Comparison of Methods for Potential Streamflow Response Analysis in the Macquarie River Basin

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Abstract: Changes in potential streamflow response due to changes in land use and farm dam development were analysed for three catchments in the Macquarie Basin in NSW, Australia. Land use impacts on streamflow response were isolated from the impacts of climatic variation using the IHACRES rainfall-runoff model to filter climatic influences on streamflow. The model was calibrated on two-year periods for each catchment. Model parameters are intended to reflect the land use and landscape attributes of the calibration period only and to be independent of the climatic nature of the period. Calibrated models were then simulated over the entire period of record for each catchment. Differences between observed and simulated discharge reflect the effect of the differences in non-climatic conditions. Two methods of analysing the trends in model residuals were employed and compared: Estimated Generalised Least Squares (EGLS) and Generalised Additive Model (GAM) method. The methods provided similar qualitative results for trends in potential streamflow response in each catchment for models with a good fit to the calibration period in terms of a number of statistics: R^2, bias and %ARPE. When the fit of models was very good in terms of these three measures, these methods found trends with similar orders of magnitude. Otherwise the trend estimates were fairly variable.

1. INTRODUCTION

Schreider *et al.* (1999) illustrate the use of two methods for identifying trends in the potential streamflow response due to increases in farm dam development, using analysis of IHACRES rainfall-runoff model residuals, in eleven catchments in the Murray-Darling Basin. This paper considers these methods in further detail, with application to three catchments in the Macquarie River Basin, where changes in farm dam development and pasture management have led to conflicting changes in the potential streamflow response of these catchments.

1.1 Potential streamflow response

Schreider *et al.* (1999) define the potential streamflow response (PSR) as a catchment property reflecting the streamflow response to a given temperature and precipitation time series under different land (use and vegetation) conditions. That is, for each land condition there is a streamflow response.

1.2 Methodology

Full details of the methodology used to calculate temporal changes in the potential streamflow response (ΔPSR) between two land conditions are given in Schreider *et al.* (1999). A summary of this methodology is as follows:

1. Calibrate the conceptual rainfall-runoff model IHACRES to a series of two year periods. The IHACRES model was described in Jakeman *et al.* (1990), Jakeman and Hornberger (1993) and Evans and Jakeman (1998). The quality of calibration was controlled by the Nash-Sutcliffe efficiency (R^2) and the model bias.
2. Generate a time series of simulated streamflow data using the calibrated IHACRES model and an input of climatic time series. Simulation runs with a calibrated model reflect the land use and landscape characteristics of the catchment over the calibration period (and whatever climatic time series are used as an input, usually some historical series for the catchments).
3. Calculate the model residuals, that is, the difference between observed and modelled values of flow. The difference between observed and modelled values primarily reflect the difference in non-climatic conditions between the period of simulation and calibration.
4. Perform trend analysis on time series of model residuals to determine the trend in ΔPSR over time. Two methods were employed for this trend analysis: Estimated Generalised Least Squares (EGLS); and the Generalised Additive Model (GAM) method.
5. Relate changes in potential streamflow response observed over the simulation period with changes in land use.

periods of missing data, serial correlation, seasonality, non-linear exogenous influences (such as climate), and heteroscedasticity. The approach is ideally suited to the analysis of "real world" hydrologic time series data, and its ability to satisfy the required statistical assumptions means that any inferences drawn regarding statistical significance are robust and accurate. A more detailed description of the GAM approach and examples of its application to a range of practical problems can be found in Nathan *et al.* (1999).

The GAM models applied were of the following general form:

$$\varepsilon = a + f(t) + g(s) + h(r) + j(\rho(\varepsilon)),$$

where ε is the model residual, a is a constant, t is time, s is season, r is rainfall, $\rho(\varepsilon)$ is the autocorrelation of the error and f(.), g(.), h(.) and j(.) denote functional relationships between the model residual and the variable concerned. The basic aim of including functional relationships as explanatory variables is to remove the influence of the selected variable. It is seen that in essence the functional relationships are treated as independent variates in order to remove, with as little bias as possible, the influence of the selected variable. It is important to note that all functional relationships are fitted jointly.

Trend analyses were completed on a monthly, quarterly and half-yearly time step, using both linear and spline function for the time trend. Seasonality was only fitted to monthly data. Rainfall was fitted with a spline function to help remove any residual model bias from the IHACRES model calibration. Results were reported for the analysis performed on a quarterly time step, unless modelling assumptions were violated. Trend values reported are for a linear time trend. In these instances, the results at a monthly or half-yearly time step were reported. This linear time trend was estimated using ordinary least squares regression on the non-linear spline time trend estimates. Significance estimates are given using a *t*-test based on the OLS estimates of trend and standard deviation. One problem with this approach is that the non-linear time trend values are likely to be autocorrelated, leading to the same problems with using OLS as were outlined in the previous section on EGLS trend analysis. In other words, in the presence of autocorrelation the significance estimates provided using the OLS method can have limited meaning.

Previous studies have indicated that outliers can significantly bias results. In order to remove this bias, an objective means of assessing the data for outliers, Cook's statistic, was adopted. Cook's statistic evaluates outliers by considering the influence of each data point on the coefficients of the fit of the data. A value of Cook's statistic of 2 was used as the basis for identification of outliers.

3.4 Determination of Statistical Significance

The results of the trend analysis are reported according to the statistical significance of the trend being investigated, under the following categories:

- statistically significant at the 5% level of significance (strong trend corresponding to a *t*-value of greater than 1.96 and a p-value of less than 0.05 for a large sample size);
- statistically significant at the 10% level of significance (weak trend corresponding to a *t*-value of greater than 1.65 and a *p*-value of less than 0.10 for a large sample size); and
- not statistically significant (no trend corresponding to a *t*-value of less than 1.65 and a *p*-value of more than 0.10 for a large sample size).

4.TREND ANALYSIS RESULTS

Trend analysis for the Ben Chifley and Green Valley Creek catchments was undertaken for two different periods, before and after 1984. These periods were chosen because evidence indicated that there had been a large change in land management, which affected PSR at that time. Before 1984 the main change in land use appears to be an increase in the development of farm dams, which would be expected to decrease ΔPSR. After 1984 pasture degradation due to declining use of fertilisers, and impacted on further by the drought of 1982/83 appears to be the most significant land use change in the catchment (NSW Dept. of Agriculture, personal communication), offsetting decreases in ΔPSR caused by farm dam development. Pasture degradation would be expected to lead to an increase in ΔPSR. The Pyramul Creek discharge record ended in 1985. Analysis of these data was undertaken for the entire period of observation. The inclusion of one year of data after 1984 in this analysis may partially account for the less significant trend results found in this catchment.

4.1 Campbell River at Ben Chifley Storage

The results for EGLS trend analysis in the Ben Chifley catchment are shown in Table 4. GAM results for this catchment are given in Table 5.

Table 4
EGLS trend results for Ben Chifley

No.	Period	Trend ML/yr	Significance
1	Before	-1047	5%
1	After	1892	5%
2	Before	-599	5%
2	After	1652	5%
3	Before	-886	5%
3	After	927	5%
4	Before	-278	Nil
4	After	530	Nil

Table 5
GAM trend results for Ben Chifley

No.	Period	Trend ML/yr	Significance
1	Before	-2100	10%
1	After	2300	Nil
2	Before	-350	Nil
2	After	120	Nil
3	Before	2700	5%
3	After	6400	Nil
4	Before	-750	Nil
4	After	-1500	Nil

The results (see the trend column) for Models 1 and 2 are qualitatively (in terms of trend direction) the same for both methods, with a decrease in ΔPSR before 1984 and an increase in ΔPSR after 1984. Results for Models 3 and 4 differ between the two methods, with EGLS giving the same qualitative results as for Models 1 and 2, and GAM finding both before and after 1984 increases in ΔPSR for Model 3 and decreases for Model 4. Trend estimates for Model 4 were insignificant using both methods. Trends found for the other models with the EGLS method were all significant, whilst only the before trends for Models 1 and 3 were significant using the GAM method.

4.2 Pyramul Creek Upstream of Hill End Rd

The majority of trends in the Pyramul Creek catchment were not found to be statistically significant (see Tables 6 and 7). A negative trend in the model residuals and therefore a reduction of PSR was evident at the 5% level of significance for one of the calibrated models using the GAM method.

Table 6
EGLS trend results in Pyramul Creek

No.	Trend ML/yr	Significance
1	-85	Nil
2	-132	Nil

Table 7
GAM trend results in Pyramul Creek

No.	Trend ML/yr	Significance
1	230	Nil
2	-1100	5%

Qualitative trends found using GAM and EGLS differed for Model 1, with EGLS finding a decrease and GAM finding an increase in ΔPSR, whilst trends for Model 2 were qualitatively the same, with decreases for both EGLS and GAM methods. However, the magnitude of the GAM trend was almost 10 times greater than that found using EGLS.

4.3 Green Valley Creek at Hill End

The residual trend analysis for Green Valley Creek (see Tables 8 and 9) demonstrates the presence of a significant negative trend in ΔPSR before 1984 and a non-significant trend in ΔPSR after 1984 in the catchment using the EGLS method. No significant trends were found using the GAM method.

Table 8
EGLS trend results in Green Valley Creek

No.	Period	Trend ML/yr	Significance
1	Before	-120	5%
1	After	32	Nil

Table 9
GAM trend results in Green Valley Creek

No.	Period	Trend ML/yr	Significance
1	Before	290	Nil
1	After	190	Nil

Trend results for this model were qualitatively different using the GAM and EGLS methods, with the GAM method obtaining a decrease in trend from the before 1984 period to the after, whilst there was an increase in trend found using the EGLS method. Interestingly the trend for the entire period (both before and after 1984) was the same as the After trend (190 ML/yr).

5. DISCUSSION

In general GAM and EGLS found similar qualitative results when analysing the trends for models calibrated during 1980-82. This period was found to be less variable in terms of rainfall than other calibration periods for each catchment. It is suggested that during such periods the IHACRES model calibrated parameters contain a much clearer signal of non-climatic catchment characteristics of the calibration period. These parameters would in turn allow for a much clearer illustration of changes in the PSR due to changes in land use. This is generally supported by better model calibration statistics for models calibrated during these periods. The EGLS method found similar qualitative changes in ΔPSR for models calibrated on less stable periods, although with a smaller significance, whilst GAM did not generally indicate the same changes. It is suggested that this may be for two reasons:

- The EGLS method may not have removed all of the autocorrelation in the residual time series, due to the requirement that the nature of autocorrelation must be estimated from the data. This may mean that trends would be more apparent and would have a larger significance than may otherwise be the case.
- The GAM method removes evidence of trends that are correlated with rainfall. However land use changes in the Macquarie catchments are indirectly correlated with rainfall, as the pasture degradation that took place after 1984 initially occurred partially in response to drought conditions, and this degradation continued into the late 1980's as rainfall increased after the drought. Thus GAM would be expected to remove much of the effect of changes in land use that are correlated with rainfall, and as such would not be able to identify the trends due to pasture degradation as strongly as the EGLS method.

GAM and EGLS did not find similar qualitative results in the Green Valley Creek catchment, even though this model was also calibrated during 1981/82. Interestingly, the GAM trend for the entire period of observation was of the same magnitude as the trend for the period after 1984. This seemingly counterintuitive result is a product of the method of estimating linear trends from a nonlinear spline time function. The production of such counterintuitive results may be seen as a weakness of the GAM method or more likely a problem with attempting to find linear trend estimates of variables (ΔPSR) that are based on more complex nonlinear functions of time. EGLS also suffers from this limitation, assuming a linear relationship between ΔPSR and time.

6. CONCLUSIONS

The GAM and EGLS methods are capable of identifying qualitative changes in the potential streamflow response due to changes in land use from IHACRES model residuals. However, these methods appear to be most reliable when the IHACRES model is fitted to periods when land use and rainfall are fairly stable. The ability of these methods to estimate trends depends largely on the quality of the model fit to the calibration period. The estimated trends, reported in ML/yr, obtained using these methods are very variable, indicating a great deal of uncertainty. The EGLS method appears to give the most consistent estimates of the order of magnitude of trends for each catchment, although it tends to indicate greater significance of trend estimates than the GAM method. The EGLS method also appears to give the most consistent estimates of the qualitative trends in the data.

Also it may be best, considering the nonlinear nature of trends in the ΔPSR, to utilise methods for calculating these nonlinear trends in ΔPSR and relating these to more detailed information on land use changes in future work.

7. REFERENCES

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