A review of Australian model parameterization studies using large basin samples

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Abstract The five major studies in Australia, using 168, 195, 221, 221 and 175 data sets, are described. The basins range in size from 1 to 8400 km^2 with an average of a few hundred km^2. The paper describes the models, data sets, methods used and results. The most promising approach shifts the problem of estimating model parameter values to that of estimating average annual runoff. Given an estimate of average annual runoff and daily rainfall and evaporation data, the AWBM rainfall–runoff model self calibrates and calculates daily runoff for the period of input data. Relationships of average annual runoff to average annual rainfall and evaporation have been established for the whole of Australia and results from these relationships with the AWBM are presented. The main problem in Australia is the estimation of areal rainfall for input to the models.

Key words AWBM; hydrological modelling; rainfall–runoff models; runoff; ungauged catchments

INTRODUCTION

Rainfall–runoff modelling in Australia has been reviewed by Boughton (2005). Because of the large area of the country (7 682 000 km^2) and small population (20 million) the network of streamgauging stations is barely adequate in the main agricultural regions, and sparse in the sparsely populated regions. This has prompted many studies directed towards estimating runoff from ungauged basins. There were some early studies in the 1970s with different models, but all with a small number of data sets and all without any useful results. More recently, there have been five studies with large numbers of data sets, and two with smaller numbers. Those studies are the subject of this paper. The models used in the major studies (SFB, MOSAZ, AWBM and SIMHYD) are described in more detail in Boughton (2005). All of these models are run on daily data.

MAJOR STUDIES

The SFB model has three parameters, with one mainly determining the amount of run-off and two determining the division of runoff between surface runoff and baseflow. Nathan & McMahon (1990a,b) calibrated the model on 168 basins of 1 to 250 km^2 in area, with median annual rainfall 600 to 1200 mm, in New South Wales and Victoria. The areal rainfall data were derived by Thiessen weights. Potential evapotranspiration (PET) was based on Morton’s wet environment areal evapotranspiration (Morton, 1983). Parameters were optimized using a Simplex search algorithm with several sets of starting values. Some 37% of the calibrations had either $r^2 < 0.60$ or differences between observed and calculated total flow >±10%. These poor calibrations were usually in basins in which the water balance problems indicated that the rainfall and PET data were not representative of the basin.

Scatter plots between calibrated model parameter values and basin characteristics were used to look for visual evidence of correlation, without success. Multiple linear regression equations were also developed between parameter values and basin characteristics (Nathan & McMahon, 1991). At the time of this study, the SFB model was in widespread use in Australia, but has since been replaced, mainly by the AWBM, and is little used at the time of writing.

The MOSAZ (Modified Semi-arid Zone) model is very simple with two parameters, one for moisture storage capacity and one for baseflow discharge. Nathan *et al.* (1996) calibrated the model on 195 basins of 4 to 8400 km^2 in area, with average annual rainfall 450 to 2300 mm, in Victoria. The areal rainfall data were derived by Thiessen weights. Mean monthly PETs were estimated by Morton's complementary procedure for regional evapotranspiration. Parameters were calibrated by selecting several sets of starting values, and then optimizing using a Simplex search algorithm to minimize the square root of difference between observed and calculated monthly flows.

Linear regressions were used to look for correlations between parameter values and nine measurable characteristics. Ten data sets were not used in determining the regressions, but retained for independent testing. The coefficients of efficiency between estimated and actual runoff on the test data sets varied from 0.015 to 0.83. The authors expressed concern about the "weak physical significance" of the equations. This was the only major study in which the MOSAZ model was used. It is not in wide use.

The AWBM model has three parameters with one determining the amount of runoff, one determining the division between surface runoff and baseflow, and one determining the rate of baseflow discharge. Boughton & Chiew (2003) calibrated the model on 221 basins of 50 to 2000 km^2 in area, with annual rainfall 300 to 2800 mm, spread over much of the main agricultural regions of Australia. The self-calibrating version of the model that automatically calibrates to a set of daily data without action by the user was used (Boughton 2003). They made no correlations between model parameters and basin characteristics; instead they tabulated the calibrated values for all 221 basins. They recommended selecting the calibrated parameter values for several of the basins nearest to the ungauged basin of interest, using tabulated basin characteristics as a guide. Variation in results from the different calibrations in a region gives some indication of potential error in estimating runoff. Taylor (2004) extended the work for the State of Tasmania by calibrations of the model on more basins than were used by Boughton & Chiew (2003) in that State.

At the time of writing, this is the only published procedure that has potential for use over most of Australia. It is too soon since its introduction to assess how much it will be used in practical applications, but the follow-on study by Taylor (2004) shows there is interest in the approach. The AWBM is in common use for rainfall–runoff modelling, and the publication of calibrated parameter values for 221 basins offers a simple extension of existing technology.

The AWBM model was used in another study by Boughton & Chiew (2006). The single parameter determining the amount of runoff can be calibrated to an estimate of average annual runoff, and the model can then be used with daily rainfall and evaporation data to estimate daily runoff with the same average annual runoff. The authors established linear equations to estimate average annual runoff from average annual rainfall and evaporation anywhere in Australia. The model has two baseflow parameters that affect the timing of runoff (but not the amount). The tabulated values of these parameters in Boughton & Chiew (2003), with the regression equations for determining the amount of runoff, provide a simple method for estimating daily runoff anywhere in Australia.

Six catchment characteristics (two topographic, two soil characteristics and two relating to vegetation cover) were tested in turn with the regression equations for estimating average annual runoff, but none produced any improvement. The lack of any significant correlation between the characteristics and runoff is anomalous. Many other studies reported in the literature show such correlations, e.g. the difference in runoff from forested and grassed catchments is extensively reported, and so the lack of correlation between runoff and the percent of woody vegetation is a significant anomaly. The basin characteristics were estimated from satellite observations and from broad scale soil mappings, not from field measurements, so there is a possible explanation in the methods used to estimate the characteristics.

The SIMHYD model (Chiew *et al*., 2002) was used by Chiew (2003) to generalize the model's seven parameters on 175 basins in southeast Queensland. The basins were divided into nine "hydrologic regions" and one set of parameter values was determined for each region to give good overall agreement between modelled and recorded monthly flows for basins in that region. The results were intended for use only within the region of study and not elsewhere.

STUDIES WITH SMALL SAMPLES

Two studies with small numbers of data sets provide additional information on model parameterization in Australia. Ibrahim & Cordery (1995) calibrated a monthly rainfall–runoff model to data from 18 basins in New South Wales for the purpose of estimating runoff and recharge volumes on ungauged basins. Post & Jakeman (1996) calibrated the daily IHACRES model on 16 small basins in Victoria with an objective of regionalizing the model parameters. Neither study produced any practical application.

MOST PROMISING APPROACH

The AWBM has only one parameter (average surface storage capacity) determining the amount of runoff. This should simplify the establishment of relationships between the parameter and basin characteristics; however, small errors in rainfall data cause very big changes in the calibrated value, sufficient to confuse any relationships. Boughton (1996) scaled rainfall data to simulate errors and showed that change of ±20% in rainfall produced changes of +98% and –68%, respectively, in the calibrated value of average surface storage capacity. Other models with a single parameter determining the amount of runoff (such as the Curve Number) show similar sensitivity. Errors of ±20% in areal rainfall data are commonplace (Boughton, 2006). This makes the calibrated values of parameters suspect for relating to basin characteristics.

However, the AWBM average surface storage capacity can be accurately calibrated to an estimate of average annual runoff in order to calculate that amount of runoff. The average capacity is simply increased and decreased by trial and error until the calculated runoff matches the estimate of runoff to any required degree of accuracy. The AWBM model, used with estimates of average annual runoff and tabulated values of baseflow parameters, offers the simplest and most robust method for estimating daily runoff from ungauged basins in Australia. This approach transfers the problem of estimating values of model parameters to estimating average annual runoff.

Table 1 shows the regression equations developed by Boughton & Chiew (2006) for estimating average annual runoff in six of the major Drainage Divisions of Australia, and for all mainland data lumped together. The coefficients of determination (r^2) and the F statistics indicate the relative accuracy of the runoff estimates on ungauged basins. The regression equations are based on groups of average annual rainfall, and the r^2 values are generally highest in the higher rainfall ranges and lowest in the lower ranges, as expected.

The AWBM has two baseflow parameters in addition to the average surface storage parameter—the baseflow index (BFI) that determines the division of runoff between surface runoff and baseflow, and the daily baseflow recession constant (Kbase) that determines the rate of baseflow discharge from storage. Boughton & Chiew (2003) documented calibrated values of these parameters on 221 basins in Australia, and Table 2 summarizes those values as median, 10 percentile and 90 percentile values for the six Drainage Divisions in Table 1. These values are used with the average surface storage capacity to estimate daily runoff from ungauged basins.

Boughton & Chiew (2006) tested the procedure using 23 years of rainfall and PET data from the 108 km^2 Boggy Creek basin in Drainage Division IV. Average annual values of rainfall, PET and runoff for the 23-year period were 1185, 1085 and 324 mm year^{-1}, respectively. Figure 1 shows a comparison of the estimated monthly and yearly runoff

Table 1 Regression equations for estimating average annual runoff.

Region	Rainfall range mm year^{-1}	N	Regression	r^2	F	df	Prob.
Div I	700–1730	12	Q = 0.544P-350	0.959	234	10	2.9E-8
Div II	>1000	41	Q = 0.641P-0.0717E-361	0.903	193	38	1.3E-20
	700–1000	40	Q = 0.619P-0.157E-206	0.620	31	37	1.1E-8
	<700	7	Use mainland				
Div III	546–2062	11	Q = 0.773P-0.902E+401	0.983	235	8	7.8E-8
Div IV	>1000	22	Q = 0.861P-0.0395E-661	0.932	129	19	8.6E-12
	700–1000	47	Q = 0.502P-0.259E+4	0.601	33	44	6.4E-7
	<700	15	Q = 0.276P-0.139E+47	0.811	23	12	7.5E-5
Div V	490–850	8	Q = 0.351P-0.171E+27	0.976	101	5	9.1E-5
Div VI	850–1050	5	Q = 0.684P-497	0.673	6	3	0.089
	390–850	5	Q = 0.124P-37	0.759	9	3	0.054
Mainland	>1000	71	Q = 0.659P-0.073E-382	0.902	333	68	7.3E-36
	700–1000	100	Q = 0.571P-0.119E-212	0.566	63	97	3.1E-18
	<700	31	Q = 0.211P-0.078E+11	0.550	19	28	7.2E-6

N, number of catchments in sample; F, F statistic; df, degrees of freedom; Prob, probability of chance result; Q: average annual runoff mm year^{-1}; P, average annual rainfall mm year^{-1}; E, average annual areal PET mm year^{-1}.

Table 2 Values of baseflow parameters by Drainage Division.

Division	BFI 90%	Median	10%	Kbase 90%	Median	10%
I	0.11	0.17	0.45	0.813	0.950	0.987
II	0.21	0.33	0.60	0.915	0.980	0.993
III	0.23	0.32	0.57	0.920	0.966	0.991
IV	0.18	0.41	0.63	0.910	0.976	0.989
V	0.20	0.29	0.45	0.950	0.958	0.985
VI	0.30	0.56	0.63	0.900	0.956	0.981

BFI, baseflow index; Kbase, daily baseflow recession constant.

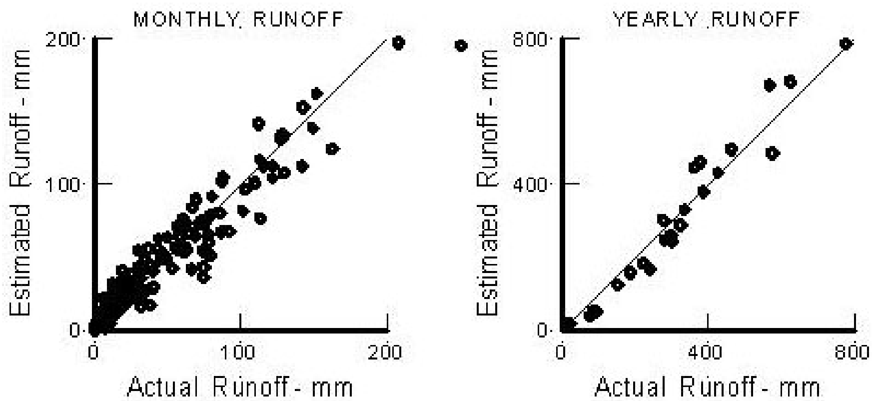

Fig. 1 Estimated and actual monthly and yearly runoff on Boggy Creek basin.

with actual values. The monthly and yearly coefficients of efficiency are 0.918 and 0.908, respectively. These Boggy Creek results are typical of the better quality results in the higher rainfall ranges, and are neither the best results nor outstanding in any way.

The statistical characteristics of the regression equations for estimating runoff from rainfall and evaporation give a measure of the possible error in the estimate of total runoff. The accuracy of daily runoff depends mainly on the accuracy of the values of the baseflow index (BFI) and the daily baseflow recession constant (Kbase). While the calibrated values in Table 2 give a guide for ungauged basins, there are substantial ranges between the 10 and 90 percentile values. At present, no relationships have been found between these parameters and basin characteristics.

FUTURE DIRECTION

The accuracy of the method using estimates of average annual runoff with the AWBM depends mainly on the accuracy of the estimate of average annual runoff. The linear regressions relating runoff to rainfall and PET in Table 1 were based on 221 data sets covering much of Australia. There are more than 10 times that number of streamgauging stations in Australia, so there is considerable potential for improving the regressions by use of more data. Other studies such as Gan *et al.* (1990) provide other approaches to the estimation of average annual runoff. The substantial variability of the Australian climate makes the estimation of runoff on ungauged catchments more difficult than in many temperate zone countries. In the study with the SFB model and the two studies with the AWBM model, there were problems of input data quality in one-third of the data sets available for use. The problems were mainly associated with the rainfall data not being representative of the areal rainfall that produced the runoff. Typical density of raingauges in Australian basins is in the order of one gauge in 10 to 100 km^2, giving a sample of one part in 300 million to 3 billion of the basin rainfall. In addition to the sampling error, there are periods of missing data, and errors and mistakes in the records. Some techniques are available for checking the consistency of rainfall and runoff data (Boughton, 1996, 2006) but these have not been used much to date. There is considerable scope for improving the studies directed towards ungauged basins by giving more attention to the quality of input data.

More than 30 years of worldwide effort directed to establishing relationships between model parameter values and basin characteristics has produced little of practical use. The substantial effect of errors in input data on the calibrated values of model parameters is one of the major problems. The transfer of the problem of estimating values for model parameters to that of estimating average annual runoff is a major change of approach that has potential for simplifying the modelling of runoff from ungauged basins.

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