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Prioritisation approach for estimating the biophysical impacts of land-use change on stream flow and salt export at a catchment scale

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ABSTRACT

Predicting the impacts of land-use change on stream flow and stream salt export at a catchment scale is hampered by limited detailed measured data, particularly with regard to hydrogeological information. A recently developed modelling approach is presented that can be used to predict the variation in likely catchment response to changes in woody cover using only broadly available data. The Biophysical Capacity to Change (BC2C) model combines a downward approach for water balance, with groundwater response using groundwater flow systems (GFS) mapping to provide hydrogeological and salinity parameters, into a spatial model for estimating the impacts of changes in woody vegetation cover across large areas. The results from the model are compared to gauged flow and salinity data for 14 stream gauging stations across the Murrumbidgee catchment, in south-eastern Australia. Considering the limited calibration of the model, the results compare favourably in broad terms, and provide a useful starting point for consideration of the impacts of land-use change on stream flow and salt load, and to guide catchment managers towards areas where more detailed study can be undertaken.

Software availability

Software: BC2C
Contact address: Matthew Stenson, CSIRO Land and Water, 120 Meiers Rd, Indooroopilly, QLD 4068, Australia. Tel.: +61 7 3214 2804; fax: +61 7 3214 2855. matthew.stenson@csiro.au
Hardware: Intel x86 based PCs with at least 512 Mb of RAM and 200 Mb of disk space
Operating system requirements: Windows 2000 or XP with .NET 2.0 runtime installed
Language: C#
Size: Core application source 13.5 k lines + TIME libraries
Availability and cost: BC2C is available free of charge from the Catchment Modelling Toolkit website (www.toolkit.net.au). More detail on the release history and system requirements is available from www.toolkit.net.au/bc2c.

1. Introduction

Changes in land-use through clearing of native vegetation, or the afforestation of previously cleared land, can affect catchment water and salt export. The effects and impacts of such land-use changes are variable – depending on factors including the land-use change itself, together with rainfall/climate, hydrogeology, topography. In areas such as Australia's Murray–Darling Basin (MDB) (area ~10^6 km^2), where land-use change has been widespread, and water resources are heavily used, the ability to predict likely impacts of land-use change on stream flow and salt load is seen as an important management tool. Given the large size of areas such as the MDB, it is not possible to undertake direct measurement of key processes everywhere, and modelling strategies need to be used to take advantage of available data/information and provide guidance on likely impacts.

One approach is to focus on a particular small study catchment site, and develop detailed conceptual models to drive computer models of catchment response. Examples of this include the work of Dawes et al. (2002) in the Wanilla catchment (area ~180 km^2, South Australia), and Hekmeijer et al. (2001) at Kamarooka (area ~100 km^2, Victoria) which both used the FLOWTUBE groundwater model (Dawes et al., 2000) to predict the impacts of recharge change on groundwater discharge and hence on areas of

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salt-affected land. It is often the stated objective of these relatively data-rich case studies to allow their findings to be extrapolated across the landscape more broadly. Unfortunately, catchment response is often complex and highly variable, which confounds attempts to directly and easily extrapolate from case studies.

Computer modelling can help assimilate data and information from case studies and provide a framework for guidance on the response of catchments to land-use change. The availability of data is a key limitation for the complexity of catchment modelling across large areas. As such, there is a role for relatively simple modelling frameworks which take advantage of the generally available broad-data sets such as topography, rainfall/climate, and hydrogeology.

The requirement to predict impacts at a catchment scale, together with limited data, and the need to focus on the dominant processes at that catchment scale, lends itself to a downward modelling approach (e.g. Klemeš, 1983; Sivapalan et al., 2003). This paper describes a downward (or top-down) modelling approach (BC2C) which uses a classification approach to help prioritise areas in terms of the possible impacts of land-use change on salt and water generation, for more detailed investigation. This type of approach also lends itself to incorporation as part of a broader integrated assessment (Letcher et al., 2007), as a component of environmental investment assessment tools (e.g. SLIM: Hajkowicz et al., 2005), or economic frameworks (e.g. Model T: Nordblom et al., 2006).

The aim of this paper is to describe a catchment modelling approach which can be used to estimate variability with respect to the impacts of land-use changes on generation of water and salt to streams from upland areas. This is built on the approach of Dawes et al. (2004) with significant additional complexity in the treatment of hydrogeology and its impacts on groundwater response times.

The paper describes the modelling approach in three sections: landscape disaggregation, water balance modelling, and groundwater response modelling. A case study of an application of the BC2C model to 14 sub-catchments of the Murrumbidgee catchment (ranging in area from 155 km^2 to ~34,000 km^2, SE Australia) is then described.

2. Landscape disaggregation

The BC2C estimates the variation in catchment response across large areas. It does this by first sub-dividing the modelled area into many smaller units, which are called Groundwater Response Units (GRUs). These GRUs are the fundamental modelling units of the BC2C model. Ideally each GRU would correspond precisely with both the extent and the scale of each of the underlying groundwater processes. However, given the over-arching requirement to model large areas in a relatively automated fashion without detailed on-ground measurement, this is not feasible.

A relatively simple and systematic framework for dealing with variation in hydrogeology across large areas is the groundwater flow systems (GFS) classification (Coram et al., 2000), which is further described in Walker et al. (2003). The GFS classification was developed as an attempt to capture the variability of hydrogeological processes and salinity processes that lead to the mobilisation and redistribution of water and salt across the Australian landscape.

The classification recognises three spatial scales: Local, Intermediate and Regional (Coram, 1998), which are generally described by the distance between recharge and discharge zones. GFS mapping is becoming more widely available across the upland areas of the MDB. GFS maps typically use a combination of geology, land slope, and "expert knowledge" to show areas which are likely to be similar from a salinity management perspective. Key hydrogeological and salinity parameters can then be assigned across the GFS classification to provide a spatial representation of their variation across large areas. It is impossible to test the accuracy of this approach (and it is expected that the updating of both the GFS mapping and parameterisation will continue into the future), so it should be viewed as a practical way of bringing together hydrogeological understanding and data and its variability across an area, rather than as "precise data".

In order to disaggregate the modelled catchment into an individual GRUs, an assumption is made that the scale of GFS can be estimated by using a break-up of land-surface topography. This assumption restricts the applicability of the BC2C model to Local (and some Intermediate) GFS where surface water and groundwater systems commonly tend to mirror each other.

For each modelled catchment in BC2C, the land-surface topography information is used to generate a stream network. This is performed using standard GIS flow-accumulation technique, which requires an input "threshold area" which sets the minimum contributing catchment area in order to initiate a stream. By varying the threshold value, a finer or coarser stream network is created. The individual GRUs are then defined as sub-catchments of the created stream network.

The water balance and groundwater response of each individual GRU are calculated independently. The location of the GRU within a particular stream network is only used for summing or grouping the results from multiple GRUs. In other words there are no feedbacks or interactions between GRUs there.

3. Water balance

The BC2C model estimates water balance terms for each individual Groundwater Response Unit (GRU) using an annual time-step. Fig. 1 shows the structure of the water balance for an individual GRU.

BC2C uses a simple water balance model to calculate (1) the partitioning of rainfall into evaporated (ET) and non-evaporated (XS) water, (2) to partition the non-evaporated (XS) component into "slow" and "quick" components (which can be loosely interpreted as "recharge" (AR) and "quick-flow"). These components are described below.

3.1. Rainfall partitioning

The approach of Zhang et al. (2001) has been used in BC2C, to partition rainfall into an evaporated and non-evaporated (i.e. catchment yield) component. Zhang et al. (2001) provide

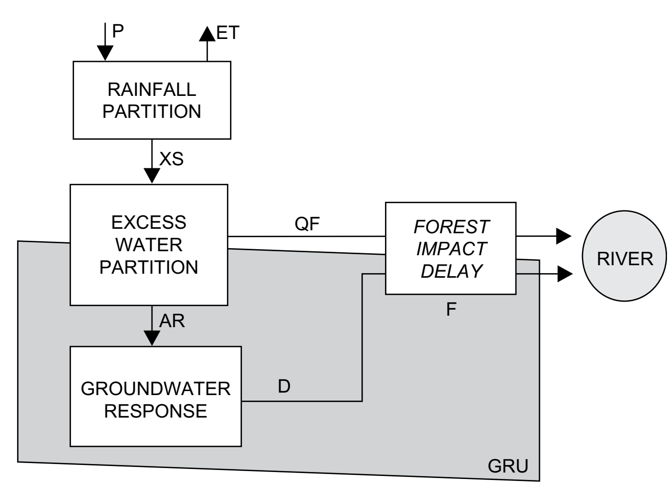

Fig. 1. Water balance for an individual GRU, showing the main pathways considered by BC2C [P = rainfall, ET = evaporation, XS = non-evaporated rainfall, QF = quick-flow, AR = recharge, D = discharge, F = forest impact delay].