Building a Modelling Toolkit for Prediction of Catchment Behaviour

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Abstract: Since 1999 the CRC for Catchment Hydrology has been developing a modelling toolkit for the prediction of catchment behaviour. The modelling toolkit is underlain by a development, management and deployment environment that supports module-based modelling services such as data loading, computation and analysis, and display. Modules are constructed through cloning of existing modules, or from scratch. Models can be built by selecting and linking relevant modules on a visual 'canvas'. This process is supported by a control and documentation system that draws upon the module code base for parameter and interface information. For deployment of models, options include command line operation of individual modules, stand-alone executable applications, and module libraries that allow testing of alternative modules with a given data set. Development of the modelling toolkit has included consideration of a broad range of social, technical and communication aspects that range beyond the provision of modelling tools. Key issues include conceptual development, user modelling practices and information management and dissemination. The modelling toolkit has a range of users, such as toolkit developers, model developers and users of applications, and a range of ways that it can be used. Each user has particular information needs, varying from parameter and data information requirements of individual modules, through user manuals for models, to meta-level information on selection of appropriate modules from those available in libraries. For deployment of some or all of the toolkit via the WWW, a system of information supply and user management must be implemented to provide relevant information and functionality, maintain security and provide user-group specific support. This paper will report on the toolkit, its range of users and uses, and development of a toolkit information system.

Keywords: *Catchment modelling; Modelling toolkit; Frameworks*

1. CATCHMENT MANAGEMENT AND MODELLING CAPABILITY

Natural resource managers in Australia are grappling with the legacy of exploitive land and water utilisation over two centuries of European settlement, compounded by a highly variable climate characterised by frequent floods and droughts. Our most pressing problems include salinised, acidified and eroded land, polluted aquifers, waterways and receiving waters and the poor biodiversity within them. We have also been left with degraded riverine and riparian habitats, river instability, and an inequitable distribution of water amongst different users, including the environment.

These environmental problems are both profound and pervasive, and will therefore be problematic to solve. Fundamentally, they are inter-connected through the catchment water cycle and addressing them requires integrated solutions. To deal with these problems it is essential to have good modelling technology that can be used to forecast how different catchment management actions will impact on water quantity, quality and environmental assets.

Whilst there is good recognition of this fact amongst natural resource managers, there is a dearth of holistic thinking and predictive tools to facilitate integrated catchment management. Thus the mission of the Cooperative Research Centre for Catchment Hydrology (CRCCH) is “to deliver to resource managers the capability to assess the hydrologic impact of land-use and water-management decisions at whole-of-catchment scale”. Supported by Commonwealth, State and Local government sponsorship totalling $60 million over a seven-year period, the CRCCH is dedicated to building an integrated Catchment Modelling Toolkit (the Toolkit) for use by the natural resources management sector. The Toolkit is being rolled out incrementally and the first phase of its development will close in 2006.

Some of the hallmarks of the CRCCH's Toolkit initiative are (i) the involvement of Australia's pre-eminent catchment science experts, (ii) the inclusion of a variety of models that can be interlinked to permit holistic analysis of catchment function at a range of scales, and (iii) a commitment to making the Toolkit widely available through the internet and facilitating its uptake through communication and education programs.

2. MODELLING IN THE CATCHMENT MANAGEMENT INDUSTRY

The modelling capability required in the Toolkit reflects the history of model use and development by the catchment management industry. In the past many models were designed to deal with the bulk delivery of water to water users. These models typically operated on monthly time steps and existed in spreadsheet and standalone executable form.

Tradeoffs between consumptive water users and the environment require consideration of short term variability of flows. This need, along with advancements in computing, led to the development of the current generation of models. These models operate on daily or sub-daily time steps and support development of water management policies to assess trade-offs. The water policies that have been developed are complex and are supported by models with complex water management rules.

Recent times have seen the development of a more holistic approach to catchment management and associated modelling. This is driven largely by a need to be able to manage and model water quality, such as salinity, as well as quantity. Subject to considerable spatial and temporal data constraints, these models must determine the source of constituents within catchments, the delivery process to streams, and the routing of constituents through river systems.

To support whole-of-catchment scale modelling in the current management climate, the emerging models need to draw together new and existing technologies for evaluation of actions, risks and impacts on the physical, economic and social systems of catchment, as well as the ecosystem. The research program of the CRCCH is actively involved in developing both knowledge and tools to support this. The primary development and delivery mechanism for the modelling of the CRCCH is the Catchment Modelling Toolkit.

3. WHAT IS A MODELLING TOOLKIT?

One of the development tasks of the Toolkit project has been identification of the features and functions of a modelling 'toolkit'. A logical association for the term 'toolkit' in a catchment modelling context is the provision of modelling tools. This includes the concepts of:

- A toolbox which contains a collection of tools, and allows them to be readily transported to different jobs,
- A set of specific tools with constrained functions, such as a hammer, an adjustable spanner and a hacksaw, and
- A set of flexible tool components, used to create the appropriate tool for a particular job, such as a socket set with a range of handles, different connectors and drive sizes, and sets of sockets.

In addition to the Toolkit contents, the ways of using a Toolkit also have a strong bearing on functions and design. From a management perspective, for example, a modelling Toolkit is something that allows re-use of models from one site or situation in another, with a minimum of re-tooling required to, say, attach different data sets, change time steps from daily to monthly, and implement a different routing scheme. For researchers, a Toolkit could provide access to code and support for creating new code modules. A Toolkit could also provide a convenient way of collating and accessing commonly used models, such as the Hydrological Recipes (Grayson *et al.*, 1996).

In early discussions on the Toolkit, in 1999, possible toolkit features included a database of models (a.k.a. 'modelbase'), a contextual help systems to provide information on appropriate selection and use of models, protocols to ensure acceptable linking of component models, and an intelligent system to support model construction using a modular approach. The key to the *provision* of modelling services for the Toolkit is a modelling environment, or framework.

4. MODELLING FRAMEWORKS

Modelling frameworks for environmental applications have been under development for 5-10 years, with examples that include the Dynamic Integration Architecture System (DIAS) (Sydelko *et al.*, 1999), the Interactive Component Modelling System (ICMS) (Rizzoli *et al.*, 1998; Reed *et al.*, 1999), Tarsier (Watson *et al.*, 1998), the Spatial Modeling Environment (SME) and associated module specification formalism (Maxwell, 1999; Voinov *et al.*, 1999) and the object user interface development of the Modular Modeling System (MMS) (Leavesley *et al.*, 1996), named MMS-OUI. A recent large initiative in this area is the European Open Modelling Interface and Environment (OMI) of the HaromonIT project (Gijsbers *et al.*, 2002).

Argent et al. (2000) provided an overview of the technical aspects of modelling frameworks used in development of the Toolkit. The features generally required for a modelling framework, and which are reflected in Microsofts' .NET™ initiative and SUN Microsystems' J2EE™, are:

- A development tool for building new components (i.e. modules);
- Libraries of components that represent various pieces of knowledge;
- Suites of components for common tasks, such as data importing, gap filling, basic analysis tasks and visualisation;
- A modelling 'canvas' or application interface used for placement of components, represented by icons, and linking of components and data;
- An integrated documentation system, ideally using metadata and the process of introspection to infer much of the documentation needs from component code;
- A file system for finding and accessing components locally or remotely, and
- A system of model execution for undertaking multiple runs as used for optimization, sensitivity analysis and scenario testing.

It is apparent from this list that current modelling environments have much to offer in provision of core support for development of the Toolkit. There are, however, aspects of usage and software system tailoring required to bridge the useability and utility gaps that lie between the generic tools such as .NET and the specific requirements of catchment modellers, much of which has been explored by CRCCH partners over recent years.

Experience of CRCCH partners with modelling frameworks and the use of modern software engineering approaches for modelling includes the development of two of the frameworks associated with the Toolkit development. The first of these is ICMS (Reed *et al.*, 1999). This was initially built during the mid 1990's based on the object model of the Open Modelling Engine (Rizzoli *et al.*, 1998). Development of this system included considerable attention to both the development of the framework within which models could be written quickly and easily, the clear representation of class and object concepts, internal checking on variable linking and management, and a sound user interface.

Tarsier (Watson *et al.*, 1998) was also initially developed in conjunction with CRCCH research, but has since progressed considerably. Much of the software engineering focus in this system was on the use of the observer pattern of object behaviour, with message passing used between objects to encourage rapid execution times. In addition to ongoing developments in Australia and overseas, development of both these frameworks provided the CRCCH with considerable insight on the issues involved in building TIME (The Invisible Modelling Environment), the primary framework used for Toolkit development.

5. TOOLKIT CONCEPTS AND FEATURES

In addition to a modelling environment, or framework, development of the Toolkit over 1999-2002 has covered aspects that include:

- Component modules and standalone models (applications)
- A documentation system
- A Toolkit 'portal' web site
- An ethos of operation – the 'Toolkit way'

These points require attention not only to the technical details of models and modules but also to the development and communication of the basic *concepts* of working with a Toolkit, for this is markedly different to traditional ways of environmental modelling.

5.1. Standalone models and component modules

Model construction in the Toolkit is undertaken using modules, or modular components. Models require not only commonly used modules such as data management and visualisation tools, but also core hydrological modules such as stochastic data routines, rainfall-runoff modules, and flow analysis tools.

In the Toolkit modules are normally provided in the form of libraries, such as the Reach Analysis, Stochastic Data or Rainfall-Runoff Libraries (RRL). Modules and module groups can be combined into applications that can be deployed either as standalone applications, such as the RRL, or web based applications that run in a generic browser. Alternatively, modules can be directly invoked from the command line, allowing the batch operation of models, which is of particular use in exploring multiple runs simulation and sensitivity analysis needs.

In Figure 1 the library concept is illustrated, with three of the modules from the RRL, namely AWBM, SimHyd and an urban hydrology module.

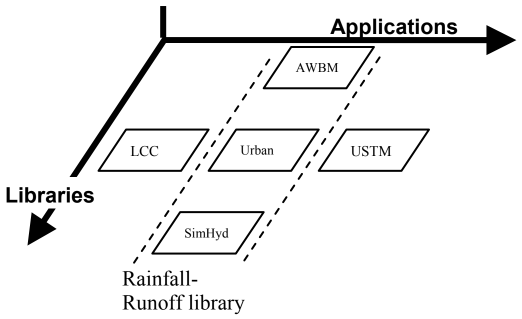

Figure 1. Collections of modules formed together in a library.

When viewed from another angle, Figure 2 shows an example of an application (MUSIC- the Model for Urban Stormwater Improvement Conceptualisation) that uses one of the RRL modules, along with a modular version of the Universal Stormwater Treatment Model (USTM), and a life cycle cost (LCC) module.

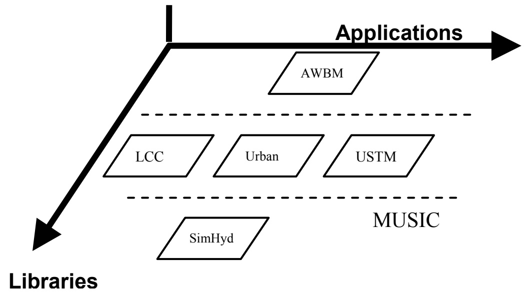

Figure 2. Collections of modules formed together in an application

This emphasizes the modular concept and how different pieces of code can be re-used and re-packaged for the needs of different users. It also emphasizes the lack of consistency in the use of the term 'model'. Under a range of usages it is possible that modules, libraries and applications could all be termed 'models', so usage is commonly determined by context.

One of the keys to supporting good modelling in the modular way described is the use of good software engineering.

5.2. Software Engineering

Given the broad audience for the Toolkit, it is important that the software technologies employed offer great flexibility in the *development* of modules, the *combination* of modules into applications and the *deployment* of modelling applications.

The Toolkit allows the development of models in several languages, including Visual Basic and Fortran. Models written in one language can seamlessly interact with models written in any other Toolkit language.

All models are implemented within a modelling environment (TIME) that insulates model developers from various repetitive development tasks, such as reading and writing data, interacting with the user and visualising data. TIME also provides a number of generic tools for testing and applying models, such as parameter optimisation tools and automatic user interface generation.

TIME is implemented using a combination of established and emerging techniques in software development. Object oriented software development supports creation of families of components that share common behaviour, such as the modules in the RRL, along with site specific models and purpose specific applications. The RRL demonstrates an application that allows rapid switching between one of several conceptual rainfall runoff models without touching model code.

One of the keys to appropriate handling of modules within an application is 'introspection'. Introspection is the ability of one component in a software system to discover, at runtime, the properties of other components of that system. TIME uses introspection to allow various generic tools, such as parameter optimisers, to discover the inputs, outputs and parameters of a new module. This allows the rapid development of modules with support tools immediately responding to changes in model configuration.

5.3. A documentation system – The Toolkit Assistant

In addition to, and often in conjunction with, the software development environment, the toolkit encompasses a documentation and information system. When modelling, appropriate documentation is required at levels that include comments in code, code metadata, module information, user information on using the modelling framework, user information for applications that have been developed for particular sites or data sets, and also information on the appropriate selection and usage of the modules available in a module library, such as a rainfall-runoff library. For the Toolkit these documentation tasks are being tackled through an information system that combines and provides core components of information into relevant documents for particular uses. The last task mentioned has spawned the concept of the Toolkit Assistant, a friendly macro-based iconic information system that assists users in defining their problem situation and selecting appropriate modules for inclusion in a model.

5.4. A Toolkit 'portal' web site

To provide access for developers and users, the toolkit web portal has been established at www.catchment.crc.org.au\~toolkit.

This web site allows visitors to access information on tools, the toolkit approach, development activities, training opportunities and feedback options. Registered users will be able to download software and update existing software.

An area of the website gives an overview of the Toolkit and the objectives and process of development, and is the primary source of information for new visitors. Available products - be they modules, libraries or applications - are described, with external links provided where necessary. Training and email group information is available for selected applications, including access to a limited amount of downloadable training material for those who wish to do it alone. Finally, background information on being part of the Toolkit phenomena and contributing to the toolkit is provided.

5.5. An ethos of operation – the 'toolkit way'

Having developed the technological aspects of the Toolkit over the past 4 years, and built on a decade of knowledge and experience, the final, and possibly largest, hurdle in developing the Toolkit is advancement of the style of modelling required to operate with the toolkit. This style includes a range of people and usage types that fit into five broad groups:

- The developers of the Toolkit software framework;
- Toolkit users who create modules and models for research and management purposes;
- Toolkit users who take existing modules and combine them to form integrated modelling solutions for general management problems, such as catchment water quality or salinity;
- Developers who tailor existing models to answer management questions for particular sites or cases, such as post-fire water quality in the upper Murrumbidgee catchment, and
- The managers and other application-focussed users who test management and policy options using tailored models.

Each of these levels of use requires an understanding not only of the nuts and bolts of the module based approach to modelling, but also the way of operating with the Toolkit.

For example, by understanding the toolkit way manager-level users can ask questions about the validity and utility of using particular module combinations for particular sites, and ensure that the parts that have been put together form a consistent whole, with similar levels of detail, knowledge and uncertainty.

The key to ensuring appropriate operation and understanding of the toolkit is communication, whereby the information that needs to be known about the multiple facets of the Toolkit reaches the right audiences.

6. THE NEED FOR GOOD COMMUNICATION

One of the key issues in building the Toolkit and having it understood and used in the research and management areas of the catchment management industry is clear communication. This encompasses communication of both the concept and the operational practicalities to the range of stakeholders in the area. Stakeholders include the end users of CRCCH and other relevant research products, the investors in and beneficiaries of good catchment hydrology research, and the researchers performing the research, determining the outcomes and ensuring that it is only the best science that is undertaken and delivered to the research and management worlds. To support the communication needs of the CRCCH in building and distributing the Toolkit as the primary mechanism for outputs from the CRCCH, a separate program of Communication and Adoption (C&A) exists. Through the development of C&A plans, communication training, ongoing liaison and a clear focus on delivery, this program acts to ensure that the toolkit message, the way, the products and the users are all connected in an effective integrated whole.

7. CONCLUSION

We recognise that catchment management is no longer something done by technocrats alone.

Increasingly, it is also about governments (of various levels) working with communities and industries to balance the many competing needs we have for catchment services. Hence, the intention of the CRCCH is to make the next generation of predictive technologies sufficiently transparent that the broad-based catchment management constituency can relate to them. To achieve this aim we are committed to developing high quality model documentation and state-of-the-art data visualisation tools, and rolling out the Toolkit in association with a range of public presentations and training programs.

Since 1999 the Toolkit has developed from a few ideas on a whiteboard and a couple of example modelling frameworks to a sophisticated research, development, modelling and management suite. The Toolkit now provides a range of tools that can be used directly for application to a research or management problem, as well as the component parts that allow construction of models for addressing hydrological problems across rural and urban landscapes. The potential for use of the Toolkit is expanding now that prototyping of a range of development and delivery approaches has been completed. Over the coming years the modules, libraries and applications available in the toolkit will be further expanded, and the Toolkit will become the primary integrated delivery vehicle for many of the outcomes of the research of the CRCCH and also of other researchers wishing to make their work accessible to, and integrated with, that of colleagues in the land and water research and management fields.

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