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Evaluation of Environmental Flow Rules in the Murrumbidgee Valley[1]

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In recent years, there has been both more widespread evidence of the declining health of many of NSW's rivers as a result of increased irrigation extractions and increasing community concerns about environmental issues. This has led to a greater focus on the need to re-balance in-stream and consumptive uses of water. In NSW, the issue is being approached mainly through the introduction of environmental flow rules across regulated catchments with the nature of such flow rules determined by community based Water Management Committees within an overall framework set by Government.

A key issue in deciding on appropriate environmental flow rules is not only the ecological benefits that arise but also the trade-offs associated with re-allocation in terms of reduced production from irrigated agriculture. This paper looks at the nature of this trade-off in the Murrumbidgee catchment. A combination of linear programming and hydrology simulation modelling is used to assess the impacts on agriculture from the implementation of environmental flow rules as developed by the Water Management Committee for the Murrumbidgee Valley.

Keywords: environmental flow rules, Murrumbidgee

[1] The views expressed in this paper are those of the authors, rather than those of NSW Agriculture or the NSW Government.

1. Introduction

River regulation and water extractions have contributed to a significant decline in the health of inland rivers across NSW. The Murrumbidgee River in Southern NSW is no exception. Median river flows in the Murrumbidgee with current levels of irrigation development are considerably lower than under natural flow conditions, despite additional water supplied by the Snowy Mountains Scheme. This has lead to the catchment experiencing a wide range of problems including algal blooms, declines in native fish species and an increase in exotic species, poor water quality (including salinity, turbidity, nutrients and pesticides), rising water tables and declines in the health of wetlands.

In response to these types of problems, State Governments have been introducing a wide range of water reforms involving the re-balancing of consumptive and environmental uses[2]. In NSW, this has mainly been approached through the introduction of environmental flow policies. In regulated catchments like the Murrumbidgee, Water Management Committees have been given key responsibility for the on-going development of environmental flow rules to address river health needs, whilst keeping the impact on water users within 10 per cent of their average annual diversions.

Environmental flows attempt to provide environmental benefits in the form of improvements in water quality and the health of natural ecosystems and aquatic biodiversity. These benefits may be achieved through the protection of low flows, providing triggers for fish and bird breeding events, mimicking natural flow variability and restoring a portion of freshes and high flows. The economic benefits attached to these environmental improvements may be significant. However, the trade-offs involved in obtaining environmental benefits may also be large, particularly in States like NSW who historically have taken a less conservative approach to allocating resources to consumptive uses.

The extent of trade-offs associated with establishing environmental allocations is an important issue in the Murrumbidgee catchment, which has a large irrigation industry dependent upon secure irrigation supplies. The objective of this paper is to evaluate the nature of these trade-offs. The opportunity costs to the agricultural sector from environmental flows are estimated through the application of an economic model of the Murrumbidgee catchment, which draws upon data from a hydrology simulation model to represent environmental flow conditions.

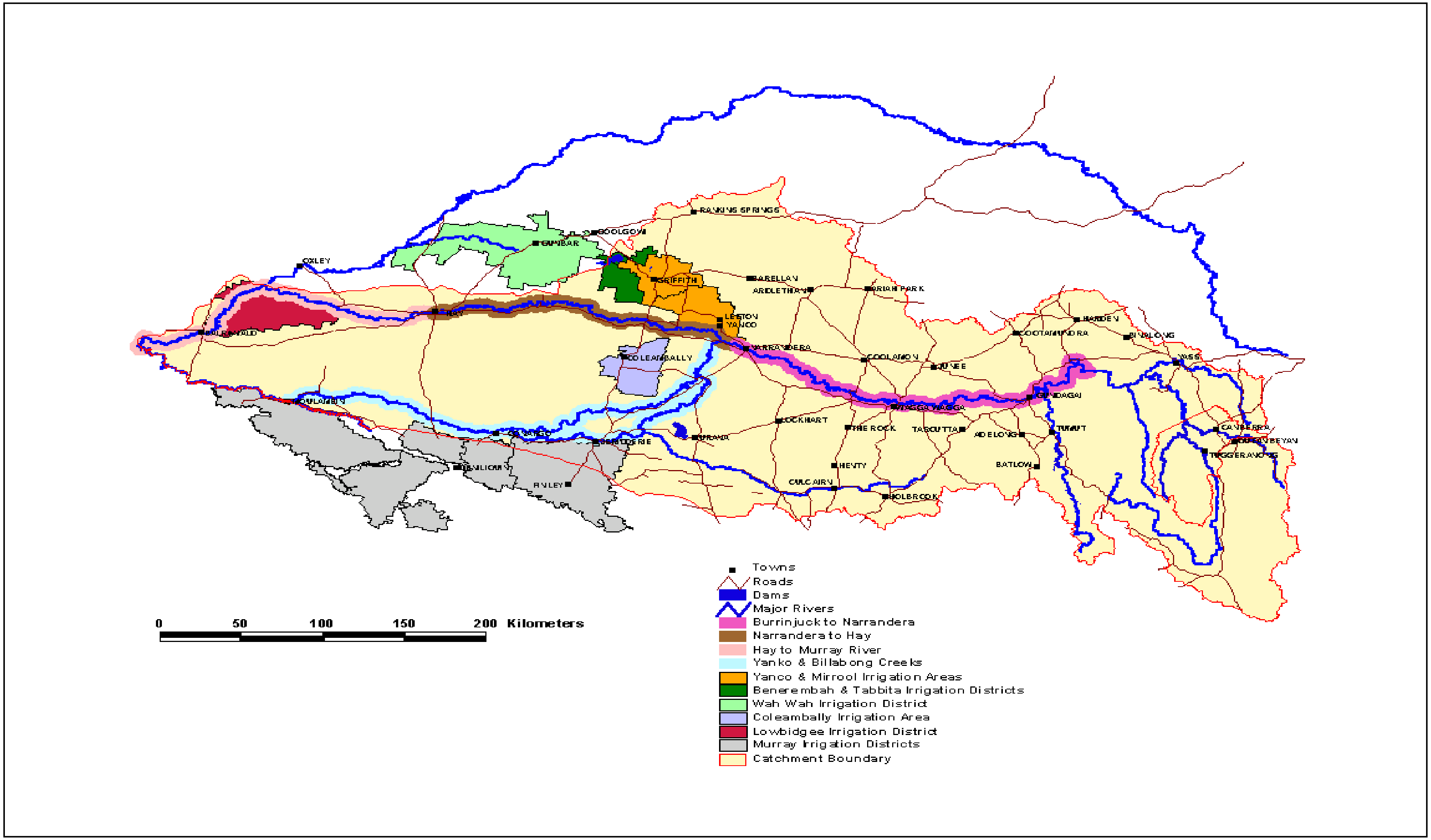
2. The Murrumbidgee Valley

2.1 Location

The Murrumbidgee River Valley is located in Southern NSW and covers an area of 84,000 square kilometres (Figure 1). The Murrumbidgee River stretches 1,600 kilometres from its source in the Snowy Mountains to the junction with the River Murray down stream from

[2] The recognition of the environment as a legitimate user of water is also a key element of the COAG water reform framework agreed to 1994, and subsequently linked to the broader suite of reforms introduced under National Competition Policy in 1995.

Figure 1: Murrumbidgee Catchment showing Production Regions



Balranald (Department of Water Resources, 1989). After flowing northwards to Canberra, the Murrumbidgee River then extends west through the main centres of Gundagai, Wagga Wagga, Narrandera, Darlington Point, Hay and Balranald, after which it joins the River Murray. The Murrumbidgee River is regulated by Burrinjuck and Blowering dams which have capacities of 1026 GL and 1632 GL, respectively.

2.2 Irrigated agriculture

Major irrigation areas and districts within the Murrumbidgee Valley include the Yanco and Mirrrool Irrigation Areas, collectively known as the Murrumbidgee Irrigation Area (MIA), Benerembah, Tabbita and Wah Wah Irrigation Districts and the Coleambally Irrigation Area (CIA) located on the southern side of the Murrumbidgee River. Irrigation also occurs along the length of Murrumbidgee River through private diverters. The principal production regions, including a number of river pumper zones are outlined in Figure 1. In addition to surface water irrigation, there is significant groundwater irrigation in the Lower Murrumbidgee covering the westernmost half of the catchment.

The major irrigated agricultural enterprises in the Murrumbidgee Valley include rice, wheat, oilseeds, citrus, winegrapes, stonefruit, vegetables, annual and perennial pastures supporting livestock enterprises, including prime lambs, wool and beef production. Rice is the most common crop irrigated in the region. ABARE estimates that 89 per cent of irrigated broadacre producers in the Murrumbidgee Valley grew rice in 1994-95. The ability of farmers to grow rice is heavily dependent on annual water allocations, which largely determine the profitability of farm businesses.

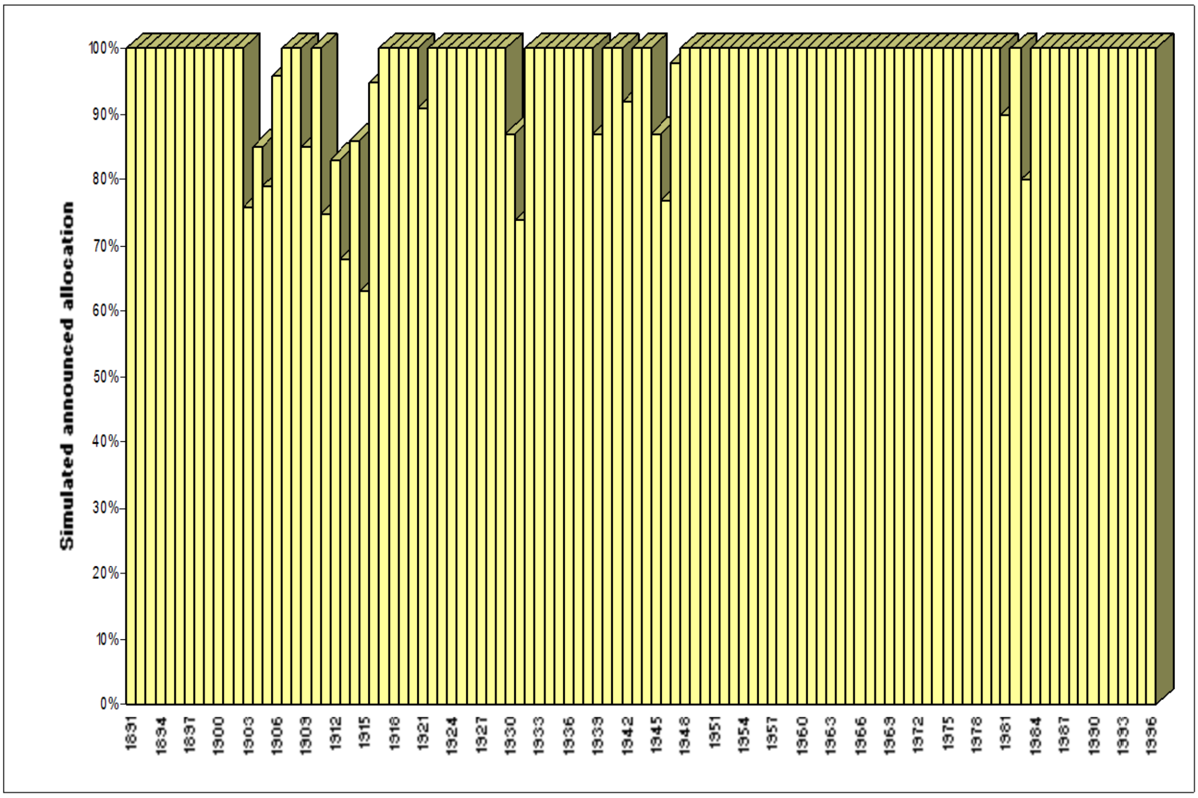
Irrigated agriculture is an important contributor to the regional economy of the Murrumbidgee Valley. Many of the dominant industries (rice and horticulture) provide inputs into high value regional processing industries. Hence, any economic impact on irrigated agriculture is likely to have flow on impacts for regional income and employment. Despite these linkages it would appear that some farms would be relatively sensitive to any change, either policy or market based, which eroded current incomes. For example, an ABARE survey in 1996-97 found that the average farm business profit for irrigation farms in the MIA and the CIA was $3,694 per farm. More than 30 per cent of these farms recorded negative business profits (Tran and Samaranayaka, 1996).

2.3 Reliability of irrigation supplies

Irrigators in the Murrumbidgee Valley have historically received very reliable irrigation supplies. Simulated hydrology data provided by DLWC shows that under base case conditions, irrigators could expect to receive their full allocations in all but the driest of years (Figure 2). The diversion of rivers in the Snowy Mountains has increased the reliability and flow volumes to the west, providing increased volumes of water for irrigation. The large storage capacity of the Snowy Scheme enables the flow to be controlled, ensuring reliable supplies during periods of low rainfall or drought. On average, the Scheme provides around 25 per cent of the flow in the Murrumbidgee River. However, during dry periods, it can provide as much as 60 per cent of the total flow (Snowy Water Inquiry, 1998).

As with each regulated system within the State, the allocations provided to irrigators in the Murrumbidgee depends upon the resources currently available in storage and those resources expected to be available during the season. An initial allocation made at the commencement of the season is updated continuously to reflect rainfall conditions in the catchment. The allocation assessment procedure is structured conservatively so that allocations will not need to be subsequently reduced during an irrigation season unless conditions realised are more severe than the worst recorded drought on record. As the period of record for critical streamflow statistics in most parts of NSW is around 100 years or so, the minimum-recorded streamflow sequence generally has about a 1 in 100 chance of occurring. That implies there is a 99 per cent chance that the announced allocations will not be reduced.

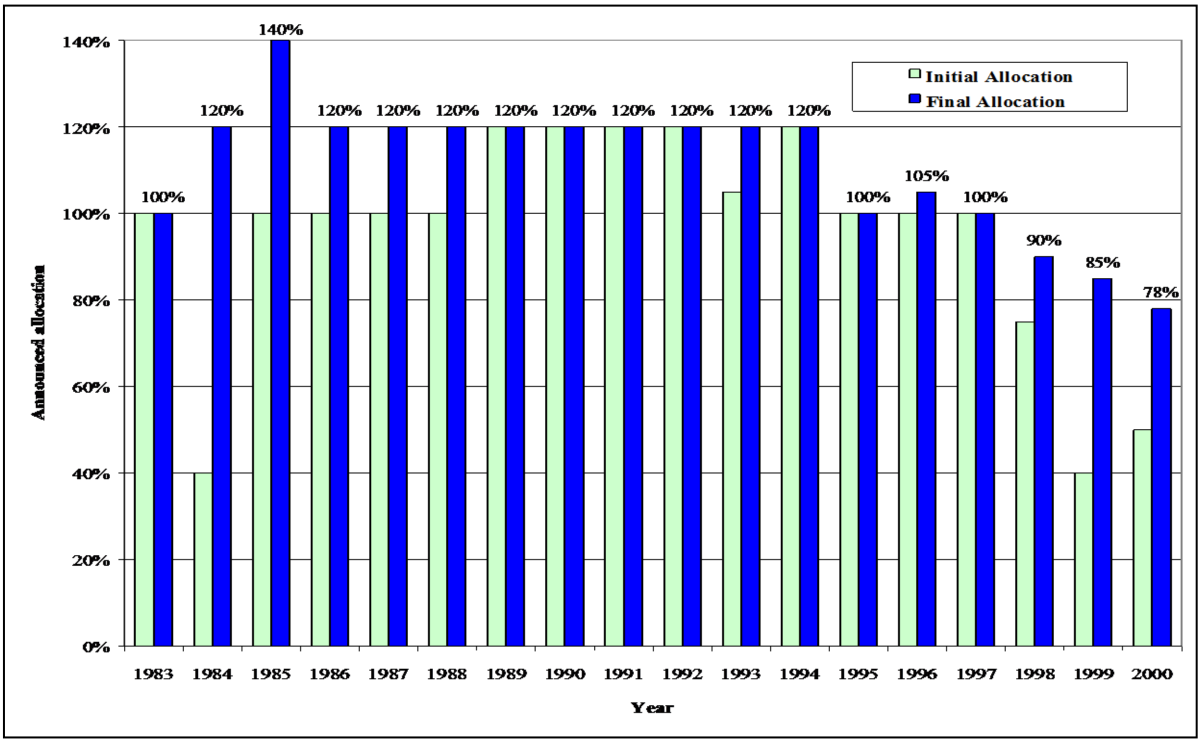
Figure 2: Simulated Murrumbidgee Valley January announced allocation percentages (1891-1996)



Not surprisingly, allocations announced at the start of the season have not been revised downwards since the introduction of volumetric allocations in the Murrumbidgee in the early 1980's. Historical allocation announcements actually show that initial allocations were either set at their maximum level (100% or higher) at the start of the irrigation season or set at a lower level and then considerably increased as the season progressed (Figure 3). Looking at those years where less than 120 per cent allocations were announced at the start of the irrigation season (13 out of 18 years), the average upward revision in allocation was 39 per cent. The lower allocation levels since 1995 onwards are due to a number of reasons. The MDBC Cap which agreed to limit irrigation development at 1993/94 levels and NSW Government's decision to equally recognise the rights of 'sleeper and dozer' licenses together with the fully active license holders are the main reasons. Drought conditions such as that occurred in 1998 also had an impact.

The reliability of irrigation supplies in the Murrumbidgee and the historically conservative nature of allocation announcements by DLWC are likely to have significant effects on the way in which irrigators respond to allocation announcements. The implication is that farmers would be unlikely to base their farm plans solely on announced allocations at the beginning of the season (August and September). This is an important issue for the estimation of the economic impacts arising from environmental flows and is further discussed later in the paper.

Figure 3: Actual announced allocations - initial and final allocations



3. Environmental flows

3.1 Environmental issues[3]

River regulation and water extractions have contributed to a significant decline in the health of the Murrumbidgee River. Under natural flow conditions, the median annual flow in the Murrumbidgee at Balranald is about 3.2 million ML/year. Model predictions indicate that under 1993-94 levels of irrigation development this has decreased to 645,000 ML/year despite additional water supplied by the Snowy Mountains Scheme. The catchment has experienced algal blooms, a significant decline in native fish species and an increase in exotic species, poor water quality (including salinity, turbidity, nutrients and pesticides), rising water tables and declines in the health of wetlands.

River regulation has adversely affected native biota (particularly fish) and wetland ecosystems. Water released from the bottom of Blowering and Burrinjuck dams is colder than natural flows, particularly in summer. There is evidence that these cold water releases have affected fish in the Murrumbidgee and Tumut Rivers as far down as Narrandera. The Lowbidgee contains one of the largest areas of lignum wetland in the State, and is a regular habitat for waterbirds in eastern Australia. Surveys indicate that the numbers of birds are progressively decreasing.

[3] This section draws on material contained in EPA (1996) "Proposed Interim Environmental Objectives for NSW Waters".

The Murrumbidgee catchment has low salinity than other major NSW inland rivers. However, dryland salinity is intensifying. Waterlogging and salinity in irrigation areas also have become major problems, along with the disposal of water draining from irrigated land. These issues are currently being addressed through Land and Water Management Plans. Phosphorus concentrations generally increase as you move downstream and greatly increase during high flows as a result of stream bank and gully erosion. Algal blooms are commonly reported in summer in the Burrinjuck dam whilst also being a problem in weir pools in the lower part of the catchment around Hay.

3.2 Environmental flow rules

The Murrumbidgee River Management Committee (MRMC) has developed a set of flow rules for the 1999-2000 season. These rules are designed to share water between users and the environment to improve river health whilst providing some level of water security to irrigators. The four individual flow rules described below[4] are implemented as an integrated package, and consequently, should be viewed as simply attributes of the 1999-2000 flow rules.

Rule 1: Dam Transparency

Dams on rivers tend to change the quantity and timing of water flow and consequently involve changes to the river environment. Dam transparency refers to ensuring the amount of water flowing into the dam is equal to the amount flowing out during certain periods. In the case of the Murrumbidgee, the rule has been put in place to protect low flows in the river immediately downstream of Burrinjuck and Blowering Dams. The rule states that flows into Burrinjuck at rates of up to 615 ML/day are passed through the dam and into the River. If the inflow is greater than 615 ML, the rate of outflow is limited to 615 ML. For the Blowering Dam, all the inflows up to 560 ML/day are passed through, with an upper limit of 560 ML/day.

Rule 2: End of System Flows

Is a flow rule aimed at achieving a certain flow target at the end of a river system. The flow rule in the Murrumbidgee addressing end of system flows is that once irrigation allocations exceed 80 per cent, a target flow of 300 ML/day at Balranald will be maintained during the year. This is calculated as an average daily flow for each month. If the allocation is less than 80 per cent, 200 ML/day at Balranald will be maintained.

Rule 3: Dam Translucency

Dam Translucency means that part of the inflow is allowed to flow through the dam. The translucency rule takes effect from the moment the dam begins to store water. In the Murrumbidgee, this rule has been put in place to ensure that, to some degree, natural flow and variability is restored downstream of Burrinjuck Dam. Both daily inflows and outflows to the Dam are examined to determine how to increase the outflows to match and mimic the inflows. Currently, early winter storms are retained in storage and later storms fill the dam to overflowing. In other words, the dam builds up storage as quickly as possible and is maintained full for the irrigation season.

[4] The description provided draws on unreferenced information published by the DLWC titled “What are the Murrumbidgee Environmental Flow Rules? 1999-2000.

There are some constraints on the volume of water that can be released under the translucency rule. While Burrinjuck Dam is below a threshold of 30 per cent, up to a maximum of 50 per cent of inflows will be released as translucent water when catchment conditions are 'wet' or 'average'. While Burrinjuck is between 30 and 50 per cent of its capacity there is a maximum of 50 per cent translucency when catchment conditions are 'average'. There is no constraint to releases when conditions are 'dry'.

Rule 4: Environmental Contingency Allowance / Provisional Storage

(a) Environmental Contingency Allowance
An environmental contingency allowance is a quantity of water set aside for future use to meet specific environmental objectives. In the Murrumbidgee under current rules, 25 GL of high security water is set aside each year in Burrinjuck to be used for environmental contingencies that may arise such as bird breeding, fish migration or blue green algae outbreaks. Until allocations reach 60 per cent, this 25 GL is included as part of the resource available for allocation. Allocations are not permitted to exceed 60 per cent until this 'borrowed' water is returned and is again available for environmental use.

(b) Provisional Storage

Provisional storage involves the retention of water in storages to meet future irrigation commitments. In the Murrumbidgee, the operation of provisional storage in Burrinjuck and Blowering Dams also helps the river environment by allowing the dams to spill earlier in the following year, providing more natural flows in the river. At the start of the water year, 25 GL is set aside as provisional storage. When the allocation exceeds 80 per cent, the amount of water stored increases linearly from 25 GL at 80 per cent to 200 GL at 100 per cent allocation. The provisional storage only becomes available to the environment in the advent of dam spills.

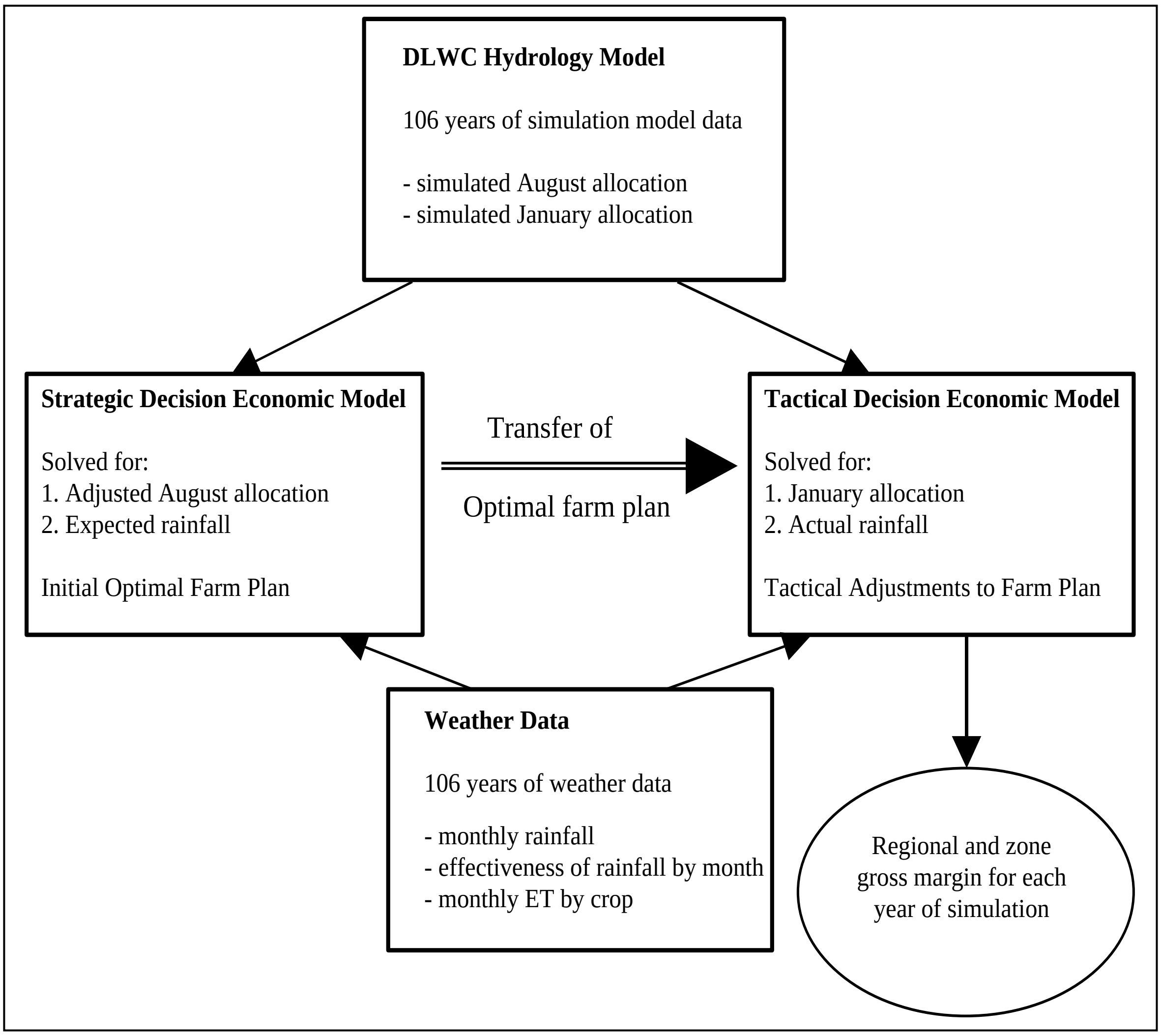
4. Methodology

4.1 Overview of modelling system

A combination of economic and hydrology simulation modelling is used to assess the impacts on agriculture from the implementation of different flow scenarios (Figure 4). The modelling system adopts a two-stage solution process reflecting conditions at the start and at the end of the irrigation season. The economic modelling system is based upon the concept that farmers can make both strategic and tactical management decisions within a season. The first stage economic model accounts for strategic decision making and determines the optimal farm plan for each zone based upon the initial announced allocation plus some expected level of allocation adjustment. The second stage economic model represents the tactical decision making by farmers and determines the adjustments to the strategically determined farm plan when an outcome of more or less water than planned for is realised.

Hydrology simulation information from DLWC's monthly hydrology model is used to represent the allocations that irrigators expect to receive under different environmental flow scenarios through time. The economic modelling uses this hydrology data, as well as rainfall, effectiveness of rainfall and evapo-transpiration data, as an input into the extent of irrigated crops grown in each zone. The agricultural impacts are determined by quantifying the difference in agricultural returns between the base scenario (water availability without environmental flows) and different environmental flow scenarios (various reduced water availabilities) for each year of the simulation period. The two stages of the modelling system are described below.

Figure 4: Structure of modelling system



Stage 1: Strategic decision economic model

The first stage strategic decision making model is solved using the expected allocation and expected rainfall values to derive the optimal farm plan for the irrigation season in each production zone. The farm plan is that which maximises regional agricultural returns (gross margins) by optimising levels and mixes of crops, pastures and livestock activities subject to resource constraints. Expected irrigation water demand is determined by crop evapo-transpiration less expected monthly rainfall for the irrigation season. The 25th percentile for monthly rainfall, rather than the mean, is used for expected rainfall to reflect assumed risk-averse decision making behaviour by irrigators.

Stage 2: Tactical decision economic model

The optimal farm plan derived in strategic economic model is then transferred to a tactical decision making model, which is solved using actual monthly rainfall, and end of season announced allocation data for each year of the 106 year simulation period. This process allows for a range of possible tactical responses by Murrumbidgee Valley irrigators if monthly rainfall and allocation availability differ to the expected values. The following tactical responses are included:

- if actual seasonal rainfall exceeds expected rainfall, total seasonal utilisation of irrigation water will be less than available allocation. No tactical responses will occur, however regional gross margin will be higher because of variable cost savings (reduced water use);
- if actual allocation availability exceeds the expected allocation the same result occurs as above (surplus water);
- if actual seasonal rainfall is less than expected rainfall then the demand for irrigation water will increase. If irrigation water is constraining then a number of tactical responses will be made. For example, conversion of irrigated crops and pastures to dryland, abandonment of crops, and fodder purchases for livestock; and
- if actual allocation availability is less than the expected allocation the same result occurs as above (on farm tactical responses).

4.2 Hydrology model

The DLWC hydrology model simulates the operation of the Murrumbidgee system by calculating the monthly announced allocation percentages and total allocation diversions for each year of a 106 year simulation period from 1891 to 1996. The model is set to represent, as closely as possible, all the factors affecting water use as they were in 1993/94. These factors include dams and water storages then in place, the water allocation rules, amount of land being irrigated, the year by year planting decisions made by farmers etc. The model is simulated with the actual rainfall, evaporation and water inflow for the period 1891 to 1996 to obtain the simulated hydrology output. This hydrology simulation approach has been used for a wide range of issues such as analysis of river flow objectives (EPA, 1996 and DLWC, 1997) and the Snowy Water Inquiry (1998).

Hydrology simulation information from DLWC’s monthly hydrology model is used as a starting basis to represent the allocations that irrigators would receive under environmental flow scenarios through time. The conservative nature of DLWC allocation announcements (discussed in the Section 2) suggest some likelihood of irrigators upwardly revising such announcements for planning purposes. The extent of such revisions ultimately depends on the irrigators’ attitude to risk, which is likely to be individual specific.

According to DLWC hydrology simulation data, allocations increase from the initial allocation (August) to the final allocation (January) under the base case situation by an average of 14 per cent. After excluding the years that reported the maximum allocation of 100 per cent in August, the average allocation increase from August to January stood at 29 per cent under the base case. It is likely that irrigators would adjust the allocation announcement by DLWC differently according to seasonal conditions.

In the absence of information about the precise nature of this seasonal adjustment, two alternative scenarios were assessed. In the first scenario, it was assumed that irrigators would upwardly revise DLWC's August announced allocation by 29 per cent[5] (with and without environmental flows) subject to a maximum allocation of 100 per cent for each year of the simulation period (ie irrigation allocations were revised upwards to a ceiling of 100 per cent). This scenario implies that irrigators are well informed about the usual increase in allocation announcements and that they base their crop planting decisions on higher water availability than that is actually announced at the start of the irrigation season[6].

In the second scenario, it was assumed that irrigators would upwardly revise DLWC's August announced allocation by just 15 per cent, subject to a maximum allocation ceiling of 100 per cent. The allocation revision was based on the advice of irrigator representatives on the MRMC who believed that an allocation revision of 29 per cent was beyond what most irrigators would normally base their crop planting decisions on.

4.3 The economic model

The economic model used in this study is based on linear programming (LP) techniques. These techniques have been applied to a wide range of resource management problems to determine the most economically efficient allocation of resources given a range of alternatives and constraints. It is particularly valuable in rapidly assessing potential changes in resource availability. LP techniques have been used extensively in regional planning (Land and Water Management Plans) and water related research (assessment of the impacts of changes in water availability, water pricing and trading). More recently, linear programming has been combined with hydrology simulation modelling to evaluate the impacts of changes in resource availability through time[7].

Changes in water availability directly impact on the area of irrigated enterprise and resulting returns. It is assumed that farmers respond to reductions in water availability by changing their crop/livestock mix to make the best use of the available water and/or convert irrigated production to dryland. In the absence of sufficient water, crops that cannot be grown without irrigation are replaced with a dryland enterprise to offset some of the income loss. NSW Agriculture's existing economic model of irrigated broadacre agriculture in the Murrumbidgee Valley[8] has been revised to analyse economic impacts of flow rules at a disaggregated level across the catchment. The disaggregated model takes into account variations in crop yields, variable costs, crop water requirements, irrigation efficiencies and

[5] A revision of 29 per cent is taken as a proportional increase in the announced allocation. Hence, under this assumption an announced allocation in August of 65 per cent would translate to irrigators' planning on receiving a 84 per cent allocation (65% x 1.29).

[6] According to historical announced allocations, the average increase in allocations between the start and the end of the irrigation season between 1983 and 2000 amounted to 39% (excluding years where 120% allocations were announced).

[7] See ABARE (1999) and NSW Agriculture (1996)

[8] Randall Jones (Economist, NSW Agriculture, Weeds CRC) initially developed the linear programming models of irrigated agriculture in the Murrumbidgee Valley. A number of people have contributed to the development and maintenance of these models since the early 1990's including Graham Marshall, Catherine Cuthoys, Lisa Wall and Namali Gunaratne. More recently, Phil Pagan, Rohan Jayasuriya and Jason Crean have revised the models and adapted them to look at different policy issues associated with the implementation of water reforms in NSW.

water use for each of the production zones. These types of variations significantly effect the profitability of irrigated agriculture and hence influence the magnitude of impacts associated with environmental flow rules.

Agricultural returns are based on crop and livestock gross margins defined as gross agricultural income less the variable costs incurred in production aggregated across the relevant production zone. This is an indication of the profitability of agriculture in the production zone and can be used for estimating the impact on the agricultural sector of reduced water availability.

The Murrumbidgee catchment was sub-divided into a total of eight separate production zones given below and shown in Figure 1. The zones cover four irrigation areas and districts and four private diverter zones along sections of the Murrumbidgee River.

- Zone 1 - Murrumbidgee Irrigation Areas (Yanco and Mirrool)
- Zone 2 - Benerembah Irrigation District (including Tabbita)
- Zone 3 - Wah Wah Irrigation District
- Zone 4 - Coleambally Irrigation Area
- Zone 5 - Private Diverters : Burrinjuck Dam to Narrandera
- Zone 6 - Private Diverters : Narrandera to Hay
- Zone 7 - Private Diverters : Hay to Murray River
- Zone 8 - Private Diverters : Yanko and Billabong Creeks

The Murrumbidgee Irrigation Area (MIA) is comprised of Yanco Irrigation Area (centred on the town of Leeton) and Mirrool Irrigation Area (centred on the town of Griffith). The enterprises modelled are rice, vegetables (onions, carrots), soybeans, wheat, canola, lucerne (hay and pasture) and sub-clover. Although there are two major soil types within this region, red brown earths and grey self-mulching clays, similar enterprises and yields can be obtained with appropriate farm management practices. Thus alternative soil types were not included in the model. Constraints apply to irrigation technology with 10 per cent of the MIA landformed border check, 55 per cent landformed contour bay and the remainder non-landformed contour bay. The licensed allocation for the MIA is 660,945 megalitres. The mean annual rainfall for Griffith is 396 millimetres.

Benerembah Irrigation District (which includes Tabbitta Irrigation District for the purpose of this study) is located adjacent to, and has similar soil types as, the MIA. The enterprises modelled are rice, vegetables (onions, carrots), soybeans, wheat, lucerne (hay and pasture) and sub-clover. The irrigable area is 42,827 hectares with 15 per cent landformed border check, 48 per cent landformed contour bay and the remainder non-landformed contour bay. The licensed allocation for the region is 228,073 megalitres.

The Wah Wah Irrigation District is situated north-west of the MIA. The main enterprises are sub-clover, soybeans, wheat and rice. The irrigable area is 24,738 hectares with 70 per cent non-landformed, 18 per cent landformed border check and 12 per cent landformed contour bay. The licensed allocation is 116,279 megalitres.

The Coleambally Irrigation Area (CIA) is located to the south of the Murrumbidgee River. Unlike the above irrigation areas and districts, the CIA has three separate soil types specified in the model; unrestricted, marginal and restricted land. Unrestricted soils are predominantly clay and have no institutional restrictions on rice growing. Marginal soils, where only one rice crop is permitted every four years, are alluvial sands while restricted soils, where no rice is permitted, are sandy soils. The areas of the three soil types are 60,347 hectares of unrestricted soils, 6,112 hectares of marginal soils and 11,160 hectares of restricted soils. The irrigation layouts for unrestricted and restricted soils were assumed to be 6 per cent landformed border check, 24 per cent landformed contour bay and 70 per cent non-landformed contour bay. Restricted soils were assumed to be 30 per cent landformed border check and 70 per cent non-landformed. The enterprises modelled for this region are rice, soybeans, wheat, canola, lucerne (hay and pasture) and sub-clover, depending on the particular irrigation layout and soil type. The licensed allocation is 446,699 megalitres.

The four private diverter zones cover the Murrumbidgee River from Burrinjuck Dam to its confluence with the Murray River. Accurate information on the nature of irrigated agriculture (crop and pasture areas, yields, rotations, irrigation layouts and efficiencies etc) is most limited in these areas. Available information was used to calibrate models but significant uncertainties remain. For private diverter zones it was assumed that each zone could produce soybeans, wheat, sub-clover, lucerne and summer pasture. Zones 6, 7 and 8 also included rice production. The layouts for each zone included landformed and non-landformed border check. Zone 8 also included landformed contour bay for specialised rice production.

The percentage of each irrigation layout for each zone of the private diverters region is as follows:

- Zone 5: 60 per cent non-landformed border check and 40 per cent landformed border check;
- Zone 6: 90 per cent non-landformed border check and 10 per cent landformed border check;
- Zone 7: 90 per cent non-landformed border check and 10 per cent landformed border check; and
- Zone 8: 75 per cent non-landformed border check and 12.5 per cent each of landformed border check and landformed contour bay.

The licensed allocations are 47,490, 190,158, 283,719 and 78,641 megalitres for Zones 5 to 8, respectively. Zone 9, which is the Lowbidgee private diverter zone does not have a licensed allocation, relying on off-allocation supplies. It has been excluded from the analysis because accurate hydrology data on the extent of irrigation diversions under different environmental scenarios is not available.

Some of the key data inputs into the economic model are discussed below:

- Commodity prices - crop and livestock commodity prices are a key input and are based on average prices received over the last three years.
- Enterprise areas - outputs are validated against a variety of information sources including departmental publications, research and extension staff within NSW Agriculture, information collected during catchment based planning initiatives (eg. Land and Water Management Planning), Australian Bureau of Statistics and DLWC crop returns.

Available areas of suitable soil types in different layouts provide constraints on some enterprises while others are imposed to represent capital and market constraints.

- Enterprise yields and variable costs - are specified for crop and livestock enterprises across different zones and irrigation layouts. Yields for pasture crops are provided on a seasonal basis. Data sources include departmental publications, research and extension staff and catchment planning initiatives. The majority of variable cost and yield data for enterprises is sourced from MIA and Districts Land and Water Management Planning evaluations (NSW Agriculture, 1996), and are specified for landformed border check and contour bay, non-landformed contour bay, and dryland layout classifications.
- Water use requirements - these are defined for all crop and pasture activities on a monthly basis across different zones and irrigation layouts. Actual crop water requirements are driven by fluctuations in rainfall availability with monthly crop evapotranspiration requirements effectively fixed. The economic model is solved on the basis of annual farm gate allocation availability, expressed as a percentage of licensed entitlement.

The economic models developed for each of the zones in the Murrumbidgee maximise zonal gross margin (M) according to the objective:

$$M = \sum_{j=1}^{n} (c_j - a_{ij}.x_j.p_i), \qquad (j = 1, \ldots\ldots\ldots\ldots n)$$

Where:

c_j denotes all the revenue from activities j;
x_j is the magnitude of activity j;
a_{ij} is the amount of resource i used per unit of activity j;
p_i is the cost of resource i; and
n is the number of *j* activities.

subject to: $$\sum_{j=1}^{n} a_{ij}.x_j \le a_i \quad (i = 1, \ldots\ldots, m)$$

The same mathematical notation could be used to denote both Strategic and Tactical Economic Models. An additional feature in the Tactical Model is that the magnitude of irrigation activities is constrained to the levels found in the Strategic Model. Within these new constraint levels the Tactical Economic Model allows conversion of some irrigation activities to dryland.

5. Results

5.1 Scenario 1 – a 29 per cent allocation revision

The agricultural impacts of environmental flow rules under Scenario 1 are estimated across the Murrumbidgee Valley in terms of reductions in agricultural returns. The average results of the 106-year simulation analysis for each zone are summarised in Table 1.

Introduction of environmental flow rules reduced the mean agricultural returns in the Murrumbidgee Valley by $2.81 million, a 1.9 per cent decline. The impact of environmental flow rules varied across different zones in the Murrumbidgee Valley. The highest impact in nominal terms of $0.99 million is estimated in the MIA, around a 1.9 per cent decrease for that zone. The impact in the Coleambally Irrigation Area (CIA) is $0.88 million, but as the gross margin for this zone is around half of that of MIA, the percentage decrease stood at a high 3.5 per cent. The first three river pumper zones ranging from Burrinjuck to Murray River did not show much impact but the Yanco and Billabong Creeks indicated a $0.25 million decrease which is around 2.9 per cent of its total.

Further analysis was undertaken to determine whether the agricultural impacts of environmental flows were statistically significant. The analysis found that the total regional impacts of environmental flows in the Murrumbidgee Valley across the 106 year simulation period were found to be statistically significant at a 95 per cent confidence level (t-statistic = 2.58).

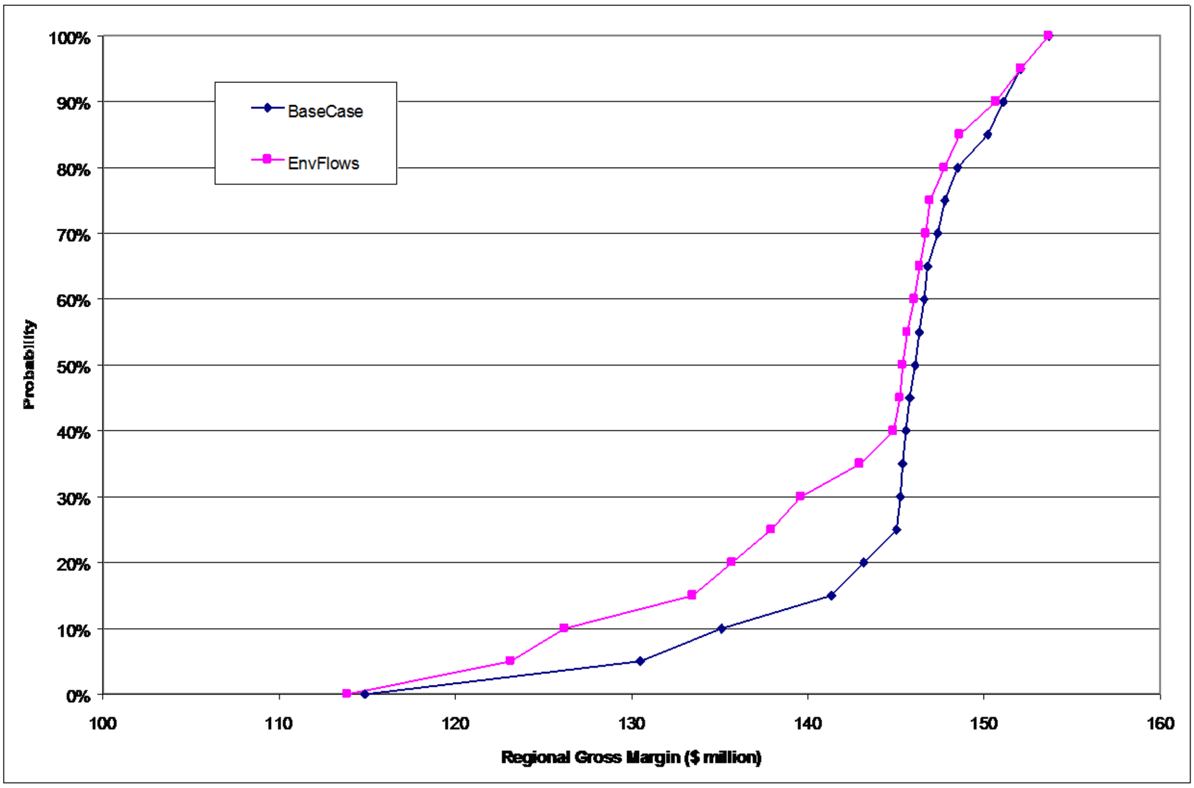
Table 1: Summary of agricultural impacts

Planning on August Announced Allocation plus 29% more, subject to a maximum allocation of 100%						
	Base Case – average January allocation 96.74%		**Environmental Flows** – average January allocation 91.71%		**Impact of Environmental Flows**	
	Mean **$ mil**	SD **$ mil**	Mean **$ mil**	SD **$ mil**	Mean **$ mil**	**%**
MIA	50.94	2.96	49.95	3.63	-0.99	-1.9%
Ben	21.71	1.19	21.17	1.61	-0.53	-2.5%
Wah	4.86	0.22	4.76	0.30	-0.10	-2.1%
CIA	24.77	1.96	23.89	2.63	-0.88	-3.5%
Zone 5	0.67	0.01	0.67	0.01	0	0%
Zone 6	14.80	0.21	14.73	0.31	-0.07	-0.5%
Zone 7	18.50	0.05	18.50	0.05	0	0%
Zone 8	8.48	0.56	8.23	0.75	-0.25	-2.9%
Total Region	**144.72**	**6.75**	**141.91**	**8.96**	**-2.81**	**-1.9%**

The non-normal distribution of allocation announcements under both the base case and environmental flows suggests that a simple comparison of results on the basis of mean and standard deviations may lead to false conclusions. A test for stochastic dominance was undertaken on the resulting distributions of the base case and environmental flow scenarios. The concepts of first, second and third degree stochastic dominance progressively use more restrictive behavioural assumptions to identify stochastically inefficient or dominated distributions (Anderson, Dillon and Hardaker, 1977).

The cumulative distribution functions (CDF's) for the base case and environmental flows are plotted in Figure 5. Results indicate that the base case dominated environmental flow rules in the order of first degree stochastic dominance with its CDF lying entirely to the right of the environmental flows CDF. First degree stochastic dominance is based on Bernoulli's principle than decision makers prefer more to less of a consequence such as profit (Anderson, Dillon and Hardaker, 1977). In this context, the results indicate that agricultural returns in the Murrumbidgee Valley is lower under situations of environmental flows than the base case across the entire probability range. Rational decision makers will always prefer the base case scenario to environmental flows under the behavioural assumption that they prefer more income to less.

Figure 5: Cumulative distribution of total regional gross margin under scenario 1



5.2 Scenario 2 – a 15 per cent allocation revision

The agricultural impacts of environmental flow rules under Scenario 2 are estimated across the Murrumbidgee Valley in terms of reductions in agricultural returns. The average results of the 106-year simulation analysis for each zone are summarised in Table 2.

Scenario 2 results indicate that the size of the allocation adjustment influences the relative impact of environmental flow rules. The reduction in mean agricultural returns due to environmental flows was estimated to be $4.1 million (2.9 per cent) under a 15 per cent allocation revision compared to $2.81 million (1.9 per cent) under a 29 per cent allocation revision. The sensitivity of impacts to assumed allocation revisions relates to hydrology simulation data provided by DLWC for the base case and environmental flows. Under the base case, 100 per cent allocations are announced at the start of the irrigation season in 56 of the 106 years. For environmental flow rules, 100 per cent allocations are announced in just 9 of the 106 years. Consequently, the allocation revision, which only operates under the analysis in years when less than 100 per cent allocations are announced, becomes a more significant factor in the determination of agricultural returns under environmental flows. More conservative allocation revisions lower agricultural returns because water actually made available in the season is not utilised by the irrigation sector and the frequency of this under utilisation increases using the hydrology data for environmental flows.

The results indicate that a more conservative allocation adjustment reduces agricultural returns for both the base case and environmental flow rules. This is because a 15 per cent allocation revision is significantly below the average revision indicated by hydrology simulation data for both the base case and environmental flow rules. The implication of this result is that agricultural returns are actually higher when irrigators base their farm plans around historical allocation adjustments or averages indicated by hydrology simulation data rather than only modest revisions like 15 per cent. This is because the benefits derived from planning on higher allocations outweigh the losses involved in years when higher allocations fail to eventuate.

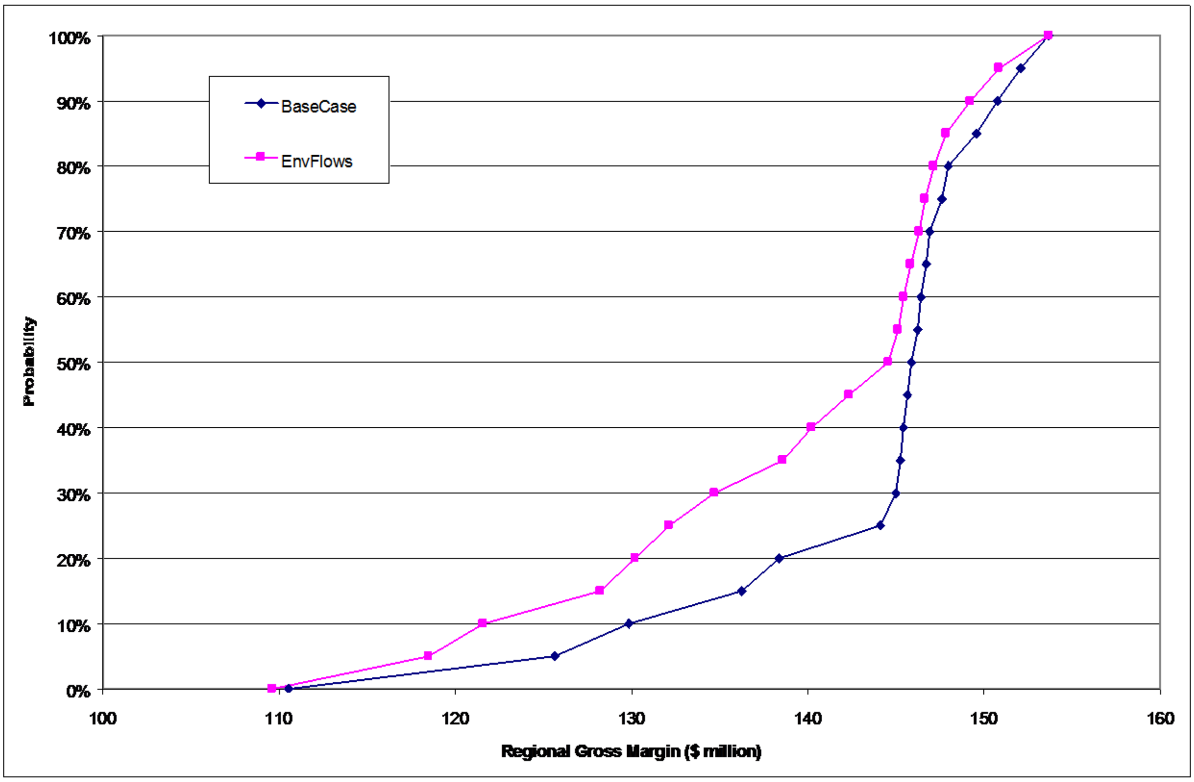
Table 2: Results of sensitivity analysis - summary of agricultural impacts

Planning on August Announced Allocation plus 15% more, subject to a maximum allocation of 100%						
	Base Case – average January allocation 96.74%		**Environmental Flows –** average January allocation 91.71%		**Impact of Environmental Flows**	
	Mean **$ mil**	SD **$ mil**	Mean **$ mil**	SD **$ mil**	Mean **$ mil**	**%**
MIA	50.45	3.46	48.96	4.16	-1.49	-3.0%
Ben	21.46	1.48	20.72	1.89	-0.75	-3.5%
Wah	4.82	0.27	4.68	0.34	-0.13	-2.8%
CIA	24.37	2.46	23.11	3.08	-1.27	-5.2%
Zone 5	0.67	0.02	0.67	0.02	0	0%
Zone 6	14.76	0.28	14.65	0.43	-0.11	-0.7%
Zone 7	18.50	0.05	18.50	0.05	0	0%
Zone 8	8.37	0.69	8.01	0.88	-0.36	-4.2%
Total Region	**143.40**	**8.35**	**139.30**	**10.54**	**-4.10**	**-2.9%**

The statistical significance of the results (at 95 per cent confidence level) were again confirmed by testing the 106 years of simulation results (t-statistic = 3.14). Agricultural returns under situations of environmental flows were found to be consistently lower than without such flows.

The non-normal nature of allocation distributions and the effect that this can have on the results of the economic model were evaluated in terms of stochastic dominance. The two scenarios under the 15 per cent allocation revision are reported as CDF's in Figure 6. The results indicate that the base case again dominated environmental flow rules in terms of first degree stochastic dominance with its CDF lying entirely to the right of the environmental flows CDF. In this context, the results indicate that agricultural returns in the Murrumbidgee Valley is lower under situations of environmental flows than the base case across the entire probability range.

Figure 6: Cumulative distribution of total regional gross margin under scenario 2



6. *Summary*

The results of the paper shed some light on the agricultural trade-offs associated with the implementation of environmental flows in the Murrumbidgee catchment. In benefit-cost terms, these costs provide an indication of the level of environmental benefits (threshold value) which would need to be obtained from the environmental flows if such a move could be supported on economic grounds. The results provide a starting point for decision makers to weigh up whether the environmental benefits (often identified and measured in physical terms, but which cannot be easily measured in monetary terms) from the proposal are considered to exceed the quantified opportunity costs.

The impact of environmental flow rules was found to be sensitive to the extent of allocation revisions made by irrigators. It was clearly shown that more conservative allocation revisions (a 15 rather than a 29 per cent allocation revision) lower agricultural returns because water actually made available in the season is not utilised by the irrigation sector. The frequency of this under utilisation increases using the hydrology data for environmental flows. This problem may be of greater significance if environmental flow policies prompt irrigators to act even more conservatively in respect to farm planning decisions.

The results of the study suggest that there is an important issue regarding strategic and tactical decision making for water allocation planning. There would appear to be insufficient tactical options available to irrigators to make up for an initial conservative farm plan. This suggests that water management agencies should consider whether the information they currently provide to irrigators is adequate in the current environment. Additional information may assist irrigators to develop more appropriate farm plans, which would assist in reducing agricultural trade-offs associated with environmental flows. Hence, a further economic research area might be to adopt some form of Bayesian approach to evaluate the benefits of improving such information which could then be compared with the costs in doing so.

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