NEWSLETTER OF THE COOPERATIVE RESEARCH CENTRE FOR CATCHMENT HYDROLOGY

CATCHWORD

NO 138 FINAL EDITION 2005

A NOTE FROM THE DIRECTOR

Rodger Grayson

Inside...

Program Roundup

FINAL ISSUE

Catchword Number 138 brings us to the end of thirteen years of the Cooperative Research Centre for Catchment Hydrology and the start of the eWater CRC, the successor to our CRC and the CRC for Freshwater Ecology.

With interest in water issues at an all time high, the expanded capability being brought to eWater means the new CRC will be ideally placed to build on our record of delivering tools and knowledge for improved land and water management in Australia.

In mid June we held our final Annual Workshop at Marysville in the Goulburn-Broken focus catchment. This was a wonderful opportunity to get "the CRC family" together, to reflect on the contributions from our CRC, and to look forward to the challenges ahead.

In this final issue of *Catchword* we have taken the opportunity for Program Leaders to summarise these contributions and to present some challenges and issues for the future, a future that is certain to be very exciting

Before looking ahead though, I would like to reflect on the journey of our CRC has taken since its first bid in 1990.

1990 was the first year of the Commonwealth's CRC Program, and our bid was one of 120 submissions. We were selected for interview but just missed out on funding. Not to be deterred, John Langford and his team, bolstered by the inclusion of the Bureau of Meteorology, successfully re-applied in 1991 with a mission to:

...improve the understanding of catchment hydrology and its application to land and water management issues"

In 1997, the NSW Department of Land and Water Conservation, DLWC (now DNR) joined the CRC.

With a new bid in 1999, the Queensland contingent of, Brisbane City Council, Griffith University, and Dept of Natural Resources (now Natural Resources and Mines) expanded the Parties to fourteen. The new bid was successful and we began the current CRC with our challenging mission to:

"deliver to resource managers the capability to assess the hydrologic impacts of land-use and water-management decisions at whole-of-catchment scale"

As I noted in the last month's *Catchword*, the CRC has evolved from an emphasis on developing understanding in the initial CRC - 'the building blocks' - to an increased emphasis on predictive capability in the existing CRC. This change reflected both the maturing of the science and an increased interest in tools to assist decision makers. In both CRCs our overall aims have always been about making a difference.

As part of the final wind-up of our CRC, through May and June this year I presented an overview of thirteen years of the CRC for Catchment Hydrology to our Parties. We compiled statistics on various aspects of the organisation - they are pretty impressive numbers.

We have supported the training of around 100 graduate students. More than 3000 people have attended training courses. Around 12,000 reports have been sold and many more downloaded from the web site. The Catchment Modelling Toolkit now boasts around 4000 members and has over 20 products.

But most importantly, we can point to some tangible effects on land and water management in Australia and improved environmental outcomes as a result of applying methods developed in our CRC.

Our Development Projects have been prime examples for the application of our methods and tools. These projects have not only resulted in improved allocation of resources and environmental outcomes, but also served as a terrific vehicle for expanding institutional capacity and providing feedback on how research outputs can best serve industry.

Other outcomes from our work have included: changes to manuals of practice (eg. Australian Rainfall and Runoff), new guidelines and manuals (eg. river restoration), the application of Water Sensitive Urban Design for stormwater management (via MUSIC), and savings to infrastructure costs resulting from new design methods.

Perhaps the most enduring legacy of our CRC though, is the extent to which it has broken down barriers across institutions and States, and the way the CRC has developed a broad family of people who enjoy working with each other. This was certainly highlighted at the CRC's Annual Workshop and is something that will continue to have a profound influence into eWater and beyond.

COOPERATIVE RESEARCH CENTRE FOR CATCHMENT HYDROLOGY

eWater CENTRE OFFICE CONTACT DETAILS

eWater CRC (eWater Ltd)
Head Office,
Building 15,
University of Canberra,
ACT 2601 Australia

Tel: +61-(0)2 6201-5168
Fax: +61-(0)2 6201-5038
Email:
pa@freshwater.canberra.edu.au
web:www.ewatercrc.com.au

I wish eWater all the best for an exciting and productive seven years of collaborative research and delivery. I have no doubt that the new CRC will have an enormous impact on our industry and keep Australia as an international leader in collaboration between industry and research in the land and water management sector.

Finally, my sincere thanks to all those associated with our CRC, from project teams and support staff to Board members and the broader users of our products. I wish you all the best in your future endeavours.

I'd also like to take the opportunity to individually thank some special individuals. To John Langford, for not only being a great mentor this past year, but also for his incredible contribution to our CRC as Chairman since its very beginning. A contribution recognised along with his many other impacts on industry in his AM, granted in the 2005 Queen's Birthday honours list. (It was a delight to learn that Russell Mein, our Director from 1995 to 2002, was also awarded AM, a fitting tribute to his role in the CRC and water research and practice generally.) To John Molloy, who has been Business Manager throughout the life of the CRC and has played a critical role in our success. To the Program Leaders, Geoff Podger, Robert Argent, Peter Wallbrink, John Tisdell, Tim Fletcher, Francis Chiew, Mike Stewardson and David Perry, who, along with all the project teams have worked tirelessly this year to 'bring home' our CRC – it's been a great effort.

As many of you know, I am taking a break for a few years but I look forward catching up with you all down the track. Best wishes to you all.

Rodger Grayson
Tel: (03) 9905 1969
Email: rodger@civenv.unimelb.edu.au

PROGRAM 1

PREDICTING CATCHMENT BEHAVIOUR

Program Leaders
GEOFF PODGER
& ROB ARGENT

Report by Robert Argent and Geoff Podger

Reflections on Predicting Catchment Behaviour

History of the Program

"Predicting Catchment Behaviour" – on the face of it, is a very ambitious name for a research program. When research planning started in July 1999 under the leadership of Rob Vertessy the idea of a 'toolkit' to underpin and help deliver science was new and exciting, and little did we know just how far we would go in six years. Members of the Program 1 team had been involved in software development over preceding years, and knew that, with the techniques emerging from the software engineering world, it was time that catchment prediction modelling was shifted into more modern times. Over the life of the Program we have seen some tremendous changes in the science of catchment prediction, the art of catchment modelling and the delivery of catchment prediction tools for use in managing natural resources. We have seen changes that we could not have imagined six years ago, and have certainly far exceeded what seems now to be modest targets of 5 toolkit software products (currently approaching 25) and 200 software users (currently approaching 4000) by the end of our CRC.

The two initial projects in Program 1 (Project 1.1: Development of a Catchment Modelling Toolkit; Project 1.2: Scaling Procedures to Support Process-based Modelling at Large Scales) were designed to provide the science and research that would allow us to build whole-of-catchment model capacity. The second round projects (Project 1.09 (1A): Implementation of the Catchment Modelling Toolkit; Project 1.10, (1B): Methods for Integration in Catchment Prediction) were designed to turn the research from the first round projects, as well as that emerging from the second round of projects across the CRC into products that could be delivered to our Partner's and the broader hydrology community.

Over 2000-2003, Projects 1.1 and 1.2 very much set the scene for our later successes. Project 1.1 under the leadership of Rob Argent, had the tasks of investigating the evolving nature of environmental modelling worldwide and deciding on a platform for the CRC to go forward with its broader catchment modelling delivery requirements. After a comprehensive survey of models (Marston *et al.* 2002), and trialling the ICMS and Tarsier modelling systems, it was decided to take a risk and build our own modelling environment, TIME (The Invisible Modelling Environment, Rahman *et al.*, 2003). An equal but less obvious achievement for this project was to embed the notion of a Catchment Modelling Toolkit firmly within our CRC, and so set up the framework for the CRC for Catchment Hydrology's research delivery efforts over 2003-2005.

Alongside Project 1.1's conceptual and technical development; Project 1.2, under the leadership of Rodger Grayson, made some excellent in-roads in scaling science, particularly in distributed modelling and terrain analysis. There was also considerable overseas collaboration in the field as well as in writing, including the publication of "Spatial Patterns in Catchment Hydrology" (edited by Grayson and Blösch). There were scientific successes including development of several new sub-grid parameterisations for runoff, erosion and salinity modelling, development of new pattern generation methods and methods for quantitative comparison of spatial patterns. Project 1.2 researchers were also involved in a comprehensive data collection exercise for soil moisture in the Murrumbidgee catchment with the Bureau of Meteorology that became part of GEWEX (the Global Energy and Water Experiment).

In the Project planning for 2003 – 2005 the CRC moved firmly into 'delivery' mode; with Program 1, under the leadership of Geoff Podger, providing the base for integration and delivery across most of the other research Programs. Essential to this was Project 1.10 (1B), under the leadership of Rob Argent, and the development of an Integration Blueprint during the research planning phase that showed where and how the component pieces of science being developed across the CRC fitted together to produce whole-of-catchment prediction approaches. This Blueprint served us well and provided a good focus for setting up co-project collaboration and exchanges of data and knowledge.

This project planning ended up with establishment of the Toolkit Strategy Group (TSG), charged with the coordination and integration of many aspects of the Catchment Modelling Toolkit.

Achievements

Over the period 1999 to the present there have been some great achievements in this Program. Some of the key achievements are described below, approximately in chronological order:

ICMS: This tool was developed within CSIRO and was first launched on the CRC website, allowing model-builders and users access to technology in the public domain. This set the foundations for model development and delivery that later became the catchment modelling toolkit (www.toolkit.net.au).

TARSIER: This modelling framework was developed by Fred Watson and substantially enhanced within the CRC. The ideas behind this framework are seen in TIME and other Toolkit products.

EMSS: Was developed within the Tarsier framework and includes the SimHyd model (Program 4 and 5), flow and pollutant routing model and a reservoir storage model. It was first applied in south east Queensland to predict sediment and nutrient fluxes in the river network and into Moreton Bay. It has now been applied to many other catchments throughout Queensland. Many of the technologies developed and lessons learnt have been passed into the next generation of the model, E2

TIME: The Invisible Modelling Environment (Rahman et. al.) is a catchment modelling framework developed within the CRC. It combines the useability of ICMS with the functionality of Tarsier into a new modelling framework. Most of the tools developed in the CRC are developed within this framework. This has grown substantially over the last few years and has more than 700,000 lines of code that are maintained by a community of developers.

The Blueprint: This document played a key role in ensuring linkages between all of the CRC projects and programs. It identified tools that would be delivered from each project and how that could be integrated together. The products that are available today can be traced back to this document.

RRL: The Rainfall Runoff Library (Perraud, et. al.) was the first product to be developed in TIME. It became the test product that was used as the standard that all other toolkit products would be based on. This includes not only the software, but the documentation and training material. Many of the document templates and product policies and guidelines are based on knowledge gained from this product. RRL has been widely applied throughout Australia and around the world. It has over 1500 registered users.

TSG: The Toolkit Strategy Group, although not a product, was probably one of the greatest successes of the CRC. This group comprising staff from Program 1 and Program 7 coordinated the delivery of all Toolkit products. It followed on from the catchment modelling blueprint as a means of coordinating and delivering software on the Toolkit web site. Some of the deliverables from this group include the 11 product policies, document templates, product managers' guides

eWater CRC STARTS SEPTEMBER 2005 – FRESHWATER ECOLOGY AND CATCHMENT HYDROLOGY CRCs COME TO A CLOSE

From September 2005, the eWater Cooperative Research Centre incorporates new participant organisations as well as those from the successful CRC for Catchment Hydrology and CRC for Freshwater Ecology. It combines the two water CRC's and the new participants' partnerships, skill bases, end-user networks, intellectual property and business systems.

eWater is a partnership between private and public water businesses and research groups across eastern Australia and seeks to produce practical products that bring economic, commercial and environmental benefits from the smart management of water.

Visit www.ewatercrc.com.au

ANNUAL REPORT ON-LINE

The CRC for Catchment Hydrology Annual Report 2004-05 is now available for downloading at www.catchment.crc.org.au/ publications

Look under 'Other Publications'

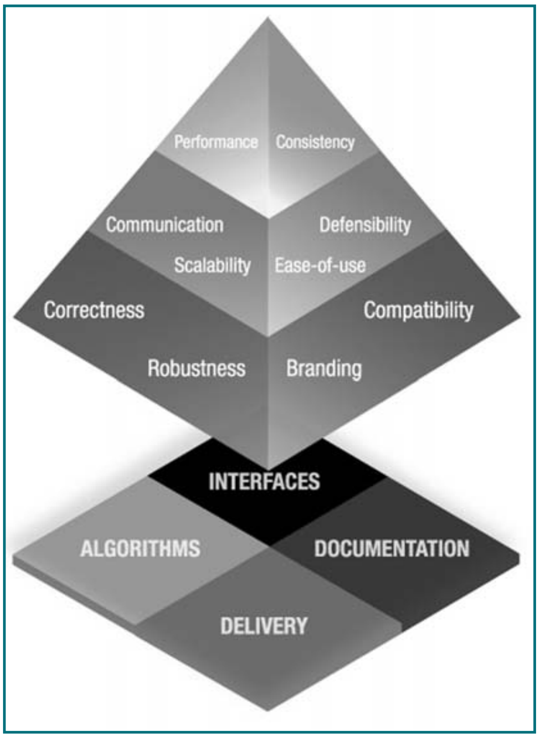

Figure 1.1 The TSG quality pyramid

and the Toolkit website. An example of what the TSG aimed to achieve in product development is shown in the quality pyramid (Figure 1.1). Hopefully you can see the aspirations of the pyramid in all of the products on the website.

RAP: The River Analysis Package is a tool that assists river managers in providing condition assessment, environmental flow planning and river restoration. It was jointly developed by Program 6 and Program 1.

SedNet: The Sediment Network model constructs sediment budgets for river networks. It was originally developed under Arcview using AMLs and converted into a TIME tool by Program 1 and Program 2.

SCL: The Stochastic Climate Library is a library of tools that allows hydrologists to generate climate data on an annual, monthly or daily basis. The algorithms were developed in Program 4 while the software was developed in Program 1.

Trend: Trend has 12 statistical tests for detecting trend/change in time series data. The algorithms were provided by Program 5 and the software was developed by Program 1.

E2: is the next generation of catchment model – being a system that supports development of whole-of-catchment models using an optional range of alternative component models. This tool truly embodies the spirit of 'horses for courses' by allowing users to select which model they wish to build, based upon consideration of the data available, and the problems being addressed. Thus, E2 can support annual load estimation for a receiving water body as readily as it supports daily estimation of streamflow. It is currently being implemented in catchments in Queensland, NSW and Victoria.

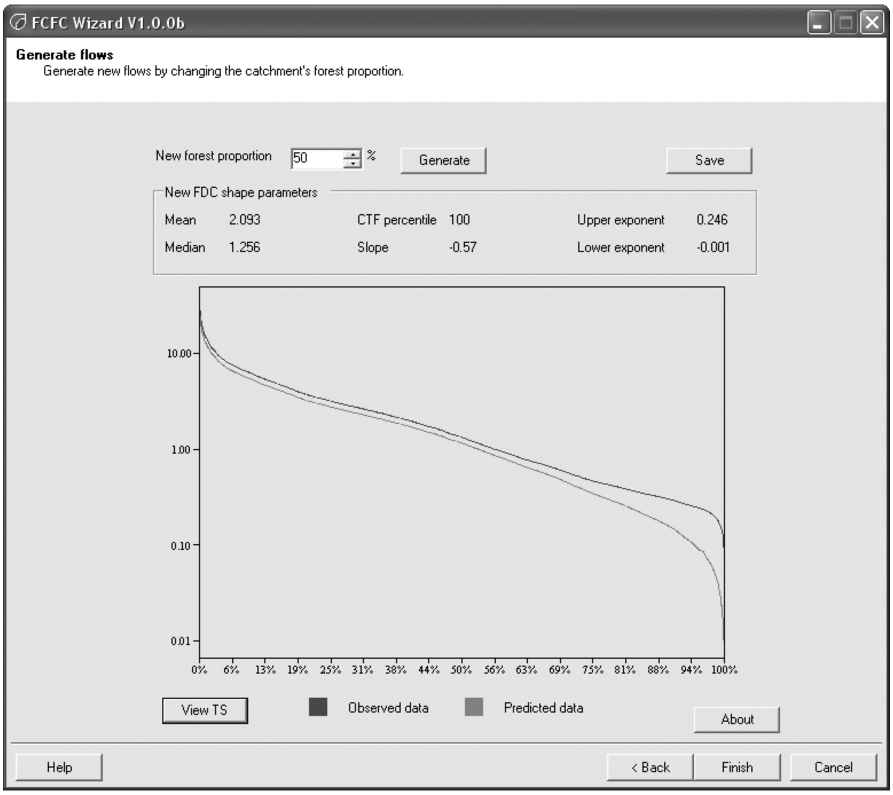

Figure 1.2: FCFC interface showing a flow duration curve for different proportions of forest cover.

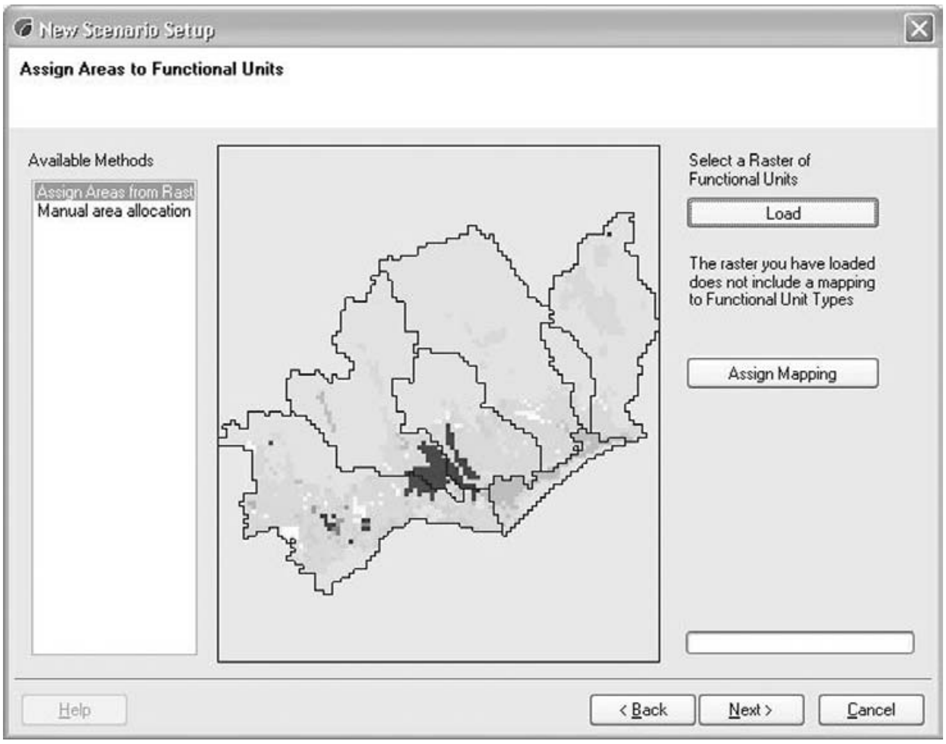

Figure 1.3: E2 interface showing assignment of functional units.

FCFC: The Forest Cover Flow Change tool provides a way to modify time series of daily flows for changes in forest cover. It allows resource managers the capability of assessing the impacts of changes in forest cover on flows. The research for this was done in Project 2.23 (2E) (Brown et. al.) and the software was developed in Program 1.

On the less successful front we had planned to develop the Toolkit Assistant – a system that was to support model selection by matching available model options with user needs. A first step along this line was to review Rainfall Runoff models to determine which ones were appropriate for use in particular circumstances. The findings of this study showed us that it was difficult to be prescriptive about which model to use in which situation – a dream from the early days of Program 1 – and led us to focus on improving information related to model selection and communication of what models can and cannot do. This focus has resulted in another useful Toolkit product, the publication series on Model Choice.

Another area that we had to cut back on was the propagation of uncertainty through models. Due to budget and resource constraints this was limited to providing visualisation tools within the E2 model. Hopefully more can be done on this in the future.

There have been many successes and a few failures over the years, but the primary message coming out of the Program 1 portfolio is that of industry change. At the start of the Program we saw that catchment modelling could be done in a more integrated and user friendly way, and have produced the science and tools to support this.

Delivering science

One of the major achievements of Program 1 has been turning science into products. The success of this relies upon a lot of factors including good management, smart software development environments, testing, delivery and feedback. We have learnt a lot along the way about delivering science some of the key points are:

Program to product: As many CRC for Catchword Hydrology product mangers will tell you, building the model is the easiest part of the job. There is a lot of work in turning a computer model into a "product". Things that need to be considered include:

- The interface and useability of the software
- Connection to data and other products
- Documentation
- Training material
- Training
- User groups
- Bug reporting and handling.

Road testing: A key to delivering a goog product relies upon testing and feedback. The Development Projects have been a very useful means of testing software, but also a very useful way of improving it. The feedback from the Development Projects has helped to design the final products that we deliver, this is very evident in the design of EMSS, Sednet, RAP and E2.

CRC WEBSITE LIVES ON

The CRC for Catchment Hydrology website at www.catchment.crc.org.au will continue to be maintained for years to come after September 2005. All CRC for Catchment Hydrology Publications from 1994 – 2005 are available under 'publications' and the majority can be downloaded as PDF files.

Selected CRC Publications are still available through the Australian Water Association (AWA) bookshop. Email: bookshop@awa.asn.au

CATCHMENT MODELLING TOOLKIT AND eWater CRC

The Catchment Modelling Toolkit is a suite of software and supporting documentation intended to improve the efficiency and standard of catchment modelling. The Toolkit currently has a total of 25 software and data products. The Toolkit will continue to be supported by eWater CRC as a resource for the land and water management industry and the research and development community supporting that industry.

Visitors to the site can continue to access a range of catchment modelling software online by registering as a Toolkit member at www.toolkit.net.au

Integration: Integration does not just happen; it requires a lot of planning up front and a lot of coordination along the way. The catchment modelling blueprint provided the planning up front, and the TSG provided the coordination along the way. Program and Project Leaders across the CRC have played a key role in integration. All of the project plans had integration clearly spelled out and the TSG and leadership ensured it was delivered.

Where to next

As we ride off into the sunset of the CRC for Catchment Hydrology, we see the new eWater CRC thundering across the horizon. For many of the Program 1 researchers this offers a fantastic opportunity to continue to advance both the theory and practice of catchment prediction, and to embrace new collaboration opportunities with both those who were members of the former CRC for Freshwater Ecology, and also the many researchers who are new to cooperative research centres.

The eWater CRC has been busy talking to industry partners and researchers, gauging what needs to be done and what is achievable over the next 7 years. Both of us have been actively involved in developing product and research plans with Geoff heading up the Catchment Modelling and Integration Research Program and Rob the Deputy Director for Product Development. It has been hard going, but things are starting to take shape now. Although not finalised, it is already clear that there is going to be a lot of development of catchment modelling capability. There will be further development of catchment models and river planning models. There will also be new development in the areas of river operations models and ecological models. There will also be a much stronger focus on risk and uncertainty in models.

After the tremendous activity in wrapping up the CRC for Catchment Hydrology, our code base and documentation requires some maintenance. So in the next few months we are going to spend some time cleaning things up and getting ready for the next generation of software development. There will still need to be quite a lot of support for the newly released version of E2, with the development of tools to support implementation and integration.

Staring into the crystal ball, in the medium term there are plans to enhance the generation of constituents that include salinity, sediment, nutrients and temperature. The in-stream and storage models will be further improved to better model the transportation, interaction and storage of constituents. The water management aspects of river systems will be improved with further work on water ordering, river operations and forecasting. There will also be integration with irrigation, river analysis and ecological tools. In the longer term more water management capability in models, ecological response models, multi-criteria analysis, groundwater/surface water interactions, floodplains, and propagation of risk and uncertainty through models.

So it is time to take a quick deep breath before we start on the next lot of work. As you can see there is still a lot to do.

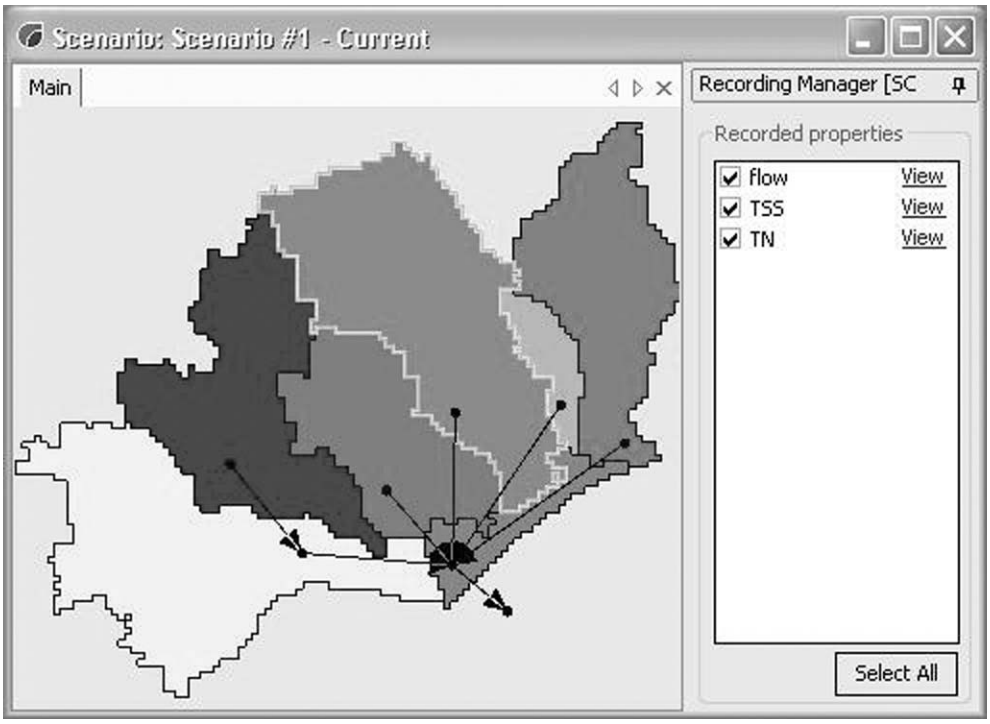

Figure 1.4: E2 provides the user with views of outputs at different points in a catchment.

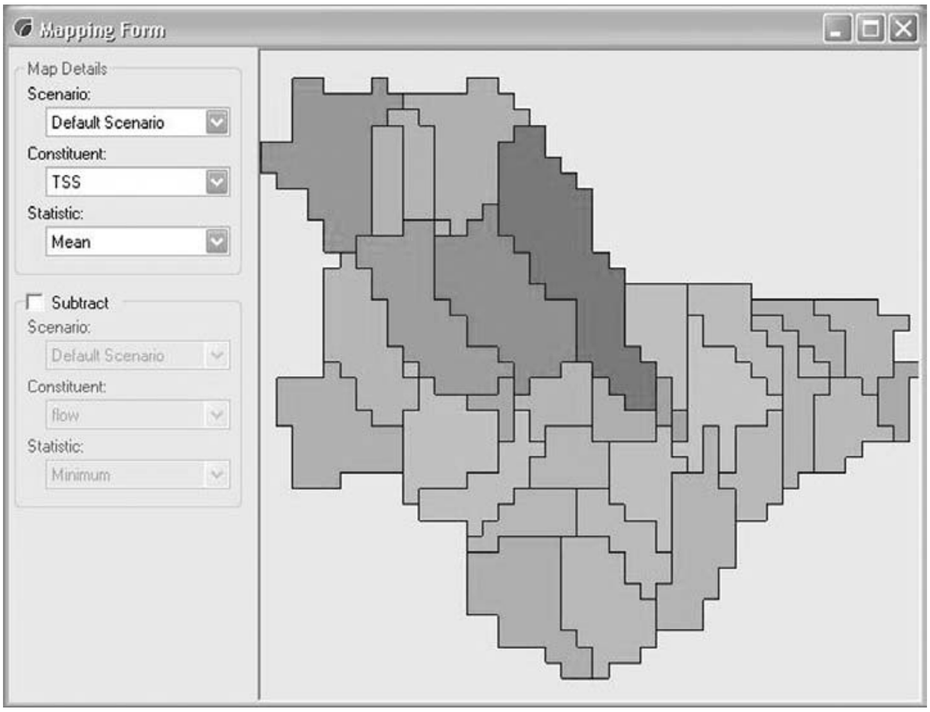

Figure 1.5: E2 map of subcatchment TSS load.

Thanks

All of this does not happen by chance, it relies upon a team of people all working extremely hard together. It is not possible to mention everyone who has been involved, but thanks go out to many people – so apologies if we have missed anyone. There are a few key people that we would like to thank:

Management: Rob Vertessy for his vision and support, Rodger Grayson for his technical guidance and keeping us on track and ensuring that we delivered good science on time.

Software developers: Joel Rahman for his vision on TIME and keeping the software on track and the team of software developers (Jean-Michel Perraud, Shane Seaton, Harold Hotham, Geoff Davis, Rob Bridgart) Also some of the other software developers from other Programs that have contribute to TIME (Matthew Stenson, Silvain Arene, John Hornbuckle, Ben Leighton, Paul Peterson and many others).

Toolkit Strategy Group: The people who coordinate the delivery of products and the Toolkit web site (Rodger Grayson, Rob Argent, Geoff Podger, Dave Perry, Joel Rahman, Jake MacMullin, Nick Murray and Susan Daly).

Others: John Molloy for keeping budgets on track, and industry and Focus Catchment Coordinators for supporting our software.

Despite the hard work we will be sad to see the end of this Program 1 and I hope we have met your expectations. Both Rob and I look forward (deep breath) to doing this all again in eWater CRC.

References

Brown, A.E., McMahon, T.A., Podger, G.M., and Zhang, L. (2005). A methodology to predict the impact of changes in forest cover on flow duration curves. Cooperative Research Centre for Catchment Hydrology.

Marston, F., Argent, R.,Vertessy, R., Cuddy, S., and Rahman, J. (2002). The status of catchment modelling in Australia. Cooperative Research Centre for Catchment Hydrology Technical Report, Report No. 02/4, 39pp.

Perraud, J. M., Vertessy, R.A., & Podger, G.M. 2003. In Boyd, M.J., Ball, J.E., Babister, M.K. and Green, J. (Eds). 28TH International Hydrology and Water Resources Symposium: Wollongong, NSW, 10-13 November 2003. The Institution of Engineers, Australia. Vol 3, pp. 115-122.

Rahman, J.M., Seaton, S.P., Perraud, J-M., Hotham, H., Verrelli, D.I. & Coleman, J.R., 2003. It's TIME for a new environmental modelling framework, In Proc. MODSIM 2003 (ed. DA Post), Modelling and Simulation Society of Australia and New Zealand, Townsville, pp 1727-1732.

Robert Argent
Tel: (03) 8344 7115
Email: r.argent@unimelb.edu.au

Geoff Podger
Tel: (02) 6246 5851
Email: geoff.podger@csiro.au

CRC PUBLICATIONS LIST

The CRC for Catchment Hydrology produces a range of publications to assist people interested in applying our research outcomes.

A final printed September 2005 Publications List is included with this issue of Catchword.

A more comprehensive list of CRC publications from 1994-2005 can be found at www.catchment.crc.org.au/ publications

eWater CRC STARTS SEPTEMBER 2005 – FRESHWATER ECOLOGY AND CATCHMENT HYDROLOGY CRCs COME TO A CLOSE

From September 2005, the eWater Cooperative Research Centre incorporates new participant organisations as well as those from the successful CRC for Catchment Hydrology and CRC for Freshwater Ecology. It combines the two water CRC's and the new participants' partnerships, skill bases, end-user networks, intellectual property and business systems.

eWater is a partnership between private and public water businesses and research groups across eastern Australia and seeks to produce practical products that bring economic, commercial and environmental benefits from the smart management of water.

Visit www.ewatercrc.com.au

PROGRAM 2

LAND-USE IMPACTS ON RIVERS

Program Leader
PETER WALLBRINK

Report by Peter Wallbrink

A brief history in catchment time: a review of Catchment Hydrology research into erosion and sedimentation impacts on rivers

Background

The current "Land-use impacts on rivers" Program has its origins in the initial CRC for Catchment Hydrology Program entitled: "Waterway management and erosion control" which supported key aspects of the CRC's initial objectives of "undertaking high quality research into catchment hydrology, in the areas of: catchment water and salt balance, waterway management and erosion control, urban hydrology and flood hydrology". The Program was initially led by Dr Cathy Wilson (CSIRO Land and Water) and comprised three core projects and an associated collaborative project. Project emphasis focussed on understanding processes such as: how sediment and nutrients move through the landscape before entering streams, sediment movement within the stream, and bank stability. The Program's core projects were

- Controlling the delivery of sediment and nutrients in water supply catchments
- Factors controlling river channel and gully stability
- Environmental flow requirements in rural catchments
- Rehabilitation and management of riparian lands, and later;
- Sediment movement in Forestry operations.

These projects were led by some of CRC's favourite sons and daughters, including Peter Hairsine, Ian Rutherfurd, Ian Prosser and Jacky Croke - all of whom continue to be major contributors to their respective disciplines. Some of the initial aims of their projects included determining:

- how managers and farmers can best reduce the input of sediment and nutrients generated by agricultural and forestry activities to streams
- the impact of logging on forest streams
- the large scale patterns of riparian zones
- the effect of bushfires on soils and soil runoff
- what is the distribution and cost of stream erosion and sedimentation, and
- how to model the ways in which riparian vegetation modifies fluxes of water, sediments and nutrients to streams.

Initial highlights

Major achievements of these initial projects included a radionuclide analysis of the origins of sediment to Tarago reservoir, the development of the Campaspe catchment management strategy, an understanding of the role of riparian zones in trapping sediments and nutrients, the development of a sediment budget for the Johnstone River catchment, as well as a series of guidelines for riparian management.

It is clear that some of the initial aims of these projects were similar to objectives of Program 2 today, whilst others have been used as a platform for further development. From 1997 the program evolved into the 'Waterway Management' Program led by Peter Hairsine, with a refined emphasis on practical management issues in stream rehabilitation, riparian zone management, and the effects of catchment shape, roads and stock tracks on water quality. Three new projects evolved from this next round:

- Controlling nutrient and sediment delivery to streams (Peter Hairsine)
- Stream restoration (Ian Rutherfurd)
- Rehabilitation and management of riparian lands: sediment, nutrients and erosion (Ian Prosser)

Achievements from this portfolio of work included:

- Demonstrating the effectiveness of buffer strips in reducing sedimentation and pollution input to north Queensland streams
- A review of the importance of large woody debris in stream geomorphology
- The completion of design guidelines for riparian buffers to satisfy legislative requirements
- Publication of the Australian Stream Rehabilitation Manual, and
- Quantification of sediment generation rates and delivery to a water supply reservoir from six different land-use types (gravelled roads, ungravelled roads, stock tracks, cultivated lands, pastureland, and forests).

Agency involvement

To facilitate uptake of the research by both industry and community, the Program vigorously applied a strategy of involving key management agencies in its research portfolio. In this way the impressive body of research work was complemented by an equally impressive collaborative effort with agency partners. For example, agreements were in place with four State agencies and field programs were established in four States with a geographical coverage from tropical Queensland to rural Tasmania.

Second round fundig – TAG

In 1999 the CRC successfully achieved second round funding, heralding an opportunity to further refine its efforts in catchment management research. Following the efforts of a 20 strong Technical Advisory Group (TAG), the Program was renamed "Land-use impacts on rivers" (again led by Peter Hairsine) and its aim was broadened to provide a better understanding of the effects of land-use change on catchment water balance and pollutant delivery to streams. The program was underpinned by four projects:

- Sediment movement, water quality and physical habitat in large river systems (Ian Prosser and Jon Olley)
- Managing pollutant delivery in dryland upland catchments (Peter Hairsine)
- Predicting the effect of land-use changes on catchment water yield and stream salinity (Lu Zhang)
- Nitrogen and carbon dynamics in riparian buffer zones (Heather Hunter)

In combination they aimed to improve our understanding of large scale regional catchments (and associated processes) to improve river health. (See Figure 2.1). Through this it was hoped to deliver to managers the capacity to better assess tradeoffs and benefits of strategies for sediment and nutrient control, and thus lead to improvements in river health. It was also envisaged that the outcomes would result in a stronger technical basis for the emerging development of river management policy and water yield/ land-use issues.

Key outcomes from this phase of research included:

- The development of a framework for constructing sediment and nutrient budgets in large catchments (later to evolve as SedNet)
- Development of the WinSeads and Pathways models
- A simple statistical method to estimate the effects of afforestation on annual flow regime involving the use of flow duration curves, and
- Quantification of the combined biological, geophysical and chemical processes and their effect on denitrification rates in riparian soils

Catchment Modelling Toolkit

By 2003 the CRC (and Program 2) had firmly embraced the concept of the Catchment Modelling Toolkit as a means of capturing and delivering the various aspects of catchment based erosion, sediment, nutrients and flow related research. As a result, Program 2 now entered its most ambitious and final project phase, effectively focussing its efforts on contributing to a 'whole-of-catchment predictive modeling capacity'.

Specific aims during this period were to develop methods (encapsulated in computer software) for predicting responses to land-use change, to predict the spatial distribution of pollutant sources for three rural

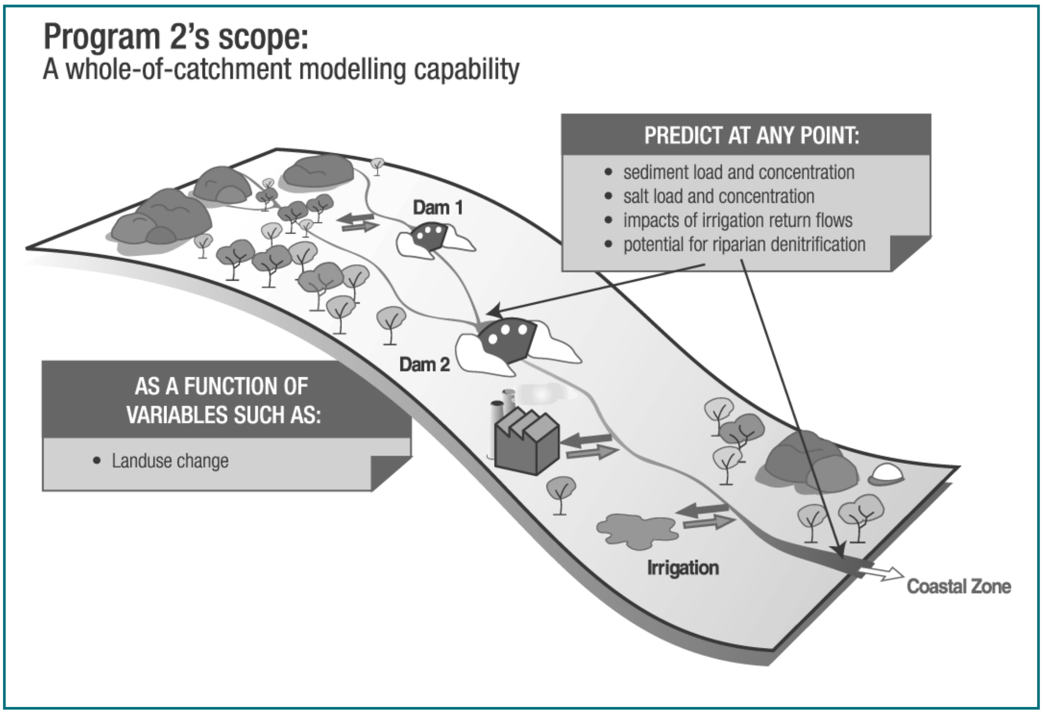

Figure 2.1: Scope of Program 2

NEW TECHNICAL REPORT

JOINT PUBLICATION WITH CRC FOR COASTAL ZONE, ESTUARY & WATERWAY MANAGEMENT

The Riparian Nitrogen Model - Basic Theory and Conceptualisation

By

David Rassam
Daniel Pagendam
Heather Hunter

Technical Report 05/9

Investigations of riparian zone hydrology and of denitrification, the microbial process whereby nitrate is converted to nitrogen gas and released to the atmosphere resulted in the development of the Riparian Nitrogen Model (RNM). Used in conjunction with catchment water quality models, the RNM can estimate nitrate transport and loss in riparian zones and predict responses to changes in management.

This report provides a detailed description of the RNM, including the conceptual basis of the model and its formulation, the data requirements and the model outputs.

This report is available for downloading as an Adobe Acrobat file from www.catchment.crc.org.au/publications

catchments, and finally, to integrate these methods into the 'whole of catchment' model E2. These were lofty goals and to realise them, Program 2 became the largest CRC for Catchment Hydrology Program in its history. Five new projects were initiated to either develop or augment existing tools or knowledge, so as to be able to predict flow, sediment load, or salt load at any point in a catchment. The projects comprising the portfolio of work were:

- Reducing the impacts of irrigation return flows on river salinity (Evan Christen)
- Improved suspended sediment and nutrient modelling through river networks (Jon Olley and later Scott Wilkinson)
- Predicting salt movement in catchments (Mark Littleboy)
- Modelling and managing nitrogen in riparian zones to improve water quality (Heather Hunter)
- Modulating daily flow duration series to reflect the impact of land-use change (Lu Zhang)

A key outcome from each of these project areas was both a module for incorporation into the 'whole-of-catchment' model E2, and a stand-alone model (Tidaluk, SedNet, 2CSalt, RNM, FCFC – see www.toolkit.net.au for further information).

The integration and development of modules involved close collaboration with, and input from, software engineers from the Program 1 team. I became involved with Program 2 from the beginning of 2004 – perfect timing to see the rewards of the master plan coming to fruition.

Toolkit and E2

There is no doubt that the knowledge generated in Program 2 (and its forbears) has contributed substantially to the current utility of the Toolkit and E2. This is solid testimony to the efforts of the many exceptional scientists involved in the development and progression of the underpinning catchment based science over the last twelve years, as well as the architects and enablers of the Toolkit - from the Director(s) down!. The delivery of catchment based science through a mechanism such as the Toolkit has proven a wise decision that will continue to be developed and supported in eWater. I have no doubt that future scientists, and their industry collaborators, will continue to evolve, adopt, adapt and refine the impressive body of work already achieved within the Program 2 'catchment science' realm.

Future challenges

Future challenges for eWater involve the development of more holistic models combining the effect of changes in contaminant fluxes (such as sediments and nutrients) with ecological outcomes and benefits. However, many challenges and pitfalls lie before the successful delivery of this form of capacity.

Finally as well as the evolution of the science, one of the most pleasing attributes to Program 2, was the ever-increasing awareness and commitment to collaboration with industry and State agency Partners.

The 'Development Projects' emerged from this commitment and history will show these to be one of the hallmark successes for both communication and adoption of research findings from the CRC.

Well done to all the Program 2 staff!

Peter Wallbrink
Tel. (02) 6246 5823
Email: peter.wallbrink@csiro.au

PROGRAM 3

SUSTAINABLE WATER ALLOCATION

Program Leader
JOHN TISDELL

Report by John Tisdell

The final word

Background – Program objective

Well, at the end of the CRC for Catchment Hydrology it is time to reflect on the successes of the Sustainable Water Allocation Program and the challenges of the future.

The overall objective of the Program for the last six years was to provide practical tools to policy makers for the sustainable allocation and use of water. The tools and knowledge capital produced by the Program have been impressive.

The tools have become the standard for research institutions and have received accolades from researchers in Australia and internationally. The knowledge capital in the CRC Technical Reports has been widely cited in industry briefing papers, conference and journal articles (see www.catchment.crc.org.au/publications).

Reports and tools

The technical report "Review of Water Management in Australia" in particular, is seen as a "must read" for new entry staff or those needing a comprehensive snapshot of the state of play in the industry. Two vital tools, WRAM and Mwater, have been developed to complement and integrate with existing industry water management models such as IQQM and REALM (Tisdell and Yu, 2004). By providing user friendly interfaces and linkages to existing software, adoption by key stakeholders, such as DNR NSW, DSE and NRMQ, has been strong. Integration with mainstream industry planning models ensures the tools will have a long life providing an important legacy from the CRC into the future. The tools are unpinned with the latest techniques and scientific information as well as extensive case information on the social and economic dimensions of water reform issues.

Modelling Projects

The objective of the 'Integration of Water Balance, Climatic and Economic Models' Project led by Gary Codner and subsequently the 'Hydrological and Economic Modelling for Water Allocation' Project led by Bofu Yu was to develop an integrated economic/hydrological model for a selection of focus catchments (Yu *et al.*, 2003). Current hydrologic river network models (i.e. IQQM and REALM) determine water demand from the existing entitlements and crop mix. They do not, however, simulate changes to cropping pattern, and temporary and permanent trade of water entitlement for economic gains.

WRAM has made a significant difference to the ability of water to model the linkages between economic and hydrological drivers in the catchment by enhancing the existing capabilities of hydrologic network models, in terms of crop mix (IQQM) (Yu *et al.*, 2003) and/or water demand (REALM) (Weinmann *et al.* 2005), by providing a dynamic link between hydrologic and economic models for water allocation.

Over the last twelve months improvements to WRAM have included:

- Modules to evaluate the impact of changes in climate, land use, and policy instruments on regional economy.
- Upgrading the stand-alone version of WRAM for the Catchment Modelling Toolkit
- Validation and testing of WRAM for the Murrumbidgee (DNR, NSW), and the Goulburn-Broken catchments (G-M Water, Vic), Nogoa-Mckenzie (NRME, Qld)
- Development of an integrated WRAM - IQQM model
- Development of a livestock module in WRAM (for DSE, Vic)
- Tools to simulate water trading among 'nodes' representing irrigation areas
- Delivery of WRAM to users directly via WRAM – IQQM, and WRAM – REALM .
- Delivery of WRAM to Toolkit

Water market project

The objective of the Project 'An evaluation of permanent water markets' was to further develop the tools developed in the initial Project 'Enhancement of the Water Market Reform Process' to explore more complex economic issues surrounding water allocation, water and other natural resource trading environments in our Focus Catchments. The focus has been on the performance of natural resource markets for resources such as water, salt, and sediment and nutrient through the combined use of optimisation models and development of Mwater. Issues addressed were concerned with:

- The principles and issues surrounding the effective reduction of point and non-point pollution entering rivers and streams in our focus catchments. Significant progress has been made in experimentally exploring the issues of moral hazard and adverse selection which can arise when developing land management and water policy to address sediment and pollution loads (Clowes, 2005).
- Effective polices to deal with the associated risks and uncertainties resulting from the fleeting and interdependent nature of its supply. Significant

NEW TECHNICAL REPORT

Modelling Water Reallocation from Temporary Trading in the Goulburn System

By Erwin Weinmann
Sergei Schreider
Barry James
Hector Malano
Mark Eigenraam
Mariyapillai Seker
Tony Sheedy
Rukman Wimalasuriya

Technical Report 05/6

The ability to model the reallocation of water resulting from water trading is critical to the implementation and assessment of the new water reform agenda for Australia.

The model used by Victorian water authorities to simulate the behaviour of their complex water supply systems is REALM (REsource ALlocation Model). Until now this modelling package lacked the capability to model the reallocation of water entitlements resulting from water trading and to assess the economic impacts of various allocation and water trading policy options.

This report summarises the outcomes of the Victorian component of Project 3A 'Hydrologic and economic modelling for water allocation', which was aimed at filling this gap in modelling capabilities.

This report is available for downloading as an Adobe Acrobat file from www.catchment.crc.org.au/publications

eWater CRC STARTS SEPTEMBER 2005 – FRESHWATER ECOLOGY AND CATCHMENT HYDROLOGY CRCs COME TO A CLOSE

From September 2005, the eWater Cooperative Research Centre incorporates new participant organisations as well as those from the successful CRC for Catchment Hydrology and CRC for Freshwater Ecology. It combines the two water CRC's and the new participants' partnerships, skill bases, end-user networks, intellectual property and business systems.

eWater is a partnership between private and public water businesses and research groups across eastern Australia and seeks to produce practical products that bring economic, commercial and environmental benefits from the smart management of water.

Visit www.ewatercrc.com.au

progress has been made in understanding risk preferences and their impact on better ways to manage water allocations (Capon and Tisdell, 2005).

- Assessment of the impact of large players in relatively "thin" water markets. This is of great concern to both water authorities and farmers. Research over the last twelve months has provided important insights into how best to design water markets to minimise the impact of large stochastic players. Closed call markets are less affected by large stochastic players than more open call or double auction structures (Tisdell et al. forthcoming).
- Separation of water entitlements into component parts raises the potential for multiple markets. How to develop such markets and operationalise them has been a significant component of the Program's research. While there are many questions still to be answered, the findings to date have proved critical in developing proofs of concept for the industry.

Water markets throughout the Murray-Darling Basin are expanding and becoming more complex (Turral, *et al.* 2005; Zaman *et al.* 2005a and 2005b). To undertake analysis and experimental work on these more complex markets required developing Mwater to a new level. Existing experimental economic platforms are not capable of simulating beyond single unit trades. For example, to effectively evaluate alternative allocation and market systems required the development of auction environments similar to those used to trade stocks and shares, in which the traders to could take differing roles. The software has provided insights which otherwise could not be modelled. Enhancing the capabilities of Mwater provides a legacy which will ensure its use well beyond the life of the CRC.

Adoption

At the end of the CRC the focus of our efforts has been on adoption through improvements in the functionality and user friendly interfaces. In the case of WRAM significant improvements to the interface greatly enhanced the functionality of the program. Mwater, while an extremely complex suite of integrated programs, maintains a simple excel data interface, requiring only very simple knowledge of spreadsheet commands and functions.

Knowledge is vital for informed decision making and the development of sound and well crafted water policies. In essence, the Sustainable Water Allocation Program has contributed to the water and natural resource industry the tools, knowledge and future staff to effectively manage Australia's water in a sustainable manner. The most important knowledge capital resides in our postgraduate students who will take the CRC's knowledge into the future of Australia's water management decision making. The program has produced an extremely talented group of graduates in whose hands the future of sustainable water management in Australia is secure.

Future Challenges

The challenges for the future, including balancing environmental and extractive demands for water, and the ever reducing supply of water on this arid continent, will be important foci for the eWater CRC crew.

In conclusion, I would like to thank all those who have worked on projects including Gary Codner, Geoff Earl, Barry James, Gary Jones, Hector Malano, Geoff Podger, Ilan Salbe, Mariyapillai Seker, John Ward, Erwin Weinmann, Bofu Yu, the postdoctoral fellows, research assistants and postgraduate students.

References

Capon, T. R. and Tisdell J.G 2005. Risk and ambiguity preferences in dynamic decision-making experiments under conditions of risk and ambiguity. International Conference on Cognitive Economics New Bulgarian University, Sofia, August 5-8, 2005.

Clowes D. (2005). The effect of abatement uncertainty on the performance of point-nonpoint water quality trading schemes: environmental and economic implications. 8th International River Symposium, Sydney.

Tisdell, J.G. (forthcoming). A comparison of call and double auction water markets with dominate players. Griffith University Discussion paper.

Tisdell, J. and Yu, B. (2004). Sustainable Water Allocation Program Report, *Catchword*, Special Edition, No. 133, November/December. 13-16.

Turral H.N., Etchells T., Malano H.M.M, Wijedasa H.A., Taylor P., McMahon T.A.M., and Austin N "Water trading at the margin": the evolution of water markets in the Murray Darling Basin. Water Resources Research. Vol 41, W07011.

Weinmann, P.E., Schreider S.Y., James, B., Malano, H., Eigenraam, M., Seker, M., Sheedy, A.J. and Rukman, W. (2005). Modelling water reallocation from temporary trading in the Goulburn System. Report 05/6, Cooperative Research Centre for Catchment Hydrology, Monash University.

Yu, B. Tisdell, J. Podger, G and I Salbe 2003. A hydrologic and economic model for water trading and reallocation using linear programming techniques. Proceedings of the MODSIM 2003 International Congress on Modelling and Simulation. Volume 3, pp. 965- 970.

Zaman A.M., Malano, H.M., Davidson B. 2005a, Temporary water trading trends in Victoria - Australia, Water Policy, Vol 7, No.4, pp 429-442

Zaman A.M., Malano, H.M., Davidson B., 2005b. Modelling Water Trading in Victoria – A Methodology, 29th Hydrology and Water Resources Symposium, Engineers Australia, 21–23 February 2005, Canberra

John Tisdell

Tel: (07) 3875 5291

Email: j.tisdell@griffith.edu.au

PROGRAM 4
URBAN STORMWATER QUALITY

Program Leader
TIM FLETCHER

Report by Tim Fletcher

Our reason for being

In the initial seven year life of the CRC, the Urban Hydrology Program began, (in 1992-93, under Tom McMahon) to tackle issues surrounding urbanisation's impact on waterways, undertaking studies on urban runoff and on stormwater treatment systems (detention basins, wetlands, ponds and gross pollutant traps). It was under this Program also, that Aquacycle was produced, to evaluate the feasibility of wastewater and stormwater reuse (www.toolkit .net.au/aquacycle).

Then, in 1999, the program was re-named the 'Urban Stormwater Quality Program', under the leadership of Tony Wong (and later Tim Fletcher). The strategy of the Urban Stormwater Quality Program was to capture existing knowledge of stormwater behaviour and management in a user-friendly software tool that could be widely used by industry. This strategy was backed strongly by the CRC's industry Parties (in particular Brisbane City Council and Melbourne Water). From that point on, almost all of the research outcomes undertaken in the Program were delivered through this software tool, called MUSIC – the Model for Urban Stormwater Improvement Conceptualisation (www.toolkit.net.au/music).

Major achievements and impacts

In the period from 1993 to 2005, some great achievements resulted from the work of the Urban Hydrology and Urban Stormwater Quality Programs. The key achievements are described below, in (roughly) chronological order:

SimHyd: Francis Chiew and Tom McMahon (Chiew & McMahon, 1999) saw the need to be able to simply and efficiently model the rainfall-runoff behaviour of urban catchments, in order (ultimately) to be able to predict pollutant loads from different catchments (1999). The model used two pervious soil stores, along with an impervious area store, and was originally applied on a daily basis. Subsequent modifications to the model, by the MUSIC team, have involved simplifying the soil stores, disaggregating the model to work at sub-daily timesteps (down to six minutes), and allowing user-specification of the behaviour of groundwater-surface water interactions (Figure 4.1).

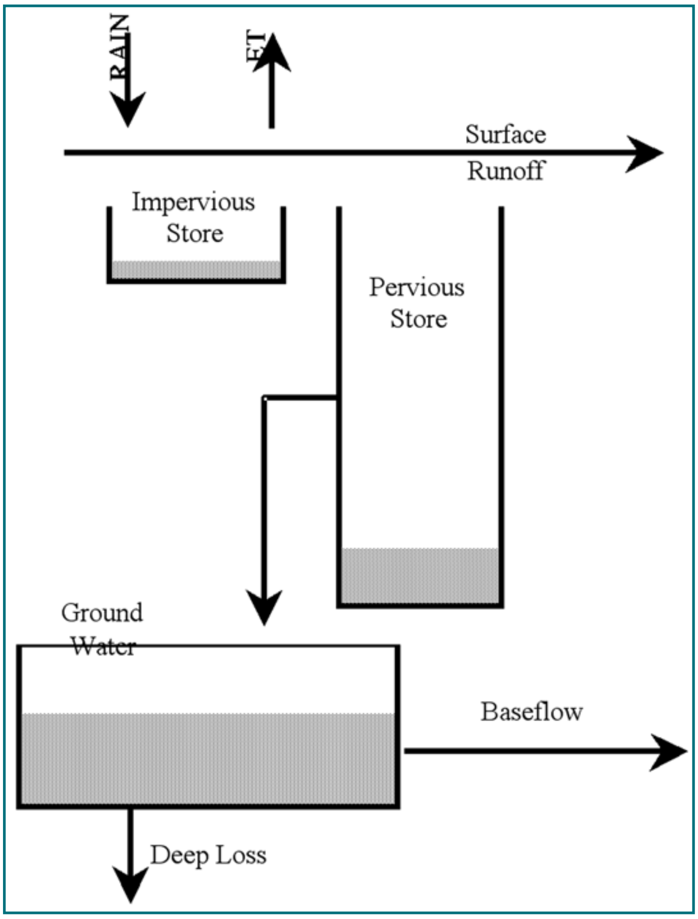

Figure 4.1. Adapted version of the SimHyd model, deployed in MUSIC v2 and above.

Statistical overview of stormwater quality: In the mid 1990s, the Urban Hydrology team recognised that there was a lack of reliable estimates of urban stormwater quality characteristics. In particular, estimates of concentrations of key pollutants (e.g. suspended solids, nitrogen, phosphorus, metals, PAHs, etc) were based on a small number of (largely) short-duration monitoring programmes. In response, Hugh Duncan undertook a feat that is the academic analogy to an "ironman triathlon". He reviewed approximately 800 separate studies, producing statistical descriptions of commonly measured parameters (Figure 4.2). This work has become probably the most cited report in the Australian stormwater industry today (Duncan, 1997).

Aquacycle: Well ahead of her time, Grace Mitchell developed an interest in the potential for stormwater and wastewater re-use, but could not find a suitable model to investigate its viability.

NEW TECHNICAL REPORT

Stormwater Flow and Quality and the Effectiveness of Non-proprietary Stormwater Treatment Measures - A Review and Gap Analysis

By
Tim Fletcher
Hugh Duncan
Peter Poelsma
Sara Lloyd

Technical Report 04/8

There is an increasing emphasis on the need to manage urban stormwater in a way that minimises the impact on receiving waters. With this increased attention, has come a rapid development in knowledge of key issues affecting stormwater management.

The NSW Environmental Protection Authority commissioned this report, to synthesise existing data and to identify and prioritise gaps, in order to direct their own future research activities. The data compiled in this report, whilst having a NSW focus in some sections, is of value to stormwater management agencies throughout Australia.

This report is available for downloading as an Adobe Acrobat file from www.catchment.crc.org.au/publications

eWater CRC STARTS SEPTEMBER 2005 – FRESHWATER ECOLOGY AND CATCHMENT HYDROLOGY CRCs COME TO A CLOSE

From September 2005, the eWater Cooperative Research Centre incorporates new participant organisations as well as those from the successful CRC for Catchment Hydrology and CRC for Freshwater Ecology. It combines the two water CRC's and the new participants' partnerships, skill bases, end-user networks, intellectual property and business systems.

eWater is a partnership between private and public water businesses and research groups across eastern Australia and seeks to produce practical products that bring economic, commercial and environmental benefits from the smart management of water.

Visit www.ewatercrc.com.au

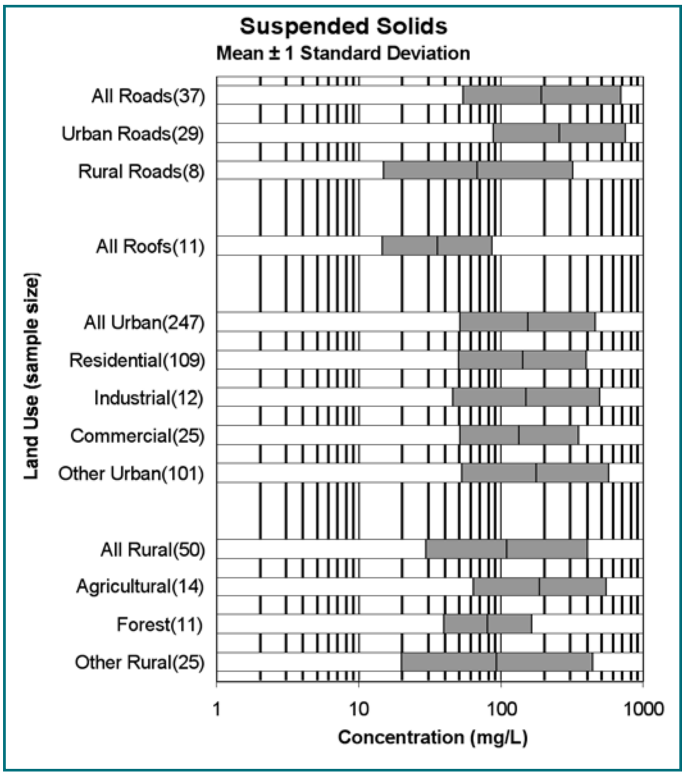

Figure 4.2. Summary of stormwater quality (source: Duncan, 1997).

As a result, she developed as part of her PhD, the Aquacycle model (available at www.toolkit.net.au/aquacycle). Aquacycle is a daily urban water balance model which has been developed to simulate the total urban water cycle as an integrated whole and provide a tool for investigating the use of locally generated stormwater and wastewater as a substitute for imported water alongside water use efficiency. The model is intended as a gaming tool rather than a design tool, giving an overall impression on the feasibility for using stormwater and wastewater at a particular site.

Constructed wetlands guidelines: Tony Wong led a team of researchers investigating the behaviour of constructed stormwater wetlands. Along with Peter Breen (CRC for Freshwater Ecology), and postgraduates Nick Somes and Sara Lloyd, they made a major advance in being able to specify appropriate wetland design to maximise water quality treatment. This work was synthesised in the CRC Industry Report entitled "Managing Urban Stormwater using Constructed Wetlands" (Wong *et al.*, 1998), which sold hundreds of copies, and had over 800 people attend the industry seminars for its launch. Ongoing developments of these guidelines have been published through a number of avenues, including the Australian Runoff Guidelines published by Engineers Australia (Wong *et al.*, 2003).

MUSIC and its underpinnings: Much of the focus of the Urban Stormwater Quality Program has been to develop a user-friendly tool which captured the latest scientific understanding of stormwater pollutant generation and treatment. Out of this strategy was born MUSIC, the Model for Urban Stormwater Improvement Conceptualisation (Wong *et al.*, 2002). MUSIC is a standard node and link model (Figure 4.3), which incorporates:

- Source nodes (where rainfall-runoff and pollutant generation is simulated)
- Drainage links (where flows and pollutants are conveyed and routed)
- Treatment nodes (where flow and water quality treatment are simulated).

Since its release in 2001, MUSIC has been refined and enhanced. For example, in Version 3, a lifecycle cost module was added (thanks to an associated project led by André Taylor), which allows users to now evaluate the flow, water quality and economic performance of alternative stormwater management strategies.

MUSIC has become the standard tool for stormwater management planning in most of Australia (and is also being used now in New Zealand, Europe and the USA). For example, Melbourne Water requires development proposals to be assessed using MUSIC, and they use it for their drainage scheme planning processes. It is being widely used by engineering consultants, for a wide range of applications, from single-treatment stormwater improvement strategies, to more complex integrated urban water management plans, involving stormwater and wastewater treatment, water harvesting and re-use, and management of groundwater-surface water interactions.

Lynbrook Estate: One of the best demonstrations of our contribution to the development and adoption of Water Sensitive Urban Design (WSUD) came from the PhD of Sara Lloyd, supervised by Tony Wong. Using Lynbrook Estate as a case study, Sara studied the hydrologic, water quality, economic and social consequences of WSUD. Sara's research demonstrated clear reductions in peak flows and in pollutant loads from the implementation of WSUD, at the same time revealing high levels of community receptivity. Lynbrook Estate

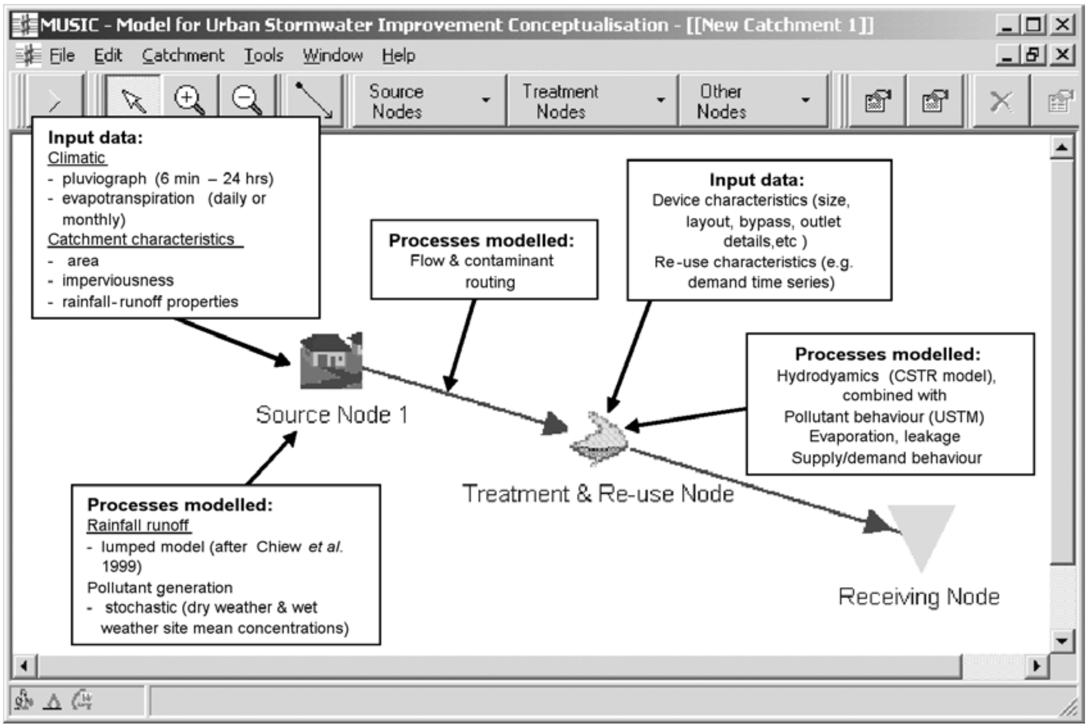

Figure 4.3. MUSIC interface layout, data input requirements, and processes modeled.

became, for a while, Australia's "most visited example" of WSUD, and the partnership between the CRC, Melbourne Water, and the Urban and Regional Land Corporation in the project won the CRC Association's Technology Transfer award. Sara's work was formally recognised again in 2004 when she won the 'Young Water Scientist of the Year Award' for this work.

Guidelines for non-structural management practices: Relative to the research undertaken on structural treatment measures, very little attention has been paid to non-structural measures such as community education, strategic planning and enforcement programmes. Recognising that this imbalance impeded the industry's ability to developed properly integrated management strategies, the CRC undertook an associated project on non-structural measures, developing guidelines for their implementation and monitoring, based on an extensive review of international literature and practices. This information is available through the CRC for Catchment Hydrology website (for example, see Taylor & Wong, 2002a, 2002b at www.crc.catchment.org.au/publications).

Ecological responses to urbanisation and stormwater management: Many (generally unsuccessful) attempts have been made to relate aquatic ecosystem health to indicators of urbanisation. In a collaboration with the CRC for Freshwater Ecology (led by Chris Walsh), some real insights have been made in this area. We have shown that the nature of drainage connection between impervious areas and receiving waters is critical, and that the consequent effective imperviousness (the proportion of a catchment made up of impervious areas which are directly connected, via pipe or similar, to receiving waters) can be reliably used to predict ecosystem health. For example, Figure 4.4 shows a relationship between effective impervious area (EIA) and SIGNAL (an index of macroinvertebrate community composition). Implications of this work have been used to develop new WSUD guidelines and objectives in New South Wales, and are also being considered in Queensland and Victoria.

Lifecycle costing and triple-bottom line assessment: In the pursuit of sustainability, stormwater managers must make decisions about the environmental, economic and social performance of stormwater management strategies. Until recently, MUSIC made a significant contribution to only the first of these areas. However, André Taylor's Associated/Additional Project has been a major step forward. MUSIC Version 3 now includes a lifecycle cost analysis tool, which allows users to predict the capital and operating costs associated with stormwater treatment trains. Coupled with new protocols for "Triple Bottom Line Assessment", stormwater managers now have a much sounder basis on which to make decisions.

Brisbane and Melbourne monitoring programmes: Major contributions to global databases of stormwater quality and treatment have been made through the

NEW TECHNICAL REPORT

Monitoring and Evaluating an Education/Participation Campaign to Reduce Littering and Stormwater Litter Loads in a Small Commercial Shopping District in Melbourne

By

André Taylor
Tim Fletcher
Justin Lewis

Technical Report 05/10

In 2001 the Cooperative Research Centre (CRC) for Catchment Hydrology formed a partnership with the Victorian Environment Protection Authority to undertake research into the use, value, cost and evaluation of non-structural best management practices to improve urban stormwater quality (non-structural BMPs).

This report presents the final evaluation results of one of the projects that was used to trial the monitoring and evaluation guidelines with the assistance of Moreland City Council.

This report is available for downloading as an Adobe Acrobat file from www.catchment.crc.org.au/publications

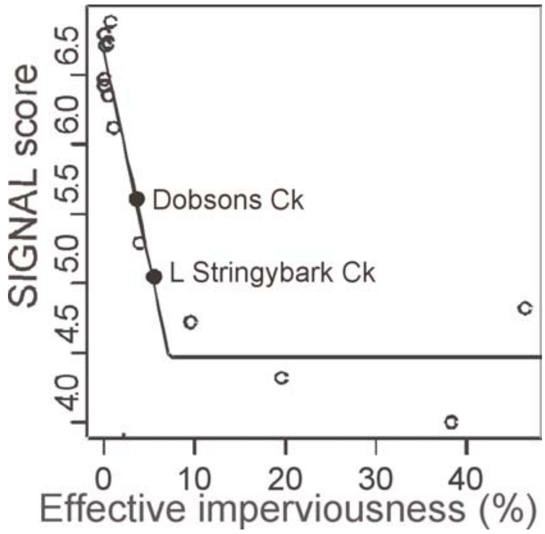

Figure 4.4 Example of relationship between EIA and ecosystem health.

CRC's contribution, including Brisbane City Council's monitoring programmes for stormwater quality and stormwater quality improvement devices. Data collected in Melbourne (through an Associated/Additional Project supported by the Victoria EPA) has been used to develop new pollutant generation models, and is being used in international research collaborations, including contributing to a UNESCO International Hydrologic Program project. Some great research has been undertaken or is being undertaken by PhD students at both Griffith and Monash Universities. Just a few examples include David Newton's work on porous pavements, Courtney Henderson's study of vegetated biofilters, Sara Lloyd's comprehensive study of WSUD, Nick Somes' analysis of constructed wetlands, Matt Francey's work on pollutant generation modelling, and Geoff Taylor's examination of nitrogen behaviour in stormwater runoff and wetlands. Jai Vaze and Muthukumaran Muthukaruppan undertook important studies on pollutant generation and transport, under the supervision of Assoc Prof Francis Chiew.

Key messages

Looking back on our experiences, there are three key messages that emerge from the enormous effort across the seven years:

1. Collaboration has been a key to not only our success, but the recent success and achievement of the Australian stormwater management industry. For example, MUSIC came about as a result of collaboration – right from the first conceptualisation – between researchers and industry. Similarly, the best examples of WSUD in Australia have resulted from collaboration between private developers and regulatory agencies. Our research into the effects of urbanisation on stream ecology came about as a result of excellent collaboration with Chris Walsh's group at CRC for Freshwater Ecology. This collaboration was both scientifically and personally rewarding and augers well for the eWater CRC.
2. Software tools as a mode of delivering research - MUSIC, and its underpinning research has substantially increased the industry's ability to design stormwater management strategies to improve environmental outcomes. The approach to our Program – to first develop a user-friendly tool which then becomes the channel for delivering new research outcomes by the team – has provided us an important template for future research activities. Despite our success to date, much work is still to be done to reduce the uncertainty and assumptions associated with predictions of stormwater quality and treatment performance.
3. Multidisciplinary teams - Stormwater management requires an understanding of hydrology, water quality, ecology, landscape architecture, sociology and institutional capacity and behaviour. Consequently, research teams must be multi-disciplinary. Without this, solutions are likely to be sub-optimal.

Looking to the future

So what's left to do, or can we all retire? Well – there's lots still to do, both in terms of "filling in the detail" and also taking our research into new places. Let me start with the latter. The big goal in our next life, under eWater, will be to improve the integration of all aspects of the urban water cycle. Under the leadership of Grace Mitchell (whose track record in this area is nationally and internationally recognised), we will produce a suite of tools to integrate management of urban water systems. Building on tools developed by the CRC such as MUSIC, Aquacycle, E2 and models of new eWater partners, we will focus on tools which allow multi-criteria analysis, across a wide range of spatial and temporal scales (a big challenge in itself!).

Within this ambitious objective, we still have some significant improvements to our understanding of stormwater systems and impacts to achieve. For example, we hope to turn our new ecosystem understanding into a module in MUSIC that predicts ecological responses to stormwater treatment strategies. We also plan to quantify and reduce uncertainty in MUSIC and its pollutant generation and treatment modules. Through a range of new initiatives, we will also continue to research and develop new technology for stormwater treatment, with a particular focus on stormwater re-use and integration with other components of the urban water cycle.

And finally…

The successes of the Urban Hydrology Program, and the Urban Stormwater Quality Program, are the result of commitment, vision and collaboration of many people associated with the programs. Whilst impossible to mention everyone in this space, I would like to identify a few key people:

Brisbane City Council: Brisbane City Council undertook critical monitoring programs, tailored to the research needs of the Program. André Taylor and Tony Weber, in their past lives, provided great technical input to the Program, and have continued to do so in their new roles (André as a Research Fellow in our Program, and Tony Weber as a consultant with WBM Oceanics, an CRC Industry Affiliate). Brisbane City Council provided great input to MUSIC, and the research underpinning it. In particular, I would like to thank Lucy Peljo, Fiona Chandler, Anne Simi and Jodie Fielding for their collective intellect. Barry Ball provided the essential high level support, right through the duration of the Program, with critical input into strategic directions.

CSIRO Land and Water: John Coleman was chief programmer for MUSIC, and responsible for conceptualising and developing the MUSIC interface, as well as many of its algorithms.

Griffith University: Margaret Greenway led the research team at Griffith University, supervising a number of CRC PhD students, along with Graham Jenkins, who was a key member of the MUSIC development team, particularly in the hydraulic components.

Melbourne Water: Along with Brisbane City Council, Melbourne Water provided both data and expertise to the Program. In particular, Graham Rooney, Matt Francey, Chris Chesterfield and Dale Browne provided ongoing input. Melbourne Water also provided extensive beta-testing of MUSIC. Most importantly of all, Melbourne Water's inkind contribution of Hugh Duncan to the Program was the kindest gift of all! Hugh's in-depth analysis, insight and patience, led to some of the best outputs of the Program (such as his statistical overview of urban stormwater quality).

Monash University: The Program 4 team at Monash displayed an enormous passion for the mission. The vision of MUSIC came from Tony Wong, and his inspirational leadership was instrumental to getting MUSIC off the ground. This was probably the most important single contribution to Program 4's success. The vision was enthusiastically adopted by the MUSIC team, including Rick Wootton. Tracey Walker, Peter Poelsma and Justin Lewis (the "stormchasers") oversaw the field monitoring programs at Monash with obsessive enthusiasm! In recent times, André Taylor led the research into non-structural stormwater management, as well as the development of MUSIC's lifecycle cost module, and triple-bottom-line assessment guidelines. Ana Deletic's arrival heralded an exciting new focus, and she delivered some great research ideas to the Program, with a voracious appetite for developing Associated Additional Projects that contributed valuable components to the "core program". Tony Ladson provided a major contribution to our research into urbanisation effects on aquatic ecosystems, along with Chris Walsh and his team from the CRC for Freshwater Ecology at Monash University. Peter Breen (also CRC Freshwater Ecology at Monash) provided a major contribution to our wetland research.

The University of Melbourne: Tom McMahon and Francis Chiew led the Program's research until 1999, producing and overseeing the tools and information resources that paved the way for the ongoing success of the Program. Their successes included SimHyd (the rainfall-runoff model), along with supervising key PhD studies by Grace Mitchell (the Aquacycle model), Robin Allison (gross pollutant generation and trapping), Jai Vaze and Muthukumaran Muthukaruppan (pollutant generation and transport). More recently, Lionel Siriwardena has skilfully provided the algorithm programming for MUSIC's pollutant generation and treatment modules.

Many other people and agencies have contributed to the success of the Urban Stormwater Quality Program (and its predecessor), and I thank them sincerely. It gives me great pleasure, when I travel around urban centres in Australia, to see the ultimate outcome of our joint efforts – vastly changed practices in the way stormwater is managed – slowly, but surely leading to improved environmental outcomes. That's what it has been all about!

References

Chiew, F. H. S., & McMahon, T. A. (1999). Modelling runoff and diffuse pollution loads in urban areas. Water Science and Technology, 39(12), pp. 241-248.

Duncan, H. P. (1997). Urban Stormwater Treatment by Storage: A Statistical Overview. Melbourne, Australia: Cooperative Research Centre for Catchment Hydrology (Report 97/1).

Taylor, A., & Wong, T. H. F. (2002a). Non-Structural Stormwater Quality Best Management Practices - An Overview (No. Technical Report 02/11). Melbourne, Australia: Cooperative Research Centre for Catchment Hydrology.

NEW TECHNICAL REPORT

Guidelines for Evaluating the Financial, Ecological and Social Aspect of Urban Stormwater Management Measures to Improve Waterway Health

By
André Taylor

Technical Report 05/11

Increasingly, urban stormwater managers in Australia are seeking to make decisions about the use of management measures within the context of the so-called 'triple-bottom-line'. That is, such decisions consider the potential financial, social and ecological impacts.

These guidelines, supported by the new life cycle costing module in MUSIC should substantially assist urban stormwater managers to make more structured, informed, rigorous, participatory, transparent, defendable, socially acceptable, ecologically sustainable and more cost-effective decisions.

This report is available for downloading as an Adobe Acrobat file from www.catchment.crc.org.au/publications

Taylor, A., & Wong, T. H. F. (2002b). Non-Structural Stormwater Quality Best Management Practices - Guidelines (No. Technical Report 03/14). Melbourne, Australia: Cooperative Research Centre for Catchment Hydrology.

Wong, T. H. F., Breen, P. F., & Lawrence, I. (2003). Constructed wetlands and ponds. In T. H. F. Wong (Ed.), Australian Runoff Quality. Sydney, Australia: Institution of Engineers, Australia.

Wong, T. H. F., Breen, P. F., Somes, L. G., & Lloyd, S. D. (1998). Managing Urban Stormwater using Constructed Wetlands (Industry Report No. 98/7). Melbourne: Cooperative Research Centre for Catchment Hydrology.

Wong, T. H. F., Fletcher, T. D., Duncan, H. P., Coleman, J. R., & Jenkins, G. A. (2002). A model for urban stormwater improvement conceptualisation. Paper presented at the 9th International Conference on Urban Drainage, Portland, Oregon, pp. 16.

Tim Fletcher
Tel: (03) 9905 2599
Email: tim.fletcher@eng.monash.edu.au

PROGRAM 5

CLIMATE VARIABILITY

Program Leader
FRANCIS CHIEW

Report by Francis Chiew, Tom McMahon, Erwin Weinmann

CRC for Catchment Hydrology mission and the Climate Variability Program

Program goal

The mission of the CRC for Catchment Hydrology 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. The goal of the Climate Variability Program is to improve our ability to quantify climate variability, by developing knowledge and tools that can be used to quantify uncertainty in environmental systems associated with climate variability. Various models and datasets developed in the Climate Variability Program have been converted into toolkit in the CRC's Catchment Modelling Toolkit.

Climate and streamflow challenges

Climate is always changing on a variety of time scales (seasonal, inter-annual, 3-7 year El Niño/Southern Oscillation, inter-decadal and "climate change") (See Figure 5.1). Hydroclimatic variability presents various challenges and opportunities to the management of land and water resources. The management challenges in Australia are compounded by Australian streamflow (and to a lesser extent climate) being more variable than elsewhere in the world, resulting in Australian droughts and floods being more severe than elsewhere in the world. On the other hand, the hydroclimate-ENSO relationship in Australia is amongst the strongest in the world and can be exploited to forecast hydroclimate variables several months in advance. The seasonal hydroclimate forecast can be used to help make better operational land and water resources management decisions.

Development of Program with collaboration

Research in the Climate Variability Program started in the initial CRC with a focus on floods. In the current CRC, the emphasis has been on modelling and forecasting rainfall and streamflow from several hours to several months ahead, on stochastic climate data generation models, and lately, on converting key research outcomes into products for the Catchment Modelling Toolkit.

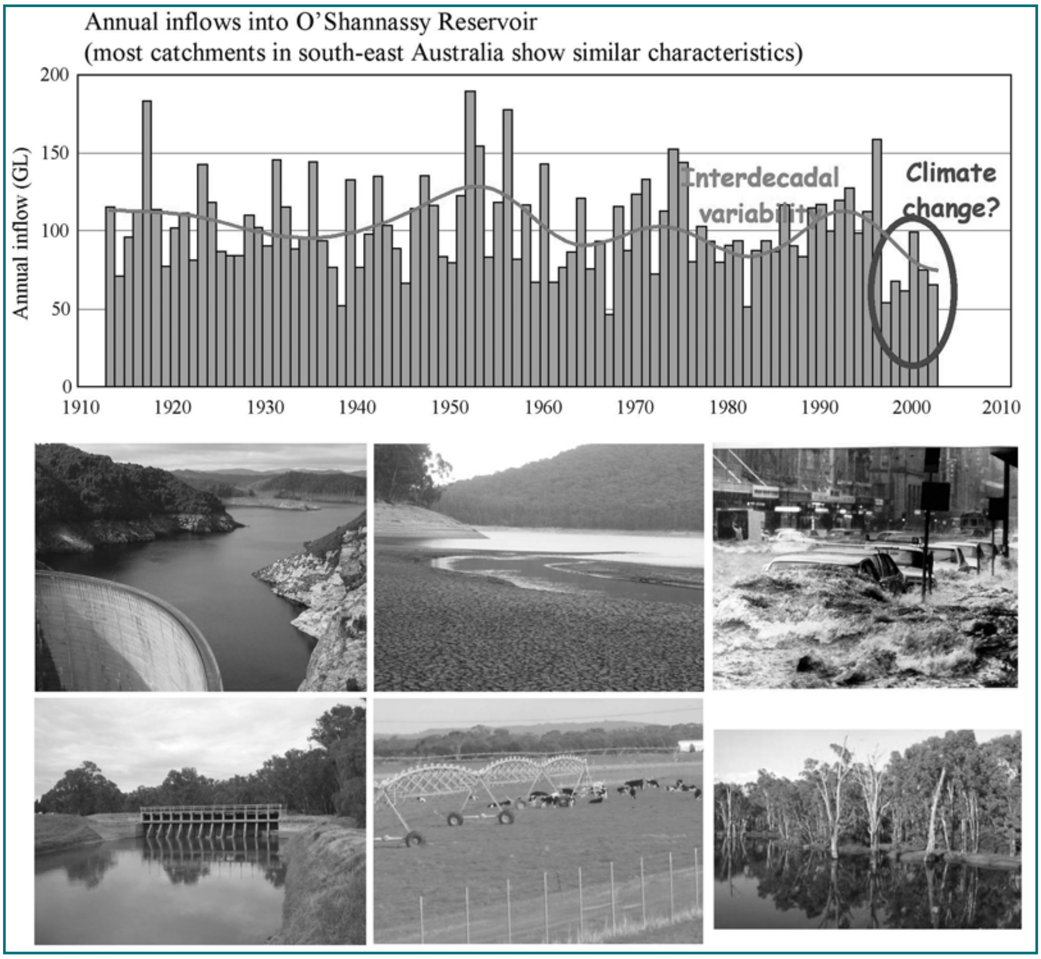

Figure 5.1 Hydroclimatic variability and land and water resources management

Most of the research studies have been carried out in collaboration with research groups in Australia and overseas, including the University of Melbourne, Bureau of Meteorology, CSIRO Land and Water, University of Newcastle, University of KwaZulu-Natal (South Africa), University of California (Los Angeles and Berkeley, USA) and the United Kingdom Meteorological Office.

Floods – Background

It is easy to forget floods in a time of drought, but floods pose a substantial risk to many Australian communities. It is estimated that Australia spends more than half a billion dollars annually on works requiring an estimate of design flood. Flood Hydrology was one of four core research programs in the initial term of the CRC (1992-1999). The goal of the program was to improve hydrologic theory so that its application will produce more reliable design flood estimates and real-time flood forecasts for practitioners.

Flood research outcomes

The six years of research led to quantum changes in Australian flood estimation methodologies and significantly improved guidance to practitioners. Some of the key outcomes from the Flood Hydrology research program include:

- new methods to derive rainfall losses for design flood estimation and to predict loss values for ungauged catchments;
- new regional approaches to flood frequency analysis and baseflow;
- a holistic approach to design flood estimation that takes into account the joint probabilities of component processes;
- the CRC-FORGE method for estimating design rainfall for extreme events (the method has been adopted by five Australian states to develop design rainfall databases); and
- the space-time rainfall model MOTIVATE that provides stochastic realisations of design storms.

Some of these research outcomes (CRC-FORGE method, areal reduction factors and loss modelling) have already been incorporated into revised sections of "Australian Rainfall and Runoff" (standard reference for Australian flood estimation practice), while others are forming important inputs to the current revision process of the Australian guidelines for design flood estimation. The MOTIVATE model has been used by Melbourne Water

NEW TECHNICAL REPORT

Stochastic Generation of Daily Rainfall at a Number of Sites

By

Ratnasingham Srikanthan

Technical Report 05/7

This report describes the development and testing of a multi-site daily rainfall model (multi-site two-part model nested in a monthly and annual model).

The model can be used to generate stochastic daily rainfall data for many sites (or catchments) that preserve the statistical characteristics at each site as well as the rainfall correlations between sites.

The stochastic daily rainfall data can then be used to drive hydrological and system models to quantify the uncertainty in environmental systems associated with hydroclimatic variability. The two-part model is a model in SCL at www.toolkit.net.au

This report is available for downloading as an Adobe Acrobat file from www.catchment.crc.org.au/publications

eWater CRC STARTS SEPTEMBER 2005 – FRESHWATER ECOLOGY AND CATCHMENT HYDROLOGY CRCs COME TO A CLOSE

From September 2005, the eWater Cooperative Research Centre incorporates new participant organisations as well as those from the successful CRC for Catchment Hydrology and CRC for Freshwater Ecology. It combines the two water CRC's and the new participants' partnerships, skill bases, end-user networks, intellectual property and business systems.

eWater is a partnership between private and public water businesses and research groups across eastern Australia and seeks to produce practical products that bring economic, commercial and environmental benefits from the smart management of water.

Visit www.ewatercrc.com.au

and Sydney Water to assess the reliability of their sewerage system and stormwater networks under a range of rainfall scenarios.

Hydroclimate forecasting

A major focus of the Climate Variability Program in the current term of the CRC (1999-2005) is to improve methods for forecasting rainfall and streamflow, from several hours to several months ahead.

The short-term rainfall nowcasting (forecasting one to two hours ahead) builds on the MOTIVATE model and significant advances in the use of radar rainfall measurements. The short-term stochastic rainfall forecasts are derived by advecting spatial (radar) rainfall forward in time. To extend the rainfall forecast to longer lead times, the CRC and the Bureau of Meteorology are currently developing methods to condition the rainfall forecasts to longer lead time deterministic rainfall forecasts (six hours or more) from numerical weather prediction models. A prototype of the model, called STEPS (Short Term Ensemble Prediction System), has been included in Rainfields, the Bureau of Meteorology system for operational real-time radar rainfall estimation and forecasting.

Numerical Weather prediction models

National weather agencies in most developed countries, including the Australian Bureau of Meteorology, run numerical weather prediction models to forecast climate variables out to seven days or more. Numerical weather prediction models are complex models made up of atmospheric, ocean and land-surface models. The land-surface modelling and the initialisation of surface variables, in particular soil moisture, significantly affect the quality of weather forecasts. Research in the Climate Variability Program has led to improvements in the land-surface modelling (model parameterisation, runoff and soil moisture simulation and flow algorithms) and better understanding of the impact of soil moisture initialisation on weather forecasts (initialisation methods, impacts of irrigation and impact of initialisation on rainfall and PET forecasts).

As part of this research, an extensive soil moisture monitoring network was established across the Murrumbidgee River Basin. This is part of the Murray-Darling Basin Continental Scale Experiment (MDB CSE) in GEWEX (Global Energy and Water Cycle Experiment), and the datasets compiled have also been used in various international studies. Research in this area has also led to a database of Soil Hydrological Properties of Australia (SHPA) and a database of Landcover for Intensive Land Use of Australia (LIZA) in the Catchment Modelling Toolkit, and parameter sets and calibration methods for application of hydrological models on ungauged catchments, which have been used in the CRC's development projects and elsewhere.

Longer-term forecasts

For longer-term forecasts, the Climate Variability Program has developed a Nonparametric Seasonal Forecasting Model (NSFM), which is also a product in the Catchment Modelling Toolkit. NSFM forecasts continuous exceedance probabilities of streamflow (or any other hydroclimate variable) several months ahead by exploiting the lag relationship between streamflow and El Niño/Southern Oscillation and the serial correlation in streamflow. The probabilistic streamflow

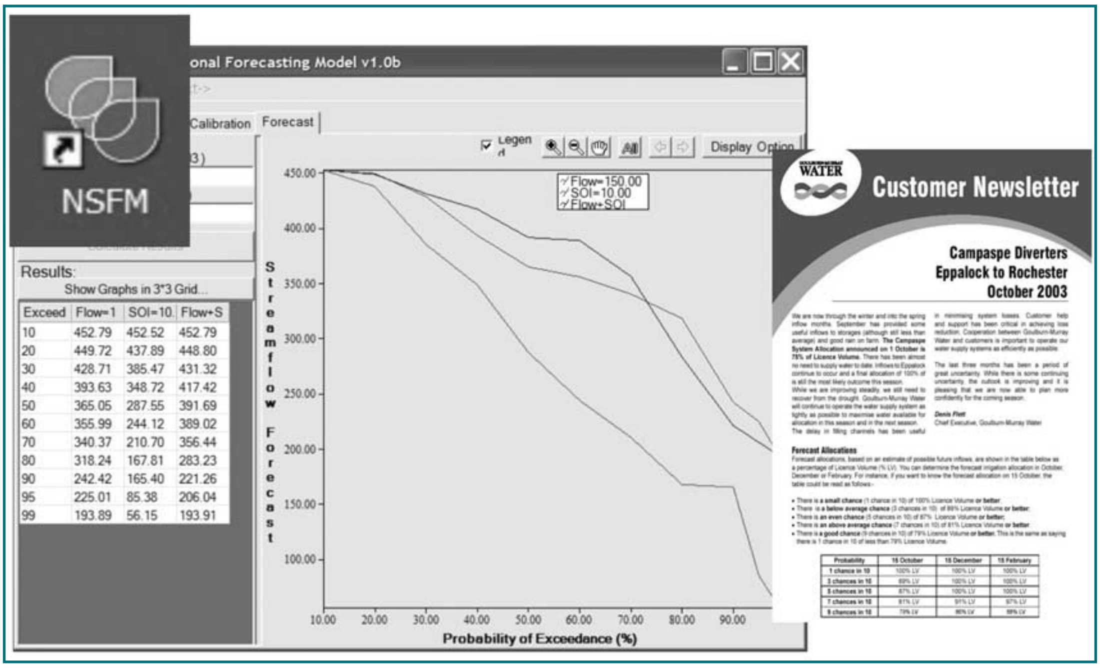

Figure 5.2 Using seasonal streamflow forecast to provide probabilistic indication of future water allocation

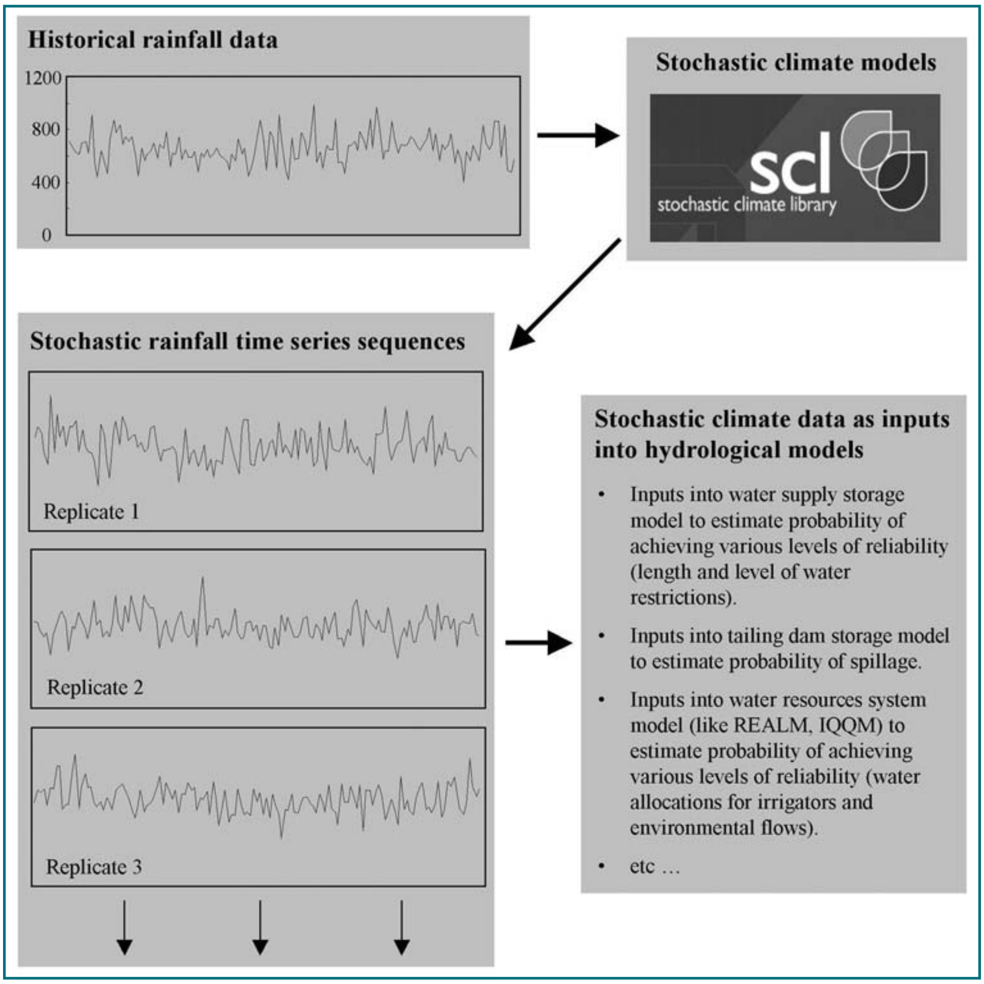

Figure 5.3 Using stochastic climate data as inputs into hydrological and ecological models to quantify uncertainty in environmental systems associated with climatic variability

forecasts can be used to provide probabilistic indication of future water allocation or water availability (some agencies such as Goulburn-Murray Water provide this information – see Figure 5.2), to make better informed risk-based decisions for farm and crop management, and to make better operational decisions on management of storage systems and water allocation for competing users.

Stochastic climate data – Background

Another key focus of the Climate Variability Program was to develop and test stochastic climate data generation models. Climate is the key driver of hydrological and environmental models. The use of historical climate data as inputs into these models provides results that are based on only one realisation of the past climate. Stochastic climate data provide alternative realisations that are equally likely to have occurred, and can therefore be used with hydrological and ecological models to quantify uncertainty in environmental systems associated with climate variability (see Figure 5.3). As an example, many replicates (say 1,000) of stochastic climate data can be used as inputs to drive water resources models (such as IQQM or REALM) to estimate system reliability for alternative allocation rules and management practices (here, the tenth worst results in the 1,000 simulations have a 1% chance of occurring).

Library of stochastic models

Research in the Climate Variability Program, in collaboration with others, has led to the development of the software, SCL, in the Catchment Modelling Toolkit. SCL (Stochastic Climate Library) is a library of robust stochastic climate data generation models, which have been tested extensively using data across Australia. SCL is relatively easy to use and is designed for hydrologists, environmental scientists, modellers, consultants and researchers to facilitate the generation of stochastic climate data. The current version of SCL (Version 2.0) has stochastic models for generating: annual, monthly, daily and sub-daily rainfall at a single site; annual, monthly and daily cross-correlated climate variables at a single site; and cross-correlated daily rainfall at multi sites.

Next challenges – climate change

The biggest climate issue at present relating to water management is climate change. This is because the potential impacts of climate change on environmental systems may require a significant planning response. The news is not good for Australia, as most models estimate that southern Australia in a greenhouse-enhanced climate will be drier, but with more intense rainfall events. The drier conditions translate to less water for competing users and the more intense rainfall and runoff events will exacerbate floods and water quality problems. However, there are large uncertainties in climate change projections, although they will reduce over time as research leads to better understanding and modelling of the climate system.

Reducing uncertainty

An important aspect of reducing this uncertainty is our ability to differentiate more clearly between climate variability and climate change. As an example, this would allow us to put the present drought in the context of inter-decadal climate variability, and take this into account in management decisions. Rainfall and streamflow data over the last 100 years show persistent periods of dry conditions lasting one or two decades followed by wet conditions. It is foreseeable that research on climate processes, climate modelling and time series analysis of climate data will lead to methods for estimating future climate that take into account climate variability resulting from both the natural oscillations in the global atmosphere-ocean system as well as global warming caused by anthropogenic enhancement of greenhouse gas concentrations.

Given the present state of science, resource managers need to appreciate the large uncertainties in climate projections and take them into account in making strategic decisions. Stakeholders need to identify system sensitivity to changes in climate, as well as thresholds in processes and cost of adaptation measures. After all, climate is always changing on a variety of time scales and being prepared for the consequences of this variability is a wise policy.

Areas for research

Some of the key areas for research on hydrologic sensitivity to changing climate include developing simple and reliable rule-of-thumb methods for quantifying hydrologic sensitivity to climate conditions, consistent modelling approaches that also take into account feedbacks between the atmosphere and land surface, and methods for converting large-scale rainfall and other climate variables from global climate models to the catchment-scale for input into hydrological models that take into account the range of uncertainties.

Impacts on water operations

From an operational perspective, recent developments in climate forecasting methods will start to significantly improve water management. On the very short time scale, forecasts of radar rainfall will significantly improve flood forecasting. On the medium time scale, improved weather forecasts out to four to seven days can be used to guide crop watering and irrigation scheduling. On the longer time scale, seasonal forecasts of hydroclimate variables (rainfall, reservoir inflows, soil moisture) several months ahead will be used to make better operational decisions on management of storage systems and water allocation for competing users, or to project droughts.

Thanks

We would like to sincerely thank the many people who have contributed to the success of the Climate Variability program and the extent to which it has influenced practice in Australia. These include researchers (in the CRC and elsewhere), software developers and practitioners in government agencies and consultancies.

The process of improving knowledge in climate variability, translating knowledge into tools that can be easily used and testing and adoption of tools by the industry was only possible through the cooperation and sharing of information, and the goodwill and passion in delivering outcomes and products that truly benefits the land and water industry.

Francis Chiew
Tel: (03) 8344 6644
Email: fhsc@unimelb.edu.au

Tom McMahon
Tel: (03) 8344 6641
Email: thomasam@unimelb.edu.au

Erwin Weinmann
Tel: (03) 9905 4979
Email: erwin.weinmann@eng.monash.edu.au

PROGRAM 6

RIVER RESTORATION

Program Leader

MIKE STEWARDSON

Report by Mike Stewardson

Six Years of the River Restoration Program

Introduction – growing awareness and investment

When the current CRC started in 1999, river restoration was a relatively minor activity for natural resources managers in Australia. There were plenty of plans for environmental flows, but very few had been implemented. Most riparian restoration was small-scale and often regarded as experimental. In-channel works were mostly intended to stabilise channels rather than achieve ecological outcomes. Since then, investment in planning and implementing environmental restoration has substantially increased. We now plan restoration at the catchment scale and the amount of money being invested is expected to improve health across landscapes.

To illustrate the scale of restoration activity currently being undertaken in Australia, we estimate that the Victoria Government alone plans to spend more than $600m on river restoration over the next five years. This includes $340m to deliver a total of 320 Gl/year in environmental flows through water recovery schemes. A similar amount is to support other river restoration measures outlined in Regional River Health strategies. Based on a sample of River Health Strategies provided by Victoria's CMAs, it seems that these funds will be spent on water quality improvement (33%), riparian restoration (32%), managing flow regimes in wetlands (15%), channel stabilisation (10%), modifying instream habitat condition including reinstatement of logs (6%), carp control (3%) and removal of fish barriers (1%). Similar levels of investments are occurring in all States around Australia.

In the following section we briefly describe some of what the CRC for Catchment Hydrology has contributed that will influence major restoration efforts planned for Australian rivers over the coming decade. Our major contribution is a set of hydro-geomorphic response models, which can be used to evaluate restoration plans both at the reach and catchment scale.

Response models for planning restoration – Environmental flows

Environmental flow studies are normally based on a conceptual model of the ecological response to flow regimes such as:

- "River blackfish spawn between November and January and the fry are ready to disperse and feed after a few weeks. The provision of freshes (or flow pulses) during the low flow period is required for the fry to disperse between pools."
- "The quality of water in pools is important to their value as a refuge habitat for macroinvertebrate production and fish survival. Sustained low flows can lead to pool stratification and degraded water quality."
- "The inundation of in-channel benches in winter and spring supports the seasonal growth of aquatic macrophytes and other riparian plants."

Usually, several of these models are applied in each environmental flow investigation. The CRC has developed a procedure for quantifying the aspects of the flow regime relevant to each conceptual response model called "The Flow Events Method" (Stewardson and Gippel, 2003). This method can be implemented using the Catchment Modelling Toolkit software product RAP (River Analysis Package – www.toolkit.net.au/rap) which has been developed under the leadership of Nick Marsh.

Ecological response models

Using the Flow Events Method, it is possible to express the conceptual response model in a quantitative form. This quantitative model is documented using a database we have developed as part of RAP, called the "Ecological Response Models library". Models within the library can be created, stored, applied to alternate sites or flow scenarios, and modified or communicated without ambiguity. This ensures consistency in the analysis of flow regimes in subsequent environmental flow studies, water resource assessment and when optimising river operation to meet environmental flow targets.

RAP predicts habitat changes for any Ecological Response Model that is available in the ERM library. For input, RAP requires (1) data characterising the channel hydraulics and (2) a daily flow series. These input data can be generated in a variety of ways. For example, the flow series may be generated by the E2 model for different upstream land-use scenarios or by a water allocation model such as IQQM for different flow management scenarios. The channel hydraulic information is normally generated using HECRAS, a freely available one-dimensional hydraulic model produced by the US Army Corp of Engineers and widely applied in Australia. We have collated RAP hydraulic input files for 114 reaches in Victoria which will soon be added as a data product on the Toolkit website.

ENVIRONMENTAL FLOW ANALYSIS

By

Mike Stewardson

Technical Report 05/13

The report captures lessons learnt through more than a decade of involvement in the hydrological aspects of environmental flow projects. There are an increasing number of hydrologists involved with environmental flow studies in Australia but few practical references to draw from. This report is intended to address this need. Rather than deal with ecological issues in detail, it focuses on the hydrological and hydraulic methods.

This report is available for downloading as an Adobe Acrobat file from www.catchment.crc.org.au/publications

eWater CRC STARTS SEPTEMBER 2005 – FRESHWATER ECOLOGY AND CATCHMENT HYDROLOGY CRCs COME TO A CLOSE

From September 2005, the eWater Cooperative Research Centre incorporates new participant organisations as well as those from the successful CRC for Catchment Hydrology and CRC for Freshwater Ecology. It combines the two water CRC's and the new participants' partnerships, skill bases, end-user networks, intellectual property and business systems.

eWater is a partnership between private and public water businesses and research groups across eastern Australia and seeks to produce practical products that bring economic, commercial and environmental benefits from the smart management of water.

Visit www.ewatercrc.com.au

Water system operations

Once environmental flow targets have been established for a river, operation of the water system would normally need to be modified to achieve these targets. In some cases, this may be a trivial task requiring little or no analysis. However in other cases, analytical techniques are required to optimise environmental operation of the water system, particularly where (1) unregulated tributary inflows can contribute to meeting targets or (2) a single release can contribute to targets at more than one downstream reach. In a case study of the Thomson River in Victoria, optimisation dramatically reduces the additional volume of water released from the Thomson Dam to meet downstream environmental flow targets (Harman and Stewardson 2005). There is considerable need for further development of techniques for optimising water resource system for both environmental and consumptive use outcomes. However, optimisation requires clear flow targets which may be specified using the Ecological Response Model libraries available with the latest version of RAP.

Riparian restoration – Revegetation project

In 2000 Nick Marsh commenced an experimental program of riparian restoration in the 1.5 km^2 catchment of Echidna Creek near Nabour in Southeast Queensland (Figure 6.1). The project ran in collaboration with (The Moreton Bay Waterways and Catchment Partnership's Healthy Waterways Program and CRC for Freshwater Ecology. The project monitored responses in channel morphology, suspended sediment load (Marsh *et al.* 2004), water temperature (Marsh *et al.* 2005) and aquatic macrophyte growth (Mackay and Marsh 2005).

It is widely expected that riparian revegetation will reduce suspended sediment loads, and control nuisance macrophyte growth. However, monitoring in Echidna Creek showed that things aren't quite that simple. Following restoration, sediment loads increased by around 100% due to disturbance of bank material and clearing of riparian weeds, and whilst shading led to a reduced distribution of some nuisance macrophytes, there is concern that these are replaced by shade-tolerant species.

An important message from this project is that stream managers should be mindful of an initial increase in sediment yield following riparian restoration. In the long-term we expect this would return to pre-restoration sediment yields or lower. Stream temperature responded in a predictable fashion to changes in canopy cover, reducing as the canopy developed.

Riparian impacts on floods

CRC Postgraduate student Brett Anderson considered the effects of riparian restoration on floods. Vegetation can increase local roughness and hence river height for a given discharge. However, at the channel network

Figure 6.1: Two experimental sites before and after restoration

scale, the effect is to slow floods and attenuate their peak magnitude. Using a model of the Murrumbidgee Catchment, Brett evaluated the combined effect on flood levels. He found that the cross-sectional effect dominates in the upper portion of the catchment but further downstream the net effect of revegetation is a reduction of peak flood levels. Brett was a Young Water Scientist of the Year finalist and presented this work at the River Symposium in Brisbane in September.

Other restoration measures

In other projects we considered various river responses to introduction of logs, channel stabilisation works and fishways. In partnership with CRC for Freshwater Ecology, Ian Rutherfurd and Dan Borg monitored pool development at artificial logs, introduced by the Goulburn Broken CMA along two sand-bed rivers in north-east Victoria (Castle and Creightons Creeks). Scour depths generally increased at the logs but the response was highly variable through time. Bob Keller and Frank Winston developed new versions of CHUTE and RIPRAP programs for designing bed and bank stabilisation works, widely used by river engineers. In his PhD, Lindsay White evaluated the performance of fishways on the Murray and developed our basic understanding of the swimming capabilities of fish.

Response modelling at catchment scales

The focus of the River Restoration Program in the first three years was on reach-scale activities. More recently we have begun to consider how we might model response to riparian restoration planning at the catchment scale. This work is planned to continue in the eWater CRC but we have already made some progress.

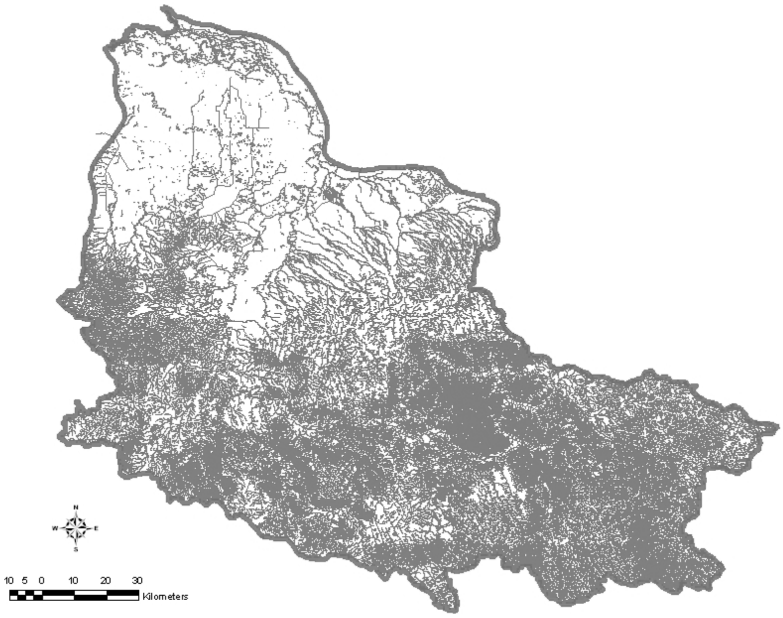

Figure 6.2: River network in the Goulburn-Broken Basin, Victoria showing (a) all waterways marked on the 1:25,000 topographic maps and (b) rivers with catchment area greater than 100 km^2.

NEW TECHNICAL REPORT

Regional Models of Stream Channel Metrics

By

Michael Stewardson
Ron DeRose
Ciaran Harman

Technical Report 05/16

This report describes the development of empirical equations to estimate hydraulic geometry metrics throughout river networks based on a large set of river surveys in Victoria.

Data sets used in this study are available at www.toolkit.net.au.

This report is available for downloading as an Adobe Acrobat file from www.catchment.crc.org.au/publications

Ron DeRose has collated a large database of hydrological properties for rivers throughout Victoria (soon to be released as a data product on the Toolkit website). In total, Ron has derived 38 hydrological attributes for 43,000 river reaches. This includes all Victorian rivers with a catchment area greater than 2 km^2. Attributes include flow statistics, reach slope, climate characteristics, catchment size and topography, river planform and catchment tree cover. We hope this database will be extended to other parts of Australia in the future.

Using these data and 114 channel surveys, Ciaran Harman, Ron DeRose and Mike Stewardson have developed empirical models relating channel metrics to catchment characteristics. At this stage it is possible to model bankfull width and depth, bankfull discharge and at-a-station hydraulic geometry throughout river networks. These metrics are needed for many river network models including E2 and SEDNET for flow routing, modelling sediment budgets and habitat assessment.

Future research to support river restoration

Most river restoration is focussed on achieving outcomes in relatively large rivers. For example, in Victoria (and elsewhere) monitoring to support river restoration planning is almost entirely limited to rivers with catchment areas greater than 100 km^2. A real challenge for river science and management is dealing with all the other river channels and their floodplains - in particular the massive length of small rivers with largely rural catchments and the anabranch and effluent channels which are a largely neglected part of the river network. Figure 6.2 illustrates this challenge by comparing the river network in the Goulburn Basin, Victoria drawn on the 1:25,000 topographic maps which has a total stream length of 41,000 km compared with those rivers with catchment area greater than 100 km^2 which has a total stream length of 1,700 km.

Catchment restoration

If we are genuinely concerned with catchment restoration, we need methods to address environmental values for the full range of river sizes and types. This will require (1) a better understanding of processes controlling river health in small rivers and anabranches (mostly ephemeral systems), (2) building our knowledge of the biological and physical connections between different parts of river network and (3) data sets and models to support planning at whole-of-network scales.

Long-term responses

We invest in river restoration to achieve long-term benefits for society. However, our understanding of longer-term responses is particularly limited. Generally we can not wait for a ten-year experimental program, and long-term environmental data sets for rivers are scarce (except streamflow records). We need to push our research towards understanding long-term responses to catchment interventions. This is a difficult area of research because of the lack of long-term data and our inability to carry out manipulative experiments. To indicate the scale of the challenge we might make a comparison with the massive research effort required to understand the relatively simple long-term effects of logging on yield from Melbourne's water supply catchments. This was a large research effort sustained for several decades. The challenge of understanding the long-term ecological effects of restoring riparian zones throughout a stream network is substantially more complex. However, this is a critical challenge if we are to plan sustainable restoration interventions. New approaches to our research are required which consider the longer-term hydrological and geomorphic effects of interventions and consequences for aquatic vegetation and fauna.

The future – some conclusions

There are three things we can say for sure about future river restoration:

- response models will always have substantial uncertainty,
- data sets will never be sufficient to fully test our models and
- decisions will continue to be made.

River restoration modelling and monitoring are the key elements of a nation-wide efforts to understand the behavior of river systems. In the past, we have treated these two activities separately. Models have been built by researchers or consultants to inform a decision. Monitoring plans have been subsequently developed by a different team with little thought to how they might improve model predictions or system understanding. A major challenge for river health practitioners (and all in the broader national resource management industry) is to integrate modelling and monitoring into a single activity optimised to support risk-based approaches. Monitoring should be targeted at those components of our models that are poorly understood but have a big influence on decisions. Our models should provide some indication of uncertainty in river responses to guide monitoring programs. Managers and the communities involved with restoration projects need tools to understand models and deal with uncertainty.

Some acknowledgements

Ian Rutherfurd led the River Restoration Program for its first three years. I took over in mid 2002 after Ian had

established substantial momentum in the program and a strong team. Numerous PhD students have been the Program's intellectual power-house. I thank all the Project Leaders: Bob Keller, Tony Ladson, Stuart Bunn, Nick Marsh and Ian Rutherfurd for their hard work, commitment, support and good company.

Nick Marsh has made a big contribution to river restoration in Australia by leading development of the River Analysis Package. He also led the Program for six months in 2004. Numerous other researchers contributed in various ways to the Program. Most recently, Ron DeRose, Ciaran Harman and Sylvain Arene have worked hard to bring the projects to a successful completion.

On behalf of the River Restoration Program I would like to thank the CRC Board and the organisations they represent for supporting this substantial research program.

References

Harman, C and M Stewardson (2005) Optimising Dam Release Rules to Meet Environmental Flow Targets, River Research and Applications 21:113-129.

Mackay S and N Marsh (2005) The response of aquatic macrophytes to riparian shading in a stream rehabilitation site? Technical Report 05/5, CRC Catchment Hydrology.

Marsh N, I Rutherfurd and S Bunn (2004) How does riparian revegetation affect suspended sediment in a southeast Queensland stream? Technical Report 04/13, CRC Catchment Hydrology.

Marsh N, I Rutherfurd and S Bunn (2005) The role of riparian vegetation in controlling stream temperature in a Queensland stream Technical Report 05/3, CRC Catchment Hydrology.

Stewardson, M and C Gippel (2003). Incorporating Flow Variability into Environmental Flow Regimes using the Flow Events Method. River Research and Applications 19:459-472

Mike Stewardson
Tel: (03) 8344 9155
Email: mjstew@unimelb.edu.au

NEW TECHNICAL REPORT

The Response of Aquatic Macrophytes to Riparian Shading in a Stream Rehabilitation Site

By

Stephen Mackay
Nick Marsh

Technical Report 05/5

The Cooperative Research Centre (CRC) for Catchment Hydrology conducted a project (2000-2003) in collaboration with the CRC for Freshwater Ecology and the Moreton Bay and Catchments Healthy Waterways Partnership to assess the impact of stream rehabilitation on a few key elements of stream health.

The results of the response of aquatic macrophyte growth to revegetation are presented in this report.

This report is available for downloading as an Adobe Acrobat file from www.catchment.crc.org.au/ publications

eWater CRC STARTS SEPTEMBER 2005 – FRESHWATER ECOLOGY AND CATCHMENT HYDROLOGY CRCs COME TO A CLOSE

From September 2005, the eWater Cooperative Research Centre incorporates new participant organisations as well as those from the successful CRC for Catchment Hydrology and CRC for Freshwater Ecology. It combines the two water CRC's and the new participants' partnerships, skill bases, end-user networks, intellectual property and business systems.

eWater is a partnership between private and public water businesses and research groups across eastern Australia and seeks to produce practical products that bring economic, commercial and environmental benefits from the smart management of water.

Visit www.ewatercrc.com.au

COMMUNICATION & ADOPTION PROGRAM

Program Leader DAVID PERRY

The Flow on Effect – Final Edition 2005

At a glance – a summary of this article

This article offers an overview of the CRC for Catchment Hydrology programs that supported the delivery and application of the CRC's research from 1992-2005. The author would like to thank all those individuals who contributed to the success of these programs and the CRC.

A personal perspective on the Communication and Adoption, and Education and Training Programs (1992-2005)

Requirement for technology transfer

One of the consistent requirements of Commonwealth's CRC funding agreements for Cooperative Research Centres has been the establishment of two key support programs, a Technology Transfer Program and an Education and Training Program. Prior to 1996, John Molloy and Russell Mein were key drivers of these programs. Thanks to Russell and John's work in the early years, the CRC quickly began to establish a culture of communication with industry. Most importantly, the CRC focussed on researching national land and water priority issues and engaging relevant industry organisations throughout the life of each CRC project. Results were communicated through the CRC Technical Report series and regular Technical Seminars, many of which were captured on video for distribution and sale.

Early approach

During 1996 Ray Leivers from the (then) Victorian Department of Natural Resources and Environment was seconded to the new position of Technology Transfer Coordinator. Ray continued to strengthen the culture through a series of planning and delivery activities that encouraged and supported project teams in developing an industry perspective for delivering research outcomes. This culture of 'delivery to industry' was cemented in 1997 by the Board's direction to introduce a target of 25% of total CRC expenditure towards technology transfer. Driven by strong commitment from project staff, and support from the Board and Executive, the CRC was already well regarded within the industry by the time I arrived as Technology Transfer Coordinator in May 1997. A couple of outstanding examples that demonstrate the CRC's early approach are:

- The CRC publication 'Hydrological Recipes – Estimation Techniques in Australian Hydrology' by Grayson et.al. was published in 1997 and provided a range of quick estimation techniques identified by researchers and industry. Within nine months of publication, over 520 copies had been sold.
- The CRC-Forge Method for Extreme Rainfall estimations addressed high uncertainties in extreme flood estimation and supported the revision of industry standard guidelines. Since its completion in Victoria, the CRC-Forge methodology has been implemented in Victoria, Tasmania, New South Wales, Queensland, South Australia and Western Australia. Years after the research project was completed, Project Leader Erwin Weinmann continues to assist the application of this research across the country. A benefit cost analysis by independent consultants ACIL later revealed a benefit-cost ratio of 4.9 based on its contribution to dam spillway upgrades alone.

Industry Reports and Industry Seminars

During the last three years of the initial CRC (1997-1999), the industry report and industry seminar series was developed and became an important vehicle for the delivery of CRC research outcomes to industry. The report series was designed to provide agencies and consultants in the Australian land- and water-use industry with improved ways of managing catchments. The reports were written in plain English and featured many diagrams and explanatory text to assist the reader in understanding and applying the research. They were written starting with a broad overview of the issue and then developed the reader's understanding progressively throughout the document. Ten of these industry reports covering a wide range of issues were published with an eleventh entitled "Afforestation in a Catchment Context – Understanding the Impacts on Water Yield and Salinity' due for publication during September 2005. In all, over 6000 printed copies of these reports have been distributed throughout the land and water management industry. Their success has seen other organisations adopt a similar approach.

The industry seminar series was designed to support the industry report series by offering participants a range of research and industry perspectives on the information documented by the reports. For example, industry seminars on 'Managing Urban Stormwater using Constructed Wetlands' to support the report of the same name were held in each Australian mainland capital except Darwin with over 800 participants attending. This report was a CRC for Catchment Hydrology and CRC for Freshwater Ecology collaboration and the seminar included speakers from both CRCs as well as industry presenters. The report sold over 1300 copies with a second edition published after twelve months, a good indicator of its value to industry practitioners. All of our industry reports can still be found on the CRC website at www.catchment.crc.org.au

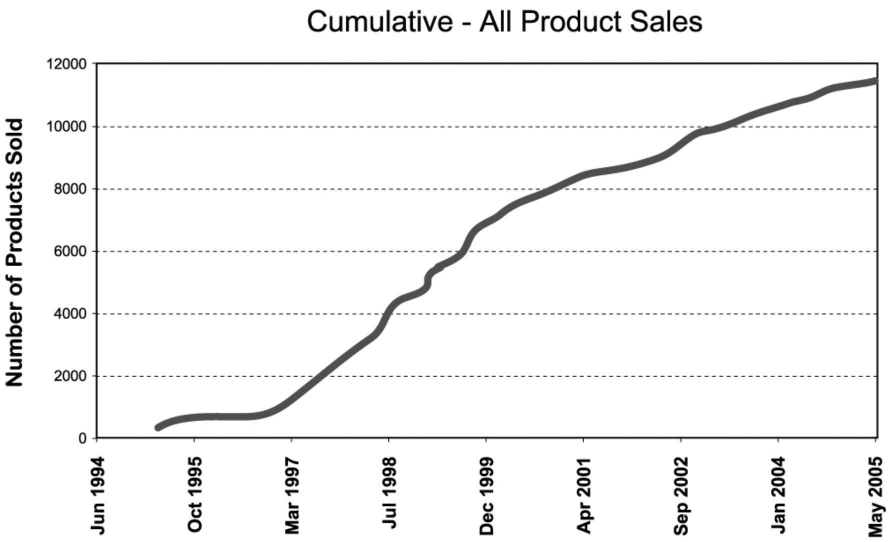

Figure 7.1 During the life of the CRC over 11,300 products (reports, proceedings, videos and CDs) were purchased through the Centre Office, an average of more than four for each day the Centre Office was open.

Current CRC (1999-2005)

With the successful application for Commonwealth funding in 1999, the CRC adopted a theme-based approach for its research program structure. The CRC's mission to "to deliver to resource managers the capability to assess the hydrologic impact of land-use and water-management decisions at whole-of-catchment scale" would prove to be a significant driver in the way our research outputs were shaped and delivered to industry. Equally important was the CRC's commitment in the 1999-2006 Business Plan - "the major performance indicator for the CRC for Catchment Hydrology will be the level of adoption of research outcomes". Combined with the establishment of a separate Communication and Adoption Program, to complement the Education and Training Program, this ensured the strong delivery focused culture of the initial CRC was strengthened.

Focus catchments

The inclusion of Focus Catchments and the roles of Focus Catchment Coordinators (FCCs) in the new CRC's planning from 1999 onwards, offered another avenue for increasing the CRC's relevance and delivery. A key challenge for the Centre was to integrate the various multidisciplinary threads of the research programs, and to realise the holistic view of catchments required by users. This would be tackled by targeting five focus catchments: the Fitzroy, Brisbane, Murrumbidgee, Goulburn-Broken and Yarra River catchment. This focus catchment activity would be coordinated by an FCC based in each catchment and the catchments were selected to:

- Cover a spectrum of spatial scales and catchment characteristics
- Span the range of issue-based problems confronting catchment managers
- Build upon existing catchment management initiatives at those sites
- Link to research networks outside the bounds of the Centre
- Satisfy the specific interests of each of the participating industry Parties.

Development projects

The Focus Catchment concept assisted the CRC to develop stronger links between industry and research, but their core value was realised when the concept of Development Projects was conceived and implemented during 2002-2005. These projects formalised relationships between the catchment management tool developers and the industry-based tool users resulting in vastly improved products and rapid skill development in many of the Focus Catchment industry and community based organisations.

MUSIC software development

During the first three years of the initial CRC, there was a strong focus on research and planning to meet the CRC's mission. The first software product released (May 2001) was the Model for Urban Stormwater Conceptualisation Improvement or more commonly 'MUSIC'. Released initially as a development version, the launch of MUSIC was supported by industry seminars around Australia by the MUSIC team. The MUSIC software benefited from the incorporation of world class science, a user friendly interface, low cost and Brisbane City Council and Melbourne Water support. Critically the commitment of the research and development teams to producing an industry ready tool underpinned its success.

The 'MUSIC model'

The 'MUSIC model of delivery' demonstrates the effectiveness of developing a best practice tool in

NEW TECHNICAL REPORT

Major Storages Water Quality Study: Upper-Mid Goulburn EMSS - A Preliminary Report on Catchment Surface Water Quality Investigations

By

Shane Papworth

Technical Report 05/12

As documented in this report a successful application of the CRC for Catchment Hydrology's EMSS model was implemented in the Upper–Mid Goulburn River Catchment. For catchment and water managers, the outcomes of this project will enable them to fully evaluate the short- and long-term outcomes of policy and land use decisions at regional scales.

This report is available for downloading as an Adobe Acrobat file from www.catchment.crc.org.au/ publications

conjunction with industry early on in a research project. Once established as best industry practice, the product, in this case software, becomes a direct channel for the delivery of new research outputs straight into the hands of the users. Three new versions of MUSIC have been released since that first development version in 2001 attracting over 400 users. There is now a strong development and support community based around MUSIC including the 190 members of the on-line support group, the MUSIC eGroup. Much of the MUSIC development was undertaken in conjunction with industry users, both internal and external to the CRC. The software is now attracting the attention of overseas interests who are interested in developing MUSIC for their own environment.

Catchment Modelling Toolkit

In many ways MUSIC demonstrated how the CRC could effectively achieve its mission. The need to develop a whole-of-catchment decision-support-system that allowed managers to predict the hydrologic consequences of land and water changes led to the Catchment Modelling Toolkit (www.toolkit.net.au).

After three years of conceptual development and trials, the Toolkit was seen as having three key roles:

- the Toolkit software framework to integrate the individual research program outputs in a form for industry use,
- the Toolkit product structure and policies to ensure a high standard of consistency and value for users and
- the Toolkit website to act as an on-line vehicle for product distribution and user support.

Indicators of success for the Toolkit

The development resources and intellectual horsepower that was applied to developing the Catchment Modelling Toolkit was significant and its current form is a testament to the integration of a range of disciplines including catchment hydrology, software engineering, project management and marketing.

To my mind, the Toolkit is the greatest example of the benefits of collaboration and integration from the CRC. It currently hosts 25 software and data products with more planned through the newly established eWater CRC. There have been more than 16,700 downloads from the site by the 4100+ registered Toolkit members.

Importance and extent of training

The level of success of the Catchment Modelling Toolkit so far has been underpinned by a key element – the provision of training. Training in the use of the software and the underlying science has enabled the industry to assess the value of Toolkit products and apply them in their own context.

The demands for training have steadily been increasing since the first MUSIC user two-day workshop in 2001 and CRC resources have been progressively redirected from industry reports and seminars to meet the need.

During the 2003/04 financial year the CRC delivered 39 workshops to support industry adoption of Toolkit products. The outstanding success of the first Catchment Modelling School held in Melbourne during February 2004 (300+ participants) led to two Schools during July this year, one each in Brisbane and Sydney. During this three week period the CRC delivered a total of 48 workshops to over 400 participants. In its last twelve months, the CRC has delivered over 60 technical training workshops to industry users around Australia.

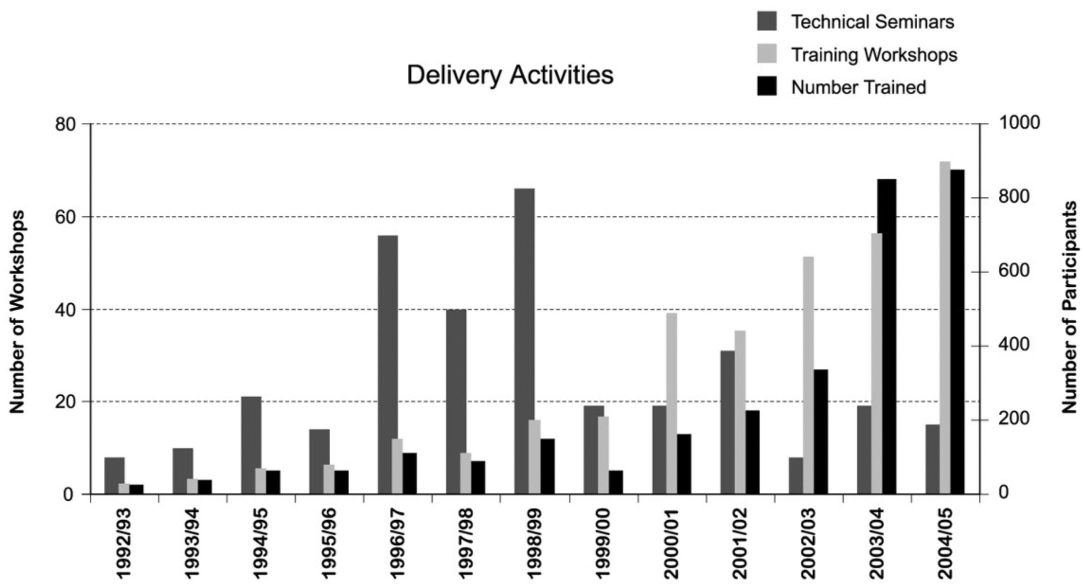

Figure 7.2 shows the change in emphasis between seminars and technical workshops during 1992-2005. The Catchment Modelling School 2005 is not included.

We are also developing other material to supplement the workshop-based training such as the Model Choice Series designed to provide background information for those relatively new to modelling and to provide guidance for choosing the "right tool for the job".

Looking forward

With the completion of the CRC for Catchment Hydrology's term, the eWater CRC is now poised to continue the momentum of delivery and application. eWater CRC is a cooperative joint venture between leading water-industry and research agencies with new participants joining the organisations that currently comprise the CRC's for Catchment Hydrology and Freshwater Ecology.

Under the leadership of the eWater Program teams, the key products of the CRC for Catchment Hydrology's twelve years of endeavour will continue to be expanded and developed. I look forward to the challenges of improving the CRC for Catchment Hydrology's record.

A sincere thank you for your contributions

The CRC has been supported by an excellent Board and executive team. My thanks also to all those research and project staff who committed their time and resources to deliver on the CRC's mission.

The CRC's Technology Transfer, Communication and Adoption, and Education and Training Programs have been particularly blessed by an impressive team of skilled people, so my greatest thanks to:

- Virginia Verrelli – Centre Office sales and support, 1994 – 2005
- John Molloy – *Catchword* Editor, 1992 – 2005
- Susan Daly – Graphic, Web and Print Design, 2002 - 2005
- Maeve O'Leary – Publications, Media and Marketing, 1997 – 2005
- Daniel Figucio – Web developer/master, 1997 - 2003
- Jake MacMullin – Web developer/master 2003 - 2005
- Tanya Jacobson, Jacqui Wise, Amanda Norman and Helen Peak for support across a myriad of communication and adoption activities
- Tom McMahon, Education and Training Program Leader, 1992 – 1999
- John Fien, Tim Smith and James Whelan, Education and Training Program Leaders 1999 – 2003
- The Focus Catchment Coordinators and Development Project Teams particularly Graham Rooney, Tony Weber, Pat Feehan, Carolyn Young, Andre Taylor, Chris Carroll, Bruce Cowie and Ross Searle (1999-2005)
- Our printers and desktop publishers: Liz Butler, Baron Frankel of Frankley Speaking, David, Andrew and Daniel at Docucopy, and Robyn, Lisa and David at Matgraphics.

Please note: The CRC for Catchment Hydrology website containing reports, research summaries and other information will continue to be accessible at www.catchment.crc.org.au for a number of years to come.

David Perry
Communication and Adoption Program
Education and Training Program
Tel: 03 9905 9600
email: david.perry@eng.monash.edu.au

COOPERATIVE RESEARCH CENTRE FOR
CATCHMENT HYDROLOGY

Print Post Approved
PP338685/00026

If undelivered return to:

Department of Civil Engineering
Building 60
Monash University
Vic 3800

SURFACE MAIL

POSTAGE PAID AUSTRALIA

CENTRE OFFICE:
CRC for Catchment Hydrology
Department of Civil Engineering
Building 60 Monash University,
Vic 3800
Telephone: +61 3 9905 2704
Facsimile: +61 3 9905 5033

crcch@eng.monash.edu.au

OUR MISSION

To deliver to resource managers the capability to assess the hydrologic impact of land-use and water-management decisions at whole-of-catchment scale.

OUR RESEARCH

To achieve our mission the CRC has six multi-disciplinary research programs:

- Predicting catchment behaviour
- Land-use impacts on rivers
- Sustainable water allocation
- Urban stormwater quality
- Climate variability
- River restoration

CRC AUSTRALIA

The Cooperative Research Centre for Catchment Hydrology is a cooperative venture formed under the Commonwealth CRC Program between:

Brisbane City Council
Bureau of Meteorology
CSIRO Land and Water
Department of Natural Resources, NSW
Department of Sustainability and Environment, Vic
Goulburn-Murray Water
Grampians Wimmera Mallee Water Authority
Griffith University
Melbourne Water
Monash University
Murray-Darling Basin Commission
Natural Resources and Mines, Qld
Southern Rural Water
The University of Melbourne

Associates:
Water Corporation of Western Australia

Research Affiliates:
Australian National University
National Institute of Water and Atmospheric Research, New Zealand
Sustainable Water Resources Research Centre, Republic of Korea
University of New South Wales

Industry Affiliates:
Earth Tech
Ecological Engineering
Sinclair Knight Merz
WBM

Successor Organisation

In September 2005 the CRC for Catchment Hydrology will cease. Its successor is the eWater CRC.

eWater CRC (eWater Ltd)
Telephone + 61 2 6201 5168
Facsimile + 61 2 6201 5038
www.ewatercrc.com.au