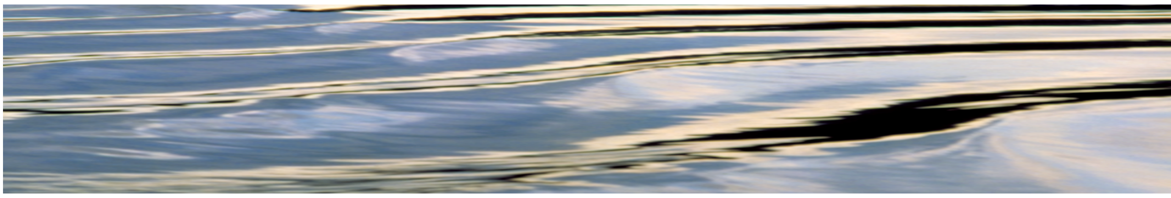
COOPERATIVE RESEARCH CENTRE FOR **CATCHMENT HYDROLOGY**

THE STATUS OF CATCHMENT MODELLING IN AUSTRALIA

TECHNICAL REPORT
Report 02/4
March 2002

Frances Marston / Robert Argent / Rob Vertessy / Susan Cuddy / Joel Rahman



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Foreword

The CRC for Catchment Hydrology is developing a new generation of catchment models and modelling support tools, integrated within a system of software known as the Catchment Modelling Toolkit. The purpose of the Toolkit is to improve the standard and efficiency of catchment modelling, and to provide much-needed enhancements in predictive capability for catchment managers.

This report describes a vital element of the planning underpinning the development of the Toolkit concept. It summarises the results of three different surveys that gauged the opinions of catchment managers, model users and model developers with respect to the status of catchment modelling in Australia. We are grateful to the many survey respondents who kindly shared their ideas with us and trust that the direction we have taken in development of the Catchment Modelling Toolkit now better suits their needs.

Dr Rob Vertessy
Deputy Director
CRC for Catchment Hydrology

Acknowledgements

The project team would like to acknowledge the valuable input made by all survey participants (listed in **Appendix 2**); without their help the study would not have been possible.

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1. Introduction

1.1 The Catchment Modelling Toolkit

Modern catchment management requires that policy development, planning and intervention be undertaken in an integrated fashion, with consideration given to physical, ecological, economic and social systems. With this in mind, the CRC for Catchment Hydrology (CRCCH) has initiated the development of a 'catchment modelling toolkit'. The ambition is to equip land and water managers, researchers and educators with an integrated collection of software tools and components designed to simulate holistic catchment response to management and climate variability, at a range of scales and using a variety of approaches.

It is recognised that models used in catchment prediction have often been developed for specific research problems or locations by individuals using software engineering practices that are now considered obsolete. The legacy of this is a range of models dealing with similar problems, using similar data input and output interpretation, but with a high diversity of operational features. Use of the Toolkit will facilitate the integration of appropriate existing and newly developed models for predicting aspects of catchment behaviour. However for this to occur and to meet the needs of managers for information and modelling related to different aspects of catchment behaviour, it is necessary to provide the capacity for managers to apply suites of different models. But which models and within what kind of software design paradigm?

The prediction of catchment behaviour cannot be achieved by simply 'plugging' existing models together. The vast range of different programming languages, computer platforms, and design approaches used in existing models precludes such an approach. There are, however a range of alternatives that can be developed to achieve this, from sets or libraries of stand-alone models and data management tools, to fully integrated model design, construction, selection and execution systems. Clearly, different approaches require the adoption of fundamentally different software design paradigms—a major issue for the Toolkit's development. Therefore, to gauge attitudes of the land and water industry and researchers with respect to current catchment modelling tools and to assist the determination of the best approach to adopt for the Toolkit, a series of surveys was undertaken. The results would provide a benchmark to revisit once the Toolkit was in production, providing a basis from which to assess its impact on the modelling community.

1.2 The Surveys

Three surveys were conducted during March to July 2001. They were targeted at catchment managers, model users, model developers and model writers, especially staff and members of the CRCCH Parties. The surveys were designed to gather information about which models were being used, types of model applications and the design/development behind the models.

Survey 1 targeted **managers** to identify:

- a prioritised list of key catchment management questions
- a list of models and modelling approaches that may be used to address the questions.

Because the CRCCH had already done a good deal of work in this area, a detailed further survey was considered inappropriate. Instead a list of issues and models was distributed for comment and annotation. This survey was designed to confirm our understanding of the issues and modelling activities.

Survey 2 targeted **model users** and sought to determine:

- what models are being used in the industry
- how satisfied users are with these models
- what improvements users would like to see made to these models
- what model development plans are in progress.

Survey 3 targeted **model developers and writers** and sought to identify current software engineering practices by asking specific questions about modelling applications on the drawing board and how they are:

- initiated
- designed
- implemented, and
- deployed.

This report describes the findings of these surveys, providing an in-depth analysis of the survey results and recommendations for the modelling toolkit project.

2. Summary of Survey Findings

2.1 Distribution and Response

While separate distribution lists were prepared for each survey, there was a strong bias towards staff in CRCCH Parties, many of whom received more than one survey. This reflected the high profile that CRCCH Parties have in the catchment modelling industry, and the importance of understanding the needs of those organisations in the CRC.

About 100 people (44% return) took the time to complete the surveys. This is considered to be a reasonable response and a sample that adequately represents the attitudes and state of the Australian catchment modelling community.

2.2 Survey 1 - Issues

Survey 1, together with previous investigations, gave a clear message that the issues of greatest importance to the respondents were:

- catchment analysis of nutrient and sediment load under different land-use
- estimates of flow and nutrients at any stream point in a catchment
- ecology-hydrology interactions and bioindicators, including water allocation to environmental flows
- catchment salt generation from land-use, and transport through the catchment.

This list is expanded in the detailed section on Survey 1.

2.3 Survey 2 - Users

Thirty-six (36) models were cited in 58 survey returns. Most of these models were used for research applications or for consulting purposes and were very important or essential to people's work, often being used on a daily or weekly basis.

Of the models cited, only 14 were used by more than one respondent, with REALM and PERFECT being most cited (14% and 11% of users, respectively). More than one-third of models were developed and written by the respondent at considerable investment of time and effort (often years). This was despite most indicating that their model could be substituted by another model. Less than 20% had actually purchased a model commercially.

Generally, model parameterisation and interpreting model results were considered challenging, and user interfaces and documentation considered adequate. Users were reasonably happy that models gave credible results.

2.4 Survey 3 - Developers/Writers

This survey had an 'internal' focus and strongly reflects the nature of research (and consequent model development) within the CRCCH, and in other parts of CSIRO. About 70% of those surveyed responded, with 70% of them describing themselves as scientists, and 50% modellers (ie 20% identified themselves as both).

About one-half of model/application development was commissioned as a result of research initiatives and for in-house use, with about one-third commissioned by external clients. However, just under half of in-house applications also expected to deliver to a wider audience of scientists, and catchment and water managers.

Most applications were a mixture of existing and 'new' models. The main reason given for developing 'new' models was that existing models either didn't contain all the processes, didn't integrate the processes, were at the wrong scale, or were not well validated.

The expertise of the intended audience, and a need for integration and a general solution strongly influenced design. Most developers did not follow any formal design method, though the use of tools such as structure, class and/or activity diagramming and UML (Unified Modeling Language) was not uncommon. Design documentation was required by about one-half of respondents, principally for maintenance and users, and, to a lesser extent, the design team itself.

Fortran 77/90 was the most widely used language, and respected by those who use it. Excel was the most widely used development environment, but it was more used than respected. However, for most developers, the final choice of language/environment came down to their expertise and the ease and speed of development in the chosen language/environment.

Most developers (85%) targeted PC/MS Windows, with 40% targeting Unix. Only 4% wanted platform independence. Third-party software was commonly incorporated, with GIS, particularly ARC/INFO, ranking most highly.

3. Survey Details

3.1 Survey 1 - Catchment Management Issues

3.1.1 Purpose

The objectives of Survey 1 were to introduce the catchment community to the Toolkit project, develop a prioritised list of key catchment management questions, and develop a list of models and modelling approaches that may be used to address the questions.

3.1.2 Design

Survey 1 was undertaken in two parts. The first part (1a) was a focussed activity with about 25 people selected to provide a good coverage of secondary and tertiary users, including consultants, state and federal agencies, and community catchment groups. The second part of the survey (1b) used a scattergun approach to contact about 100 catchment management representatives across most of Australia.

Survey 1a provided a list of issues/model needs and asked the respondent to:

- add issues to the list
- indicate the two issues of highest priority
- suggest existing models that might be appropriate to have in a toolkit to meet the needs expressed above, and
- indicate which model/program/algorithm/ estimation method they would most like to see included in the toolkit.

Survey 1b targeted a broader audience and had 2 questions, based on the responses from Survey 1a, that firstly asked the respondent to:

- indicate the one or two issues that they would like to see addressed in modelling development in the coming years (if the list included the issues of highest priority to them)
- add one or two extra issues, and their priority (if the list did not include the issues of highest priority to them).

Secondly, Survey 1b asked respondents to list the catchment management related models with which they were familiar and to identify which of them they would like to see further developed.

3.1.3 Findings

Survey 1a returned a 65% response rate, with some respondents adding to the issues list, most identifying priorities, and few considering models. Respondents added 12 issues to the 8 provided, resulting in the priority rating indicated in **Table 1**.

These results indicate the broad range of issues of interest to catchment managers. The modelling questions were answered by only a few of the respondents, and the responses provided no information upon which changes to existing models could be suggested or made.

A much lower return (20%) to Survey 1b indicated that we had identified the top modelling priorities, with no new priorities becoming apparent.

3.1.4 Implications and Recommendations for the Toolkit

It is acknowledged that our modelling priorities are going to be directed partly towards issues that are specified in the CRCCH Business Plan[1]. However there is a strong correlation between the Business Plan and **Table 1**, the main omission being in the areas of pesticides and human water quality issues.

The lack of specific requests for particular model components in the Toolkit highlights clearly the need for a toolkit-based modelling approach that allows models to be constructed as the result of a process that selects and combines appropriate components to fit the modelling solution to the problem.

Thus from Survey 1, two specific recommendations are made:

Recommendation 1.1:
That the modelling priorities for the Toolkit be:

- *Catchment analysis of nutrient and sediment load under different land-use*
- *Estimates of flow and nutrients at any stream point in a catchment*
- *Ecology-hydrology interactions and bio-indicators, including water allocation to environmental flows*
- *Catchment salt generation from land-use, and transport through the catchment*

Recommendation 1.2:
That components that meet the requirements of Recommendation 1.1 be treated as priorities for development.

1. Cooperative Research Centre for Catchment Hydrology (1998). Business Plan 1998 Selection Round. Unpublished Report, 20p.

Table 1 Catchment Management Issues and Priorities

Issue/Need	Priority (1a)	Priority (1b)
Point estimates of water balance components over time and groundwater effect	★	★★
Point analysis of land-use practice effects on acid sulphate soils		
Paddock scale analysis of sediment and nutrient transport to streams	★★	
Stream reach analysis of pest plant migration		
Stream reach analysis of terrestrial habitat in riparian zones		
Estimates of flow and nutrients at any stream point in a catchment	★★	★★★★
Flood peak and inundation estimates for different floods	★	
Catchment analysis of nutrient and sediment load under different land-use	★★★	★★★★
Yield impacts from catchment land-use and climate variability/change	★	★★
Catchment salt generation from land-use, and transport through the catchment	★★	★★
Interaction between ground and surface water systems; resultant impacts on water quality of each system		
Land-use based export rates; expressed as functions of geology, soil, pollutants	★	
Best combination (inc. cost) of urban stormwater treatments to meet point and downstream requirements	★★	★
How to use export based models to meet concentration based water quality objectives		
How to add in treatment processes to an export rate water quality model		
Ecology-hydrology interaction and bioindicators (including water allocation to environmental flows—added for 1b)	★★★	★★★★★★
Pesticides—transport and fate		
Human water quality issues—giardia, cryptosporidium		
Nutrient and chemical leaching into groundwater		

NOTES:

Shaded cells indicate list provided to respondents in Survey 1a
Bold text indicates issues listed in Survey 1b
Unshaded cells indicate additional issues supplied by respondents to Survey 1a
Priority rating indicates number of supportive responses

3.2 Survey 2 - Model Users

3.2.1 Purpose

The purpose of the survey was to:

- list the catchment hydrologic models being used by CRCCH Parties and affiliates
- determine (in a broad sense) the desirable and undesirable features of the main models in use (including realism, parameterisation, interfaces, documentation, quality assurance)
- classify the models in terms of their (a) issue focus, (b) structure, (c) complexity, and (d) coding style
- comment on the importance of each model to the hydrologic modelling community, classifying them as (a) critical, (b) important, or (c) handy to have, or some such hierarchy
- ascertain the future intentions of the model users/ authors with respect to continuing application and development of these models
- assess gaps in the suite of hydrologic modelling tools currently available to the CRCCH Parties and affiliates
- determine a short list of models (possibly including new ones to be developed in other CRCCH projects) that should be integrated into the modelling Toolkit in the first three years and beyond.

Survey questions were aimed at determining:

- what models are being used in the industry
- how satisfied users are with these models
- what improvements users would like to see made to these models
- what model development programs or plans are in progress.

3.2.2 Design

This survey contained 20 questions to be answered about one or more models, specifically:

- model's name (Q2)
- its use (eg research, teaching, design, consulting) (Q3)
- importance to work (Q4)
- frequency of use (Q5)
- method of acquisition (eg purchased, borrowed, written) (Q6)
- (if model not self-written) how it was known about (read, conference, recommendation) (Q7)
- amount of time used at work (learning cycle/ application, not model development time) (Q8)
- ease of parameterisation (Q10)
- interface (good, bad) (Q11)
- credibility of results (Q9)
- ease of interpretation and explanation of results (Q12)
- documentation (good, bad) (Q13)
- acceptance by peers (Q14)
- additional features that would be useful (Q19)
- other models that could do the job (Q15).

If the respondent was the developer of the model or a contributor to its coding (Q16),

- the 'health' of the code (Q17)
- intention to further develop the model or commission changes to the model (Q18)
- availability of the model (Q20).

3.2.3 Findings

Some 46 participants contributed 58 survey returns citing 36 different models. Forty-three percent of participants worked for CSIRO, 22% worked for State departments, 15% worked for consulting firms and 20% worked for Universities. Most respondents used models for research applications or for consulting purposes, indicating that few models were really used for 'real world' applications.

Of the 36 different models cited, only 14 were used by more than one respondent and, of those 14, most were used by 2 respondents; 3 had 3 users, 1 had 4 users, and 1 had 5 users (**Figure 1**).

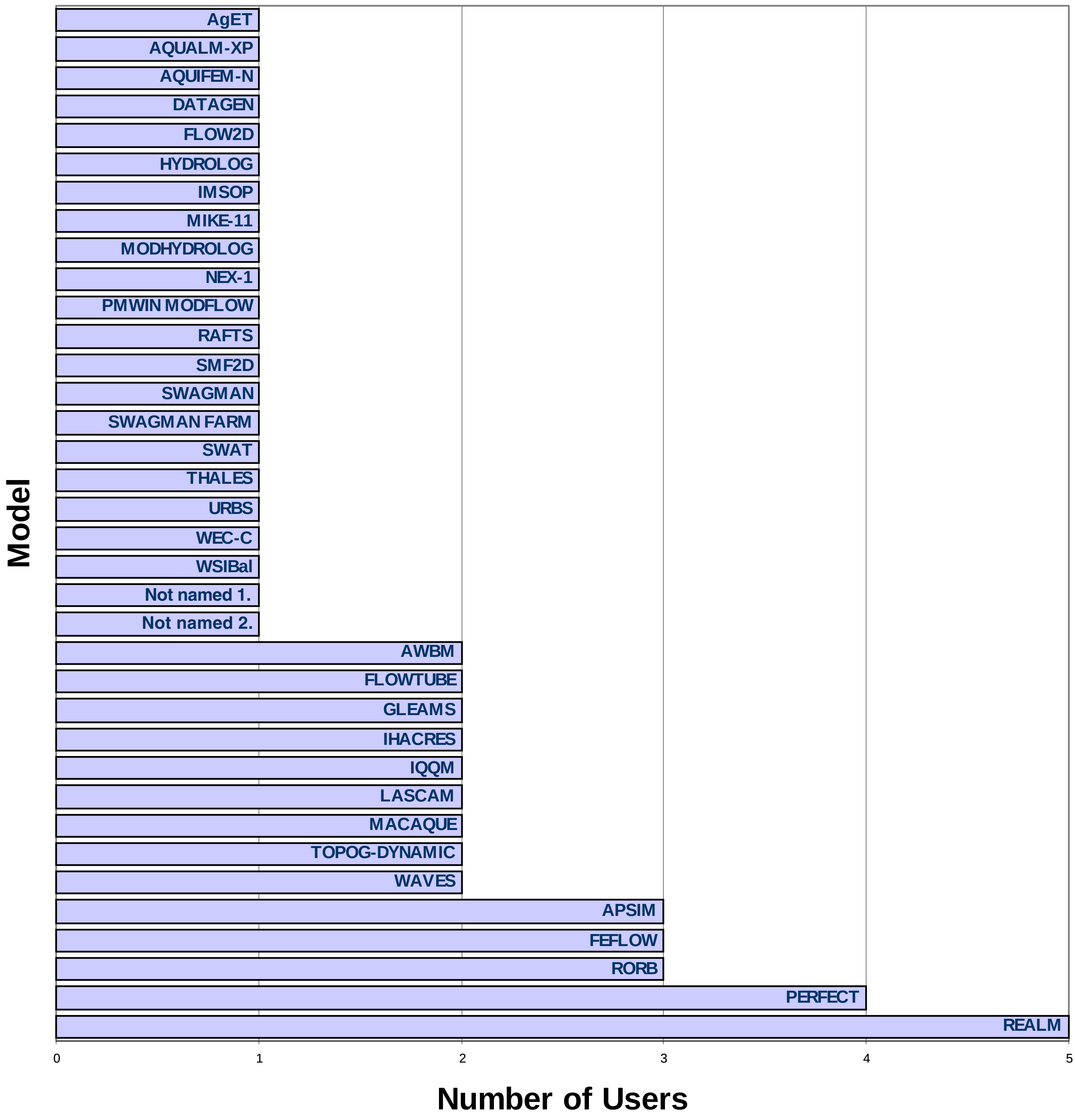

Figure 1 Model Use

Model Use

Models were most often used for research purposes, with consulting being the next most common use (**Table 2**). The listed models were rarely used in teaching and design.

Table 2 Model Use

Model	No. Users	Research	Teaching	Design	Consulting
AgET	1	✓	✓		
APSIM	3	✓	✓		
AQUALM-XP	1			✓	✓
AQUIFEM-N	1	✓			✓
AWBM	2	✓			✓
DATAGEN	1		✓		
FEFLOW	3	✓			✓
FLOW2D	1	✓			
FLOWTUBE	2	✓			✓
GLEAMS	2	✓			
HYDROLOG	1	✓			
IHACRES	2	✓			✓
IMSOP	1	✓	✓		
IQQM	2	✓			✓
LASCAM	2	✓	✓	✓	✓
MACAQUE	2	✓			✓
MIKE-11	1	✓			✓
MODHYDROLOG	1	✓			
NEX-1	1				✓
PERFECT	4	✓	✓		
PMWIN MODFLOW	1	✓		✓	
RAFTS	1			✓	✓
REALM	5	✓	✓	✓	✓
RORB	3			✓	✓
SMF2D	1	✓			✓
SWAGMAN	1	✓			
SWAGMAN FARM	1	✓			
SWAT	1	✓			
THALES	1	✓			
TOPOG-DYNAMIC	2	✓			
URBS	1				
WAVES	2	✓			✓
WEC-C	1	✓		✓	
WSIBal	1	✓			✓
Not Named 1	1	✓			
Not Named 2	1	✓			

Most models were developed and written by the respondent (38%—**Figure 2**) at considerable investment of time and effort (34% in months; 31% in years—**Figure 3**) and relatively few respondents had actually purchased a model commercially (19%—**Figure 2**).

Most models could be substituted by another model (93%). Most users wanted more features incorporated into the models (86%) and many would contribute to the future development of them (53%).

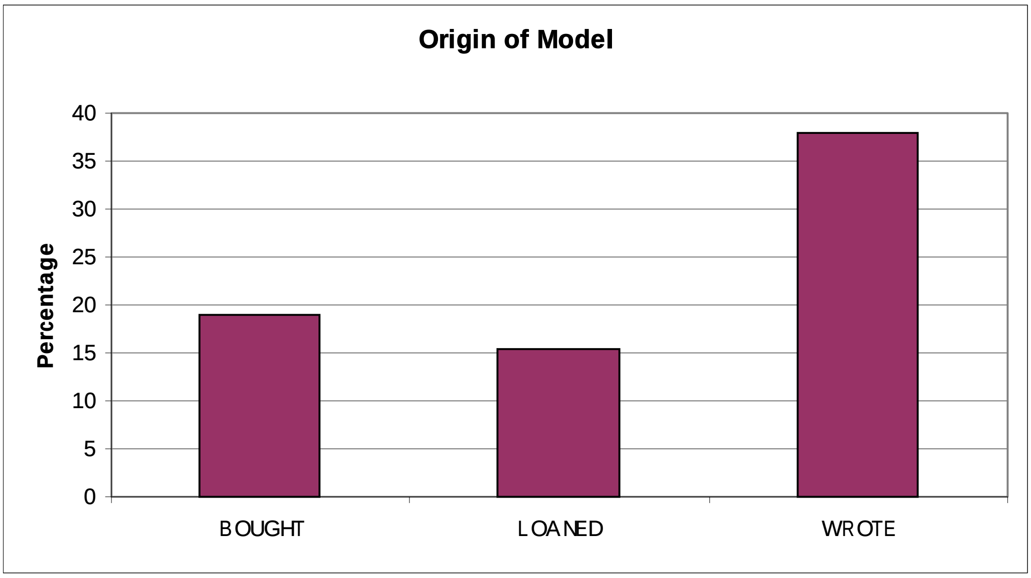

Figure 2 Model Origins

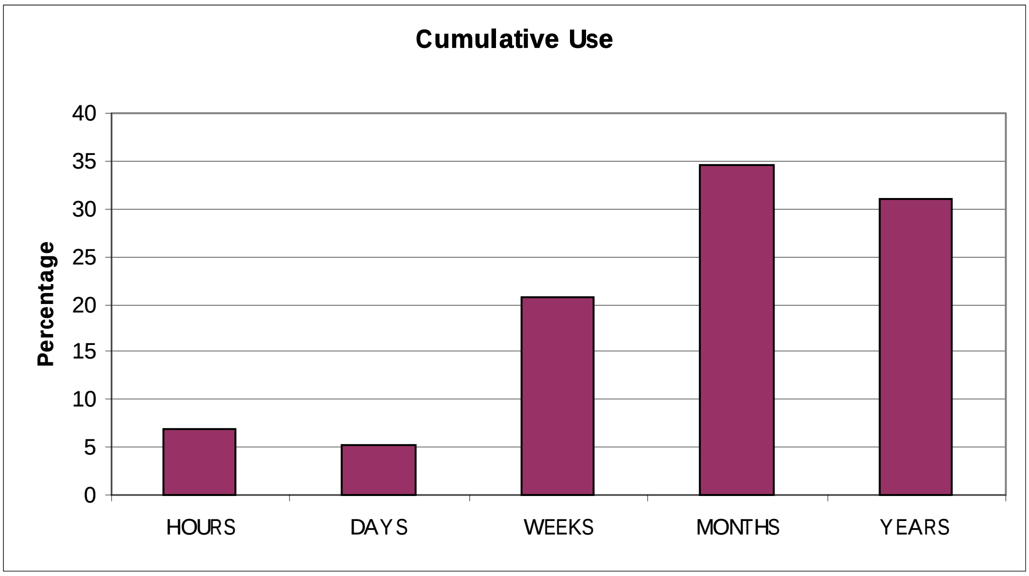

Figure 3 Development Investment

Most respondents claimed that using models was essential (62%) or important (31%) to their work (**Figure 4**), many using models on a daily (31%) or weekly (24%) basis, although 29% of models were used only sporadically (**Figure 5**).

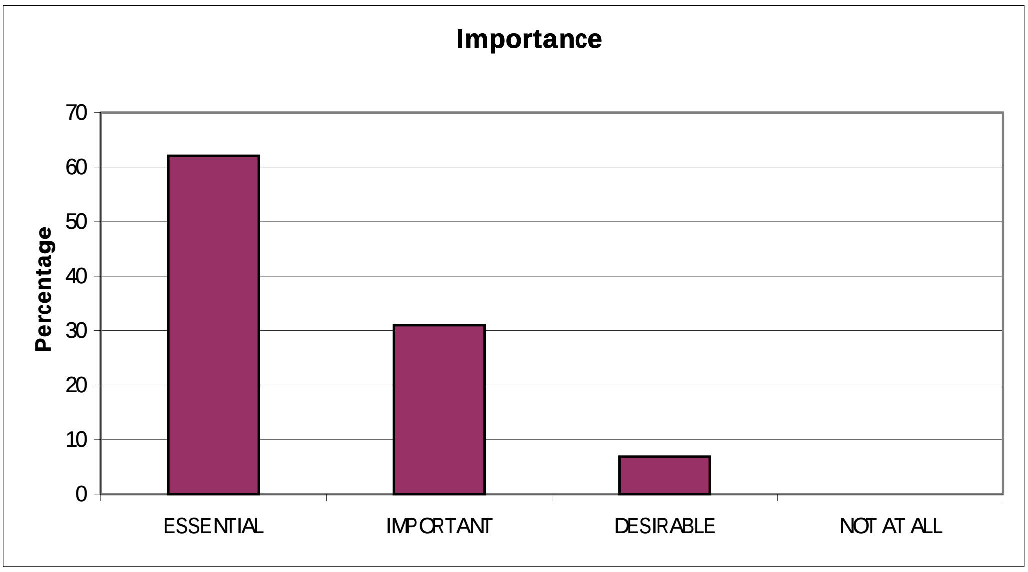

Figure 4 Importance to Work

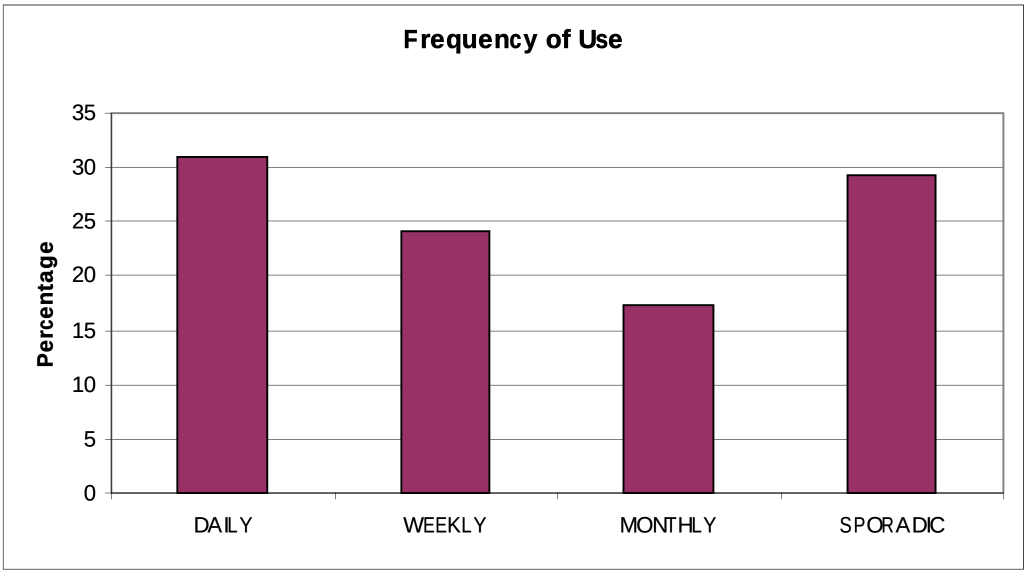

Figure 5 Usage

Many respondents contributed to coding of the models and considered they had a significant developer role (**Figure 6**). Consequently the resultant code condition (ie architecture and modularity of the code, the amount of detail and commenting, the variable naming conventions and their protection, error and exception handling, the reuse of program parts or composition and inheritance, design patterns, use of software components) was rather varied (**Figure 7**)! Most anticipated further development of the models, though this obviously depended on the availability of source code which is variable.

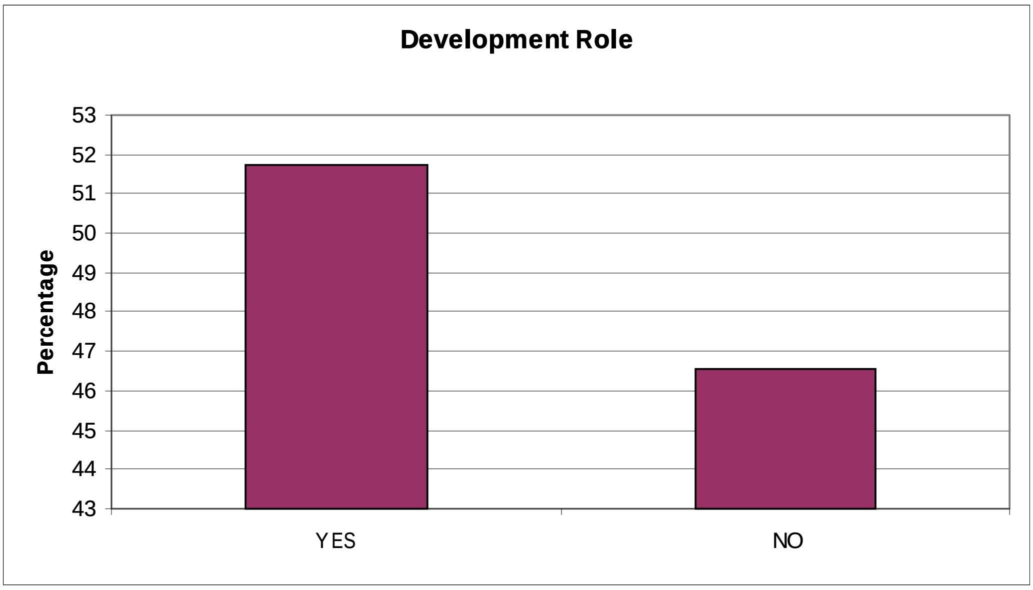

Figure 6 Roles

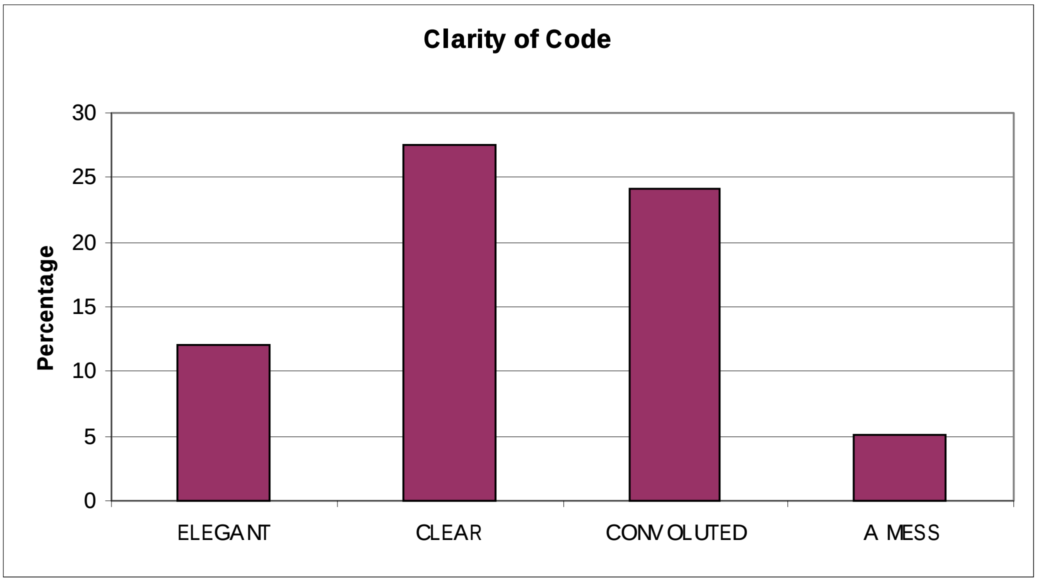

Figure 7 Condition of Model Code

The survey asked a number of questions related to model use (**Figure 8**). These covered issues like setting up the model (parameterisation, user interface, documentation), interpreting and explaining the results, and the credibility of those results.

Generally, interpreting model results was not easy (tricky (53%), hard (17%), simple (38%)), the quality of user interface was considered adequate, as was documentation, and model parameterisation was identified as being a bit of a challenge. Users were reasonably happy that models gave credible results. These results are probably skewed towards the positive as most respondents were also the model developer.

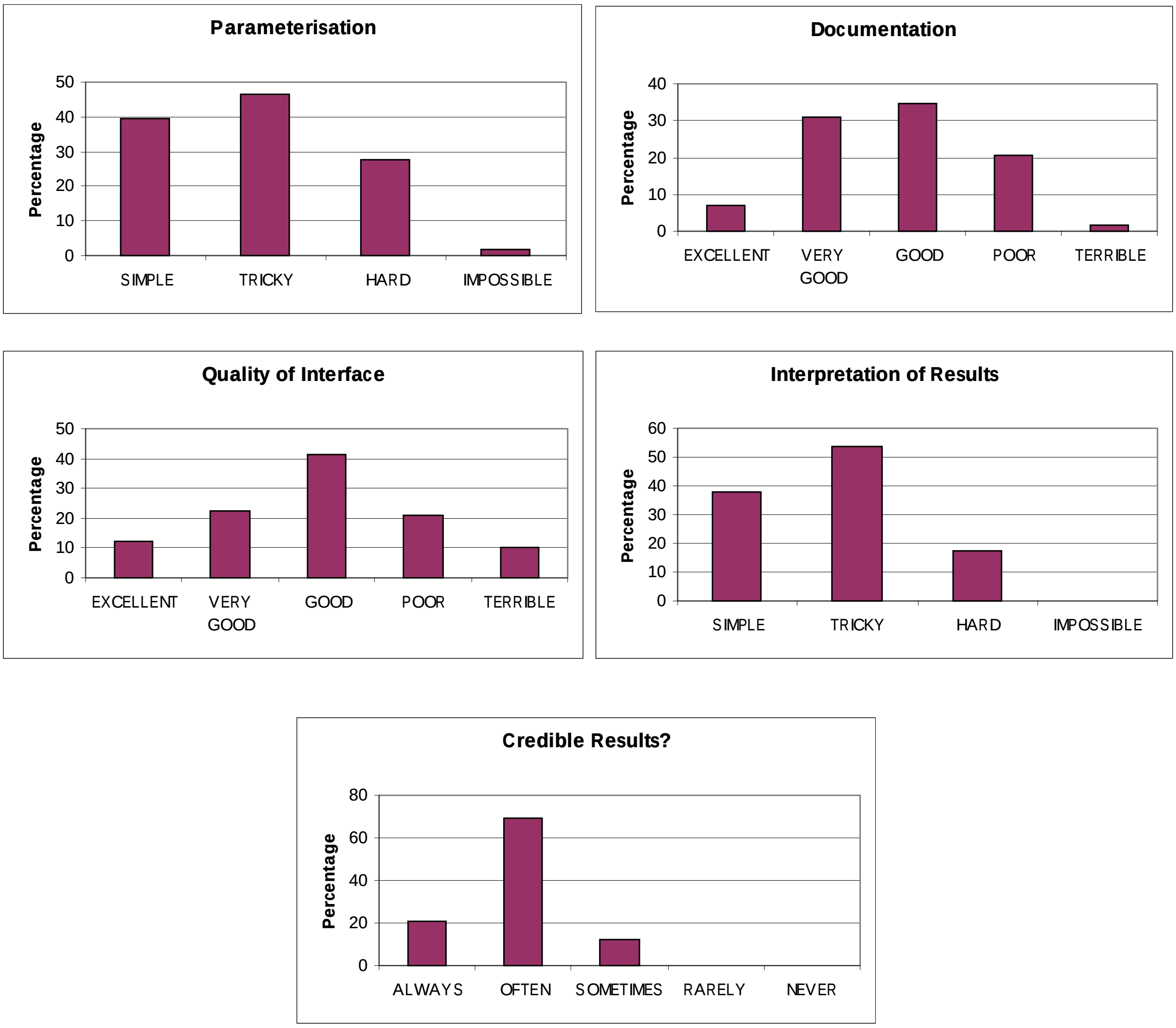

Figure 8 Model Usability

Model Acceptance

Asked whether the models were well accepted by the industry peer group, the general consensus was in the affirmative (**Table 3**). Generally, those who had developed the models themselves tended to be most confident of peer acceptance.

Table 3 Model Acceptance

Model	Developer	Industry Acceptance			
		Definitely	Probably	Probably Not	Definitely Not
AgET		✓	✓		
APSIM		✓	✓	✓	
AQUALM-XP	✓	✓	✓		
AQUIFEM-N			✓		
AWBM			✓		
DATAGEN					
FEFLOW		✓	✓		
FLOW2D		✓			
FLOWTUBE	✓	✓			
GLEAMS		✓	✓		
HYDROLOG			✓		
IHACRES	✓	✓		✓	
IMSOP					
IQQM		✓	✓		
LASCAM	✓		✓		
MACAQUE	✓		✓		
MIKE-11			✓		
MODHYDROLOG					
NEX-1	✓		✓		
PERFECT		✓	✓	✓	
PMWIN MODFLOW		✓			
RAFTS			✓		
REALM	✓	✓	✓		
RORB		✓			
SMF2D	✓				✓
SWAGMAN	✓	✓			
SWAGMAN FARM	✓	✓			
SWAT		✓			
THALES	✓		✓		
TOPOG-DYNAMIC	✓		✓		
URBS		✓			
WAVES	✓	✓			
WEC-C	✓		✓		
WSIBal	✓				✓
Not Named 1	✓			✓	
Not Named 2	✓				✓

3.2.4 Implications and Recommendations for the Toolkit

Survey 2 indicates that there is very little standardisation of hydrological model development or application. Researchers prefer to develop their own models, even at considerable expense in time and resources. A major implication for the Toolkit is that users are highly technically literate and the Toolkit must provide an interface for scientists that provides access to all data and the workings of the model(s).

Recommendation 2.1:

The Toolkit must provide an appropriate interface that enables all users to access all data and model components.

3.3 Survey 3 - Model Developers/Writers

3.3.1 Purpose

The purpose of the survey was to identify current software engineering practices, particularly in the areas of:

- problem definition
- solution design and implementation
- solution transfer (to customer).

3.3.2 Design

The 5-part survey (**Table 4**) was distributed to 38 people, principally to selected CRCCH participants and other CSIRO Land and Water programmers and model developers, with a response rate of just above 70%.

Table 4 Survey 3

Part	Title	Intended to discover	Questions asked
1	Definition	How the ‘problem’ is defined	1. How application is ‘commissioned’ 2. How well defined were the ‘boundaries’ 3. What else affected scoping of the application 4. Whether making ‘new’ models or modifying existing ones 5. How developers decide on style eg process-based, empirical, distributed, non-spatial
2	Design	How developers move from the problem definition to a solution	1. The people issues which influence the design 2. The technical issues which influence the design 3. The management issues which influence the design 4. Whether building on previous work 5. The point of design 6. The formal design methods used 7. If not formal, how best to describe design approach 8. The need to document design and for who 9. Ways of documenting design that developers would like to try
3	Implementation	What environments and tools developers use to implement solutions	1. The development environments used 2. The programming languages used 3. What finally decides choice of 1 and 2 4. The computing platforms 5. The main factors in choosing these platforms 6. Interaction with commercial software packages 7. Third party libraries/components currently used or would consider using
4	Delivery	Customers and transfer mechanisms	1. Client groups (in-house or other) 2. Target users 3. Delivery medium 4. What is being distributed 5. Need for third party software licences
5	Background	Developers’ background and training	1. Modeller/scientist/programmer/etc 2. Computer Science background 3. Catchment hydrology/management background 4. Skills in GIS a/o environmental modelling 5. How keep up-to-date with software development

3.3.3 Findings

Charts detailing the actual responses to most of the questions that could be answered quantitatively (1 to 3 indicating low to major influence; or yes or no) are presented throughout this section.

Problem Definition Phase

Most applications were commissioned as research initiatives (56%), followed by requests from external clients (35%). Scoping of the problem was most affected by the purpose of the application and data availability, rather than the client. In most development projects the boundaries of the applications were reasonably well specified, though outputs were generally less well defined than scales and inputs.

Most applications were a mixture of existing and 'new' models. The main reason given for developing 'new' models was that existing models either didn't contain all the processes, didn't integrate the processes, were at the wrong scale, or were not well validated.

The degree of problem definition (**Figure 9**) was surprising, considering the 'loose' commissioning of much of the model development. This probably reflects the expertise of the developers who are well versed in the problem domain.

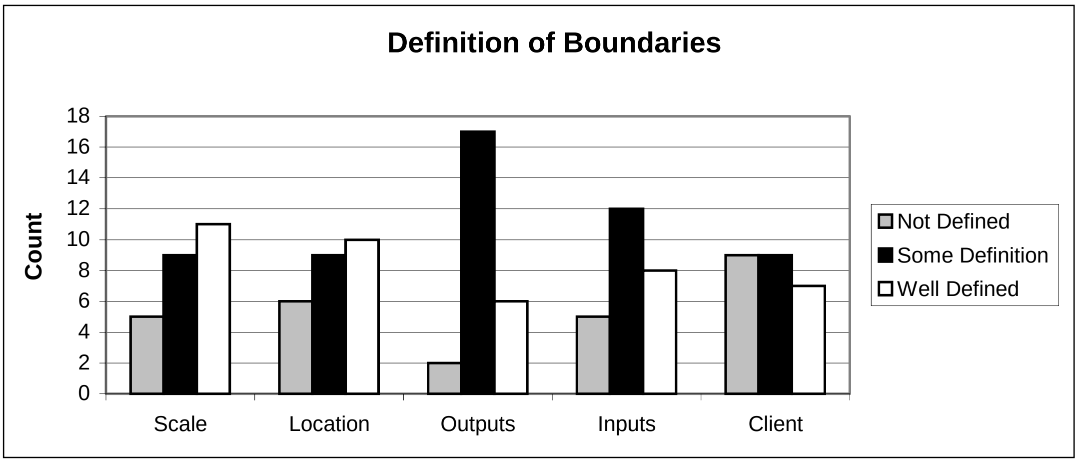

Figure 9 Problem Definition

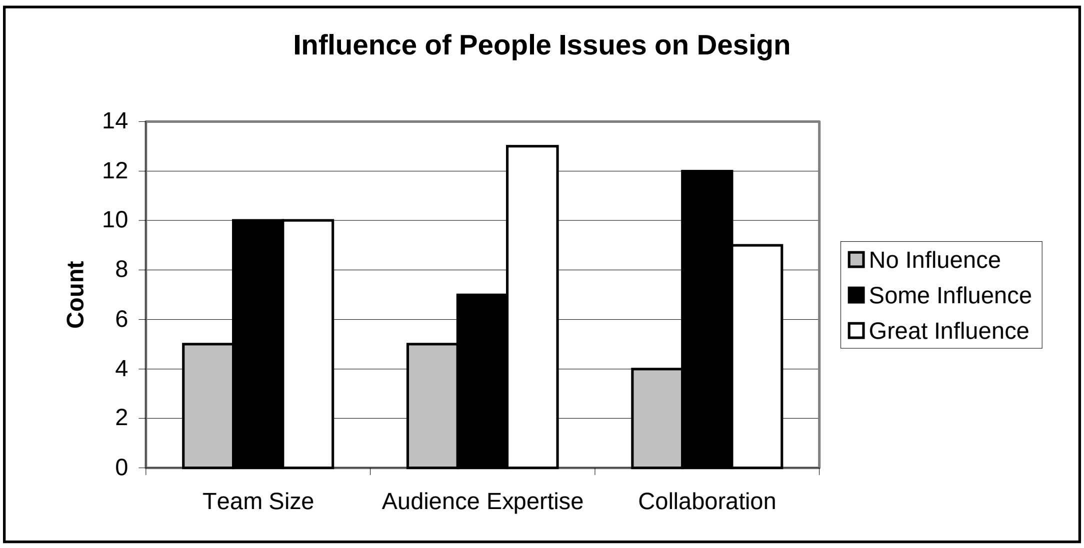

Figure 10 People Issues and Design

Design Phase

People, technical issues and management were all shown to influence design, with a slight bias towards people and management. Consideration of expertise of intended audience, need for integration and a general solution (as opposed to being specific to a particular dataset) were the most frequently cited influences on design (**Figure 10**). Interestingly, while the need for Quality Assurance (QA) was acknowledged, formal knowledge about QA was low.

Most developers used no formal approach to design, and relied on whiteboarding, brainstorming and coding to move from definition to implementation (prototyping in the loosest sense). In spite of the lack of formal approach, recourse to tools such as structure, class and/or activity diagramming and UML (Unified Modeling Language) was not uncommon. Less than one-third of the respondents used 'classical' tools such as flowcharts. Half the respondents indicated that they need to document design, principally for maintenance and users, and, to a lesser extent, the design team itself (**Figure 11**).

The low priority given to the level of computing resources of the intended audience influencing the design was surprising. This probably reflects an assumption that clients can, and will, upgrade computing resources (**Figure 12**).

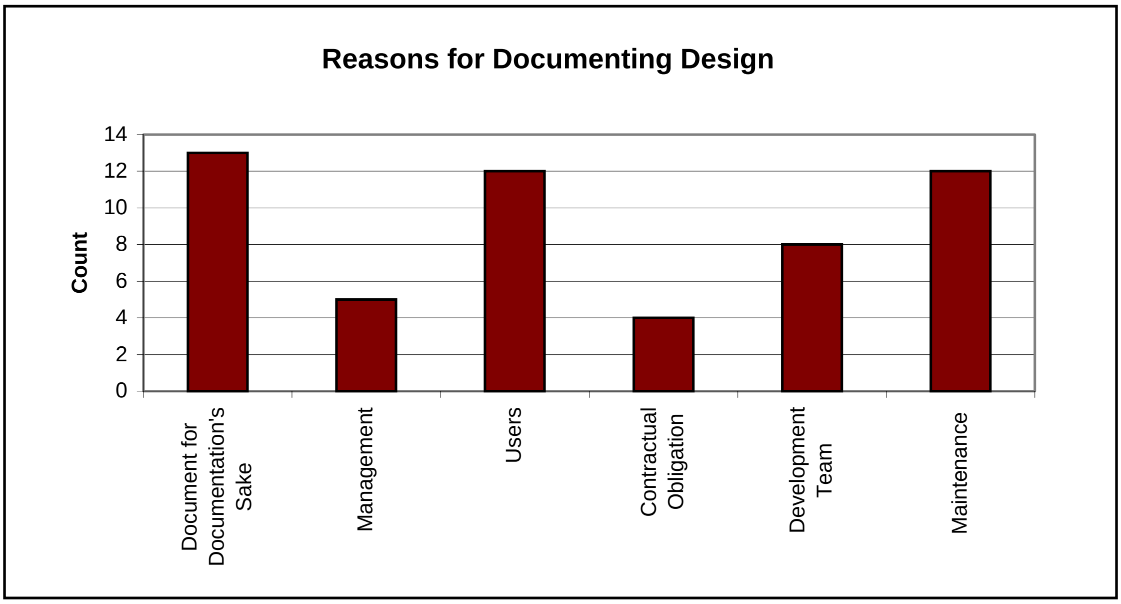

Figure 11 Design Documentation

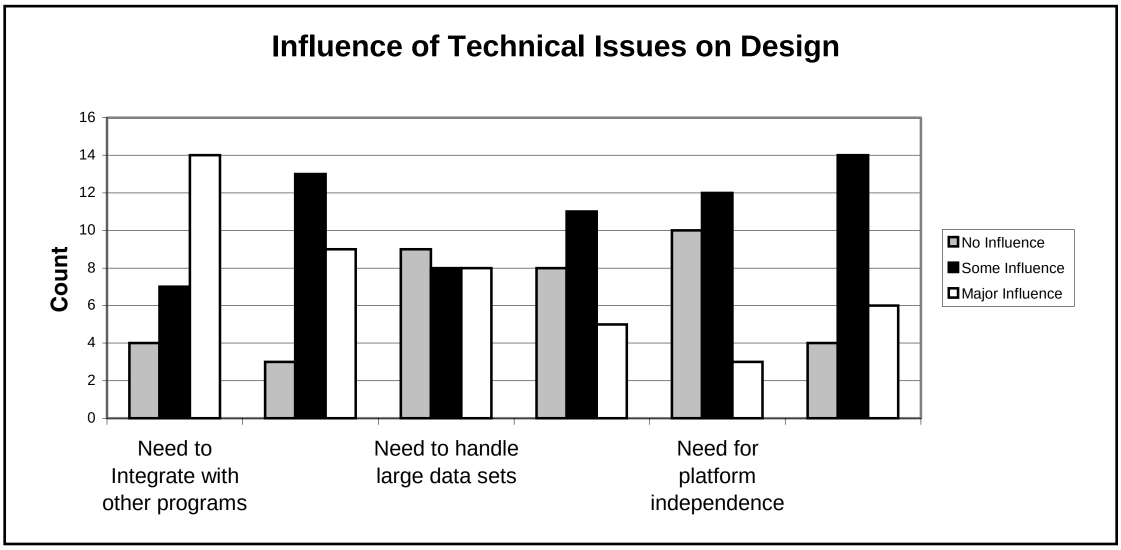

Figure 12 Technical Issues and Design

Implementation Phase

Developers were asked to rank their use (and like) of different development environments and programming languages. The most commonly used language was Fortran 77/90 and users were very enthusiastic about its capability (**Figure 13**). Excel was the most widely used development environment, but it was more used than respected for this type of work (**Figure 14)**. The high number of Fortran users was expected, and the level of support for other languages and environments indicates a general willingness to try new approaches where appropriate. However, for most developers, the final choice of language/environment came down to the developer's personal expertise and the ease and speed of development in the chosen language/environment (**Figure 15**). Availability was also a consideration, though of much lower influence.

Choice of platform (**Figure 16**) was interesting with 85% targeting PC/MS Windows, 40% targeting Unix. Only 4% looked for platform independence. However, 80% of those targeting Unix were also targeting PC/MS Windows. This is a bit of a surprise given the traditional use of Unix in scientific computing. None of those surveyed targeted MacOS. The strong support of PC suggests that platform independence is not a high priority for model developers.

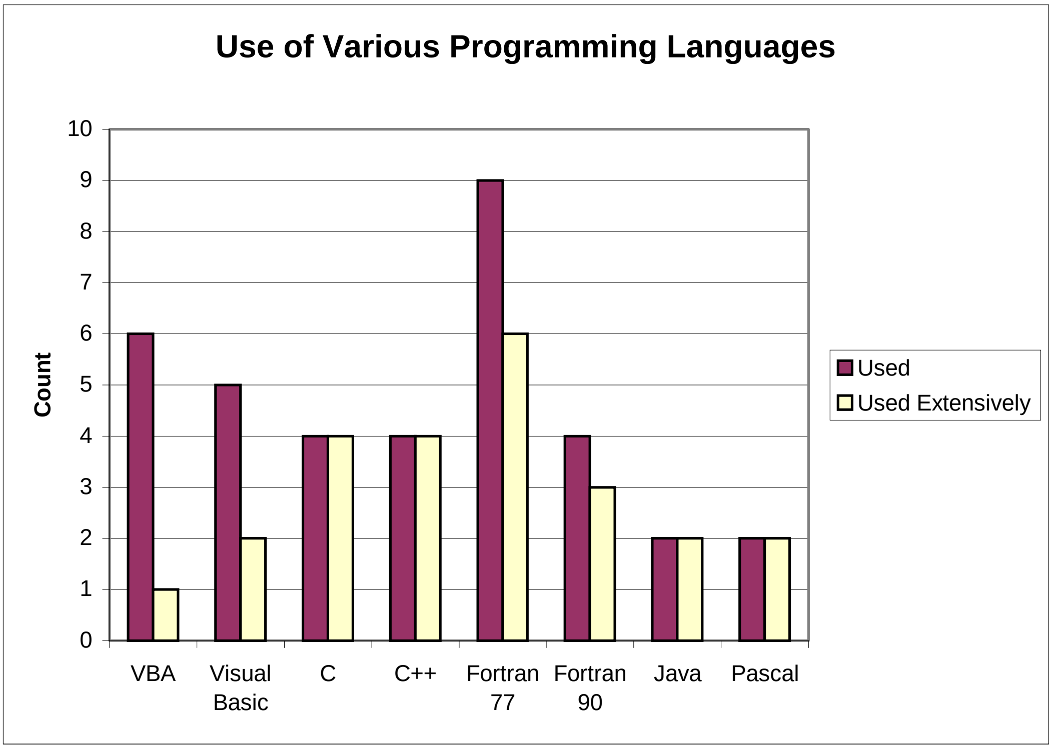

Figure 13 Programming Languages

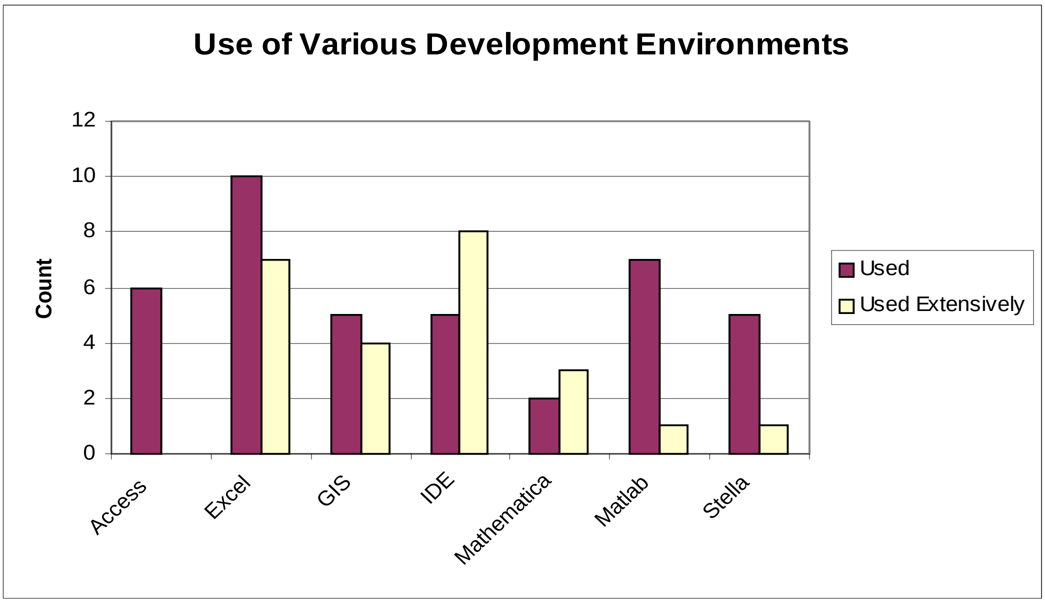

Figure 14 Development Environments

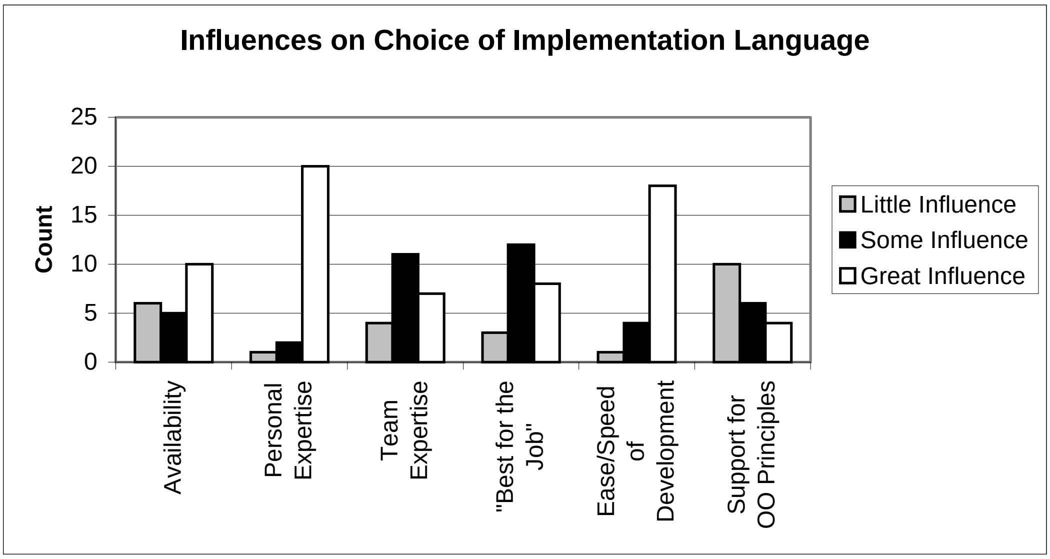

Figure 15 Influences on Choice

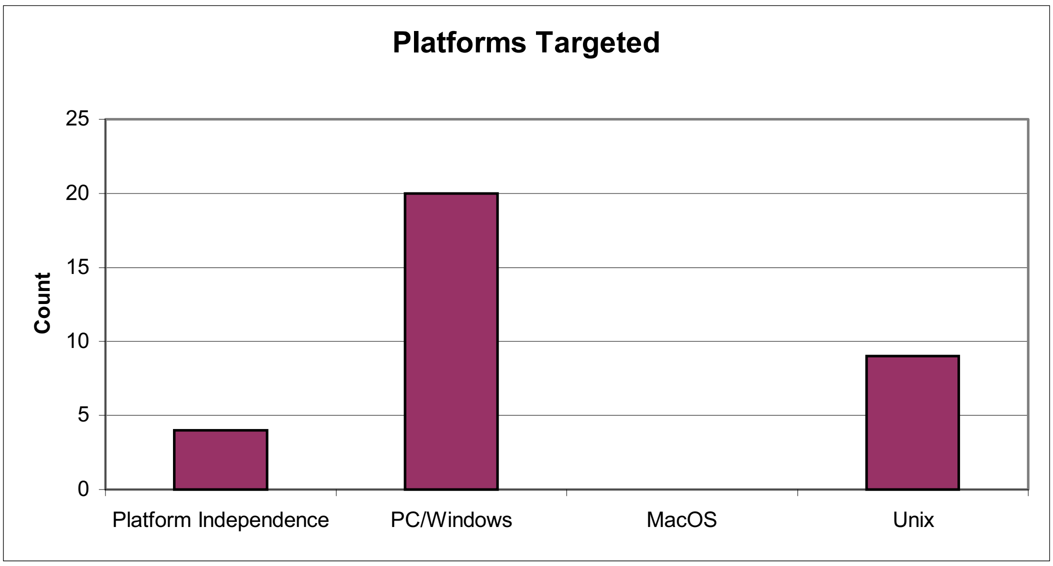

Figure 16 Computer Platform

While respondents gave quite a list of third party software that their applications intended to interact with, very few of these had a major influence. GIS, particularly ARC/INFO, scored the highest. CAD ranked very low with visualisation and data management tools given a middle ranking.

Delivery Phase

80% of applications listed in the survey were for in-house use and 50% for specific clients. Slightly less than half of in-house applications were also expected to deliver to specific clients. Of the in-house applications not expecting to deliver to specific clients, 70% expressed interest in delivering to a wider audience (**Figure 17**). The intended audience was quite wide—with scientists being the prime target, followed by catchment and water managers (**Figure 18**).

The high degree of only in-house application was surprising and probably reflects the fact that model development within the CRRCH is still dominated by the need to service the requirements of CRCCH researchers themselves. This interpretation is supported by the fact that scientists were the primary audience for most models.

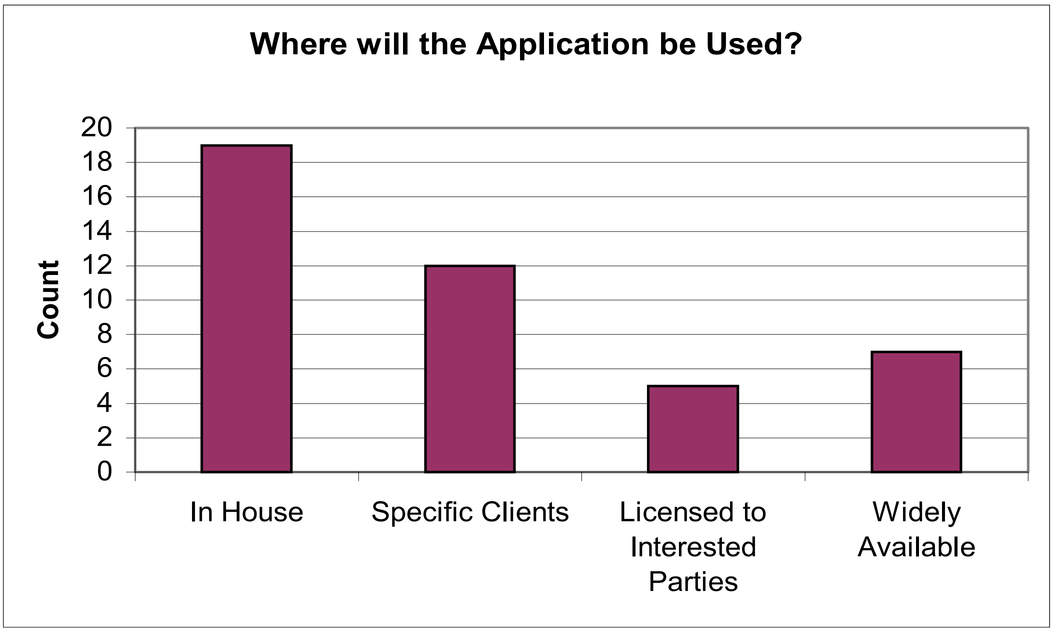

Figure 17 Model Availability

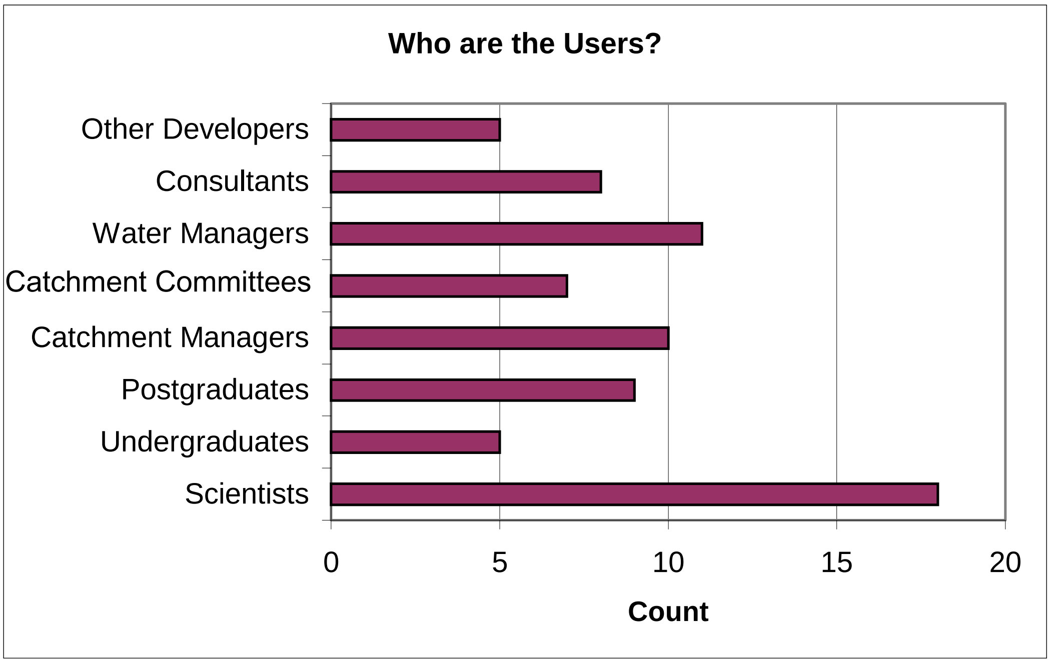

Figure 18 Target Audience

The internet was the most favoured deployment medium followed closely by CD-ROM and then on-site installation and training (**Figure 19**). Only one respondent was interested in commercial licensing. Most developers intended to distribute the executable, sample data and users manuals. 40% intended to distribute source code as well (**Figure 20**). Interestingly, 35% of applications would require users to have licences (or possibly access) to third party software.

Developers' Background

The survey indicated that model development was mostly undertaken by research scientists with postgraduate training in a hydrology-related field.

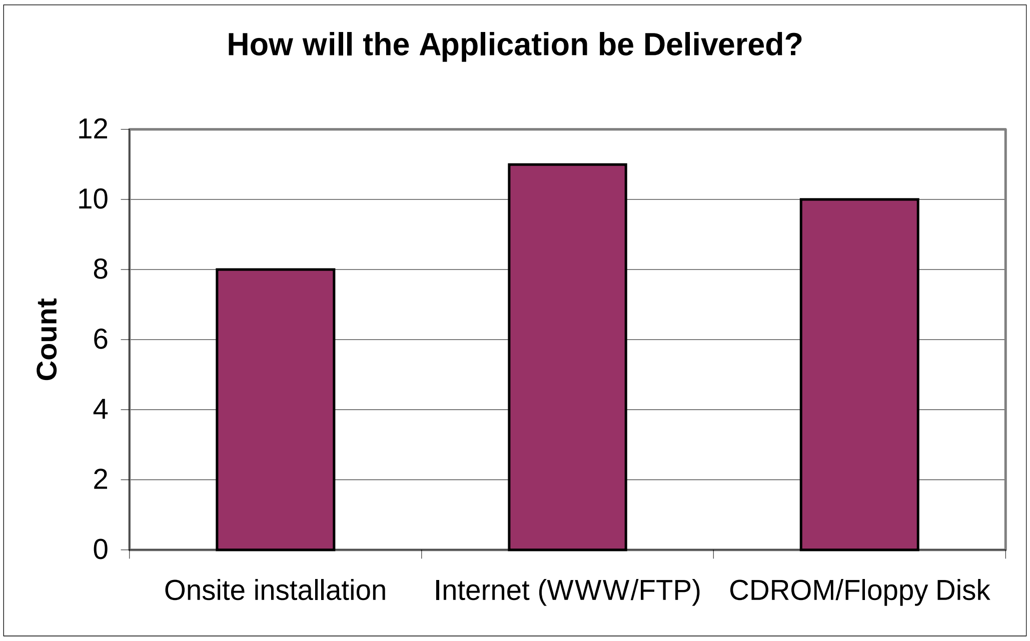

Figure 19 Delivery Media

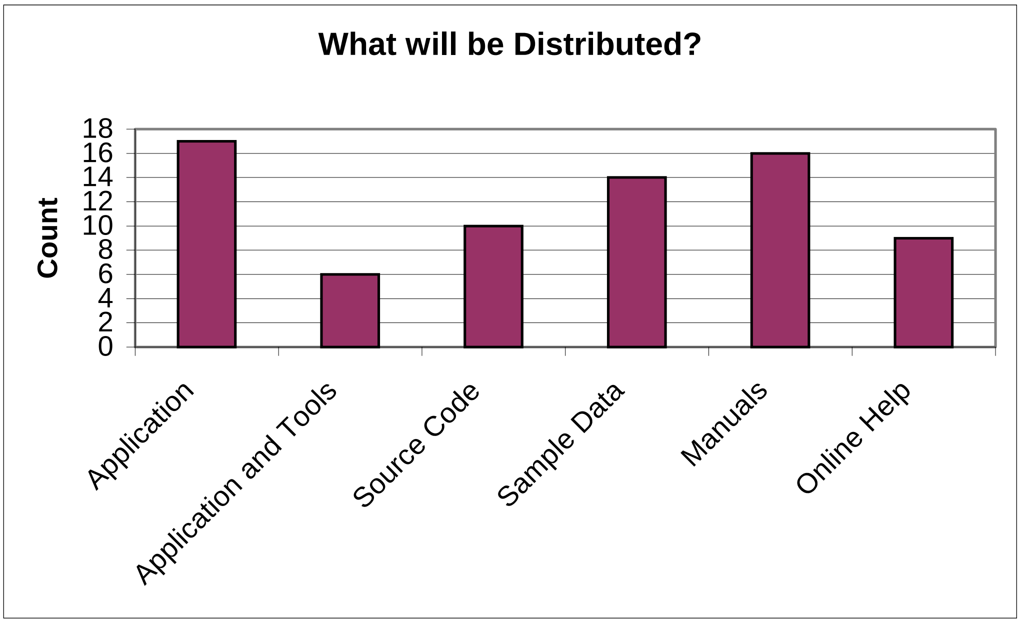

Figure 20 Distribution Components

Developers (**Figure 21**) were both scientists (70%) and modellers (50%), though 50% of scientists also described themselves as modellers. A few people were modellers and not scientists. 45% of respondents considered themselves programmers.

Professionally, most respondents were self-taught in computer science, though 40% had done some undergraduate computer science units. Respondents were better qualified in catchment hydrology/ management fields with 60% having postgraduate/ undergraduate degrees, and the other 40% being self-taught (**Figure 22**). Of the 50% who made some effort to keep up-to-date with software development practices, most was through magazines, journals and the internet (**Figure 23**).

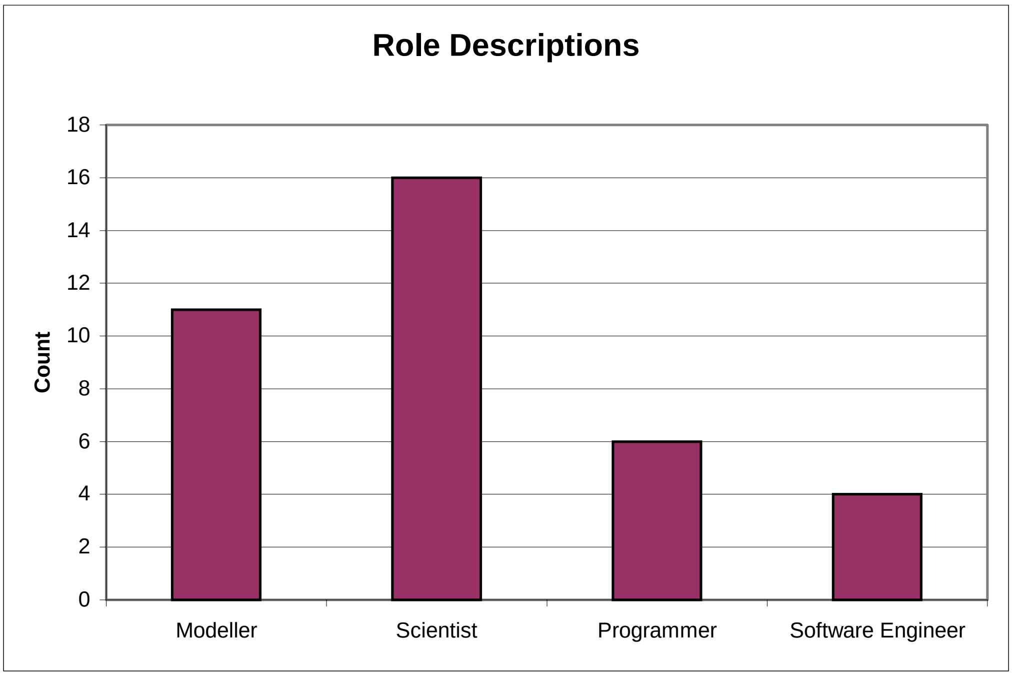

Figure 21 Characteristic Developer

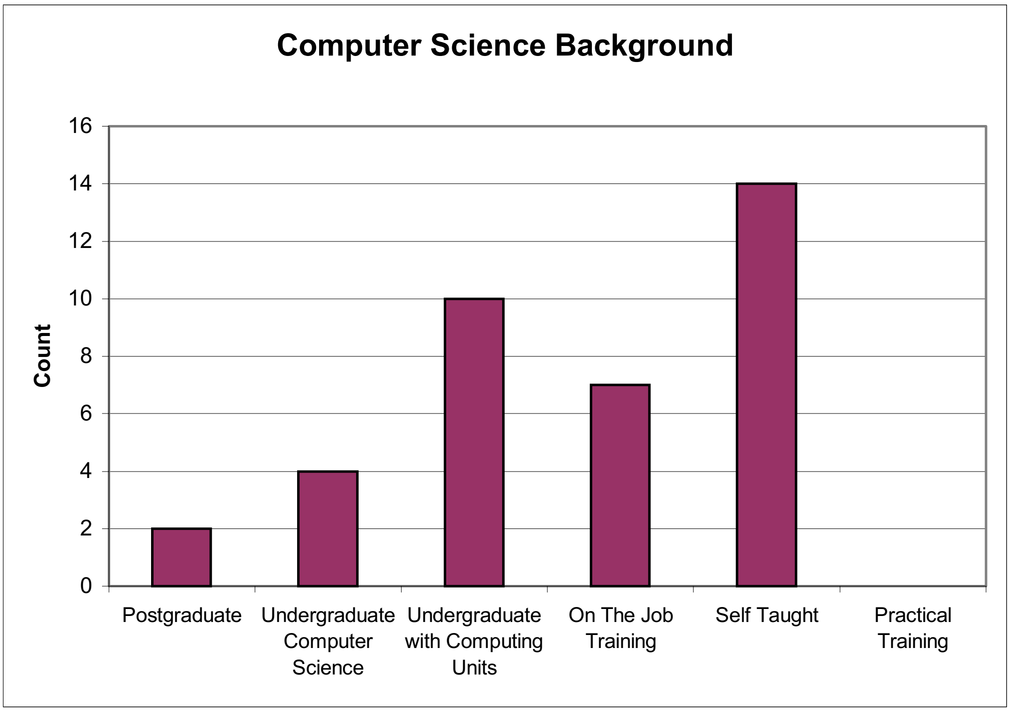

Figure 22 Computing Background

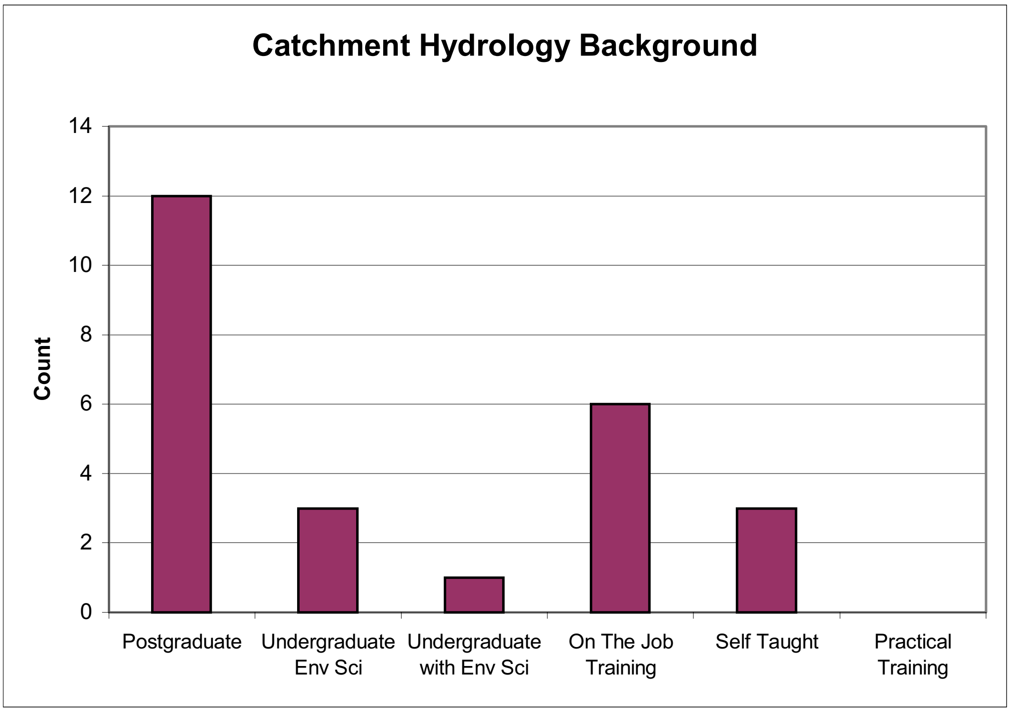

Figure 23 Catchment Hydrology Background

3.3.4 Implications and Recommendations for the Toolkit

Eight major recommendations for how the Toolkit might support the development of modelling applications, from initial definition through to deployment, have emerged from the model developers' survey.

Problem Definition Phase

As much as we would like to support model developers with their current development practices, the Toolkit will involve some procedural changes to the way people develop models. We should provide guidance at the problem definition phase of the product development to help people get in the Toolkit "frame of mind". This may involve questions and checklists about the system boundaries that guide the developer to one or more Toolkit features.

Recommendation 3.1:

Produce a problem definition phase checklist that helps developers consider the critical definition phase issues and, where appropriate, guides developers to Toolkit features.

Design Phase

Sound software engineering requires some basic design documentation, particularly as we know that collaborative research and model development is on the increase. The Toolkit should assist developers by adopting a design notation, the major requirements being minimum overhead and maximum usefulness and provision for collaborative model development. As there is no design notation established in the group, the choice, or development, is open.

Recommendation 3.2:

The Toolkit should adopt a design notation (which may be supported directly by the software) capable of integrating, either directly or through data/model standards, with other programs.

Implementation Phase

The high popularity of Fortran 77/90 amongst our model developers suggests that the Toolkit should support model development in Fortran. This may be discounted by the fact that most developers are self-taught programmers and would be able to spend some time learning a new environment. Additionally, as Excel is used extensively, the Toolkit should support Excel developers in some way (perhaps through some VBA infrastructure).

Recommendation 3.3:

The Toolkit should have some support for application development in Fortran and Excel.

Support for cross platform/platform independent development is not important to the developers. PC/Windows is by far the most common platform targeted and is targeted mainly because of ease of use and availability.

Recommendation 3.4:

Platform independence does not have to be a major feature of the Toolkit but provision for PC Windows is essential.

Delivery Phase

Most developers intend scientists to be the major users of their applications, followed by water or catchment managers. Each group will have different user interface requirements. This requires models to be developed independently of particular user interfaces.

Recommendation 3.5:

The Toolkit must support multiple or separate interfaces to underlying models.

Given that there were a reasonable number of people who expressed the desire to distribute source code, the Toolkit needs to be based on open software, with clearly defined intellectual property between the framework, the models, and the associated tools.

Recommendation 3.6:

The Toolkit must support all distribution methods and be freely available under licence.

While the survey did not elicit whether applications were web dynamic, the web is certainly seen as the principal delivery tool. There were no recommendations from this aspect of the results, however provision should be made for internet deployment.

Recommendation 3.7:

The Toolkit should support developers in managing the deployment phase by providing features that enable web site upload and maintenance.

Background

While we are looking to build the Toolkit on sound software engineering principles, it is important that model developers are not expected to have formal training in software engineering techniques.

Recommendation 3.8:

The Toolkit structure should encourage and facilitate sound software development.

4. Summary of Recommendations

The surveys provide clear messages about both the focus of modelling activity and how that activity should be conducted and supported by the Catchment Modelling Toolkit.

The issues identified in **Survey 1** contain no surprises and confirm those identified by the project team. However, the fact that the issues have not significantly changed over the past few years is interesting. Whether the current suite of models matches these issues needs to be further explored.

Recommendation 1.1:

That the modelling priorities for the Toolkit be:

- *Catchment analysis of nutrient and sediment load under different land-use*
- *Estimates of flow and nutrients at any stream point in a catchment*
- *Ecology-hydrology interactions and bioindicators, including water allocation to environmental flows*
- *Catchment salt generation from land-use, and transport through the catchment*

Recommendation 1.2:

That, given the lack of specific requests for particular model components in the Toolkit, components that meet the requirements of Recommendation 1.1 be treated as priorities for development.

Survey 2 clearly indicates that there is very little standardisation of hydrological model development or application. Researchers prefer to develop their own models, even at considerable expense in time and resources. A major implication for the Toolkit is that users are highly technically literate and the Toolkit must provide an interface for scientists that provides access to all data and the workings of the model(s).

Recommendation 2.1:

The Toolkit must provide an appropriate interface that enables all users to access all data and model components.

Survey 3 gives us good insight into the type of model developer that the Toolkit must support (and attract) and what the Toolkit must offer them. The low level of professional programming expertise reinforces the need for the Toolkit to encourage and facilitate sound software development, without dependence or insistence on formal software engineering practices. There is obviously room for the Toolkit to contribute to all stages of development, from initial description, through the design and implementation stage, to delivery.

Recommendation 3.1:

Produce a problem definition phase checklist that helps developers consider the critical definition phase issues and, where appropriate, guides developers to Toolkit features.

Recommendation 3.2:

The Toolkit should adopt a design notation (which may be supported directly by the software) capable of integrating, either directly or through data/model standards, with other programs.

Recommendation 3.3:

The Toolkit should have some support for application development in Fortran and Excel.

Recommendation 3.4:

Platform independence does not have to be a major feature of the Toolkit but provision for PC Windows is essential.

Recommendation 3.5:

The Toolkit must support multiple or separate interfaces to underlying models.

Recommendation 3.6:

The Toolkit must support all distribution methods and be freely available under licence.

Recommendation 3.7:

The Toolkit should support developers in managing the deployment phase by providing features that enable web site upload and maintenance.

Recommendation 3.8:

The Toolkit structure should encourage and facilitate sound software development.

Appendix 1: List and Brief Description of Models

Note: all web links were active at time of compilation in December 2001 but we do not guarantee their currency.

AgET

AgET is a simple water balance calculator that is designed to show how differing climates, plants, soils and rotations influence components of the water balance (i.e. evapotranspiration, runoff and deep flow). The model uses 'average' climate, and 'representative' soil and plant information obtained within the agricultural areas of Western Australia. To operate AgET, the user selects a site, soil unit, and plant or farming system of interest, and then runs the model against any other farming systems that may be suited to that environment. These calculations can be undertaken for a range of annual or perennial plants used within current farming systems.

(Source: http://www.civag.unimelb.edu.au/~argent/aget/)

APSIM

APSIM stands for Agricultural Production Systems sIMulator.

The APSIM modelling framework has the ability to integrate models derived in fragmented research efforts. This enables research from one discipline or domain to be transported to the benefit of some other discipline or domain. It also facilitates comparison of models or sub-models on a common platform.

This functionality has been achieved via the implementation of a "plug-in-pull-out" approach to APSIM design. APSIM has been developed in a way that allows the user to configure a model by choosing a set of sub-models from a suite of crop, soil and utility modules. Any logical combination of modules can be simply specified by the user "plugging-in" required modules and "pulling out" any modules no longer required.

As with any system, there are logical boundaries in that a system being simulated will require the necessary elements (in this case, modules) of that system to be valid, but the possible valid permutations of sub-models are many and varied. For example, APSIM could easily allow the user to simulate a cropping system using 2 different water balances, 2 different soil Nitrogen balances and 3 separate wheat models. The user would be able to try all 12 permutations of cropping system sub-models. However, it would be nonsense to try a simulation without a water balance (or surrogate). The simulation would fail due to lack of information for other modules. It is possible to create this invalid system in APSIM but it is destined to fail due to specification inadequacies.

In short, APSIM allows the coupling of models from separate research efforts but it is up to the designers and users of the sub-model to ensure that it will operate correctly as a component of the system described in conjunction with other APSIM modules.

(Source: http://www.apsru.gov.au/Products/apsim.htm)

AQUALM-XP

This is a comprehensive water resources quality management package with components for generating surface and subsurface runoff, point-source and non point-source pollutant export and pollutant transport and routing. It incorporates a graphical expert environment which is a friendly object oriented graphic user interface with a range of decision support functions.

(Source: http://www.xpsoftware.com.au/pdf/Aqmtdes.pdf)

AQUIFEM-N

AQUIFEM-N is a multi-layered quasi-3D finite-element model capable of predicting groundwater flow in two or three dimensions and solute transport in two dimensions. AQUIFEM-N uses linear triangular finite elements to represent the geometry of an aquifer and has very flexible options for assigning the spatial distributions of aquifer properties and the spatial and temporal distributions of boundary values.

AQUIFEM-N can be used to study steady and transient groundwater flow and contaminant transport in a single aquifer, steady and transient groundwater flow in a system of coupled aquifers, and steady flow and steady and transient contaminant transport in a two-dimensional vertical section. AQUIFEM-N was developed in 1984-85 as a multi-layered extension of AQUIFEM-1.

(Source: http://www.scisoftware.com/products/aquifem-n_overview/aquifem-n_overview.html)

AWBM

The AWBM is a catchment water balance model that can relate runoff to rainfall with daily or hourly data, and calculate losses from rainfall for flood hydrograph modelling.

(Source: http://www.catchment.crc.org.au/products/models/the_models/awbm/awbm.htm)

DATAGEN

A software tool that stochastically generates multi-site monthly streamflow and climatic data, taking into account non-continuous records. The software was purpose-built for Melbourne Water by Q.J. Wang, formerly of the Department of Civil and Environmental Engineering, The University of Melbourne.

(Source: Pers. Comm. Prof. T.A. McMahon, Department of Civil and Environmental Engineering, The University of Melbourne)

FEFLOW

Feflow is a groundwater modeling software package that combines powerful graphical features with sophisticated analysis tools and robust numerical algorithms for density-dependent flow (salt water intrusion); transient or steady-state flow; saturated and unsaturated flow; multiple free surfaces (perched water table); and mass and heat transport.

Feflow has been specifically designed to meet the advanced technology requirements of expert modelling professionals involved in complex groundwater modelling projects. The primary components of Feflow include a comprehensive selection of graphical tools for building the finite element mesh, assigning property zones and setting; boundary conditions; data import and interpolation routines including an ArcInfo (ESRI) GIS data interface; robust numerical algorithms and solution techniques; real-time data interpretation; and state-of-the-art 3-D visualization.

(Source: http://www.ssg-int.com/html/feflow_details.html)

FLOW2D

The model simulates transient 2-dimensional groundwater flow in a saturated confined or unconfined aquifer and nitrate transport via this flow. The model considers both pumping of water and outflow by rivers as well as recharging by groundwater renewal. It was designed as the hydro-geological part of a multi-disciplinary model describing the drainage of nitrate in the district of Vechta in Lower Saxony, Germany. The whole model is considering ecological, economical and sociological aspects. Nevertheless, FLOW2D is a 'stand-alone' groundwater flow model and is therefore transferable to virtually every location (consisting of a soil structure that is sufficiently homogenous).

The model works on a rectangular area with a system of nodes superimposed on it. Each node is representing a smaller sub-area of the domain. This is achieved by spatially discretizating the area, which divides it into smaller rectangles. These rectangles need not be of the same size. Each of them is assumed to be homogenous and both level of the groundwater and the concentration of nitrate in the element are calculated for it's central point, thus providing a discrete groundwater level and a discrete nitrate distribution for the domain. Transmission boundary conditions according to Shamir and Harlemann (1967) (concentration gradient to the inside has to equal concentration gradient to the outside) are used on the edges.

(Source: http://www.gsf.de/UFIS/ufis/modell54/modell.html)

FLOWTUBE

This is a simple groundwater calculator for use by agency staff, consultants and farmers to allow "what if" questions to be asked of management options. Flowtube is an initiative of the Western Australian Department of Agriculture.

(Source: http://www.civag.unimelb.edu.au/~argent/flowtube/)

GLEAMS

Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) is a continuous simulation, field scale model, which was developed as an extension of the Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) model. GLEAMS assumes that a field has homogeneous land-use, soils, and precipitation. It consists of four major components: hydrology, erosion/sediment yield, pesticide transport, and nutrients. GLEAMS was developed to evaluate the impact of management practices on potential pesticide and nutrient leaching within, through, and below the root zone. It also estimates surface runoff and sediment losses from the field. GLEAMS was not developed as an absolute predictor of pollutant loading. It is a tool for comparative analysis of complex pesticide chemistry, soil properties, and climate. GLEAMS can be used to assess the effect of farm level management decisions on water quality.

GLEAMS can provide estimates of the impact management systems, such as planting dates, cropping systems, irrigation scheduling, and tillage operations, have on the potential for chemical movement.

Application rates, methods, and timing can be altered to account for these systems and to reduce the possibility of root zone leaching. The model also accounts for varying soils and weather in determining leaching potential. GLEAMS can also be useful in long-term simulations for pesticide screening of soil/management. The model tracks movement of pesticides with percolated water, runoff, and sediment.

Upward movement of pesticides and plant uptake are simulated with evaporation and transpiration. Degradation into metabolites is also simulated for compounds that have potentially toxic bi-products.

Erosion in overland flow areas is estimated using a modified Universal Soil Loss Equation. Erosion in chemicals and deposition in temporary impoundments such as tile outlet terraces are used to determine sediment yield at the edge of the field.

Some of the features of GLEAMS include automatic irrigation, manual irrigation, and chemigation options; a comprehensive erosion/sediment yield component, allowing the user to describe in detail the topographic features of the field; all channels in the field are assumed to be naturally eroded; the evapotranspiration and canopy interception modules allow simulation of management alternatives in forested areas.

(Source: http://sacs.cpes.peachnet.edu/sewrl/Gleams/gleams_y2k_update.htm#General Overview of GLEAMS)

HYDROLOG

HYDROLOG is a catchment response model for simulation of daily stream flows that attempts to model physical processes. It synthesizes daily discharge on a continuous basis using daily rainfall and evaporation data. In using HYDROLOG, a catchment is divided into sub-areas, each of which is modeled independently. Up to four hydrologic regimes may be specified to model spatial variations in physical characteristics.

(Source: Porter, J. W. and McMahon, T. A. (1971). A model for the simulation of streamflow data from climatic records. Journal of Hydrology 13:297-324.)

IHACRES

IHACRES employs a transfer function/unit hydrograph (UH) approach to catchment-scale (lumped) rainfall-runoff modeling developed jointly by the ANU and the Institute of Hydrology. It will assist hydrologists and water resource engineers include investigations in small catchments instrumented for special studies, regional studies using readily-available data for large catchments, and quality assurance of strategically-important streamflow and rainfall records. IHACRES is used in higher education as an aid to teaching unit hydrograph theory and application.

IHACRES allows the simulation of streamflow either continuously or for individual events using discrete time interval data. Using time series data of rainfall, streamflow and temperature only—no catchment descriptive data, e.g., topography, vegetation, soils, are required—IHACRES can identify unit hydrographs (UH) for total streamflow, rather than for just a direct runoff component of streamflow. The UH for total flow can often be resolved into ‘quick’ and ‘slow’ UHs, corresponding to flow components which act in parallel. These quick and slow UHs allow the modeled hydrograph to be separated into its dominant quick and slow flow components, a feature of IHACRES which has potential application across a wide range of water quantity and quality investigations. When the hydrograph can be separated in this way, a Slow Flow Index (SFI) is a by-product of the analysis.

Data time intervals can range from less than hourly, for modelling small catchments with flashy responses, to daily or even monthly, for larger catchments with more subdued responses. The IHACRES methodology has been successfully applied to humid region catchments (perennial streamflow) with basin areas ranging from less than 1 km^2 to almost 10,000 km^2.

IHACRES comprises two modules in series. The first module operates nonlinearly to calculate effective rainfall from rainfall and temperature data. The second module (the UH part) operates linearly to convert the effective rainfall to streamflow. With three parameters in the first module, and typically three in the second, the IHACRES model is parametrically parsimonious. When good model-fits are obtained, the parameters characterize the hydrological response of the catchment.

(Source: http://www.mpassociates.gr/software/environment/ihacres.html)

IMSOP

IMSOP (Irrigation Main System OPeration) is a steady-state hydraulic model that simulates the operation of the main and secondary canals in an irrigation system. The model is designed to work in irrigation systems where there are a large number of outlets supplying either large groups of small farmers or single large farms. Demand in this model is driven by crop water requirements, although an arranged demand schedule can also be modelled. The model can be used to plan the operation of an irrigation supply systems, analyse the operational performance based on monitoring actual operation or simulate near-real time operation of the system for scheduling and computing flows to meet demand.

(Source: Pers. Comm. A/Prof Hector M Malano, International Technologies Centre, Department of Civil and Environmental Engineering, The University of Melbourne.)

IQQM

The Integrated Quality and Quantity Model (IQQM) is a planning model that is used to investigate impacts of water resources management options in regulated and unregulated river systems.

It is a hydrologic river system simulation package that operates at a daily time step. It is more effective in investigating contemporary water-sharing issues than the traditional monthly models. Processes simulated include dam operations, crop irrigation, wetland water requirements and salinity.

(Source: http://www.dlwc.nsw.gov.au/care/water/iqqm/)

LASCAM

LASCAM (Large-Scale Catchment Model) can be used to predict the long-term impact of land-use and climatic changes on the daily trends of streamflow and water quality (represented by salt, sediments and nutrients). The model is unique in that it was developed for Australian conditions that can make predictions on water quantity and quality for a large catchment. The model simulates the hydrological processes at the sub-catchment scale, before being aggregated to yield the response of the entire catchment.

Recent applications include the prediction of the water yield, salinity and sediment and nutrient outflows from the Swan-Avon. River Basin in Western Australia (catchment size 140,000 km^2). It is presently being used as a management tool to evaluate a number of catchment management options for sediment and nutrients inputs to a number of catchments feeding the Swan River, near Perth. LASCAM has also been used to assess land-use changes in tropical environments (Sarawak, Malaysia).

(Source: http://www.cwr.uwa.edu.au/~ttfadmin/model/lascam/lascam.html)

MACAQUE

Macaque is a large scale, physically based, distributed hydrological model that works at a daily time step over periods of hundreds of years on catchments up to about 100 km^2. It was developed by Fred Watson (The University of Melbourne), Rodger Grayson (The University of Melbourne), and Rob Vertessy (CSIRO

Land and Water) to predict long term changes in forest water yield resulting from changes in land cover. It is based on previous models such as RHESSys, MT-CLIM, TOPMODEL, Topog, and FOREST-BGC.

(Source: http://earthsystems.monterey.edu/~fwatson)

MIKE-11

MIKE-11 is a professional engineering software tool for the simulation of hydrology, hydraulics, water quality and sediment transport in estuaries, rivers, irrigation systems and other inland waters.

Its features include fast and robust numerical scheme; a wide range of hydrologic modules; advanced cohesive and non-cohesive sediment transport modules; comprehensive water quality and eutrophication modules; links to advanced hydrological, sewer and coastal modelling tools; and GIS add-on modules.

(Source: http://www.dhisoftware.com/mike11/)

MODHYDROLOG

Based on HYDROLOG, this model provides simulations of stream-aquifer interaction and the groundwater seepage processes to model rainfall-runoff at catchment scales. It uses daily rainfall and climate data to estimate runoff.

(Source: Hook, R. (1997). Predicting farm production and catchment processes. A directory of Australian modelling groups and models. CSIRO Publishing, Collingwood, Australia.)

NEX-1

NEX-1 (One Dimensional Hydrodynamic Program) works by using a network representation of the area of interest, and using a special technique to simulate the wetting and drying of the flood plain without having to use artificial slots, NEX-1 can accurately simulate the flood levels and velocities across the flood plain. Because it simulates structures such as bridges, broad-crested weirs, and culverts, NEX-1 can determine the impact of changes to a river system caused by urban development, canal development, highway or railway embankments, bridges, levees, ring tanks and drainage works.

NEX-1 also includes the effects of inertia and can therefore correctly simulate the impact of changes to an estuary on tidal flows.

(Source: http://www.chaselingmcgiffin.com.au/hydrosoft.html)

PERFECT

PERFECT (Productivity Erosion Runoff Functions to Evaluate Conservation Techniques) was developed for cereal growing areas of the sub-tropics of Australia. It is a paddock scale model that predicts the effects of climate, soil type, crop sequence and fallow management on the water balance, erosion, and productivity. It is a mechanistic model. The overall structure is physically based but individual processes may be represented by empirical relationships.

Simulation is performed on a daily time step.

Runoff is calculated as a function of rainfall, soil water deficit, surface roughness, surface residue and crop cover. Partial area runoff processes or subsurface flow are not considered.

Soil water is updated on a daily basis by any rainfall exceeding the daily runoff volume. For dry profiles this infiltration may flow directly into lower profile layer/s using an optional soil cracking algorithm. Infiltration is redistributed through the profile using a linear routing method. Redistribution from the lowest profile layer is assumed lost to the system as deep drainage.

Transpiration is represented as a function of potential evaporation, leaf area and soil moisture. Water is removed from the profile according to the current depth and distribution of roots.

Soil evaporation is based on Ritchie's two-stage evaporation algorithm. Following infiltration, it is assumed that drying occurs at potential rate to a user defined limit. When this limit is reached the second and slower stage of soil evaporation commences.

Soil loss is estimated a function of runoff volume, cover, peak runoff rate, rainfall erosivity, soil erodibility, management practice and catchment characteristics.

Either a Modified Universal Soil Loss Equation or a simpler method requiring no runoff rate or erosivity inputs can be used.

PERFECT can simulate crop growth at different levels of complexity. Et:pan (ratio of evapotranspiration to pan evaporation) or leaf area index models are the simplest forms of crop models with user defined annual distributions of Et:pan or leaf area index which determine plant water use. These types of simple plant water use models can be linked with yield prediction equations to give a yield index.

Dynamic wheat, sorghum and sunflower crop models use functions to predict leaf area and dry matter as functions of radiation, potential evaporation, transpiration and transpiration efficiency. Yield is predicted via equations based on dry matter accumulation up to flowering and crop growth rate at flowering.

Phenology is driven by cumulative degree days or phenology equations using temperature and photoperiod.

A daily balance of crop residue weight on the surface is maintained. At harvest, above ground crop dry matter is added to the residue pool. Residue decay and incorporation with tillage are related to residue type and tillage implement.

(Source: http://www.apsru.gov.au/Products/Perfect.htm)

PMWIN MODFLOW

PMWIN is a groundwater simulation system.

MODFLOW is designed to simulate aquifer systems in which (1) saturated-flow conditions exist, (2) Darcy's Law applies, (3) the density of groundwater is constant, and (4) the principal directions of horizontal hydraulic conductivity or transmissivity do not vary within the system. These conditions are met for many aquifer systems for which there is an interest in analysis of groundwater flow and contaminant movement. For these systems, MODFLOW can simulate a wide variety of hydrologic features and processes. Steady-state and transient flow can be simulated in unconfined aquifers, confined aquifers, and confining units. A variety of features and processes such as rivers, streams, drains, springs, reservoirs, wells, evapotranspiration, and recharge from precipitation and irrigation also can be simulated. At least four different solution methods have been implemented for solving the finite-difference equations that MODFLOW constructs. The availability of different solution approaches allows model users to select the most efficient method for their problem.

(Source: http://water.usgs.gov/software/modflow-2000.html)

RAFTS/XP-RAFTS

A rainfall and runoff networked model, XP-RAFTS uses the Laurensen non-linear runoff routing procedure to develop a stormwater runoff hydrograph from either an actual event (recorded rainfall time series) or a design storm utilizing Intensity-Frequency-Duration data together with dimensionless storm temporal patterns as well as standard Australian Rainfall and Runoff (AR&R) 1987 data.

(Source: http://www.xpsoftware.com.au/products2.htm#XP-RAFTS)

REALM

REsource ALlocation Model is a water supply system simulation package. It is general in that any water supply system can be configured as a network of nodes and carriers representing reservoirs, demand centres, waterways and pipes. It is flexible in that it can be used as a "what if" tool to address various options (new operating rules, physical system modifications). System changes can be quickly and easily configured and investigated. A wide range of operating rules can be modeled either directly or by exploiting the basic set of node and carrier types and their corresponding attributes.

(Source: REALM Getting Started Manual. VUT and DNRE, 1997.)

RORB

This is a rainfall-runoff event model for flood estimation, flood routing, retarding basin design and flood forecasting.

(Source: http://www-civil.eng.monash.edu.au/research/groups/water/RORB)

SMF2D

No information currently available. Please contact Mike Trefry, at CSIRO Land and Water.

(Source: Trefry, M G. SMF2D: a general continuum code for simulating transport in stratified porous media; development and validation. In: Johnston, C.D. (Ed) (1999). Proceedings of the 1999 contaminated site remediation conference; March 21-25, 1999. Fremantle, WA. Wembley, WA: Centre for Groundwater Studies, pp 274-280.)

SWAGMAN

The SWAGMAN (Salt Water And Groundwater MANagement) series of computer models has been developed to determine the impacts of management and climate on water tables, salinisation and yield, and the trade-offs between environmental objectives and profitability.

(Source: http://farrer.csu.edu.au/rice/research/program1/reports/waterable.html)

SWAGMAN FARM

SWAGMAN Farm is a farm scale optimisation model which predicts the most economic cropping mixes that meet specified net recharge and root zone salinity objectives, taking into account farmer preferences. Regional groundwater models have been developed to evaluate the impacts of climate and management on watertables.

(Source: http://farrer.csu.edu.au/rice/research/program1/reports/waterable.html)

SWAT

This is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds.

(Source: http://www.brc.tamus.edu/swat/)

THALES

Best regarded as a modelling framework, Thales dynamically simulates storm events and has the capacity to simulate runoff produced by Hortonian overland flow, saturation overland flow and subsurface flow. The model predicts flow depth and velocity, and discharge at any point in a catchment. Simulations are based on vector elevation data.

Thales was specifically developed to test hypotheses, analyse field data and explore general issues related to model use, including identifying barriers to improving small scale catchment hydrology modelling using distributed-parameter, process-based models.

(Source: Hook, R. (1997). Predicting farm production and catchment processes. A directory of Australian modelling groups and models. CSIRO Publishing, Collingwood, Australia.)

TOPOG-DYNAMIC

TOPOG-DYNAMIC is a terrain analysis-based hydrologic modelling package which can be used to (1) describe the topographic attributes of complex three dimensional landscapes, (2) predict the spatial distribution of steady state waterlogging, erosion hazard and landslide risk indices, (3) simulate the transient hydrologic behaviour of catchments, and how this is affected by changing catchment vegetation, (4) model the growth of vegetation and how this impacts on the water balance, (5) model solute movement through the soil and (6) model sediment movement over the soil surface.

TOPOG-DYNAMIC is a daily time step model that describes how water moves through landscapes; over the land surface, into the soil, through the soil and groundwater and back to the atmosphere via evaporation. Plant growth, conservative solute movement and sediment transport are also simulated.

(Source: http://www.clw.csiro.au/topog/)

URBS/URBS-CM

This is an event based runoff routing model suitable for integrated catchment management and flood forecasting.

URBS-CM is a non-linear runoff-routing networked model of sub-catchments based on centroidal inflows. Three routing models are available to describe catchment and channel storage routing behaviour. The Basic Model is a RORB-like model where stream length (or derivative) is assumed to be representative of both catchment and channel storage. The Combined Model combines the sub-catchment area and stream length or derivative to be representative of the catchment and channel storage, whereas the Split Model separates the channel and catchment storage components of each sub-catchment for routing purposes. Irrespective of the model used, each storage component is conceptually represented as a non-linear reservoir and Muskingum routing is used for channel routing.

(Source: http://www.wmo.ch/web/homs/homs/k22212.html)

WAVES

WAVES is a one-dimensional daily-timestep model that simulates the fluxes of mass and energy between the atmosphere, vegetation, and soil systems, which has been under development since 1993. It is a process-based model that couples these systems by modelling the interactions and feedbacks between them. WAVES attempts to model each sub-system with a consistent level of detail, so that no area is over emphasized or requires too many parameters, and similarly no area is treated in a trivial manner.

(Source: http://www.clw.csiro.au/waves/)

WEC-C

The Water and Environmental Consultants-Catchment application has a spatial discretization in the form of a rectangular, uniform grid, operates in a continuous temporal mode, and predicts movement of water and non-point based solutes. It requires inputs of topography, soils, and climate, and provides outputs of water and solute movement. It has been applied over areas up to 50 km^2. The application models vertical and lateral fluxes via a split solver routine, with solute transport primarily advection based.

(Source: Croton, J.T. and Barry, D.A. (In press). WEC-C: A fully distributed, deterministic catchment model—foundation, formulation, testing and application. Journal of Hydrology (submitted).)

WSIBal

WSIBal is a computer model that simultaneously solves the coupled mass balances of water, a conservative solute tracer (e.g. chloride) and environmental isotope tracers (e.g. d 2H, d 18O). The model can be used to solve for unknown components of the lake water balance, with the coupled environmental isotope tracer balance in WSIBal providing additional model constraints that extend the conventional water and solute balance approach.

(Source: http://www.cig.ensmp.fr/~iahs/redbooks/a262/26277.htm)

Appendix 2: Survey Participants

The project team gratefully acknowledges all the survey respondents and thanks them for their honesty and support in participating in the project. Participants are listed below:

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