New generation models for catchment modelling: developments in the eWater CRC

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Abstract

The Cooperative Research Centre (CRC) for Catchment Hydrology made considerable progress in development of an integrated catchment model for quantity and quality of runoff with the EMSS and E2 modelling systems. E2 has been available on the Catchment Modelling Toolkit website for over 12 months and more than 60 people have been trained in applying E2 to their catchment modelling applications. The new eWater CRC are working on the evolution of catchment water quantity and quality modelling in a dedicated product development project. This paper has two aims: to discuss innovations in the past and present application of E2 to real catchments, and to outline the vision for future development of WaterCAST by the eWater CRC. The paper describes calibration and application of the E2 model to estimate flow and nutrient loads. It discusses the use of The Invisible Modelling Environment (TIME) to develop new algorithms for sewerage treatment plant discharge and automated processing of results from E2. The paper goes on to outline the plans and progress of the eWater CRC in developing catchment models that have improved modelling of groundwater/surface water interaction, constituent generation and transformation and use of stochastic climate data and model parameters. It will also describe improvements to the software interface that will enhance model set up and reporting, and analysis of results.

Keywords

Surface water modelling, water quantity, water quality, software development

Introduction

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Applications

Introduction to the E2 framework
E2 is a catchment modelling framework based conceptually on two previous software packages, the Environmental Management Support System (EMSS, Cuddy 2003) and the Integrated Quantity and Quality Model (IQQM, Podger 2004). E2 is a subcatchment-node-link system, with generation and filtering of flow and material taking place in sub-catchments from where they pass to a node before being routed and possibly processed along links.

The major components of the model in each sub-catchment are broken into blocks of options (Figure 1) related to the processes of runoff generation, constituent generation, and filtering. This enables a “menu” of different algorithms to be available for each process in each sub-catchment, delivering the resulting flows and loads to the sub-catchment node. From a node, the flow and constituents pass through the system via a series of links and nodes to the catchment outlet/s. Processing and management of material and flows along links includes routing, storage, and in-stream processing. A more detailed description of the E2 framework can be found in Argent *et al*. (2005) and Perraud *et al*. (2005).

E2 has been available on the Catchment Modelling Toolkit website (www.toolkit.net.au) for over 12 months and more than 60 people have been trained in applying E2 to their catchment modelling applications.

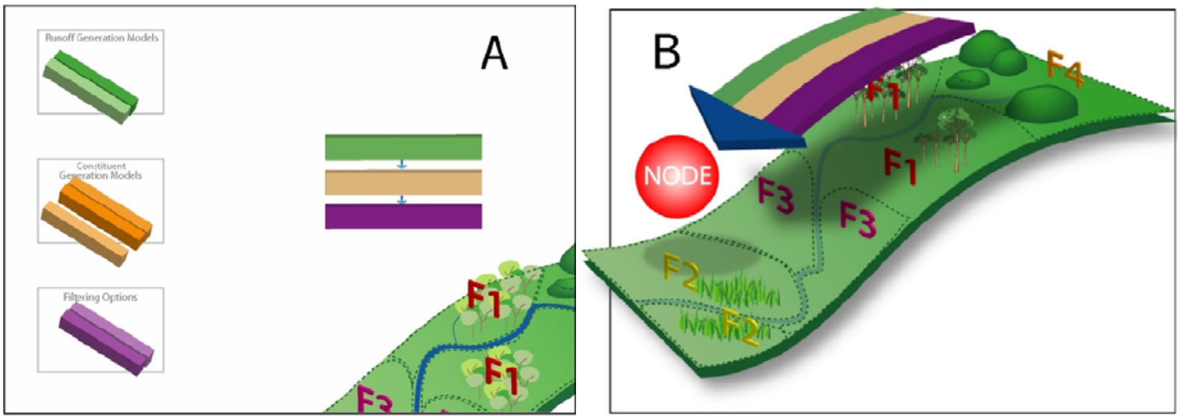

Figure 1. Conceptual structure of sub-catchment options for runoff generation, constituent generation and filtering (from Argent *et al*., 2005).

Model integration and plug-ins

E2 supports a range of approaches to the integration of component models. The first of these is intrinsic to the E2 structure and scenario construction, and occurs when component models are selected to represent processes, such as with rainfall-runoff and constituent generation models. The second approach uses component models for which specific user interfaces have been constructed, and which need to be manually loaded into the structure of an E2 model. The 2CSalt model (Weeks *et al*., 2005) is an example of this. The third model integration approach is through plug-ins, where compatible component models are loaded into E2 and run alongside an E2 model, using, for example, output from an E2 scenario run.

The following two subsections discuss plug-ins that were written in the TIME environment (Rahman *et al*., 2003) for specific application to modelling flows and constituent loads in the Hornsby Shire, a municipality in to the north of Sydney.

A model for generating flows and constituent loads from sewage treatment plant discharge

As part of the recent development of the Hornsby Shire Council Sustainable Total Water Cycle Management Strategy, a whole of catchment water cycle model was developed in the E2 modelling framework to allow flow and constituent loads to be estimated from subcatchments in the shire. Two sewerage treatment plants (STP) within Hornsby Shire act as point sources of flow, sediment and nutrients. Due to its subcatchment-node-link arrangement, E2 in its current form is not ideally set up to deal with point sources, such as STPs. A plug-in was developed to generate the flows and constituent loads that are associated with STP inputs. The raster layer of land-use for the model was modified, so that one of the 25 m x 25 m pixels was set to an "STP" land use type. A custom "rainfall runoff" model was coded in the TIME environment and this model was then assigned to the STP land use class. Internally, the model computes the daily volume of sewage discharged to the stream, using the following equation:

$$Q_{STP} = p(y)\bar{r}f(d) \quad (1)$$

where $p(y)$ is the population connected to the STP in a given year, y, $\bar{r}$ is the average daily volume of sewage discharged from the STP per person connected and $f(d)$ is a factor relating the sewage discharged on a particular day of the week, d, to the average daily volume discharged.

The population connected can be set to a constant value to represent the discharge under current conditions or for some future scenario of population growth. Alternatively, a projected population growth rate can be provided to the model to estimate future sewage discharges. The average daily volume discharged per person was estimated by analysing daily output data from dry weather conditions, which for Hornsby was found to be 224 L/p/d.

An analysis of water quality monitoring of discharges from the STPs showed that concentrations of TSS, TN and TP, since the STP upgrades in 2002, were relatively consistent. It was therefore expected in modelling the current and future development scenarios for Hornsby that the concentrations of TSS, TN and TP in the effluent would remain constant (at their post-2002 levels). An Event Mean Concentration/Dry Weather Concentration (EMC/DWC) model, which is a standard constituent generation model in E2, was applied with the value of EMC equal to the value of DWC for each constituent. For further discussion of this application, see Jordan *et al*. (2006).

A model component for automated reporting of output to a spreadsheet
Another application of the TIME software system within E2 is in automated reporting of outputs from within the framework to other pieces of software. Hornsby Shire Council was interested in obtaining model reports of flow, constituent load and constituent concentrations at each of their monitoring locations throughout the Shire as well as at catchment outlets. A plug-in was developed that reported, for about 40 locations:

- Mean annual flow;
- Median and 75th percentile daily flows;
- Mean annual load of TSS, TN and TP;
- Median, 25th and 75th percentile concentrations of TSS, TN and TP.

The quantities were estimated from the model output over the entire simulation period and exported to a comma separated variable (csv) file format. A Microsoft Excel spreadsheet, containing a macro coded in Visual Basic for Applications (VBA) was developed. This VBA macro reads in the csv file produced by the plug-in in E2 and re-formats the program output to make it visually more appealing, changing the text format and cell colours. These summary outputs from different runs of the E2 model can be compared to test the effect of different land use scenarios on water quantity and quality at different locations in the catchment.

The Future: the eWater CRC's WaterCAST product project

The eWater CRC
The eWater Cooperative Research Centre (CRC) builds and supports decision systems and models for total water cycle management in urban and rural catchments, integrating water quality and quantity, stream ecology and economics. The eWater CRC is a cooperative joint venture between major private and public water businesses and research groups across eastern Australia. Many of the participants in eWater were also involved in the previous CRCs for Catchment Hydrology and Freshwater Ecology.

WaterCAST
The Water and Contaminant Analysis and Simulation Tool (WaterCAST) is one of the eight product projects of the eWater CRC. Product projects have been deliberately established at the outset of the eWater CRC to provide a conduit for delivery of research outcomes to users in a directly accessible form.

The purpose of the WaterCAST product project is to provide managers of predominantly rural catchments with the capability to make informed decisions as to how changes in catchment management influence the quantity and quality of runoff to receiving waters. The product will be developed to facilitate improved and consistent evaluation of flows, loads and concentrations of constituents, under scenarios that could include actual or planned changes in land use, actual or planned changes in land management, climate variability and climate change. The tool will be designed to operate best on rural and peri-urban catchments between 1 and 5000 km^2 in area. This section of the paper outlines the ambitious program for development activities that are planned for WaterCAST over the coming years.

Integration between eWater CRC products
Modelling components developed within WaterCAST will be available to the other eWater products, via the use of common software development architecture. It is very likely that the E2 software framework will act as a shared framework between WaterCAST, the river operations, river management and planning and regional urban products. In particular, algorithms for runoff generation, routing and constituent generation will be shared between these products. Ecological response models, developed within the TIME framework, will be available to be plugged into WaterCAST and the other eWater CRC products.

Incorporation of stochastic climate data for assessing effects of climate variability and change
Catchment models, including E2, have traditionally been set up with the primary purpose of modelling catchments using observed climatic and streamflow data inputs. A typical example would involve supplying the runoff generation algorithm within E2 with an observed time series of say 50 years of observed rainfall and 50 years of observed evaporation data from a climatic observation site within or near the catchment. Alternatively, spatially defined observed climatic data, for example from SILO, could be used.

Stochastic climate data can be incorporated into E2 and similar modelling packages. Relatively easy to use routines are now readily available for stochastic climate data (for example in the Stochastic Climate Library product, Srikanthan *et al*., 2004). However, uptake of stochastic modelling has been limited by the capacity of models to deal with stochastic data in a simple manner on the "input" and "output" ends. As part of the WaterCAST project, it is planned to develop the catchment modelling framework to more easily integrate rainfall, evaporation and temperature data that is generated using the stochastic climate library routines. The use of historical data limits the model to analyses that reflect the variability in climatic conditions represented by the historical climatic period. For some purposes, particularly the analysis of catchment response to climatic extremes, application of stochastic climate data will be valuable. The will be able to capture the responses under potentially a wider range of climatic conditions. Techniques for incorporating climate change projections into the stochastic data generation process will also be brought into WaterCAST as they are developed from research. Users require the ability to analyse and interpret the outcomes of stochastic runs in a manner that is useful and meaningful. Software modules will be written to help model users interrogate the results from the multiple (typically tens to thousands) of individual simulations that will be produced using stochastic climate data.

Enhancement of streamflow routing methods
Streamflow routing models are not currently included in many models of upland catchments, which assume that all runoff that reaches the stream network arrives at the catchment outlet in the same (daily) time step. This simplifying assumption is reasonable where the primary purpose of the model is to consider fluxes of water and constituents over periods of one month and longer. The desire of many potential users of this framework is to consider flows and constituent loads on much shorter temporal scales, often daily or even hourly. To move to daily timestep on catchments at the larger end of the range of interest (greater than about 100 km^2 in area) requires more sophisticated modelling of flows in the stream channel that incorporates delays in the fluxes of water and constituents.

E2 currently has the capacity to perform routing of streamflows using several different hydrological routing models, including Muskingum-Cunge, linear storage and non-linear storage approaches (Mein *et al*., 1974), which are widely accepted means of replicating routing in streams. The E2 formulation currently requires that the model parameter values are set on a reach-by-reach basis, which can be inconvenient and time consuming. The purpose of this component of WaterCAST will be to easily integrate known physical characteristics (such as stream length, slope, bankfull cross-sectional area or "stream roughness") from available data sources to provide a "catchment wide" parameterisation of routing characteristics. The model will retain hydrological routing methods and will not involve hydraulic modelling of stream reaches. Components could be provided, however, to allow for exporting of model outputs from the WaterCAST product in formats that are compatible with readily available hydraulic modelling packages, such as those produced by HEC-RAS (USACE, 2002), DELFT or DHI.

Improved modelling of runoff generation, hillslope and groundwater transport processes
Existing "whole of catchment" hydrological models concentrate primarily on either surface or subsurface transmission pathways for fluxes of water and contaminants. For example, the WaterCAST primarily models runoff and constituent generation from the unsaturated zone via surface flow pathways. By contrast, the 2CSalt model (Weeks *et al*., 2005) for example concentrates on transmission of subsurface flows and fluxes of salt. The current E2 model subdivides the catchment using a subcatchment-node-link structure, with the subcatchments defined using a digital elevation model of the catchment, thereby effectively capturing surface flow pathways, albeit in a "lumped" manner. By contrast, the current 2CSalt model subdivides the catchment into groundwater aquifer hydrological response units, which represent saturated zone pathways in hillslope and alluvial aquifers. The unsaturated zone is not modelled explicitly in 2CSalt and drainage from the unsaturated zone into the groundwater hydrological response units is modelled using routines that are external to 2CSalt.

The purpose of this component will be to link together these two processes into one model that allows for hydrologic modelling of both surface runoff and subsurface flow pathways. In this task, software coding will be undertaken to link the surface hydrology in E2 with the subsurface hydrology of a model like 2CSalt. This will involve tracking the fluxes of water and constituents:

- from surface runoff to the stream network;
- drainage from the surface water functional units to the groundwater aquifer units that underlie them; and
- lateral drainage between surface water functional units in the unsaturated zone.

Where possible, fluxes of constituents will be "tagged" so that load contributions can be tracked back to find the relative contributions for pathways within the catchment to loads at the catchment outlet.

Modelling of small distributed water storages

Storages that are small in size but distributed in nature are generally ignored in most catchment models. This component of the WaterCAST project will enhance catchment models using modules that handle the water and constituent balance for distributed surface water storages. In terms of water balance, this will involve modelling inflows, extractive use, spills, low flow bypasses and seepage to groundwater. The storages will also affect constituent balance by acting as sinks for some constituents, which then may be partially (or completely) flushed during high flow events.

As part of this model component, tools will be built to facilitate setting up the model using spatial data on small distributed storages. This will involve linkage with GIS to locate the storages and software modules to facilitate the setup of the water and constituent balance for a large number of storages, which will be difficult and time consuming to do on an individual storage-by-storage basis. Alternative approaches could also be provided, whereby distributed storages are generated using a stochastic approach across the subcatchment, with their size and position within the subcatchment determined by random sampling from distributions that are input by the program user, which is the approach that is currently adopted in TEDI (Nathan *et al*., 2005). Existing models, known as TEDI and CHEAT (Nathan *et al*., 2005), have been developed for this purpose of modelling the impact of small catchment dams on streamflows. However, these models do not model constituent dynamics at all. The WaterCress model (Cresswell *et al*., 2002) can also model the effects of small catchment dams. The existing algorithms within these models could be used as a starting point for the proposed component within WaterCAST.

Enhancement of in-stream transport, routing and transformation of constituents

E2 currently has the capacity to include models along links to simulate transport of water and constituents. Most previous applications have focussed upon salt, TSS, TN and TP, which are essentially conservative constituents. Although these previous applications have run E2 using a daily time step, the primary objectives have been to assess constituent loads (or changes in constituent loads) over periods of months to years. Potential model users have prioritised the ability to model constituents that are non-conservative in nature and to consider how the concentrations and loads of these constituents might be changing over finer time scales than have been considered in previous studies. Enhancements to modelling of transport and transformation of constituents are under discussion between the research and product development teams within eWater. Research work is currently under way to develop capacity to model generation, delivery and transport of Nitrogen and Phosphorus, including speciation of nutrients.

Conclusions

An application of the E2 model to estimate flow and nutrient loads is described. It discusses the use of TIME to develop new algorithms for sewerage treatment plant discharge and automated processing of results from E2. As part of the Water and Contaminant Simulation Tool (WaterCAST) project in the eWater CRC, plans are being implemented for enhancements to the catchment modelling framework over the coming years. The plans for enhancing the catchment models include facilitating the use of stochastically generated climate data in catchment models, improved modelling of surface water and ground water transport processes, modelling of small distributed water storages and improved modelling of constituent transport, routing and transformation.

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