Jul 1st, 12:00 AM

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Abstract: Reliable rainfall and streamflow forecasts several months ahead can benefit the management of water resource systems, particularly in Australia where the hydroclimate variability is high. Previous studies have shown that streamflow can be forecast by exploiting the lag relationship between streamflow and ENSO and the serial correlation in streamflow. This paper investigates the potential for seasonal forecasts to increase the profitability of irrigation production decisions, using an integrated hydrologic-economic model. Alternative water allocation policies and climate regimes are considered using a scenario-based approach and the potential value of climate forecasts estimated using the integrated model. The results can be used to identify opportunities for and likely value of seasonal forecasts to water managers and policy makers.

Keywords: seasonal forecasting, ENSO, decision model, water resources, irrigation system.

1   INTRODUCTION

Climatic variability is a significant factor influencing agricultural production decisions in Australia. Historically, Australian farmers and governments have invested heavily in reducing the influence of this variability on agricultural production. This investment has included construction of large dams on major river systems throughout the country, primarily for irrigation purposes, and allocation and development of groundwater resources (see for example Davidson, 1969). This development policy placed large pressures on ecosystems and has significantly modified river systems. In 1994 the Council of Australian Governments began a period of water reform, essentially entering a new management phase for water resources. These reforms have included assessment of the sustainable yield from aquifer systems, often found to be below current allocation and even extraction levels, as well as allocation of a proportion of flows to the environment (COAG, 1994). In many catchments these water reforms have not only reduced irrigators' access to some types of water, but have also implicitly increased the effect of climate variability on their decision-making by increasing their reliance on pumping of variable river flows.

These management and allocation pressures are compounded by Australian streamflow (and to a lesser extent climate) being much more variable than elsewhere in the world. The inter-annual variability of river flows in temperate Australia (and Southern Africa) is about twice that of river flows elsewhere in the world (see Peel et al., 2001). This means that temperate Australia is more vulnerable to river flow related droughts and floods than elsewhere in the world. In such a challenging environment, the use of forecasting tools that support improved decision-making resulting in efficiencies in water use and reduced risk taking is highly desirable. The development and use of such tools is the focus of considerable research and extension activity in government and industry.

This paper presents results from an integrated model demonstrating the potential value of seasonal forecasts to irrigated farmers reliant on uncertain river flows. These results can be considered to be indicative of the potential benefits of seasonal forecasting in eastern Australia. Although the complexity of different production systems and many of the influences on real life decisions are not considered here, this analysis does provide an interesting insight into the potential for forecasting methods to help farmers adjust away from the impacts of climate variability.

2 CASE STUDY

This study investigates the potential benefits of using seasonal forecasts to make farm level decisions and the returns in an irrigated cropping system. The choice of case study was based on the premise that the potential benefit of seasonal forecasts is probably greatest in a farming system subject to significant uncertainty. For this reason the farming system represented in the decision-making models is that of an irrigated cotton producer operating on an unregulated river system, relying on pumping variable river flows for irrigation purposes during the season. This type of farm is typical of many occurring in unregulated areas of the Namoi Basin, in the Northern Murray-Darling Basin, particularly the Cox's Creek area (see Figure 1).

The modelling here should be considered to represent a theoretical or model farm rather than a farm from a particular system, as the value of forecasts was tested on this farm using forecasts and flows from many different river systems in eastern NSW. This was done in order to test the sensitivity of the results to the hydrology and climate of the river system.

Four decision alternatives are compared: decisions based on forecasts (based on three forecast models – see later); decisions based on perfect knowledge (indicating maximum possible gain to the farmer from using knowledge about climate variability; decisions based on climatology (same "average" condition for every year); and decisions based on a naïve expectation (condition for a given year is the same as the last year).
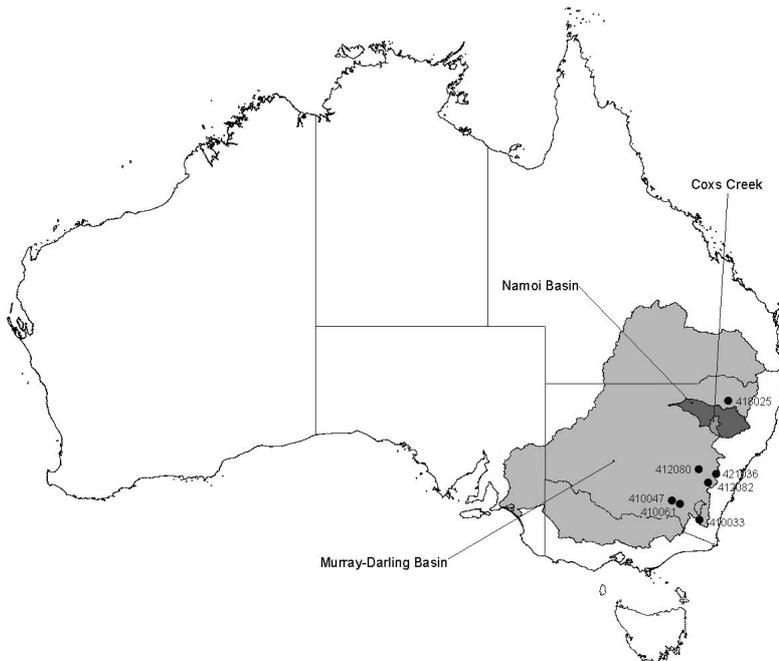

Figure 1. Map of case study region

Given that the model farm is assumed to be pumping from the river for irrigation supply, their production and water availability is limited by the number of days on which they can pump from the river. In order to mimic the types of flow rules on these unregulated systems and to test the sensitivity of results to these rules, two pumping thresholds were considered – the 20th percentile and 50th percentile of flow (that is, flow that is exceeded 20% or 50% of the time).

The information (or forecast) required for each year is therefore the number of days that are above these pumping thresholds (ie. the number of days on which pumping is allowed). The model farmer factors this forecast and the total volume of water allowed to be pumped on each such day (the daily extraction limit – defined by policy as a fixed volume of water) into their planting decision.

Climate forecasts were constructed over an 86 year period for seven catchments and the two pumping threshold regimes using three forecast methods. Seven catchments were chosen to represent a range of forecast skills and pumping conditions so as to test the sensitivity of the

results to these factors. Farmer decisions were then simulated using these three forecast methods as the basis of the decision, as well as using three other decision alternatives for comparison.

3   SEASONAL FORECAST MODELS

The relationship between streamflow and ENSO and the serial correlation in streamflow can be exploited to forecast streamflow several months ahead (see Chiew and McMahon, 2002, 2003). To make risk-based management decisions, forecasts expressed as exceedance probabilities are required (e.g. probability of getting at least ten pumping days). In this study, exceedance probability forecasts are derived at the tributary scale for the seven unimpaired catchments in the Murray-Darling Basin. The catchments were selected

because of their relative proximity to the Namoi Basin (all within the Murray-Darling Basin in New South Wales – see Figure 1) and to reflect a range of rainfall-runoff conditions and forecast skills. Proximity to the Namoi Basin is to support coupling with the decision-making models that have been developed by Letcher *et al.* (in press) within the water management regulatory framework in the Namoi Basin, though they simulate representative farmer behaviour.

Daily streamflow data from 1912-1997 are used. The data include extended streamflow data estimated using a conceptual daily rainfall-runoff model (see Chiew et al., 2002). The catchment locations and long-term average rainfall-runoff characteristics are summarised in Table 1.

Table 1. Catchment characteristics

	LAT	LONG	AREA (km2)	Rainfall (mm)	Runoff (mm)	Runoff Coeff (%)	% days flow (> 0.1 mm)	20th percentile flows (mm)	50th percentile flows (mm)
410033 Murrumbidgee R @ Mittagang Crossing	36.17	149.09	1891	882	134	10-15	71	0.55	0.28
410047 Tarcutta Ck @ Old Borambola	35.15	147.66	1660	818	110	10-15	50	0.68	0.31
410061 Adelong Ck @ Batlow Road	35.33	148.07	155	1138	256	>20	89	0.97	0.44
412080 Flyers Creek @ Beneree	33.50	149.04	98	915	106	10-15	50	0.65	0.29
412082 Phils Creek @ Fullerton	34.23	149.55	106	821	124	10-15	62	0.58	0.27
418025 Halls Creek @ Bingara	29.91	150.58	156	755	44	6	24	0.22	0.14
421036 Duckmaloi River @ Below Dam Site	33.77	149.94	112	967	244	>20	80	0.95	0.40

Forecasts are made for the number of days in October-February that the daily flow exceeds the two pumping thresholds under consideration. The 20th and 50th percentiles daily flow thresholds are calculated based on flow days only, defined as days when the daily flow exceeds 0.1 mm. The forecast is derived by relating the number of days in October-February that the daily flow exceeds a threshold to explanatory variables available at the end of September. The explanatory variables used are the SOI value averaged over August and September, and the total flow volume in August

and September. The forecast is derived using the nonparametric seasonal forecast model described in Piechota et al. (2001) and expressed as exceedance probabilities.

Three forecast models are used:
- forecast derived from flow volume in August to September (FLOW)
- forecast derived from SOI value in August to September (SOI), and
- forecast derived from flow volume and SOI value in August to September (FLOW+SOI).

Table 2. Forecast skill

CATCHMENT	CASE	FLOW		SOI		FLOW+SOI	
		E	LEPS	E	LEPS	E	LEPS
410033 Murrumbidgee R @ Mittagang Crossing	days >20%P	0.35	27.1	0.23	11.6	0.58	41.7
	days >50%P	0.36	23.1	0.19	12.2	0.60	39.7
410047 Tarcutta Ck @ Old Borambola	days >20%P	0.41	32.8	0.23	17.6	0.57	46.4
	days >50%P	0.39	26.2	0.18	11.2	0.50	36.0
410061 Adelong Ck @ Batlow Road	days >10%P	0.54	41.4	0.16	12.0	0.64	49.5
	days >20%P	0.63	42.0	0.17	11.1	0.71	50.4
412080 Flyers Creek @ Beneree	days >20%P	0.34	25.8	0.22	10.2	0.54	37.6
	days >50%P	0.42	28.8	0.22	10.9	0.56	40.0
412082 Phils Creek @ Fullerton	days >20%P	0.40	19.2	0.22	12.3	0.59	32.1
	days >50%P	0.54	30.0	0.22	12.2	0.64	39.7
418025 Halls Creek @ Bingara	days >20%P	0.13	12.4	0.16	11.7	0.29	26.3
	days >50%P	0.26	15.3	0.16	13.0	0.44	31.5
421036 Duckmaloi River @ Below Dam	days >20%P	0.16	12.3	0.24	13.5	0.45	28.1
	days >50%P	0.24	16.7	0.27	17.7	0.51	34.0

4   FORECAST MODELS RESULTS

All models exhibit significant skill in the forecast, summarised in Table 2. Two measures of forecast skill are used – Nash-Sutcliffe E and LEPS score. The Nash-Sutcliffe E (Nash and Sutcliffe, 1970) provides a measure of the agreement between the "mean" forecast (close to the 50% exceedance probability forecast) and the actual number of days in October-February that the daily flow exceeds a threshold. A higher value of E indicates a better agreement between the forecast and actual values, with an E value of 1.0 indicating that all the "mean" forecasts for all years are exactly the same as the actual values.

The LEPS score (see Piechota et al., 2001) attempts to compare the distribution of forecast (forecast for various exceedance probabilities) with the actual number of days in October-February that the daily flow exceeds a threshold. A LEPS score of 10% generally indicates that the forecast skill is statistically significant. A forecast based solely on climatology (same forecast for every year based on the historical data) has a LEPS score of 0.

The LEPS score in all the forecast models are greater than 10% indicating significant skill in the forecast. The SOI model has similar skill in the seven catchments, with E values of about 0.2 and LEPS score of 10-15%. The FLOW model is considerably better than the SOI model in five catchments (410033, 410047, 410061, 412080, 412082 – E generally greater than 0.35 and LEPS generally greater than 25%), and similar at the other two catchments (418025, 421036). In all seven catchments, the FLOW+SOI model has greater skill than the FLOW or SOI model alone. In the five catchments where the FLOW model has greater skill than the SOI model, the E and LEPS for the FLOW+SOI model are generally greater than 0.5 and 40% respectively (compared to 0.35 and 25% in the FLOW model). In the other two catchments where the FLOW model and SOI model have similar skill, the E and LEPS for the FLOW+SOI model are generally greater than 0.3 and 25% (compared to less than 0.25 and 20% in the FLOW or SOI model alone).

5   DECISION-MAKING MODELS

All decisions were modelled using a simple farm model which assumed that farmers act to maximize gross margin each year, given constraints on land and water available to them in the year. This model is a modified version of a decision model for the Cox's Creek catchment developed in Letcher et al. (in press). Total farm gross margin was analysed for all catchments, pumping thresholds and forecast methods using four different possible decision methods:

1. Seasonal forecast decisions. The decisions are made assuming the 20th and 50th percentile exceedance probability forecasts

(using SOI, FLOW and SOI+FLOW) for the number of pumping days are correct.

2. Naïve decision. The decision is made assuming that the number of pumping days this year is equal to the number of pumping days observed last year.

3. Average climate decision. The decision is made assuming that the number of days for which pumping is possible in each year is the same and equal to the average number of days pumping is permitted over the entire 86 year period.

4. Perfect knowledge decision. The decision is made with full knowledge of the actual number of days on which pumping is possible in each year. This is essentially used to standardize the results as it is a measure of the greatest gross margin possible in each year given resource constraints.

The same simple farm model is used in all cases. This model allows the farm to choose between three cropping regimes - irrigated cotton with winter wheat rotation, dryland sorghum and winter wheat rotation, and dryland cotton and winter wheat rotation. Costs of production are incurred on planting the crop, so areas planted for which insufficient water is available over the year generate a loss. Where insufficient water is available to fully irrigate a crop it is assumed that the area irrigated is cut back and a dryland yield is achieved on the remaining area planted.

6   MODELLING RESULTS

For each catchment, models were run over the 86 year period for every combination of pumping threshold, forecast and decision-making method. The total gross margin achieved by "the farm" over the entire simulation period under each of the decision models and forecasting methods is charted for the 20th percentile (Figure 2) and the 50th percentile (Figure 3) pumping threshold respectively. The x-axis labels are the seven catchment identifiers and the y-axis is the total gross margin in Australian dollars.

These figures show a consistent set of results:

• use of any of the three forecast methods leads to a greater gross margin than either the average or the naïve decision methods;

• in general, the SOI+FLOW method gives the greatest gross margin of the three forecast methods, with SOI generally providing the lowest gross margin;

• the forecast methods provide a substantial return in gross margin relative to the total achievable gross margin (via the perfect decision model) in each case (on average 55% of the possible maximum).

To investigate the consistency of the forecast skill, the percentage of time during the simulation period during which different income levels were exceeded for each decision model and forecast method was derived. Results for a single catchment (410033) for the 20th percentile pumping threshold are presented in Figure 4.

Several observations can be made about the consistency of the forecasts:

• negative gross margins (losses) are experienced in a greater number of years for both the average and naïve decision methods (>7% of time) than for any of the seasonal forecast methods (<3.5%) when all catchments are considered;

• the naïve and average decision methods give a lower income at almost all exceedance probabilities and, for those areas where they are greater, the difference is very small; and

• the naïve decision method gives a greater gross margin for very high gross margin years (2.4% of the time).
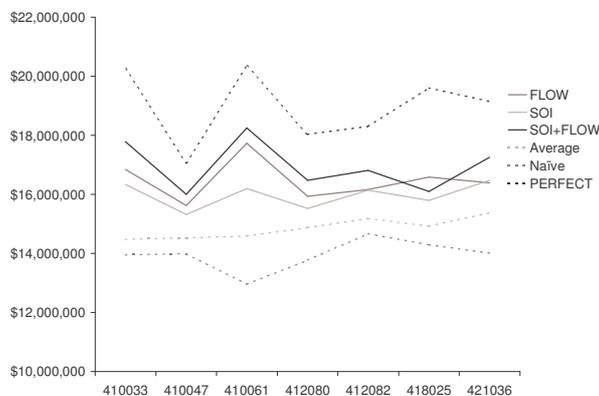

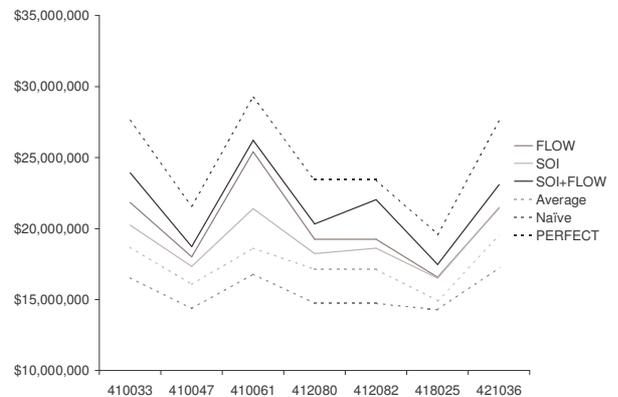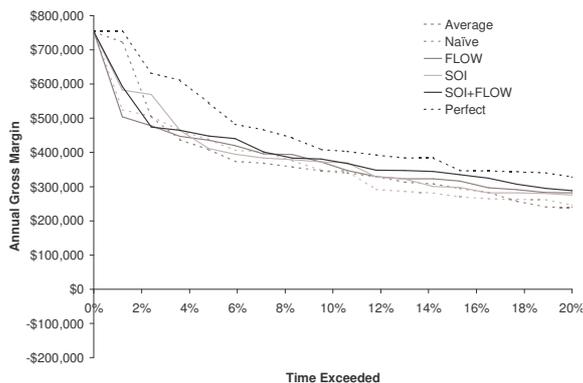**Figure 2. Farm gross margin for the 20th percentile**

Figure 3. Farm gross margin for the 50th percentile

Figure 4. Consistency of forecast skill (410033, 20th percentile)

7 CONCLUSIONS

The results in this paper clearly demonstrate the potential for gains to be made in the use of seasonal forecasting methods. The question remains as to why these methods are not currently being adopted. One issue may be with the presentation and perceived accuracy of these methods. Clearly more work needs to be done not only in enhancing the accuracy of these methods but in determining the type of forecasting products required by the farming community and appropriate strategies for improving their adoption.

8 ACKNOWLEDGEMENTS

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