Conceptual catchment model parameter transfer investigations in the Southern Cape

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Abstract

Two conceptual catchment models, using monthly data, have been calibrated on five catchments in the Southern Cape coastal region. Although the parameters of the two models discussed do not have any direct physical meaning, approximate graphical relationships between catchment slope and some of the major runoff generating parameters are suggested for this region. These relationships were found to be useful in providing guidelines for the transfer of parameters into three test catchments. The results of this parameter transfer approach are compared with the results of using already published regional parameter values for one of the models. The comparison reveals that the more complex transfer approach gives only marginally better estimates of observed flow characteristics. An improved set of regional parameters which can perform as well as the transferred parameters in most of the catchments studied, is suggested. It is proposed that similar work is needed in other regions to determine whether the results obtained in the Southern Cape are unique or not.

Introduction

It is frequently noted that while a large number of mathematical conceptual hydrological models have been developed few have successfully found a place in the 'tool box' of the practising engineer or water resource analyst. They have been used most extensively for record extension on gauged catchments where calibration is possible, but they have not been as successful in ungauged situations where some kind of parameter transfer technique is required. Roberts (1984) suggests that this is due to a general "lack of confidence in the degree to which the parameters represent physical properties." Roberts (1984) also points out that the conceptual structure of many models is not based upon a realistic picture of the movement of water within a catchment. It is certainly true that a large proportion of the available models have a conceptual structure that is based more on the Hortonian ideas of runoff generation (Horton, 1940) than the more recent ideas incorporating the partial and/or variable source area concepts (Hewlett and Hibbert, 1967; Dunne, 1978; Weyman, 1978). However, when considering the structure of course time period models (i.e. monthly models), this may not be a serious fault. It may be necessary simply to reinterpret the components of flow output from the model and refer to them as quick flow (from whatever source) and delayed flow rather than 'overland flow' and 'base flow'.

A move toward more physically realistic models is a trend that most hydrologists would support, but is it a clear certainty that the use of such models will be practical, in the ungauged situation, for catchments larger than a few square kilometres? Complex models may be difficult to use in medium sized catchments (say, 20 km^2 - 200 km^2) and larger as the level of hydrological heterogeneity would make the measurement of the physically based parameter values difficult and time consuming, if not impossible and impractical. If the values of parameters in a physically based model have to be estimated or guessed due to the lack of available field measurements, then the results are not likely to be any more reliable than results obtained using a simpler conceptual model. There are clearly applications for which more physically realistic models are needed, particularly in integrated catchment modelling (Fleming, 1984) where water quality, sediment and aspects such as groundwater recharge become important model outputs as well as just streamflow quantity (Roberts, 1984). For example, it would be more important to differentiate between surface and subsurface flow in a model designed to estimate sediment and/or total dissolved solids output from a catchment than one designed for just streamflow quantity. However, it is the author's belief that the possibilities of parameter transfer into ungauged situations, using currently available models, have not been sufficiently explored to be condemned out of hand at the present time. It is equally recognised that any parameter transfer technique will always have its limitations whether it be related to the applicability of the model structure to the hydrological regime of the problem catchment or to other factors such as the quality of the available input data. However, most hydrological estimation techniques, however good, have certain limitations.

This paper presents the application and results of a procedure used to estimate monthly sequences of streamflow volume in ungauged catchments in one region of South Africa where the climate and physiography, while not being homogeneous, have relatively well defined spatial patterns of change.

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The study area and available data

The study region is the sub-humid coastal area of the southern Cape Province bounded in the east and west by Storms River and Mossel Bay respectively and in the north and south by the Outeniqua Mountains and the Coast (Hughes and Görgens, 1981). The major physiographic zones of the region are the mountains themselves, the foothills area and the deeply incised coastal platform (Tyson, 1971; Hughes and Görgens, 1981). Within this region there are some 30 daily rainfall stations and 13 streamflow gauging stations operated by the Weather Bureau of the Department of Transport and the Division of Hydrology of the Department of Water Affairs (DWA) respectively (Table 1). The western part of the region and some of the rainfall and streamflow gauging sites are illustrated in Figure 1. Of the thirteen catchments, three were not used to calibrate the models but were used for later testing of the parameter transfer procedure. Of the remaining ten, two were rejected due to uncertainties in the reliability of the streamflow records. (Table 1). The monthly rainfall model inputs were obtained by taking the average of weighted monthly rainfalls from nearby stations. The station rainfalls were weighted by the ratio of catchment mean annual precipitation (MAP) to gauge MAP. The catchment MAP's were estimated using a regression equation based upon altitude, longitude and an index of exposure and following the technique described in Hughes (1982a). Three of the eight catchments with reliable streamflow records have physiographic patterns that are considered likely to promote localised rainshadow effects which are not adequately represented by the regression equation (Hughes, 1982b, section 6.2). These three were consequently rejected from the analysis due to a lack of confidence in the estimates of catchment rainfall input (Table 1).

Evaporation data are sadly lacking in the region, the only pan not located at sea level being the Symons pan at George (K3E01). Consequently, potential evapotranspiration inputs to the models was in the form of mean monthly S-pan values for this station, corrected using regionalised pan to reservoir conversion factors supplied by the DWA (Gouveya, 1981).

Five catchments were therefore used in the calibration of the models and some of their physical characteristics are given in Table 1 along with some summary statistics of observed streamflows. The major physiographic differences between the catchments are a reflection of the proportion of their areas that are occupied by the different physiographic zones of the region (mountains, foothills and coastal plateau). Superimposed upon this are land use differences that partly depend upon the extent to which the natural indigenous forest and mountain fynbos vegetation has been replaced by conifer plantations and farming land (Table 1).

The models: FLEXIFIT and HRUM

Two models were selected for testing; the relatively well known Pitman model (HRUM) developed by Pitman (1973, 1978) at the Hydrological Research Unit of the University of the Witwatersrand and the lesser known model FLEXIFIT developed by Roberts (1979) from the hourly single event model of Krzystofowicz and Diskin (1978). Both are lumped parameter models using monthly input data and while they have common features such as the interception store function and the monthly rainfall disaggregation method, the central structure of the moisture accounting system is different. The detailed structure of the models is not discussed here as reference can be made to the original authors or Hughes (1982b). One interesting feature of FLEXIFIT that deserves mention is that the separation of total flow into rapid or 'surface runoff' and delayed or 'base flow' is a function of the total flow rather than the soil moisture level. The essential structure of the two models is illustrated in Figures 2 and 3, while a brief description of the parameters is given in Table 2.

Calibration results

The models were calibrated on five catchments (2-4 and 7-9 in Table 1). The basis for calibration was a combination of four objective functions; percentage error in mean annual runoff (M) and variance of monthly flows (V), and the coefficients of efficiency (E) and determination (D). The coefficient of determination is simply the square of the correlation coefficient (between observed and simulated monthly totals) but as this is not sensitive to systematic error E was also included where:

TABLE 1
GAUGED CATCHMENTS IN THE SOUTHERN CAPE COASTAL REGION

Catchment	Location	Area (km²)	Gauge Ht. (m)	Median alt. above weir (m)	Catchment slope	% Forest		% Farm land	MAP (mm)	Calibration data	Verification data	Test data	Obs. data over calib. or test period		
						Ind.	Plant.						MAP (mm)	MAR (mm)	V.M.F. (mm)**
1. Great Brak K2M02	34°02'S 22°13'E	131			0,28				rejected due to upstream abstractions						
2. Kaaimans K3M01	33°58'S 22°33'E	48	61	442	0,42	14,5	12,0	0,5	940	1 962 – 70	—	—	975	383	107
3. Maalgate K3M03	34°00'S 22°21'E	145	116	139	0,21	7,0	21,7	51,7	834	1 962 – 67	1 969 – 71	—	909	262	143
4. Malgas K3M04	33°57'S 22°25'E	34	198	336	0,39	5,9	14,7	5,9	1 015	1 962 – 75	1 976 – 80	—	990	446	76
5. Touw K3M05	33°57'S 22°37'E	80	137	427	0,36	3,9	14,8	0,2	760*	1 970 – 75	1 976 – 78	—	679	154	20
6. Hoëkraal K4M01	33°59'S 22°48'E	111	15	369	0,28	24,1	18,5	9,3	rejected due to unreliable streamflow data						
7. Karatara K4M02	33°53'S 22°50'E	22	244	354	0,43	—	19,1	—	1 130	1 963 – 71	1 977 – 80	—	1 100	496	43
8. Diep K4M03	33°55'S 22°42'E	71	213	320	0,28	2,9	54,3	0,7	750*	1 965 – 74	—	—	684	137	16
9. Gouna K5M01	33°59'S 23°02'E	89	61	259	0,17	61,6	29,3	—	973	1 962 – 68	—	—	965	157	8
10. Knysna K5M02	33°53'S 23°02'E	130	183	389	0,28	11,4	29,7	—	820*	1 962 – 70	—	—	815	216	47
11. Bloukrans K7M01	33°57'S 23°39'E	57	33	470	0,45	10,0		—	1 027	—	—	1 972 – 83	998	354	49
12. Kruis K8M01	33°59'S 24°01'E	26	230	484	0,59	2,0		—	1 193	—	—	1 962 – 82	1 152	792	104
13. Elands K8M02	33°59'S 24°03'E	35	210	390	0,47	10,0		—	1 145	—	—	1 966 – 83	1 188	488	66

*Lack of confidence in these estimates
**Variance of monthly flows

$$E = 1 - \frac{\Sigma (O - S)^2}{\Sigma (O - \bar{O})^2} \qquad \text{(equation 1)}$$

O = observed monthly flows
$\bar{O}$ = observed mean monthly flow
S = simulated monthly flows
Σ indicates summation over all available months.

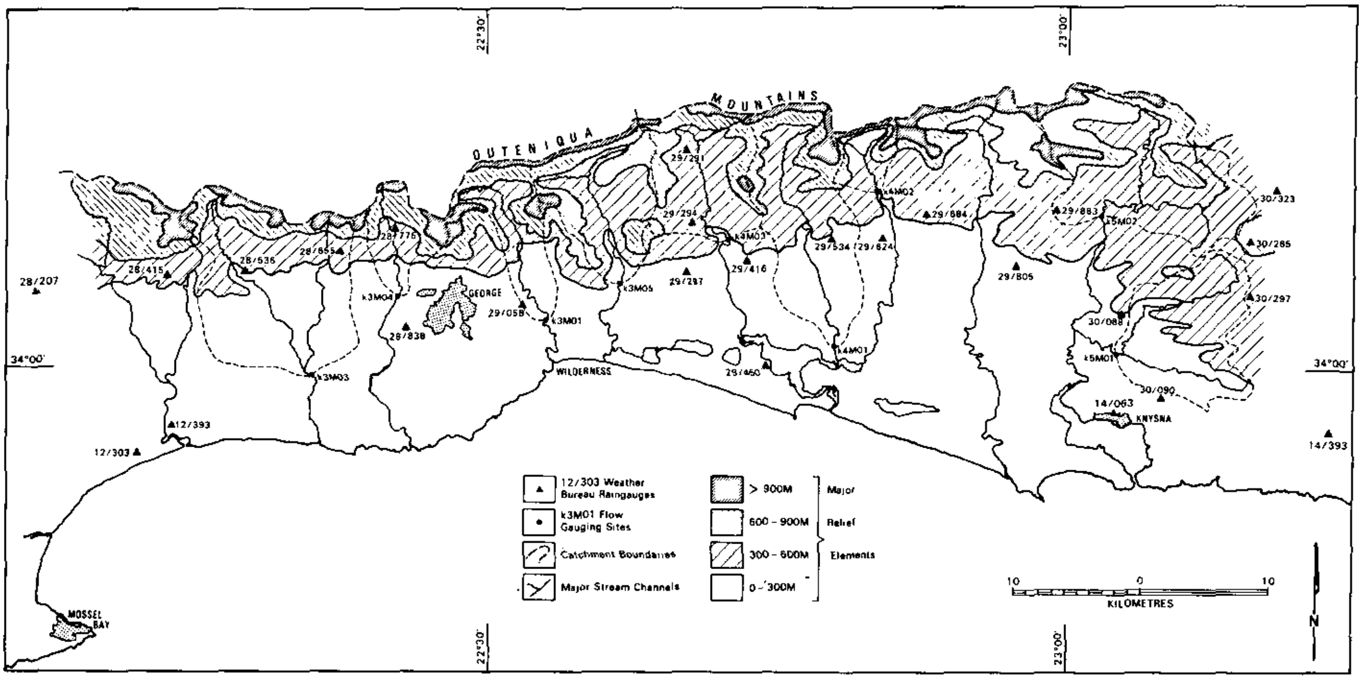


Figure 1
Physiography and the location of raingauges and gauged catchments in part of the Southern Cape coastal region.

The closer that D and E are to 1 the better the performance of the model or the better the "goodness of fit" between observed and simulated streamflows (exact correspondence occurs at D and E equal to 1).

The first step in the calibration method consisted of sensitivity tests of the model parameters using the Karatara and Gouna catchments. These two catchments were selected as being at either end of the range of physiographic conditions represented within all five. Although the sensitivity analysis involved a large number of model runs, the information gained proved to be very useful and decreased the number of runs required to calibrate the models on the other catchments. Inevitably, when using four objective functions it is difficult to arrive at a single optimum calibration result. In addition, parameter interaction can mean that similar results are obtained if more than one parameter is changed at the same time. These two factors indicate that the choice of a 'final' parameter set is relatively flexible when calibrating on single catchments in isolation.

By using some intuitive ideas about how gross differences in catchment characteristics should influence parameter values, the flexibility of 'final' parameter values should be reduced. A simple example of such an intuitive idea is that the maximum soil moisture storage capacity would be lower for the headwater catchment with steep slopes and relatively thinner soils (Karatara) than for the catchments occupying the foothills and plateau areas with lower slopes (Maalgate and Gouna). Thus a calibration result that suggested a higher value for moisture storage capacity on the Karatara than for the Gouna or Maalgate would not be considered acceptable. This technique does not imply any direct physical relevance of the model parameters, merely that differences in parameter values may be reflected in differences in those catchment characteristics that affect runoff response and *vice versa*. It must also be noted that the results of the method will, to a certain extent, reflect the intuitive ideas of the user. However, assuming that data errors are not clouding the situation and that the model is representative of the catchments' hydrology, these intuitive ideas would be shown up to be wrong if satisfactory calibration on the group of catchments was not possible by following them. The final parameter set is selected when the objective functions are at their 'best' values. Inevitably, compromise is necessary and depending upon the application of the model emphasis may be placed on certain objective functions. In this study, the coefficient of efficiency was adopted as the major criterion of fit but at the same time attempting to ensure that the errors in MAR and monthly variance did not exceed ~ 10 per cent.

Following the calibration, verification tests (also referred to as validation tests by some authors) were run where additional years of data were available. The parameter values resulting from the calibration are not reproduced here but can be found in Hughes (1982b) in which a more complete discussion of the expected associations between physical characteristics and model parameters is also included. The objective function values for both calibration and verification runs are given in Table 4 to allow comparison with the parameter transfer results.

Parameter transfer

The final parameter value set for the 5 calibration catchments was examined more closely to see if improved guidelines for parameter transfer could be obtained through graphical relationships with some catchment characteristics. Catchment slope

TABLE 2
BRIEF DESCRIPTIONS OF THE MODEL'S PARAMETERS

FLEXIFIT		HRUM	
SSM	– Maximum soil moisture capacity.	POW	– Power of soil moisture-runoff equation.
B1	– Curve shape factor relating soil storage ratio to rainfall loss factor.	SL	– Soil moisture storage level below which runoff ceases.
B2	– Curve shape factor relating the ratio of actual/potential evap. to soil storage ratio.	ST	– Maximum soil moisture capacity.
PMAX	– Maximum amount of percolation to groundwater.	FT	– Runoff amount from soil moisture at full capacity.
PCUR	– Curve shape factor relating total runoff to groundwater percolation.	GW	– Maximum groundwater runoff.
GDEC	– Base flow decay constant.	AI	– Impervious fractions of catchments.
SOIL	– Deep percolation parameter.	ZMIN	– Min. catchment absorption rate.
AFOR	– Ratio of evapotrans. from forest areas to that from natural bush.	ZMAX	– Max. catchment absorption rate.
		PI	– Interception storage.
		GL	– Lag of runoff from soil moisture.
		TL	– Lag of runoff from other sources.
		R	– Controls relationship between ratio actual/potential evap. and soil moisture.
		FF	– Ratio of evapotrans. from forest areas to that from natural bush.

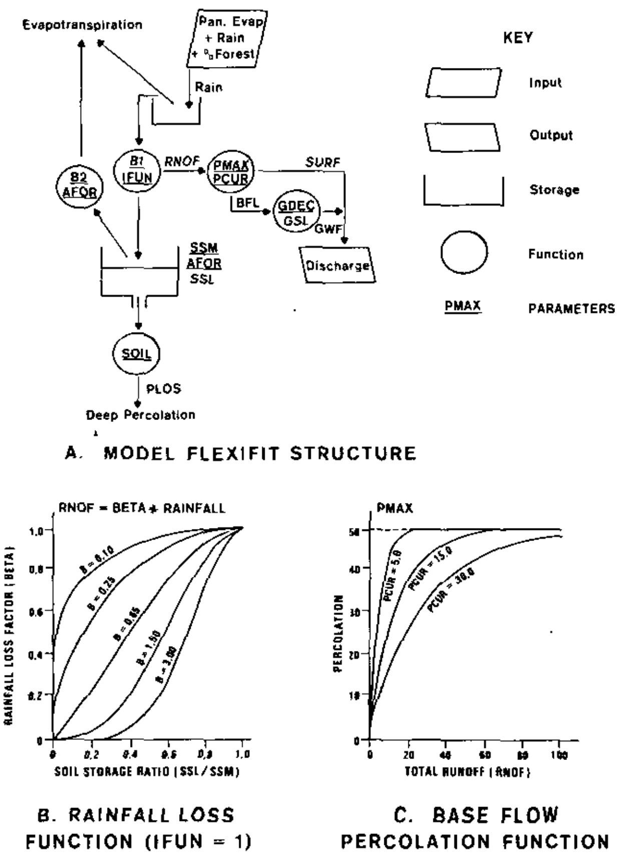


Figure 2
The structure of model FLEXIFIT and the form of the main model functions.

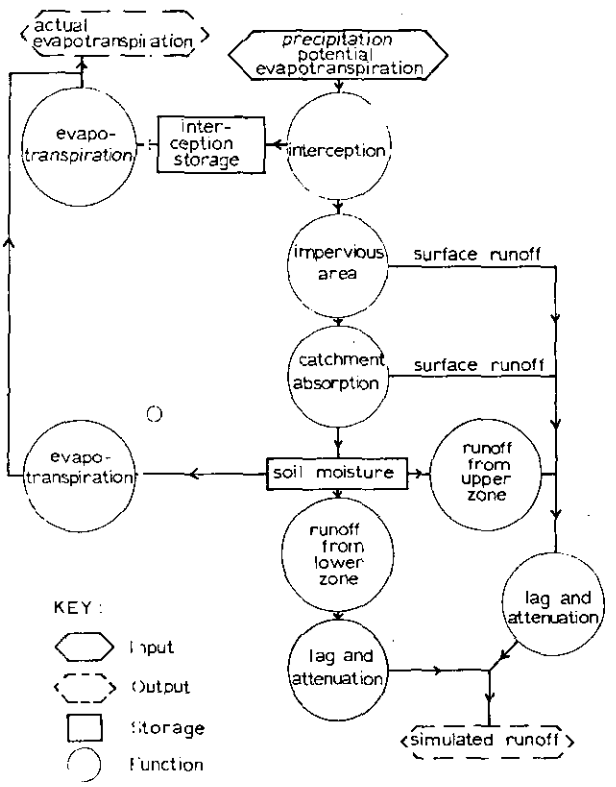
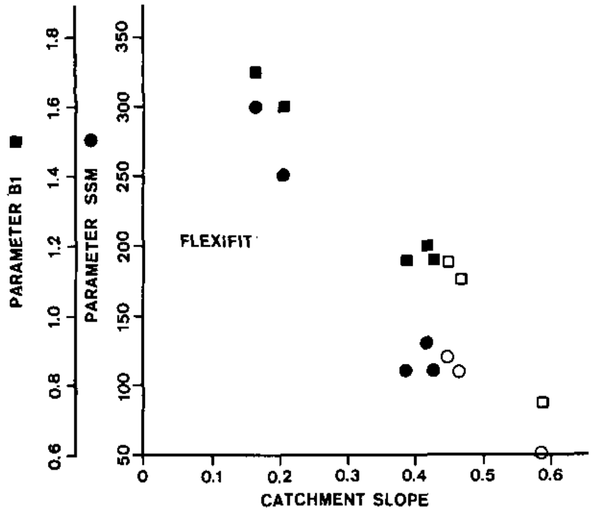
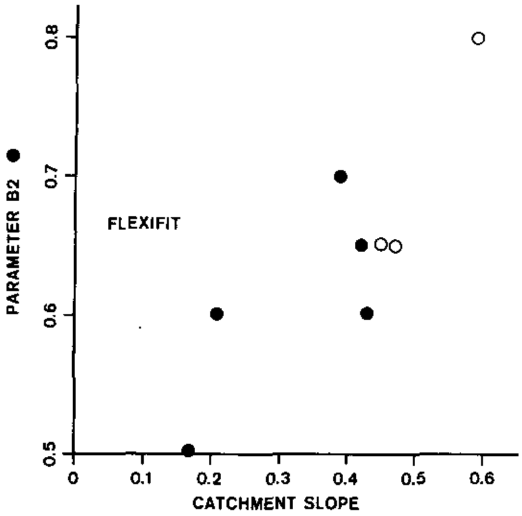
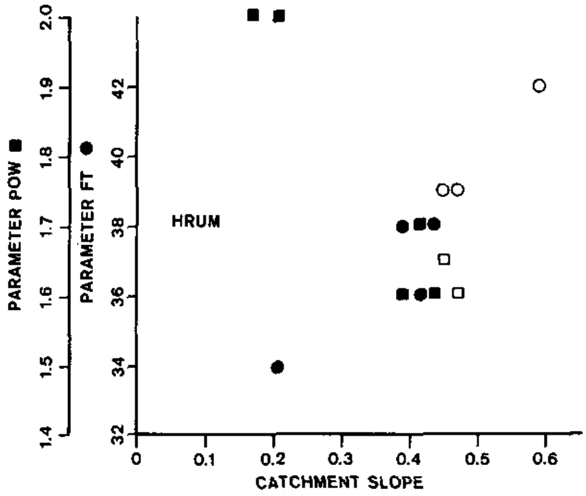


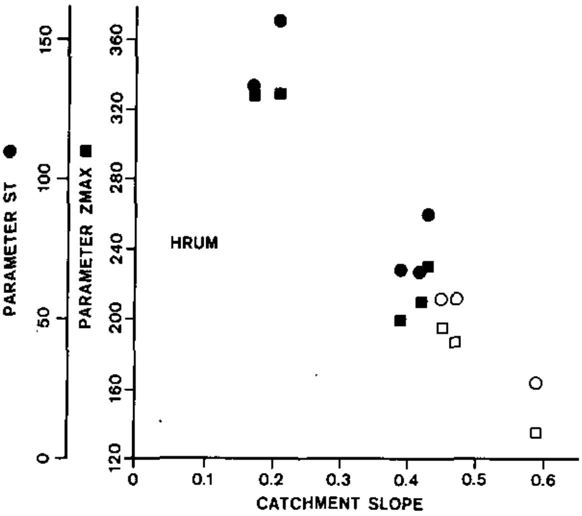
Figure 3
The structure of model HRUM (from Pitman, 1973).

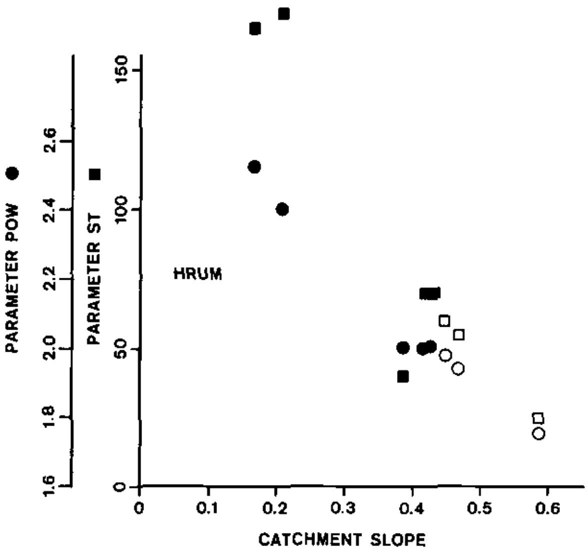
(Total contour length-contour interval/catchment area) had already been identified as an important variable in determining runoff response on an annual basis. Hughes (1983) found that slope (determined from 1:50 000 scale maps) was the most important factor explaining the variance in long term mean annual runoff ratios in this area of the Southern Cape (correlation coefficient between Log$_e$ (runoff ratio) and slope was 0,96). Slope was also revealed to be highly correlated with other catchment characteristics such as vegetation cover. It was no surprise therefore that slope also seemed to be the best easily measurable variable to assist in the parameter transfer process. This result is likely to be unique to the type of region studied, where such factors as elevation, vegetation, soils, local climate, land use, etc. are closely inter-linked and apparently integrated in the slope











CALIBRATED VALUES ■ or ●
TRANSFERRED VALUES □ or ○

Figure 4
Graphical relationships between catchment slope and some model parameters.

variable. In other regions it may be necessary to consider a wider combination of variables.

With these reservations in mind some graphical relationships between slope and the main moisture accounting and runoff producing parameters of the models are presented in Figure 4. Model HRUM has two sets of parameters as the model was calibrated using the absorption parameter ZMAX as well as not using it. The diagrams illustrate that while the relationships are far from being precise they do offer some guidelines for transferred values (open symbols). These guidelines were used to estimate values for the model parameters for the three test catchments, the Bloukrans, Kruis and Elands. The transferred parameter values, which were interpolated from the graphs by eye, are given in Table 3 and it should be noted that those parameters not included in Figure 4 have only small effects on the overall runoff patterns and were transferred more or less directly from the steeper calibration catchments.

Table 4 presents the results, in terms of the values for the four objective functions, for the calibrations, verifications and parameter transfer as well as some comparative values derived from available regional parameter estimates. The regional values derive from two reports of the HRU at the University of the Witwatersrand. The first, HRU 2/73, are given in Pitman (1973) where for the region in question POW = 2,0, ST = 200, FT = 30, and PI = 1,5. The second, HRU 13/81 are given in Pitman *et al.* (1981) where POW = 2,0, ST = 250, FT = 40, ZMAX = 400 and

TABLE 3
TRANSFERRED PARAMETER VALUES

	FLEXIFIT				HRUM (ZMAX)			HRUM (NO ZMAX)		
	Blouk.	Kruis	Elands		Blouk.	Kruis	Elands	Blouk.	Kruis	Elands
SSM	120	50	110	POW	1,65	1,41	1,60	1,98	1,76	1,94
B1	1,15	0,75	1,1	SL	0	0	0	0	0	0
B2	0,65	0,80	0,65	ST	70	40	70	60	25	55
PMAX	8,0	5,0	5,0	FT	39	42	39	60	70	60
PCUR	30,0	40,0	35,0	GW	3,5	3,0	3,0	3,5	3,0	3,0
GDEC	0,1	0,1	0,1	AI	0	0	0	0	0	0
SOIL	0,005	0,005	0,005	ZMIN	0	0	0	—	—	—
AFOR	1,4	1,4	1,4	ZMAX	216	155	208	—	—	—
				PI	1,8	1,8	1,8	1,4	1,4	1,4
				TL	0	0	0	0	0	0
				GL	0,2	0,1	0,1	0,2	0,1	0,1
				R	0,0	0,1	0,0	0,3	0,4	0,3
				FF	1,1	1,1	1,1	1,1	1,1	1,1

TABLE 4
COMPARISON OF OBJECTIVE FUNCTION VALUES USING CALIBRATION, VERIFICATION, PARAMETER TRANSFER AND REGIONAL PARAMETER VALUES

		Kaaimans	Maalgate	Malgas	Karatara	Gouna	Bloukrans	Kruis	Elands
	M	0,6	3,4 (-14,8)	1,5 (29,0)	0,4 (9,5)	-1,4	-19,1	-11,9	15,4
FLEX	V	-9,4	-1,1 (-13,5)	-17,7 (68,1)	2,7 (-5,3)	-2,5	29,5	-48,8	3,9
	D	0,81	0.84 (0,78)	0,72 (0,72)	0,74 (0,95)	0,50	0,79	0,71	0,75
	E	0,81	0,84 (0,73)	0,72 (0,43)	0,71 (0,94)	0,42	0,69	0,66	0,71
	M	1,3	2,0 (-13,1)	3,0 (27,3)	-0,5 (1,6)	0,4	21,7	-10,3	15,8
HRUM	V	-4,6	6,4 (-65,3)	-16,5 (69,2)	2,0 (-30,3)	-4,7	42,9	-37,8	10,6
(ZMAX)	D	0,80	0,80 (0,81)	0,72 (0,70)	0,69 (0,88)	0,62	0,79	0,71	0,75
	E	0,79	0,78 (0,70)	0,71 (0,40)	0,66 (0,87)	0,58	0,69	0,66	0,71
	M	-0,4	7,7 (-5,4)	1,6 (25,4)	-2,6 (3,7)	-0,1	17,6	-19,8	10,7
HRUM	V	-9,2	7,8 (-61,9)	-13,7 (60,0)	1,3 (-30,9)	-2,2	33,2	-43,9	7,4
(NO ZMAX)	D	0,79	0,82 (0,58)	0,72 (0,70)	0,66 (0,83)	0,49	0,77	0,68	0,72
	E	0,79	0,80 (0,56)	0,71 (0,42)	0,62 (0,82)	0,40	0,66	0,63	0,67
REGIONAL	M	-19,3	3,6	-19,1	-19,3	-17,6	-4,2	-37,2	-5,2
HRUM	V	-41,9	-16,3	-45,1	-37,1	-62,9	-22,4	-63,9	-23,3
13/81	D	0,79	0,76	0,67	0,64	0,53	0,79	0,64	0,72
	E	0,76	0,76	0,64	0,61	0,46	0,79	0,45	0,72
REGIONAL	M	-30,3	-9,5	-32,5	-29,5	-26,3	-19,4	-44,5	-15,2
HRUM	V	-28,0	0,0	-37,4	-18,3	-67,6	-4,4	-56,5	-8,7
2/73	D	0,72	0,80	0,57	0,58	0,28	0,73	0,64	0,72
	E	0,68	0,79	0,50	0,49	0,16	0,67	0,41	0,69

M = % error MAR
V = % error monthly variance
D = Coeff. of determination
E = Coeff. of efficiency

Note: Figures in brackets refer to verification results

PI = 1,5. The other parameters in HRUM are set to zero or in the first case not used (ZMIN, ZMAX = 999) except parameter FF (not part of the original model) which was set at 1,1 in both cases.

The final three columns of Table 4 illustrate that while the parameter transfer exercise was relatively successful some of the monthly variance errors are quite high and for the three catchments the more complicated procedure is not a great improvement on the results given by using the regional parameters. However, the regional parameter results have to be seen in the context of the degree of success achieved by using the same parameters on the other five catchments. Using the HRU 13/81 parameters the estimates of MAR and the general fit (D and E) are acceptable for most purposes (for example MAR errors $< \sim 20\%$). The monthly variance errors are high for most of the transferred or regional parameter sets. However, this is also true for the verification results which may be thought of as a temporal transfer of parameters. Table 5 is presented in an attempt to compare the results of applying the different parameter sets (transferred and regional) to the three catchments (Bloukrans, Kruis and Elands) by combining the effects of all four objective functions. Mean values for each of the objective functions are calculated over all 15 situations (5 methods × 3 catchments) and the sum of the standardised deviations from these means calculated for each method. The equations are constructed so that negative deviations imply a better fit than the mean and are given below Table 5. Finally, the deviations for the four objective functions are added to give an overall value for each method. The use of standardised deviations from the mean values eliminates the effect of different size ranges between the four objective functions and provides a way of combining them for between-method comparisons. The table illustrates that while there is a variation between the best method depending on the objective function, the transfer methods appear to be superior on the basis of the total deviations.

Discussion and conclusions

In this mountainous region of the coastal Southern Cape it has been possible to identify some approximate relationships between the main runoff volume parameters of two monthly conceptual models and catchment slope. Catchment slope appears to have a special significance within this region and differences in this variable reflect differences in other variables that are related to the response of streamflow to rainfall. Such a relationship is unlikely to hold in other regions where the association between physiography, soils and land use is more complex. However, it may be possible to find suitable, measureable indices of catchment characteristics in other regions that can be used to assist in the evaluation of model parameters for ungauged catchments.

The results of the parameter transfer test on three catchments are encouraging, in that errors in the estimation of MAR are better than $\sim 20\%$ and there are no large systematic errors in the one to one fits. However, the use of two sets of regionalised parameter values on these three as well as the five calibration catchments reveals that similar (or in some cases better) levels of estimation accuracy can be achieved by a less complicated and time consuming procedure which involves no calibration. When all four objective functions are considered together, for each model or regional parameter set, then the calibration-transfer methods are shown to be marginally better (Table 5). This is largely due to the fact that the regional parameters fail quite badly on the Kruis catchment. This observation may be important and perhaps illustrates the lack of reliability of the regional parameters in extreme situations. However, it could also be an isolated example and further tests would be required to confirm or deny this suggestion.

A point of interest that would be of importance to a potential user of the regional parameters, is that the MAR's and monthly variances are almost always underpredicted. In general, a decrease in parameters ST and ZMAX of model HRUM will increase both the MAR and monthly variance. Although it was not the original intention of this study to adjust already available regional parameters, it was considered that the paper would be incomplete if the effect of some adjustments was not investigated. Table 4 clearly indicates that if adjustments were made to improve the fit on those catchments having very high negative % errors, those with very low errors may suffer. Table 6 lists the effects on the objective functions of reducing parameters ST (to 150) and ZMAX (to 250) in the regional parameter set of HRU 13/81 (Pitman *et al.*, 1981). It can be seen that the majority of the percentage errors are now below 20% and 6 out of the 8 catchments exhibit improved overall fits. In addition the fits using this new set of regional parameters become highly competitive with any results that have been obtained through the more complex parameter transfer method.

TABLE 5
COMPARISON OF STANDARDISED OBJECTIVE FUNCTIONS DEVIATIONS FROM MEAN VALUES FOR ALL TRANSFER METHODS (NEGATIVE VALUES INDICATE BETTER FITS)

Method	% error MAR	% error Mnth. var.	D	E	Total
FLEX	– 0,408	– 0,176	– 0,095	– 0,150	– 0,829
HRUM (ZMAX)	– 0,330	0,138	– 0,095	– 0,150	– 0,437
HRUM (NO ZMAX)	– 0,313	– 0,096	0,015	0,0	– 0,394
HRUM 13/81	– 0,396	0,767	0,043	– 0,003	0,411
HRUM 2/73	1,419	– 0,608	0,125	0,294	1,230

Deviation data tabulated are based on the following equations:

$\bar{OF}$ = mean value of obj. function for all methods for all 3 catchments.

OF_{ij} = obj. function value for i'th method for j'th catchment.

Deviation for

$$\text{method } i = \sum_{j=1}^{3} \frac{(OF_{ij} - \bar{OF})}{OF} \text{ for M,V} \quad \text{OR} \quad \sum_{j=1}^{3} \frac{(\bar{OF} - OF_{ij})}{OF} \text{ for D,E}$$

TABLE 6
EFFECT OF REDUCING ST TO 150 AND ZMAX TO 250 FOR REGIONAL PARAMETERS 13/81

	M	V	D	E
Kaaimans	– 7,0	– 19,0	0,80	0,80
Maalgate	19,4	43,1	0,80	0,69
Malgas	– 4,3	– 18,0	0,69	0,69
Karatara	– 7,4	– 6,2	0,69	0,66
Gouna	– 9,0	4,7	0,64	0,57
Bloukrans	13,0	27,1	0,78	0,71
Kruis	– 26,5	– 50,0	0,69	0,60
Elands	8,2	0,3	0,72	0,69

The fact that a set of regionalised parameters can perform as well as the transferred parameters, where some account is taken of differences in catchment characteristics does not necessarily invalidate the transfer method used. The relative success of both methods may be a feature that is unique to this region where there is perhaps a higher degree of homogeneity in the rainfall-runoff process than in other areas. However, this possibility cannot be confirmed or denied until similar studies are carried out in other regions. The results suggest that within this region of the Southern Cape, monthly streamflow sequences could be generated for ungauged catchments using either the transfer approach or the modified regional parameters. If the methods are applied to catchments that are not too dissimilar (in terms of size, physiography, vegetation, etc.) to any of those used here for calibration and testing, then the estimation errors are likely to be within acceptable limits for practising hydrologists or engineers. A major conclusion of this study is that the results obtained in the Southern Cape coastal region are sufficiently successful to warrant similar studies in other regions of Southern Africa.

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