Integrating Environmental Models for Nutrient Movement Analysis and Visualisation within Multi-Use Catchments.

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ABSTRACT Blooms of toxic blue-green algae in the Murray-Darling Basin (MDB) have caused community groups in the catchment to seek land management techniques that will reduce the problem. A generic spatial modelling and visualisation framework capable of interactively linking catchment water quantity and quality models and a Geographical Information System (GIS) for analysis of the effects of changing land use and management practices on the quality of runoff for large creek systems (up to 10 000 km^2 in area) has been developed to test the effect of alternate practice before implementation. Both ground and surface waters for a network of small catchments of different land use, soil types and sizes in the Queensland portion of the MDB have been and are being monitored to provide data for calibration of the models. Visualisation of model output can either be done through a software environment developed at the Advanced Computational Modelling Centre (ACMC [1997]), or through a sophisticated 3D-visualisation environment – PolyTRIM (CLR [1997]). This will allow catchment managers to make more informed decisions on appropriate land use and management practices in the MDB.

1 INTRODUCTION

PC-based modelling environments have been widely used where Graphical User Interfaces (GUIs), models and visualisation tools are all combined into one package. Another direction used in this work is to have the model components and the visualisation all stand-alone and interact in a modular way on a wide variety of computer platforms. This means that the user is no longer constrained by their modelling package and a possibly low performance computer. Instead, they can use the computer platform to suit their modelling needs, rather than be artificially restricted by hardware constraints.

The Murray-Darling Basin (MDB), the largest river system in Australia, had many blooms of blue-green algae in its waters during the summer of 1991-2, with a bloom over 1000 kilometre stretch of the Darling River being the worst (Johnstone [1992]). These blooms have several detrimental effects including death of domestic stock, extra treatment or closure of domestic and irrigation water supplies and loss of recreational use.

Algal blooms are caused by a combination of a number of factors with the main ones being high concentrations of plant nutrients in the water, slow flowing or stagnant water, warm water temperature and sunlight. The first three of these can be manipulated to some extent by human activity. Phosphorous (P), the most influential nutrient, and Nitrogen (N), arise from concentrated or point sources such as sewerage treatment plants and intensive livestock industries and diffuse sources such as in runoff from urban and rural areas. Instream flow is dependent on natural rainfall/runoff processes and management of any impoundments on the stream. This latter item can also influence water temperature.

Any improvement in the current situation requires input by those controlling land use and management practices within a catchment on a whole catchment basis. This is best carried out through the informed action of individual users and managers of the catchment resources. The Integrated Catchment Management strategy (QDPI [1991]) and similar strategies are suitable mechanisms for fostering the necessary changes. However, implementation of change requires identification of opportunities for reducing the problem, awareness of these by catchment managers and the adoption of effective management practices.

The work reported on in this paper is aimed at producing information on issues identified by Johnstone (1992) which should benefit the catchment managers in their search for implementation of possible control practices. Those issues include:

- Definition of nutrient contribution and composition from diffuse sources of alternate land use management.
- Development of a generic Decision Support System (DSS) to facilitate the development of catchment nutrient management plans.
- The integration of a Geographical Information System (GIS) with the DSS.
- The development of a program of community education relating to effect of catchment management on runoff water quality.

The DSS (Decision Support System) included here is a generic spatial modelling and visualisation framework capable of interactively linking simulation models and providing visual summaries for analysis of effects on changing land use and management practices. In particular it has

- a modular modelling and visualisation environment, providing linkage of different hydrological models;
- a platform independent software environment based on Khoros (KRI [1997]);
- an interactive Graphical User Interface (GUI) for efficient data control;
- a visualisation environment for displaying visual summaries and model interaction.

2 MODELLING FRAMEWORK

Advanced Khoros (KRI [1997]) was used to provide a software platform with which to visually develop a GUI. Khoros consists of a set of various programming tools that support data analysis and visualisation, visual programming, GUI creation and custom client server software development. Developmental work has been carried out on a network of workstations consisting of 4 Silicon Graphics Indy's and a Silicon Graphics Indigo machine. This network has provided the power, along with the graphical capabilities, necessary for the high visualisation requirements of the output presentation.

2.1 Data Preparation:

2.1.1 Model Input Preparation

Hand preparation of the large amounts of data required by many models is very time consuming and tedious, being prone to error. Generating input data is simplified using available GIS programs, such as ARC/INFO (ESRI [1997]). Time saved by utilising the computer can be allocated towards the execution of the model. A model's execution time can take anywhere from a few minutes to many hours depending upon the size of the data file and amount of detail required for analysis.

For example, AGNPS (Agricultural NonPoint Source), a single storm event hydrological model (Young [1989]) requires one data file for execution. Preparation of the file requires the use of ARC/INFO AML (ARC Macro Language) scripts. These scripts interpret data files such as topography, vegetation, landuse, soil type and DEM (Digital Elevation Model) files and produce the required input file for AGNPS execution. Execution time for a catchment with approx 22000 cells will take approximately 2.5 minutes and approximately 30 seconds for 5000 cells on the Silicon Graphics Indy machine that has 64 Mb RAM.

2.1.2 Model Output Preparation

Model output files contain vast amounts of information. These files must be filtered or processed so that only relevant information will be used for the visualisation and analysis. In conjunction with this process, a mask file is created to aid with the visualisation of the output. The mask image file nullifies all cells outside the study watershed. To visualise the output, the mask file is overlayed on top of the particular output of interest. Once complete, exporting the information into the Khoros Data Format (KDF) is performed in order to take efficient advantage of Khoros's datafile structure.

2.1.3 Khoros Data Format

The Khoros Data Format consists of five different segments. These segments include time, value, location, map and mask. The time segment allows many images to be incorporated to one file. This has an advantage when long term simulation models are used.

Visualising the modified ascii output requires transformation into a new file format, Khoros Data Format (KDF). This prepares for faster GUI editing and scenario analysis in a fast and efficient form.

2.2 About Khoros:

A visual network of glyphs depicting transportation of data and control flow allows a user to program with ease in the program Cantata. Upon creating a workspace of glyphs, a global GUI can be created with dependent variables being declared in the main interface (Figure 1).

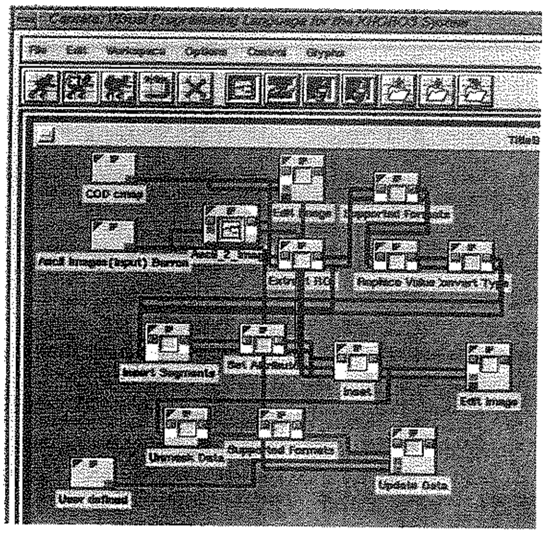

Figure 1 Sample Cantata Workspace.

Not only can workspaces be turned into GUIs but also any program can be created with its own GUI (Figure 2). This can then be incorporated into any other workspace or GUI.

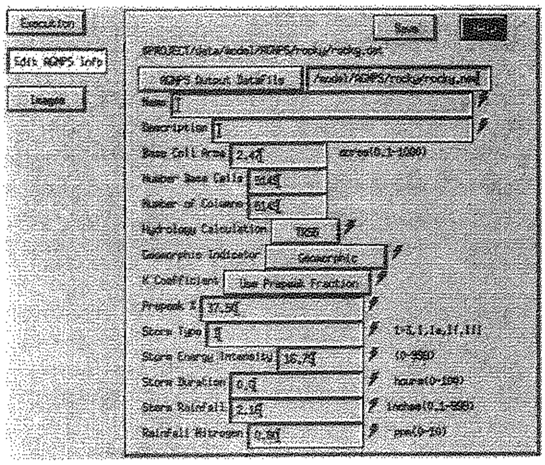

Figure 2 Example of a program GUI displaying general data for a storm event at Rocky Cr.

Most glyphs can be executed from both the command line and via a GUI. This allows any other program, for example PolyTRIM (CLR [1997]), to execute the glyph from an implemental widget or a hot key.

2.3 Distributed Computing:

From within the Cantata workspace, it is possible to incorporate the added potential of a network of computers to aid in the computation and execution of glyphs. Such use of an environment is called distributed computing.

Distributed computing can take the form of fine-grained or coarse-grained. In the case of coarse-grain computing, a number of scenarios can be executed in parallel, with visual displays, on different machines occurring simultaneously (Figure 3).

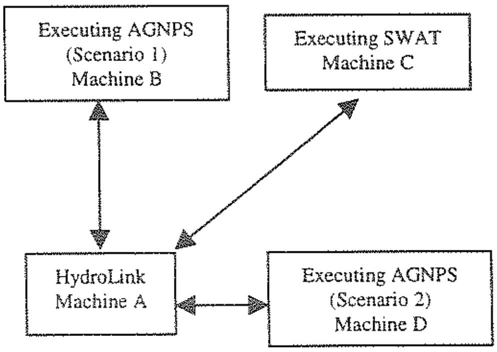

Figure 3 Sample flowchart of coarse-grained computing.

Fine-grained computing can be used to speed-up performance of the execution of one model. An example is the generation of the curve numbers (CN's) and K-soil factors, from pieces of code from the PERFECT model (Littleboy [1997]), where a number of processors are used to distribute the calculation workload which ensures faster integration in the AGNPS [10] dataset for quicker execution (Figure 4).

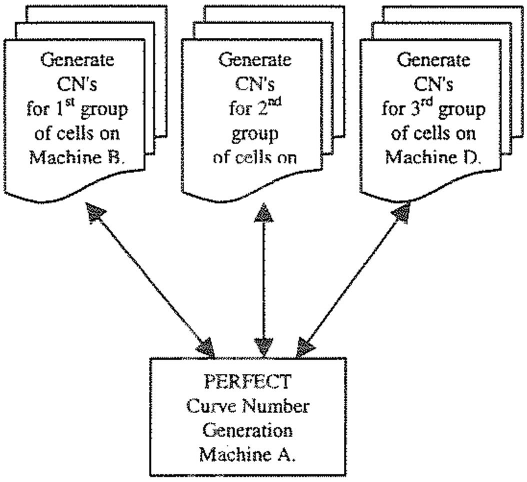

Figure 4 Sample flowchart for fine-grained distributed computing.

Languages that can be used at any level of parallel computing include PVM (Parallel Virtual Machine) (PVM [1997]) and MPI (Message Passing Interface) (MPI [1997]). Data transportation and communication between procedures present the majority of latency time but is insignificant when dealing with large amounts of data.

3 GENERIC SYSTEM

The primary objective of this modelling framework is to have as generic as possible a base with which any environment model can be integrated.

3.1 Models Included:

Many different types of catchment water quality models are available for use. The criteria used in selecting models for implementation here were: the way that the models interacts with the datasets; the efficiency and effectiveness of the model in practical simulations; and the ease of graphical adaptation of output. AGNPS satisfies these requirements. But for reasons discussed below it was also decided to allow the use of other models such as PERFECT (Littleboy [1997]) and SWAT (Arnold [1993]) in the HydroLink environment.

3.1.1 Agricultural NonPoint Source(AGNPS)

AGNPS was initially used to develop the underlying graphical processing and visualisation requirements. Due to AGNPS maintaining a regular grid for variable calculations, it possessed visual qualities that allowed forward adaptation to Khoros software. More precisely, the data could be formatted into matrices that could then be visualised through the Khoral software.

Input data required for the model that can be modified, once visualised, include the curve numbers, overland Mannings roughness coefficients, and nitrogen & phosphorous present in the soil (Figures 5 and 6).

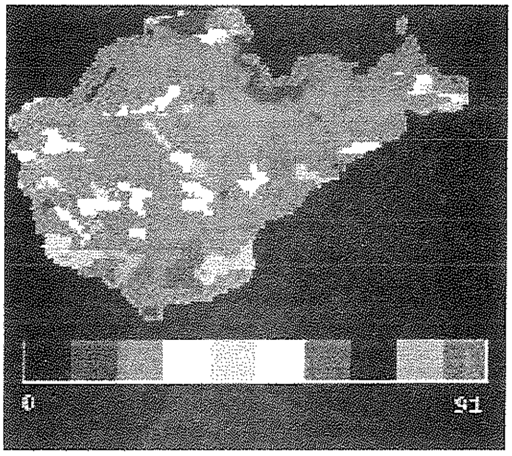

Figure 5 2D view of the curve numbers dataset for Rocky Cr.

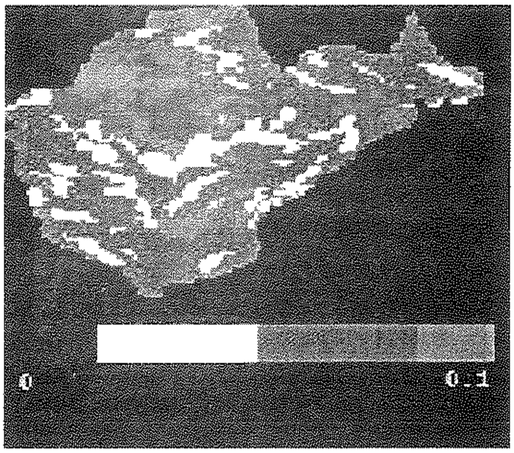

Figure 6 2D view of the overland Mannings roughness coefficient dataset for Rocky Cr.

As AGNPS is a single storm event model, it was only able to provide static variable output. Other models would be used for long term simulation.

An enhancement was then added where the user could decide if curve numbers and K-Soil factors, calculated by extracted PERFECT routines, be used as data in the AGNPS model.

3.1.2 PERFECT

Dr Littleboy (pers. com.) has provided routines that calculate the curve numbers and soil erodibility factors for each cell in the watershed. These routines have been converted to run under a parallel environment such as displayed in Figure 4. Data required to calculate these parameters, for each cell, include antecedent soil water level, soil structure and permeability class, and the percentages of fine sand, coarse sand, silt and organic matter.

If the user decides to integrate the PERFECT derived curve numbers, for example, they replace the current data in the models file ready for the execution of the model. Depending upon the derivation of the original curve numbers, tests can then be carried out on the different methods and results obtained from the two different calculations.

3.1.3 Soil Water Assessment Tool(SWAT)

With the SWAT model now integrated in the framework, users have the opportunity to compare attributes of various models output. With SWAT's capabilities of running either single event or continuous simulation, this provides an excellent base for the generic needs for catchment management.

Research has been ongoing, in the Department of Geography at the State University of New York of Buffalo (Bian [1996]), into the development of Arc/Info GUIs using AML scripts. External resources such as the SWAT AML scripts allow for greater flexibility for user choice of hydrological model. Third-party utilities can be integrated and executed with the greatest of ease, providing they meet discussed guidelines.

No longer is it required that one model be used but rather one can be chosen depending on the application. If more than one is selected, they can be executed in parallel providing beneficial information otherwise absent from just one models output.

3.2 DSS Enhancements:

With computer hardware performance forever increasing at an exponential rate, so will the demand on the amount of output similarly increase. This can be reflected also in the amount of input data required by models.

Scripting through ARC/INFO is just one example of a technique used to computationally create data files required by the model being used. Arc Macro Languages (AML) have been designed to create data files for both AGNPS and SWAT. These scripts can be executing while other preparations, such as initialising the distributed environment, take place.

Of major importance is the interaction between the user and the program. For example, editing data files manually has been time consuming but through simple selections, with the aid of the mouse, of models general and variable data, alterations for scenario events now have a faster throughput.

Output either can be visualised by internal procedures or be exported into other packages such as PolyTRIM, a public domain GIS. Exporting output has been achieved by converting output into a different image format (RGB) then draping this image over a 3D digital elevation model. PolyTRIM allows flight paths to be recorded and played back.

4 OUTCOMES

To facilitate the development of catchment nutrient management plans, alternative scenarios needed to be tested with ease and proficiency.

4.1 Visual Editing

Fast and easy scenario editing allow the end user to perform test after test until the final desired outcomes are obtained. HydroLink GUIs provide the front end for editing the data (Figure 7).

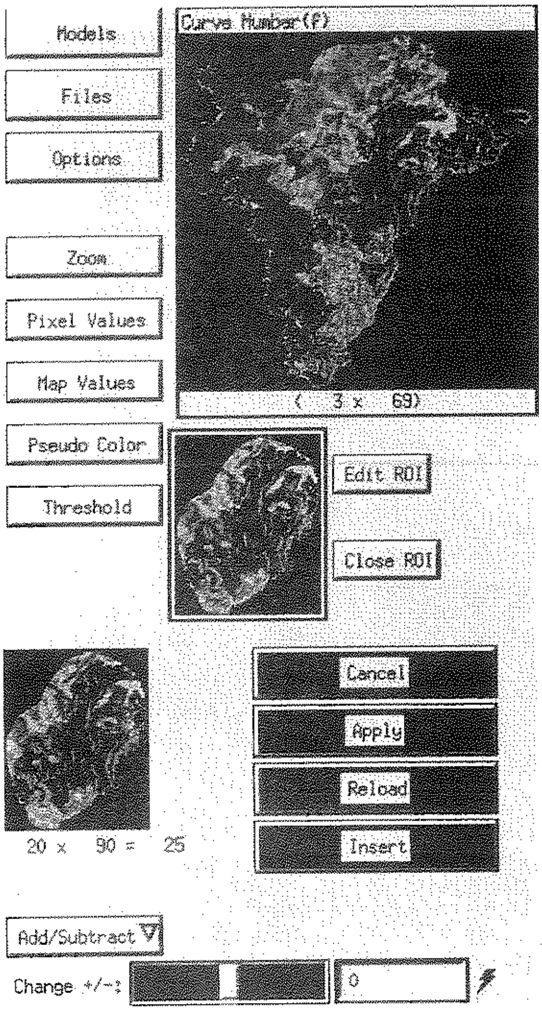

Figure 7 GUI showing selected region of interest to be modified. Data from Barron river catchment.

Different scenarios are created by selectively editing a region of interest (ROI), to which global changes are applied. Current types of changes include a percentage change, an addition/subtraction change and a replacement value change. After modifications have been carried out, the new scenario then becomes the input to the model. Output from the new execution of the model can then be compared with previous scenarios. Under the distributed environment, many scenarios can be executed and visualised simultaneously thus allowing for faster analysis and throughput of ideas.

4.2 3D Visual Interaction

Visualising data under 2D does not necessarily give the user the proper impression of the data under study. At times, it is convenient and easier to interact with and visualise the data under 3D. Incorporated into HydroLink is a convenient function that allows third party software to be executed for visualising (and interacting with) the data.

GIS packages were to be the aim of the 3D-visualisation software as the potential use of the geographical features incorporated within the GIS software was great. For example, visualising farm boundaries, landmark features, roads and streams would help analysts to have a better understanding of the how the land works without having first hand experience of the locals. The GIS package being used with this project is PolyTRIM (CLR [1997]).

Not only are GIS packages able to be used but 3D visualisation packages could be incorporated as well. Developed at ACMC, Planetary Vision has capabilities beyond the scope of this paper but its primary function allows 3D interaction of the data (Figure 8).

Figure 8 3D view of curve number variable generated from Planetary Vision.

5 CONCLUSIONS

Editing hydrological data via graphical displays aid in the speed and delivery of scenario analysis for better management practices. Development has focussed on allowing integration of other models and utilities to further the decision making of the user. Data visualisation, model interaction and sophisticated GUI/data interfaces will give the user greater insights into environmental concerns.

6 ACKNOWLEDGEMENTS

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