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A HYDROGRAPH-BASED MODEL FOR ESTIMATING THE WATER YIELD OF UNGAUGED CATCHMENTS

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SUMMARY The AWBM is a saturation overland flow model which uses daily rainfalls and estimates of catchment evapotranspiration to calculate daily values of runoff from gauged or ungauged catchments using a daily water balance. The AWBM is simple enough for use on ungauged catchments but can simulate the runoff from gauged catchments with an accuracy equal to that of far more complex models. It can be used as a simple 1-parameter model on small ungauged catchments where there is no baseflow, or a 3-parameter model on ungauged catchments which have a significant baseflow component of runoff. Where streamflow data are available for calibration, the parameters in the model can be directly evaluated without any need for trial and error optimisation, eliminating the problem of parameter interaction which occurs with trial and error fitting. The model is tested on 4 catchments with widely different hydrological characteristics in southeast Queensland . The model shows which partial areas of a catchment are producing runoff in individual runoff events and at different times in a single event. On one of the catchments in this study, runoff was produced from the whole catchment in only one out of five runoff events. This has significance for study of flood hydrograph models and methods of design flood estimation.

INTRODUCTION

A continuous record of streamflow contains a lot of information about the hydrological characteristics of the catchment from which the streamflow originated. When the streamflow data are analysed with rainfall and evaporation data, the analysis can identify errors and inconsistencies in the data, determine the values of and variations in surface storage capacity over the catchment, and evaluate the amounts and rates of water entering and leaving baseflow storage (Boughton, 1987).

The analytical methods set out by Boughton (1987) have been codified into a simple water balance model, the AWBM, for estimating the water yield of ungauged catchments and extending the records of gauged catchments. The model uses daily records of rainfall and estimates of catchment evapotranspiration, and calculates daily values of runoff.

Where streamflow data are available for calibration, the parameters in the model can be directly evaluated without any need for trial and error optimisation. This is a major advantage because of the problems of interrelationships among the parameters of other models which have prevented the identification of unique sets of parameters values for relating to catchment characteristics. Direct evaluation of the AWBM parameters produces a unique set of values whenever sufficient data are available. As a general guide, the length of data record should be long enough to include a sustained dry period in which each of the surface storages is emptied of moisture, and a wet period that is sufficient to fill all of the surface storages and produce runoff from all of the catchment.

The model can be used as a simple 1-parameter model on small ungauged catchments where there is no baseflow, or a 3-parameter model on ungauged catchments which have a baseflow component of runoff. The three parameters are: (i) an average value of surface storage capacity, (ii) the baseflow index, which is the ratio of the amount of streamflow appearing as baseflow to the total amount of streamflow, and (iii) the daily baseflow recession constant. The set of parameters, being one surface storage parameter and two baseflow parameters, is very similar to the set of parameters in the SFB model (Boughton, 1984), but the baseflow parameters of the AWBM model are directly related to characteristics of the streamflow hydrograph whereas those of the SFB model are merely a mathematical contrivance for simulating baseflow. Much of the experience which has been gained with evaluation of the surface storage capacity for the SFB model can be directly applied to use of the AWBM.

One version of the model, with hourly instead of daily time steps, has been successfully used with a flood hydrograph model for flood forecasting (see paper by Boughton and Carroll, this symposium). The ability to estimate the starting times and volumes of surface runoff events with an accuracy adequate for flood forecasting is a significant advantage of the AWBM over other water balance models of similar or even greater complexity.

The model shows which partial areas of a catchment are producing runoff in individual runoff events and at different times in a single event. One of the catchments reported in this paper produced runoff from the whole catchment in only one out of five runoff events, which is significant for the study of flood hydrograph models and flood frequencies.

This paper deals with the use of the AWBM for its original purposes - extending the streamflow records of gauged catchments, and estimating the water yield of ungauged catchments.

DESCRIPTION OF THE MODEL

The AWBM is a saturation overland flow model which allows for variable source areas of surface runoff in different storms and in different periods of a single storm. The baseflow component of the model simulates the recharge and discharge of a shallow groundwater store.

The structure of the model is shown in Figure 1. Three capacities are used to represent different values of surface storage capacity over a catchment area, which allows for different source areas of surface runoff. In each daily time step, the daily precipitation is added to and the daily evaporation is subtracted from each of the surface stores. Surface runoff and recharge of baseflow storage occur when one or more of the stores is over-filled and overflow occurs.

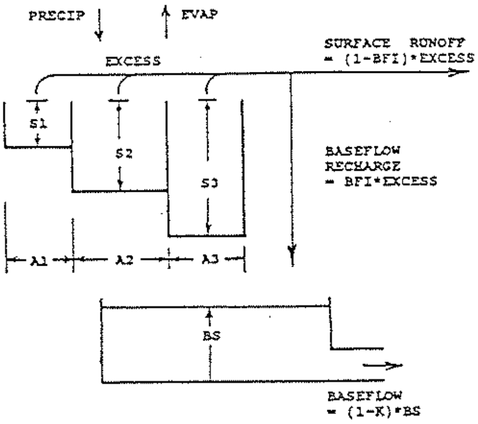

Figure 1. AWBM Structure

The recharge of baseflow storage is a fixed proportion of the amount of surface runoff and occurs when surface runoff is occurring. This was found to give the most realistic simulation of actual hydrographs during a study of models for automatic partitioning of streamflow by computer (Boughton, 1988). When the daily water balance of precipitation into and evaporation out of the surface stores creates an overflow, the excess is partitioned into (i) surface runoff = (1.0 - BFI)*excess; and (ii) recharge of baseflow storage = BFI*excess; where BFI is the baseflow index, i.e. the ratio of the amount of baseflow to the total amount of streamflow.

The discharge from baseflow storage is assumed to follow the commonly used relationship -

$$Q_{t+1} = K*Q_t \tag{1}$$

where Q_t = baseflow discharge on day t
Q_{t+1} = baseflow discharge on day (t+1)
K = daily recession constant

This form of relationship implies that the baseflow recession is a straight line on a semi-log plot, and also that the daily discharge from baseflow storage is given by:

$$B = (1.0 - K)*BS \tag{2}$$

where B = the daily discharge from baseflow storage
BS = the amount of water currently held in the baseflow storage

The two baseflow parameters of the model are the baseflow index and the daily baseflow recession constant. For use on ungauged catchments, an average value of surface storage capacity is used as the third parameter and preset values are used to disaggregate the average into 3 capacities of surface storage and the partial areas of the catchment represented by each capacity. When the model is used on gauged catchments, the 3 capacities of surface storage and their partial areas and the baseflow parameters are directly calculated from the rainfall and streamflow data.

USE OF THE MODEL ON GAUGED CATCHMENTS

Where concurrent rainfall and streamflow data are available for calibration, the following procedure can be used to directly evaluate the model parameters.

1. Using daily values of streamflow (or shorter periods if data are available), separate surface runoff from baseflow using any of the established techniques (e.g see Boughton, 1988, Nathan and McMahon, 1990b, Lyne and Hollick, 1979). If the catchment has no significant baseflow and runoff is only surface runoff, steps 1 to 4 are not applicable and only steps 5 and 6 apply.

2. Using the periods of baseflow recession between surface runoff events, determine the daily recession constant. This determines the amount of discharge from baseflow storage on each day according to the amount of water currently in baseflow storage - see equation 2. Methods of evaluating the daily recession constant are described by Toebes and Strang (1964), Klaassen and Pilgrim (1975), and Nathan and McMahon (1990b).

3. Calculate the ratio of the amount of baseflow to the amount of total streamflow. This parameter is the Baseflow Index (BFI) developed by the Institute of Hydrology (1980) - see also Nathan and McMahon (1990b) - and is used in the AWBM to determine the recharge of the baseflow store when rainfall is sufficient to overflow one or more of the surface stores.

4. Using the partitioned streamflow from 1. above, calculate the amount of surface runoff in each of the surface runoff events. Where there is baseflow in the runoff, increase the amount of runoff in each event by the factor 1.0/(1.0 - BFI) to allow for the recharge of baseflow storage.

5. Check each surface runoff event for inconsistencies between the amounts of rainfall and runoff using the methods set out by Boughton (1987a). Events where inconsistencies occur indicate errors in either rainfall or streamflow data, and are excluded from further analysis.

6. Using the adjusted amounts of runoff in each event from step 4, determine the capacities of the three surface stores and the partial areas of the catchment represented by each storage. The method is set out in detail in Boughton (1987b, 1990). Only a brief summary is given here. The smallest of the three capacities is fixed as a first step such that the start of surface runoff is modelled as well as possible in each of the surface runoff events. With that capacity fixed, the partial area of the catchment it represents is evaluated as the ratio of actual runoff to calculated runoff for those periods when only the smallest store is generating surface runoff. The estimated runoff from the smallest store is then subtracted from each of the surface runoff events, and the residual values are used to fix the second surface storage capacity and its partial area. The procedure is continued to fix the largest storage capacity using those periods when all of the catchment is generating surface runoff.

RESULTS ON GAUGED CATCHMENTS

The model has been tested on four catchments in Queensland with widely different physical and hydrological characteristics. The catchments range in size from 0.168 sq km to 155.6 sq km. The average annual runoff ranges from 42 mm to 920 mm. Baseflow ranges from zero to about one-half of total runoff.

Table 1 shows the results of calibrating the model on a 16.8 ha catchment situated on the Brigalow Research Station of the Queensland Department of Primary Industries, located about 400 km northwest of Brisbane. It is covered by native brigalow (Acacia harpophylla) forest. Soils are heavy textured with some duplex profiles. Land slopes average about 2.5%.

Rainfall during the 12-year study period (1967-1978 inclusive) averaged 700 mm per annum while runoff averaged 42 mm per annum, i.e. 6% of rainfall. Runoff is ephemeral and consists wholly of surface runoff with an average of fewer than two runoff events each year. The baseflow index was set to zero and the daily baseflow recession constant was set to 1.0. The calculation of the capacities and partial areas of surface storage is set out in Boughton (1990), and the parameter values used for calculating the results in Table 1 are summarised in Table 5.

Table 2 shows the results obtained by using the model with data from the 7 sq km Back Creek catchment at the Beechmont streamgauging station, located some 75 km south of Brisbane. The drainage area is the Beechmont Plateau, some 500 to 600 metres above sea level, which was formed from the eruption of the Mt Warning volcano in the Tertiary Era. Soils are derived from the parent material. The original sub-tropical rainforest of the catchment area has been replaced by pasture grasses. Land use is mainly dairy farming. Average annual rainfall is about 1670 mm and average annual runoff about 920 mm, some 55% of rainfall. There is a large baseflow component in the runoff, comprising about half of the total flow. The stream did not cease to flow in the 8 years of record used in this study. The records contain some substantial inconsistencies in several of the major runoff events (see Boughton, 1987a) and these months have been excluded from the results. The parameter values used for calculating the results in Table 2 are summarised in Table 5.

Table 1. Comparison of actual and estimated monthly totals of runoff - Brigalow catchment.

	1967		1968		1969		1970	
	Act	Est	Act	Est	Act	Est	Act	Est
J	4	3	.	.	.	.	1	.
F	.	.	.	1	1	2	.	.
M	.	.	.	.	.	.	.	.
A	.	.	5	4	.	.	.	.
M	.	.	.	.	.	.	.	.
J	.	.	.	.	.	.	.	.
J	.	.	.	.	.	.	.	.
A	.	.	.	.	.	.	.	.
S	.	.	.	.	.	.	.	.
O	.	.	.	.	.	.	.	.
N	.	.	.	.	.	.	.	.
D	.	.	.	.	.	.	.	4
Y	4	3	5	5	1	2	1	4

	1971		1972		1973		1974	
	Act	Est	Act	Est	Act	Est	Act	Est
J	1	1	.	.	.	.	.	.
F	110	128	10	5	.	.	.	.
M	.	.	.	.	.	.	.	.
A	.	.	.	.	.	.	.	.
M	.	.	.	.	.	.	.	.
J	.	.	.	.	.	.	.	.
J	.	.	.	.	4	4	.	.
A	.	.	.	.	.	.	.	1
S	.	.	.	.	.	.	.	1
O	.	.	.	.	.	.	.	.
N	.	.	.	.	.	.	1	.
D	.	.	.	.	42	46	.	.
Y	111	129	10	5	46	50	1	2

	1975		1976		1977		1978	
	Act	Est	Act	Est	Act	Est	Act	Est
J	.	.	.	.	.	.	.	.
F	2	3	.	.	.	.	108	109
M	.	.	.	.	.	.	.	.
A	.	.	.	.	.	.	.	.
M	.	.	.	.	.	4	.	.
J	.	.	.	.	.	.	.	.
J	.	.	.	.	.	.	8	1
A	.	.	.	.	.	.	.	2
S	.	.	.	.	.	.	3	14
O	.	.	.	.	.	.	.	.
N	.	.	.	.	.	.	42	19
D	157	147	.	.	.	.	.	.
Y	159	150	.	.	.	4	161	145

Table 2. Comparison of actual and estimated monthly totals of runoff - Back Creek catchment.

	1972		1973		1974		1975	
	Act	Est	Act	Est	Act	Est	Act	Est
J	**	**	27	23	**	**	22	8
F	**	**	74	89	**	**	40	40
M	**	**	51	35	**	**	88	56
A	**	**	33	21	**	**	36	18
M	61	61	22	14	121	168	21	12
J	30	33	14	9	138	179	14	7
J	19	22	255	218	48	78	12	6
A	13	14	47	54	35	51	9	3
S	8	8	28	33	18	31	12	2
O	**	**	29	21	21	20	21	9
N	82	69	22	13	24	12	32	31
D	34	35	32	21	16	8	26	32
Y	247	242	634	552	421	547	333	226

	1976		1977		1978		1979	
	Act	Est	Act	Est	Act	Est	Act	Est
J	**	**	16	8	4	7	73	74
F	**	**	29	17	7	12	79	52
M	**	**	76	68	158	159	52	33
A	**	**	53	58	110	105	16	17
M	58	73	40	49	44	44	12	11
J	32	40	25	21	21	27	51	53
J	22	38	25	14	17	18	32	42
A	17	21	12	9	13	11	20	22
S	12	13	12	5	17	13	10	13
O	15	9	7	3	10	6	9	9
N	31	27	7	2	13	4	14	10
D	31	20	2	1	21	12	8	5
Y	218	241	304	257	435	416	356	341

NB ** denotes months when errors make the data unusable for comparison.

Table 3 shows the results obtained by using the model with data from the 55 sq km Munduran Creek catchment, located between Gladstone and Rockhampton on the Queensland coast, some 500 km north of Brisbane. The valley floor is relatively flat and not much above sea level, but the sides of the catchment are steep with some peaks up to 300 m above sea level.

Runoff averages about 130 mm/yr with a small baseflow component amounting to about 6% of total flow. The creek ceases to flow for substantial periods.

Oxley Creek is the largest of the creeks which cross the Brisbane urban area. The creek flows from south to north rising at Flinders Peak and joining the Brisbane River at Graceville. The data used in this study are from the streamgauging station at Beattie Road (no.143019) which is above the tidal effects in the lower reaches. The catchment area at the gauging station is 155.6 sq km. The station is a key warning station for downstream flood-prone properties whose annual average damage is in the order of $1 million. The catchment is very sandy for 10 km or so upstream of the gauging station. For the last 50 years, this part of the creek's floodplain and banks have been the major source of sand for the construction industry in the Brisbane region.

This catchment is used to demonstrate the application of the AWBM to flood forecasting in an accompanying paper (Boughton and Carroll, this symposium) and is included here for comparison with the other catchments which have been studied. Table 4 shows the results which have been obtained and Table 5 summarises the parameter values which were used to obtain those results.

Table 3. Comparison of actual and estimated monthly totals of runoff - Munduran Creek catchment.

	1978		1979		1980		1981	
	Act	Est	Act	Est	Act	Est	Act	Est
J	170	158	10	1	40	39	19	35
F	50	61	1	.	68	13	36	86
M	1	4	123	102	4	4	10	2
A	.	2	3	2	.	.	47	30
M	.	2	2	1	.	.	47	7
J	1	.	1	1	1	.	4	1
J	32	13	1	1	1	.	1	.
A	3	2	.	.	1	.	1	.
S	5	1	.	.	1	.	.	.
O	.	.	.	.	.	.	.	.
N	27	45	1	.	.	.	1	1
D	25	3	.	.	.	3	.	.
Y	314	291	142	108	116	59	166	162

	1982		1983		1984		1985	
	Act	Est	Act	Est	Act	Est	Act	Est
J	.	1	23	39	.	2	.	.
F	1	4	.	1	.	.	.	1
M	1	.	42	61	1	1	27	10
A	.	.	40	23	1	.	.	.
M	.	.	131	147	.	.	.	.
J	.	.	14	3	.	.	1	2
J	.	.	1	2	3	4	.	.
A	.	.	1	1	.	.	.	.
S	.	.	.	.	.	.	.	.
O	.	.	.	.	.	.	.	.
N	.	.	2	.	.	.	.	.
D	.	.	1	.	9	3	.	.
Y	2	5	255	277	14	10	28	13

Table 4. Comparison of actual and estimated monthly totals of runoff in mm - Oxley Creek catchment.

	1990		1991	
	Act	Est	Act	Est
J	20	20	7	6
F	90	91	38	31
M	86	75	7	6
A	213	154	6	5
M	108	126	8	5
J	33	36	8	5
J	8	8	8	5
A	8	7	12	4
S	6	7	15	4
O	6	7	13	4
N	6	6	11	4
D	6	6	122	118
Y	591	543	254	197

COMMENTS ON THE RESULTS

(i) Correlation of actual and estimated runoff.

The monthly totals of actual and estimated runoff were compared by fitting a linear regression with actual runoff as the dependent variable and estimated runoff as the independent variable. The results of the regression are shown in Table 5.

Table 5. Summary of parameter values and statistics of results

	Brig	Back	Mund	Oxly
Area	0.168	7	55	156
Flow	42	429	130	423
A1	0.15	0.25	0.10	0.02
A2	0.55	0.25	0.50	0.58
A3	0.30	0.50	0.40	0.40
S1	55	50	50	10
S2	85	75	100	95
S3	200	150	200	260
Ave S	115	106	135	159
K	.	0.985	0.978	0.998
BFI	.	0.55	0.06	0.23
a	0.983	0.907	0.929	1.107
con	0.06	4.94	1.86	1.09
r^2	0.976	0.905	0.849	0.946

Legend for Table 5.

Area = catchment area, sq km
Flow = annual flow, mm/yr
A1 = fraction of area represented by S1
A2 = fraction of area represented by S2
A3 = fraction of area represented by S3
S1 = smallest surface storage capacity
S2 = middle surface storage capacity
S3 = largest surface storage capacity
Ave S = average surface storage capacity
K = daily baseflow recession constant
BFI = baseflow index
a = slope of regression equation
con = constant in regression equation

Regression equation is : Act = a*Est + con
where Act is actual monthly flow
and Est is estimated monthly flow

The correlation coefficients are high, indicating that the accuracy of the estimates is high. They are highest for the catchments where rainfall data are most reliable and lowest where the rainfall data are least reliable. The Brigalow catchment is a small research catchment with several rain gauges in and around a small area, and this is reflected by the high correlation coefficient. Munduran Creek catchment is 55 sq km in area with only a single daily rain gauge providing the input rainfall data, hence it has the lowest correlation coefficient. Oxley Creek is the largest of the four catchments but the rainfall data are better than usual for a catchment of this size due to the flood warning system in operation. The effect of the better rainfall data is evident in the high correlation coefficient between actual and estimated runoff on this catchment.

Three of the four regression slopes are less than 1.0 showing a slight tendency for the model to overestimate high values and underestimate low values, but this bias is very small.

(ii) Travel time of runoff

The estimated runoff shown in Tables 1 to 4 is reported for the days on which the model calculates that the runoff occurs, and there is no provision made for the time taken for runoff to reach the outlets of the catchments. The Munduran Creek catchment shows the effects of travel time on the results when the estimated runoff is at the end of a month. In November-December 1978, the estimated total for the two months is close to the actual total but the results of the model indicate most of the rainfall excess occurred at the end of November. In March-April 1983, the estimated total for the two months is very close to the total of actual runoff but again the occurrence of the rainfall excess at the end of March gives a misleading result when only monthly totals are shown.

(iii) Errors in the data

Errors in the measurement of both rainfall and runoff data are a major limitation to the accuracy which can be achieved with water balance models at catchment scale. The errors in the data of the 7 sq km Back Creek catchment have been documented in an earlier paper (Boughton, 1987a) and were the reason for the months of missing data in Table 2. The Oxley Creek data show two significant data errors in Table 4. Watering of domestic gardens in suburbs of Brisbane that are just upstream of the gauging station have produced erroneous low flows in the months of August-November 1991 as can be shown by increases in low flows in a period of severe drought. There are high flow data errors in February 1990, due to suspected instrument malfunction, and in April 1990 due to the collapse of a dam upstream of the gauging station (see paper by Boughton and Carroll, this symposium).

(iv) Sensitivity of the parameters

The calculated amount of runoff depends only on the average surface storage capacity and not on the two baseflow parameters. The baseflow index divides the runoff between baseflow and surface runoff but does not affect the total amount of runoff. The daily recession constant affects the timing of the baseflow discharge but not its amount. The two baseflow parameters influence only the timing, not the quantity, of runoff.

An increase in the average surface storage capacity decreases the total amount of runoff and vice versa. The Oxley Creek data were used to test the sensitivity of the results to change in the average surface storage capacity. A change of +/-10% in each of the three surface storage capacities produced a change of only -/+4% in the total amount of runoff. This is a very low level of sensitivity compared to the Curve Number Method in which a change of +/-10% in the curve number changes the estimated runoff by about -/+50%.

Similarly, the results are affected very little by the pattern of disaggregation of the average surface storage capacity among the partial areas. As an example, the two smallest surface storage capacities on the Oxley Creek catchment were increased by 20% and the largest capacity was reduced to keep the average capacity unchanged. This resulted in a decrease of only 1% in total runoff. The sensitivity will be different on different catchments but the example demonstrates that the sensitivity of the estimated runoff to change in the parameter values is among the lowest of any of the rainfall-runoff models now in use.

The baseflow index is a ratio (the amount of baseflow divided by the total amount of runoff); therefore, the change in output is in direct proportion to change in the parameter; e.g. a change of +10% in the baseflow index increases the baseflow by 10% and decreases the amount of surface runoff by that amount.

The daily recession constant affects the timing of runoff in a complicated way ~~because it~~ is not a true parameter. The real parameter is (1.0 - K) which is the fraction of the baseflow storage that discharges each day. If (1.0 - K) is increased by 10%, there is a 10% increase in the fraction of the baseflow storage that is discharged each day.

USE OF THE MODEL ON UNGAUGED CATCHMENTS

Information for estimating the values of parameters in any water balance model for use on ungauged catchments is still meagre, but there is now published information which can be used to estimate each of the AWBM parameters in south-eastern Australia when streamflow data are not available for calibration.

On very small ungauged agricultural catchments without any baseflow component of runoff, the model can be used as a single parameter model in a manner similar to the USDA SCS Curve Number Method (Boughton, 1989). The baseflow parameters are nullified by setting the baseflow index to zero and the daily recession constant to 1.0. The user estimates a value of AVERAGE SURFACE STORAGE CAPACITY and the computer program disaggregates that value into a set of 3 capacities and 3 fractions of the catchment area corresponding to those capacities. The preset values used for disaggregation of the average capacity are S1 = 0.5*Ave, S2 = 0.75*Ave, and S3 = 1.5*Ave. The partial areas of the catchment represented by each of these capacities are A1 = 0.2, A2 = 0.4, and A3 = 0.4 .

The average surface storage capacity of the AWBM is sufficiently akin to the surface storage parameter S of the SFB model that the accumulated information from tests of the SFB model can be used to estimate the average surface storage capacity. Nathan and McMahon (1990a) calibrated the SFB model on 184 rural catchments, 1 to 250 sq km in area, in south-eastern mainland Australia, but they were able to obtain significant predictive regression equations for parameter S in only 2 out of the 8 regional groups into which their catchments were divided. A more generalised use of their results was suggested by Boughton (1991) who adapted the codified USA experience with the USDA SCS Curve Number method into recommendations for estimating surface storage capacity on Australian catchments. Figure 2 shows a histogram of the calibrated values of SFB parameter S by Nathan and McMahon, and Table 6 gives the recommendations of Boughton for the effects of soil type and land use on this parameter. The histogram shows that the median value of surface storage capacity on Australian catchments is about 120 mm, and also shows the spread of values.

Table 6. Average surface storage capacity (mm) for hydrologic soil-cover complexes.

Land Use or Cover	Treatment /Practice	HC	Hydrologic Soil Group			
			A	B	C	D
Fallow	Str row	P	134	72	41	23
Row crops	Str row	P	172	196	60	41
	Str row	G	212	127	79	53
	Contrd	P	188	120	86	60
	Contrd	G	229	149	99	72
	C & ter	P	221	157	113	99
	C & ter	G	256	180	127	106
Small grain	Str row	P	229	142	86	60
	Str row	G	247	149	92	66
	Contrd	P	247	157	99	79
	Contrd	G	265	164	106	86
	C & ter	P	265	172	120	99
	C & ter	G	283	188	127	106
Close seeded or rotation meadow	Str row	P	221	134	79	53
	Str row	G	293	172	106	79
	Contrd	P	238	149	92	79
	Contrd	G	323	196	127	92
	C & ter	P	247	164	113	92
	C & ter	G	365	212	142	113
Pasture or range		P	204	120	72	53
		F	-	196	120	86
		G	-	265	157	113
	Contrd	P	-	212	106	60
	Contrd	F	-	283	149	92
	Contrd	G	-	-	188	120
	Meadow	G	-	293	180	127
	Woodlands	P	-	221	134	92
		F	-	274	164	120
		G	-	323	188	134
Roads - dirt			172	99	66	53
Roads - hard surfaced			157	86	47	35

Legend for Table 6

HC	Hydrologic condition
P	Poor
F	Fair
G	Good
Str row	Straight row
Contrd	Contoured
C & ter	Contoured & terraced

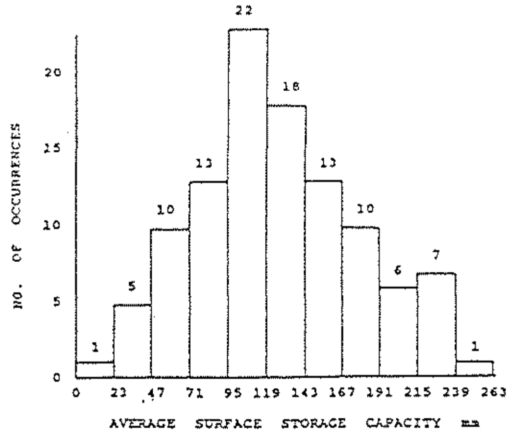

Figure 2. Histogram of calibrated S values of SFB Model

On ungauged catchments where baseflow is a significant component of flow, it is necessary to estimate the two baseflow parameters as well as the average surface storage capacity. The average surface storage capacity is estimated in the same way as for ephemeral catchments, described above.

The DAILY RECESSION CONSTANT has been studied in New South Wales by Klaassen and Pilgrim (1975) and in Victoria and New South Wales by Nathan and McMahon (1991a,b).

The report by Klaassen and Pilgrim gives a range of values for 29 streams and documents the difference between coastal and inland streams. The streamflow data were from medium to large catchments, 311 to 16400 sq km in area. Fig. 3 shows a histogram of their results, divided into coastal and inland streams. Klaassen and Pilgrim reported that "recession constants tend to be higher, and therefore recessions are flatter and more sustained, on the coastal catchments than for those west of the Great Dividing Range. Broad-scale geological evidence supported those general regional differences." They attempted to relate baseflow recession constants to indices of alluvium, aquifers and topographic characteristics with only limited success. Klaassen and Pilgrim summarise the values of recession constants of 172 overseas catchments as well as reporting the results from the New South Wales catchments.

At the time of writing this paper, the values of baseflow recession constant on 184 catchments, 1 to 250 sq km in area, derived by Nathan and McMahon (1990c) were not available to the writer for inclusion here; but these values are a major source of information to which reference should be made if the AWBM model is to be used on ungauged catchments.

The major source of information about the BASEFLOW INDEX is contained in the reports by Nathan and McMahon (1990c, 1991a). These author used linear regression equations to relate the baseflow index to catchment characteristics on 184 catchments in south-eastern Australia. The catchments were divided into 8 groups and a regression equation was derived for each group. Each regression equation used from 1 to 5 independent variables with an average of 3. A total of 11 different independent variables were used in the 8 equations. This study is the only significant source of information about the baseflow index for use on ungauged catchments.

CONCLUSIONS

The AWBM is simple enough for use on ungauged catchments but can simulate the runoff from gauged catchments with an accuracy equal to that of far more complex models. On small ungauged catchments where there is no baseflow, the model can be used as a 1-parameter model, equalling the simplicity of the USDA SCS Curve Number method but retaining the advantages of water balance modelling. On ungauged catchments with significant baseflow, the model has 3 parameters, similar to the SFB model but with more realistic baseflow parameters which facilitates the estimation of the parameters.

There is information already available in Australian publications from which the 3 parameters - average surface storage capacity, baseflow index and daily baseflow recession constant - can be estimated when the model is used on ungauged catchments. The major sources of this information are documented in the paper.

Where streamflow data are available for calibration, the parameters in the model can be directly evaluated without a need for trial and error optimisation. This avoids the interactions among parameters which have caused many problems with the optimisation of rainfall-runoff models in the past.

The model shows which partial areas of a catchment are producing runoff in individual runoff events and at different times in a single event. One of the catchments used in this study produced runoff from the whole catchment in only one out of five runoff events. This has significance for the study of flood hydrograph models and methods of design flood estimation.

Despite the simplicity of the model, the accuracy of reproducing the streamflow pattern of gauged catchments is equal to those of far more complicated models. The main limitation on the accuracy of catchment scale rainfall-runoff modelling is now the quality of input rainfall data and not the quality of the model.

There are some aspects of streamflow which the model does not address and on which further research is needed. The model does not simulate transmission loss in stream channels, which can be important in many catchments. The baseflow store simulates a shallow groundwater storage, and the model cannot simulate baseflow from melt of snowpack or slow drainage from lakes or similar sources. Baseflow will become of increasing importance in the future for environmental reasons, and the simplicity of the baseflow discharge versus storage relationship in the AWBM might be inadequate for some purposes.

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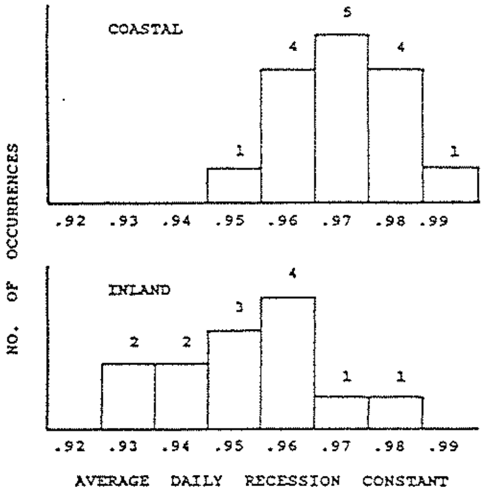

Figure 3. Histogram of daily baseflow recession constants - NSW catchments (from Klaassen and Pilgrim, 1975)

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