAF} = 3.741\ \underset{(0.031)}{A^{1.015}}\ \underset{(0.097)}{\mathrm{ASPRAT}^{-0.515}}$	0.945	0.182
2. $\mathrm{QMAFSD} = 2.673\ \underset{(0.035)}{A^{0.868}}\ \underset{(0.110)}{\mathrm{ASPRAT}^{-0.302}}$	0.906	0.207
3. $\mathrm{QBAR} = 0.129\ \underset{(0.059)}{A^{1.157}}\ \underset{(0.176)}{\mathrm{ASPRAT}^{-0.781}}$	0.877	0.329
4. $\mathrm{QBARSD} = 0.221\ \underset{(0.054)}{A^{1.053}}\ \underset{(0.160)}{\mathrm{ASPRAT}^{-0.544}}$	0.875	0.300
5. $\mathrm{Q50} = 0.061\ \underset{(0.077)}{A^{1.212}}\ \underset{(0.230)}{\mathrm{ASPRAT}^{-0.838}}$	0.820	0.430

Notes: as for Table 4.

TABLE 5—Prediction Equations for Hydrologic Variables Using Reduced Data Set

It was additionally intended to develop prediction equations for the various indices of flow variability listed in Table 1. The correlation coefficients in Table 2 suggest that this is not feasible, and stepwise regression equations that were computed gave poor fits to the data set. Examination of the results gave no indication of the reason for the lack of association between channel morphology and flow variability; for the South Island rivers studied the suggestion (Stevens *et al.*, 1975) that flow variability controls channel character cannot be accepted as valid.

Finally, an equation was computed to predict bankfull discharge QBF, using the final sample of 63 sites:

$$\mathrm{QBF} = 8.913\,\mathrm{A}^{\underset{(0.018)}{1.27}}\,\mathrm{P/R}^{\underset{(0.026)}{-0.267}}\,\mathrm{SLOPE}^{\underset{(0.018)}{0.317}}\quad (\mathrm{R}^2 = 0.995;\ \mathrm{se} = 0.055) \qquad (1)$$

It may be compared with a similar equation recently presented by Williams (1978) using data from the USA:

$$\mathrm{QBF} = 4.0\,\mathrm{A}^{1.21}\,\mathrm{SLOPE}^{0.28}\quad (\mathrm{R}^2 = 0.96;\ \mathrm{se} = 0.17) \qquad (2)$$

EVALUATION

The high standard errors of estimate of equations 3 to 5 in Table 5 render them of little value for predictive purposes. Although there is an identifiable relationship between channel size and shape and flood discharge parameters, mean and median flow are contained well within the bankfull channel, so there is probably little relationship between these flows and bankfull channel morphology. Similarly, no useful predictors of flow variability indices from channel morphology could be produced.

The equation to predict bankfull discharge from channel characteristics has a high coefficient of determination and low standard error which must be partly an artifact of the method of computing bankfull discharge (for which the equation $\mathrm{QBF} = \mathrm{AR}^{0.667}\,\mathrm{S}^{0.5}\,\mathrm{n}^{-1}$ was used). The good fit is therefore somewhat spurious, but for the purposes of prediction of the discharge at which overbank flow starts to occur the equation is acceptable, notwithstanding the extremely wide range of conditions of channels included in the data set.

Finally, we may consider the prediction equation for mean annual flood (QMAF) (equation 1, Table 5). The antilogarithm of the standard error of estimate of log QMAF gives the percentage error range for the predicted values. As the residuals from equation 1 (Table 5) are approximately normally distributed, 68% of actual floods are within the range +52% to −57% of the prediction. It is possible to compare the standard error of estimate of the prediction equation for QMAF with that based on N years of flow records, using the approximate equation (Flood Studies Report, 1976, p. 342) $\mathrm{se}\ (\mathrm{Log\,QMAF}) = (0.434\,\mathrm{CV})/\sqrt{\mathrm{N}}$ where se (log QMAF) is the standard error of mean annual flood, estimated from N years of record and CV is the coefficient of variation of the annual floods. Values of CV for the 73 South Island sites used herein vary widely, with a range from 0.18 (Grey River, site 91401) to 1.12 (Rocky Gully, site 69614) with a mean of 0.5. Substitution into the equation of these values of CV and the value of se for equation 1 (Table 5) show that 0.18 and 7.13 years of flow record are required to produce for sites 91401 and 69621 respectively estimates of QMAF as reliable as that given by equation 1 (Table 5), and 1.42 years of record are required for the South Island. However, CV varies consistently across the island, with low values in South Westland and high values in the drier areas of Otago and South Canterbury, while smaller catchments tend to have large values of CV, (Mosley, in prep.). Broadly, then, the prediction equation for QMAF is of most value for small catchments, in areas with highly variable precipitation characteristics, and of least value for large catchments in areas with little year-to-year variation in precipitation.

The equation to predict QMAF from channel morphology may also be compared with equations to predict it from drainage basin characteristics. Beable and McKerchar (in prep.) found, for 63 sites in the South Island, (not the same as the 63 used herein), that QMAF can be predicted from an equation

$$\mathrm{QMAF} = 4.46 \times 10^{-3}\,\mathrm{AREA}^{0.85}\,\mathrm{I224}^{1.27}\,(1 + \mathrm{FOREST}/100)^{1.65} \qquad (3)$$

in which AREA is catchment area, I224 is the 24 hour precipitation total with a two year recurrence interval, and FOREST is percent forest cover in the catchment. The standard error of estimate of log QMAF in equation 3 is 0.256, and its coefficient of determination R^2 is 0.91. They improved the fit of equation 3 by dividing the South Island into four regions and comparing individual equations for each, after first deleting five outliers from the data set. The regional equations had standard errors of estimate of log QMAF between 0.105 and 0.148. This substantial improvement in precision is not as great as it first appears, because there are uncertainties inherent in defining regions. There can never be confidence at any specifiable level in our ability to assign a new site to the correct region and hence to select the appropriate prediction equation, nor confidence in the true validity of the regions identified. Beable and McKerchar's four regions were delimited by grouping together sites having residuals from equation 3 of similar sign, but discriminant analysis (Mosley, in prep.) calls into question the internal hydrologic homogeneity of the four regions. Cluster analysis produced an alternative four region scheme that is physically and hydrologically more justifiable, but requires a substantial regrouping of sites (Mosley, in prep.). Because geographic location is an inefficient surrogate for the factors that directly control hydrologic response, a site within a given region may have less hydrologic similarity with other sites in the same region than with sites in other regions, and the precise delineation of regional boundaries presents difficulties because the hydrologic characteristics of only a small sample of sites are known. Incorrect assignment of a site close to a regional boundary results in selection of an inappropriate prediction equation and may cause large errors in prediction. Use of a single equation to predict QMAF from channel morphology eliminates these uncertainties at the cost of a loss in precision that can be defined by the relative standard errors of estimate of the equations.

CONCLUSIONS

It is possible to predict mean annual flood for ungauged sites using an equation relating it to indices of river channel size and shape. The standard error of estimate of the equation is larger than those of four regional equations developed by Beable and McKerchar (in prep.) to predict mean annual flood from catchment characteristics, but use of the single equation eliminates the uncertainties inherent in defining hydrological regions. Prediction of mean annual flood for ungauged sites using either method has additional disadvantages and limitations. Use of channel morphology requires that one or more cross-sections be surveyed at the site of interest, although presumably cross-sections will be required for any purpose that requires prediction of mean annual flood. On the other hand, reference to maps and tables of mean annual rainfall and the 2-year recurrence interval 24 hour rainfall, both of dubious accuracy because of lack of data for the rugged, sparsely populated South Island, is required by equations using catchment characteristics. Both equations have limitations regarding sites for which they may be used. Beable and McKerchar deleted catchments in which significant ponding effects were present and used no catchments with areas greater than 1100 km^2, while channel morphology can be used as a predictor only for stable alluvial channels with no bedrock or other control. Consequently, it is best to combine the two methods.

The utility of the equations to predict mean annual flood from either channel morphology or catchment characteristics varies with the variability of the annual floods. Where the magnitude of annual floods is highly variable, as in parts of Otago, the equations give predictions as reliable as those provided by several years of hydrologic record. On the other hand, in areas such as South Westland where annual floods are less variable, only a very short record is required.

The residuals from the equation to predict mean annual flood from channel morphology suggest that the lack of fit is frequently associated with short flow records, and hence is possible due to errors in the value of mean annual flood estimated from the record. The precision of the equation could therefore be improved as more hydrologic data become available.

Bankfull discharge is the only hydrologic parameter other than mean annual flood and the standard deviation of the annual floods which can be predicted from channel morphology. Channel morphology is evidently controlled primarily by flood flows (with recurrence intervals of 1 to 2 years) that fill the channel; lower flows (such as median discharge and mean discharge) are contained within the channel and do not modify or control its shape. Similarly, there appears to be little relationship between channel morphology and any simple index of discharge variability, so that the latter cannot be estimated from the former. Despite much recent interest in this aspect of river morphology, the influence of flow variability is evidently of minor importance relative to other controls on channel form.

ACKNOWLEDGEMENTS

The hydrologic data were supplied by the Ministry of Works and Development, and I thank the staff of the Christchurch Science Centre for considerable assistance with data processing. Much assistance with field survey and data collection was given by staff of the Forest Research

Institute, Geohydrology Section, particularly C. Cooper and C. Smith, and with data analysis by M. McLennan and A. Watson.

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