Assessing the Natural Variability of Runoff : Clarence Basin Catchments, N.S.W., Australia

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ABSTRACT A lumped-parameter rainfall-runoff model is used to predict the long term natural variability of runoff from approximately 100 years of daily rainfall and temperature data. Two catchments from the Clarence Basin in Australia illustrate the simplicity and accuracy of the approach which can work quite well even if only two to three years of daily streamflow have been recorded for model calibration.

1. INTRODUCTION

To assess the natural variability of runoff, for purposes including water supply evaluation, requires long term records, or scenarios of climate variables, a rainfall-runoff model for the catchment of interest and, preferably, stream discharge records to aid the model development. The types of rainfall runoff models available for predicting supply at the catchment outlet are physically based, empirical and conceptual. Arguably, conceptual models offer the best combination of ease of application and predictive accuracy. In this paper we apply a simple conceptual model to two catchments in the Clarence Basin, NSW, Australia, to develop an appreciation of the natural variability of runoff under current land cover conditions, and under dry to medium rainfall inputs.

2. CATCHMENTS IN THE CLARENCE BASIN

2.1 The Nymboida and Orara Catchments

The Nymboida and Orara catchments are in the Clarence Basin in northern New South Wales, Australia. Both catchments are large, with the area of the two catchments being 1660 km^2 and 440 km^2 respectively.

The catchment for the most part traverses undulating or hilly country, but also contains some high peaks in the central and southern portions. It is bounded in the west by the Great Dividing Range, in south by an eastward spur of the same range, in the east by the hilly to steep ranges from Coffs Harbour to Woodenborg and in the north by the McPherson Range.

Within these boundaries a variety of landforms exist. The northern tributaries of the upper Clarence flow southwards and have generally widened their valleys in the soft, sedimentary rocks, resulting in the development of considerable areas of good, arable land. Some of these streams have formed alluvial flood plains. Between the valleys are steep, basalt capped ridges supporting a dense vegetative cover. The streams flowing east from the New England Tablelands enter some very rugged country after they leave the plateau margin. On the descent to the lowlands they have become entrenched in deep valleys and gorges and the surrounding country is deeply dissected by their tributaries. Much of this broken country is suitable only for low density grazing.

Land slopes over the Clarence Valley are classified proportionately as follows: one sixth of the valley has a generally flat surface; one sixth is undulating to hilly; one third is hilly to steep; one third is rugged or mountainous terrain. Thus rugged and steep slopes are predominant in the Clarence River Valley.

The original land cover of the valley has been little disturbed over much of the central, rugged area, but medium or heavy clearing has taken place in other sections. Rainforests are found on the coastal plateau and range tops which are of the subtropical jungle type. Arable land is limited being confined by virtue of topography to about one third of the catchment.

Figure 1 shows the flow duration curves for the catchments over the period 1979-1991, showing that Orara is the drier of the two catchments.

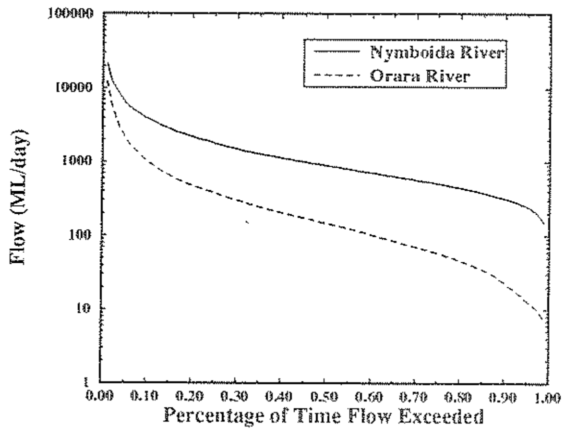

Figure 1: Flow Duration Curves for the period 1979-1991

2.2 Data Availability and Reliability

Daily rainfall data for the period 1899 to present is available, with daily streamflow data starting in 1967 for Nymboida and 1972 for Orara. Figure 2 show double mass plots for successive three-year periods for both catchments. They illustrate the degree of non-linearity in the observed rainfall-runoff relationship, providing an indication of dry and wet periods, and of the varying proportion of flow to rain.

3. THE IHACRES MODEL

The conceptual model used here, IHACRES (Jakeman et al., 1990; Jakeman and Hornberger, 1993), extends unit hydrograph theory by assuming a linear relationship not only between effective rainfall and quick flow, but between effective rainfall and other identifiable hydrograph response components.

The model consists of a nonlinear rainfall loss module which converts observed rainfall, r_k, at timestep k, into effective or excess rainfall, u_k, and a linear module which converts the excess rainfall into observed streamflow, q_k. Usually the two modules use seven or eight parameters, also called dynamic response characteristics (Jakeman and Hornberger, 1993), to describe the way in which observed rainfall becomes observed streamflow.

The nonlinear rainfall loss module used here transforms the measured precipitation, r_k, into effective rainfall, u_k,

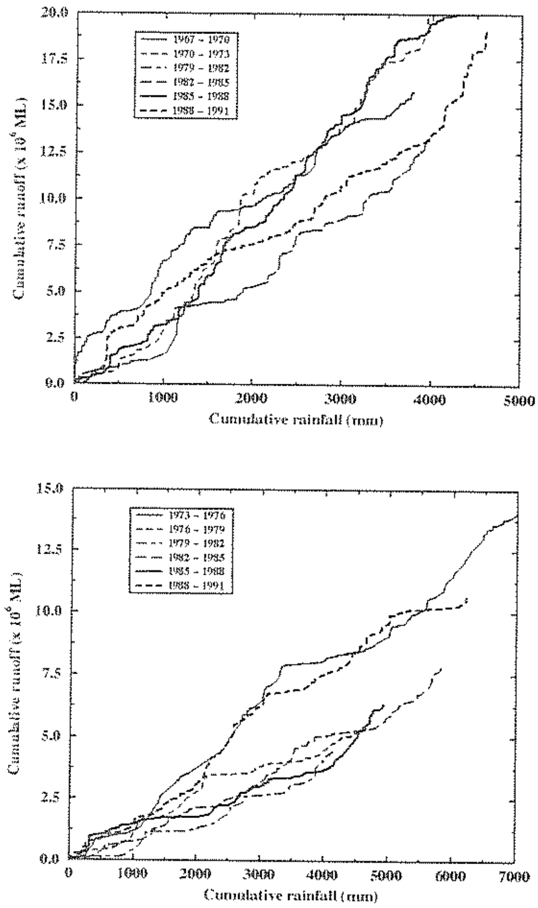

Figure 2: The double-mass plots for several subperiods for the Nymboida catchment (above) and the Orara catchment (below)

using

$$u_k = \begin{cases} s_k^p r_k, & \text{if } r_k > l; \\ 0, & \text{if } r_k \leq l. \end{cases} \quad (1)$$

where s_k is the catchment wetness index, a function of T_k, the evaporation at time k and three dynamic response characteristics - τ_w, a time constant for the decline in the catchment wetness index, f, which regulates the degree of evaporation dependence of the loss time constant, and c, which is selected to conserve the mass-balance of the catchment. The exponential loss parameter p, and a non-zero threshold value for rain to give streamflow, l, may sometimes be required to account for extra loss of rainfall in the catchment (Ye et al., submitted, 1995).

The linear module uses a transfer function to allow the rainfall to pass through any combination of stores, in parallel and series, in becoming streamflow. The most common configuration uses two stores in parallel, one attributed to quick flow, $x_k^{(q)}$, and one to slow flow, $x_k^{(s)}$.

These combine to yield the streamflow, $\hat{q}_k$,

$$\hat{q}_k = x_k^{(q)} + x_k^{(s)} \qquad (2)$$

The parameters can be rewritten to give an easier physical interpretation in terms of time constants, τ_q and τ_s, and relative volumetric throughputs, v_q and v_s. In this case the linear module has three dynamic response characteristics, τ_q, τ_s and v_q ($v_s = 1 - v_q$), making a total of seven or eight (if l is non-zero) parameters for the model.

Various statistics are used to measure the performance of the model including the absolute deviation (A), the bias (B) and the observed streamflow variance explained (R^2). The best model is chosen as the one with the superior values of the preferred statistics. In this study an objective function is defined,

$$O = \sum_{i=1}^{N} (\sqrt{q_i} - \sqrt{\hat{q}_i})^2 \qquad (3)$$

where q_i is the observed streamflow and $\hat{q}_i$ is the modelled, which provides a model which yields a compromise between fitting high and low flows.

To find or calibrate the appropriate values of the parameters for a particular data set, the parameter space of the parameters, τ_w, f, p and l, from the nonlinear module is sampled. The effective rainfall series is then calculated and a simple refined instrumental variable technique (SRIV) used to estimate the linear module parameters automatically (Jakeman et al., 1990). The preferred model here is the the one which, for sample τ_w, f, p and l values, yields the minimum value in O.

The model output statistics are calculated in the SRIV step. Usually a subperiod of the entire data set is used to calibrate the model, and then those parameters can be used to simulate over other subperiods, with output statistics again being calculated.

4. MODEL EVALUATION

To assess the long term natural variabity of daily runoff in these catchments, a suitable model calibration period was selected. The model was then "validated" on another subperiod where discharge data are available. Once a suitable model was found, a simulation over the entire rainfall record, from 1899, was made, and the natural variability of the runoff assessed.

4.1 Calibrating the Model

The model was initially calibrated on three year periods where both rainfall and runoff were available. The model for each subperiod was run on other subperiods to check if any model or subperiod gave results which were better or worse than any other. Tables 1a and 1b give these "validation" matrices. A dash entry denotes a non-converged model. If a particular period contained substantial rainfall or runoff data errors, or other problems, this would be anticipated to manifest as an associated model for that period yielding inferior R^2 values. The rows in Tables 2 and 1 which appear to have generally inferior R^2 values, compared to the other rows, are those for the 1985-88 and 1988-91 models. These periods have initially been omitted from the calibration and validation exercises here. It may be that the data in these two wet periods (see Figure 2) are reliable, although this remains to be checked. As the emphasis of the modelling exercise was to obtain reliable estimates of low flow particularly, it was considered acceptable to proceed with models which worked well on dry

Table 1: Nymboida - Validation Matrix

Model	Period				
	70-73	79-82	82-85	85-88	88-91
70-73	0.76	0.07	0.61	-	0.77
79-82	0.57	0.76	0.57	-	0.65
82-85	0.69	0.67	0.73	-	0.75
85-88	-	-	-	-	-
88-91	0.68	0.57	0.58	-	0.79

Table 2: Orara - Validation Matrix

Model	Period					
	73-76	76-79	79-82	82-85	85-88	88-91
73-76	0.93	0.74	0.87	0.73	-	0.76
76-79	0.87	0.92	0.92	0.83	-	0.73
79-82	0.89	0.86	0.93	0.84	-	0.76
82-85	0.85	0.85	0.90	0.85	-	0.72
85-88	0.82	0.51	0.84	0.81	0.81	0.75
88-91	0.88	0.50	0.61	0.65	0.07	0.78

Table 3: Model Parameters

	Nymboida	Orara
non-linear module parameters		
τ_w	5	12
f	15	24
c	0.0018	0.0035
l	0.0	0.15
p	0.0	0.8
linear module parameters		
τ_q	1.50	1.10
τ_s	43.57	36.88
v_s	0.512	0.741

Table 4: Nymboida River - Model Statistics

	Calibration	Validation
R^2	0.88	0.63
Bias of Residuals, B	2.3	6.6
Absolute Mean Error, A	5.6	9.3
Objective Function, O	894.6	3490.
Ratio of Total Mod. / Obs.	0.87	0.69

Table 5: Orara River - Model Statistics

	Calibration	Validation
R^2	0.93	0.86
Bias of Residuals, B	0.37	1.4
Absolute Mean Error, A	2.12	2.87
Objective Function, O	442.3	1048.
Ratio of Total Mod. / Obs.	0.93	0.81

to medium periods. The dry sub-period of approximately January 1977 - December 1979 was chosen to calibrate the model. Figures 3 and 4 show the calibration fit for the two catchments.

4.2 Validating the Model

These models can then be validated on a period where both rainfall and runoff are available, in this case January 1980 - December 1985. The model parameters used for the validation are included in Table 3. The validation of

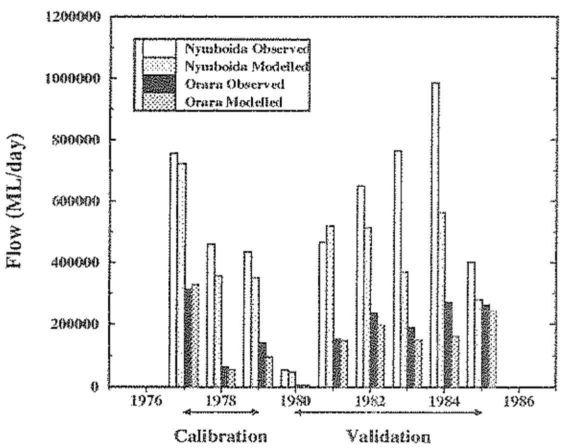

Figure 5: Annual Discharges for both catchments

these models can be seen in Figures 3 and 4 - after the calibration period. Both the calibration and validation model statistics have been included in Tables 4 and 5. Although the models do not perform quite as well on the validation as the calibration period, they still model the validation period quite well.

Figure 5 shows both the modelled and observed annual discharge from the two catchments. The Orara annual flows are modelled well in almost all years, while the Nymboida are inferior in the wet years of 1983-85.

5. LONG TERM RUNOFF VARIABILITY

The model can now be used to run a simulation over the entire rainfall record to model the streamflow discharge over that time. Figures 6 and 7 show the flow duration curve for this simulation and the flow duration curve over the observed streamflow record. This shows the natural

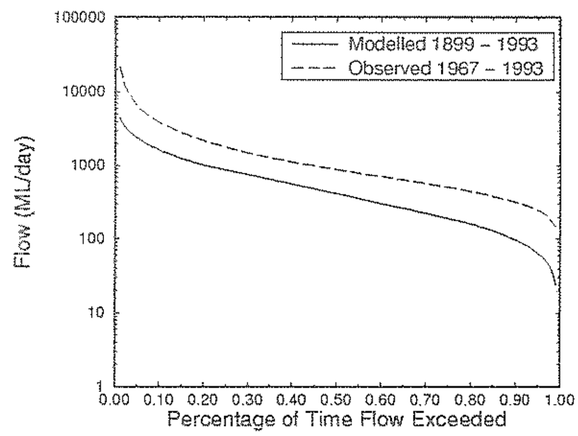

Figure 6: Nymboida River Flow Duration Curve - Simulation Period

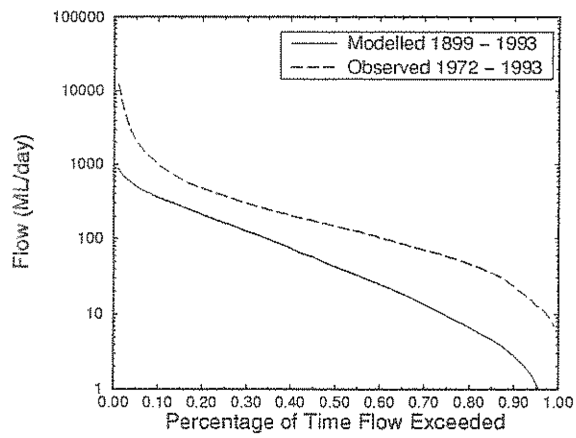

Figure 7: Orara River Flow Duration Curve - Simulation Period

variability of the catchment over time, with the observed

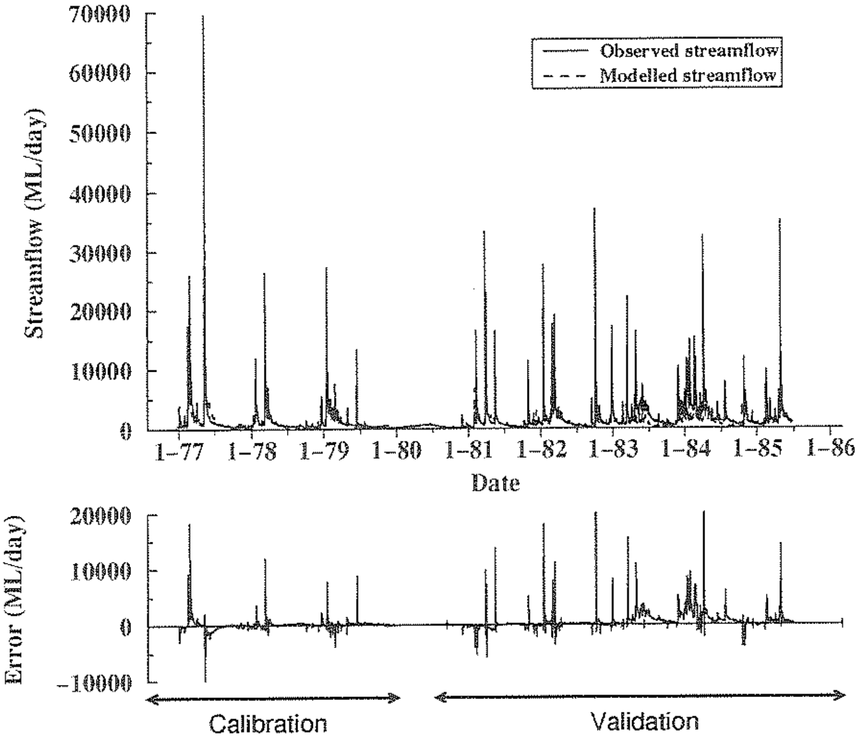

Figure 3: Calibration (1977-1979) and Validation (1980-1985) model fit for the Nymboida catchment

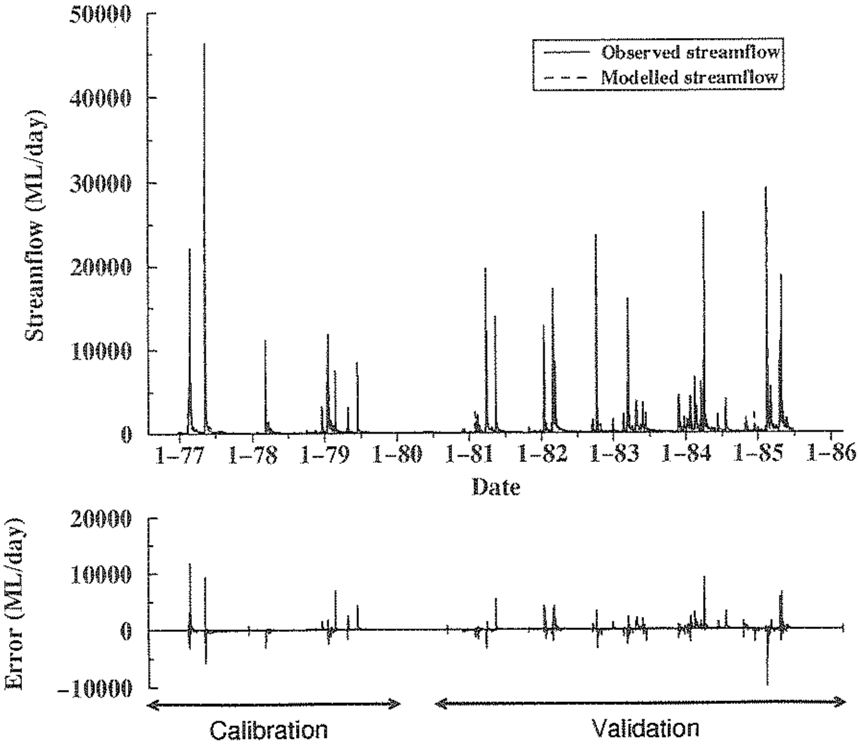

Figure 4: Calibration (1977-1979) and Validation (1980-1985) model fit for the Orara catchment

short term streamflow record from 1972-1993 much different to the longer term (simulated) record from 1899. Figures 8 and 9 show the annual discharge over the simulation period of the two catchments.

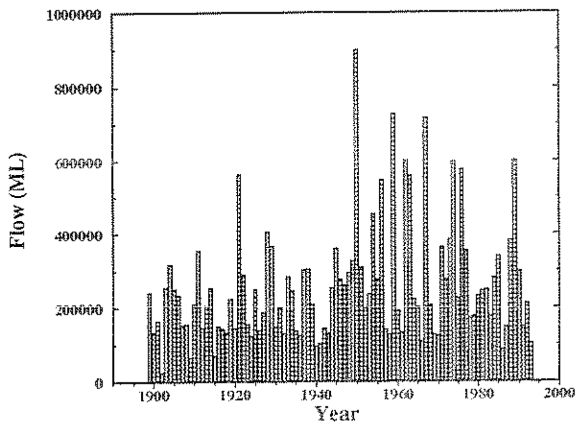

Figure 8: Nymboida River Annual Discharge - Simulated

6. CONCLUSIONS

A rainfall-runoff model has been used to predict the variability of discharge in two catchments from 1899. The model requires only a few years of discharge records to be calibrated. It predicts daily discharge well in the dry to medium periods which are the most important for assessing worst cases of supply.

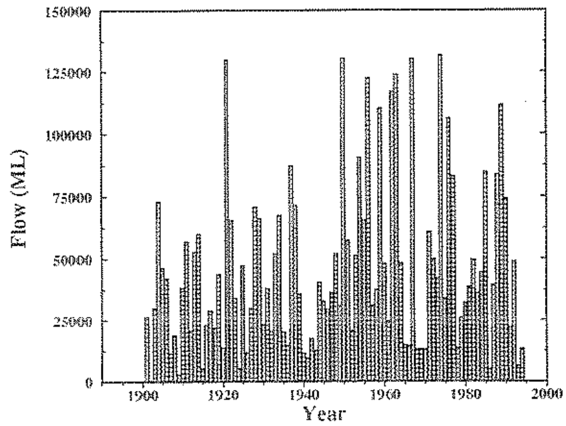

Figure 9: Orara River Annual Discharge - Simulated

7. REFERENCES

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