INVITED

Proposed Environmental Flows Decision Support System

W.J.Young and J.R.Davis
CSIRO Division of Water Resources, Canberra

Abstract The Sustainable Rivers Program established by the Murray-Darling Basin Commission aims to improve the health and sustainability of the riverine environment of the major rivers in the Murray-Darling Basin. The first phase of this program is addressing flow-related river health. This phase aims to develop tools to assist in the objective setting of environment flows, based on the rational that in the longer term, the setting of environmental flows should be based upon an understanding of the environment and its response to flow. It is proposed that the central tool be a decision support system (DSS). The proposed DSS will therefore involve river modelling, and the prediction of environmental responses to flow changes. The DSS is intended to facilitate community involvement in the decision making process. This paper describes the necessary components of a decision support system to fulfil this role, describes the system architecture required to integrate these components, and discusses a suitable procedure for the implementation of the proposed DSS.

1. INTRODUCTION

In late 1994 the Murray-Darling Basin Commission (MDBC) established the Sustainable Rivers Program (SRP) under its Natural Resources Management Strategy. The philosophy and essential elements of the SRP are described by Banens *et al.* (1994) and Banens *et al.* (1995). The Program has the broad aim of improving the health and sustainability of the riverine environment of the major rivers in the Murray-Darling Basin, and is to be based upon the definition of Riverine Management Zones (RMZs). RMZs are discrete sections of the river and its floodplain which are able to be managed as single entities. A classification system for identifying RMZs has yet to be developed.

The SRP has a number of distinct phases; the first phase addresses flow-related issues of river health. Other issues important for river health and sustainability, such as improving water quality, maintaining riparian vegetation and ensuring appropriate floodplain land-uses will be addressed in later phases of the program.

The principal objective of the first phase of the SRP is to develop tools to help determine the environmental impacts of changes in flow regime. Behind this objective lies the broader, and perhaps more difficult task, of facilitating an informed trade-off process between environmental flow requirements and consumptive flow requirements.

The rational behind the environmental flows project of the SRP is that in the longer term, the setting of environmental flows should be based upon an understanding of the environment and its response to flow. There is widespread agreement between both the scientific and water management community that this is both appropriate and desirable, and this ideal is supported by the National Principles recently developed by ARMCANZ/ANZECC (1995). Whether this is fully possible is yet to be determined. Nonetheless, this can be viewed as the overall goal or task. The process by which this is achieved however, is less well defined.

Many of the recent decisions made in Australia regarding environmental flows could be viewed as being the result of a 'top-down' decision making process. That is, while they may or may not have been science-based, they have been government-driven. The MDBC believes that a 'bottom-up', or community-driven, decision making process needs be adopted, and this is also endorsed by the National Principles. While there seems to be agreement in principle amongst water managers that this too is both appropriate and desirable, there is also a certain degree of caution, as the details of how such a process would take place in practice have not yet been clarified.

The tools which are appropriate for decision making depend both upon the nature of the task and the decision making process. For completing the task as defined above, in a bottom-up decision making process, a number of tools are likely to be useful. There is a recent history in Australia of the successful use of decision support systems (DSS) for assisting in natural resource management issues via a bottom-up approach. For example, DSSs have been used in community-based catchment management (Young, *et al.*, 1994). This history suggests that a DSS may be one appropriate tool for assisting in environmental flows decision making.

Before a suitable DSS can be designed and built, there needs to be a firmer agreement on, and better definition of, the decision making process to be adopted. However, this does not prevent us from describing the general nature of a suitable DSS, and discussing how such a tool might be used. This is the focus of this paper.

Before embarking on this description and discussion, there are a number of other important assumptions about the process and appropriate tools for the determination of environmental flows inherent in the SRP. These are:

- consideration of the impacts of flow management decisions on consumptive uses should be made separately to a consideration of environmental impacts. Hence it is inappropriate for a single DSS to consider both these aspects. This view is not shared by all State agency officers.

- the trade-off between environmental and consumptive uses is best dealt with outside of a DSS (ie. the trade-off should not be arrived at by computational analyses).
- information exists to enable the prediction of the environmental responses to flow.

By accepting the above assumptions, including the general notion of a bottom-up decision making approach, one can proceed to design a DSS which:

- maximises the utilisation of available information relating the riverine ecology and the flow regime,
- provides a predictive capability for assessing environmental responses to flow change,
- facilitates an adaptive approach to decision making (ie. one which can take advantage of emerging understanding),
- and facilitates community involvement in the decision making process.

2. DSS COMPONENTS

To meet the objectives of the SRP a DSS will require a number of basic components. These include a model that predicts river flows, a library of environmental models, a number of databases (spatial and aspatial) and a graphical user interface. The nature of these components, and the most appropriate software and hardware to deliver them stem largely from the intended use. The implications of the intended use and the aforementioned components are discussed below. More details of the system architecture and of what existing software can be used to rapidly develop the DSS can be found in Young *et al.* (1995).

2.1 Intended Use

The intended community use and the intention of using best available scientific ecological information are the most important aspects of the intended use. The overall intention is to present scientifically reliable information in an integrated, understandable and enhanced manner to the particular audience.

Probably the single most important criterion in designing a DSS is to ensure that it meets the needs and *modus operandi* of the users. Whilst this may sound self-evident, it is the case that many software developers, especially scientifically trained ones, produce software that suits scientific rather than decision maker needs. Thus, scientific complexity and rigour can be emphasised at the expense of relevance, simplicity, transparency and reliability.

It has been agreed that the DSS would be used as a part of a bottom-up decision making process. That is, the emphasis should be upon use with community groups. It is likely that a decision making group would consist of community representatives assisted by technically trained staff from State agencies. The community representatives would probably include local government representatives, TCM/ICM members, representatives of rural production groups (especially those that rely directly on river water) and representatives of local environmental groups. It would be reasonable to assume that few of the non-agency people would understand traditional hydrologic representations such as flow-duration curves. Instead they would expect impacts of a particular flow regime on the environment to be represented in more understandable terms. These could include colour-coded maps and simple graphical representations of environmental indicator values, as well as qualitative assessments of river health (acceptable, degraded, etc).

Although the DSS will be used in community workshops, it is likely that it will also be used in-house by State agency officers. While the nature of the outputs described above would certainly be useful to this audience, the ability to present more numerically detailed information would also be advantageous. This might include graphical outputs of the type commonly used by engineering hydrologists (flow duration curves, time series plots etc.), as well as statistical information describing confidence limits on results or expected temporal variability in model predictions. Thus, two levels of presentation of model predictions are envisaged. One will be aimed at hydrologically trained users, the second will be aimed at community participants at workshops.

It is envisaged that community workshops will be held in towns throughout the Murray-Darling Basin using computing equipment either commonly available in those towns or able to be provided there by Departmental officers. IBM-PC computers are the standard equipment in most regional offices and would be the preferred equipment for use in the workshops. Windows 3.1 or 3.11 are the current standard operating systems for these computers. It is possible to use a client-server structure whereby the main DSS and models are run on a central computer (often a UNIX workstation), and the local PC provides a convenient user interface. This architecture is becoming increasingly common as it can deliver considerable computing power to remote sites. However, it is dependent on reliable communications between remote and central sites, and is somewhat more complex to set up than stand-alone computers. This architecture is not recommended for the current system. Rather, use of a stand-alone IBM-PC computer is suggested.

2.2 River Model

The river model used may be a water balance model, hydrologic model or a hydraulic model. The difference is important in the context of designing a DSS with certain predictive capabilities. The need for a hydraulic model will depend upon the data requirements of available environmental models. It is likely that while some hydraulic data will be required, the core model of the DSS will be a hydrologic model of the RMZ, with hydraulic modelling restricted to 'representative sections'. Within the Murray-Darling Basin there are a number of river models currently used by State agencies. These include:

- the daily hydraulic Lower River Murray Model (LRRM),
- the daily hydrologic Integrated Quantity-Quality Model (IQQM),
- the monthly water balance Resource Allocation Model (REALM),
- the water balance Monthly Simulation Model (MSM),
- the daily hydrologic WARWSIM model,
- the monthly Water Allocation Model (WAM).

From a software development perspective, these would ideally be reduced to just one model for use Basin-wide. However, for a number of reasons this is unlikely. The resource investment in developing and calibrating the different models in different parts of the Basin has been significant, and irrespective of what model(s) are used in the proposed DSS, agencies will continue to use their own models in-house for various investigative purposes.

LRMM is the best suited to environmental flow investigations as it is a hydraulic model, but it is only applicable to the lower river. IQQM, while not providing the hydraulic detail of LRMM, does provide daily flow predictions, and of the models used in the upper river basin is certainly the most amenable to use in environmental investigations. Use of monthly flow models (eg. MSM) would severely limit the range of ecological tools that can be used.

The decision of which model(s) to use should be determined by the required inputs to environmental models. However, the extra data needed to run daily models (over monthly) or hydraulic models (over hydrologic) will often be unavailable, and the calibration of more detailed models is always time-consuming. It is therefore most likely that at least initially monthly water balance models will need to be used. The DSS architecture will therefore need to allow for the substitution of different core river models.

This facility however, needs be kept relatively simple. Each model can be run for the time period, and over the RMZ of interest, independently of the DSS. There is no need to have the other DSS components interact with the hydrologic/hydraulic model whilst the latter is running. The output file of flows and water quality at each prediction point can then be taken as an input to the ecological tools. The major purpose of the interface between flow models and the DSS would be to handle the differing output formats of the hydrologic/hydraulic models. It is possible that the necessary hydrologic outputs will vary from one RMZ to another depending on the particular environmental models which are to be used. To avoid this, it will be necessary to compile a comprehensive list of the useful hydrologic output parameters. These would form the basis of a standard file format for input to the DSS.

It was recommended above that client-server architectures be avoided. Thus the hydrologic models would need to be run on the computers being used at the workshops. One solution would be to have each model run independently of the DSS, using whatever user interface comes with the flow model. This would need hydrologically trained staff to be in attendance, as the local community members would be unlikely to be able to set up and operate the model relevant to their RMZ. A better solution would be to write a common user interface for all the hydrologic models, that was specifically designed for community use. This would be a part of the DSS interface, and would replace the existing interfaces used by the flow models.

There are no hydraulic models in use in the Basin upstream of Lock 10 on the Murray River. Hydrologic models can only provide very limited hydraulic information, and so for RMZs in this part of the Basin it may be possible to use outputs from a hydrologic model as inputs to a hydraulic model of some representative section(s) and sensitive environments of the RMZ. Examples of the latter include wetlands, recreation areas and bird breeding sites. Hydraulic modelling may be undertaken for the instream environment, and/or the floodplain environment depending upon the indicator species of interest. Instream hydraulic parameters of interest include depths and velocities (and their spatial distribution), and possibly bed and/or bank shear stresses. Floodplain hydraulics will be mainly concerned with depths of inundation, and the spatial and temporal distribution of floodplain inundation.

Hydraulic models will require additional data. These include channel cross-sections and possibly roughness factors for instream hydraulics, and floodplain topography for floodplain hydraulics. Outputs from the hydraulic models could then be used as inputs to ecological tools, such as the habitat simulation models incorporated in the PHABSIM software (Bovee and Milhouse, 1978). Local knowledge of typical river section shapes and bed characteristics may be available, which can provide estimates to drive such hydraulic models. The accuracy of these data needs to be recorded and translated into errors in the resulting predictions.

Local hydrologic knowledge may also be available. This may enable (for instance) relating stage height at gauged sites, to stage heights and extent of inundation at ungauged sites of ecological interest such as floodplain forests and wetlands. These relationships can be represented as either simple mathematical response functions, or as sets of rules. Use of this type of information extends the range of possible inputs for ecological tools from those typically available from hydrologic models built primarily for engineering purposes.

A necessary component of the modelling system will most likely be a water quality model or models. These will also provide inputs to the ecological models (eg. DO, temperature) or provide useful surrogate indicators where ecological models do not currently exist. The water quality parameters which should be modelled will be those required as inputs to existing ecological models. Some of the river models, such as IQQM, have water quality components already available. However, in some cases, it will be necessary to provide separate models for this purpose.

2.3 Environmental Models

One major objective of the proposed DSS is to provide a means for incorporating best available environmental information into the process for setting environmental flows. The intention is therefore to make explicit (or as explicit as possible) predictions about the environmental impacts of flow management scenarios. This is what distinguishes the proposed DSS from previous integrated river modelling tools, where the environment has been represented by the flow requirements considered necessary to maintain habitats for specific fish species.

Making environmental impacts explicit will require a library of environmental models. The library will primarily contain ecological models, but may also contain geomorphic models because of the importance of geomorphology to the concept of river health. In this paper we confine the discussion to ecological models.

The term 'model' is used to describe any module which predicts the response of some system or part of a system to some change. A simple dichotomy is to distinguish process models from empirical models. The former represent models that are built on an understanding of underlying processes, whereas the latter are simple models representing observed (but not understood) relationships. Empirical models are normally developed before process models because they can arise from a preliminary analysis of field data. An important assumption for the DSS design is that the understanding of flow effects on the riverine environment is so limited that most models that will be included are likely to be empirical rather than causal. The feasibility of the DSS depends on the existence of such models, and its usefulness depends to some extent on the sophistication of these models.

These models can be either quantitative and qualitative. They are likely to be quite simple; being in most cases response functions of the different parts of the environment to flows. Some of the knowledge about a particular RMZ can be incorporated into the library of environmental models prior to a community workshop; for example, understandings arrived at by an expert panel (Cross *et. al.*, 1994) in that RMZ. Some of this prior knowledge may be common to a number of RMZs, coming from experimental work believed to be relevant to broad sections of the Murray-Darling Basin. However, it is extremely important that local information is also sought and used in these ecological models. Not only will this increase the sense of involvement by local communities in each RMZ, but will supplement gaps in the scientific information. For example, the extent of floodplain inundation by flows of a particular size may be known to the local community of a particular RMZ.

In addition to a library of prior ecological models and the inclusion of local knowledge, a detailed knowledge-base of general ecological information (related to flows) could be a part of the DSS. This would provide a valuable resource (and education tool) for workshop participants to use (together with local knowledge) when selecting and defining ecological models appropriate to a particular RMZ. As an education tool, it may even be beneficial to include photographic and video images in the knowledge-base. These visual images could be most valuable in developing an understanding of the nature and functioning of specific environments such as the extent of floodplain inundation during floods.

For a particular location then, the ecological models used will be a mix of those selected from a preloaded library, and those defined in the workshop using local knowledge and information contained in the knowledge-base. They will also be a mixture of qualitative and quantitative models. Given this diversity of information it is very important that sources, reliabilities and relevant qualifications be recorded and made available to decision makers when the models are used. This is not normally done with scientifically developed models, leading them to acquire an aura of accuracy often not deserved. The models in this library must be much more transparent and qualified than most conventional models.

2.4 Proposed DSS Architecture

Figure 1 shows the proposed structure of the DSS incorporating the components discussed above. The flow of information and control within the DSS is described below.

The alternative river models are shown at the top of the diagram. The proposed operating rules for releases from storages and extractions from the river would be input to the model that was calibrated for a particular RMZ, and the model would then be run. The model would produce a file of daily (or, in the cases of MSM and REALM, monthly) flow and water quality data at reporting points within the RMZ. The reporting points would include gauging stations and environmentally sensitive points within the RMZ. These flow files would be stored in a standard format irrespective of the river model being used. This may involve a modification to the output routines of the river models. This should not be difficult, but will require a comprehensive suite of the ecologically relevant flow parameters to be identified. Many of these may require statistical analyses of output flow records; for example, to assess frequency of flooding on the far floodplain.

The flow file would then be supplied to a local hydraulic model of the type presently used in PHABSIM to produce hydraulic predictions for representative instream sections of the RMZ. These predictions would include instream depths and velocities and their spatial and temporal distribution. The hydraulic model will require river cross-sectional data and these data may not be available for all locations of interest in the RMZ.

The use of local knowledge and/or data from remote sensing and GIS to model floodplain hydraulics is proposed. This will be used to estimate the extent and duration of floodplain inundation based on the predicted flow at gauging points. This would provide essential information about the near and far floodplains. This component of the DSS is shown behind the hydraulic models in Figure 1.

The ecological models in the model library at left of Figure 1 include both the results of scientific input acquired prior to a community workshop, and the information provided during a workshop. The former would typically come from expert panel assessments and general scientific understanding; the latter from local experience about environmental responses to different flow regimes. These models would be written as either continuous response functions, or a set of rules describing the response of different parts of the ecology to flow. The model input shown at the top of the model library is the mechanism for adding new models or modifying existing ones.

The knowledge base shown below the ecological models contains information to be used during a workshop by community participants. It is not directly connected to other parts of the DSS. Rather, it provides a repository of background information, useful when local ecological models are being added. Information in the knowledge base may include text, graphs, pictures and perhaps video files. The knowledge base will expand as new knowledge is acquired. This component is not essential in the first version of the DSS.

The ecological models would take the flow and water quality predictions from the hydrology model, and the extent of flooding and (if available) river height and velocity information from the hydraulic model and predict the ecological responses. These responses would be provided as values of a number of ecological indicators.

The user interface receives input from both the ecological models and the hydrology/hydraulic models. Ecological indicator values could be superimposed on a map of the RMZ to indicate the spatial variation. The outputs of the hydrology model would be developed from the standard flow data file which could be summarised as graphs or relevant statistics. The uncertainty attached to the prediction of ecological responses and other pertinent information (traceable to sources such as outcomes of expert panels or the knowledge base) would also be available to the users.

The GIS is shown to the right of Figure 1. It is not an integral part of the DSS, since it is unlikely that spatial data analysis functions, such as overlaying coverages (which necessitates coordinate geometry calculations), will be required for the ecological modelling. Visual map overlay functions may be required for output displays; these can be handled by mapping software within the DSS.

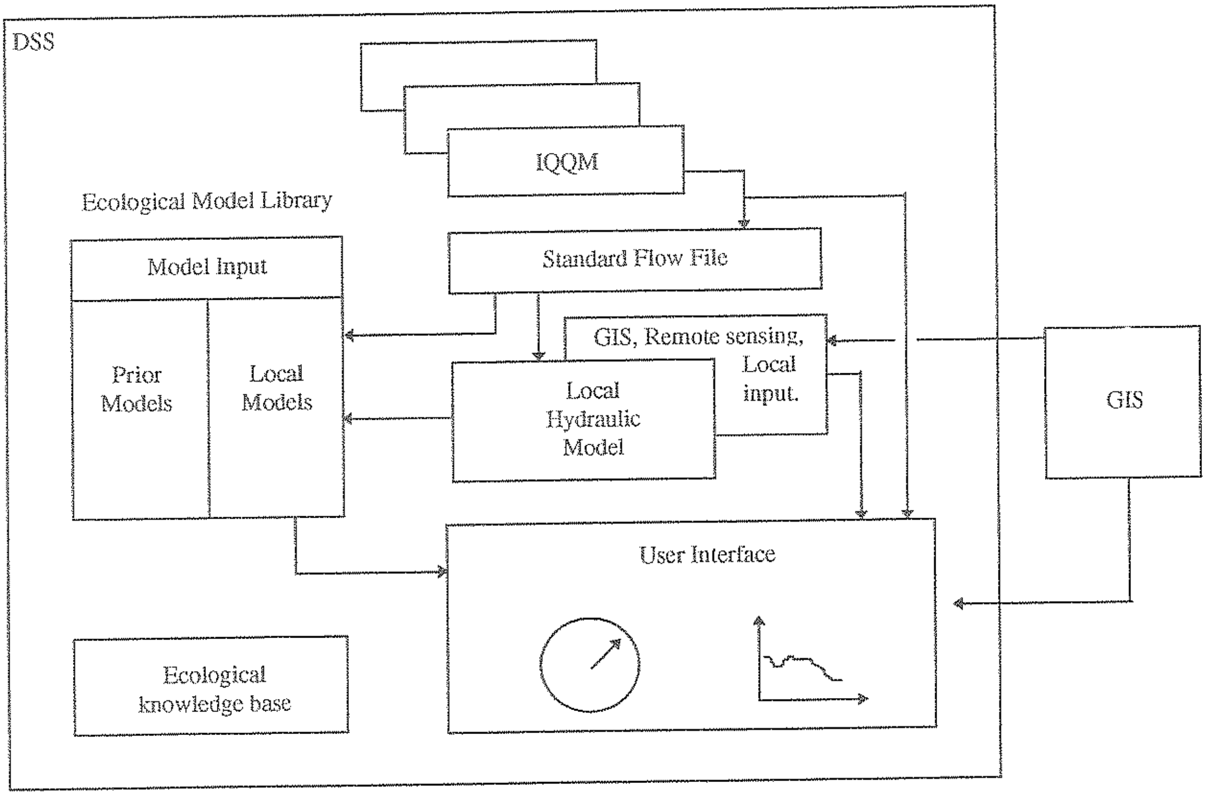

Figure 1: **Proposed DSS architecture**

The GIS will provide a range of spatial input data for use in the ecological models. In addition, it is likely that ecological model outputs will be exported back to the GIS for storage, use in other investigations, or for producing quality hard copy maps of scenario results.

The sort of information likely to be stored in the GIS include: floodplain topographic data for floodplain hydraulics, extent and location of important wetlands and floodplain forests, and information derived from monitoring describing the current environmental condition of each RMZ. Ideally, the current condition would be assessed in terms of the same indicators used in the predictive modelling. This would allow for comparisons to be made between likely future state and current state, as a means of assessing the magnitude and direction of change.

It is assumed that hydrology models such as IQQM have been calibrated in advance and so will not need access to GIS data, such as land-use, during the community workshops. Only mapping and display would be required as functions of the DSS. This can easily be achieved with mapping software on the PC.

3. DDS IMPLEMENTATION

Before a full "functional definition" of the DSS can be achieved a better definition of the decision making process in which the DSS will be used is required. The specific questions to be answered are:

- how will the trade-offs between competing water uses take place? Both within a RMZ and across the Basin.
- how will the downstream implications of proposed flow management decisions be dealt with?
- who will use the proposed DSS? (community groups, State agency staff...)
- in what situation will the DSS be used? (workshop, regional offices, Head Offices...)

In addition, for the proposed DSS to adopted, there will need to be widespread agreement on the details of the decision making process, and how these will be achieved. Much of the current confusion and disagreement over appropriate "tools" and "techniques" stems from the lack of a well defined and widely accepted decision making process.

It is proposed that to develop and refine the decision making process, and to provide the focus for the development of the DSS, an initial case study be undertaken. Examples can be cited of pilot studies to trial DSSs where, for expediency, the appropriate decision making process has been short-cut. Experience shows this often does more harm than good for acceptance of the tool. Trialing the DSS within a decision making process that is agreed to be feasible and appropriate Basin-wide is therefore important.

The general steps should be:

1. Select the RMZ for the case study. The site should be one that is 'typical' in terms of data availability, environmental sensitivity and public concern. Selection should be made in consultation with the relevant State agency.
2. Establish a working group of stakeholders and decision makers. This step is critical, and there should be detailed discussion with TCM/ICM groups, farmer groups, environmental groups and local government bodies. This is where the education begins, and so initial discussion should focus on the real and perceived problems relating to flow management, including environmental damage, irrigation supply security, and public health and recreation. Initial discussion should familiarise stakeholders with the DSS and its capabilities.
3. Identify and assemble the available data for the RMZ. Identify generic ecological models applicable to the RMZ.
4. Hold an initial workshop to present available data and knowledge, identify specific issues of concern (particular species, or environments eg. wetlands) and decide upon how to quickly obtain data/information on these specific issues. This may include assembling an expert panel to provide advice, undertaking a 'snap-shot' survey of the ecological status of the RMZ, acquiring data for instream and/or floodplain hydraulics (channel cross-sections, floodplain topography).
5. Acquire and process these additional data.
6. Set-up and calibrate the flow model for the RMZ.
7. Hold a second workshop to present data and information from 4., 5. and 6. The expert panel should be in attendance to assist in the development of local ecological models, and to help capture and interpret local knowledge of ecology and/or hydrology (eg. floodplain inundation).
8. Identify the range of possible flow management scenarios. This should include the current situation, the 'do-nothing' scenario, possible future changes in allocations, both considering increases and decreases to consumptive use.
9. Run these scenarios through the flow model and produce the necessary output flow file(s) for input to the DSS.
10. Hold a third workshop to investigate the environmental impacts of the range of scenarios. Observation of environmental responses may lead to modification of the local ecological models. Stakeholders will need to rank (assess relative merit of) the various scenarios in terms of environmental acceptability.
11. By this stage an informed trade-off can commence. The details of how this will occur are yet to be settled. In particular, the issue of how local (RMZ) objectives are reconciled with catchment and Basin-wide objectives needs to be addressed.

In the above procedure it has been assumed that a range of scenarios would be run prior to a workshop. This reduces the ability to interactively investigate different scenarios, but avoids the problem of long run-times for the flow model. However, depending on the scale of RMZs, it may well be possible to run the flow model in the workshops and so allow 'fine-tuning' of scenarios within the workshop. This would require agency staff familiar with operation of the model to be present to run the scenarios of interest. If run-times prove to be restrictive, it may be necessary to run two 'scenario workshops', so that attendees can propose new scenarios on the basis of the results from the first set.

Even while a case study is in progress, attention needs to be given to the compilation of a comprehensive Basin-wide knowledge base of environmental flow relationships. This information will form the basis of the ecology models (both generic and local) which provide the predictive ability of the DSS. This ability is central to the philosophy of this approach and assembling this knowledge is thus critical to its success. Discussions with ecologists have led to the belief that such information is available at least in qualitative or simple quantitative form. However, the defensibility of predictions will depend directly on this knowledge, on its level of accuracy, and on how well the complexities of ecosystem response are understood. This includes identifying and understanding confounding factors, understanding both the spatial and temporal variability of ecosystem responses, and understanding the interactions that stem from high species diversity, complex food webs and highly variable hydrology. The belief guiding the design of the DSS is that it is possible to explicitly predict the environmental effects of different flow management scenarios using simple models. This would represent a significant step forward in planning the availability of water for environmental needs.

To this end, it is strongly recommended that the available knowledge to form the basis of simple predictive ecological models be compiled into a useable form. This should be done with guidance from the DSS developers to ensure that the knowledge is provided in an appropriate form for inclusion into the DSS.

4. CONCLUSIONS

To facilitate the objective setting of environmental flows a DSS is to be developed which explicitly predicts the environmental effects of different flow management scenarios. The DSS will have as its core a river flow model, which will provide input to a number of simple environmental models. The DSS will be a flexible and adaptive modelling tool, and is intended to facilitate community involvement in the setting of environmental flows for the major rivers of the Murray-Darling Basin.

5. ACKNOWLEDGMENTS

The funding for this work (a part of the Sustainable Rivers Program) was provided by the Murray-Darling Basin Commission under its Natural Resource Management Strategy (Investigations and Education Program). Particular thanks are due to Dr Banens of the Commission for his guidance.

Special thanks also go to Drs Bowmer and Fairweather of CSIRO Division of Water Resources for their advice on ecology and environmental modelling, and the interest they have shown in decision support systems.

6. REFERENCES

ARMCANZ/ANZECC (1995), National principles for the provision of water for the environment, ARMCANZ/ANZECC.

Banens, B., Blackmore, D., Lawrence, B., Shafron, M. and Sharley, A. (1994). A program for the sustainable management of the rivers of the Murray-Darling Basin, Australia. In: '*Classification of Rivers, and Environmental Health Indicators*', Uys, M. (Ed), pp 287-300, Proceedings of a Joint South African Australian Workshop, Cape Town.

Banens, R.J., A.J. Sharley, and D.J. Blackmore (1995), Integrated flow management: The Murray-Darling Basin Commission approach, paper presented at the Conference on Geomorphology and River Health in New South Wales, Macquarie University, Sydney

Bovee, K.D. and Milhouse, R. (1978) Hydraulic simulation in instream flow studies: theory and techniques. *Instream Flow Info. Paper*, 5. US Fish and Wildlife Service, FWS/OBS-78/33.

Cross, H., Ardill S., and Shaw, J. (1994), Management of environmental flows in NSW: a review of techniques. In Environmental Flows Seminar, proceedings, Canberra, 70-75

Young, W.J., Verhoeven, T.J., and Cuddy, S.M. (1994), Nutrient management at a catchment scale, in Water Down Under, Vol. 1, 79-83

Young, W.J., Davis, J.R., Bowmer, K.B. and Fairweather, P.G. (1995) The feasibility of a decision support system for environmental flows. Final report to the Murray-Darling Basin Commission. CSIRO Division of Water Resources Consultancy Report No. 95/19.