An integrated model for water allocation in the Namoi River: economic module

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Abstract. Increasing pressures on water resources and associated cuts in allocation currently threaten many irrigators in the Namoi River catchment. In particular, cuts to groundwater allocation in many zones are expected to have significant negative social and economic impacts. Changed access to off-allocation water has been seen by many in the catchment as one possibility for mediating the impacts of these cuts. This paper discusses water allocation problems in the Namoi River catchment and the way in which off-allocation water may be utilised under various management strategies. A conceptual framework for an integrated economic and hydrological model for considering these options is developed, and details of the economic module are presented.

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1. INTRODUCTION

1.1 Management Issue

The Namoi River Catchment, which covers approximately 42,000 km^2 in northern NSW, is an important irrigation area. Water resources are currently under great pressure in the catchment, with groundwater and surface water supplies being overallocated in many areas. Management options for dealing with this overallocation are likely to have significant social, economic and environmental impacts.

Water management and use falls into three main areas in the catchment: unregulated and regulated system surface water, and groundwater. Groundwater resources are particularly stressed in the catchment, with allocations for extraction in many areas exceeding sustainable levels. Surface water resources in the Namoi catchment have been divided into two classes for the purposes of management: regulated and unregulated water. The unregulated system consists of those subcatchments of the Basin which are above the major dams (Keepit, Split Rock, and Chaffey dam). The regulated system consists of the river below these storages, including the Peel river below Chaffey Dam. Water that spills from the dams, or that flows into the regulated system from the unregulated system is referred to as off-allocation water and is not currently allocated to any specific users by a licence or other type of property right. Currently, this off-allocation water may be extracted when it exceeds users' demands and identified environmental needs, after an announcement is made by the NSW regulator, the Department of Land and Water Conservation. Such extractions are not counted against the users' licensed allocations (see for example DLWC,1999). In the Namoi, off-allocation water is usually made available during periods of high river flow (generally in the winter months) and producers store the water for the irrigation season in turkeys nest dams. Under current management, off-allocation may account for approximately one-third of surface water extracted in the catchment, with this proportion varying greatly between years with differences in climate (Donaldson Planning and Management Services, 1996). Historically no property right has been given over this off-allocation water, with access being at the discretion of the Department. The lack of such defined property rights or licences to this resource has resulted in this water being viewed as part of a solution to water allocation problems in the catchment.

This paper outlines the economic component of an integrated hydrologic-economic framework being developed to investigate the following management question:

What is the economically optimal access policy for off-allocation water in the Namoi catchment given:

- *overallocation of groundwater and the phase in of groundwater allocation reductions expected over a 5-10 year period in most groundwater zones in the catchment;*
- *expected activation of sleeper licences and further development of irrigation in the unregulated system, where the irrigation industry has historically been less developed than in the lower catchment;*
- *the dependence of traditional users of off-allocation water on this resource; and*
- *environmental flow requirements. The interim rules for off-allocation in the catchment includes a 50:50 sharing rule of off-allocation water with the environment.*

This management question and the alternative scenarios considered in the model have been developed using an iterative process of stakeholder consultation. The involvement of stakeholders so far in the problem framing and model development phases of this project is described in Letcher *et al.* (2000).

This management issue has two fundamental features: it is a question pertaining to the spatial distribution of a resource (a questions of trade-offs between upstream and downstream users); and it is critically intertemporal in nature. In particular, management options for this resource rely on the construction of significant levels of infrastructure, such as channels or dams. Thus the way in which capital is treated in any model considering this issue is critically important. The two levels at which decisions are made (considered to be "catchment manager" and "regional farmer" in this paper) must also be considered.

1.2 Brief Overview of Treatment of Capital in Economic Theory and Practice

1.2.1. Theory of capital

Hicks (1960) defined capital as consisting ". . . of all those goods, existing at a particular time, which can be used in such as way so as to satisfy wants during the subsequent period". He determined that there are two types of capital: single use producer goods; and, durable use producer goods. The type of capital being discussed in this paper, that is irrigation infrastructure, would be defined as a durable use producer good. Hicks divides durable use producer goods into two main types: land, including agricultural and urban land as well as mines; and fixed capital, including buildings, machines and tools. He states that most durable use goods which do wear out in time are fixed capital. It can be argued that the types of irrigation infrastructure which are being discussed here, including investment in laying out additional areas of land to irrigation, fall under this definition of fixed capital. These producer goods fall into the class of such goods described by Hicks (1960) as such that a percentage of existing supply can be expected to wear out in any given year. New units of these goods can also be produced as additions to supply or as replacements for those worn out.

In his book on "Value and Capital", Hicks (1948) describes the basis for entrepreneurs selecting a "preferred production plan" in a dynamic situation. He states that the basis for selecting a preferred production plan is the maximisation of the capitalised value of a stream of surpluses. Hicks theorises that, assuming an entrepreneur can borrow and lend freely at the given market rate and that he is only in business in order to obtain income, then the entrepreneur's preferred business plan must be that with the greatest present capitalised value. If prospective net receipts are defined as the anticipated surplus minus any charges which the entrepreneur may have to meet as a result of contracts entered into in the past, then maximising the capital value of the prospective surplus is equivalent to maximising prospective net receipts. This is because once the interest rate is given, the capital value of these charges resulting from past contracts (such as interest or debentures) is a given magnitude. Thus in order to determine the preferred production plan, the entrepreneur can be said to maximise the present value of a stream of prospective net receipts, where:

net receipts = (outputs-inputs) - charges arising out of past contracts

or that he maximises profits where:

profits = net receipts - depreciation

This theory is particularly relevant in the study of many natural resource management problems as the period of time over which the stocks of a resource may be depleted or renewed are often longer than the lifespan of many pieces of fixed capital. Additionally changes in the allocation of these resources may require significant investment in capital infrastructure in order for the resource to be utilised effectively. Optimising production in these situations requires the consideration not only of short term resource constraints but also of longer term costs of structural adjustment and changes in capital infrastructure.

1.2.2. Treatment of capital in applied work on water allocation issues.

Many economic models have been built to consider the issues of water trading and water reforms in Australia and more generally (eg. Hall *et al.* (1994), McClintock and Gooday (1998), Branson *et al.* (1998)). However most of these models have been focused on the short term, ignoring the possibility of structural adjustment in the face of reform. Few models have considered the costs of additional infrastructure, both to the farmer and the catchment manager, of changing access to irrigation water. Changing access to irrigation water supplies will in many cases mean additional capital costs to both the farmer and the catchment manager. To the catchment manager, changing the spatial distribution of access to irrigation water within a catchment will mean additional channels may need to be constructed and maintained. Programs implemented by the catchment manager to improve irrigation efficiency within the catchment will also carry a cost to the catchment manager. Where a farmer chooses to adopt such efficiency improvements, costs to the farmer can also be expected to increase. Farmers may require additional storage capacity in order to capture less secure or differently timed water supplies, such as off-allocation water. Increasing efficiency and activation of sleeper licences will in many cases involve costs involved with laying out additional areas to irrigation. Economic models developed to consider water reform have generally ignored these longer term structural adjustment costs.

Hall *et al.* (1994) described a spatial equilibrium model developed to consider tradeable water entitlements in the Southern Murray-Darling Basin. While this model considered the running costs of the distribution system and the costs of renewals of capital assets, it did not consider capital adjustment. The model was able to indicate likely pressures for adjustment, but could not consider structural adjustment as a result of trade. Farm capital was considered through constraints on the area which could be irrigated in the model, while regional capital was considered through channel capacity constraints. Similarly Branson *et al.* (1998) describes a spatial equilibrium model using a number of regional linear programming models previously developed for areas in NSW and Victoria (Branson and Eigenraam (1996a); Branson and Eigenraam (1996b); Curthoys *et al.* (1994); Gunaratne *et al.* (1995a); Gunaratne *et al.* (1995b); Gunaratne *et al.* (1995c); Jones (1991); Pagan *et al.* (1996); Wall *et al.* (1994) from Branson *et al.* (1998)) in which channel capacity was used as a constraint. Farm adjustment was limited to changing the enterprise mix through the linear programming models.

McClintock and Gooday (1998) developed a model for investigating water demands within and between irrigation seasons. This model was used to explore the implications of water policy reforms and the efficiency costs of not using a water market to reallocate water. Short run production decisions were simulated at a farm level using a linear programming model. No consideration was given to the costs to the catchment manager of additional infrastructure needed for water markets (constraints of channel capacity on farm were used). The number of on-farm storages and pumps was able to be changed by the user, but the model did not consider the costs of this additional infrastructure. Maintenance costs for reuse, storage systems and groundwater pumps were included with other fixed costs outside the linear programming module, but have no impact on the production decision.

2. MODEL STRUCTURE

2.1 Regional Structure

It was decided that to best consider the management issue described in Section 1.1, an integrated modelling framework should be developed. This integrated model consists of a regional scale economic model, underlaid by a hydrologic flow network. This paper considers the structure of the economic model component, in particular the way in which capital is treated in the model. The regions used for this model are given in Figure 1. These regions were developed using an iterative approach. Regions were developed on the basis of groundwater zones, subcatchments, and production activities and were successively refined on the basis of suggestions made by various stakeholders in the catchment. Further detail on this process can be found in Letcher *et al.* (2000).

Production in each of these regions is modelled as though controlled by a single profit maximising regional farmer. This assumes that water (and land) is costlessly transferable between farmers within each of these regions.

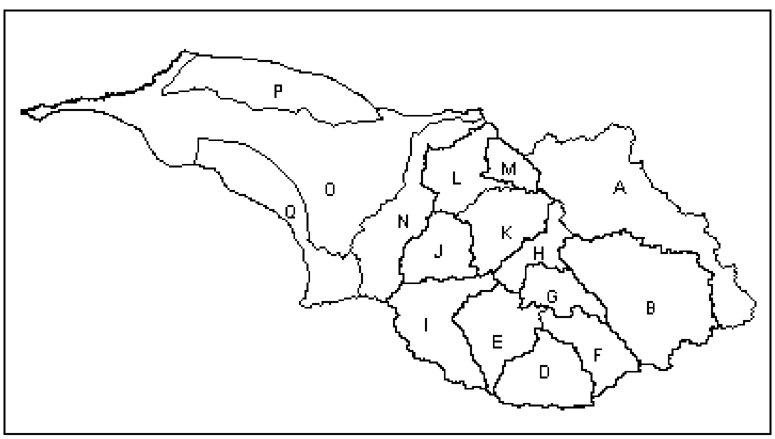

Figure 1 - Model regions in the Namoi

Each of these regions corresponds to a flow node in the model. The underlying hydrological network used is presented in Figure 2. Further detail on this network can be found in Letcher *et al.* (2001). Flow is routed through this network so that impacts of decisions made in a region are simulated on downstream regions.

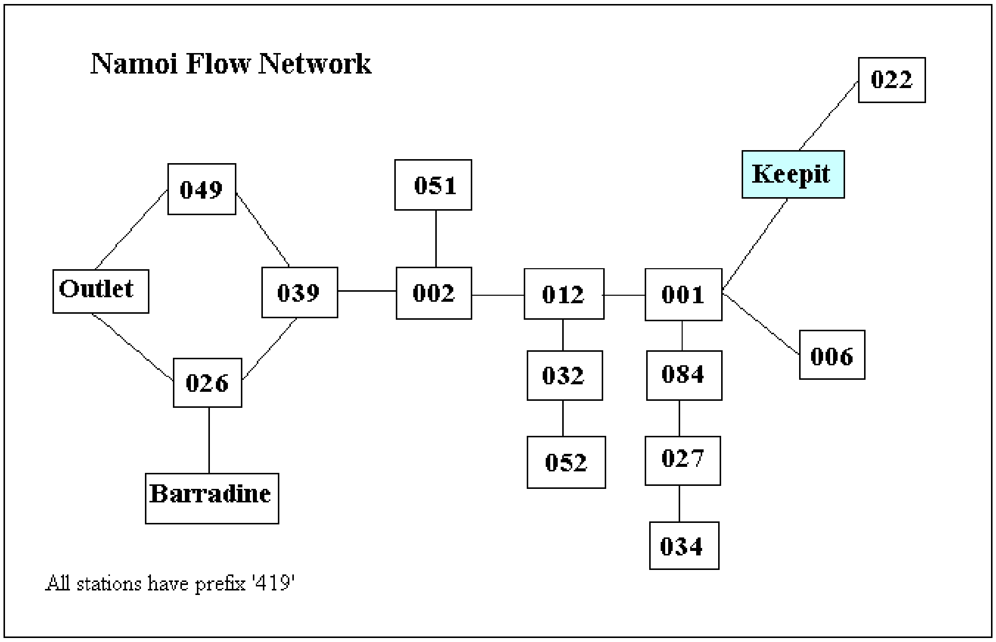

Figure 2 - Flow network in the Namoi

2.2 Decoupling decision levels in the model

The management issue described in Section 1.1 is affected by two levels of decision making: "catchment manager"; and "regional farmer". The catchment manager introduces policies into the catchment so that the well-being of the catchment as a whole is optimised. This well-being may be measured in purely economic terms or may also include environmental and social goals. Once a policy has been implemented by the catchment manager, regional farmers are free to adjust their individual production decisions in response to this change. This adjustment will affect the optimal policy for the catchment as a whole. In particular, changing water use by upstream users can be expected to affect the water available to downstream users, as well as the income of the whole catchment. The model separates and simulates these two levels of decision making in the catchment.

Regional farmer level decisions are simulated through a set of linear programming modules. These modules choose production activities to maximise farm profit given constraints of available water and land, and levels of irrigation efficiency. An overarching mathematical programming approach is then used to optimise total catchment profits given a set of irrigation technology scenarios and a set of possible policy scenarios for access to off-allocation water. Impacts on river health of various scenario combinations can be signalled through links with the hydrological model previously discussed.

3. MANAGEMENT SCENARIOS

3.1 Irrigation Technology Scenarios

Irrigation scenarios differ by region. Regions A and B (see Figure 1) have only one scenario: current spray irrigation. All other regions will be modelled to consider three irrigation scenarios: current flood irrigation; 10-15% improvement; and, 15-20% improvement. It is assumed that these improvements in irrigation technology are the result of a program introduced by the catchment manager. A constant rate of adoption, based on adoption rates of similar rural technologies, is assumed across the catchment. A program to improve irrigation efficiency can be introduced in any year. Once efficiency has improved, no further improvements are made, and irrigation efficiency stays constant at the new, higher level.

3.2 Policy Scenarios

There are six main policy scenarios considered by the model. The way in which these are enacted in each region will depend on the groundwater situation in each region, as well as whether the region is in a regulated or unregulated subcatchment. These are:

1. Surface water allocation limited to active use. Off-allocation access is dictated by a first in rule, with no off-allocation water being transferred to groundwater users. This is the "current" situation.

2. Surface water allocation is limited to active use plus half of the sleeper licences activating. In the unregulated system these activations occur at the volumetric conversion rate for sleeper licences. In the regulated system they occur at allocation. Off-allocation access is dictated by a first in rule, with no off-allocation water being transferred to groundwater users.

3. Surface water allocation is limited to active use plus all sleeper licences activating. In the unregulated system these activations occur at the volumetric conversion rate for sleeper licences. In the regulated system they occur at allocation. Off-allocation access is dictated by a first in rule, with no off-allocation water being transferred to groundwater users.

4. Surface water allocation is limited to active use. Available off-allocation (or additional allocation water in the unregulated system) is allocated to groundwater users in zones where current active use is greater than future allocation.

5. Surface water allocation is limited to active use plus half of the sleeper licences activating. In the unregulated system these activations occur at the volumetric conversion rate for sleeper licences. In the regulated system they occur at allocation. Available off-allocation (or additional allocation water in the unregulated system) is allocated to groundwater users in zones where current active use is greater than future allocation.

6. Surface water allocation is limited to active use plus all sleeper licences activating. In the unregulated system these activations occur at the volumetric conversion rate for sleeper licences. In the regulated system they occur at allocation. Available off-allocation (or additional allocation water in the unregulated system) is allocated to groundwater users in zones where current active use is greater than future allocation.

4. TREATMENT OF CAPITAL

Changes to capital in the model arise from the two major scenarios or decisions undertaken by the catchment manager: policy scenarios; and, irrigation technology scenarios (as previously described in section 3). However the costs of these changes are felt at both the regional farmer level and at the catchment manager level. This section describes the types of capital changes considered by the model and the way in which the costs of these changes have been incorporated into the model.

4.1 Irrigation Technology scenarios

These scenarios refer to a change in irrigation efficiency across the catchment in response to a program for efficiency improvement being implemented by the catchment manager (see Section 3.1). Changes to irrigation efficiency can be implemented in any year, but once an improvement is made it is assumed that the level of irrigation efficiency stays constant at this new level for the rest of the period of model simulation. A constant rate of adoption for these programs is also assumed. The sensitivity of the model to the level of this adoption rate will be tested. A change in irrigation efficiency will incur costs to both the catchment manager and the regional farmer.

4.1.1. Costs to the catchment manager

The catchment manager incurs a fixed cost of implementing any irrigation efficiency program. A cost is incurred regardless of the rate of adoption, but may be greater for a greater level of adoption (for example if subsidies are paid). In the model it has been assumed that this cost can be annuatised over the period of the model. This cost, that is the annuatised policy implementation cost, is incurred in the first year during which a policy is implemented and every year after this. The cost is zero in years before implementation and is included as a constant program implementation cost discounted at the market rate for each time period after implementation in the mathematical programming module. This cost is shown in equations as $D^t(k,\xi)$.

4.1.2. Costs to the regional farmer

If a regional farmer decides to adopt a program of improved irrigation efficiency then the farmer faces additional costs associated with improvements to their irrigation method, above any subsidy that may be paid by the catchment manager. The types of improvements covered by these costs may include activities such as laser levelling fields, installing subsurface drip irrigation or lining dams. In the model these costs have been included as a constant cost deducted from returns in the linear programming objective function. This constant cost is the annuatised cost to the farmer of increasing irrigation efficiency from the base level (i.e. the current level of technology) minus any subsidies paid by the catchment manager. This cost is only incurred at the rate of adoption and is denoted by $\Psi(k)\times\xi$ is the model equations section.

4.2 Policy scenarios

These scenarios refer to changes in the way off-allocation water is allocated within the catchment, as described in Section 3.2. These policies are implemented from the first year of the simulation and remain constant for the entire period of simulation. Costs of changes in capital required to take advantage of these policies are borne by both the catchment manager and the regional farmer.

4.2.1. Catchment manager

If additional off-allocation water is supplied to groundwater licence holders then additional channels and distribution networks will be required to supply these users with this water. The costs of these capital works are incurred by the catchment manager. These costs can be assumed to include an initial fixed cost in the first period (t=0) and a maintenance cost in all successive periods which will differ in each region considered by the model. These costs will be included in the objective function for the mathematical programming component. These costs are referred to in the equations section as $C^t_\alpha(k,p)$.

4.2.2. Regional farmer

Dam capacity

In order for off-allocation water to be used by a regional farmer, sufficient farm dam capacity must exist for the farmer to store off-allocation water until it is required. Where off-allocation water is being reallocated to traditional groundwater licence holders or where sleeper licences are activating in the unregulated sections of the catchment, additional dam capacity will be required for farmers to use this water. The cost of increasing dam capacity must be weighed in their decision on what areas to irrigate. This cost is included in the objective function of the linear programming model as a constant cost. This cost represents the annuatised cost of increasing dam capacity in that region. The model is then simulated for a number of discrete possible levels of additional dam capacity in each affected region, and the mathematical programming module optimisation performed over these. Not all regions will need to be considered.

Areas laid out to irrigation

The model assumes that where cuts to groundwater do not reduce allocation to below current active use, and sleeper licences are being allowed to activate, it is possible that additional areas may be developed for irrigation. The decision to increase area laid out to irrigation will depend on the cost. This cost is included as a constant cost in the objective function of the linear programming component for such a region. This is the annuatised cost of laying out a given additional area to irrigation. The model is then simulated for a number of discrete possible amounts of additional irrigation area in each affected region, and the mathematical programming module optimisation performed over these.

5. MAIN MODEL EQUATIONS

5.1 Mathematical programming component

The objective function of the mathematical programming component is

$$\underset{k,p,d,\Omega}{Max} \quad \sum_{t=0}^{n}\left(\sum_{\alpha}\frac{1}{(1+r)^t}\left(\Pi^t{}_{\alpha}(k,p,d,\Omega)-C^t{}_{\alpha}(k,p)\right)-\frac{1}{(1+r)^t}\left(D^t(k,\xi)\right)\right)$$

where

α is an index for the region;

n is the total simulation period;

r is the discount factor;

$\Pi^t_\alpha(k,p,d,\Omega)$ is the optimised value of the linear programming objective function given irrigation technology scenario k, policy scenario p, d(α) of additional dam capacity in region α, and $\Omega(\alpha)$ of additional area laid out to irrigation in region α;

$C^t_\alpha(k,p)$ is the cost to the catchment manager of works associated with delivering additional off-allocation water to non-traditional users. This includes is an initial fixed cost (in t=0) for constructing works, and a maintenance cost in all successive years;

$D^t(k,\xi)$ is the annuatised cost to the catchment manager of implementing irrigation technology scenario k with adoption rate ξ.

5.2 Linear programming component

The objective function of each of the linear programming component modules has the form:

$$\text{Max} \quad \Pi^t_\alpha(k,p,d,\Omega) = \sum_{j=1}^{m}\left(P_j y_j - c_j\right)a_j - \Psi(k).\xi - \lambda(d,p) - \tau(\Omega,p)$$

where

P_j is the price of a unit produced by activity j;

y_j is the yield per unit area of activity j;

c_j is the cost per unit area of activity j;

a_j is the amount of area used for activity j, decided by the LP;

m is the total number of activities available;

$\Psi(k)$ is the annuatised cost to the farmer of improving irrigation efficiency from the base level under scenario k minus any subsidies from the catchment manager and ξ is the level of adoption (constant);

$\lambda(d,p)$ is the annuatised cost to the farmer of additional dam capacity (d) of a specified amount. For some regions and some policies this may be zero (as no additional dam capcity will be required);

$\tau(\Omega,p)$ is the annuatised cost to the farmer of increasing areas laid out to irrigation by a given amount Ω. For some regions and some policies this may be zero (as no additional area will be laid out).

6. CONCLUSIONS AND FUTURE WORK

This paper describes the economic module of an integrated economic-hydrological model developed for considering policies for off-allocation access in the Namoi River catchment. In particular the way in which structural adjustment and changes in capital are considered by the model were detailed. The model described here is still in development. The model is currently being coded and final details of the way in which the overarching mathematical programming module will run are being considered. This paper demonstrated that explicit account needs to be taken of changes in investment in capital in order to account for the full costs and benefits of many water policy reforms. The model developed here demonstrates a 'first-pass' method for inclusion of some of these changes.

At present it is considered that the model will be run over a large number of randomly generated climate scenarios and the derived distributions of these model runs be used to explore trade-offs within the model. Work is also currently being completed to develop a method for looking at issues of uncertainty and sensitivity in such large integrative models.

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8. REFERENCES

Branson, J., and Eigenraam, M. (1996a). “Northern Irrigation Region Mixed Linear Program.” , Victorian Department of Natural Resources and Environment.

Branson, J., and Eigenraam, M.(1996b). “Water policy in Victoria - A regional perspective.” *Paper presented to the 40th Annual Conference of Australian Agricultural and Resource Economics Society*, Melbourne.

Branson, J., Eigraam, M., Stoneham, G., Crean, J., and Pagan, P. (1998). “Structural adjustment pressures in irrigated broadacre farming in the Southern Murray-Darling

Basin." *MDBC I&E Project No. I6041*, Economic Services Unit, NSW Agriculture. Economic Branch, Dept. of Natural Resources and Environment (Vic).

Curthoys, C., Marshall, G., and Jones, R. (1994). "Economics of On-farm Proposals: A Report to the Community Working Group of the Coleambally Land and Water Management Plan." , Economic Services Unit, NSW Agriculture.

DLWC (1999). "Guidelines for River, Groundwater and Water Management Committees, Namoi River Catchment", NSW Department of Land and Water Conservation, October 1999.

Donaldson Planning and Management Services (1996) "Namoi Community Catchment Plan Situation Statement", prepared for the Namoi Catchment Planning Taskforce by Donaldson Planning and Management Services, March 1996.

Gunaratne, N., Wall, L., Marshall, G., and Jones, R. (1995a). "Economics of on-farm proposals: A report to the Community Working Group of the Cadell Land and Management Plan." , Economic Services Unit, NSW Agriculture.

Gunaratne, N., Wall, L., Marshall, G., and Jones, R. (1995b). "Economics of on-farm proposals: A report to the Community Working Group of the Denimein Land and Management Plan." , Economic Services Unit, NSW Agriculture.

Gunaratne, N., Wall, L., Marshall, G., and Jones, R. (1995c). "Economics of on-farm proposals: A report to the Community Working Group of the Wakool Land and Management Plan." , Economic Services Unit, NSW Agriculture.

Hall, N., Poulter, D., and Curtotti, R. (1994). "ABARE model of irrigation farming in the Southern Murray Darling Basin." *94.4*, ABARE, Canberra.

Hicks, J. R. (1948). *Value and Capital: An inquiry into some fundamntal principles of economic history*, Oxford University Press, Oxford, UK.

Hicks, J. R. (1960). *The Social Framework: An introduction to economics*, Oxford University Press, Oxford, UK.

Jones, R. E. (1991). "Optimal irrigation water allocation and supply reliability in the Murrumbidgee Valley," M.Econ, University of New England, Armidale.

Letcher, R.A., Cuddy, S.M., and Reed, M. (2000). "An Integrated Catchment Management System: a socioeconomic approach to water allocation in the Namoi", *Hydro2000 Conference Proceedings*, Perth, 20-23 November 2000.

Letcher, R., Watson, W. and Jakeman, A.J. (2001). "An integrated modelling framework for assessing water allocation in the Namoi River Basin", paper to be presented at the *19th Federal Convention of the Australian Water Association* (Water Odyssey 2001), 1-5 April, 2001.

McClintock, A., and Gooday, J. "A method for assessing the impact of water policy reforms: A case study of irrigated broadacre farming." *Proceedings of the Bioeconomic Workshop*, Armidale, 77-94.

Pagan, P., Curthoys, C., Marshall, G., and Jones, R. (1996). "Economics of on-farm proposals: A report to the Community Working Group of the Murrumbidgee Irrigation Areas and Districts Land and Water Management Plan." , Economic Services Unit, NSW Agriculture.

Wall, L., Marshall, G., Jones, R., and Darvall, D. (1994). "Economics of on-farm proposals: A report to the Community Working Group of the Berriquin Land and Water Management Plan." , Economic Services Unit, NSW Agriculture.