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Runoff Model Selection on Performance Criteria

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SUMMARY. A procedure for runoff model selection is presented, based on the logical relationship between modelling objectives , performance criteria and model capabilities. Models relevant to stormwater management of an urbanising catchment are evaluated and a case study of model selection in this field presented. The importance of local validation in an appropriate form is highlighted and further comment is offered on this and other key issues in the conclusions.

1. INTRODUCTION.

This paper has been written for the practising Engineer, as a guide to runoff model evaluation and selection.

Over the last decade or two, the profession has been presented with a rather overwhelming range of alternate procedures for modelling runoff. In most cases, these newer models are much improved in their capabilities and potential accuracy. However, despite these improvements , the newer models have to date been little used.

Given the rather considerable increase in computation associated with most of these new models, the small scale of most drainage projects and uncertainty as to the cost savings arising from use of these models ,it is hardly surprising that the Rational Method remains the dominant procedure in use today for modelling runoff(peaks).

There is however, every reason to believe that this situation is changing and changing rapidly. If this observation is correct, the profession can expect to encounter many real problems. The art in runoff modelling is considerable, making it difficult to transform into quantified guidelines. The lack of such guidelines, and rapid adoption of runoff modelling by the civil engineering profession at large, must inevitably introduce problems associated with lack of experience on the part of the user.

2. THE GROWTH OF MODELLING

Inherent in past arguments against adoption of more comprehensive procedures for runoff modeling are several assumptions which may have been reasonable in the past, but which are clearly not true at the present time. In particular,

> Increased computational effort is no longer prohibitive in time or cost. Most models can now be run on a desk top microcomputer (although data preparation can be time consuming).
>
> We can be confident that use of more comprehensive models will significantly improve the accuracy of our results, provided that the model has been appropriately selected and calibrated.

Whilst these changes alone would not be sufficient to precipitate a move towards more sophisticated runoff modelling procedures - changes in our approach to stormwater runoff management and the law, now seem destined to force the issue.

The objectives and methods of stormwater management have now been well researched, tested, published and applied in practice.(Local Govt. Shires Assoc.,1982),(ASCE,1975). We are no longer working on the fringe of a new approach to drainage design in discussing such subjects as, for example, major and minor drainage systems, flood ways and flood plains, retardation and retention storages . There is no longer any reasonable excuse for current drainage design failing to meet these management objectives.

If we are to ensure that these objectives have been met in our design, it will also mean in most cases that we must look to the more comprehensive runoff modelling procedures for confirmation.

Additionally, there is an increasing awareness of our responsibility at law, in undertaking drainage works which could adversly affect others. Whilst we may be tempted to accept the inherent inaccuracy of older procedures, because of their ease of use and familiarity , neither a flooded land owner nor the courts are likely to be impressed by or accept such reasoning.

Use of older procedures must represent a degree of negligence if use of a more comprehensive model would have made the problem apparent and prevented its occurrence.

With the advent and widespread use of mainframe, mini and desk top micro computers in engineering design offices there now seems no justifiable reason why advanced runoff modelling procedures should not be used whenever their functionality is required and adequate data for calibration is available.

Accepting therefore, that the trend towards widespread use of the newer and generally more comprehensive runoff models is here to stay, we must now face the question of "how do I choose and what can I expect" from the array of available models.

It is the authors' observation that the answer is frequently made without reference to the problem, on the basis of familiarity and ready availability of a specific model, with no real appreciation of what can be expected .

It cannot be denied that a substantial demand on the users time is created when a runoff model is used for the first time. There is equally and more importantly however, a considerable risk in attempting to model processes with a model that does not provide the necessary level of functionality. If we cannot be confident that we have improved our modelling accuracy in utilising a more comprehensive model, then we have defeated our sole purpose in using it.

Selection of a model on a more logical (performance criteria) basis is however greatly hampered by the proliferation of models, their considerable functional differences, and the limited amount of published documentation in support of any particular model. This is particularly true in respect to published experiences in validating and applying models in Australia. Even where such experiences are published, they generally do not contain adequate data for a new user to duplicate results, greatly reducing the value of the work in establishing user confidence.

Given the rather confused state of the art ,it is clear that there is a need for guidance as to more logical selection and application of these tools. The ready availability of an increasing variety of sophisticated models and a tendency to apply models without local validation, may otherwise be confidently relied on to create chaos .

The need for guidance, is in the authors' opinion, both immediate and real. With respect to model selection, the following outlines and offers comment on a procedure which the authors have developed as an aid to,

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3. MODEL SELECTION.

Runoff Model selection may be divided into six logical steps as follows:

3.1 Definition of Problem and Objectives.

The first step in the solution of any problem, is to define the problem and establish clearly the related objectives.

Primary objectives should first be established through consideration of the class of problem and any statutory requirements that may be applicable. A decision should then be made as to the general approach to be used in dealing with the problem. This decision will, in tandem with the primary objectives, lead to a list of secondary, more detailed objectives covering both the problem and the proposed method of solution.

3.2 Establishment of Performance Criteria.

This step may be regarded as a description of required model outputs. Having defined the problem and its associated objectives , the designer or analyst must use his engineering skills and judgement to determine what information is required and in what format it should be presented, to most readily confirm that the stated objectives have been met.

Having established the required performance criteria, a decision as to the level of capability required should be considered. Some criteria will certainly be more important than others, demanding a higher capability in that area of the model.

3.3 Inventory of Data.

It is likely that each of the models investigated will require differing types and amounts of input data. It is important therefore to take stock of what data is either available or obtainable before attempting to select a suitable model. The lack of specific data may be a quite significant constraint in the final selection process.

However, no matter how simple and readily available the required data is , the Engineer should always visit the site to see, feel and sample what his model is representing.

3.4 Review Of Published Validation Studies.

Before a runoff model may be used with any confidence in a specific locality it must be validated by testing and/or calibrating the model using local data.

Where local testing and/or calibration of a specific model has not previously been undertaken, a program of local validation should be implemented, or the model removed from the inventory of locally accepted models.

3.5. Model Inventory

It would be an almost impossible task to produce a list of all runoff models (and their many descendants) available at the present time - such is the profusion of models.

Many models will however be of little interest to a specific user, given the restricted range of problems he normally encounters.

In this respect the following inventory and tabular dissection has been oriented to the author's own main area of interest - that of stormwater management of an urbanising catchment. Other areas of application will certainly lead to a different inventory of models of interest.

MODEL	(REFERENCE)	FEATURES
ARBM	(Inst.Eng.Aust.,1977)	CSIRO developmental
CJSUH	(Johnston-Cross,1949)	Unit hydrograph
CWSUH	(Cordery-Webb,1974)	Development of CJSUH
FLOUT	(Price,1977)	UK Flood Studies Model
HEC1	(HEC,1973)	US Army Comprehensive suite
ILLSD2	(Yen et al,1976)	Cost optimising design
ILLUDAS	(Terstriep,1974)	Design of minor system
ILLUDAS	(Fok et al,1977)	Cont Simulation Vers.
ILLUDAS	(Han-Delleur,1979)	Cont Sim and Quality
ILLUDAS	(Patry-Raymond,1979)	Interactive Mini
ILLUDAS	(Han-Rao,1980)	Least Cost Design Vers.
ILLUDAS	(Watson,1981)	Metric Version
ISS	(Sevuk et al,1973)	Pipe flow anal/des.
PIPENET	(Bloomfield,1980)	Comprehensive Rational
PSRM	(Kibler-Aron,1979)	SWM ,Kinematic wave.
PSRMM	(Rigby-Watts,1983)	Metric version
RATIONAL	(Mulvaney,1851)	Rational introduced
RATIONAL	(Inst.Eng.Aust.,1977)	Deterministic
RATIONAL	(Pilgrim-McDermott,1981)	Statistical
RORB	(Mein et al,1974)	Runoff Routing
RFF	(Boyd,1978)	Regional Flood Freq.
RSWM	(Goyen-Aitken,1976)	SWM ,Runoff Routing
STORM	(HEC,1977)	Simple Water Quality
SWMM	(Metcalf et al,1971)	Advanced quality

TRRL	(RRL,1976)Early Minor sys design.	
URBHYD	(Moodie,1979)SWM ,VPMC routing	
URBCON	(" ")Water qual. ext.	
URBODO	(" ")" " "	
WBNM1	(Boyd et al,1979)Simple Runoff Routing	
WBNM2	(" " ")Areally varied rain	
WASSP	(Price et al,1982)Soph. urban design	

An individual assessment of the capability of a select range of the above models is presented in Table 1. Capabilities not available in the current version of an original model but provided in a descendant version are indicated in the table thus (+).

3.6 Model Selection

In comparing performance requirements with model capabilities , it will become clear as to which models are most suited to the problem and available data.

Allowing for necessary local validation will typically reduce the final choice to only one or two models.

It is quite likely that that there will be times when no model meets all performance criteria. In such cases, it will be necessary to look at those models which come closest to matching the set of performance criteria. If the areas of noncompliance are not critical, it may still be possible to accept some models. Where this is done, the intending user must however understand in depth, the significance of non compliance.

In the general case, the ultimate choice as to which model is used , will typically be determined by how well the model meets or exceeds those criteria considered critical by the user.

It will be prudent however, in most cases to apply at least one other model to the problem, as a check on the chosen models' results.

4. MODEL VALIDATION.

It cannot be over emphasised that, no matter how well a model is respected and how well it meets the performance criteria set for the particular problem at hand, if the model has not been tested and calibrated for the specific conditions in the locality in which it is to be used then it should not be used in that area. The onus is upon the user (or reviewer) to confirm to his satisfaction that this validation has been undertaken before using (or accepting) results from the model.

There are in general two types of runoff model validation that should be undertaken before the model is put into service. These are,

A) Program (Code) Validation

B) Model (Performance) Validation.

4.1 Program (Code) Validation.

Validation of the program coding clearly refers only to the computer based models in use. Such validation involves checking of the program code in order to make sure that the program is functioning as the programmer intended. Since this is impossible without source code, a user should be most careful in using runoff models for which sources are not available.

Assuming that the basic coding meets the users criteria for installation on his system, the program is then normally compiled and run with a series of sample problems supplied by the program author. In this way cross checking of results can be undertaken as a further test of code stability.

This phase, being related solely to the internal structure of the program, need only be undertaken once by a user implementing a particular model.

4.2 Model (performance) Validation.

In contrast, model validation will normally be required for each change in locality of application of the model due to differences in rainfall and physical characteristics of catchments. Additionally, since models may be applied in either design or analysis mode, there arises a need for the form of model validation to reflect the mode of model application.

Design Mode

In design mode ,statistically generated rainfall is combined with data based on average catchment conditions to simulate the resulting runoff.

Analysis Mode

In analysis mode, an actual (historic) hyetograph of rainfall is combined with data based on actual catchment conditions to produce the simulated runoff .

Errors in both the statistical analysis of rainfall and assessment of average catchment conditions will be locked into the calibration parameters of any design mode calibration . This poses no problem whilst the model is used in design mode, but could lead to quite incorrect results if the model was then applied in analysis mode without recalibration.

5. A CASE STUDY - LAND DEVELOPMENT IN THE ILLAWARRA.

The procedure outlined above was used to review the range of models suited to implementation of a stormwater management scheme for an urbanising catchment at Cordeaux Heights (a suburb of Wollongong), and to select the model upon which final design would be based.

The study catchment occupies an area of about one square kilometre in the foothills of the steep Illawarra escarpment. Signifigant characteristics of the area are its high rainfall intensities and rainfall gradients, steep well defined catchments in the foothills and relative impermeability of the underlying talus clays.

5.1. Statement of Objectives.

The primary stormwater management objectives were generally to;

Economically provide for the conveyance of runoff of stormwater from the development at a standard equal to or in excess of that expected by the public and/or required by the relevant authorities, and

Absorb, retain and/or treat , on the site, runoff to the extent that after development the quantity and quality of water leaving the

TABLE 1.

MODEL DISSECTION

	SWMM	HEC1	WASSP	ILLSD2	STORM	RSWM	RORB	PSRM	ISS	ILLUDAS	FLOUT	URBHYD	WBNM	TRRL	CWSUH	A RATNL	P RATNL	EXAMPLE
GENERALLY.																		
Overall -Ease of Use			*	*	**	*	*	*	*	**	*	*	***	**	**	***	***	**
-Capability	***	***	***	**	**	**	**	**	**	**	**	**	*	*	*			**
-Validation(Overall)	***	***	*	**	***	*	**	**	*	***	**	*	*	**	*	**	*	**
-Validation(local)#						**	**	**			*		**		**	**	*	***
-User Base (Overall)	***	***	*	**	***	*	**	**	*	***	**			**	**	***	*	**
-User Base (Aust.)						*	**	*			*				***	***	*	***
-Source Code Available	***	***	*	***	***		***	***	***	***	*	***	***	***	NA	NA	NA	***
-Metric I/O			***			***	***	(+)		(+)	***	***	***	***	***	***	***	***
Simulation -Single Event	***	***	***	***		***	***	***	***	***	***	***	***	***	***	***	***	***
-Continuous	***	***	*	*	***	*	*	*	*	*	*	*	*	*	*			
Type -Process(Deterministic)	**	**	**	***	**	*	*	***	***	***	***	***	*	***	**	***		***
-Blackbox(Stochastic)	**	**	**	*	**	***	***	*	*	*	*	*	***	*	**	*	***	
Application -Analysis	***	***	***	***	*	***	***	***	**	**	**	**	*	**	*			**
-Design	**	**	***	***	*	*	*	*	**	***	*	*	*	**	*	*	*	***
-Planning	***	**	*	*	***	*	*	**	*	*	*	*	*	*	*	*	*	**
BASIC CAPABILITIES																		
1.Data Input Generally	***	***	***	**	*	**	**	**	*	**	**	**	*	*				**
-Calibration Insensitivity	*	*	*	**	*	*	*	**	**	**	**	**	*		**	**		**
2.Rainfall Model Generally	***	***	**		*	**	**	**	**	**	*	*	*	*				**
-Temporal Variability Accommodated	***	***	***		**	***	***	***	***	***	**	**	**	**	*			***
-Spatial Variability Accommodated	***	***	***			**	**	***		**	*	*						**
3.Loss Model Generally	***	***	**		*	**	*	**	*	**	*	*	*	*	*			**
-Pervious Surfaces Accommodated	**	**	**		**	**	**	**	**	**	**	**	**	**	**			**
-Impervious Surfaces Accommodated	**	**	**		**	**	**	**	**	**	**	**	**	**				**
-Temporal Variability Accommodated	**	**	**		*	**	*	**	*	**	*	*	*	*	*			**
-Spatial Variability Accommodated	**	**	**			**	*	**	*	**	*	*						**
-AMC Adjustment of losses	**	**	*			*	*	**		**								
4.Overland Flow Model Generally	***	***	**	*	*	*	*	**	*	*	*	*	*	*	*			**
-Topog. Variability Accommodated	**	**	*	*				**		*								**
-Separate Perv/Imp Runoff Routing	**	*		*				**		**								**
5.Pipe/Streamflow Model	***	***	***	***		**	**	**	***	**	***	***		*				**
-Major / Minor System Accommodated	**	**	**	*		**	*	***	*	*				*				***
-Floodplain Flows Accommodated	**	**				**	**	*			***	***						
-Special Storages Accommodated	***	***	**	*		**	**	**	*	*		**		*				***
-Elements Designed			***	***					***	**				**				***
-Minor System HGL Determined									***	(+)								**
6.Data Output Generally	***	***	***	***	**	***	***	***	**	***	**	**	*	**				**
-User Control	***	***	***	***	**	***	***	***	**	**	*	*	*	*				**
-Full Hyeto/Hydrographs Output	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***			***
-Minor Sys. Surcharge Detailed	*	*	*	*		**	*	**	*	*				*				*
-Graphic Presentation Available	*	*	*			*	*	*						(+)				*
MISCELLANEOUS CAPABILITIES																		
A.Water Quality Model Generally	***	***			***					(+)		(+)						
B.Water Treatment Model Generally	***	***			***					(+)								
C.Cost Optimisation Model Generally	**	**	**	***						(+)								
D.Flood Damages Model Generally	**	**																

Local-Illawarra (NSW.)

LEGEND : | *** | High/Max | ** | Average | * | Low/Min | | None |
| (+) | Available in a descendant model.

developed site would neither create nor increase any existing (runoff related) problems.

Arising from these generalised objectives were several more specific objectives, the two most important being,

Within the development, no flooding of private property should occur in the 1:100 year flood event.

There should be no increase in peak discharge at the catchment outlet as a result of development.

After a review of alternate approaches it was decided that a major/minor storm drainage system should be provided utilising the existing creek system insofar as this was practicable. The minor system would lead into a piped "dry weather flow" network and the major system would incorporate retarding basins to control peak discharge.

This decision , lead in turn to other secondary objectives relating to the depth of basins, depth and frequency of inundation of roads etc.

5.2 Establishment of Performance Criteria.

To meet these various objectives, the selected model would preferably be design and planning oriented, with sound regional (design mode) validation as the study catchment was ungauged. An ability to model the interactive major/minor system flows would be a necessity , as would facility to model special storage structures.

A physically based (process oriented) model would be desirable to account for variations in topography, soil type, cover and the effects of urbanisation. An ability to accept comprehensive input specification of the special storages and to output in a practical format details of their interaction would also be most desirable.

5.3 Inventory of data

Topography and cover were well documented with detail contour information and both high and low altitude aerial photography.

Soil type and stratigraphy had been well documented from a geotechnical point of view, but quantified data was lacking on soil infiltration characteristics.

Recent rainfall intensity-frequency-duration data was available from the Bureau of Meteorology.

5.4 Review of Published Validation Studies.

Since the closest gauged catchment was several kilometres away , any regionally based model validation studies would require additional consideration before their results could be confidently applied to the Cordeaux Heights catchment.

Given the constraints of time and project scale, it was decided to accept the conclusions of regionally based studies provided ,

When applied to the Cordeaux Heights catchment, using regionally based calibration parameters, models produced similar results (w.r.t. peak, shape, volume of the runoff hydrograph).

Since the majority of regionally validated models had only been calibrated for design mode rural use this intermodel comparison was performed on the catchment in its predevelopment form.

Agreement between these models (PSRM, RORB, WBNM1, CWSUH, Rational(ARRO), Rational(PMc)), was quite good, with only one model (Rational(PMc)) producing results sufficiently out of range to warrant its exclusion.

5.5 Model Inventory

The models described in Table 1. were those considered as most relevant to the class of problem involved (storm water management of an urbanising catchment).

5.6 Model Selection

When the performance requirements (EXAMPLE in Table 1) are compared with model capabilities , those models most suited to the task can be seen to be

RORB RSWM and PSRM.

RSWM was however, not considered further as source code, rated essential by the authors, was not available.

Both RORB and PSRM failed to meet the criteria for design of elements and check of the minor system HGL. Since this noncompliance was common to both and related in the main to usefullness rather than accuracy of output, it was not considered sufficient reason to reject either model.

With respect to additional features, the physical approach taken by PSRM was considered a substantial benefit in reviewing the impact of urbanisation . The "peak flow presentation table" of PSRM was also rated highly because of its ability to assist the designer in planning and reviewing the performance of special storages.

PSRM was therefore finally chosen as the model upon which design would be based although some areas of output were duplicated by RORB and various other models as an ongoing check on model stability.

6. CONCLUSIONS.

6.1. The selection process should begin with a definition of the problem and its related objectives - output required to meet these objectives becoming in turn, performance criteria for model selection. In this way, the most suitable model will be selected for the job at hand.

6.2. Runoff model implementation and validation requires a considerable amount of time . Much time can be saved by first deciding what is relevant and restricting consideration to real alternatives.

6.3. Discussion on validation has justly dominated this paper. It's importance can not be overemphasised. Model users should take care in reviewing validation claims to ensure that the level and mode of validation is appropriate to the application.

Models calibrated in design mode should not be used in analysis mode without recalibration (and vice-versa).

In addition, there are many levels of validation possible. Users or those relying on the results of models should make sure that they understand how the model was calibrated (viz. discharge from a recollected flood height in 1921 or yesterdays stream gauge reading.)

This level of validation takes on particular signifigance whenever a model is used in a review capacity . Given the profusion of and mounting enthusiasm for use of more sophisticated models, disputes between the reviewing authority and designer are almost guaranteed.

A mandatory requirement for sound local validation before any model is used in a review capacity is clearly warranted.

6.4. In preparing for the future, all Local Government Authorities should start collecting and collating basic rainfall and runoff data for their area. Any area without this basic data is certain to otherwise find itself in the middle of many modelling related arguments.

6.5. Finally , no practising Engineer should feel intimidated by these apparently sophisticated computer based models. Often the techniques employed will be found to be disturbingly simple, the high respect commanded being at times quite unjustified. The profession needs to bring experience and stability into this field if runoff modelling is to be of real value in the eighties.

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