E2 – Past, Present and Future

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EXTENDED ABSTRACT

The E2 catchment modelling software (Figure 1) was initially developed in concept and application over 2003/04 and released in 2005. Its design and construction drew on many previous examples and experiences with catchment modelling systems, in addition to a set of new needs for a science delivery system, and many years of experience in conceptualising and modelling catchment processes. The system combines the abstract concepts of generation, delivery and filtering of flow and constituents with a flexible spatial discretisation system and the ability to accumulate, move and manage fluxes through complex networks.

Since the first public release, E2 has gained acceptance in areas of Australia as a flexible modelling tool. Some of the advantages of E2 have been the flexibility of choice of methods for almost all facets of the catchment modelling process, the capacity to build and plug-in new models if those available are not appropriate, and the capacity to add extra functionality through external plug-ins.

The user community for E2 has been very supportive, providing feedback on design and operational issues, and supporting information exchange on applications. The developers have also contributed significantly, managing an ever-increasing set of new features requests, handling bugs created by software platform changes and the idiosyncrasies of a new and extremely flexible modelling system. The underlying system for E2 has now developed to the point where it will serve as the basis for a broader set of environmental modelling and research tools.

The features provided in E2 have expanded steadily since the first release, both due to the longer time for development of these, as well as the enlargement of the needs of users, and extension of application of E2 to a broader set of problem situations. The current version (V 1.3.2) has been downloaded some 450 times, and is supported by an email user groups with approximately 70 members.

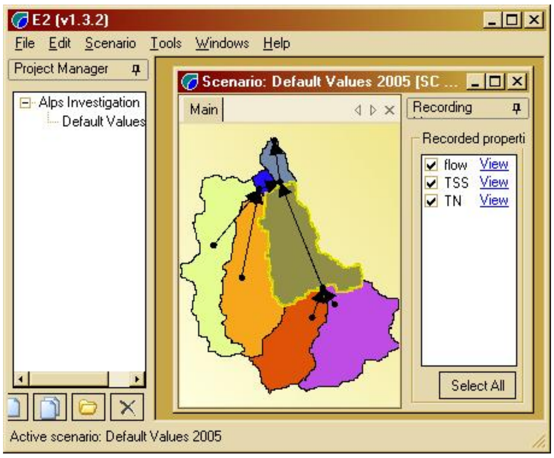

Figure 1. The E2 Catchment Modelling Software

In its 3-year life E2 has been applied to a broad range of catchment modelling problems, including decision support for water quality improvement, nutrient fate and transport modelling for algal bloom prediction, estimation of nutrient loads from dairy systems, assessment of the impacts of runoff from bushfire affected forests, and investigation of development options and sewage treatment in urban growth areas.

Current E2 development is separating the underlying 'engine' from the E2 modelling application. The engine provides a robust architecture (i.e. component-based river system modelling with functional units, node and loss models, flows, filtering and constituents) for basic catchment modelling needs, and is being developed to meet further needs. This expanded engine will be used in future to provide the basis for a suite of modelling tools for specific uses, such as river management or restoration.

The inheritor to the E2 catchment modelling software tool, built upon this base, is WaterCAST, which was developed to provide not only the features available in the current E2 system, but also access to enhanced features that include stochastic data inputs and more and better models representing catchment flow paths, fluxes and transformations.

1. INTRODUCTION

Dynamic modelling of catchment systems has been undertaken in various ways over the past few decades, using a range of conceptual approaches and also a range of technical methods. The E2 catchment modelling system has been available for three years, and is being applied to an increasing variety of catchment problems. The technical issues and applications of E2 have been covered in numerous papers (e.g. Argent *et al.*, 2005; Feikema *et al.*, 2005; Kandel and Argent, 2005; Perraud *et al.*, 2005; e.g. Argent, 2006; Jordan *et al.*, 2006; Perraud *et al.*, 2006; Podger *et al.*, 2006). This paper provides a broad overview of the history of E2, highlights some of the current usage, and previews future developments.

1.1. Contributors to E2

Development of E2 has been built on a considerable component of teamwork, including people with a wide variety of talents and experience. R Argent, R Grayson and G Podger were instrumental in early developments due particularly to previous experience. J Rahman, J-M Perraud and S Seaton contributed considerable expertise to the transformation of concepts into a working and workable software application. In recent times, as the concept of E2 has shifted from solely catchment modelling software to encompass the broader 'engine' underpinning a number of new applications, the development team has expanded to include direct contributors (eg B Leighton, G Davis, R Bridgart) in addition to many of the people contributing to the TIME code base.

Other contributors have come from outside the research arena, such as NRM modellers and catchment managers who encouraged the core team to develop a system that was much more than 'half-arsed'. The likes of Tony Weber and Phillip Jordan, who have used and tested E2, play an ongoing role in development.

This paper has been written as an acknowledgement to all those involved in the past, present and future of E2, and aims to reflect on the thinking that went into development of E2 originally, the developments that have thus taken place, and some of the future directions that are being pursued.

2. E2 PAST

Initial development of E2 was built upon years of experience with both the concepts and practice of catchment modelling, and was necessitated by the desire NOT to develop the 'Mother of all Models' whilst at the same time developing a rich 'shell' within which alternate models could be housed.

For much of the 90's the rapid developments in desktop computing and graphical programming environments offered the promise of temporally dynamic and spatially explicit modelling for environmental management needs. An early example was a QuickBasic modelling shell (Figure 2) used for Adaptive Environmental Assessment and Modelling (AEAM), and offered to Grayson and Argent as freeware by Carl Walters. Due to the desktop access to QuickBasic and the fast run times, this shell offered, for the first time, an ability for modellers to construct models 'on the fly' and run them for scenario exploration in public meetings. Use of this tool allowed the conceptualisation, design and construction of an integrated catchment model (with customised algorithms) for the North Johnstone River (Qld) in four days, a feat that may now be possible with E2, but which certainly has not been emulated.

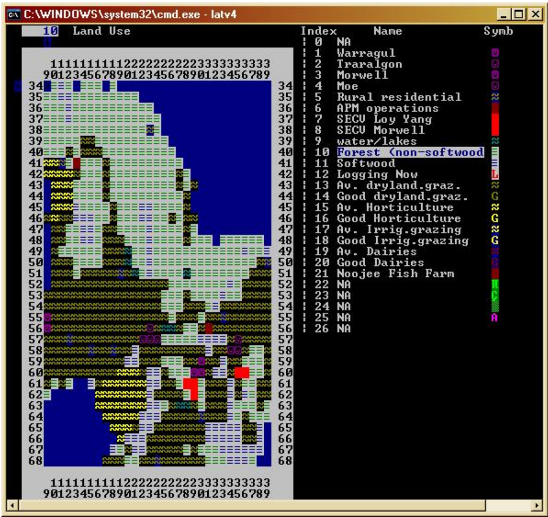

Figure 2. Manual editing land use per cell in QuickBasic Shell

The arrival of VisualBasic saw development of this application into a Windows environment, and subsequent application to a number of catchments across Australia in the mid 90's.

ICMS (formerly the Integrated Catchment Management System) (Cuddy *et al.*, 2002) also provided a new modelling paradigm and environment during the late 1990's, with an object-based framework (Reed *et al.*, 1999), a user environment that allowed logical construction of conceptual and physical catchment models, and the ability to code (albeit, in a largely un-documented language), compile and run models on the fly – a boon for model developers.

At around this time Fred Watson, a doctoral student at The University of Melbourne, was investigating water dynamics in Eucalypt forests, and created a modelling system to support this. Being trained in computer science, Watson's system (Tarsier) (Watson and Rahman, 2004) was designed with a view to broader applications and modular modelling, whereby 'component' models relevant to a particular application are combined to build an integrated model. This tool was used as the development platform for the highly influential EMSS (An Environmental Management Support System for South East Queensland) – a forerunner to E2 and one to which, in some ways, the application still aspires, such as with the land use change method shown in Figure 3. The starting point for E2 development can be traced to discussions over September/October 2003, culminating in an early December meeting to discuss development of "EMSS II", quickly shortened to E2.

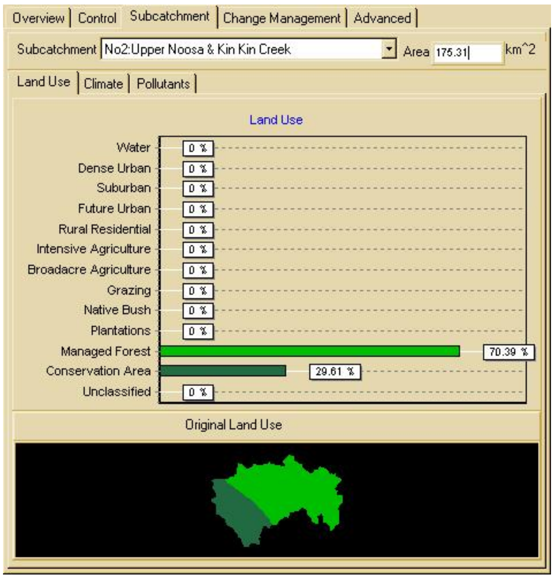

Figure 3. EMSS Land use percentages for a sub-catchment

River system modelling was another component that strongly influenced the design of E2, drawing particularly upon the experiences of Podger over many years of development of the Integrated Quantity and Quality Model (IQQM) in application to many of the managed river systems in New South Wales and Queensland. Much of the complexity of river system modelling arises not from the physics of water movement, but rather from the management perspectives that encompass demand and supply, accounting, allocations, forward ordering, alternative supplies and environmental and other operation rules that influence when and how much water can be moved from place to place.

The AEAM shell, ICMS, Tarsier, EMSS, IQQM and various other modelling software and approaches were strong influences on not only the conceptual design of E2, but also the features and functions of the system, both current and future.

With these influences in the background, and the decision made to re-develop EMSS in TIME (Rahman *et al.*, 2003) whilst at the same time create a system giving access to the science outputs of the then CRC for Catchment Hydrology (CRCCH), the conceptual development for E2 took place. This effort was focussed over the early to middle months of 2004, albeit intermingled with the considerable distractions of the first Catchment Modelling School run by CRCCH. Considerable discussion over a number of months took place before the conceptual structures for E2 were settled. There were six key factors that drove this:

1. Spatial explicitness – much of catchment management and catchment processes depend not only on what is happening but also where it is happening

2. Sub-area variability – many of the mistakes of modelling occur when systems are modelled at a finer scale than truly necessary. For E2 we wished to support a level of sub-area variability (eg in land cover, behaviour, geology) whilst not necessarily requiring representation of fine special scales

3. Generic handling of material – creating a template or conceptual space within which models of almost any material or property of interest could be modelled to some degree

4. Water management – explicit handling of water and constituents through river networks

5. Simplification and separation of primary processes – aiming to reduce processes through abstraction to a small number of types or classes

6. Flexibility, through support for multiple methods for as many processes and functions as possible

The last of these is possibly the most interesting – one of the key issues in catchment modelling is that there are often many alternate methods for doing anything – from data loading, through definition of catchments, to analysis and reporting. Thus, a key factor in design of E2 was not only implementation of functions (eg runoff generation), but also conceptualisation and implementation of an *abstraction* of that function, so that it could be implemented in different ways in future. Of course, this concept is fundamental to modern programming, so it fit well with the intentions in designing and developing E2.

The above six considerations, amongst others, led to the conceptual design decisions described in the following.

2.1. Functional Units

Functional Units (FUs) arose from factor 2, above, and are an abstraction of concepts such as hydrological response units (HRUs). In this case, the generic concept was to define areas of a sub-catchment that *function* differently in some way – ie they may function the same hydrologically, but may be subject to different types of management.

2.2. Sub-catchment

To support the movement of material or properties through a system, it is necessary for materials being generated and transported from catchments to be combined at some point for routing. Sub-catchments provide this nexus, supporting a flexible spatial discretisation and a range of methods of catchment definition. Use of sub-catchments provides one of the key user requirements, with catchment definition occurring, for example, automatically from a DEM, by defining nodes (eg gauges) for catchments, or from pre-defined sub-catchments identified by clients or other studies.

2.3. Node-Link Network

A stream network, wherein discharge, materials and properties can be moved and managed, is the standard method used to address factor 4 above. In river systems, wherever there are gauges, extractions, inflows or control structures, the use of a node-link network provides the necessary discretisation of the system to support representation of these factors, in addition to providing the point or node information used for calibrating systems.

2.4. Constituents

To address factor 3 it was decided to use the generic concept of 'constituents'; the generation, transport and transformation of which could then be modelled at whatever level of complexity was appropriate. The use of generic 'constituents' overcame the issue of people having modelling preferences for, say, sediment or nitrogen, whilst providing the abstract structure to support any of these.

2.5. Generation, Filtering, Routing, Transformation

A final conceptual development that has not been undertaken in previous models is the clear conceptual separation of runoff generation, constituent generation on sub-catchments (Figure 4), constituent filtering, routing, and instream transformation. All that is needed to model any constituent is a generation method (examples include unit area and flow dependent generation), to which can be applied filtering and transformation if required.

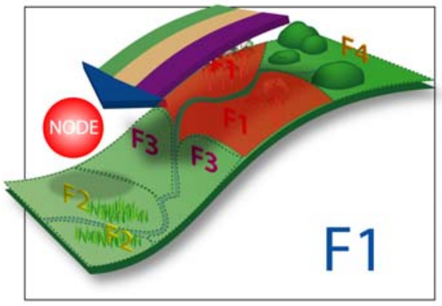

Figure 4. Conceptual representation of flow (green), constituent (orange) and filter (purple) models combined to produce load from a FU

These conceptual structures were combined and constructed with a number of beta versions of E2 during 2004, with the first public beta release occurring in February 2005.

3. E2 PRESENT

Use, understanding and development of E2 has continued to grow since it's initial public release in 2005. Subsequent releases have occurred in July (V 1.2.0), September (1.2.1) and December (1.2.2) 2005, August (1.3.0) and September (1.3.1) 2006, and February 2007. The current public release (1.3.2) has been downloaded some 450 times.

E2 training has been given at regular intervals over the past few years, with over 50 individuals being trained in the application of E2. Some training has occurred as part of individual projects, while others have been focussed more broadly on general application, understanding of the concepts of E2 and exploration of the range of modelling methods that are available.

E2 has been applied to over 50 projects around Australia, and is supported by an email-based user group that has some 70 subscribers. Additional support is provided by the E2 web site (www.toolkit.net.au/e2), with access to example data sets, user and reference guides, slide presentations, publications on E2 and applications, and general user information.

Applications of E2 include:

- Bushfire damage assessment in alpine areas (Feikema *et al.*, 2005)
- Urban development and sewage treatment plant impacts, Hornsby Shire (Jordan *et al.*, 2006)
- Nutrient fate and transport for prediction of *Lyngbya majuscula* blooms in Deception Bay, South East Queensland, and
- Decision support for receiving water quality improvement in Port Phillip and Western Port Bays, Victoria (Argent, 2006)

Beyond the provision of services to end users, one of the advantages of these types of applications is the feedback that is received and used to inform future development. Behind the scenes the JIRA software issue tracking and management system is used to support development planning and bug fixing. Since inception there have been approximately 600 issues listed on the E2 JIRA system, ranging from minor feature suggestions (eg changing the colour of nodes on the Scenario window) through major annoyances (e.g. unable to load old projects with custom plug-ins) to significant problems that affect E2 use (e.g. E2 crashes when loading SILO rainfall data). These are all allocated for attention to specific developers as part of various planned fixes and software releases.

3.1. Interesting Features

Two interesting aspects of development of E2 have been the use of advanced/developmental code, and the use of plug-ins.

E2 has a hidden menu that gives access to code and features that are either being tested for potential release, or which provide access to deep features of use to developers and software testers. Examples include an automatically generated network of any number of sub-catchments, a logging window for listening to code messages as the model runs (e.g. "Node 422233 contains a Demand Node Model that has no supply setup") and a system exploration window that provides access to all model parameters and state variables, and which allows time series to be 'played' into a parameter to support variable parameterisation over time (Figure 5). Although not in common usage, this feature is useful in advanced modelling situations where the time series of a model state variable (eg storage volume or soil moisture store) is of interest in tracking and attempting to replicate system behaviour.

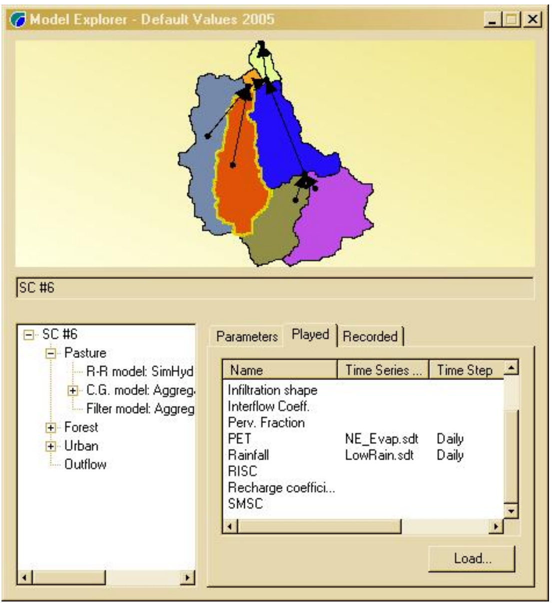

Figure 5. Model Explorer window

Plug-ins are another area of E2 that provide a set of features that are useful, but possibly not used to full potential. Examples include the data calculator, data converters, rule-based data modifier, and the terrain analysis tools. The first of these allows manipulation (e.g. linear scaling, addition, difference) of time series and rasters, and the other tools provide similarly useful features.

4. E2 FUTURE

One of the key developments over 2006/07 has been the recognition of the value of the underlying software 'engine' supporting E2, and the planned expansion of this engine to support a broader range of modelling applications. The idea used here is that the underlying framework (component-based river system modelling with functional units, node and loss models, flows, filtering and constituents) supports a much broader range of modelling needs that that covered by E2.

Thus the future development of E2 is aiming to both enhance the components model collection upon which any modelling system can draw, and to develop applications (drawing upon these components) to meet various sets of user needs. These developments are strongly influenced by the development of software Products by the eWater Cooperative Research Centre, a group of some 45 parties across the public and private sector water research and management areas in Australia.

Example products which draw upon the E2 engine and inherit various aspects are WaterCAST, RiverManager and a restoration planning tool.

4.1. WaterCAST

WaterCAST is designed to be the primary replacement for the E2 catchment modelling software, and inherits all of the primary functions of the current release of E2, as well as a number of significant developments. One of the developments envisaged is the use of a geo-referenced iconic system layout, such as provided to some degree in ICMS and WaterCRESS (waterselect.com.au).

Another development, the incorporation of stochastic data to drive the runoff models, has been implemented and is currently being tested, while enhanced modelling of surface/groundwater interactions and in-stream processing are in various stages of development, from theoretical development of extra flow paths in E2, to coding and testing.

4.2. RiverManager and Restoration Planning

One of the newest products being built upon the E2 engine is RiverManager, a tool to support management of water in systems with multi-party water ownership and trading, complex water accounting and rule-based management, and subject to short and long tern stresses such as droughts, floods and high inter-annual variability of flow. RiverManager combines many of the component models already used in the E2 catchment modelling software, such as catchment definition, runoff generation, node-link network, demand-supply links and routing. Additionally, a number of new components have been built, including a system for assigning ownership to water, tracking ownership of water as it moves through the system, sharing of losses or gains between owners, and accounting for ownership change due to water trading.

Restoration planning, and prioritisation is an area that extends the current E2 catchment modelling system to consider not only the effects of a management action in one or more FUs or sub-catchments, but which also looks at the options and trade-offs between alternative catchment management actions in one or more places in a catchment. In this area, the E2 engine is being extended to support a range of products, including a catchment planning tool that provides quantitative prediction of the ecological responses to resource management decisions.

One of the key aspects to the successful future of E2 is the planning of component development. There are many different levels of process integration, or 'grain sizes', that can be selected for component model conceptualisation and development, so the eWater CRC and other developers are putting considerable effort into taking both broad and detailed views and endeavouring to ensure that, for example, new component models:

- Fit well with previously developed models
- Provide a level of 'granularity' of function that ensures we have a manageable number of components of a manageable size
- Fit into an architecture that is consistently 'whole' and remains flexible and extensible in the face of future needs for different products (combining different groups of components) but which still 'look and feel' like Toolkit products

Thus, the future of E2, both in terms of catchment modelling and a component-based modelling engine, is looking good.

5. CONCLUSIONS

E2 has come a long way since the original inception of a flexible system for science delivery under the former CRCCH. Developers and users have, over the past 3 years, provided incredible support for the design, development, testing and application of the system, and applications of the E2 catchment modelling software have truly benefited the catchment management and science communities.

Further, longer term benefits are now accruing through the development of the E2 engine and a broader library of component models, which will provide both increased functionality for catchment modelling, via WaterCAST, and a broader range of E2-based tools designed to meet the wider modelling needs of catchment managers.

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