AN INTEGRATED MODELLING APPROACH FOR ASSESSING WATER ALLOCATION RULES

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ABSTRACT

Understanding the magnitude and location of environmental and economic trade-offs is the main aim of the COAG Water Reforms process (DLWC 1999a). Since its inception in the early nineties, Catchment Management Committees and Boards have sought to develop and implement methods for determining appropriate water allocation policy rules at the catchment scale in NSW. This paper outlines a modelling methodology developed to assess water allocation rules as part of the COAG Water Reform Process. The first part of the paper introduces the concept of modelling nodes, a fundamental concept in model development and integration. This is illustrated by presentation of the model conceptual framework. Subsequent sections describe the process of identifying economic modelling units and economic techniques employed to achieve the study aims. Specifically, the study approach identifies why these techniques were selected and how they were utilised in a linear programming formulation. A major component of the work not discussed in detail is the hydrological and habitat system components that are integrated with the economic system. However, aspects of integration with the hydrological system are introduced.

INTRODUCTION

The main aim of this study was to identify impacts upon the hydrological and economic systems by imposing multiple policy options as defined by the water reform process. To achieve this aim, a conceptual model of the catchment system, defining economic production systems and environmental systems was developed. Steps in model development were as follows;

- The first step was to define the hydrological network with flows through time. This was achieved with the aid of a daily rainfall run-off model and the Integrated Catchment Management System (ICMS) software platform. This allowed development of the hydrological network.
- A second step involved defining relatively homogenous Land Management Units (LMU) for Yass catchment. The process identified current economic production systems spatially as well as defining their operation through time.
- Linear programming was used to define a profit maximising objective function subject to land use, policy and hydrological constraints.

A separate process was developed to facilitate model integration between economic and hydrological systems in space and time. This was based upon development of modelling arcs and nodes to define system responses to changes in water demand or supply. This paper is focused upon the last two points

Yass Catchment Water Allocation Problems: The COAG Reform Process

Yass catchment, an unregulated river system located in the Upper Murrumbidgee was selected for model development. The catchment suffers from water quality and quantity related problems as a result of current and past land use systems.

Three water policies are currently operating or will be introduced into the catchment under the Water Reform Agenda. They are the Farm Dams Policy, Volumetric Conversions and a Salinity Management Strategy (DLWC 1999b). A further aim was to understand the magnitude of imposing these three water policy options given changes in the economic production system under rural structural adjustment. As a result, the modelling approach presents a framework for assessing appropriate water allocation rules given changes in both water supply (water policy adjustment) and water demand (land use change).

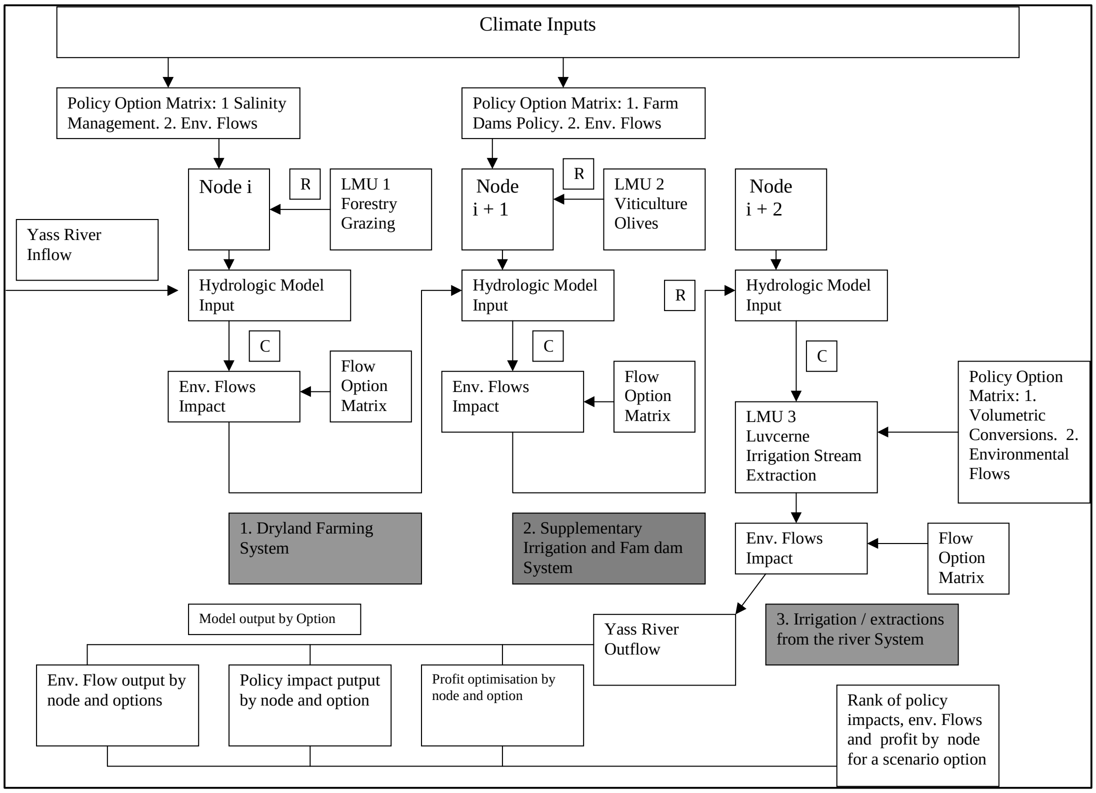
CONCEPTUAL FRAMEWORK: NODAL NETWORK SYSTEM

The conceptual framework for model development is illustrated by Figure 1. Major points of interaction between the hydrological and economic system are the main features of the framework. As illustrated, the Yass river daily hydrological flow is the foundation for model integration. Water is extracted or added to river flow by the action of economic units. Three general economic production node types were identified for this catchment system from which specific agricultural production systems and associated decision rules were defined.

The dryland farming system, supplementary irrigation farming systems and Irrigation farming system impose changes to daily water flow given economic options available to the farm production system. In addition, decisions made by an economic production system are influenced by water policy options. These are defined by an array of potential options as represented by the policy matrix in the conceptual framework. A policy option matrix is inclusive of a limited type of production system. For instance, any policy option pertaining to a change in a volumetric water allocation is restricted to influencing irrigation production systems. Similarly, water availability for the dryland farming node is affected by changes to the Farm Dams Policy.

The conceptual framework allows downstream trade-offs to be identified by linking flows to production systems in the catchment. Where this occurs, the link is defined by a routing of flows; given by 'R' in Figure 1. A second link occurs in the form of a conversion from daily flows to seasonal flows. The conversion to a larger time-space frame is made to better represent the time-space scale at which economic decisions are made. This occurrence is represented by 'C' in Figure 1. The exact interaction of production systems and the agricultural production system is unique to a Land Management Unit. Modelling nodes and Land Management Units (LMU) define the nature of model integration between system components

Figure 1: Conceptual Framework for model development



MODELLING NODES

System response is calculated at modelling nodes. A modelling node is a spatially defined point in the catchment that responds in a unique way to changes in model variables. More importantly, a node is the point at which integration between economic, land and water systems occurs.

In this study, modelling nodes were defined for the economic production systems, hydrological systems and habitat systems of Yass catchment. A Geographic Information System (GIS) was utilised to identify hydrological nodes based upon sub-catchment area and elevation. This allowed identification of flow inputs at points in the catchment as a result of run-off direction and tributary contribution. Run off and tributary input were required owing to the land management system and policy questions under analysis; namely the Farm Dams Policy, Salt Management Strategy and instream Water Allocation Rules (DLWC 1999b). The first two directly affect run off to streams while the second affects instream flows. The nodes were refined by identifying land management units (LMU's).

ECONOMIC PRODUCTIONS SYSTEM AS LAND MANAGEMENT UNITS

The purpose of defining LMU's was to identify economically homogenous areas that react in a defined way to system changes. Identification of each LMU proceeded by profiling economic production systems specific to the catchment system. Table 2 illustrates the features of all eight LMU’s. Within a land management unit, a set of current land use activities and potential alternatives were defined using biophysical attributes from a GIS and economic information about the current production systems. Seven alternative land management options were defined. Each option has a choice of at least two commodities. Table 2 illustrates the current activities, potential commodity production, and alternative land use options that are available to regional LMU types. In addition, each node and LMU combination has a series of potential water policy options. The policy option is defined by the production system and the nature of its link to the hydrological system.

Table 2: LMU type current production systems and potential alternatives under water policy options

Region and Node type	Current Activities	Alternative Activities	Policy Options	Water System link
1. Supplementary Irrigation	Rotational cropping, grazing	Viticulture, Olives Horticulture	Farm Dams Policy Environmental Flows	Farm Dam construction
2 Dryland	Grazing, Viticulture	Forestry	Salinity Management Environmental Flows	Run-off to streamflow
3. Irrigation /Supplementary	Irrigation, rotational cropping, grazing	Viticulture Olives	Volumetric Conversions Environmental Flows Farm Dams Policy	Farm dam construction Stream Extractions
4. Irrigation / Dryland Supplementary	Irrigation, rotational cropping, grazing,	Forestry Viticulture Olives	Volumetric Conversions Farm Dams Policy Environmental Flows	Farm Dams Stream Extractions
5. Dryland	Grazing,	Forestry	Salinity Management Environmental Flows	Run-off
6. Dryland / Suppl	Grazing, rotational cropping, Horticulture	Forestry Viticulture Olives	Salinity Management Farm Dams Policy Environmental Flows	Farm dams Runoff
7 and 8. Dryland	Grazing	Forestry	Salinity Management Environmental Flows	Run-off
9. Irrigation/Suppl	Irrigation, Rotational Cropping, Horticulture	Viticulture Olives	Volumetric Conversions Farm Dams Policy Environmental Flows	Farm Dams Stream Extractions

The decision to choose an activity is based upon a series of constraints that are defined quantitatively; formulated as a linear programming problem. Land use change is a function of water availability and economic viability of the operation. A decision to pursue an operation is defined by a series of economic decision rules as described in the next section. This part of the modelling approach invokes a series of economic techniques to achieve this.

Node Operation and Interaction in Space and Time

To assess trade-offs, nodes are linked by the operation of economic decision rules through changes to the hydrology of the catchment over time (a daily to seasonal time step). However, not all nodes are linked in a chronological order from the top of the catchment system to the smallest exit tributary. The characteristic of the water policy, the spatial position of the activity in the catchment as well as the length and type of the production cycle determine the type of integration between nodes. For instance, a Farm Dams policy option upstream also associated with a change to viticulture will impact upon volumetric conversion policy and any land use change option downstream. The link is not upheld for Farm dam policy elsewhere in the catchment with the exception of a link where a unique spatial feature allows links to take place through the hydrological system that is specific to Yass catchment. Figure 2 illustrates the nature of links as a result of activity choices associated with the water policy options. In summary, some nodes are skipped under the scenario analysis depending on the activity chosen or the policy selected.

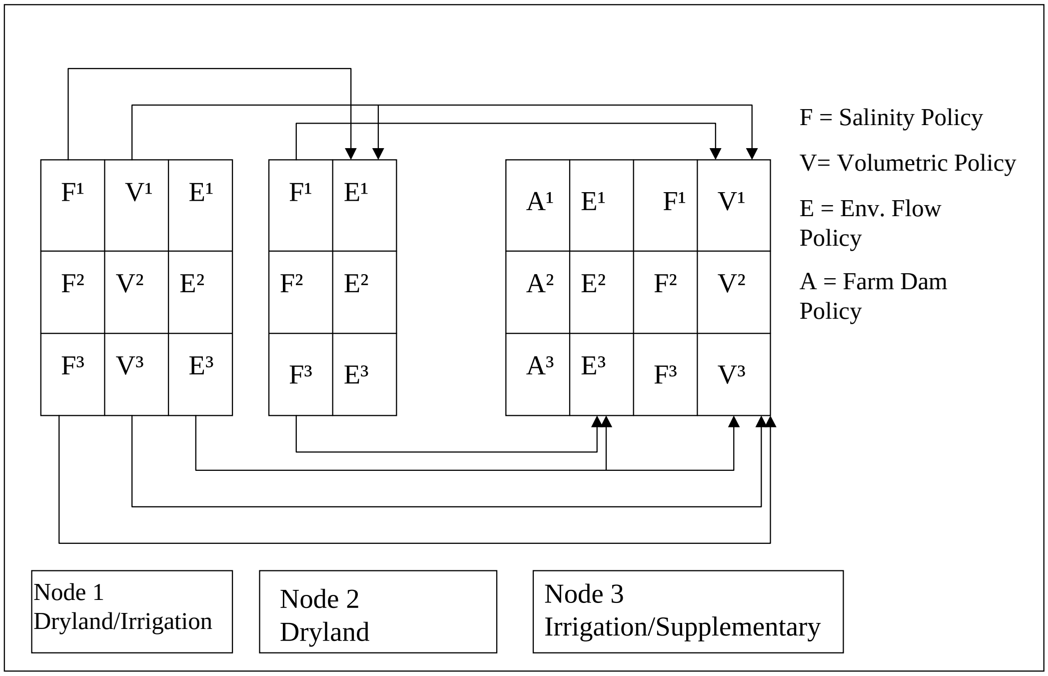


Figure 2: Policy Option Matrix defining interpolicy integration within the node system

The production cycle of activities in the catchment vary in time greatly. Short run decisions by activities with long production cycle have very little influence over the short run decisions of other activities as is the case for a forestry operation upon irrigation. The link may become stronger over time as runoff changes stream flow contribution. However, the short run decisions of some activities have an immediate impact upon short run decisions of other catchment activities such as the impact of diversion for farm dam development upon lucerne irrigation for a season. Thus, integration between activities varies in magnitude and strength of link over time. The next section uses an example to illustrate this.

ECONOMIC INTEGRATION: THE OPTIMISATION FRAMEWORK

The optimisation framework consisted of identifying production profile and economic decision rules over the short run initially. Long run production choices, involving choices between activities under a given water policy formed the second part of representing the catchments production system in time and space. This section describes the decision rules and the economic techniques for long run analysis.

Economic Decision Rules

Exogenous: Catchment Scale Economic Decision Rules and Effects

A key feature of Yass catchment system is the role of off farm income in supporting activities. This also produces an unusual relationship in the way labour is acquired and used on the farm. Value added activities use family labour to operate the activity. For other activities, off farm income is used to subsidise the activity. This feature is built into the modelling approach as a means of representing key economic parameters in the modelling approach.

In addition, a changing tenure system associated with land valuation influences the choice to pursue a rural activity. Thus, the decision to select an activity is not merely as a result of substitution between activities as a result of price changes for the commodity produced. These two aspects have been included in the modelling approach, identifying what are catchment scale decision rules influencing all activities.

Endogenous: Activity Scale Economic Decision Rules and Effects

In addition to economic factors that affect decision rules at the catchment scale, there are a suite of decision rules that determine the nature of the operation and what type of activity will take place at a given LMU. In the modelling approach, these represent short run production system decisions. Each decision rule is tied to the hydrological cycle, with a number of options varying in detail as a result of the level of integration.

Table 3 illustrates the simplest production system in the activity profile, the dryland cattle grazing system. Two parameters drive the farmers decision making with regard to the operation of the activity, namely rainfall and temperature. Information to make these decisions are integrated with the daily rainfall run-off model IHACRES. The dryland production system consists of four short run decisions to complete a production cycle.

Temporal Operation: Decision Rule, Short Run	**Integration Criteria**
Year 0-1: Initial Investment costs	Antecedent water availability will determine choice of grazing if availability is low (an annual estimate)
Year 1: A: Decision to grow out at 12 months as yearling feeder steers **or** B: grow out to 2 year grass fed cattle	A: no less then 25mm rain over a 2 week period for Autumn. Temperature no less then 18 degrees average seasonal B: Less then average conditions in rainfall and temperature
Year 1 Concurrent Decision: Pasture or Grain Fed cattle	Pasture Fed: Tied to Rainfall and Temperature conditions for the crop. Grow out as two year olds for less yield Grain Fed: Grow out as yearlings for a greater yield
Year 2: Decision to sell remaining cattle at end of season	Grazed cattle sold for less at end of second year
End Year 2: New Production Cycle	

Table 3: Economic Decision rules and their integration with the hydrological cycle (dryland production example).

Long run decisions are carried out with the aid of an optimisation framework. This determines the selection between a current and alternative activity over the scenario time frame of 20 to 25 years. The next section describes the economic techniques employed to carry the long run analysis out.

ECONOMIC TECHNIQUES

Linear Programming

A linear programming (LP) formulation was utilised to build a production system model of Yass catchment. At each modelling node, a profit maximising optimisation takes place subject to agronomic factors such as rotational timing, market conditions and hydrological conditions. The first two factors are determined by current prices as well as gross margin farm budgets. In addition, a set of economic decision rules is included in the model structure to determine water use through time and spatially.

The LP formulation was specified by an objective function to determine a profit maximisation at each node. The specification of the objective function was determined by the choice of economic technique utilised to maximise profit (Mills 1990). In Yass catchment, Cost Benefit Analysis was utilised for this purpose.

Cost Benefit Analysis

Cost benefit analysis (CBA) is utilised to determine an efficient allocation of resources spatially. It ensures that allocative efficiency is maximised by ensuring that the production of a commodity unit is equal to the cost of production (Dept. Of Finance, 1992)(Mishan, E.S,1982). In this study, CBA was utilised to conduct a short run analysis by investigating output decisions for a single chosen commodity given availability of water in the hydrological system.

The choice of production system is determined by a long run analysis. This is included by optimising profit over a multi-period model simulation (ie. 25 years). The optimisation is carried out by calculation of a Net Present Value (NPV) for a production option at a node. Therefore, the value of any activity is determined by summing the cash benefits of an activity (minus variable costs) over each year through time. In order to reflect value through time, a discount rate is applied over the simulation period. This produces a stream of net benefits through time. A simple decision rule is applied wherein, if the NPV is less then zero, production does not take place. Where a NPV is equal to or greater than zero, production takes place.

The objective function is therefore given by;

$$\mathrm{Max} \prod{}_{j} = \sum_{i}^{t} \left[\left(p_{ij} \bullet q_{ij} \right)_{t} - \left(V_{ij} \bullet q_{ij} \right) \right] \times \sum_{i}^{t} \left(\frac{1}{r} - \frac{1}{r(1+r)^{t}} \right)$$

where

i = commodity produced, j = region or land management unit

r = discount rate, t = time, p = price of the commodity,

q = quantity produced, V = total costs of production,

$\prod$ = profit,

In addition, the objective function is optimised subject to a series of constraints. The constraints define an array of physical and economic limits to operation of the activity. Land capability and soil type are examples of physical constraints on economic activities. The LP formulation does not place restrictions upon the spatial operation of activities by considering decreasing economies of scale endogenously. However, coefficients determined exogenously limit production by broad assumptions as to what is an economically viable operation in space. The dryland production system is the simplest model. Examples of dryland system constraints are given by the following equations;

$$\sum_{ij}^{t} q = \sum L_{ij} . S_{rij}$$

$$\sum_{ij}^{t} S_{rijy} = \frac{\sum T^{(t-t^0)}}{\sum S_{rcoeff}{}^{(t-t^0)}}$$

$$\sum_{ij}^{t} S_{rijy} = \sum R^{(t-t^0)} . \sum R_{fs}$$

$$\sum_{ij}^{t} R \le \sum R_{fs}$$

q = quantity of yearling and 2 year steers produced
L_{ij} = land available for activity i in region j
S_{rij} = stocking rate of all commodities in region j
S_{rijy} = stocking rate of yearlings in region j
T = temperature
R = rainfall
$R^{(t-t^o)}$ = average rainfall over the season
R_{fs} = coeffecient of rainfall to pasture growth
$S_{r\,coeff}$ = coefficient of temperature to pasture growth

The formulation represents a number of factors to produce one commodity in time, cattle. The constraints tie the economic decision rule to driving parameters in the farmers decision to grow out to yearling feeders or two year old steers, namely temperature and rainfall. The Grass-Gro model developed by CSIRO will be utilised to identify relationships between these two parameters and pasture growth for an season. As the constraint illustrates, if the average of the parameters is below a threshold determined by the Grass-Gro model, the model will choose to grow out the cattle to two year olds. The example illustrates how the model represents economic decisions in time. Spatial decisions are given by the available land constraint.

ECONOMIC ASSUMPTIONS

Key economic assumptions underlie the modelling approach. Further work will involve testing these assumptions and incorporating techniques into the approach for the purpose of appropriately representing economic production systems and their operation in Yass catchment. A fundamental assumption is no investment decisions that involve technological change. Thus, water use for each activity is static in time. Options available to a LMU are limited to current technologies. All operation are assumed to have a constant returns to scale. However, spatial growth occurs within an acceptable limit over the life time of the activity. The farming community operate within a small economic system with the result that all are price takers. There is no influence over market prices or demand as a result of land use change. The activity adjusts to changes in water over a short term by varying production. Over the long term, decisions to invest in an alternative is identified by a discount rate regardless of the time for an economic cycle to complete.

SCENARIO GENERATION

Scenario generation proceeds by perturbation of a policy option at a single node. A scenario is generated over the period of the longest production cycle at any node. Similarly, land use change takes place through the optimisation. As a result, the model structure allows the impacts of policy options to be identified at spatially defined places in the catchment. Trade-offs are measured at other nodes as a result of policy imposition at a pre-defined node. Limits on land use change as a result of available water, impact of the development of value added industries as a result of a 10% run off rule and environmental impacts are identified by the approach.

CONCLUSIONS

The modelling approach, although specific for Yass catchment and the Upper Murrumbidgee, is generic enough to be applied to other unregulated river systems. The approach could be utilised for other upper catchment systems that are undergoing land use change to value added agricultural industries. The analysis also assists the current lack of information as to how new water reforms will impact upon unregulated catchments. In this way, the model could be extended to a decision support system to aid the choice of water policy. In particular, the Farm Dams Policy, Salinity Management Strategies and in stream extraction rules.

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