SERIES ON MODEL CHOICE

Designed to assist you to better understand catchment modelling and model selection

www.toolkit.net.au/modelchoice

2 Water quality models - sediments and nutrients

CONTENTS

COOPERATIVE RESEARCH CENTRE FOR CATCHMENT HYDROLOGY

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Summary

- Many applications of models from the Catchment Modelling Toolkit (www.toolkit.net.au) relate to predicting sediment and nutrient loads and concentrations from catchments under a range of management scenarios.
- While there are numerous water quality models, the fundamental concepts on which they are based are relatively few and quite simple. There are three basic components of most water quality models – generation, delivery and transport. Model users should understand the basic approaches implemented to represent each component.
- Models are based on different types of averaging across time (daily versus long-term), space (paddock to catchment) and processes (eg. hillslope, gully and streambank erosion separately or lumped together). The way in which averaging is done strongly affects the way results should be interpreted as well as the types of problems for which the models are suited.
- While the basic concepts that underpin models of sediment and nutrient movement are relatively well known, the data to calibrate and fully test models is generally inadequate. Limited high quality data will almost certainly be the greatest constraint on the accuracy of models of sediment and nutrient generation, transformation and movement.
- Without good calibration data, water quality models are really an "educated guess". It is fair to say that, in practice, there is virtually never enough appropriate data to undertake a formal validation of models of this type. Nevertheless, confidence will be greatly improved by utilising any good data.
- Often water quality modelling is used more in a comparative rather than absolute sense. In either case it is critical that the modeller knows their model and data well, is able to realistically interpret the results, and is aware of how the assumptions in the modelling will affect uncertainty in both absolute and relative results. This uncertainty must also be conveyed to the users of the information.
- Despite the uncertainty inherent in modelling a complex system with often limited data, water quality models are an important tool to assist managers. It is virtually impossible to assess the effectiveness of management actions without using modelling to represent the actions, as well as climate and influences unrelated to the actual management actions. Models can also assist in setting realistic targets and measuring performance against targets.
- This paper discusses the fundamentals of water quality modelling and the models CMSS, AEAM, SedNet, EMSS, MUSIC and IQQM in relation to these fundamentals and the "model choice decision loop" discussed in Paper No.1 of this series (see www.toolkit.net.au/modelchoice).

Background

SEDIMENT AND NUTRIENT LOADS – A WIDESPREAD CATCHMENT ISSUE

One of the most common applications of models from the Catchment Modelling Toolkit relates to predicting sediment and nutrient loads and concentrations from catchments under a range of management scenarios.

The National Action Plan for Salinity and Water Quality and several other State and national initiatives have been put in place to assist regional groups to manage high sediment and nutrient loads and sources in their catchments. Effective management requires a rational basis for assessing those sources and their variation over time and location.

MAIN CRC MODELS AVAILABLE

The three main models currently available through the CRC are SedNet, EMSS and for the urban environment, MUSIC. SedNet and MUSIC can be downloaded from www.toolkit.net.au, but EMSS is supported only for current CRC Development Projects and a small number of consultants. The reason for this is that EMSS is being replaced by a more flexible modelling framework known as E2, version 1 of which is scheduled to be available in February 2005.

E2 will enable models like EMSS to be built but with more options and the ability to alter the level of complexity to best match the available data. Both simpler and more complex models will be able to be built with E2. E2 will be released as a Toolkit product and fully supported. Two other models will be discussed and are available through CRC Parties, although they are not yet available from the Toolkit website. These are the Catchment Management Support System (CMSS) and IQQM (Integrated Quantity and Quality Model), both of which have been used widely in Australia. Adaptive Environmental Assessment and Management (AEAM) models as used for catchment-scale water quality are also discussed since these have been widely used in some states and similar capability will be available in the Toolkit. Note however that this paper is not a comprehensive review of sediment and nutrient models.

PURPOSE OF THIS PAPER

The purpose of this paper is to introduce the basic concepts that underpin water quality models and then discuss in more detail the use of several models available - SedNet, MUSIC, EMSS, CMSS, AEAM and IQQM.

KEY CONSIDERATIONS IN MODEL CHOICE

Our discussion of models is based around the four key considerations in model choice, as outlined in Paper No.1 - namely,

- the sorts of questions (or modelling objectives) for which each is ideally suited;
- data requirements;
- expertise requirements and
- resource requirements (time and money).

SALINITY NOT INCLUDED

Note that this paper does not include the modelling of salinity, where interactions with groundwater are significant. This is dealt with in Paper No.3 of this series.

SEDIMENT VERSUS NUTRIENT MODELS

In general, sediment modelling is ahead of nutrient modelling in terms of the understanding of processes and the confidence in the model results. This is because there is usually more sediment data available and the processes are somewhat simpler with fewer chemical interactions.

Part 1 - Basic modelling approaches

IN THIS SECTION:

Readers who are familiar with the basic concepts in water quality modelling may wish to skip to the later section - *Considerations in model choice - specific examples of CRC-related Sediment and Nutrient models.*

MANY MODELS - BASED ON A FEW CONCEPTS

There are literally hundreds of water quality models available – here are just a few from the bewildering array of acronyms - AGNPS, CREAMS, GLEAMS, EMSS, CMSS, ANSWERS, GUESS, SWMM, STORM, SWRRB, SWAT, AQUALM, LASCAM, AEAM, IQQM, USLE, RUSLE, MEDLI, QUAL2E, WEC, MUSIC, Filter, UVQ, SedNet, HSP-F, MIKE-SHE, CAT, EPIC, WEPP, Catchmods...

While the number of models is staggering, the fundamental concepts on which they are based are relatively few and quite simple. The large number arises from different combinations of these basic ideas and (often minor) differences in the algorithms used to represent particular processes.

It is important for model users to have an understanding of the basic approaches implemented in the particular model they are using.

There are three basic components of most water quality models – generation, delivery and transport (of the sediment, nutrient or pollutant) (Figure 1).

The range of models derives from different levels of complexity of each of these components.

FIGURE 1. BASIC COMPONENTS OF WATER QUALITY MODELS.

Generation

Estimating how much sediment, nutrient or pollutant is produced in a catchment.

In approximate order of complexity, approaches to generation are:

1. AVERAGE ANNUAL AREAL RATES PER LAND-USE (MASS/AREA/YR).

This is a simple approach where, usually on the basis of data from many studies on particular land-uses, approximate values of long-term average loads are derived.

If the area of each land-use in a catchment is known, the total average load can be obtained by multiplying these average loading rates by the area. The results indicate which land-uses are contributing to the total load.

IN THIS SECTION:

GENERATION

DELIVERY

TRANSPORT

DATA LIMITATIONS - A FUNDAMENTAL PROBLEM IN WATER QUALITY MODELLING

This is the basis of CMSS (which also allows point sources to be added) and many GIS-based models. Table 1 shows some example data – note the wide range of values for each land-use. As with all modelling, it is necessary to have local data to narrow this range and reduce the uncertainty in results.

The average annual rate approach (for example, as used in CMSS) lumps all of the individual sediment and nutrient sources that occur in a particular land-use together. Depending on how the factors were derived, this may also include channel incision or streambank erosion.

TABLE 1. EXAMPLE AREAL LOADING RATES FROM NEXSYS (YOUNG *ET AL.*, 1997)

Land-use	TSS (T/ha/yr)	TP (kg/ha/yr)	TN (kg/ha/yr)
Forest	0.05 - 1	0.01 - 0.5	0.5 - 10
Pasture	0.09 - 3	0.03 - 0.3	0.1 - 10
Urban	0.2 - 5	0.4 - 5	3 - 20

2. EVENT (OR EFFECTIVE) MEAN CONCENTRATION, EMC (MASS/VOLUME).

This approach is similar to method 1, except that EMCs are a *concentration* rather than a *load*.

The EMC represents the *average concentration* in runoff from, for example, a particular land-use.

This means that to compute loads, runoff (or streamflow) data are also required. The result is that a *time series* of loads is produced, enabling response to particular events, high flows versus low flows etc. to be distinguished.

Of course the quality of the load estimates becomes a function of the accuracy of both flow and EMC values. The latter are generally the most uncertain since EMCs are generally average values for a particular land-use, and even if calibrated to local data, will not represent the event-to-event variability that is common (i.e. will give average expected loads).

Nevertheless, the great attraction of this approach is the ability to get a time series of loads.

Table 2 shows typical EMC values from the literature – again notice the very wide range, emphasising the need for local data to calibrate this approach to local conditions if at all possible. Most AEAM models used in Australia (eg. Grayson *et al.*, 1994; Grayson and Argent, 2002) use this approach, commonly on monthly flows.

Uncertainty in EMC may be represented by a stochastic approach[1], in which a distribution is used to generate the concentration time-series, based on the mean and standard deviations (or some other measure of spread in the EMCs) that have been specified by the user.

In some cases, EMC values are derived from some function of discharge to enable larger values for larger flows – a commonly observed phenomenon with water quality data. This is conceptually attractive but can be difficult to calibrate.

[1] See Paper No.1 for discussion of stochastic approaches.

TABLE 2. TYPICAL EFFECTIVE MEAN CONCENTRATIONS FOR DIFFERENT LAND-USES.

Land-use	TSS (mg/L)	TP (mg/L)	TN (mg/L)
Forest	5 - 57	0.01 - 0.2	0.3 - 2
Pasture	8 - 350	0.02 - 0.7	0.4 - 4.2
Urban	5 - 200	0.06 - 0.4	1.1 - 2.1
Horticulture	8 - 550	0.07 - 1.5	0.2 - 9

3. EMC AND DRY WEATHER CONCENTRATION, (DWC, MASS/VOLUME).

This approach is an extension of method 2, where the flow is separated into high flow ("events") and low flows (i.e. "baseflow") and two different average concentrations are applied to these two types of flow.

This recognises the common situation where there are clearly two different "populations" of water quality – one during low flows and the other during rainfall induced runoff.

This dual approach is used in EMSS and MUSIC. It is preferable to the 'EMC' approach described in method 2, provided there are sufficient data available to separate the two "populations" of water quality data over the particular time scale of the model. For example, models that use a daily or sub-daily time step benefit from this approach because it is clear at this time scale whether flows are "event" or "baseflow".

Models that have monthly or annual time steps do not benefit because "events" affecting water quality are generally difficult to distinguish at the monthly or annual time scale.

As with method 2, a stochastic approach can be incorporated by defining the parameters of a statistical distribution for the EMC and DWC values. Similarly with method 2, the event values can be made a function of discharge to introduce additional variability, however good data are needed for calibration.

4. SEPARATE PROCESSES OF GENERATION

Models such as SedNet are based on estimating average annual loads, but rather than lumping all generation processes together, an effort is made to separate out key types of generation.

In the case of SedNet, generation from hillslopes, gullies and streambanks are separated. Separate models are used to estimate generation from each of these major sources.

Hillslope erosion commonly uses approaches based on the "Universal Soil Loss Equation" (USLE) which is a simple empirical model where factors related to land management, rainfall intensity, soil characteristics, slope, hillslope length and ground cover are used to generate average annual loads.

With SedNet, average loads from gullies are estimated from local information on the size and extent of gully networks.

Streambank erosion in SedNet is estimated using empirical functions related to streamflow and the riparian cover (Prosser *et al.*, 2001).

Whereas methods 2 and 3 provide a basis for temporal detail (since they are based on hydrology), a model like SedNet integrates temporal variation over the long-term.

For models that produce long-term average loads, it is possible to "disaggregate" these loads into a time series by, for example, using a concentration rating curve scaled to the location of interest, and daily flow time series. This approach will be used with SedNet in the near future.

5. PROCESS BASED APPROACHES.

These approaches attempt to mathematically represent the detailed processes involved in soil/water and other interactions.

These processes include, for example, soil detachment due to raindrops and surface flow, contaminant build-up and wash off from surfaces, scour by overland flow etc.

Ideally the mathematical representations separate out all the sources (and often detailed processes within each source) such as in method 4, but also use hydrological inputs to result in a time series of outputs. These representations or algorithms can become very complex and require a great deal of data to determine parameter values with certainty.

If the algorithms are able to explicitly represent all the key processes and pathways, and sufficient data are available to test them, they are very flexible and powerful tools.

The more common situation however is that they focus on particular components (of importance to the original authors) while treating others simply or not at all. This "imbalance" can undermine the potential advantages of such approaches for general application.

Key points about modelling generation of sediments, nutrients and pollutants

To summarise:

With respect to hydrological requirements of each approach:

- Method 1 does not need any hydrology.
- Methods 2, 3 and 5 require hydrology modelling (generally sub-daily to daily but perhaps up to monthly).
- Method 4 requires hydrological information to produce long-term average values.

With respect to the representation of generation processes of each approach:

- Methods 1, 2, 3 assume empirical relationships between land-use and generation processes.
- Method 4 conceptually describes individual erosion processes, but in the case of SedNet as long-term averages.
- Method 5 describes individual erosion processes at particular time scales – often daily or even sub-daily.

A particular challenge with all the methods is to deal with different particle sizes. Methods 1, 2 and 3, commonly consider "total suspended solids" as a single entity and bedload is often ignored or treated separately. In reality, sediment moved in streams is made up of a continuum of particle sizes that each behave differently. Method 4 approaches sometimes take account of particle sizes in a crude way (eg. by assuming different sources have different mixes of say suspended or bedload – i.e. fine and coarse sediment) but generally only method 5 approaches are structured to deal with particle size issues seriously and these require very extensive data sets to usefully implement.

Delivery

Modelling how sediment, nutrient or pollutant loads get to a stream.

Once material is generated, it must be delivered to a stream via some pathway from the land unit or sub-catchment. The delivery phase is often where management actions can be represented such as the use of riparian filter strips/buffers, dams for trapping material, alterations to surface cover (that will affect both generation and delivery), wetlands, detention ponds etc.

There are several basic approaches to dealing with delivery:

1. NET GENERATION

Here there is no explicit process of delivery represented, but the *generation rates* are determined such that they incorporate the effects of *delivery*.

For example, at a small plot scale, there may be very high generation of sediment, but by the time this gets to a stream there may have been a lot of deposition so only a small proportion actually makes it to the stream. If EMC or DWC values were derived from data at points in a stream, they are really measuring "net generation" since they implicitly account for any changes between the point of generation and the stream.

The "net generation" approach is very simple in concept, but interpreting the effects of management interventions can become complex or uncertain.

For example, the effect of a buffer strip on net generation from a particular land-use has probably been derived from a detailed field study where the inputs and outputs to a buffer have been measured to give an overall trapping efficiency. But if all we know is the net generation from a large area of approximately uniform land-use, the trapping efficiency value from the experiment cannot be directly applied – some estimate of its effect on this net value needs to be made, introducing additional uncertainty.

2. DELIVERY RATIO

This is a very common approach where it is assumed that a proportion (the delivery ratio) of what is generated makes it to a stream.

This proportion may be a constant, or some function of attributes such as terrain, vegetation types, the amount of material generated, particle size etc.

It is also possible to include some representation of *transformation* processes, particularly for chemical species. For example the delivery of nitrogen to a stream may depend on the time water spends in the ground before making it to the stream (to allow for denitrification processes).

3. EXPLICIT PATHWAYS/PROCESS-BASED

Here the detailed pathways of movement from source of generation to stream are explicitly modelled.

In general the same comments apply here to method 5 in generation - i.e. these are good approaches but require a lot of data.

There are some areas where process-based approaches have been developed that require only general information for application to particular pathways or particular modifications to a pathway that represent management effects. For example, there are approaches for the settlement of sediment in ponds and riparian buffers, the effects of wetlands and infiltration trenches, and the denitrification of some subsurface flows. Some of these are incorporated into Toolkit products such as MUSIC and E2.

Transport

Modelling how sediment, nutrient or pollutant loads are transported downstream in a catchment.

Once material makes it to a stream, it is available for transport through the stream network. Again there are several basic approaches. Each of these can be applied to particular classes of particle sizes (if such information is available) or lumped together:

1. NO EXPLICIT TRANSPORT

In other words all the material that makes it to a stream is assumed to make it out of the catchment. All the inputs are simply summed to give the output.

2. ROUTING WITH WATER

Flow "routing" means to allow for the time it takes for a flood wave to move through a stream network. Constituents such as sediment or nutrients can be assumed to travel with this water.

There are 'hydrologic' routing functions built into EMSS, E2, IQQM and MUSIC which model the speed of the flood wave. It is also possible to apply a simple delay term to the routing of sediment or nutrient to allow for the difference between the velocity of the actual water in the stream and the speed (celerity) of the flood wave. The more complex 'hydraulic' routing models explicitly represent both wave celerity and water velocity.

3. ROUTING ALLOWING FOR TRANSFORMATIONS

Here the constituent is routed, but it is possible for it to be altered on the way. For example, sediment may deposit or be re-suspended, nutrients may alter form, decay, enrich etc.

Some simple transformations are allowed for in EMSS, E2 and IQQM.

The modelling of transformations is relatively well advanced from a mathematical point of view (i.e. there are a number of established algorithms available), but to be practically useful, a large amount of specific data are needed to calibrate the relationships. In many cases a simple decay term is used i.e. the longer it takes to get to the outlet, the more that drops out, but on an exponential basis with most dropping out early and less towards the end.

4. FLOODPLAIN INTERACTIONS

This is not really a "basic approach" to transport, but rather a very important component that may dominate behaviour in some systems.

When a river breaks its banks and interacts with the surrounding floodplain, many processes are triggered that may need to be accounted for. For example, sediment deposition is much more likely in the slow flow across a floodplain than in the fast flow of a river. Nutrient transformations and interactions with wetlands will be much more active and so on.

SedNet takes a statistical approach to floodplain deposition to deal with the proportion of overbank flow in the long term.

Models that include time series of streamflows can include more detailed floodplain interactions, based on cross-sectional information about river and floodplain reaches. This is planned for in E2, but only at a relatively simplistic level.

As interest increases in the "reconnection" of floodplains, modelling of interactions will need to be improved.

5. ROUTING IN MANAGED SYSTEMS

The flow in some stream networks is dominated by the release and impoundment in weirs and dams.

In these cases, the routing models (with or without transformations) can be applied to flow in the reaches, but the amount of water available must be obtained from a representation of the management interventions (eg. dam releases), not just rainfall-runoff.

It is also likely that transformation models for constituents in the dams will be needed.

Models such as IQQM are specifically designed to replicate the behaviour of these managed systems and a large proportion of the modelling effort is in establishing the appropriate rules of operation of the managed system.

There are also models designed to deal with the specifics of transformations in dams and storages (eg. DYRESM-CAEDYM from the University of Western Australia).

Data limitations - a fundamental problem in water quality modelling

CALIBRATING AND TESTING MODELS - DATA IS AN ISSUE

While the basic concepts that underpin models of sediment and nutrient movement are relatively well known, the data to calibrate and test models is generally woefully inadequate.

LIMITED 'COVERAGE' OF DATA TO ESTIMATE LOADS

The data that are more commonly available (eg. monthly or quarterly grab samples) are of limited use in establishing values of catchment loads or relationships between flow and concentration and require careful interpretation to establish parameters such as EMCs (eg. Chiew and Scanlon, 2002 – CRC Report 02/2) or compute long term loads (eg. Grayson *et al.*, 2001).

UNDER-REPRESENTATION OF MAJOR EVENTS

Another limitation of commonly available data is that they generally under-represent major events such as the effects of bushfires or cyclones. This means that the simulated behaviour under these conditions is much more uncertain than under the common conditions that are more likely to be represented in the available data.

The under-representation of large events may also lead to calculated long-term loads under-estimating the actual loads.

Figures 2A to 2D show how different types of data and spatial representations result in different types of output information. The simplest models require limited data on, for example, loading rates and land-uses. These provide output that does not vary in time – e.g. average annual loads (Figure 2A).

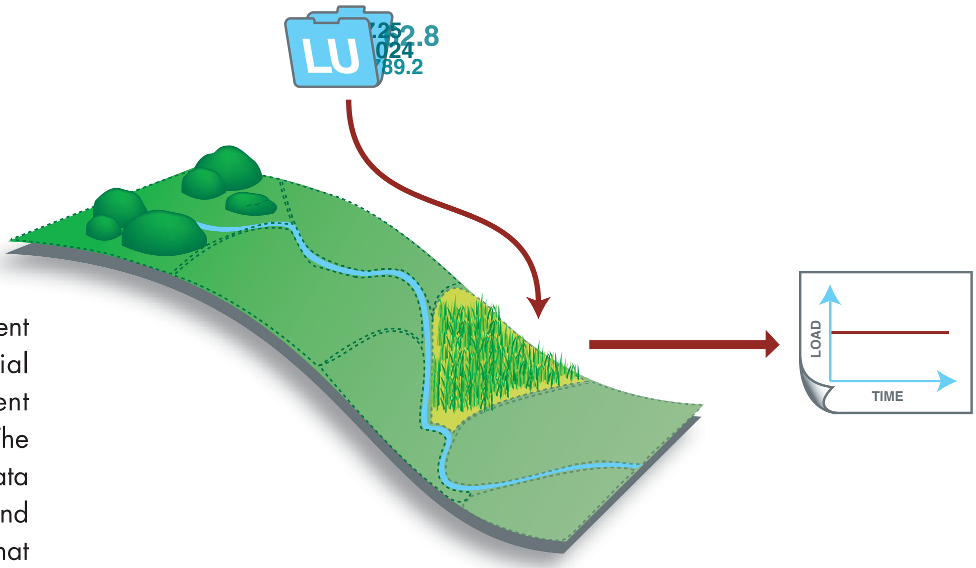


FIGURE 2A

LU = Generation rates for different land-uses.

Models such as the current version of SedNet use a lot more spatial data and some statistics of hydrological inputs to provide a lot more spatial detail on the sources of long-term loads, but the output does not vary with time (Figure 2B).

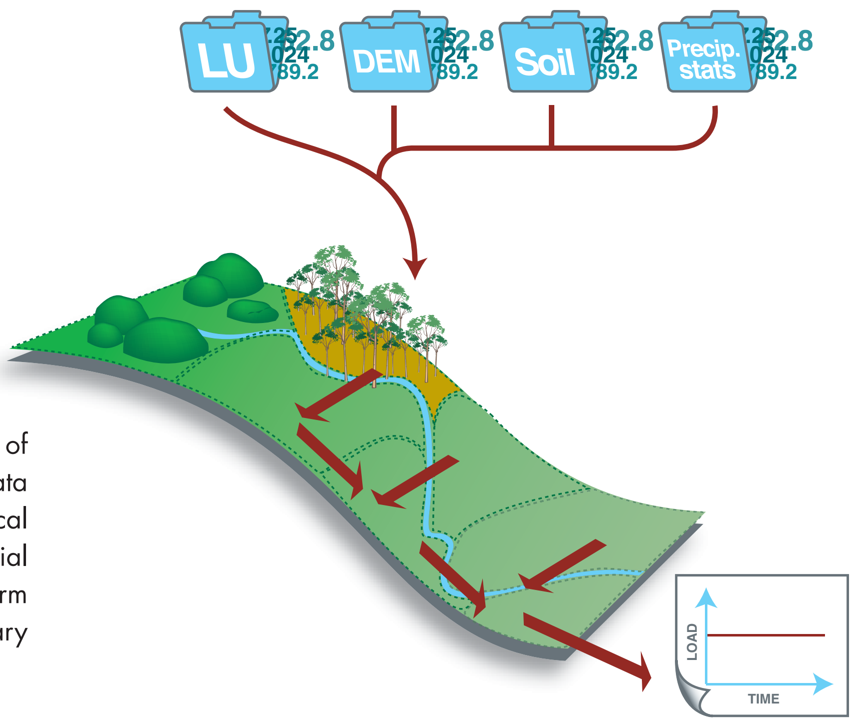
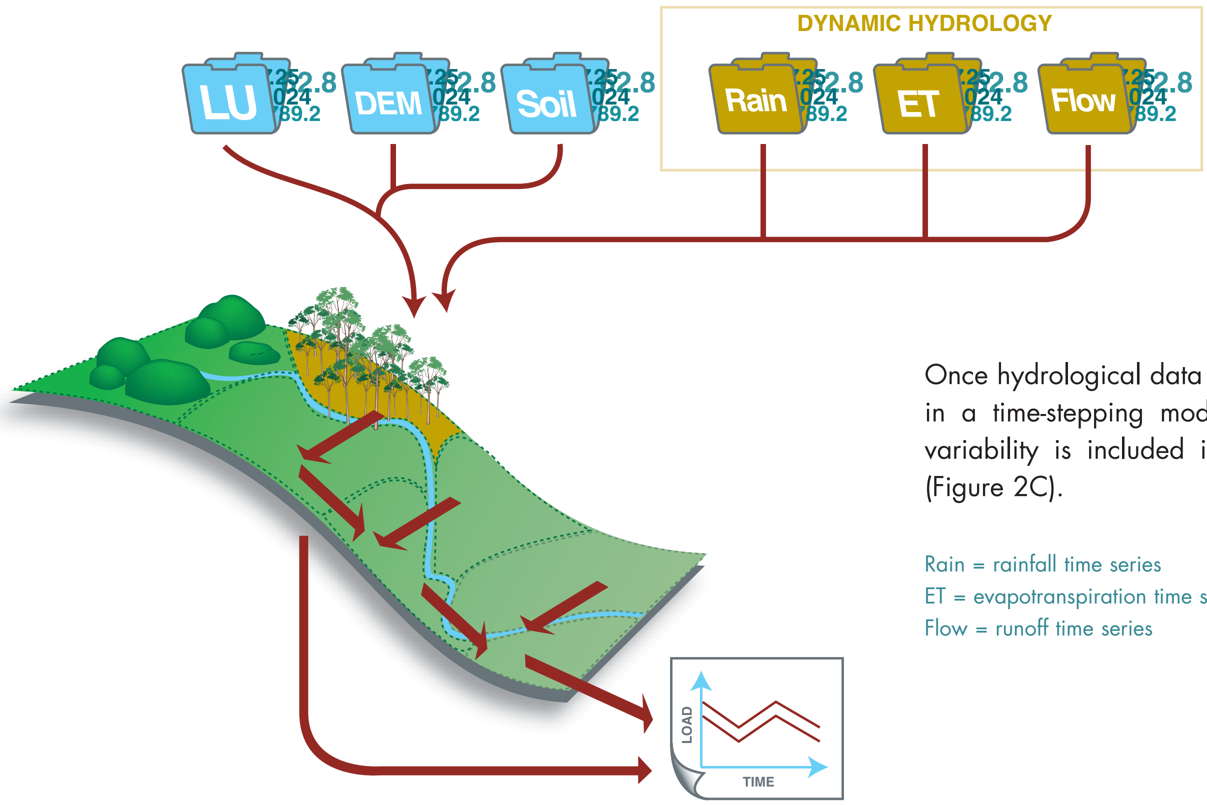


FIGURE 2B

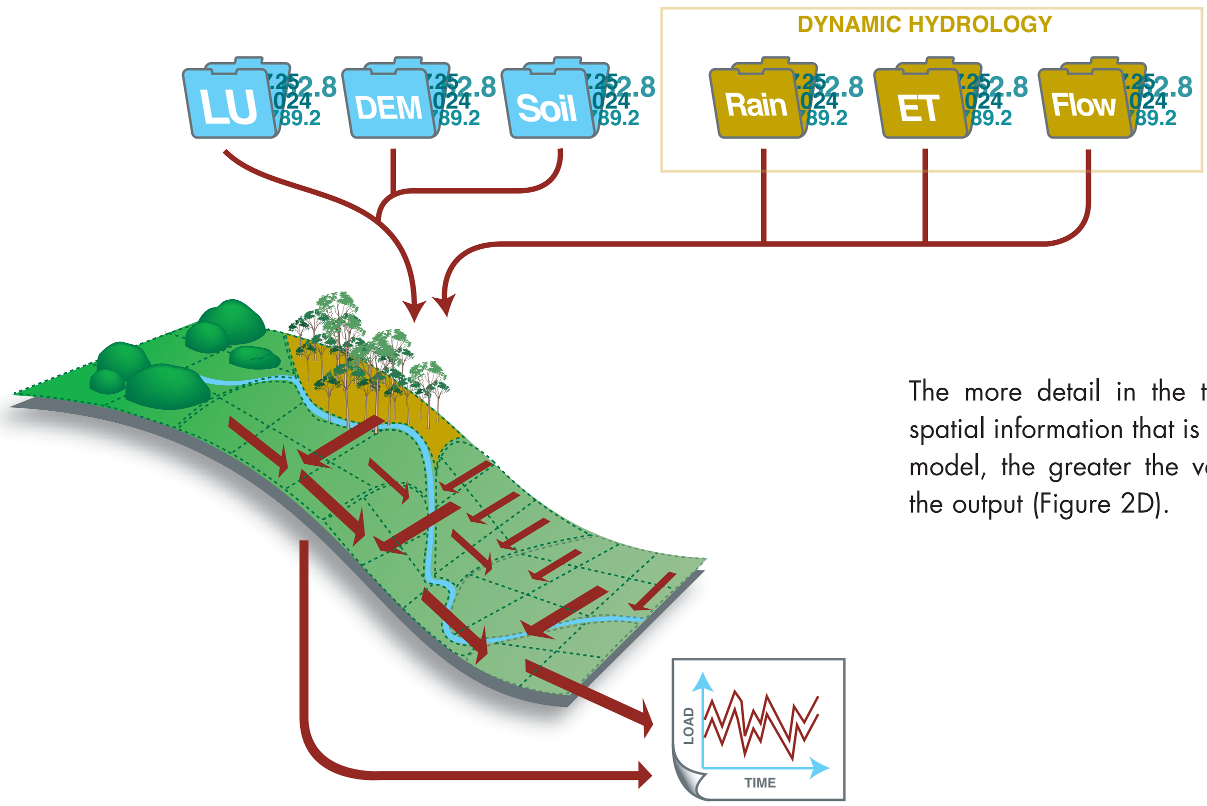
DEM = digital elevation model
Soil = soils information
Precip. stats = precipitation statistics



Once hydrological data are included in a time-stepping model, temporal variability is included in the output (Figure 2C).

Rain = rainfall time series
ET = evapotranspiration time series
Flow = runoff time series

FIGURE 2C



The more detail in the temporal or spatial information that is used by the model, the greater the variability in the output (Figure 2D).

FIGURE 2D

IN THIS SECTION:

The accuracy of the various forms of output must be compared to actual measurements wherever possible to improve confidence in the modelling exercise. Also, the point in the stream network at which data are available affects the interpretation significantly. For example, if we have weekly grab sample data from a catchment that has one major land-use, we might be able to derive estimates of *areal loading rates* or *EMCs* that are appropriate for that land-use at that scale, but if the catchment has many land-uses, it is not a possible to derive EMCs for all those land-uses from that data.

PUBLISHED PARAMETER VALUES - LIMITATIONS

It is commonly necessary to rely on published values for some parameters and to expect a high degree of uncertainty in these values (eg. see Tables 1 and 2 above). Compilations of the results of a large number of studies can be particularly useful such as the NexSys data base of Young *et al.* 1997, which summarises many studies on areal loading rates, or the database that sits behind the stochastic EMC/DWC generation module and Universal Stormwater Treatment Module (USTM) in the MUSIC model (Duncan *et al.*, 1999; Wong *et al.*, 2001).

ACCURACY OF MODELS – LIMITED DATA IS A CONSTRAINT

Limited water quality data will almost certainly be the greatest constraint on the accuracy of models of sediment and nutrient generation, transformation and movement.

This is being increasingly recognised by agencies and efforts are being made in collecting data suitable for the calibration and testing of models, but this situation is going to take some time to significantly improve.

DATA FOR MODEL CALIBRATION

If water quality data are being collected for the purpose of calibrating a model, then the model's data requirements should be explicitly considered before embarking on the monitoring program. For example, where modelling is ultimately to include ecological impacts, it is common to need information not only on total loads of nutrients, but also on the particular chemical species (eg. PO4, NH_3, NO_x etc.) requiring both additional analyses of samples and probably more complex modelling.

Without some calibration data, water quality models are really an "educated guess". It is fair to say that there is virtually never enough appropriate data to undertake a *formal validation* of models of this type, nor to formally determine uncertainty in estimates, although confidence will be greatly improved by any good data.

USING MODELS FOR COMPARATIVE PURPOSES - AWARENESS OF MODELLING AND ASSUMPTIONS IMPORTANT

Often water quality modelling is used more in a *comparative* rather than *absolute* sense.

Comparisons between model runs can be instructive, and some of the uncertainty in the absolute values disappears. In either case it is critical that the modeller knows their model and data well, is able to realistically interpret the results, and is aware of how the assumptions in the modelling will affect uncertainty in both absolute and relative results. This uncertainty must also be conveyed to the users of the information.

Part 2 - Considerations in model choice

SPECIFIC EXAMPLES OF CRC-RELATED SEDIMENT AND NUTRIENT MODELS*

Key considerations and models covered

In the following sections, we summarise the key considerations in model choice outlined in Paper No.1 of this series as they relate to particular models.

These considerations are:

- the kinds of objectives for which the model is suited
- data requirements
- expertise requirements
- resource requirements

The models included are CMSS, SedNet, AEAM, EMSS, IQQM and MUSIC. More will be added over time.

* (Note - Paper No.3 deals with salinity modelling)

IN THIS SECTION:

Catchment Management Support System (CMSS)

(Ref: Davis and Farley, 1997)

CMSS is a model that uses generation based on average annual loading rates (T/ha/yr). The rates are representative of "net delivery" (i.e. the delivery process is not explicitly represented) and the results are simply summed over an area. Both diffuse (i.e. areal) and point sources are included when calculating total load. CMSS is generally used for nutrient loads, but any pollutant can be included provided the areal loading rates are known.

It supports two types of policy development and enquiry – land-use change and adoption of alternate land and stream management practices. These policies can be grouped into sets because, in practice, policy developers consider and cost multiple policies simultaneously.

Land-uses is a general term to describe different generating activities and can be factored to include the influence of catchment condition (eg. extent of gullying) and location (eg. rainfall, slope) by altering generation rates.

Routing is achieved by using an hierarchical numbering scheme which identifies the ordering of sub-catchments, within catchments, within basins. Loads are summed (and attenuated if that is considered important) as they are 'routed' through sub-catchments.

Uncertainty is captured in the generation rates and practice costs (input by the user) and predicted loads are expressed as a range (ie x ± y kg/yr).

APPROPRIATE OBJECTIVES

CMSS was designed with the needs of policy analysts in mind, especially the need to maintain a balance between the precision of the model and the precision of the policy statements. It is ideally suited to "first cut" analysis of the major contributors of sediment or nutrients from a catchment.

Most applications use published data for the loading rates from different land-uses, modified for local conditions if such data exist. The process of collating the information on land-uses, point sources and loading rates can be built into a wider process of stakeholder engagement and so CMSS can be very useful tool for gaining a shared understanding about the basics of water quality in an area. Unless it is highly tuned to local data, CMSS is not appropriate for use in target setting or applications where accurate quantitative estimates are necessary.

CMSS does not consider hydrology or any time-variant components so is restricted to long-term average behaviour.

The strengths of CMSS lie in its simplicity and its ability to encapsulate a wide range of policy initiatives. Policy scenarios can be easily developed and compared.

DATA REQUIREMENTS

These are quite modest, requiring data on the areas of different land-uses in a catchment and significant point sources (average annual loads from these). Look-up tables can be used to give areal loading rates for the land-uses (eg. NEXSYS, Young *et al.*, 1997) but these are best checked against local data if available.

EXPERTISE REQUIREMENTS

CMSS is a simple modelling approach and can be quickly learnt and explained to others. Basic computer and data manipulation skills are needed. Interpretation is also simple, but the limitations resulting from the average annual areal loading rates approach and extent to which local testing is undertaken need to be clearly understood and articulated.

RESOURCE REQUIREMENTS

Assuming the basic land-use and point source data are available, CMSS can be set up in a matter of hours to a day or two - i.e. resource requirements are low compared to other models discussed below.

IN THIS SECTION:

SedNet

(Ref: Prosser *et al.*, 2001)

SedNet is a model that constructs sediment budgets[2] for river networks to identify patterns in the long term erosion and deposition throughout a catchment.

The model represents sediment generation from hillslope, gully and streambank erosion. It constructs separate budgets for suspended and bedload.

Complete delivery to the stream network of sediment from gully and bank erosion is assumed (net generation), and a delivery ratio is used for sediment from hillslope erosion.

SedNet incorporates a transport capacity for long-term bedload, and bedload deposition within streams and reservoirs. Suspended sediment deposition is represented on floodplains and in reservoirs.

The generation, delivery, transport and transformation terms in the sediment budgets are mean-annual averages for the conditions defined. Depending on the erosion and hydrology data used, the averages are valid over periods of 20 years, or longer.

In the terminology introduced in Paper No.1, SedNet is a spatially explicit, temporally lumped model. It uses a link-node structure to construct separate sediment budgets for many (hundreds) of sub-catchments.

APPROPRIATE OBJECTIVES

SedNet is particularly useful for targeting catchment and river management actions to the most important erosion sources and locations.

It can assess, and assist in setting long-term targets for suspended sediment loads. Because it constructs bedload budgets, it can also assess long-term bedload sedimentation of habitat. It identifies where, and what erosion process are contributing to sediment loads. It is most useful at a regional scale (>2,000 km^2). SedNet provides budgets over the long-term so if there are recent changes in the relative contribution of load sources, the SedNet patterns may not represent the contemporary situation.

There have been several applications of SedNet to assist in target setting (e.g: DeRose *et al.*, 2003; Wilkinson *et al.*, in press). The capacity of the model to correctly represent the spatial patterns of sediment sources and fluxes is well regarded and has been tested against observed loads and sediment tracing studies.

While the effects of management actions are determined as long-term averages, comparison between different management scenarios indicates their relative effectiveness. Long term average response is generally adequate for planning management actions that take long periods to have full effect, for example tree planting. If target setting requires shorter time frames such as 1, 5 or 10 years, the temporal lumping in SedNet may limit its applicability.

Scenario modelling can be undertaken to represent the long-term effects of riparian vegetation change affecting bank erosion, gully stabilisation affecting gully erosion, land-use change affecting hillslope erosion, and flow regulation and modification changes affecting bedload sediment transport capacity, bank erosion and floodplain deposition.

2 A sediment budget is an account of the major sources, stores and fluxes of sediment throughout a catchment and river network.

DATA REQUIREMENTS

SedNet requires detailed spatial data on land-use, topography, gully characteristics, riparian vegetation and some long term hydrological data on rainfall and streamflow. Much of this data is available via national databases, although commonly more detailed local data improves the accuracy of the modelling.

EXPERTISE REQUIREMENTS

SedNet has been designed for a range of different users with different backgrounds. Running management scenarios of riparian revegetation, gully stabilisation or land-use change with an existing model is relatively straight forward. Building the model in a new catchment requires GIS and data analysis experience. Interpreting model operation and results, and comparing model outputs with observations, requires experience and knowledge of long-term landscape processes. Model testing requires careful interpretation to account for the temporal averaging.

RESOURCE REQUIREMENTS

SedNet takes of the order of weeks to months to apply, depending on the state and availability of the data.

GIS and spatial data manipulation may be required to prepare data and this can be time consuming. Some data collection may be required for things such as gully erosion.

Because of the long-term average nature of the results, direct data for testing must also be in the form of long-term averages. For example, average bank erosion rate over several decades can be estimated from aerial photo analysis, or historical records.

Where greater levels of accuracy are required, model results can be tested against observed sediment loads, deposition rates on floodplains from soil cores and sediment tracing using geochemical and isotopic signatures (e.g: Olley *et al.*, 1993; Olley and Deere, 2003).

Adaptive Environmental Assessment and Management (AEAM)

(Ref:, Grayson *et al.*, 1994; Walters, 1997; Lee, 1999; Ladson and Argent, 2002)

AEAM is actually a process that is broader than just water quality models and often does not include computer models at all (Holling, 1978; Walters, 1986; Walters, 1997).

Here we restrict discussion to AEAM as it has been applied to catchment water quality modelling largely in Victoria (eg. Grayson *et al.*, 1994; Grayson and Argent, 2002). (There are, however, AEAM-style models that are very different to those described below; Gilmour *et al.*, 1999.)

The water quality, AEAM-type models have been based on EMC approaches for different land-uses using monthly data, summed over periods of 10-20 years to give long term averages, but statistics on shorter temporal scales.

The models are spatially explicit, using a cell-based approach with cells of the order of 1-16 km^2.

Representation of surface erosion hazard, streambank erosion hazard, point sources and water management is generally incorporated.

In some cases, the output of other models has been integrated into the AEAM models, such as streamflow from water management models.

APPROPRIATE OBJECTIVES

AEAM includes the close involvement of stakeholders in model development, so the model is useful where participation is a key objective of the modelling exercise. It has generally been used to assist in priority setting and coming to understand the basic influences on water quality in a catchment.

AEAM accounts for dynamic hydrology (at a monthly level) so can represent (at least to some extent) the different behaviour of water quality during high and low flows. However, it has not been used to separate out key sources such as gullies, hillslopes and streambanks in the way that SedNet does.

AEAM has been used for target setting and to assess the potential for different management actions to achieve particular targets (eg. East and West Gippsland water quality plans) and as an educational tool for undergraduates.

DATA REQUIREMENTS

AEAM models generally require information on land-use, topography, point sources (ideally monthly time series), erosion hazard, riparian condition, rainfall, streamflow, water extractions and returns.

The models can be modified to use what data are available (see ‘Expertise requirements’ below), but uncertainty is very high unless good data are available for model testing.

EXPERTISE REQUIREMENTS

AEAM models are generally tailored to a particular application, so expertise is needed not only in basic hydrological and water quality modelling, but also in computer programming (in Visual Basic).

Recently a shell has been developed to assist in model development (Argent and Grayson, 2003), but considerable expertise is still needed to modify or develop models.

In some cases, existing models have been used with changes only to data inputs and key parameters. This does not require programming skills.

As mentioned, AEAM is generally used as part of a participatory process, so communication skills are vital. Use of the software for scenario testing is simple.

RESOURCE REQUIREMENTS

Provided the expertise and data are available, AEAM models can be developed in the order of a few weeks to a couple of months, including testing.

One of the principles that underpins AEAM modelling is that the model complexity is tailored to the available data. This obviously limits the objectives that can be met, but keeps resource requirement relatively low.

IN THIS SECTION:

Environmental Management Support System (EMSS)

(Ref: Vertessy *et al.*, 2002)

EMSS was developed from a catchment-scale sediment and nutrient modelling project in South East Queensland and has now been applied in several catchments around Australia.

It is a link-node based model that separates a catchment into many (perhaps hundreds) of sub-catchments.

Sediment and nutrient generation is based on EMC/DWC and the model is generally run at a daily time step. Point sources can be represented, as can dams/storages where simple model of transformations to sediment and nutrients are available.

Runoff and contaminant routing is included, as is the ability to represent management actions such as land-use change, land management change (by altering EMC/DWC) and riparian buffer management.

It does not include complex water management, although simple release from dams is possible.

APPROPRIATE OBJECTIVES

The EMSS objectives are similar to those for CMSS, SedNet and AEAM.

The primary advantage of EMSS is that it runs on a daily time step so is useful for applications where detailed temporal information is required (eg. some ecological and estuary modelling requires daily inputs).

EMSS does not separate generation into the source erosion processes in the way that SedNet does, nor does it represent sediment deposition on floodplains. This can reduce the spatial accuracy of predicted patterns in generation and loads in some catchments.

By simulating daily flows and loads, EMSS can represent management actions that have different effects on different parts of the flow regime.

DATA REQUIREMENTS

EMSS has data requirements similar to AEAM (i.e. topography, land-use, rainfall, streamflow, water quality), but these include higher temporal resolution rainfall and streamflow data.

The data needed for testing is also more extensive, both because of the finer time scales, but also because the applications for EMSS commonly call for a higher level of absolute accuracy than the “first cut” CMSS and AEAM approaches.

The EMSS model relies on the accuracy of EMC and DWC values for different land-uses and as shown earlier, these cover a wide range. Local data is needed to specify these with certainty.

EXPERTISE REQUIREMENTS

EMSS is a relatively complex model and requires skills in GIS and data analysis, hydrological and water quality modelling.

The setting up and calibration of EMSS from scratch requires considerable skill and experience.

Once a catchment model is set up, use for scenario testing is much simpler through user-friendly interfaces. There is still a need for good understanding of the model assumptions to ensure sound interpretation of output.

If used as part of a wider process of community engagement, high level communication skills are required.

RESOURCE REQUIREMENTS

Setting up an EMSS model for a new catchment would be expected to take of the order of 4 - 8 person months depending on the availability of data.

Once a catchment is set up and calibrated, defining and running scenarios is rapid.

Users to date indicate that the data collation and analysis phase is very time consuming - this is true of any model that has relatively fine spatial and temporal resolution.

EMSS is being replaced by the CRC's E2 modelling framework. This is discussed further below.

Integrated Quality and Quantity Model (IQQM)

(Ref: Simons *et al.*, 1996; Javam *et al.*, 2000)

IQQM is a hydrologic network model used in planning and evaluating water resource management policies.

It is a generalised hydrologic simulation package, which is capable of application to regulated and unregulated streams, and is designed to be capable of addressing water quality and environmental issues as well as water quantity issues.

The model is structured for investigating and resolving water sharing issues:

- at the inter-state or international level, and
- between competing groups of users, including the environment.

The model operates on a continuous basis and can be used to simulate river system behaviour for periods ranging up to hundreds of years. It is designed to operate at a daily time step, but some processes can be simulated at time steps down to one hour.

IQQM uses the Sacramento rainfall-runoff model for the generation of sub-catchment runoff and uses regression-based relationships for the generation of load. However, it is capable of using time series flow and load inputs from other models such as E2 or EMSS.

The water quality components of IQQM are based on QUAL2E, developed for the US EPA. IQQM can model the following:

- Movement of conservative and non-conservative substances, such as salinity, sediment and pesticides,
- Nitrogen cycle,
- Dissolved oxygen (DO),
- Biochemical oxygen demand (BOD),
- Phosphorus cycle,
- Coliforms, and
- Algae.

For movement of conservative and non-conservative substances, a volumetric routing procedure that assumes fully mixed flow in each routing reach is available.

Parameters such as DO and BOD are modelled using a modified Streeter-Phelps equation. The nitrogen and phosphorus cycles are modelled using first-order kinetics. Algal growth simulation is based on well known equations for nutrient-light limitations on algal growth rate. IQQM requires the inputs of these constituents from the catchments to be specified.

In Australia, IQQM has been applied throughout New South Wales and Queensland. IQQM is currently being implemented by Murray-Darling Basin Commission for the Murray River. Internationally IQQM has been applied in Indonesia (Lombok), Mekong River (South-east Asia) and Zambia. The climatic zones for which IQQM has been applied range from tropical to arid as well as coastal and inland. IQQM has been implemented for both regulated and unregulated streams.

APPROPRIATE OBJECTIVES

IQQM is a sophisticated modelling package intended to provide detailed input to decision making related to water sharing in regulated and unregulated systems.

It is able to deal with issues including demand modelling, water ordering, annual accounting, annual accounting with carry over, continuous accounting and capacity sharing.

The major strength of IQQM is in water quantity. Water quality can be represented but requires a large amount of data to really exploit the capability.

The complexity of IQQM means that it is mainly used for analysis of major water resource management and planning issues, although it has been used for smaller scale mining and wetland studies.

DATA REQUIREMENTS

IQQM requires a large amount of data to exploit its capability.

The rainfall-runoff modelling in IQQM requires catchment-wide rainfall and evaporation data, and sufficient streamflow data to calibrate the sub-catchment models.

For a major river network, detailed characteristics of dams (volume/area, head/discharge or other outlet information, release rules…), channel networks, extraction information and irrigation areas, crop mix, and infrastructure (pumps, channels, on farm storages and delivery systems) can be included.

Water quality data depends on the constituents being modelled, but is likely to be extensive. For most water quality constituents, temperature data is required.

EXPERTISE REQUIREMENTS

IQQM is designed for use by experienced water resource modellers.

It requires a sound knowledge of hydrology and water resource management principles and practices.

Both the breadth and politically sensitive nature of the issues modelled in IQQM means that modelling teams need to include good communicators.

RESOURCE REQUIREMENTS

Because of its complexity (and capability), IQQM is resource-hungry to set up, calibrate and operate.

A typical application for a regulated river basin will require months to years to implement. For example, the IQQM model of the Murrumbidgee system has had a team of 3 people working for 2 to 3 years, although the application in the Mekong system was relatively straight forward requiring 2 people for 6 months.

MUSIC

(Ref: Wong *et al.*, 2001)

MUSIC is a tool to assist in the design of urban stormwater drainage systems.

It simulates runoff, sediment and nutrient generation, movement and "treatment" through typical components of an urban system such as swale drains, biofiltration trenches, gross pollutant traps, infiltration systems, detention ponds, and wetlands.

MUSIC operates at a range of temporal and spatial scales; catchments from 0.01 km^2 to 100km^2 and modelling time steps ranging from 6 minutes to 24 hours to match the catchment scale.

MUSIC is designed for urban stormwater engineers, planners, policy staff and managers in consultancies and State, regional and local government agencies. Both Melbourne Water and Brisbane City Council have published "MUSIC Modelling Guidelines".

APPROPRIATE OBJECTIVES

MUSIC allows complex stormwater management scenarios to be quickly and efficiently created and so is particularly well suited to the design of new urban developments (or retrofitting of older areas) to meet specified water quality guidelines.

It is also suitable for conceptual design of large drainage schemes, where water quality works are part of the planned strategy to accommodate new development.

A lifecycle costing module is also included so that tradeoffs and long-term maintenance costs can be derived.

The current pollutant generation model in MUSIC uses the EMC/DWC approach based on an extensive database (Duncan, 1999, Duncan, 2003) which enables some stochastic representation of variability in these parameters.

MUSIC has had widespread application around Australia, including its use by:

- Melbourne Water to plan and assess land development proposals, and to design stormwater treatment strategies for new and existing drainage schemes.
- Brisbane City Council for urban catchment planning, and to design new stormwater treatment measures in Brisbane.
- Engineering consultants around Australia to design urban development proposals to meet Water Sensitive Urban Design standards.

DATA REQUIREMENTS

MUSIC requires 6 minute rainfall data, and daily or monthly evapotranspiration data, available from the Bureau of Meteorology (although climate data are provided for many Australian cities, with the MUSIC program).

Ideally, runoff and water quality data from the catchment of interest should be obtained to allow calibration of the MUSIC model.

Users may need mapping or concept designs of the layout of proposed developments.

Default mean and standard deviation are used to derive stochastic sediment and nutrient generation distributions, although locally-derived data are recommended.

EXPERTISE REQUIREMENTS

The MUSIC user-interface is very easy to use, and most users can readily begin using the model with 1 to 2 days of training.

However, MUSIC requires a sound knowledge of urban stormwater management principles and practices as well as basic hydrological and water quality modelling skills.

As with all modelling, it is important for users to understand the underlying assumptions and limitations thereof. These are explained in the user documentation.

RESOURCE REQUIREMENTS

It typically takes less than 2 hours to construct a MUSIC model (depending on the complexity of the network being modelled), once climate data has been obtained.

A simple model can be built in less than 15 minutes.

Whilst the MUSIC program includes pre-installed climate data for many Australian towns, obtaining specific local data from the Bureau of Meteorology may be required (which may take a few days to be supplied).

Calibration of the rainfall-runoff model is recommended wherever local or appropriate data are available. Such calibration may take in the order of 1 to 2 days (again depending on complexity).

LIMITATIONS OF EXISTING MODELS

The models described above are relatively inflexible in terms of the algorithms and assumptions on which they are based. Each has been designed to do a particular range of tasks in a particular way. This is OK if the tasks they are designed to do are quite common, but does limit the flexibility to include new or alternative algorithms, or to develop a simple model and add complexity as new information becomes available (unless the model is recoded).

PURPOSE AND CONCEPT OF E2

The modelling framework E2 (*Catchword* November/December 2004, available at http://www.catchment.crc.org.au/catchword) has been designed to provide a flexible capability to support construction of models for analysis of the impacts of land-use and water management decisions at the whole of catchment scale very much aligned with the mission of the CRC for Catchment Hydrology.

The concept for E2 is to make it easy to develop "horses for courses" models, reduce overheads in tailoring a model to a problem, provide an architecture for inclusion of more modules, and encourage "systems" thinking and multiple outputs (for more comprehensive assessment).

E2 is being designed to provide a system that is rigid enough so that much of our existing library of Catchment Modelling Toolkit tools can be made available to users. But it is also flexible enough to support a range of modelling approaches of different complexity and at different spatial and temporal scales.

BUILDING CAPABILITY BUT WITH WIDER MODELLING CHOICES

E2 will be used to construct models with similar capability to CMSS, AEAM, EMSS and in the future IQQM, but with a wider choice of algorithms for specific tasks. For example instead of being constrained to EMC/DWC in EMSS, it will be possible to represent generation of sediment using a disaggregated version of SedNet modelling. Work being undertaken in the CRC on denitrification in riparian areas and water quality from irrigation areas will be available and several other projects are developing components that will add to the E2 framework.

Like EMSS and IQQM, E2 is based on a node-link approach to representing a catchment.

Users will choose particular modelling approaches from libraries for rainfall-runoff, sediment and nutrient generation, delivery (or filtering) of contaminants before entering a stream, and a range of choices for routing and transformation through a channel network.

Details will be made available when E2 is released in February 2005.

Concluding Comments

This paper provides a background to the fundamental approaches to water quality modelling and a summary of "considerations in model choice" as they relate to key water quality models either available in the Catchment Modelling Tookit or widely used by CRC Parties.

In Table 3 we have attempted to provide a comparison between the models discussed in this paper with respect to some common management objectives and three aspects of the models are rated using a scale from A to E. These are:

i) confidence in results (this is based on past experience with the models by researchers and managers), A = high confidence,

ii) suitability of the basic model structure for the problem at hand, A = very suitable, and

iii) practicalities of use which largely relates to the amount of data and preparation needed to achieve the stated confidence, A = simple to use / low data needs.

Of course these rankings are partly subjective and will depend on the specific details of particular applications, but the Table is intended to provide a general guide to assist potential model users. It should be noted that:

- MUSIC is ranked on the basis of application to urban areas.
- IQQM focuses on the behaviour of river networks so is not rated for the objectives related to water quality from catchments (it has water quality algorithms for in-stream quality but requires as input the catchment loads).
- E2 is rated as if it is applied in its most complete form expected by June 2005 (ratings are therefore expected values). As noted above, it is structured to allow models of a range of complexity to be applied.
- SedNet is undergoing continual improvement and some significant changes are expected later in 2005. Hence there are ratings for SedNet in both its present and expected form.
- CMSS has (as noted above) major strengths as a "first cut" analysis tool and for rapidly assessing a range of policy options. This point tends to be lost in the detail of the Table.
- Assessment against targets implies that there is a need to model relatively short periods of time (eg. < 10yr) and deal with gradual implementation of management actions. Therefore time-stepping models tend to rank higher than long-term models for this objective.

This paper is not a comprehensive review of what models are available, but rather provides some basic understanding of what components are needed in water quality models, and to assist a user in deciding what capability is needed to answer particular questions. It also summarises the water quality models available through the Catchment Modelling Toolkit, some models that are commonly used in industry, and outlines future developments for the CRC's modelling framework, E2.

Uncertainty in water quality modelling is commonly high due to data limitations. In general, uncertainty in model results increases as we move from suspended sediment, to total nutrients, to nutrient species and different particle sizes of sediment, to pathogens and so on. The results from water quality models are often used as input to other modelling such as the biogeochemical behaviour of estuaries and water storages. It is important to recognise the potential for uncertainty to compound, and it is necessary to undertake some sort of sensitivity analysis (or stochastic modelling) to help understand how uncertain final results may be.

Despite the uncertainty inherent in modelling a complex system with often limited data, water quality models are an important tool to assist managers. It is virtually impossible to assess the effectiveness of a range of management actions without using modelling to allow for the effects of climate and other impacts unrelated to the actual management actions. Models can also assist in setting realistic targets and measuring performance against targets (see discussion in *Catchword*, May 2004 www.catchment.crc.org.au/catchword).

There is an increasing recognition of the need for good data and reliable models for water quality. There are positive signs that this is leading to additional resources being made available for monitoring, providing vital data for both target assessment and reducing uncertainty in model results.

KEY

Confidence
A = high confidence E = low confidence

Suitability
A = very suitable E = not suitable

Practicalities of use
A = simple to use/low data needs E = difficult to use/high data needs

TBA = to be announced

	SedNet			SedNet (2nd half 2005)			EMSS			E2 (June 2005)			IQQM			MUSIC			CMSS			AEAM		
	Confidence	Suitability	Practicalities of use	Confidence	Suitability	Practicalities of use	Confidence	Suitability	Practicalities of use	Confidence	Suitability	Practicalities of use	Confidence	Suitability	Practicalities of use	Confidence	Suitability	Practicalities of use	Confidence	Suitability	Practicalities of use	Confidence	Suitability	Practicalities of use
Hydrology																								
Model time series of runoff							B	A	C	B	A	C	B	A	C	B	A	C				B	B	B
Represent water allocation and system behaviour							C	D	D	C	C	D	A	A	D							C	C	C
Sediment																								
Prioritise erosion control activities	B	B	C	A	A	C	C	C	D	B	B	D							D	D	A	C	C	C
Simulate erosion control to set end-of-valley sediment load targets	B	B	C	B	A	C	C	C	D	B	A	D							D	D	A	C	C	C
Assess performance against end-of-valley sediment load targets (<10Yr)				B	B	C	C	B	D	B	A	D										D	C	C
Assess the distribution of sand slugs	C	C	C	B	A	C				TBA	TBA	TBA												
Investigate temporal patterns of sediment delivery				C	C	C	C	B	D	B	B	D				B	B	D				C	C	D
Investigate the impact of different land-uses on long term sediment loads	B	C	C	A	A	C	C	B	C	B	A	D				B	B	D	C	C	A	C	C	C
Investigate role of point sources in sediment loads				TBA	TBA	TBA	B	A	C	B	A	C				B	A	C	C	D	B	B	A	C
Investigate role of riparian management in sediment loads from streambank erosion	B	B	C	B	B	C				TBA	TBA	TBA							D	D	B	C	B	D
Investigate role of riparian management in buffering of sub-catchment sediment loads							C	C	D	B	B	D				C	B	D	D	D	B	C	B	D
Nutrient																								
Prioritise nutrient reduction activities				C	B	D	C	C	E	C	B	E				B	B	D	D	D	A	C	C	C
Simulate nutrient reduction to set end-of-valley nutrient load targets				C	B	D	C	C	E	C	B	E				B	B	D	D	D	A	C	C	C
Assess performance against end-of-valley nutrient load targets (<10yr)				C	C	D	C	C	E	C	B	E				B	B	D				D	C	C
Investigate temporal patterns of nutrient delivery				C	C	D	C	C	E	C	B	E				B	B	D				D	C	D
Investigate the impact of different land-uses on long term nutrient loads				B	B	D	C	C	D	B	B	E				B	B	D	C	D	A	C	C	C
Investigate the role of point sources in nutrient loads				B	A	C	B	A	C	B	A	C				B	A	C	D	D	B	B	A	C
Investigate the role of denitrification processes in the riparian zone				TBA	TBA	TBA				C	B	E				D	C	C						
Salt																								
Model salt loads at catchment scale										B	B	E	C	D	C							D	C	B
Other																								
Model stream water temperature at catchment scale										B	B	D	B	B	D							C	C	C
Assist in design of monitoring networks					B			B			B			C									C	
Urban stormwater management																								
Design urban stormwater treatment																B	A	D						

TABLE 3. COMPARISON BETWEEN THE MODELS

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