Nordic Hydrology, 22, 1991, 109-122

Transposition of Monthly Streamflow Data to Ungauged Catchments

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Various forms of the regressional relationship between the concurrent monthly discharges of neighbouring catchments are explored, with a view to generalising the relationship for a region. This enables monthly streamflow data to be transposed from a gauged catchment to an ungauged catchment, provided that certain transfer coefficients can be estimated from the physical catchment and rainfall characteristics. Most of the methods are based on a linear relationship between the concurrent monthly discharges of a pair of catchments with only one transfer coefficient. This may be estimated in a number of ways for a pair of gauged-ungauged catchments, however, errors in the individual transposed flows are high.

Introduction

The transposition of streamflow data from one catchment to another may be used to extend or infill a streamflow record by reference to a longer one once the relationship between the two records has been established. Brown (1961) gave several examples of monthly streamflow correlations that were useful in extending short-term streamflow records in the Snowy Mountains region of Australia. The methods used were in the main, simple linear correlation between two sets of concurrent discharges, with the data either real or logarithmically transformed, or stratified by seasons, precipitation, temperature or some other physical parameter. Multiple regressions using the discharges of several neighbouring stations as independent variables were also used. Wright (1976) used a similar method to infill monthly streamflow data for a given gauging station using surrounding stations with longer records. Hirsch (1979) discussed four methods to reconstruct streamflow records for sites where no records or only a short record exist using nearby long-term records *i.e.,* the use of drainage area ratios, regression-based estimates of monthly means and standard deviations using basin characteristics, linear and logarithmic correlation of concurrent streamflow records. More sophisticated methods of record extension by exploiting inter-station correlation between nearby stations are found in Hirsch (1982). Dey and Goswami (1984) found that concurrent discharges were well correlated linearly for Himalayan rivers during the snow melt period.

However, the transposition of streamflow data to an ungauged catchment presents the obstacle that no records pertaining to the latter are available for such a relationship to be directly established. This problem has been inadequately explored in hydrology, as with most other work dealing with ungauged catchments. While rainfall-runoff modelling, synthetic data generation and streamflow correlations have reached a high state of art, these are largely inapplicable in the case of the totally ungauged catchment where no period of historical record exists for model calibration or parameter estimation. In this research, least squares regression is used to investigate the relationship between the concurrent monthly streamflow data of pairs of catchments at varying distances apart, the object being to determine the best regression model, to study how the regression fit changes with the distance apart between catchments and to develop generalised regression coefficients for the study region. The rationale is that the indirect estimation of regression coefficients will enable the transposition of streamflow data from a gauged catchment to an ungauged one.

Data Used

All monthly streamflow data used were recorded in south-east Victoria. Although the study region is not large, there are graduated differences in the climate, streamflow, physiography and geology. The rainfall for the region is between 700 and 1,400 mm increasing in a northerly direction, with a concentration of rain in the winter half-year except for the eastern section which has equal amounts in summer and winter. Weather systems are highly mobile and variable, with a general west to east movement of pressure cells. The physiography consists of a section of deeply dissected highlands in the northern half of the region, a coastal plain in the southern half, and small areas of upland interrupting the coastal plain. The geology is complex, with Palaeozoic volcanic rocks, granite and basalts in the highlands while marine Tertiary rocks of sands, silts and clays underlie the coastal plain. The median annual runoff rates vary from less than 125 mm to over 500 mm. Streams are generally perennial, but with high flow variability from month to month and from year to year. Summer and autumn are typically periods of receding flows. Thus, it is not possible to regard the entire region as a single hydrologically homogeneous region.

Sixty individual catchments were used, and they were cross-matched randomly to form 59 pairs of catchments for developing the method, with concurrent streamflow records varying from 5 to 25 years, of varying distances apart, and of different relative sizes. For each pair of catchments, the distances between the plan area centroids of the catchments (approximately identified) were measured from the 1:100,000 topographic maps. Inter-centroid distances varied from less than 1 km to over 77 km. The sizes of individual catchments ranged from 0.06 km^2 to 246 km^2. Twelve pairs of catchments, distinct from the 59 pairs used to develop the transpositional relationship, were used to test the data transfer. The 12 pairs of test catchments comprised 19 separate catchments and are detailed in Table 1. Some of the techniques that were explored required relationships to be developed between monthly flow parameters on the one hand and catchment physiographic and rainfall parameters on the other. To achieve these, the data base was expanded to include 81 separate catchments in south-east Victoria.

Table 1 – Characteristics of catchment pairs used to test the transposition of monthly streamflow depths: distance between catchment centroids (DIST); catchment area (AREA); the START, END and length (LEN) of the concurrent historical streamflow records

No.	*Y*-STN	*X*-STN	DIST (km)	*Y*-AREA (km^2)	*X*-AREA (km^2)	Streamflow record START (yr mth)	Streamflow record END (yr mth)	LEN (mths)
1	229121	229122	0.5	0.17	0.10	1970 8	1976 4	69
2	229121	229125	5.0	0.17	0.06	1970 7	1976 4	70
3	229122	229119	11.5	0.10	0.65	1970 8	1976 4	69
4	228230	228226	60.0	21.8	12.9	1975 5	1985 3	119
5	227228	227227	34.5	44.3	106.0	1971 5	1978 12	92
6	226406	226404	20.0	53.6	40.7	1961 9	1981 12	244
7	226405	226410	10.0	69.2	88.8	1955 7	1981 1	307
8	226212	227211	8.0	23.3	67.3	1957 2	1964 8	91
9	227216	226405	9.0	41.2	69.2	1964 7	1982 1	211
10	227208	226405	7.0	31.1	69.2	1955 7	1963 12	102
11	226215	227208	6.5	42.0	31.1	1954 10	1962 12	99
12	226222	229214	13.0	62.2	140.0	1971 6	1985 1	164

Streamflow Transposition by Origin Model

Linear regression through the origin was first attempted, of the form

$$Y = BX \tag{1}$$

where X, Y are the concurrent monthly flow depths (flow volume/catchment area) of the larger and smaller catchments respectively of a pair. With only one regression coefficient B, this is the simplest possible model. If, however, instead of regressing Y on X, the variable Y/S_Y is regressed against X/S_X, where S_Y, S_X are the standard deviations of Y and X respectively, then

$$\frac{Y}{S_Y} = \beta \frac{X}{S_X} \tag{2}$$

The regression coefficient in Eq. (2) is termed the beta coefficient. The regression in Eq. (2) standardises the variables by accounting for their different spread in values. It has exactly the same coefficient of determination (R^2) as Eq. (1) because S_Y and S_X are constants and moreover, its standard error is related to that of Eq. (1) by a constant. However, it is only necessary to perform regression Eq. (1) because by comparing Eqs. (1) and (2) it may be seen that

$$\beta = \frac{BS_X}{S_Y} \tag{3}$$

Thus, regression Eq. (2) may be quoted simply as a statistic of regression Eq. (1) *i.e.* its beta coefficient. For 59 pairs of catchments the concurrent monthly flow depths were regressed according to Eq. (1) and the regressions were classed according to the distance between the centroids of the two catchments. Average regression statistics were computed for each class to determine if they differ significantly. These were: the coefficient of determination (R^2); standard error of regression (SE); regression coefficient (B); standard error of B(SE B); and the beta coefficient (β).

The results in Table 2 shows that R^2 decreases as the distance between the centroids of the catchment pair increases. The SE which depends on the ranges in flow depths of the Y-stations, shows no discernible trend with distance. The average regression coefficient B, varies from class to class without consistency. For all classes, the standard error of B is small. In general, the average beta values decline slowly with increasing catchment inter-centroid distance, but are confined to a narrow range of values.

It is possible to use the Origin Model, $Y=BX$, to transpose monthly streamflow depths from a gauged X-catchment to an ungauged Y-catchment provided that the coefficient B can be generalised. Two approaches were attempted:

Table 2 – Average statistics for the regression of concurrent monthly streamflow depths of pairs of catchments, using the Origin model ($Y=BX$) for classes of catchment intercentroid distance

Class	N	inter-centroid distance (km)*	R^2	SE (mm)	B	$SE\ B$	β
1	12	<5	0.914	13.6	0.954	0.032	0.956
2	10	5 - 10	0.924	9.4	1.058	0.023	0.961
3	8	10 - 15	0.882	17.7	1.130	0.035	0.939
4	9	15 - 20	0.864	14.9	1.294	0.047	0.929
5	9	20 - 30	0.765	21.7	1.239	0.066	0.873
6	11	>30	0.716	20.3	1.149	0.062	0.844

* An inter-centroid distance falling at a class boundary is placed in the first named class. N=number of regressions, R^2=coeff. of determination, SE=standard error, B=regression coeff., $SE\ B$=standard error of B and β=beta coeff.

I: By Using Beta Coefficients

By re-arranging Eq. (3),

$$B = \frac{\beta\, S_Y}{S_X} \tag{4}$$

and hence,

$$Y = \frac{\beta\, S_Y X}{S_X} \tag{5}$$

An average value of $\beta=0.917$ was calculated from the individual regressions of 59 catchment pairs, based on Table 2. S_X, the standard deviation of the streamflow depths of the gauged X-catchment (mm) may be calculated from the historical streamflow data while S_Y, the standard deviation of the streamflow depths of the ungauged Y-catchment (mm) may be estimated from the following regression equation which was derived from 81 catchments within the study region.

$$S_Y = 0.205\, A^{0.066}\, R_m^{0.715}\, R_{cv}^{0.806} \tag{6}$$

$(R^2 = 0.97,\ \%\ SE = -37,\ 59)$

where A is the catchment area (km^2), R_m the mean annual catchment rainfall (mm) and R_{cv} the coefficient of variation of monthly rainfall. For Eq. (6), R^2 is the coefficient of determination and $\%\ SE$ the standard error of regression as a percentage of the value of the dependent variable. Its use presumes that monthly rainfall data is available for the ungauged catchment. Eq. (5) may then be used to transpose a record of monthly streamflow data (X values) to another catchment (Y values).

II: Using a Regression Formula for B

It was thought that the coefficient B in $Y=BX$ may be related to certain definable characteristics of the X- and Y-catchments. Hence, the coefficient B as derived from the historical monthly flow records for 59 pairs of catchments was regressed against the stramflow and rainfall parameters of both the X- and Y-catchments as well as against ratios of these parameters with the following best result obtained, after the exclusion of one outlier

$$B \equiv \left[\frac{SD_Y}{SD_X}\right]^{0.285} \left[\frac{Q_Y}{Q_X}\right]^{0.598} \left[\frac{A_Y}{A_X}\right]^{-0.862} \tag{7}$$

$(R^2 = 0.93, \quad \% \; SE = -12, \; 14)$

where the subscripts X, Y refer to the gauged and ungauged catchments respectively and SD = standard deviation of monthly discharge (volume units), Q = mean annual discharge (volume units) and A = catchment area. For the ungauged catchment, SD_Y may be estimated from Eq. (6) ($SD_Y=S_YA_Y$) while Q_Y may be obtained from Eq. (8), derived by least squares regression using an expanded dataset of 81 catchments, where A=catchment area (km^2), R_m=mean annual rainfall (mm) and Q_Y is in million m^3

$$Q_Y \equiv 9.28\times10^{-6} A^{0.990} R_m^{1.48} \tag{8}$$

$(R^2 = 0.97, \quad \% \; SE = -35, 54)$

For 12 pairs of test catchments with characteristics as shown in Table 1, monthly streamflow data were transposed by using beta coefficients (Origin Model I) and B-

Table 3 – Mean absolute percentage errors in the transposition of monthly streamflow data by various models. Catchment pairs numbered may be identified in Table 1

No.	Origin I (beta)	Origin II (B-regress)	Log Origin	Seasonal Origin	Linear Intercept	Runoff Coeff.	Fourier Origin
1	46.7	41.3	86.4	52.2	41.2	49.0	23.1
2	79.7	47.8	82.4	76.2	58.4	59.8	14.7
3	37.1	29.2	93.7	28.2	20.2	843.8	71.3
4	51.9	47.2	78.7	50.2	46.5	65.8	51.4
5	58.8	48.4	86.7	57.1	84.3	128.8	58.2
6	54.7	54.7	81.0	55.8	27.7	64.6	50.6
7	31.4	25.6	72.0	33.1	147.4	32.2	39.6
8	51.2	40.8	90.3	53.3	28.5	91.6	30.2
9	52.0	41.8	86.7	48.5	29.3	40.2	37.2
10	56.5	45.2	91.3	53.5	28.4	67.2	40.2
11	62.5	55.2	66.8	63.8	83.4	59.4	59.4
12	28.0	16.7	90.6	37.5	22.4	48.1	27.9

regression formula (Origin Model II) as described above. For each month, the percentage error in transposition was calculated by reference to the historical streamflow data for the Y-catchment. The mean absolute percentage error in transposition for the period considered was derived by summing the absolute values of all the monthly percentage errors and dividing this by the number of months. It was chosen as the test statistic as it gives adequate representation to both the high and low flows without giving a bias to either. This was calculated for the entire transposition period for each pair of catchments and shown in Table 3 from which it may be observed that for almost all catchment pairs, lower errors were encountered using the B-regression formula.

Other Methods of Streamflow Transposition

The following methods of streamflow transposition were also attempted:

1. Using a Log-Origin Model

As the logarithms of hydrologic events are often better correlated than their actual recorded values (Langbein 1960), in this version called the Log-Origin Model, the logarithms of the streamflow depths were used instead of their actual values as in Eq. (9)

$$\text{Log}\, Y = B_L \,\text{Log}\, X \tag{9}$$

where Log represents the logarithm to base 10, B_L the regression coefficient, while X, Y are the concurrent monthly stramflow depths of the X- and Y-catchments. The regressions by Eq. (9) performed for the 59 pairs of catchments when compared with the corresponding regressions performed with untransformed data show in general, higher coefficients of determination, somewhat altered regression coefficients, lower standard errors of the regression coefficients while the beta values are higher and are confined to an even narrower range of values. Thus, the Log-Origin Model appears to be a better fit to the data than the Origin Model.

For the transposition exercise, Eq. (10) was used, which is analogous to Eq. (5)

$$\text{Log}\, Y = \beta_L \frac{S_{LY}}{S_{LX}} \,\text{Log}\, X \tag{10}$$

where an average value of β_L=0.969 was used for the study region and S_{LX}, S_{LY} are the standard deviations of the log 10 monthly flow depths of the gauged X- and ungauged Y-catchments respectively. S_{LX} may be derived from the historical streamflow record of the gauged catchment while S_{LY} was estimated from the following regression equation, derived from 81 catchments

$$\frac{S_{LY}}{S_{LX}} \equiv \left[\frac{A_Y}{A_X} \right]^{0.108} \left[\frac{R_{mY}}{R_{mX}} \right]^{-0.914} \left[\frac{R_{csY}}{R_{csX}} \right]^{-0.148} \qquad (11)$$

$(R^2 = 0.37\ ;\ \%\ SE = -43, 75)$

where R_{cs}= coefficient of skew of monthly rainfall and the other variables are as defined for Eq. (8). However, for the 12 pairs of test catchments in Table 2, the percentage errors in transposition using the Log-Origin Model were generally larger compared to the Origin Models (Table 3). Thus, while the former appears to be a better fit to concurrent streamflow data, this improvement occurs only in the log domain and transformation back into the real domain results in larger errors.

2. Using a Seasonal-Origin Model

For many catchments across the study region, it was noticed that total flows for the first half of the year were lower than for the second half. Hence, linear regression through the origin ($Y=BX$) was performed separately for two half-year periods, January to June (dry season) and July to December (wet season). The results for 59 pairs of catchments were classed according to catchment inter-centroid distance. The average regression statistics for each class show the following features when compared to those in Table 2, for non-seasonal regressions: R^2 and β for the dry season are generally lower while R^2 and β for the wet season are generally higher than the corresponding non-seasonal values; *SE* for the dry season are slightly reduced while *SE* for the wet season are about similar when compared to the corresponding non-seasonal values; the regression coefficients, B(dry) and B(wet) are typically increased for one season and decreased for the other in comparison with the corresponding non-seasonal values.

Monthly streamflow transpositions were performed in accordance with Eq. (5), but with the parameters β, S_Y and S_X defined separately for the two seasons. Regional averages of β(dry)=0.887 and (wet)=0.936 were used while S_Y for each season may be estimated from Eqs. (12) and (13) which were derived from the expanded base of 81 catchments. The variables are as defined for Eq. (6)

$$S_Y(\text{dry}) \equiv 0.059\, A^{1.12}\, R_m^{\ 0.959}\, R_{cv}^{\ 2.36} \qquad (12)$$

$(R^2 = 0.96\ ;\ \%\ SE = -44, 78)$

$$S_Y(\text{wet}) \equiv 0.287\, A^{1.05}\, R_m^{\ 0.608} \qquad (13)$$

$(R^2 = 0.97\ ,\ \%\ SE = -35, 54)$

However, for the same 12 pairs of test catchments, the mean absolute percentage errors were very similar to those obtained for the non-seasonal Origin Model I, and worse off compared to Origin Model II (Table 3).

3. Using Linear-Intercept Model

This is an extension of the Origin Model to include an intercept, as below

$$Y = CX + D \tag{14}$$

where X, Y are the concurrent monthly streamflow depths of two catchments and C, D are regression coefficients. For the 59 pairs of catchments, R^2 values were higher than their corresponding values by the Origin Model as may be expected while the coefficient C was observed to be rather similar to the coefficient B of $Y=BX$. The coefficient D varied greatly between regressions and were quite large in some instances. Regression Eqs. (15) and (16) for C and D were derived using the streamflow parameters of the X and Y catchment as independent variables as below

$$C \equiv \left[\frac{SD_Y}{SD_X}\right]^{0.812} \left[\frac{Q_Y}{Q_X}\right]^{0.038} \left[\frac{A_Y}{A_X}\right]^{-0.797} \tag{15}$$

$(R^2 = 0.81 \;;\; \%\, SE = -17,\ 20)$

$$D = 2.63\,\mathrm{Log}\left[\frac{A_Y}{A_X}\right] - 46.8\,\mathrm{Log}\left[\frac{CV_X}{CV_Y}\right] + 2.79 \tag{16}$$

$(R^2 = 0.79 \;,\quad SE = 4.67)$

where Log=logarithm to base 10, CV= coefficient of variation of monthly streamflow and the other variables are as defined for Eq. (7). Note that SD_Y, and CV_Y, being parameters of the ungauged Y-catchment, must first be obtained from Eqs. (6) and (8) $SD_Y=S_YA_Y$ and $CV_Y=S_YA_Y/Q_Y$. With estimated values for C and D, streamflow transposition was performed for pairs of gauged-ungauged catchments by Eq. (14). The results for the 12 test catchments were mixed, showing an improvement for some pairs and a worsening for others when compared to the Origin Models (Table 3).

4. Using Runoff coefficients

The runoff coefficient was defined as the ratio of the flow depth to rainfall depth for monthly time periods. It is proposed that for two neighbouring catchments, the runoff coefficients are similar for concurrent monthly time periods, *i.e.,* for any one month

$$\frac{D_Y}{R_Y} \equiv \frac{D_X}{R_X} \tag{17}$$

where the subscripts X, Y refer to the gauged and ungauged catchment respectively, D = monthly flow depth and R = monthly rainfall depth. Hence, the unknown quantity, D_Y can be calculated by Eq. (17) from a knowledge of the other three, *i.e.*

$D_Y=D_XR_Y/R_X$. (The formula will be inapplicable if R_X equals zero, however, there were no months of zero rainfall encountered in the testing). For the same 12 test catchments, monthly streamflow data were transposed using this concept. The results of the Runoff Coefficient Model are generally worse when compared to the Origin Models, with erratically high mean absolute percentage errors for some catchment pairs (Table 3).

5. Using a Fourier-Origin Model

In this model, linear regression through the origin ($Y=BX$) is used to correlate the streamflow depths of two catchments. However, the coefficient B is assumed to vary according to the month of the year in an annual cycle. If the Fourier series of one harmonic is used to describe the periodic variation in B, then

$$Y = B_\tau X \text{ , and}$$

$$B_\tau = B^* + S\cos\left(\frac{2\pi\tau}{12}\right) + T\sin\left(\frac{2\pi\tau}{12}\right) \qquad (18)$$

$$\tau = 1, \ldots, 12$$

where B^* is the mean of the twelve values of B_τ and S, T are the Fourier series coefficents. Thus, the three parameters, B^*, S and T are required to be estimated for a given pair of gauged-ungauged catchments for streamflow transposition to be performed.

For 27 catchment pairs each with at least 10 years of concurrent streamflow data, the regression of concurrent streamflow depths was performed separately for each month of the year, using the form $Y = B_\tau X$ ($\tau=1$ for January and $\tau=12$ for December). For almost all the catchment pairs, B_τ when plotted against τ showed a sinusoidal cycle, thus confirming the validity of the Fourier approach. For each catchment pair, B^*, S and T were derived by mathematical formulations (Sals *et al.* 1980, pp. 77-78). Each coefficient was then regressed against the streamflow, rainfall and physiographic parameters of the catchment pair, thus giving predictive Eqs. (19)-(21) that can be used for a given pair of gauged X- and ungauged Y-catchments within the study region

$$B^* = 1.03\left[\frac{SD_Y}{SD_X}\right]^{-0.468}\left[\frac{Q_Y}{Q_X}\right]^{1.39}\left[\frac{A_Y}{A_X}\right]^{-0.953} \qquad (19)$$

$$(R^2 = 0.96 \text{ ; } SE = -10,\ 12)$$

$$T = 0.733 \text{ Log } B^* - 0.408 \text{ Log FOREST}_X + 0.934 \qquad (20)$$

$$(R^2 = 0.48 \text{ ; } SE = 0.33)$$

$$S = 0.477\, T + 5.58\times10^{-6}\, Q_X - 1.05\times10^{-4}\, SD_X + 0.097 \qquad (21)$$

$$(R^2 = 0.84 \text{ ; } SE = 0.17)$$

Table 4 – Percentage differences in the monthly statistical parameters of transposed and historical data for 12 pairs of test catchments. Monthly flows were transposed by the Fourier-Origin model

No.	*Y*-Catch	*X*-Catch	Percentage Difference in Monthly Statistics			
			Mean	Std. Dev.	Coef. Var.	Coef. Skew
1	229121	229122	3.7	17.4	13.2	40.2
2	229121	229125	15.6	–16.9	–25.1	–23.9
3	229122	229119	–3.0	6.1	9.3	41.3
4	228230	228226	–46.9	–45.2	3.1	10.1
5	227228	227227	–26.6	–25.7	4.4	–8.4
6	226406	226404	–11.3	39.8	57.6	91.0
7	226405	226410	15.2	22.5	6.4	48.2
8	226212	227211	–22.9	–20.9	2.6	–7.8
9	227216	226405	–32.6	–30.7	2.8	–7.4
10	227208	226405	–24.5	–2.9	28.6	30.6
11	226215	227208	–14.1	–40.7	–31.0	–49.3
12	226222	229214	–25.7	–13.0	17.1	36.8

FOREST = percentage of catchment area covered by dense and medium forests while the other variables are defined as for Eq. (7). Q_Y and SD_Y must first be estimated from Eqs. (6) and (8). With B^*, S and T estimated from catchment characteristics, transposition of monthly streamflow data can then be performed by Eq. (18). The results for 12 test catchments (Table 3) did not show that the Fourier-Origin Model is superior to the Origin Model II where only the one coefficient B was estimated from catchment characteristics. The mean errors were reduced for some catchment pairs, but worse off the others.

The preservation of the major statistical parameters of the monthly streamflow sequence as transposed by the Fourier-Origin Model is examined in Table 4, which gives the percentage differences in these parameters as compared to the actual (historical) streamflow sequence. The percentage differences were calculated as $100(S_T\text{-}S_H)/S_H$ where S_T, S_H are the values derived from the transposed and historical flows respectively. It may be observed from Table 4 that the reproduction of the monthly statistical parameters range from good to moderately good despite the large errors in the individually transposed monthly flows.

Conclusions

The transposition of monthly streamflow data from a gauged catchment to an ungauged catchment is a difficult exercise, whereby great accuracy is not to be expected. The relationship between the concurrent streamflows of two hydrologically similar catchments is essentially a linear one. It is sufficiently accurate if expressed as $Y=BX$, where X, Y represent concurrent monthly discharges. The exact value of B tends to vary from one catchment pair to another within a fairly narrow band, but even if this is well estimated, the individual transposed flows may still be much in error as the regression line only represents an average relationship between the flows of two catchments. Relatively, the best method that was examined appears to be one which relates B to a number of catchment parameters (Origin Model II). However, the Fourier-Origin Model which assumes a periodic variation of B in an annual cycle has a sounder theoretical basis and moreover, only requires three coefficients to be estimated. The statistical parameters of the transposed flows were moderately well reproduced considering (i) it is assumed that absolutely no flow records were available at the ungauged catchments and (ii) the simplicity of the procedure used.

Naturally, the two catchments involved in the transposition should be nearby and hydrologically similar. This method is best suited where an estimate of the individual monthly historical flows are required for an ungauged catchment for the operational simulation of a water resources system or as input into a complex hydrologic model. As the system or model generally contains many in-built assumptions and approximations, great accuracy in the transposed flows may not be warranted. The compensating effect of random over and under-estimation of individual flows may not greatly influence the final results. This method has the advantage over synthtic data generation in that the actual sequencing of flows would be much more accurately represented. However, it is not suited for such engineering design where extreme flows must be well estimated as for instance, in the design of drains, bridges and culverts. Because extreme events tend to plot as outliers to a regression line, they could be poorly estimated.

However, the object of this paper is mainly exploratory rather than to present a definitive solution to the problem of estimating streamflow data for ungauged catchments. There are some problems with regard to the use of regression equations. They are specific to the region for which they have been developed, are not readily transferable and are applicable only over the range of data from which they have been developed. The use of regressions equations may ensure the best estimate of individual streamflow values, however, they are not designed to preserve any particular statistical characteristics in the estimated flow series. Extreme and unusual events are susceptible to large errors in estimation as the variance of the estimated series is normaly reduced. The use of nested regression equations, whereby one depends on another for solution, increases the errors for which confidence intervals are difficult to define. Hence, other methods may need to be investigated.

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First received: 5 March, 1990
Revised version received: 28 July, 1990
Accepted: 8 October, 1990

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