Adaptive Environmental Assessment and Management (AEAM) and Integrated Catchment Management

Occasional Paper No. 1/95

R B Grayson[1] and J M Doolan[2]

1. Centre for Environmental Applied Hydrology, Department of Civil and Environmental Engineering, University of Melbourne, Victoria.
2. Division of Catchment and Land Management, Department of Conservation and Natural Resources, Victoria.

Land & Water Resources
Research & Development Corporation

Project supported by the Land and Water Resources Research and Development Corporation

April 1995

Published by:

The Land and Water Resources Research and Development Corporation

Land and Water Resources Research and Development Corporation
GPO Box 2182
Canberra ACT 2601
Phone: (06) 257 3379
Fax: (06) 257 3420

Publication Data:

Grayson, R. B. and Doolan, J. M. (1995). Adaptive Environmental Assessment and Management (AEAM) and Integrated Catchment Management. LWRRDC Occasional Paper No. 1/95.

ISSN 1320-0992

ISBN 0 642 20603 1

Typesetting:

Onyx Design, Canberra

Table of Contents

Preface

AEAM (Adaptive Environmental Assessment and Management) is a process that has generated considerable interest from groups working in catchment management. While AEAM is many things to many people, there are some fundamental features of the process that are important to understand and to consider in order to decide if the approach is appropriate for use with your issue.

The purpose of this report is to present the basics of AEAM and summarise two applications to catchment management issues in Victoria. This should not be seen as "the definitive" description of AEAM, but rather as an attempt to put down on paper some local experiences in the use of the methodology.

The report begins with a broad outline of AEAM, its underlying philosophy, a description of the process itself and some benefits. This is followed by a discussion of how and why AEAM may be applicable to catchment management. Two examples from catchment management exercises in Victoria are described in some detail. Finally we reflect on the process and discuss some limitations and requirements for success.

Introduction to AEAM

AEAM is a process for the development and exploration of management options for complex systems and is particularly applicable to environmental management issues. It has been applied throughout the world since the 1970s (Walters, 1974, 1986; Holling, 1978; ESSA, 1982) to problems ranging from managing the Florida Everglades to assessing the ecological impacts of hydroelectric schemes.

In Australia, the process has been used on problems such as the impacts of a proposed ocean outfall and sustainable harvesting strategies for Rock Lobsters, as well as integrated catchment management issues (Grayson et al., 1994).

The major focus of the approach is the production of a computer simulation model of the system to be managed. The model is developed in a series of workshops involving representatives from a wide range of technical and non-technical groups including discipline specialists, planners, decision makers and other stakeholders. This group defines the scope and output requirements of the model and provides the information required to represent each of the important processes and the linkages between the different areas. The involvement of the whole group in model development ensures a product that is consistent with user requirements and incorporates best available knowledge of the system at an agreed time and space scale.

The computer model is then used as a gaming tool whereby various management options can be represented and the estimated effect on key indicator variables assessed. The aim of the gaming is to arrive at a set of agreed options which show the greatest promise. At a later date, as more information becomes available and as the results of those options are tested, the model can be modified and improved and used for further gaming. The intention of the gaming is to facilitate innovative management.

However, the model is not the only, nor the most significant, outcome of the AEAM process. The workshop process itself can provide the opportunity to generate ongoing linkages within the group of stakeholders, and for that group to develop a common understanding of their problem and joint ownership of the solution.

Therefore, the AEAM process can offer two major benefits:

The creation of a common understanding, expectations, commitment and ownership amongst a group of stakeholders.

The development of a broad-based computer simulation model of the system which utilises the best information available and matches the requirements of the planning exercise.

This report presents details of AEAM methodology with particular emphasis on its use in integrated catchment management issues. Two examples of AEAM from Victorian catchments are included, along with the authors' view of key elements necessary for successful applications. It should be noted that AEAM is a dynamic process that is continually evolving. The information presented here is intended to provide a basic understanding of AEAM philosophy and practice but is by no means the only way it can be done.

Philosophy of AEAM

AEAM is a philosophical and methodological framework designed to deal with the uncertainties inherent in environmental change. It recognises that precise prediction of ecosystem responses to human management activities and natural changes is not practically feasible. Instead, an exploratory and adaptive approach to management is taken, based on assessment of "whole system" responses. The historical variability and patterns of change are used, along with some insight into system dynamics, to characterise the fundamental variability of the system as a whole without attempting to represent every detail of individual processes.

This is done with a computer simulation model which can be used to predict the response of the system to a range of management options, leading to the development of a set of preferred management actions. Monitoring programmes can then be designed to measure system responses to management actions. The information collected can be used to refine the initial simulation model which assists in further refinement or modification of the management actions and so on. In this way both the management of the system and the understanding of system behaviour are enhanced in an adaptive manner.

The AEAM process

AEAM is a process aimed at developing links between people with a common problem and utilising the existing knowledge about the system in question as efficiently as possible in order to develop and evaluate management options. The focus of the process is the development of a computer simulation model of the system which can be used to evaluate the effects of various management options. There must be an acceptance at the outset that not all the required information will be available to fully describe every component of the system. The model, however, provides a framework for the presentation and manipulation of best available knowledge at a consistent temporal and spatial scale.

A series of structured workshops are used to develop the model and collate the information required as input or for process representation. These workshops involve policy, management, technical and lay people, all of whom have some knowledge of the system under consideration. The workshop participants undertake the following activities:

(i) Definition of the model scope including:
- possible management actions;
- indicator variables of the system that will test the efficacy of the management actions;
- the required spatial scale for the model; and
- the simulation time step and overall period of simulation.

(ii) Formation of the modelling sub-groups:
- Management actions and indicators are grouped into thematic sub-groups so that sub-models of the various components of the system can be developed and integrated at a later stage; and
- People are assigned to each sub-group on the basis of knowledge and skills and the information requirements of the sub-groups are identified.

(iii) Development of the sub-models:
- Within each sub-group, existing information is collated and synthesised in order to model the behaviour of the indicator variables and the effect of the management actions on the indicator variables; and
- A sub-model of each component of the system is then developed by a modeller assigned to the sub-group.

(iv) Development of the integrated model:

- The sub-models are linked to form an integrated model of the system which is then tested and validated by the sub-groups.

(v) Gaming:

- The model is used by the group as a whole to develop management scenarios and to compare the effects of the various management actions. This produces a series of agreed options to be implemented.

(vi) On going development:

- The model is a dynamic entity which develops as further information becomes available or as different management options need to be evaluated.

The computer model is the tangible outcome of the process. However, the modelling workshops are of primary importance. Workshops are a highly efficient medium for the accumulation of information about the system and require participants to clearly focus on problems and achievable solutions from the outset. The involvement of the stakeholders throughout the process fosters the development of a common understanding of the problem as well as some commitment to the outcome.

In addition, by choosing the temporal and spatial scales at the start, it is possible to avoid the temptation to "over model" those aspects about which there is detailed information. This ensures that the complexity of sub-models is in keeping with the available data and the questions to be asked of the final model.

The direct involvement of all participants in the model development de-mystifies computer modelling for those who are not computer literate and ensures that the capabilities and limitations of the model are well understood by all. This is a very different approach compared to many computer simulations of natural systems wherein the assumptions and limitations are often concealed rather than revealed.

Applicability to catchment management

Catchment management generally involves a large number of stakeholders. These include landholders, local government, industry, water and waterway management authorities, a variety of government departments and community groups all of which have an interest in or responsibility for managing narrowly defined aspects of a catchment. It has been widely recognised that to achieve sustainable management of both the land and water in a catchment, there is a need to coordinate these often competing interests.

A common approach is to involve stakeholders in the development of a catchment plan which would then be used to direct the actions of all the players within a catchment. The objectives of the catchment plan will integrate the range of social, environmental and economic concerns occurring in the catchment. The plan itself should be based on a sound technical knowledge of the processes operating within a catchment. The major issues to achieve such a coordinated approach to catchment management are:

- How can technical information be integrated within the predominantly social processes of decision-making for catchment management?
- How can socio-economic and environmental considerations be integrated in the process?
- How can stakeholders be involved in the process in a way that fosters compromises amongst the various narrow interests and commitment to the outcome?

Given these issues, the AEAM process appears to be highly suitable for use in catchment planning and management. The development of the model provides the capacity to base decisions on the best available technical information. The workshop process offers the opportunity to develop a cohesive group of people with common understanding and commitment. The process overall provides a mechanism for integrating ecological, economic and social considerations.

Examples of applications

AEAM has been used in two catchment management exercises in Victoria to develop:

- a Water Quality Management Strategy for the Latrobe River Catchment; and
- a Nutrient Management Strategy for the Goulburn and Broken Rivers catchments.

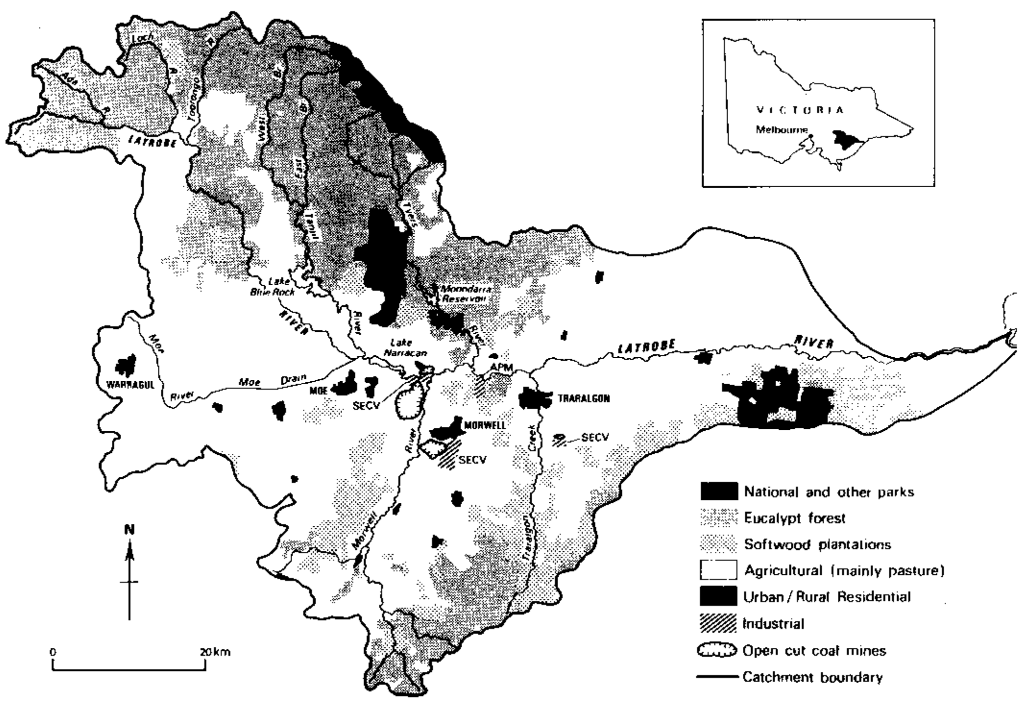
The two discs supplied with this report contain these two AEAM models. These exercises will be discussed in detail in this section. Brief descriptions of some other AEAM applications, carried out by Professor Carl Walters at the University of British Columbia in Canada, are provided in Appendix A to give a broader idea of the types of problems to which the methodology has been applied.

Application of AEAM to water quality in the Latrobe River

The Latrobe River in south eastern Australia drains an area of approximately 5,000 km^2 upstream of its confluence with the Thomson River (Figure One). The catchment contains a wide range of land uses including alpine wilderness, dryland and irrigated farming, a brown coal power industry operated by the State Electricity Commission (SECV), a paper mill (APM) and logging of both native forest and pine plantations (Figure One).

Approximately 130,000 people live in the catchment and the river discharges into Lake Wellington, one of the Gippsland Lakes which are both a major tourist attraction and contain wetlands of international significance. A number of water quality problems have been identified in the region including high turbidity of the middle and lower Latrobe, high nutrient loads, river bank instability, algal blooms in Lake Wellington and generally poor aquatic and riparian habitat along many reaches of the main river and its tributaries (Erskine et al., 1990; DWR, 1989).

Figure One
Latrobe River Catchment



In response to community concern over the water quality of the Latrobe River, the Environment Protection Authority of Victoria (EPA) undertook a review of the State Environment Protection Policy (SEPP) for the region with a view to proposing to Government a revised set of water quality objectives. A Water Quality Management Strategy was also being developed by the EPA in conjunction with community representatives to ensure the new objectives could be achieved and provide a mechanism for the adoption of recommendations. A component in the development of the Water Quality Management Strategy was an application of the AEAM methodology.

The application of the AEAM approach in the Latrobe River Catchment involved people with a diverse range of skills including water resource and environmental planners, limnologists, geomorphologists, hydrologists, waterway and wastewater engineers, hydrochemists, agronomists, foresters and land managers. In all, the process involved a group of approximately 40 people.

To develop the model of water quality in the Latrobe River system, the group went through all of the components of the AEAM workshop procedure outlined above. These stages are briefly described below.

Definition of model parameters

In the initial phase of defining the model parameters, the group identified 29 management actions that they felt could be realistically implemented and that would have some impact on river water quality. These fell into four major categories based on the type of water quality indicator variable predominantly affected (Table One). The group also identified 30 possible indicator variables of the environmental, economic and social health of the Latrobe River Catchment which they would ideally wish to monitor (Table Two).

Sub-groups

The indicators fell into four obvious groupings that became the basis for the sub-models. These were:

- Hydrology;
- Water Quality;
- Ecology; and
- Economics.

People from the initial workshop were assigned into these sub-groups on the basis of skills and knowledge. The sub-groups then considered the list of indicators and categorised them on the basis of their significance to water quality and on the practicality of actually modelling them. The aims of this categorisation were to determine indicators of:

- high priority to be included in the first cut of the model;
- low priority to be incorporated in the model at a later date; and
- low significance or for which insufficient information was available to formulate useful algorithms or where the scale was inappropriate for then to be represented. These were dropped from the exercise.

Table Two shows the indicators that were incorporated into the first cut of the model and the sub-group responsible for the algorithm formulation. It should be noted that there was insufficient information to include any of the economic indicators. This was unfortunate since one of the advantages of AEAM is the capacity to include a range of considerations. However, this relies on the skills and desires of the sub-group, as well as their access to appropriate information.

Table One
Management Actions (together with the water quality indicator variables they would predominantly affect, proposed in the initial workshop phase).

MANAGEMENT ACTION	WATER VARIABLE PREDOMINANTLY AFFECTED
1. Management of point source pollution	**Water quality of point source inputs and receiving waters**
• review existing licence discharges	
• treatment of urban wastewater	
• land disposal of wastes	
• ocean disposal of wastes	
• promotion of "best management practice" in industry	
• introduce polluter pays and transferable entitlements	
• improved domestic sewage systems	
2. Management of diffuse source pollution	**Water quality variables of surface runoff**
• land use controls	
• adoption of sustainable agricultural practices	
• control of extractive industries	
• forestry controls	
• erosion controls for construction sites and roads	
• retention ponds for urban, industrial and rural runoff	
• vegetation conservation and revegetation	
• regulation of dairy waste disposal	
• encouragement of recycling and reuse of water	
• establishment of buffer zones	**Water quality variables of runoff and instream habitat variables**
— revegetation of riparian zones and stream banks	
— controlling grazing	
— controlling access	
— policy on leases of streamside reserves	
3. Management of river flows	**Streamflow variables**
• storage operations	
— flow regimes	
— environmental allocations	
— rates of release	
— hydro-power operation	
• diversions	
— within catchment	
— between catchments	
• controls on farm dams	
• water recycling	
• regulation of wastewater discharges	
• introduction of new pricing policies	
• groundwater use	
• de-snagging	**Instream habitat variables**
• meander reinstatement	**Instream habitat variables**
4. Management of the instream environment	**River W.Q. and instream habitat variables**
• stream bed and bank stabilisation	
• willow control	
• establishment of macrophytes	

Table Two
Indicator Variables (identified by the initial workshop along with the sub-group assigned and the priority determined by that sub-group).

SUB-GROUP	INDICATOR VARIABLE	PRIORITY	COMMENTS
Hydrology	Streamflow		
	• discharge	High	
	• velocity at selected sites	High	
	Surface Runoff	High	
	Reservoir Levels	High	
	Groundwater		
	• depth	Not included	Not important to the catchment behaviour
	• aquifer pressure wetland	Not included	
	• water depth	Not included	Outside the catchment
	• period of inundation	Not included	
	Water Quality	Suspended solids	High
	Phosphorous		
	• soluble	High	
	• attached to suspended solids	High	
	Total dissolved solids	High	
	Total nitrogen	Low	
	Chlorophyll A	Low	
	Temperature	Not included	Not significant
	pH Not included	Not significant	
	BOD	Not included	Insufficient data
	Colour	Not included	Not significant
	Dissolved metals	Not included	Insufficient data
	Total organic residues	Not included	Insufficient data
	Total hydrocarbon residues	Not included	Insufficient data
	Bacterial levels	Not included	Insufficient data
Ecology	Algae		
	• macrophytes	Not included	Insufficient data
	• diatoms	Not included	Insufficient data
	Macroinvertebrates		
	• community index	High	
	Native fish	Not included	Insufficient data
	Introduced fish	Not included	Insufficient data
	Platypus	Not included	Insufficient data
	Potential fish habitat	High	
Economic	Agricultural productivity	Not included	Insufficient data
	Industrial productivity	Not included	Insufficient data
	Land prices	Not included	Insufficient data
	Employment	Not included	Insufficient data
	Production costs	Not included	Insufficient data
	Gross regional product	Not included	Insufficient data

Each sub-group then used their expertise and knowledge to synthesise existing information to represent the behaviour of their indicators in the model. The roles of each of the sub-groups in the development of the model were slightly different. In modelling their indicator variables, the Hydrology sub-group was required to develop a simple water balance model that enabled simulation of water movement through the catchment as well as a representation of the reservoir behaviour.

The Water Quality sub-group defined relationships between water quality indicator variables and various land types and uses and river condition based on information from the catchment and the literature. These were "driven" by the output from the hydrology sub-model. The Ecology sub-group established relationships between the ecological indicators and water quality and streamflow characteristics.

Representation of the Latrobe River Catchment

AEAM models are commonly written in QuickBASIC® and generally adapted from a model used in a similar AEAM application elsewhere. It should be noted that any software can be used to write AEAM models and in recent times, VisualBASIC® has been used due to the high quality of the user interface. What is important about an AEAM model is that it is a gaming tool which encourages exploration of management options.

The basic models can be considered in two parts. The first is the shell which handles the input/output and provides the structures to manage the spatial and temporal data. The second is the dynamic simulation which performs the numerical simulation of the system. In this section, we will not attempt to describe the Latrobe model fully but rather highlight the major features of the application to the Latrobe River Catchment.

The catchment is represented in the model by "cells" that are 2 x 2 km. The information for each cell includes the land use, stream condition (i.e. stability of the banks and bed), condition of riparian vegetation, erosion potential (based on soil type and slope) and the presence of point source discharges. Seventeen land uses are defined. These include two levels of management (average and good) for each agricultural land use to enable the impact of management practice to be simulated. The information on erosion potential, riparian vegetation and stream condition is given as a five class rating from excellent to very poor. All of the information was gleaned from existing surveys by various authorities mapped at 1:250,000 and checked by participants at the workshops.

For each land use, information is provided on the concentration in runoff of suspended solids, total dissolved solids, soluble phosphorus and phosphorus attached to sediment. In the case of point discharges, the discharge volumes and concentrations of each contaminant are provided. The original parameter set was prepared from existing information such as the technical papers prepared by local and state water authorities, analysis of existing water quality data, a review of related literature and advice from the Water Quality Sub-Group.

The model simulates the behaviour of five variables: total suspended solids (TSS), total phosphorus, salt (TDS), macroinvertebrate community index and index of potential fish habitat, each on monthly basis. For each variable, algorithms were developed by the ecology and water quality sub-groups based on flow estimates from the simple water balance model developed by the hydrology sub-group. This was based on monthly rainfall from the period 1978 to 1986 which covers periods of unusually high and low precipitation.

The algorithms for TSS and TDS are based on the concentrations of each parameter in runoff. In the case of TSS there is a non-linear relationship with runoff volume to account for increased concentration with flow. If the cell contains a stream, the TSS concentration is affected by stream condition and if not, it is affected by the erosion potential. Phosphorus is represented both as a soluble input and as a fraction of the TSS since much of the P is attached to soil. Each parameter can be viewed as a concentration at various points within the catchment or as a load at the catchment outlet. Cumulative annual loads are also calculated.

The ecological variables are derived from relationships between water quality and flow and community structure or habitat suitability. They are calculated at just three sites within the catchment which were considered by the ecology sub-group to be important indicator sites. In the case of the macroinvertebrate community index, the algorithm was derived from the work of Marchant (1985). In the case of the fish habitat suitability index, the ecology sub-group agreed on conditions suitable for two indicator species namely Pygmy Perch and Blackfish using information from Harasymiw (1986) and Koehn (1986).

Management scenarios are simulated by altering the characteristics of the grid cell maps or the parameters associated with the land uses or the point source discharges. In addition, the general behaviour of the two major reservoirs (Figure One) under different water use scenarios was identified as important by the workshops. The user can alter reservoir operating rules such as the level of Blue Rock Dam above which water can be released for hydro-power as well as industrial, agricultural, environmental and urban demands. This part of the model is crude and not designed to replace the detailed water use models currently applied in the Latrobe River. It simply provides the user with a way of getting a feel for the sensitivity of the system to changes in water demand.

Calibration and testing of the model was undertaken by the sub-groups and differed somewhat from "traditional" approaches. It was both a qualitative and quantitative process requiring the users to make a judgement on the ability of the model to represent the fundamental response of the system. The only output directly comparable with measured values was streamflow because other important variables such as water quality parameters were not monitored in a way that allows direct comparison with the modelled values. The model simulates the mean monthly concentration of a water quality parameter whereas field measurements are generally instantaneous. Only indirect comparisons such as simulated versus calculated total annual loads and seasonal means (from long term data) could be used to "test" the model. "Testing" was essentially a qualitative assessment of whether, when compared to the informed user's perception of system behaviour, the model could be invalidated.

The "testing" by sub-groups is a particularly important part of the AEAM process because it is the point at which participants see their algorithms "in action". This highlights the capabilities and limitations of the overall model.

The next phase of the process is gaming. Unfortunately in the Latrobe River application, a formal gaming workshop was not held. This meant that many participants did not come to realise the value of their input. Nevertheless, the model was used by a smaller group to develop potential management options and to assess their likely relative impact on the catchment as a whole.

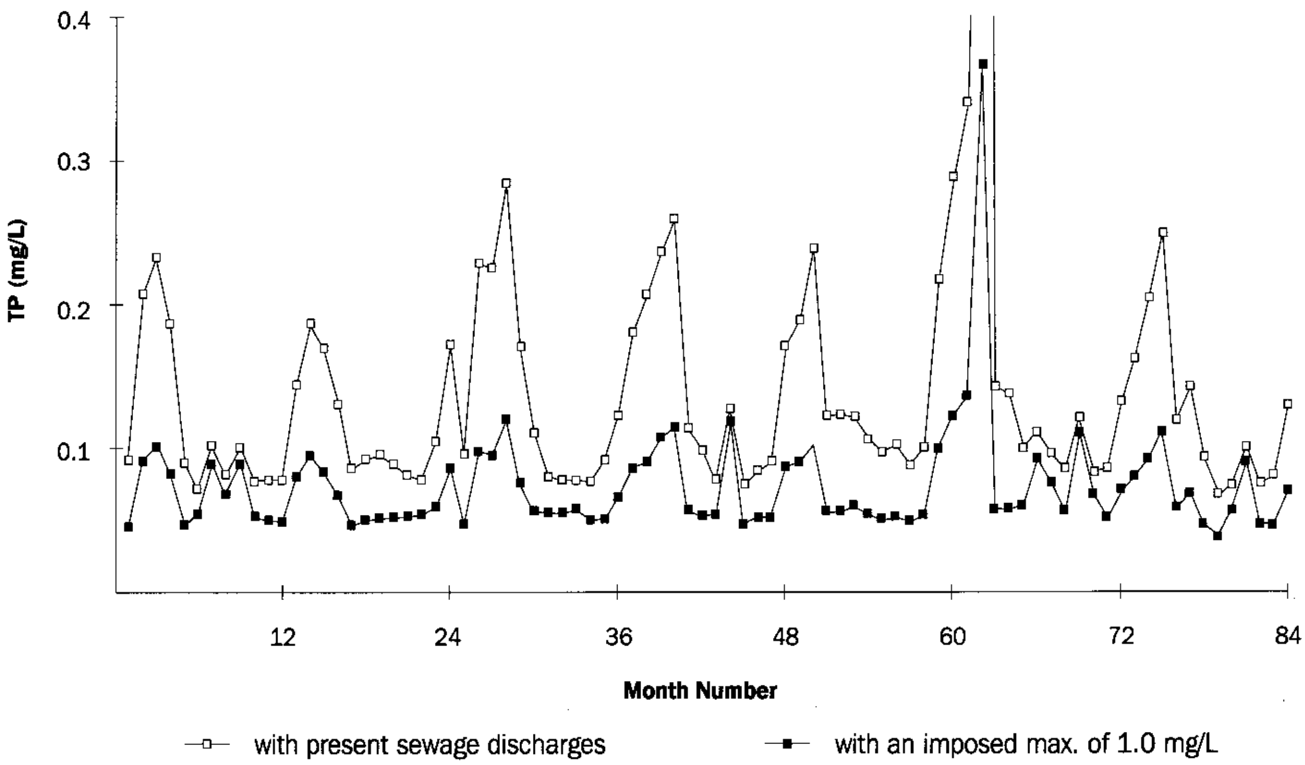
Key outcomes and conclusions from the exercise

The major conclusions to be drawn from the informal gaming sessions included the following:

- Recognition of the importance of point sources of total phosphorus (TP), particularly the Moe and Warragul sewage treatment discharges. This became clear in the early stages of the model development and was first thought to be a "mistake". Further checking supported the original conclusion. It is now generally accepted that these sources are more important in the Latrobe River than previously recognised. Figure Two shows simulated monthly total P concentrations with present sewage discharges and with an imposed maximum concentration of 1.0 mg/L for the seven year simulation period.

- Recognition that discharge timing (as well as reduction) may be a useful management option to improve the water quality in summer. Changing the timing does not affect total annual loads. However, it reduces concentrations in river during low flows, with potential ecological benefits.
- A general understanding of the different issues under different flow regimes. The priorities given to management options are heavily dependent on the detail of the key issues. Is total load or peak concentration of TSS the key issue? Perhaps TP is the real problem in which case a very different set of priorities should be established. The model enables exploration of these and similar issues.
- The results of the gaming were used as part of the development of the new State Environment Protection Policy (SEPP) for the region and the model has had on-going use by Gippsland Water in their management plans for sewage disposal.

Figure Two
Simulated total P Concentration in the Latrobe River at Kilmany South



AEAM in the Goulburn and Broken Rivers catchments

Many aspects of this application parallel those of the Latrobe River application. This section concentrates on the differences, particularly in the wider role of the process.

The Goulburn and Broken Rivers basins are the largest catchment complex in Victoria, covering 2.3 million hectares. The catchments drain north into the Murray River. The area is important for primary production, producing over 25% of Victoria's rural output (SKRDC 1993). There are significant areas of both dryland and irrigated agriculture including activities such as fruit and vegetable growing, dairy farming, cereal crops and oilseeds and livestock.

In addition, there are several large urban and industrial centres. Primary producers in the region have built a reputation for the production of clean food. However, these activities in the catchments have led to a number of water quality problems including increased nutrients, turbidity, weed proliferation, declining river vegetation and the recent occurrence of blue-green algal blooms.

The local population recognised that the riverine environment is degrading and the capacity to produce clean food is threatened by the decline in water quality. Moreover, the catchment has been identified as a major contributor to nutrient in the Murray River. Consequently, there is strong pressure to improve water quality within the catchments. As a first step, the local catchment communities initiated the development of a Nutrient Management Strategy.

One of the major issues in the development of such a strategy is the difficulty in getting consensus from competing interests in the catchments on the activities that contribute the major nutrient inputs and that should be targeted for nutrient reduction. Requirements for nutrient reduction have considerable economic implications for any of the stakeholders. Thus, it was agreed that the strategy would be developed in two stages:

Stage One broad scale catchment assessment, identification of the activities responsible for high nutrient inputs to the rivers and the generation of broad-scale management options for reducing these inputs; and

Stage Two detailed analysis of the management options identified in Stage One.

AEAM was used as the decision-making support system for Stage One because of its capacity to involve stakeholders and resolve conflicts. The specific objectives were:

1. To determine, on a broad scale, the relative nutrient inputs and outputs of the various activities taking place in the Goulburn and Broken Rivers catchments.
2. To identify area and activities which generate or reduce the levels of nutrients.
3. To develop broad-scale management options for reducing the nutrient inputs from the priority activities.
4. To predict the impact on the Murray River of current activities and possible future management options.

In the Goulburn and Broken Rivers catchments study, approximately 50 people were involved in the AEAM workshops, including representatives of local farmer groups, recreation and conservation groups, local water and river management authorities, local salinity management and irrigation groups, local government, government departments, researchers, managers, policy analysts, and industry groups. The group undertook each of the workshop activities outlined above and where these differed from the Latrobe River application, they are noted below.

Definition of model parameters

The group listed approximately 100 management actions and these are shown in Table Three. The group then identified 38 possible indicator variables which are listed in Table Four.

Sub-groups

The same four groups were used as for the Latrobe, i.e. Hydrology, Water Quality, Ecology and Economics.

Sub-models were developed in a similar way to the Latrobe application. The indicators that were incorporated in the model and the sub-group that dealt with them are shown in Table Four. Note that again, no economic indicators were modelled. However, in this case it occurred because the

Table Three
Management Actions (together with the water variables they would predominantly affect, proposed in the initial workshop).

MANAGEMENT ACTION	WATER VARIABLE PREDOMINANTLY AFFECTED
1. Management of point source pollution	**Water quality variables of point source inputs**
• review existing licence discharges	
— sewage treatment plants	
— fish farms	
— feedlots and piggeries	
• treatment of urban wastewater	
• land disposal of wastes and reuse of waste and wastewater	
• low P detergent	
• promotion of best management practices in industry	
• improved domestic sewage systems	
• sewering unsewered towns	
• dual systems	
• waste minimisation practices	
• introduction of polluter pays and transferable entitlements	
2. Management of diffuse source pollution	**Water quality variables of surface runoff**
• land use controls	
• set water quality objectives	
• adoption of best management practices in irrigation areas	
— re-use on farm and from district drains	
— scheduling	
— use of technology, e.g. laser grading, drip sprinklers	
• variation of fertiliser application rates, type and timing	
• adoption of best management practices for cropping	
• grazing management	
• control of extractive industries	
• forestry controls	
• erosion controls on construction sites and roads	
• retention ponds for urban, industrial and agricultural runoff	
• stormwater management	
— treatment and reuse	
— street cleaning regulations	
• vegetation retention and revegetation	
• management of intensive animal industries	
— licence and planning controls	
— treatment ponds and reuse	
• encouragement of recycling and reduced water use	
• control of chemical use	
• establishment of buffer zones	**Water quality variables of surface runoff and instream habitat variables**
— revegetation of stream banks and riparian zones	
— controlled grazing and access	

Table Three (Continued)

MANAGEMENT ACTION	WATER VARIABLE PREDOMINANTLY AFFECTED
3. Management of river flows	Streamflow variables
• storage operations	
— environmental allocations	
— dilution flows	
— management of storage levels to reduce nutrient release	
— de-stratification and multi-level off-take	
— discharge timing	
— desilting	
• controls on farm dams	
• introduction of pricing policies	
• sub-surface water management	
— control pumping and timing of disposal	
4. Management of in-stream environment	River water quality variables and in-stream habitat variables
• stream bed and bank stabilisation	
• control of aquatic weeds	
• establishment of macrophytes	
• controls on sand and gravel extraction	
• wetland protection	

group decided that the important economic considerations could be more efficiently investigated following the outcomes of Stage One. So while there were no economic indicators in the model, there was a process defined by which impacts could be considered.

The emphasis in the Stage One objectives on nutrients meant that many of the indicators identified in the first workshop were not directly relevant and hence were given low priority.

Representation of the Goulburn and Broken Rivers catchments

The model is based on a 5 x 5 km cell size and runs on a monthly time step. Information is provided on land use and erosion risk, major point sources (e.g. sewage treatment plants and fish farms), septic tanks and small urban areas, groundwater pumps and drains in irrigation areas and stormwater run-off from the major towns. Data on current nutrient generation are provided for all these catchment activities, derived from the literature and information from the catchments.

The hydrology of the catchments is dominated by the regulation of water storages and diversion structures. This made the development of a dynamic hydrological model impractical in the time available. Instead, the output from a comprehensive Resource Allocation Model (REALM) of water movement through the basins was used as input to the AEAM model. A range of key water use scenarios were identified by the sub-group and these were simulated using REALM. The output is available in the AEAM model by choosing the desired water use scenario from a menu.

Management scenarios can be generated by changing any model parameter, for example by changing land use, river operations (including providing environmental flows), irrigation drainage, and point source inputs.

Table Four
Identified Indicators (from the initial workshop phase of the application of AEAM in the Goulburn and Broken Rivers catchments study).

SUB-GROUP	INDICATOR VARIABLE	PRIORITY	COMMENTS
Hydrology	Streamflow		
	• discharge	High	
	• storm discharge	Not included	Not possible using monthly simulation
	• velocity surface runoff	Not included	Not required in ecological parameters
	• irrigation areas	High	
	• dryland areas	High	
	— storage levels and operations	High	Use of flow scenarios
	— groundwater		
	• depth wetland	Not included	Not significant in nutrient management
	• water depth	Not included	Scale too coarse
	• period of inundation	Not included	Scale too coarse
Water quality	Phosphorus		
	• total P	High	
	• DRP	Not included	Too difficult to differentiate from TP
	— total dissolved solids	Low	Not required for NMS
	— temperature	High	Surrogate used for ecological indicators
	— suspended solids	Low	Only if needed for nutrient modelling
	— turbidity	Low	Only if needed for nutrient modelling
	— nitrogen		
	• total N	High	
	• NH4	Not included	Only if needed for nutrient modelling
	— Silica	Low	
	— pH	Not included	Not required for ecological parameters
	— chlorophyll A	Not included	Insufficient data
	— BOD	Not included	Not relevant to NMS
	— DO	Not included	Not relevant to NMS
	— heavy metals	Not included	Not relevant to NMS
	— bacteria	Not included	Not relevant to NMS
	— potassium	Not included	Not relevant to NMS
	— pesticides and herbicides	Not included	Not relevant to NMS
	— chlorine and fluorine	Not included	Not relevant to NMS
	— colour, odour, taste, hardness	Not included	Not relevant to NMS
Ecology	Algae		
	• blue-green algae		
	• blooms	High	
	• species and counts	Not included	Insufficient data
	• filamentous	High	

Table Four (continued)

SUB-GROUP	INDICATOR VARIABLE	PRIORITY	COMMENTS
	• macrophytes diversity	Not included	Insufficient data
	— macro-invertebrate		
	• diversity	High	
	— native fish	Not included	Insufficient data
	— carp	Not included	Insufficient data
	— platypus	Not included	Insufficient data
	— wetland	Not included	Scale too coarse and insufficient data
	— streamside vegetation	Not included	Unlikely to vary with nutrient levels
Economic	Agricultural productivity	Not included	Insufficient data
	• industrial productivity	Not included	Insufficient data
	• employment	Not included	Insufficient data
	• community health	Not included	Insufficient data
	• community satisfaction	Not included	Insufficient data
	• investment	Not included	Insufficient data
	• cost of management actions	Not included	To be covered in Stage Two
	• cost and benefit ratios of management actions versus nutrient reduction	Not included	To be covered in Stage Two
	• economic impact of algal blooms	Not included	To be covered in Stage Two

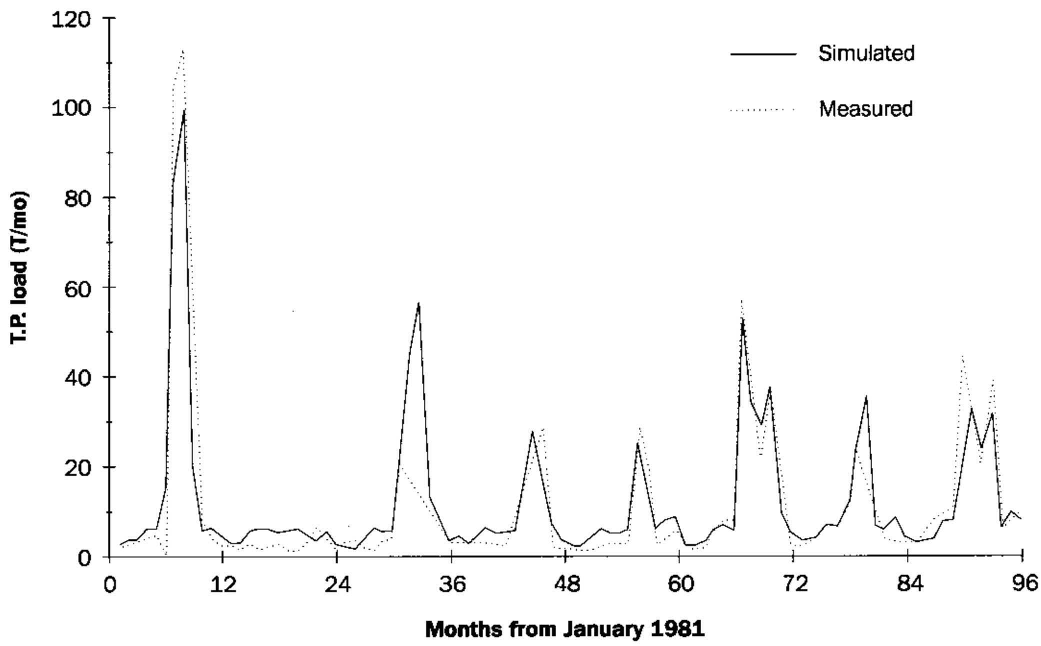
The indicators are loads of Total P and Total N; concentration of Total P and Total N; and algal risk and macroinvertebrate diversity indicators at two key points in the system. The impact on the Murray River is represented in graphs which show the load coming down the Murray River as well as that coming out of the Goulburn and Broken Rivers catchments system. This is the sum of discharges from the Goulburn and Broken Rivers as well as the irrigation drains that flow directly into the Murray River.

Testing and validation was carried out in the same way as in the Latrobe River application. The model could be invalidated through a combination of direct comparison with available data and a qualitative assessment by the informed users of the system. Note that qualitative assessment can invalidate a model either because of model failure or incorrect user perception. The testing and validation process is aimed at determining which of these options is correct and acting accordingly.

Figure Three shows the measured and simulated loads of total P for the Goulburn River at McCoys Bridge during the simulation period. Note that the model assumes present levels of development throughout the period. Consequently, it would be expected to provide better simulations for the most recent period.

The AEAM model is a simplistic representation of processes occurring in the Goulburn and Broken Rivers catchments. However, it was designed for a policy development project aimed at the regional rather than the local scale.

Figure Three
Measured and Simulated Loads of Total P for the Goulburn River at McCoys Bridge



Key outcomes and conclusions from the exercise

The model was used by the entire stakeholder group in a final "gaming" workshop to specifically fulfil the objectives of Stage One. The group examined a number of management scenarios and reached the following conclusions.

NUTRIENT LOADS

The activities producing the major nutrient loads were:

- the dryland areas during high flows (these were of little significance at other times);
- the irrigation areas in both high and low flows (peak loads in winter, peak concentrations in summer); and
- sewage treatment plants in the lower reaches of the Goulburn (particularly important in summer).

The reason for high loads from irrigation areas in winter was unclear. The data collated for the exercise clearly illustrated high levels of nutrients in the irrigation drains during these periods and determining their exact source was identified as a priority for Stage Two. It is important to note that the sort of management options which reduce the impact of irrigation areas under low flow conditions (i.e. minimising water application and zero drainage strategies) would not affect the rain dominated runoff in winter.

NUTRIENT CONCENTRATIONS

The major activities causing high nutrient concentrations at low flows and thus creating the potential for algal blooms were:

- sewage treatment plants in the lower reaches of the Goulburn; and
- irrigation drains (note that these carry discharges from sources other than just irrigation runoff).

The group investigated possible management options for reducing both nutrient loads and concentrations at low flows. In the irrigation area, a combination of best management practices could substantially reduce nutrient inputs. Changing seasonal patterns of sewage discharges to minimise discharge during low flows substantially reduced nutrient concentrations during these periods and thus the likelihood of algal blooms. Flow management was shown to be a realistic option for controlling low flow concentrations.

The group unanimously agreed that Stage Two in the development of a Nutrient Management Strategy for the Goulburn and Broken Rivers catchments should concentrate on a detailed investigation of these areas.

OTHER ISSUES

Septic tank discharge and stormwater from urban areas were shown not to be important at the catchment wide scale (although these could be locally important). Similarly, the influence of fish farms in the upper catchment had a local impact but was not significant for the catchment as a whole due to the use and diversion of the water from these areas.

The application of AEAM in Stage One of the development of the Nutrient Management Strategy for the Goulburn and Broken Rivers catchments was considered to be highly successful by the participants. All objectives were met including the need for stakeholder consensus on the outcomes.

Try for yourself

The models for the Latrobe River and Goulburn and Broken Rivers catchments, together with some user notes, are provided with this report (Appendix Two). Readers are encouraged to try the models for themselves. The tutorial and user notes are set up for the Goulburn and Broken Rivers catchments model but the Latrobe River model is very similar to use.

Reflections on the process

Limitations of the modelling

There are limitations to AEAM processes with respect to the models. They are obviously simplified representations of real systems. By using a coarse resolution in both space and time, it is possible to use relatively simple relationships. However, the subsequent smoothing of catchment response masks some behaviour. For example, storms cannot be specifically represented at the monthly level except to the extent that the loads are reflected in average monthly data. Nevertheless, it is possible to include relationships based on information such as peak intensities occurring in the month or some similar indicator of storm behaviour if this is thought to be critical.

It must be remembered, however, that AEAM models are not formulated as quantitative forecasting tools. They are flexible representations of complex systems designed to capture the fundamental response of the system to deviations. An AEAM model also acts as a platform for the exploration of system behaviour.

Great uncertainty exists in the scientific literature regarding the quantitative impact on water quality and ecological indicators of management actions. Consequently AEAM models require the user to make their own judgement of impacts by altering, for example, the parameter describing the concentration of TSS in runoff. The user is then able to see the effects of that action (say a 10% or 90% reduction for a certain land use) at the catchment scale.

This approach forces the user to be informed and to use the model as an exploratory tool. It also discourages unerring and uncritical belief in quantitative answers which is a common symptom affecting users of computer models of natural systems (Grayson et al., 1993, Grayson et al., 1992, Beven, 1989; Hillel, 1986).

Benefits

One may ask, "What use is a methodology that leads to a model which is not intended to give precise, quantitative output?" Firstly, it is important to recognise that the model is only part of the process and that significant benefits accrue from the workshops and sub-group meetings.

The workshops involve a group of stakeholders, i.e. people who have the knowledge of, and an interest in, the problem at hand. Bringing them together enables cross-interest links to be formed and focuses the group on defining achievable management options and agreeing on important indicators of the system. The cross-disciplinary make-up of the group enables researchers to appreciate where, and in what form, their information is useful to others.

This highlights areas where information is lacking and where the form of the information is not appropriate for use by others. For example, information on the relationship between water quality and ecological variables is generally poor, as is, data on the water quality response of urban areas to storms).

False expectations are avoided through full and frank discussion of available knowledge and data from the range of disciplines involved. The sub-group's work can be considered a critical review of published and unpublished research and utilises the considerable personal experience of the participants, all with a sharply focussed objective. The direct involvement of the stakeholders throughout the process ensures a feeling of ownership over the model. This increases the likelihood of final outcomes being adopted.

Secondly, the model should accurately reflect the available level of knowledge about the system. It can be used for comparison of management options and should prove to be a useful educational tool, both for those directly involved in its development and for other users.

It is often said that model formulation teaches more than model use (e.g. Hillel, 1986) and by involving many people in that formulation, these benefits are widely enjoyed. The model is also an efficient way of presenting technical information in an "easily digestible" form. For example, research into management effects of nutrient generation from irrigated areas can be easily incorporated via the appropriate parameters and the impact at the catchment level evaluated. This capability should prove useful at public meetings where the impact of scenarios identified by attendees can be instantly displayed.

It must also be remembered that AEAM is a tool for use in the adaptive management of a catchment system. It is a tool designed purely to assist in decision making and does not substitute for the complex processes of judgement which involve diverse scientific, technical and political inputs. The full value of this tool will be realised when the model itself is adaptively modified. Implementation of exploratory management programmes must be accompanied by appropriate monitoring so that over time, the AEAM model can be refined as pertinent data on system responses is acquired.

Advice for future applications

Some cautionary notes

AEAM is a tool to assist in decision making and just one of a number of such tools available. Before deciding whether it is the best tool for your particular issue, you need to consider whether the potential benefits are relevant for you. AEAM is not a process that can be applied to every single problem or issue. For the benefits of the process to be realised, there should be a need for some (if not all) of the following:

- integration of a number of factor;
- some dispute or lack of clarity regarding the source of the problem(s);
- competing interests involved;
- community and stakeholder involvement;
- a technical information base; and
- setting of priorities for action.

Issues that could be handled more effectively by other methods include those:

- that are essentially a single focus problem;
- where stakeholder agreement has been reached;
- where specific objective for the AEAM exercise cannot be elucidated; or
- where resources are extremely limited.

Not only must the issue lend itself to the AEAM process, but the motivations of those involved must be appropriate. It is vital that those involved, and particularly the sponsoring group, have:

- a clear understanding of the objectives and outcomes of the exercise and how AEAM fits in with the overall planning process;
- a realistic understanding of the time frame involved;
- the resources to employ a facilitator and modeller;
- the ability to motivate the key stakeholders in the catchment; and
- a management set-up that is held in high regard by those living in the area to enhance rapid, open communication between the different interest groups.

Some pre-requisites for a successful AEAM application

We believe the following points to be key pre-requisites for applications of AEAM.

A clearly defined role for AEAM

AEAM is not a panacea for lack of information or direction. It will be successful only if careful thought is given to whether the benefits of the exercise outweigh the costs and whether the actual issue is appropriate for an AEAM application. Deciding these will require a good knowledge of AEAM and probably some assistance from individuals with experience in AEAM such as those listed at the end of this report.

A clearly defined (and agreed) set of objectives for the exercise

A clear statement of the objectives is crucial. All participants must be aware of these since they will "drive" virtually all aspects of the exercise from who is involved to what data in needed. Furthermore, the role of the AEAM application in the overall planning exercise needs to be clearly understood and articulated.

A problem which needs the integration and communication benefits

There are many ways to build a computer model, most of which are much easier (at least for the modeller) than the modelling part of an AEAM application. It is therefore important that the reason for applying AEAM is not to just produce a model. In fact the model is really a small part of applications in ICM. There must be a real need for communication and greater understanding of "whole of system". There must also be a problem that lends itself to "gaming" with enough information to make the game realistic.

An enthusiastic and committed group driving the exercise

The process needs to be driven by people with local knowledge and the respect of their community. They must ensure open and accessible communication with all stakeholders. They are also vital in choosing the people to be represented in the workshops. The modeller/facilitator will be heavily reliant on the motivation and commitment of the "driving" group.

Expectation management needed at every stage

As with most processes with wide involvement, management of expectations is paramount. Articulation of the objectives is the first stage but by no means the last. An AEAM exercise should achieve a great deal, but there will be a lot that is not included. Many participants will be motivated by local issues, yet the objectives may call for broad scale assessment. In this case, it is important that the participants see that, even though their "pet" issue will not be addressed in detail, the overall exercise is still useful. If too many people are disillusioned or marginalised, the process will fail.

Communication throughout the process

One of the major perceived benefits of AEAM is its capacity for community and stakeholder involvement. It is therefore essential to have ongoing communication with all stakeholders. This will need to be at several levels to ensure that the representatives of the stakeholder groups directly involved are fully informed and that they are reporting back to their "constituents".

The AEAM applications described here formed part of larger processes. If you are thinking that AEAM might be helpful to you, it is important that you come to understand the basic philosophy, benefits and limitations of the process and to give careful consideration to whether it is right for you. Should you wish to proceed, contact Dr Phil Price at the Land and Water Resources Research and Development Corporation who maintains a list of people with expertise in AEAM.

Acknowledgments

The authors wish to acknowledge the help and encouragement of Mr. Trevor Blake from the Environment Protection Authority, Victoria who was the initiator of the Latrobe River AEAM application.

We also wish to give special thanks to Professor Carl Walters at the University of British Columbia in Canada who has been very supportive of our efforts in AEAM and so keen to share his knowledge and experience.

Robert Argent at the Centre for Environmental Applied Hydrology and Glenn Conroy at the Land and Water Resources Research and Development Corporation provided editorial guidance in the production of this Occasional Paper.

References

Beven, K. (1989). Changing ideas in hydrology—The case of physically-based models, Journal of Hydrology 105, 157–172.

Department of Water Resources, Victoria (1989). A resource handbook, Victorian Government Printer, 312p.

Erskine, W.D., Rutherfurd I.D. and Tilleard J.W. (1990). Fluvial geomorphology of tributaries to the Gippsland Lakes, Department of Conservation and the Environment, Victoria, Australia. 186p.

ESSA (Environmental and Social Systems Analysts Ltd.) (1982). Review and Evaluation of Adaptive Environmental Assessment and Management, Environment Canada.

Grayson, R. B. , Bloeschl G., Barling R. D. and Moore I. D. (1993). Process, Scale and constraints to hydrologic modelling in GIS. HYDROGIS'93. IAHS Int'l Conf. on applications of GIS to Hydrology and Water Resources, Baden, Vienna April 19–22.

Grayson, R.B., Moore I.D. and McMahon T.A. (1992). Physically based hydrologic modelling II—Is the concept realistic?, Water Resources Research, 28, 2659–2666.

Grayson, R.B, Doolan, J.M and Blake,T (1994) Application of AEAM (Adaptive Environmental Assessment and Management) to water quality in the Latrobe River Catchment Journal of Environmental Management. 41(3), pp. 245–258.

Harasmiw, B.J. (1986). Fish survey of Traralgon Creek. State Electricity Commission Research and Development Department Report no SO/85/99.

Hillel, D. (1986). Modelling in soil physics: a critical review. In 'Future Developments on Soil Science Research', SSSA annual meeting in New Orleans, Los Angeles, 35–42.

Holling, C.S. (1978). Adaptive Environmental Assessment and Management, John Wiley and Sons, Chichester.

Koehn, J. (1986). Approaches to determining flow and habitat requirements for freshwater native fish in Victoria. In Campbell I. (ed.). Stream protection: the management of rivers for instream uses. Water Studies Centre, Chisholm Institute of Technology.

Marchant, R., Metzeling L., Graesser A. and Suter P. (1985). The organisation of macroinvertebrate communities in the major tributaries of the Latrobe River, Victoria, Australia. Freshwater Biology, 15, 315–331

SKRDC Shepparton, Kyabram,Rodney Development Corporation (1993) Submission to the Regional Task Force.

Walters C. (1974). An interdisciplinary approach to development of watershed simulation models. Technological Forecasting and Social Change, 6, 299–323.

Walters C. (1986). Adaptive Management of Renewable Resources, Macmillan, New York.

APPENDIX A

A sample of other AEAM applications

Spotted Owl

This AEAM exercise was undertaken to look at the options for preserving habitat for the rare spotted owl in the north western United States. The model user can define a map of suitable habitat and impose various controls on its change over time. One of the key questions was whether it is best to have habitat patches spread over a large area or to have larger (but fewer) areas. The simulation model is of a stochastic nature and represents the reproduction and mortality of the owls based on knowledge of their behaviour. The offspring attempt to fly to new areas and establish a new breeding couple. The distances they fly and areas in which they establish are based on the available research. The directions are stochastic. The model is run many times to establish a statistical view of the population responses to a given land management scenario.

Forestry Management

Many of the AEAM applications have been in the north west of the United States and in Canada. In these areas, forestry is a major industry and several aspects of logging have been the focus of AEAM applications. The question of buffer zones around logging coups was modelled using a shell very similar to that of the Latrobe River model. It imposed various rules about the ways in which a road network would develop under different rules on the buffer area required around a coup and costs of haulage etc. The model deals with water quality issues, habitat maintenance (for coho salmon and deer) and the economics of different logging scenarios.

Village in the Austrian Alps

One of the earliest applications of AEAM was in the Austrian Alps. A group of scientists and government people asked Professor Carl Walters at the University of British Columbia in Canada to look at an area they had been doing research on for many years. The study was initially intended to concentrate on the environmental impacts of hotel development in the valley. However, once the workshops began, it became clear that there were social and economic considerations that were likely to dominate.

The problem was that families felt that the only way to keep together in the area was for each offspring to build a hotel so the development was likely to continue as population increased. The model ended up concentrating on the economics of development, demographics of the villages as well as the environmental amenity. It became clear to the locals that unless the employment base was broadened, the land would run out and the environmental amenity would deteriorate to the point that the hotel industry would decline. In response to community interests, the emphasis of the exercise shifted away from the intended catchment impact focus to instead deal with the root cause of the perceived environmental issue.

APPENDIX B

User notes for the AEAM model for the Goulburn and Broken Rivers catchments

These notes briefly describe how to use the AEAM model for the Goulburn and Broken Rivers catchments. You will need to have an IBM compatible computer, preferably a 486 or 386 with a co-processor.

1. Copy all the files from the disc marked "Goulburn and Broken Rivers AEAM Model" to a new sub-directory on your computer's hard disc.
2. To run the model, type "GOUL". This is the name of the program and also of the default settings for the maps and model parameters.
3. For the Latrobe model, copy the files from the disc marked "Latrobe River AEAM Model" to a separate sub-directory on your computer's hard disc. To run the model, type "LAT".
4. The models are essentially self explanatory and one follows the menu instructions. The cursor keys are used to move around the screen and "Enter" is used to confirm choices. The "Esc" key enables you to swap screens.
5. When the programs are started, the default maps, graphs and parameters are loaded. These essentially correspond with present conditions. If you wish to use different information from the start, you can choose it before the simulation begins. You can also choose to simulate for less than the total years of data if you wish.
6. Once you have changed either parameters or maps, you can save them for later use. If you choose this option, a list of existing files of that type appear. Do not use an existing name, choose a new one. There is provision for inserting a short description of the file as a header. Similarly you can restore a file that has been previously saved.

The various parameter screens in the Goulburn and Broken Rivers catchments model are briefly described below:

Edit water quality and discharge parameters

The run-off factor enables the user to affect the amount of run-off from the particular land use, e.g. 0.8 means 80% of the water comes off that area (see note in the next section). This factor affects run-off all year.

Edit point source data

The point sources are defined by the area in which they discharge, the annual discharge volume, the flow pattern, and the water quality. The flow pattern is chosen from one of four options listed at the bottom of the screen. These figures are the proportion of annual flow discharged in each month.

Edit irrigation area flow and groundwater pump data

The irrigation and groundwater parameters relate to the specific irrigation areas. The runoff factor in this screen works the same way as above except that it is only in summer.

The groundwater pumps are represented in a rather complex manner. The number of private and public pumps proposed in each area are given and the proportion of the public pump discharge that goes to channels is defined. The discharge from private pumps and the remainder of the public pump flow goes to drains. Re-use of the groundwater discharge from drains can be defined. In the table of years and months at the bottom of the screen, you choose the particular months of particular years in which the reuse actually operates i.e. the re-use factor gives the proportion of re-use provided the particular month and year is identified by a "1" in the bottom table.

Edit septic tank and urban data

Septic tanks and urban runoff are given by the number of tanks and the urban area respectively, for each sub-catchment. Total P and total N factors can be changed.

Edit ecology index parameters

The ecology screen gives the flow and TP triggers for each index. Where the upper and lower flow triggers are the same, it means there is really just one trigger, i.e. above or below the limit. If these flows are different, there are three ranges—above, between and below.

Important points

- At the end of a simulation run, any map information, e.g. Land Use, is returned to the default. The number of years of simulation, the graphs chosen and the parameters used are carried over to any overlay or new runs. This is important to remember since you might be compounding changes rather than looking at individual effects.
- When the runoff factors are changed, the effect is seen and modelled on the load and concentration relationships but not in the flow graphs. This is a quirk of the model so consider the loads and concentrations since they incorporate the effects of reduced and increased run-off.
- Remember that the model works by applying your chosen scenario to a 15 year period of flow data. This period covers a range of flows from years of flood to years of drought. The model does not say what actually happened in a particular year but rather what might have happened had your scenario been in place, i.e. we use a real period to provide a realistic range of flows.

A tutorial in the use of an AEAM model

The purpose of this section is to enable you to become familiar with the operation of the existing models and to see just what sort of management actions they can simulate.

The following specific exercises can be used as a starting point for your own exploration. These are set up for use with the Goulburn and Broken Rivers catchments model. The modelling system is contained in a series of files (see Disc Two—Goulburn and Broken Rivers AEAM Model) beginning with the prefix GOUL. You may also wish to play with the Latrobe River model (see user Disc One—Latrobe River AEAM Model) that is set up a little differently.

Scenario One—Septic tanks and urban runoff

1. Set graphs (by placing an X in the appropriate box in the "Set graph pane choices" screen and using a "space" to turn off unwanted graphs) to flow at McCoys ("T/mo TP Goul.@McCo"), Seymour ("T/mo TP Goul. u/s Se") and the Broken River at Shepparton ("T/mo TP Broken R.").
2. Re-run with all septic and urban set to zero. If you like you can also look at cumulative annual loads.

Scenario Two—Diffuse inputs

1. Set graphs to Seymour flow, P load ("T/mo TP Goul. u/s Se") and P conc ("mg/l TP Goul. u/s Se").
2. Set simulation time to five years and run.
3. Re-run with the restored map "FOREST" which simulates all forest upstream. You can make and save this map (or something like it) yourself. What are the relative impacts at different flow regimes? While at Seymour, look at the influence of fish farms and compare them to what you have seen due to agriculture.

Scenario Three—Irrigation

1. Set graphs to total P at "all G/B" (this includes the Goulburn and Broken Rivers as well as drains which go directly into the Murray River), Seymour ("T/mo TP Goul. u/s Se") and flow at McCoys as well as cumulative P for the whole catchment-run.
2. Restore the map "DRYLAND" (or manually change all irrigation). Note that approximately 8% of the catchment area is irrigated.

Scenario Four—Sewage discharge

1. Set graphs to P conc. at McCoys, Seymour, flow at McCoys and cumulative P for the whole catchment-run.
2. Turn sewage discharges to zero (try also different timings, levels of treatment etc). Note the flow effects. What does it say about management options?

Scenario Five—Flow management

1. Set graph to P conc. and flow at McCoys.
2. Try different flow scenarios: natural (B), environmental flow change (D).

Further information

An additional discussion paper on the AEAM process entitled "Notes for Potential AEAM Modellers and Facilitators", dated April 1995, is available free of charge by contacting the Land and Water Resources Research and Development Corporation. The address is GPO Box 2182, Canberra, ACT 2601. Telephone (06) 257 3379 and facsimile (06) 257 3420.

This paper covers various topics including:

- The role and responsibilities of the facilitator and modeller;
- Software issues;
- How AEAM is done;
- Approaches to communication;
- Checklists for each stage;
- AEAM user notes;
- A tutorial in the use of AEAM model;
- Notes to programmers; and the
- Resource Allocation Model (REALM) for the Goulburn River model.