Integrated Assessment
2003, Vol. 4, No. 2, pp. 73–89

1389-5176/03/0402-073$16.00

Application of an Adaptive Method for Integrated Assessment of Water Allocation Issues in the Namoi River Catchment, Australia

R.A. LETCHER[1] AND A.J. JAKEMAN[1, 2]

[1]Integrated Catchment Assessment and Management Centre, and [2]Centre for Resource and Environmental Studies,
The Australian National University, Canberra, ACT, Australia

ABSTRACT

Integrated Assessment is increasingly being applied to manage natural resource problems internationally. The development of Integrated Assessment models requires application of an adaptive process of model development, incorporating both stakeholder and scientific knowledge in model development. Such a process should allow the development of trust between stakeholders and scientists to help overcome conflicts arising from model application. This paper outlines one such adaptive approach to Integrated Assessment modelling. It examines an integrated assessment model which has been developed using this process to assess long term outcomes of management options for water allocation in the Namoi River catchment, Australia. The development of this tool has been undertaken using an iterative approach with key stakeholders. The approach embraces collaboration with relevant stakeholder groups on the issues to be addressed by the model (conceptualisation, regional discretisation, system knowledge, scenario framing and results) and preferred future directions of model development. A key aspect of the model framework is that it has been developed to be sufficiently general for reapplication and extension to a wide range of water allocation issues in other catchments. Lessons are drawn from this experience in framework development for the field of integrated assessment.

Keywords: Integrated Assessment, agricultural production modelling, hydrology, stakeholder participation.

1. INTRODUCTION

Integrated assessment (IA) of natural resource management issues is increasingly being adopted by Government agencies internationally. In Australia, the concept of Integrated Catchment Management has been strongly supported at both the national and state level (e.g., [1]). However, the development of integrative tools for assessing the trade-offs involved with various policy and regulation options is at an early stage.

Park and Seaton [2] stress the importance of linking scientific research to policy, and see the need for an integrated approach, particularly with the social sciences, for making this come about. Geurts and Joldersma [3] state that 'policy analysts that use traditional formal modeling techniques have limited impact on policy makers regarding complex policy problems.' They argue that 'these kinds of problems require the combination of scientific insights with subjective knowledge resources and improved communication between various parties involved in the policy problem.' Villa and Costanza [4] propose that different modelling approaches need to be integrated into higher-level simulation models because of the 'increasing complexity and multidisciplinarity of environmental research and management problems, the spatial and cultural delocalization of research groups, and the increasing recognition of the need for a multiplicity of scales to be considered at the same time.'

Parson and Fisher-Vanden [5] support integration stating that '[i]t is plausible that most useful assessment is integrated to some degree, since few real policy issues or decisions can be usefully advised by drawing only on the knowledge of a single research community.' Rotmans and Van Asselt [6] stress the importance of integrated models to allow for analysis of the dynamic behaviour of complex systems and to show the interrelations and feedbacks between various issues. They maintain that integrated models are useful to make uncertainties explicit, to analyse accumulation of errors and to develop end-to-end strategies. They state that 'integrated assessment models can help in framing the relevant issues and signifying the policy challenges. Such models can be outstanding means of communication among exponents of all kinds of disciplines as well as between scientists and decision makers.' Risbey et al. [7] support the use of integrated assessment techniques suggesting that the unifying nature of integrated assessments provides insights into system processes, such as feedbacks,

Address correspondence to: R.A. Letcher, Integrated Catchment Assessment and Management Centre, Building 48a, The Australian National University, Canberra, ACT 0200, Australia. E-mail: rebecca.letcher@anu.edu.au

non-linear phenomena and uncertainty, that are not able to be provided through analysis of single causal links. They stress that integrated assessment and modelling (IAM) is more than just a model building exercise, it is also a 'methodology that can be used for gaining insight over an array of environmental problems spanning a wide variety of spatial and temporal scales.'

Rotmans and Van Asselt [6] define IAM as 'an inter-disciplinary and participatory process combining, interpreting and communicating knowledge from diverse scientific disciplines to allow a better understanding of complex phenomena.' They stress the importance of integrated assessment models as frameworks to organise recent disciplinary research and note that the explicit purpose of IAM is to inform policy and to support decision making. They argue that IAM, as an intuitively based process, is not new and conclude that the new element in IAM is the use of integrated frameworks such as conceptual frameworks or computer-based simulation models. They note the ideal state of IAM as an iterative process of investigation and recommendation, stressing the importance of communication not only of results from scientists to decision-makers, but also of lessons learned by decision-makers and the visions and views expressed by society, from stakeholders back to the scientist. Jakeman and Letcher [8] summarise the common features of IAM and illustrate their importance in three case studies. In particular, they state that there is a need for generic frameworks for integrated models but that it is 'mainly by continuing to perform IA on specific problems that this emergent discipline [IAM] will fully mature.' Parker et al. [9] discuss the current state of the science of IAM. They conclude that 'IAM needs to focus on moving forward beyond single issues to improve broader ecological sustainability, to improve decision-making, to integrate insights from natural and social sciences, to seek validation of IAM processes, and to maintain integrity and rigour through openess, transparency and honesty in the processes used.'

This paper provides details of an adaptive approach to integrated assessment modelling. This approach was applied to an integrated assessment project that was undertaken in the Namoi River Basin in northern New South Wales (NSW), Australia. The project focused on the development of an integrative modelling framework for considering water allocation issues in the catchment. Integration in this project involved both an integration of disciplinary approaches (principally economics and hydrology) as well as the integration of stakeholders into the model development process. The modelling framework could also be extended to include a larger range of issues, such as water quality or biodiversity. This paper outlines background to the framework developed and then discusses feedback from stakeholders on their views of the advantages and limitations of the modelling approach. Several lessons for integrated assessment and modelling arising from this project are also discussed.

It should be noted that this paper describes only one approach to integrated assessment of water resource management issues. Many recent studies have focused on this theme, across a broad range of countries and management issues, and utilizing a variety of modeling approaches. Key examples are European Union (EU) projects such as MULINO [10, 11], FIRMA [12, 13], IRMA [14] and IRMLA [15], as well as non-EU projects such as the IWRAM project [16, 17], INSIGHT [18] and the SWIM project [19, 20]. A comprehensive review of these and other integrated water resource projects is outside the scope of this paper.

2. AN ADAPTIVE METHOD FOR INTEGRATED ASSESSMENT

Integrated Assessment Modelling focuses on developing modelling frameworks that are understood and 'acceptable' to scientists as well as stakeholders. IA is a problem driven science, where assessment is focused on integrating perspectives from researchers from different disciplinary backgrounds, as well as from various stakeholder groups to solve real world natural resource management problems. This type of modelling calls for an adaptive, on-going approach to model building where models are developed through a number of iterations of stakeholder consultation. This is in order to allow for trust to develop between stakeholders and researchers and to allow the evolving system understanding to be taken on board by those involved in the assessment.

Figure 1 demonstrates one such adaptive integrated modelling process. It shows the flow of information between model development, stakeholders and researchers. It is important to note that scientists learn through their interaction with stakeholders, as stakeholders learn through their interaction with scientists. All communication flows are two way, rather than uni-directional. Concepts such as extension and education are important in Integrated Assessment but are in no way confined to a flow of information from scientists to stakeholders. In this way stakeholders

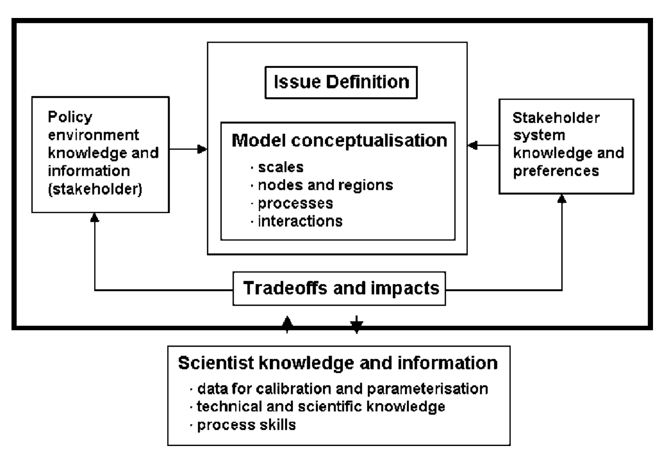

Fig. 1. Model development process.

'collaborate' in a much truer sense rather than 'participate' in the assessment.

Issue definition and model conceptualisation critically depend on knowledge and information provided by stakeholders, both on the policy environment and on the key systems and processes considered, such as agricultural production decisions. The lessons available from various iterations of model development are then passed back to these stakeholders and the issue definition and model conceptualisation are refined using additional stakeholder driven information. Outputs from the model showing trade-offs and impacts, as well as details of the assumptions and other model issues raised during the conceptualisation, help to inform stakeholders. This changes their system understanding and influences their preferences. Throughout this process scientists inform the assessment through their knowledge and skills as well as enhancing their own system understanding through the model development process and their interaction with stakeholders. Thus this framework describes an adaptive and integrated approach to model building.

Timeframes involved with this iterative process are longer than those associated with other Integrated Assessment processes (for example, processes such as AEAM [21, 22] where models are generally built in real time during modelling workshops with the collaboration of stakeholders). Longer timeframes in model development (e.g., development of the model over several years) are considered necessary for several reasons:

- in order to build trust with various stakeholder groups and allow an opportunity for stakeholders not present at initial meetings to come forward to comment on model conceptualisation and development throughout the process of model development. Generally stakeholders feel they understand the model to a point, but would require further testing and explanation before being completely confident in accepting model outcomes, or understanding where their application is appropriate. A longer timeframe allows stakeholders to develop confidence in publicly questioning model assumptions and outputs as well as building trust between stakeholders and scientists.
- to allow more complex 'scientist' based knowledge to be incorporated with stakeholder knowledge in the system. This is particularly the case with biophysical components of the system, where comprehensive scientific knowledge of the system may already exist or may be attainable with further measurement or monitoring. Short time frames often mean that components are modelled very simply or using assumptions that are not well tested or scientifically sound. Longer time frames allow models of appropriate complexity for the problem to be developed incorporating not only the best available stakeholder understanding but also the best available scientific understanding of the system.
- to allow stakeholders more time to gauge their reactions to various components of the model conceptualisation. In many cases stakeholders raise issues which they would like to be considered and tested in the system. These issues are often raised in a 'what if' framework rather than being a final conclusion on components that should be changed. Stakeholders may feel that something is not necessarily represented the way they consider it, but would like more information on the way in which the assumption interacts with the system before deciding before or against its inclusion. It is also important to realise that stakeholder knowledge, not just scientific knowledge, changes and adapts as a project develops. Short time frames do not allow stakeholders time to reflect on their increased understanding and to map this to their previous system understanding. Often it is the insights gained through this process that illustrate many of the issues not previously considered by scientists.

The next section outlines an integrated assessment project considering water allocation issues in the Namoi River catchment, Australia. The adaptive approach to modelling outlined above has been developed and applied in this case study.

3. WATER ALLOCATION IN THE NAMOI CATCHMENT

The Namoi River Catchment, covers approximately 42,000 km^2 in northern NSW, Australia and is an important irrigation area (see Fig. 2). Groundwater and surface water supplies are 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 surface water, and groundwater. Groundwater allocations for extraction in many areas of the catchment currently exceed 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.

Off-allocation water is water that spills from the dams, or that flows into the regulated system from the unregulated system (i.e., from tributaries into the river below the major storages). This water 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. These off-allocation extractions are not counted against the users' licensed allocations (see, for example, [23]). Off-allocation water is usually made available during periods of high river flow (generally corresponding to the winter months in the Namoi catchment). Producers then store the

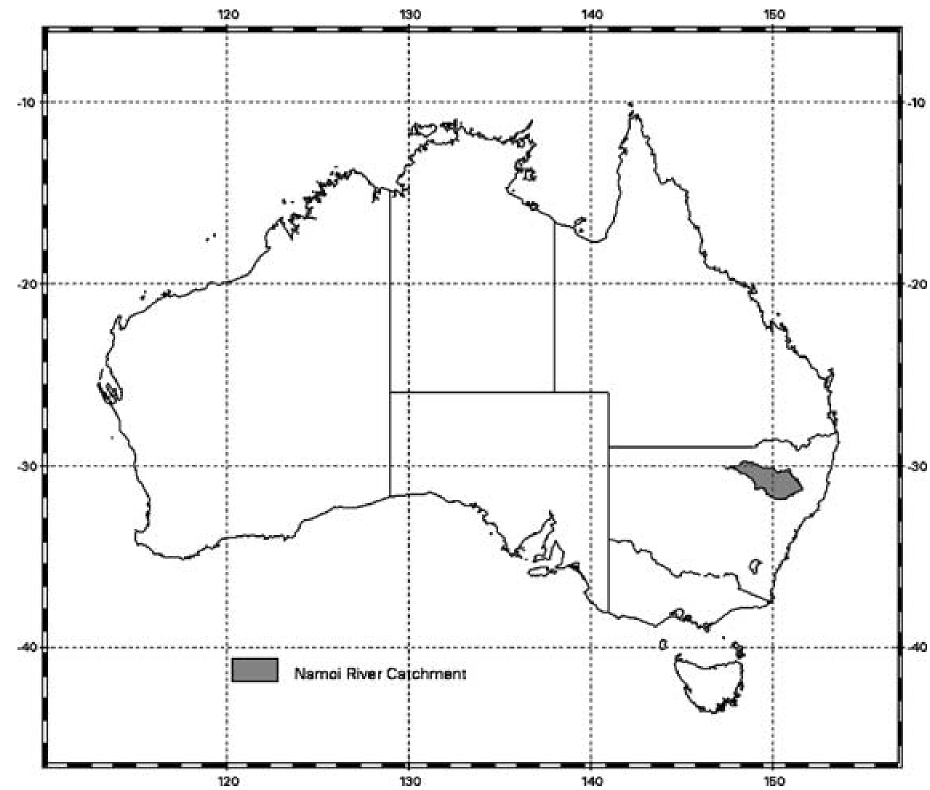

Fig. 2. Namoi River Catchment.

water for the irrigation season in on-farm storages. 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 [24]. In the past no property right has been given over this off-allocation water, with access being at the discretion of the NSW Department of Land and Water Conservation. The lack of such defined property rights or licences to this resource has resulted in off-allocation water being viewed as part of a solution to water allocation problems in the catchment.

Particular water allocation policies which were in the process of being implemented while the model was being developed, and which needed to be incorporated in the model framework include:

1. Volumetric conversions on unregulated river reaches. Surface water licences on unregulated river reaches were previously determined on an area basis. Reforms implemented in NSW involved breaking the ties between land and water and converting these licences to a water volume. This conversion process included an assessment of the historical crop water requirements met by these area based licences, water availability and climate zone.
2. Development of daily flow allocation rules. These rules involve commence and cease to pump volumes, as well as daily extraction limits, applied on a river reach basis. These rules are being developed to protect key environmental flows while maintaining irrigator access to flow. At the time of writing this paper, a general version of these rules had been developed but modifications necessary for implementing this on individual reaches had not been made.
3. Groundwater allocation reductions. Groundwater allocations are to be reduced by up to 70% in some groundwater zones in the catchments. These reductions are to be phased-in over a 5–10 year period, varying by zone, depending on the magnitude of impacts likely to result from these changes. Zones where impacts are expected to be large have a longer phase-in period.
4. Development of water sharing plans, including rules for sharing off-allocation flows between individual agricultural users and between such users and the environment. At the time of writing this paper these water sharing plans had yet to be finalised and signed off on by the Minister. Draft versions were available however.
5. Implementation of the Murray-Darling Basin Cap. This is a Cap on diversion, set to the volume of water that could have been diverted under 1993/94 levels of development. The performance of each valley in the Basin (including the Namoi River) is measured. The water sharing plans contain strategies for reducing water use in line with the Cap in the case of increased growth and development. This growth could include activation of sleeper licences, that is, licences which have been allocated to farmers but

have not been used. These licences exist in all three (groundwater, regulated and unregulated) systems.

6. Development of water trading in the catchment. Temporary and permanent transfers of water allocation are allowed under water trading rules. Currently the DLWC assesses potential water trades on an individual basis. Generic rules for inter and intra-valley trade have not been developed.

The next section briefly outlines an integrated hydrologic-economic model which has been developed to investigate the following management question:

What are the trade-offs involved with different policies 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 [25];*
- *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.*

4. MODELLING FRAMEWORK

The management question outlined above involves both spatial and temporal features which needed to be considered by the modelling framework. The problem is intrinsically spatial in nature, as it relates to trade-offs between environmental and production values in different parts of the catchment for different 'types' of users as a result of policy implementation. For example, even where the catchment as a whole is made better off economically, this may have negative impacts on small groups of users in particular parts of the catchment, or on the environment. These spatial trade-offs can be considered as upstream-downstream trade-offs. The two features of the framework which allow it to consider these types of spatial trade-offs are:

- the regional-scale agricultural production (economic) model framework. The catchment has been divided into a number of relatively homogenous regions, each of which is modelled as though it is controlled by a single profit maximising farmer (further details are given in Section 4.1). This framework is used to consider the spatial nature of economic impacts throughout the catchment arising from various policies. It allows model users to see which industries are affected as well as to evaluate the differing effects of policy on users in different parts of the catchment.
- the nodal network structure used for hydrological modelling and for integrating the hydrology with the economics. Details of this structure are given in Section 4.3. This structure allows the impacts of upstream water use on downstream water users (through changes to water availability) and the environment to be evaluated.

There are three ways in which the model accounts for key temporal features of the system. These are:

- a long-run economic decision making model is used to simulate agricultural production decisions. This model considers investment decisions relating to three key types of capital: area laid out to irrigation; the level of on-farm storage capacity; and, the level of water use efficiency. The model simulates farmers as being able to invest in any of these three types of capital at any time over the twenty-year simulation period. This has been included in the model structure to account for the ability of farmers to adjust away from negative economic impacts in the face of policy change. It also reflects the uncertain nature of off-allocation and unregulated water supply in the catchment. This uncertainty means that farmers must have access to considerable volumes of on-farm storage capacity to be able to use these water resources. Any policy which looks at redistributing these supplies between farmers must account for the ability of farmers to use this water given existing storage capacity as well as the costs involved with increasing capacity to the levels required to access these resources.
- annual production decisions (i.e., the crop rotations to plant each year) are simulated each year over the twenty-year simulation period. These are sensitive to varying annual resource limits including the phase-in of groundwater allocation reductions and variability resulting from the interaction between climate, policy and water availability.
- daily flow models are run over the simulation period to allow the calculation of water availability given daily flow extraction rules. These models also allow for the calculation of the impacts of extraction on daily flows, both at the site of the extraction, and at other sites downstream.

The following sections describe the components of the modelling framework in more detail as well as the way in which the hydrological and economic components of the model are integrated.

4.1. Regional Agricultural Production (Economic) Model Framework

Irrigators have different access to surface and groundwater sources throughout the catchment, with different types of licences and different levels of security of access. This means that the question of where to provide access to off-allocation water involves a trade-off between upstream and downstream users, and is intrinsically spatial in nature. Thus to address this issue a framework that accounts for the important spatial variability of this management problem is required. For the consideration of this off-allocation problem, this required that the catchment be mapped into a number of relatively homogenous regions. The term 'relatively homogenous' is with respect to important economic and social scales for water allocation in the catchment. In the case of off-allocation access, this means that regions are chosen to be relatively homogenous in terms of groundwater policy, surface water

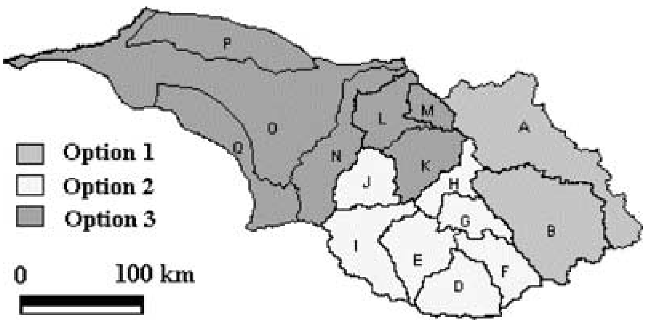

Fig. 3. Region definitions and their land use options for Namoi Catchment.

Table 1. Main Regional Features for the Water Allocation Model.

Region	Description	Stream gauge[a]	LU[c]
A	Above Keepit	419022	1
B	Peel River	419006	1
D	Mooki River catchment to Caroona	419034	2
E	Western side of Mooki River catchment from Caroona to Breeza	419027	2
F	Eastern side of Mooki catchment from Caroona to Breeza	419027	2
G	Mooki River from Breeza to Gunnedah	419084	2
H	Namoi from Carroll Gap to Gunnedah	419001	2
I	Cox's Creek above Mullaley	419052	2
J	Cox's Creek Mullaley to Boggabri	419032	2
K	Namoi River from Gunnedah to Boggabri	419012	3
L	Namoi River from Boggabri to Narrabri	419002	3
M	Maules Creek	419051	3
N	Namoi River from Narrabri to Mollee	419039	3
O	Namoi River from Mollee to Walgett	419026	3
P	Pian Creek	419049	3
Q	Barradine Creek	[b]	3

[a][26] Pinneena data base gauge numbers.
[b]Ungauged calibration used (see [27]).

[c]Land use options:

Option 1 (Regions A and B)
1. Irrigated Lucerne
2. Dryland Wheat

Option 2 (Regions D,E,F,G,H,I,J)
1. Irrigated wheat/cotton rotation
2. Dryland wheat/sorghum rotation
3. Dryland wheat/cotton rotation

Option 3 (Regions K to Q)
1. Irrigated cotton/wheat rotation
2. Irrigated continuous cotton
3. Irrigated cotton/faba bean rotation
4. Dryland cotton/wheat rotation
5. Dryland sorghum/wheat rotation

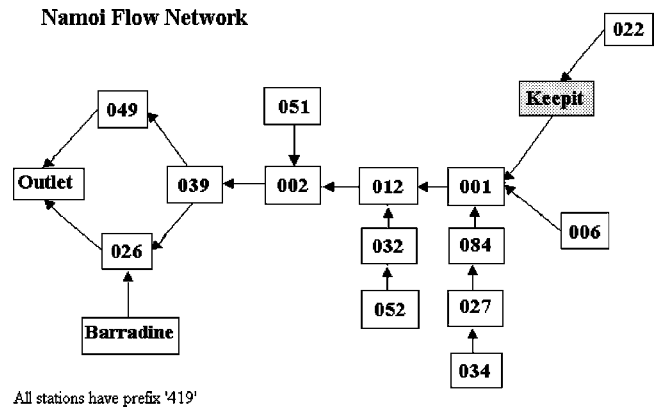

Fig. 4. Hydrological Network for the Water Allocation Model of the Namoi Catchment.

policy and production type. The development of these regional boundaries involved an iterative process with stakeholder input into each stage of model framework development. Details of stakeholder participation in the issue framing and model development stages of this project are in Section 5.

A first disaggregation into regions was developed by overlaying groundwater zones and subcatchment areas, and was further refined on the basis of advice on regional production differences provided by various stakeholders. The final regions developed in this framework are shown in Figure 3. A summary of the major features of these regions is given in Table 1. A set of alternative cropping activities was developed for each region. These activities represent those likely to be undertaken in each region on potentially irrigable land.

Each region also corresponds to a hydrological node (regions E and F share a hydrological node, other regions have a unique node). These are the stream gauge sites stipulated in Table 1 and Figure 4. Fortunately for most regions the regional disaggregation was of a sufficiently large scale that there remained a stream gauge, with historic recordings of flow, that could be used as nodes. The exception to this was Barradine Creek (Region Q) where the only gauge was too high up in the catchment to be used to represent flow at the node. In this case an 'ungauged' model, which used model parameters derived from physical characteristics of the catchment, was used to simulate flow at the catchment outlet. Details of this can be found in [27]. This integrated model structure, of regions and a corresponding nodal network of flow, forms the basis of the links between hydrological and economic components of the model.

4.2. Agricultural Production (Economic) Model Description

Each of these regions is modelled as though controlled by a single profit maximising farmer. Farmers may choose in the long run to change their area laid out to irrigation, on-farm storage capacity and/or irrigation efficiency. This choice is modelled using a dynamic programming approach. Short run production decisions in each year are then modelled using a set of nested linear programming models, according to constraints on the amount of water and land available. The model considers only potentially irrigable land, and considers dryland cropping as the only alternative to irrigated cropping (i.e., grazing is not considered by the model). Further details on the agricultural production model formulation are given in [28].

4.3. Hydrologic Network

Each of the regions shown in Figure 3 is linked to a flow node. The hydrological network used in the model is shown in Figure 4. The integrated model uses the IHACRES model [29, 30] to represent rainfall-runoff generation. Flow routing between nodes is done using a simple transfer function approach.

This flow network provides the limits of surface water extraction and allocation in each of the regions detailed in Figure 3 and Table 1, and can be considered to provide some of the constraints in the regional agricultural production model. Additionally any extraction decision made in each region can be fed through the hydrological network in order to determine the impacts of different allocation decisions on catchment discharge.

A detailed description of the hydrological modelling undertaken in this case study is given in [27].

4.4. Links to the Hydrology

The economic and hydrological models, as described above, are linked by two models as shown in Figure 5. The first of these models, the policy model, mimics daily extraction rules and other off-allocation and regulated system policy rules which have been suggested in NSW. The daily flow extraction rules are based on a series of flow classes, with maximum extraction rules in each class for each subcatchment. This model takes daily modelled streamflow and calculates from this an annual extraction limit for unregulated, regulated and off-allocation water in each region. The second link is through the daily extraction model. This model takes the annual extraction decision from the agricultural production model and uses it to determine daily flows left after extraction. These extracted flows are then routed downstream. In this way, production decisions at upstream nodes impact on resource availability at downstream nodes.

4.5. Model Assumptions

The key assumptions made in the model formulation are summarised in Table 2. This table demonstrates the comparatively large number of assumptions which are required for such a large integrative model. Further discussion of model assumptions and stakeholder reactions to these are given in Section 6.

4.6. Model Evaluation

Traditionally, validation of models has required a well known combination of 'history matching' and 'peer review' (for e.g., see [9]). However these traditional norms are not sufficient, or often not even possible, for most integrated assessment models.

[31] defines validation as evaluating a model's forecasting ability on 'data *other than that used in the identification and estimation studies*.' He states that the 'validation exercise is a continuing procedure since the model will need to be reassessed in the light of future developments and additional data.' While this validation paradigm is sufficient (and possible) for many purely disciplinary models, for integrative models it is often not possible, as data are not normally collected that are capable of being compared to such integrative outputs. An additional consideration is the difficulty in identifying parameters in integrative models. Fitting a single or even multiple time series with a model containing up to hundreds of parameters (as is the case in many integrative models) is not sufficient to consider the model valid, as the degrees of freedom available are too great for this test alone to prove a model valid or otherwise (as without secondary data, it is impossible to uniquely identify the parameters in such a complex model). Thus a more comprehensive process of evaluation which does not rely heavily on history matching of all model outputs is required for integrative models.

By contrast to this traditional approach to validation, [9] state that 'the essential, contemporary questions one would like to have answered when seeking to evaluate a model (are):

(i) Has the model been constructed of approved materials i.e., approved constituent hypotheses (in scientific terms)?
(ii) Does its behaviour approximate well that observed in respect of the real thing?
(iii) Does it work i.e., does it fulfil its designated task, or serve its intended purpose?

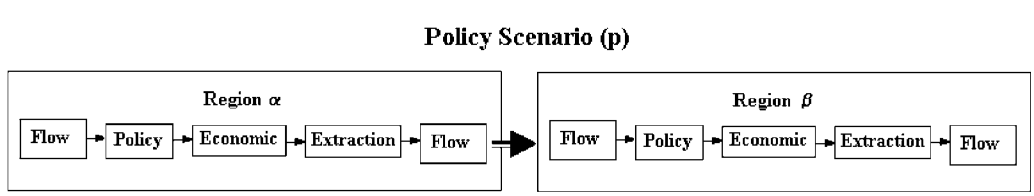

Fig. 5. Conceptual framework for the model.

Table 2. Namoi model assumptions.

Assumption	Comment
Agricultural production model	
1. Constant returns to scale	A constant short run return per unit area (price, yield, cost) is assumed
2. Complete divisibility of land and water resources	This implies that paddock constraints on land use are not important
3. Perfect knowledge	Farmers are able to know the exact price, cost and yield of all production, as well as available water before they make decisions
4. Farmers act solely to maximise profit	Social and lifestyle preferences and constraints are not included
5. Production choice is limited only by available land, water and irrigation capital	Labour constraints and also disease or pest problems caused by back-to-back rotations of the same crop are not considered. Also non-irrigation capital is not considered
6. Sufficient non-irrigation capital (e.g. tractors) exist for any land use choice available in the model	The model focuses on 'irrigation capital' only, not other types of capital required to run an enterprise
7. The limited choice of crop rotations considered by the model is sufficient to capture the major differences in the production system between regions	This assumes that the differences between dryland versus irrigated cropping dominate compared to different dryland or irrigated crop rotations
8. Farmers choose to use their water in a specific order (groundwater, regulated water, unregulated water, off-allocation)	This is a simplification which comes from assuming that each region is controlled by a single farmer – actually farmers have different access to water and so would use water from each of their available sources depending on needs and availability
9. On-farm storage capacity volumes are able to be determined from storage surface using a relationship determined for a small group of storages on the Mooki system	Survey data was used to develop a relationship between storage surface area and volume – this was then applied to a data set of storage surface areas across the catchment
10. The costs of investing in various forms of capital are constant per ML or Ha	This assumes constant costs to scale for capital investment
11. The irrigation efficiency of entrants (i.e. activating sleepers) is the same as incumbent users	Stakeholders commented that there were good reasons why efficiency of entrants could be either greater than or less than that of incumbents
12. Labour costs (etc) are the same for new areas laid out to irrigation as for pre-existing areas	A constant labour cost per hectare was assumed for different crop rotations
Policy model	
1. The Commence/cease to pump (CTP) and extraction limits were calculated using instructions in draft documents from the DLWC	These are currently out of date with what is being signed off by the Catchment Management Board
2. Distribution of CTP and extraction limits is possible within subcatchments using the methods described in [28]	The way in which this will be done in reality has not yet been determined
3. Allocations are as given by the best available data	These data have been extrapolated where necessary using area to volume relationships
Extraction model	
1. Annual unregulated and off-allocation extraction is distributed proportionally to possible extractions determined by the crop model	
2. Regulated water releases occur and are extracted during the year according to historically determined average releases by month	
Hydrological model	
1. Constant infiltration per unit river length	This was estimated using historical data between two gauges down one stretch of the river
2. The period where models have been calibrated is representative of 'natural' i.e. pre-extraction flows	
3. There is no explicit link between the river and aquifers in the catchment except through infiltration losses from the stream and through slowflow occurring within a catchment	
System	
1. Crop yields are independent of climate and soils	
2. The Peel River is unregulated and managed as a part of the Namoi catchment. Chaffey Dam is ignored	
3. Keepit and Split Rock dams are treated as a single dam	

They conclude that the process of evaluating Integrated Assessment Models is 'likely to be less dependent on the previous convention of classical peer review and history matching and more dependent on protocols and tests yet to be developed.' They suggest the importance of process over final content in Integrated Assessment and Modelling (IAM) may mean that a protocol of evaluation may be needed more for the 'evolving structure and content of IAM, as opposed to the eventually finished product.'

[7] suggest that in order to establish quality control measures in integrated assessment the following features must be considered:

- Assumptions – it is important not only to document assumptions and make them explicit but also to examine their implications for model results and the implications of alternative sets of model assumptions.
- Anchoring – there is a tendency for certain reasonable results to become established within the IA community. This is a problem because the community becomes anchored not only to the results but also to the assumptions which produced the result without these being made explicit or being questioned. This is especially a problem where future work is then judged not on its internal consistency but on the agreement between the results of that work and other 'established,' reasonable results.
- Transparency – the adequacy of the whole model, not only each of the component parts must be tested. In order to establish transparency and reproducibility, model results and insights must be traceable through the model structure to the starting assumptions and input analysis. Transparency issues must be considered at all times in the modelling process.
- Diversity – it is important to recognise that ideological and disciplinary backgrounds influence the selection and integration of different disciplinary components in integrated assessment studies. The inclusion of the broadest possible range of perspectives is vital in ensuring legitimacy for IA.
- Use of results – results from IAM are intended for use outside the modelling community, so that integrated modellers cannot assume that end-users of information know how to use and interpret the results. It is vital then that results are accompanied by instructions on the appropriate and inappropriate use of results and insights from the analysis.
- A place for dirty laundry – problems experienced in constructing complex integrative models need to be openly discussed in order for solutions to these problems to be found, and to facilitate the appropriate level of trust in model results.

Ravetz [32] argues for validation (or evaluation) of the process, rather than the product, of IAM stating that in such circumstances 'the inherently more difficult path of testing, of the process, may actually be more practical.' He finds that in general 'the quality of a model is assured only by the quality of its production.'

However the fundamental components of such a validation or process, or even the recipe for 'good practice' in IAM, have yet to be established. Ravetz [32] states that good practice will need to include an 'uncertainty and quality audit' on scientific information which will be required to enable users to make their own reasoned judgments of its strengths for their purposes.

Following this line of reasoning, the model described in this paper has been (and will continue to be) evaluated using a range of criteria. Largely these criteria have been based on evaluating the process by which the model has been developed. In this way, there is no statement of the validity or otherwise of the model. Rather, a number of criteria have been investigated and openly analysed to allow stakeholders, readers and future model users to judge for themselves the validity of the model for their purposes. The components of this evaluation include:

1. Testing and traditional validation of individual model components, such as the hydrological models calibrated for the catchment. Limitations of these individual component models have been openly discussed and analysed (see [27, 28]).
2. Testing of the plausibility of outputs given inputs of the integrated systems model (including presentation of this to a broad range of stakeholders to gauge their reactions to output changes).
3. Complete disclosure of the structure of all component models, their input data and assumptions, and the process by which stakeholders have been included in the model development.
4. Delineation of the major limitations of the system model including those components of the model that have been marginalised by the use of simplifying assumptions. This includes a discussion of the implications of these simplifications for results from the model.
5. A limited uncertainty analysis of the whole model has been undertaken. This has been presented to local stakeholders for their feedback.
6. Presentation of all the above information to local stakeholders and inclusion of their evaluation of the model, and the process by which it was constructed.
7. A review and documentation of many of the model's assumptions and their implications for recommendations produced by the model.

Full details of this evaluation are given in [27] and [28]. This is obviously not a complete validation in a traditional sense (although it contains components that a traditional validation would not). It is hoped, however, that it provides sufficient information to allow policy makers and other stakeholders to evaluate the usefulness (or otherwise) of the model for their purposes. It should also be stressed that this evaluation process is on-going as the model is adapted and updated according to stakeholder feedback.

5. STAKEHOLDER INTERACTION

In the context of this project, the term 'stakeholder' is used to refer to local community members, staff at the various departmental offices within the catchment and members of the various River Management Committees (RMCs) operating in the catchment. RMCs are themselves composed of representatives from Government departments, irrigators and environmentalists. Stakeholders have been utilised in several ways in the development of this model framework as discussed in the following sections.

5.1. Issue Framing

Initial choice and focusing of the modelling issues, and the alternative management options available, were determined using stakeholder views and concerns expressed in different fora. Nancarrow et al. surveyed stakeholders in the catchment regarding re-allocation of groundwater and the development of environmental flows in the catchment. These surveys demonstrated many of the allocation concerns of various stakeholders in the catchment, as well as identifying stakeholder priorities and preferences with regard to re-allocation policies [33, 34]. These surveys provided important background information for scoping management issues in the catchment, the complexity of the water allocation issues in the catchment and possible solutions seen by stakeholders to these problems.

A meeting of the Unregulated, Regulated and Groundwater River Management Committees was also held in the Namoi catchment in August 1999. This meeting brought together members of all these committees for a facilitated discussion of management issues and priorities in the catchment. Attendees were required to identify the needs and immediate concerns of each of these committees as well as the community as a whole, to identify areas of overlap between these needs and issues, and to identify alternative options to address these requirements. The outcomes and discussion that took place during this meeting were observed and documented. They were used to focus attention on management issues in the catchment, in particular water allocation, and the alternative options available to the catchment managers. Of particular interest and concern was the fact that access to off-allocation water was identified by all three committees as a possible solution to their management issues. The focus of this project and initial ideas for alternative management scenarios arose from attendance at this meeting.

5.2. Model Development

Definitions of relatively homogeneous regions were refined using an iterative process with various stakeholders. An initial definition of regional boundaries and features was taken to the stakeholders for comment. These comments were elicited through a series of small, informal group meetings with stakeholders. Stakeholders were invited to comment on the appropriateness of regional boundaries and the regional structure was progressively refined with the comments of various stakeholders, using local knowledge of production systems and resources in the catchment. In this way stakeholders were encouraged to understand the way in which the model was being constructed and the assumptions behind its construction. This involvement was also important in allowing stakeholders to query and, in many cases, correct modelling assumptions. It is felt that this process assisted stakeholders and researchers in acquiring a better understanding of the assumptions and limitations of the model, as well as in having greater appreciation of the strengths and limitations of the model developed and its outputs. Stakeholders were also consulted on alternative management scenarios that they wished to be considered by the model. Their knowledge of various aspects of the production system was used to determine not just the current characteristics of each region, but also to identify alternative resource use and management scenarios that could be employed by producers in each region. This interaction was to ensure that the model represented the needs of catchment stakeholders as well as system details.

5.3. Model Testing and Communication of Results and Conclusions

The model developed was presented to a variety of stakeholders during a series of public seminars and discussion sessions. Details of model input assumptions, structure and also advantages and limitations of the approach were given. Stakeholders were then asked to provide feedback on numerous issues, including whether or not they felt the model would be useful for policy, and what future they would like the model to have (if any). In the first instance feedback was informal, through observation and documentation of comments provided by stakeholders during and after these sessions. There was also an opportunity for formal feedback, in the form of a written questionnaire.

It should be noted that the model described in this paper is thus considered to be a ‘first pass’ model. This is because stakeholder feedback described in this paper provides considerable direction on modifications and additions which may be undertaken in the future. In this way the modelling process is both adaptive and iterative.

6. STAKEHOLDER FEEDBACK

Final feedback on this ‘first pass’ model was sought from a large group of stakeholders through a series of public seminars and discussions. A detailed presentation on the model structure, input data assumptions and results was given at each of these public seminars. This presentation also included an open discussion of the intended purpose of the model and limitations of its current state of development. Stakeholders provided feedback on the model both verbally during and after these presentations, as well as in writing through a feedback questionnaire (which could be answered anonymously). This section provides details of some of the responses of stakeholders to the model. Stakeholders were also asked to prioritise their preferences for future developments of the model. The key areas stakeholders were asked to comments on were: advantages of the modelling approach; limitations; preferences for additional model components; assumptions in the model; results; ownership; and, future issues the model could be used to consider.

6.1. Advantages of the Model

Stakeholders were asked to list the advantages they saw of the modelling approach presented to them. A number of stakeholders stressed the importance of the integrated approach used in the model, with the combination of economics and hydrology being seen to 'help make better policy decisions.' The modelling approach was widely assessed to be capable of *clarifying the relative impacts of changes at the large scale* because, as summarised in the words of one respondent, it is 'starting to actually quantify in dollars the impact of changes in water allocation.'

Some stakeholders stressed the importance of the ability of the model to be used in *extension of information* from technical staff to Catchment Management Boards and other management committees. One respondent stated that the model 'allows for a much quicker explanation process for committees, acceptance of scenario outcomes when all parties can participate in model runs' and that the model would be 'good for demonstrating downstream impacts of upstream decision making.' Other stakeholders also mentioned the *flexibility* and *accessibility* of the model as strengths of the approach, with one stakeholder stating that it 'should be possible to adapt the model to a wide range of catchments and policy/natural resource issues.'

Finally the *open process of model development* was considered to be an advantage for some stakeholders. One stakeholder stated that it was important to involve farmers in the model development process. He felt that it was necessary to ensure that the model remained *transparent* and *accessible* to irrigators, especially those on the management boards and committees, in order that the model was not a 'black box' to these groups.

6.2. Limitations of the Model

Several limitations of the current model were referred to by stakeholders providing feedback. The emphasis that stakeholders placed on these limitations differed greatly, depending in many cases on the background of the respondent. Most limitations involved the model structure. The main limitations that were mentioned by stakeholders were:

- the lack of a groundwater modelling component, and thus the lack of links between groundwater and surface water systems.
- crop yields and water use not being linked to climate.
- assumptions about pumping flood flows – some stakeholders suggested that irrigators are unlikely to pump the rising stage of a flood flow in many areas of the catchment as they risk losing their pumps; it was suggested that the model should allow for this, otherwise the amount of water available to irrigators is overestimated.
- assumptions about the decision making behaviour of farmers; several stakeholders raised concerns about
  - assuming farmers are profit maximising;
  - assuming each region is controlled by a single farmer;
  - the lack of differentiation between farmers especially with respect to their levels of knowledge and expertise, and their financial ability to invest and change production.
- the simplified representation of the Peel River subcatchment – some stakeholders suggested this should be replaced with a more detailed nodal network for this region to allow investigation of trade-offs between the Peel River users and the rest of the Namoi catchment.

One key set of limitations encompassed assumptions in farmer decision making. These were discussed at a number of the meetings. Stakeholders' opinions on the importance of this assumption to model outcomes differed widely. Some stakeholders raised this as an issue of concern, whilst others were unconcerned or supportive of the approach taken in the model. On the whole, most stakeholders seemed to accept that these simplifying assumptions still allowed relative magnitudes of impacts to be estimated, whilst keeping the analysis of the impacts relatively simple. However, further discussion and consideration of alternatives with a broader range of stakeholders is required to refine these assumptions for use in a decision support tool.

Stakeholders were also challenged to consider alternative decision rules that would better represent farmer decision making in the catchment. The flexibility of the framework to allow use of a 'decision tree' approach or other type of decision making formulation was raised. In many cases stakeholders were seen to raise an assumption as an issue, follow their own line of reasoning through the pros and cons of the assumption and then decide in favour of the more simple assumption currently present in the model. Several stakeholders felt that starting simple, and then adding complexity to the model through discussions with stakeholder groups, was a good approach to take. They felt that this would allow them to see the advantages and disadvantages of each additional piece of model complexity, to see whether additional complexity actually had any real impact on the results. They also felt that testing the model at each of these stages of development would allow users to better understand the implications of new assumptions.

As a part of the presentations made to stakeholders, the appropriate uses of the model were stressed. In particular it was pointed out that the model did not provide information about impacts on individual producers, rather it should be used to consider 'catchment scale' impacts and trade-offs between upstream and downstream users. One stakeholder expressed concern at the lack of 'individual producer' impacts provided by the model. A strategy for including nested scale (farm to catchment) models in the modelling approach was discussed. For example, impacts on representative farmers who are constrained by particular infrastructure or water licences could be produced by nesting representative farm-scale models within the regional-scale modelling framework.

Several stakeholders expressed a desire to see further validation and testing of the model, especially before it is widely adopted for policy analysis in the catchment. One stakeholder expressed concerns over the hydrological models, wanting further details of hydrological model validation and testing to be made available. This may indicate that follow-up work, focusing on delivering more detailed information on model validation (or evaluation) may be required in the future to ensure acceptance and adoption of model results and recommendations.

One final warning was provided by another stakeholder on the use of the model. This concerned the relative ease of grabbing a 'single number' from the model as an outcome, rather than providing relative changes. This may affect the way in which the system should provide output to stakeholders. For example, should it only report percentage changes from some 'base case' scenario? It was recommended to stakeholders that the use of multiple, rather than single, climate scenarios should be considered when providing policy recommendations. This is because model outcomes are sensitive to the sequence of climate years, so a result needs to be present over a range of climate scenarios in order for it to be considered to be robust, and not just a result of a single set of climatic conditions (which may never occur in practice).

6.3. Additional Model Components

Stakeholders were asked if there were any additional model developments that they wished to see undertaken. Formal feedback from the questionnaire on these responses is summarised in Figure 6. These results show stakeholders have a preference for seeing development of a groundwater modelling component in the model, and also modelling crop yields and water use using an empirical relationship with rainfall. This corresponds well with verbal comments and preferences expressed during the public meetings.

6.4. Revising Assumptions

Stakeholders were asked if there were any assumptions in the model that they thought should be changed. These assumptions ranged from structural features of the model (including the integrative framework and definitions of region boundaries used) to values of input data. Several major assumptions were questioned and alternatives suggested. In many cases the assumptions that stakeholders queried are reflected in their requests for additional model components. However, several other key assumptions were suggested as requiring change by stakeholders. The assumptions raised by stakeholders are summarised in Table 3.

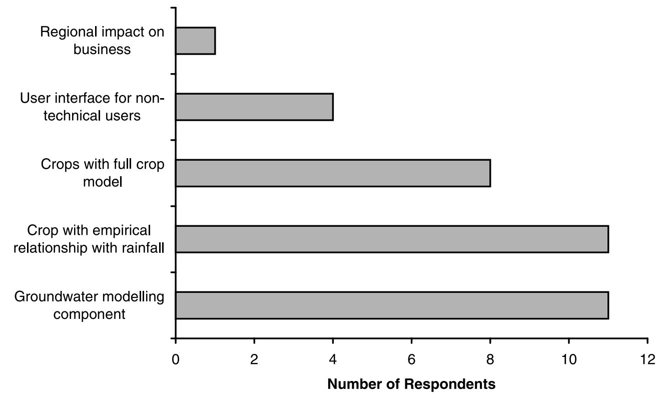

Fig. 6. Additional model components requested by stakeholders.

As can be seen in Table 3, a general consensus on alternative assumptions, or even the need for changing assumptions, was not reached in most cases. Further follow-on work, discussing suggested changes with a broader range of stakeholders and canvassing their opinions on these changes, is needed before many of these should be revised. One exception to this is the assumption that crop yields and water use are independent of rainfall. This was raised at all meetings and in many of the formal questionnaires as a priority for future development of the model.

6.5. Results

Some results from the model were provided to stakeholders, both to demonstrate the types of outputs able to be provided by the model, as well as to elicit feedback on the reasonableness (or otherwise) of results from the current model. Most stakeholders agreed that results presented looked reasonable. However it was acknowledged by many that they were not sufficiently aware of the internal workings of the model to comment beyond this. This may mean that several follow-up sessions, presenting a wide range of results, will be necessary in the future to ensure stakeholders are at least sufficiently comfortable with the model.

One stakeholder suggested that the results looked 'reasonable given the assumptions but some of the assumptions could be varied to arguably what is more realistic.' Another suggested that 'the model should be trailed widely and all bugs eliminated before general release.' This stakeholder concluded that it 'could take years to refine to a high degree of reliability and general acceptance.' This sentiment was echoed by another who said current results looked 'OK' but that they would have to be 'more convinced of predictive capacity through further validation.'

Table 3. Suggested changes in Namoi model assumptions from stakeholder feedback.

Assumption	Change required	Consensus
Sleeper licences activate at same water use efficiency as incumbent users	Sleeper licences are less efficient	Some stakeholders disagreed with this change, citing reason why sleepers may be more efficient rather than less, others agreed that new licences would be less efficient
Water use efficiency depends on water type used	Efficiency depends more on storage and layout than water type	Suggested in written comments, no other stakeholders had a chance to respond to this suggestion
Water use efficiency does not depend on which region in catchment water is used in	Efficiency should vary by region	Suggested by stakeholders at end of final meeting, no one else had chance to react to this suggestion
Crop yields and water use are independent of climate	Crop yields and water use should vary depending on rainfall	General consensus that crop yields and water use should be made sensitive to rainfall
No interaction between surface and groundwater systems except through infiltration losses from stream	Groundwater model, with links between system, should be added	Most stakeholders agreed with this. However, one stakeholder raised this verbally after the talk and said he felt that it was 'not such a big deal' as water being pumped from aquifers at present is very old so recharge to groundwater system is not so important for problems over a 20-year time frame.
Decision making is based on profit maximisation	Other factors such as risk, uncertainty and social constraints are important	Several people raised this as an issue. No one suggested an alternative assumption. Many stakeholders said that for considering magnitude and direction of impacts this was not so important.

6.6. Ownership

The questionnaire asked stakeholders to comment on how they thought the model should be delivered, and on who should have access to results from the model. Several options were suggested and room for other suggestions was provided. One option suggested was to house the model within one or more of several Government Agencies and allow access to their staff only. Another option was to continue housing the model at the Australian National University (ANU), with access being provided to one or more groups. An equal number of people suggested housing the model in either location, with most people indifferent between the ANU and State Government Agency options. The greatest differences in opinion between stakeholders arose with respect to who should be given direct access to the model and any results.

Figure 7 shows the breakdown of preferred access/ownership where the model would be housed within a State Government Agency. The strongest support was for the model to be housed and accessible by staff at the DLWC Regional Office (Tamworth). Figure 8 demonstrates the preferred access groups where the model would remain housed within the ANU, showing a preference for State Government Agencies and other management authorities to be provided with access.

Several stakeholders expressed reservations about making the model directly accessible to local community members (with some being concerned about direct provision to Catchment Management Boards and River Management Committees). One stakeholder summed these feelings up by stating it would be 'possibly good to have access by CMB's and State Government Agencies but only for an agreed model' but that this would 'depend on user friendliness of interface.' He concluded that what is required is 'a NSW Agriculture/DLWC combined approach to the model.'

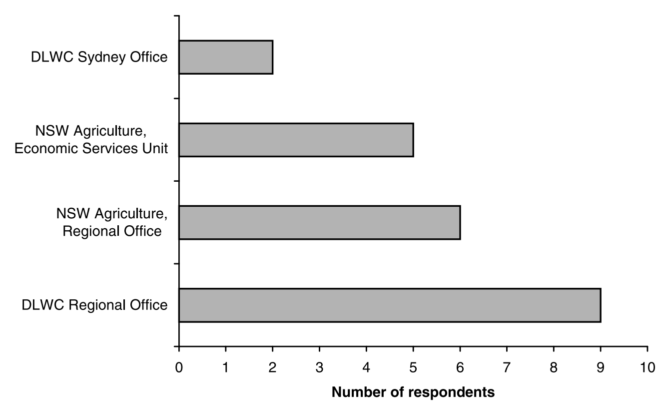

Fig. 7. Preferred State Government Agency access/ownership where model resides with an Agency.

6.7. Future Issues

Stakeholders were also asked to comment on what future issues they felt the model may be useful in addressing.

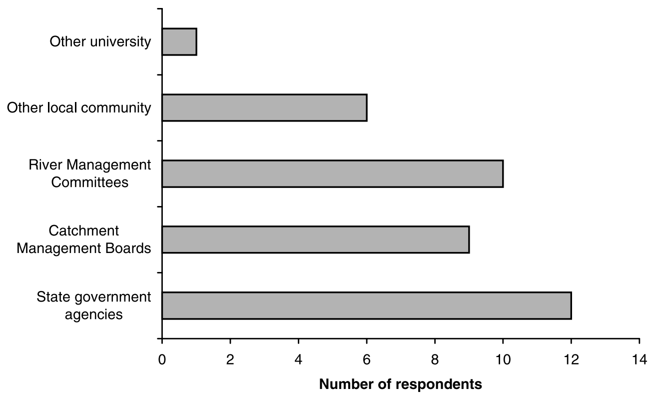

Fig. 8. Preferred access groups where the model remains housed at the ANU.

The issues raised were:

- future water management plans on water management committees including five-year reviews of current plans and new plans for non-stressed catchments;
- off-farm impacts of changes in water availability;
- impact of environmental re-allocations on farm viability with a view to assessing relevant compensation;
- floodplain management and water quality;
- relative impacts, distribution of impacts, understanding of likely response to policy and sensitivity of policy/regulation parameters;
- regional socioeconomic analysis of water quality issues and environmental flows;
- water sharing rules; and
- water trading issues.

7. DISCUSSION

There is now a useful literature (e.g., [1–9, 35–37]) on practical issues associated with the construction and on-going development and application of IA models. These issues include uncertainty, participatory methods, communication and model complexity. In this section some of these issue are discussed and illustrated in the context of the case study presented in this paper.

Integrated models tend to be fairly complex, containing a representation of a number of distinct system features. In order to keep the modelling and analysis of results tractable a large number of assumptions are made about interactions between system components, and simplifications of individual system components are required. The large-scale issue focus that drives most IAMs means that a number of 'boundaries' have to be placed on the system considered.

Results from a very complex or comprehensive model can also become quite difficult to analyse in more than a rudimentary sense. The large number of relationships in the system can make it difficult in many cases to see cause and effect within the results. The trade-off between simplicity and complexity in the model should be driven by the issue focus and the required accuracy of the model. Often components that are peripheral to the central issue can be ignored or simplified, at least on the 'first pass' of development. Including these more complex details after the simpler model has been tested (rather than the other way around) can allow the user to better understand the internal workings and trade-offs in the model (and the underlying system). Being faced immediately with the results from a model which tries to capture all or most of the system complexity may mean that none of the more basic (and often more meaningful) relationships within the model are able to be seen and understood because they are obscured by the more complex, often peripherally important interactions.

The need to find an appropriate balance between complexity and simplicity in the model means that an adaptive, on-going process of model development is preferable to focusing on a 'final product.' It also means that the limitations and assumptions of the model need to be clearly stated and communicated, especially to stakeholder groups who are likely to use the model and/or its outputs for considering policy questions. One of the problems with this approach is whether or not this message is heard, and used, by stakeholders and policy makers. The tendency to rely heavily on 'one number' in policy, and the desire to use such complex, integrative models for these purposes is problematic. Integrated assessment models are rarely developed to be capable of finding such precise, 'single number' answers to policy. They should normally be developed to allow investigation of the trade-offs of various policies and so are best used to estimate the order of magnitude and directions of change (at most) rather than for precise prediction. The problem in many cases is the misuse of such information in policy, where model results may be given much greater credence than is often warranted. One positive benefit of an adaptive, on-going process of development – which includes a dialogue between stakeholders and researchers – is that researchers are in a better position to educate on good model practice, in particular on the uses and misuses of integrative models. It also means that stakeholders are able to communicate their changing policy environment to researchers so that the model maintains its relevance to the community that it serves.

In the case study model discussed in this paper the focus of initial model development was on developing a framework for integration that would be useful for considering water allocation, but which was flexible enough to allow for further refinement and development on the basis of stakeholder needs and the continuously changing policy environment in the catchment. This means that the model discussed in this paper is not and should not be seen as a 'final product.' It is the product of a 'first pass' in an adaptive process of model building and integrated assessment that will hopefully continue for many years. In the words of one of the stakeholders surveyed on their views of the current model, it is 'best to start simple and then, if needed, add more detail.'

In terms of this case study, an adaptive process of modelling is likely to contain a number of future options. Stakeholders have suggested a number of model modifications that they would like to see including:

- development of a groundwater modelling component;
- updates to daily extraction rules once these have been signed off by the Minister;
- inclusion of conceptual/empirical crop modelling components, preferably utilising results from models already in use in the catchment;
- development of a more comprehensive network for the Peel system to better represent this system; and
- development of a graphical user interface able to be accessed at some level by managers in the catchment, possibly housed with regional staff at State Government Agencies in the catchment.

These suggestions were made by a fairly broad group of stakeholders, each with a different priority for the future of the model. At the time of writing this paper, the future of the model was still open for discussion with a variety of stakeholders. It was generally agreed, however, that stakeholders saw its future as a tool available to catchment managers in the region. The focus from these discussions was placed mostly on continuing development of the model past the life of this first project, so that a 'consensus' model would be available to managers for the five-year review of current operating rules (~2005).

One of the most positive aspects of the model mentioned by stakeholders was the openness with which the model was presented for their feedback. Stakeholders were very receptive to the broad consultative, adaptive approach undertaken to developing the model, and felt that this would lead to fewer misunderstandings about the model and its appropriate use. In particular, previous models used to consider management issues in the catchment were seen as being 'black box' approaches. A general feeling of mistrust of the results from such approaches was expressed by members of the Catchment Management Boards. The open, on-going process of model development trialed in the case study of this paper was seen as having the potential to overcome these issues of mistrust.

Uncertainty in both individual component models and also in the whole system representation is an important feature of integrated assessment models. Component, disciplinary models may be fairly inaccurate where insufficient data are available to identify model parameters, and to accurately reproduce observed behaviour. This uncertainty is often compounded by linking these inaccurate, uncertain component models together, often in a nonlinear way. The level of uncertainty in the final integrative model structure can therefore be large, and also very difficult to measure. Error accumulation in such complex models must be considered.

These uncertainty issues also imply the necessity for an on-going dialogue between researchers and stakeholders in model development. It is necessary that researchers strike a balance in communicating clearly the large levels of uncertainty inherent in such complex, integrative models to stakeholders while retaining a clear view of the useability (or otherwise) of the model for investigating policy questions. Illustrating this issue was the feedback from one stakeholder on the model described in the paper, who raised the following concern:

> It is too easy for people to grab a specific figure as the outcome rather than the relative change.

This type of concern can only be overcome where a close relationship is maintained between model users and developers so that users can develop an appreciation of the uncertainty inherent in the model. The success of this will depend on how honest and open researchers are in discussing the shortcomings of their work in a public forum – not necessarily an easy task in an area of research that relies heavily on a client focus and external funds. Stakeholders need to be allowed the opportunity to provide feedback to researchers throughout the development process. In this way both researchers and stakeholders can come to a better understanding of the uncertainties in the model and their importance when considering policy outcomes.

Integrated assessment projects are normally focused on one or more management issues in the region of interest. This focus is required to set the boundaries of the system and of the assessment to be undertaken. It is also ideal for ensuring strong, ongoing relationships between researchers and stakeholder groups. However the length of time required to undertake a comprehensive integrated assessment means that the initial focus issue may be much less important or irrelevant by the time the model is available to consider it (2–3 years is not an unusual length of time for model development). An obvious question then is: Was the effort in developing the model wasted? This problem requires that techniques used for considering IA problems utilise transferable, flexible approaches. It also depends on the broadness of the initial problem focus and model conceptualisation. So long as the problem focus is relatively broad and the conceptualisation is sufficiently flexible to allow future development of additional system components, then it is likely that the integrative model which is developed will be broad enough for reapplication and extension to a number of issues. In this case an issue focus is very useful for fixing the appropriate boundaries of the assessment that is undertaken and for focusing interaction between stakeholders and researchers.

8. CONCLUSIONS

This paper has described the first stage in the application of an adaptive on-going approach to model building and decision support in the Namoi River catchment, Australia. This integrated assessment involved the development of an integrated economic-hydrologic modelling approach for considering economic and environmental trade-offs relating to a number of different water allocation options. Stakeholder feedback on the model and its assumptions was sought throughout the modelling process and has been presented in this paper. This feedback has illustrated the potential of such an integrated assessment approach for developing tools that are useful to consider such water allocation and natural resource management issues. It also illustrates the long timeframes involved in integrated assessment, where models are not considered to be 'complete' so much as being the next stage in an adaptive, on-going process of assessment.

For the model outlined in this paper the next step in the process is a second project aimed at progressing model development for the Namoi catchment in line with comments received from stakeholders as outlined in this paper. The integrated model framework and development approach will then be applied to a second catchment in the Murray-Darling Basin, the Gwydir River catchment, which lies immediately to the north of the Namoi river catchment. This will allow the flexibility of the framework for considering different catchment situations to be tested. This second project involves a close collaboration with both NSW Agriculture and NSW Department of Land and Water Conservation, the main Agencies involved with water reforms and associated policy implementation in NSW, and has been funded by a major irrigation industry in the catchment.

While it is clearly too early to critically evaluate the outcomes of the project or of the adaptive approach recommended in this paper at this time, several observations about the strengths and weaknesses of the approach can be made.

- The process outlined in this paper is inappropriate for 'simpler' problems, where the problem time frames are small or where the solution of the problem is likely to result in relatively small benefits compared to the cost of undertaking the IA research. It is most appropriate for complex problems where adaptive management and relatively long-time frames are characteristics of the problem.
- Even where the process is appropriate, it is very demanding in terms of time and other resources from both researchers and stakeholders. A serious commitment of time needs to be made by both groups to ensuring the process is successful. As such the process is also critically dependent on the skills and personalities of the parties involved in the process to allow sufficient trust and goodwill to be developed throughout the project to ensure that the final product is useful and appropriate.
- The advantages to both stakeholders and researchers in the learning that is core to the adaptive development process occur to some extent regardless of the success and uptake of any 'final product' or decision support tool. One of the key outcomes of the process is the development of a shared and more comprehensive understanding of the nature of the problem being addressed. This and the development of a dialogue between policy makers, stakeholders and researchers is as important an outcome as the development of any modelling tool at the end of an IA project. This is demonstrated by many of the stakeholder comments on the modelling framework provided in this paper.

Finally it is important to emphasise that the intention of IA is as a learning process for both researchers and other community members. As such we should hope to improve outcomes, but we must also allow for an investigative mind set. Many of the most important and enduring outcomes from an IA exercise, such as the one outlined in this paper, will not relate directly to any software tools or models that are developed as part of the project. Instead they will often relate to improved communication and understanding between government agency staff, farmers and researchers. In this dialogue the emphasis of IA should remain on differentiating between outcomes or policies, not on accurate prediction. A second focus for IA should be on educating stakeholders as a whole to have more realistic expectations of the models which they are likely to use, and an understanding of the situations in which they are appropriate and inappropriate. Only in this way can misuse of model results be reduced and stakeholder concerns about a 'one number' approach to modelling be allayed. An ongoing relationship through a series of projects focused around an integrated assessment is a good way to achieve many of these aims. In this way the IAM process can be adaptive to the changing social, economic and political environment of the area being considered.

ACKNOWLEDGMENTS

Rebecca Letcher completed the work described in this paper as a part of her PhD thesis. Her scholarship was funded in part by CSIRO Land and Water. The follow-up project mentioned in the paper incorporating stakeholder comments is funded by the Cotton Research and Development Corporation (CRDC), and includes substantial in-kind contributions by NSW Agriculture and the NSW Department of Land and Water Conservation (DLWC).

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