# Two Modelling Approaches for Predicting Water and Salt Generation to Upland Streams: BC2C & 2CSalt

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**EXTENDED ABSTRACT**

Predicting the impact of land-use change on water and salt generation from upland areas at a catchment scale is a difficult task. Across large catchments there are often limited field measurements, and so predictions are forced to rely on modelling. However, at this scale input data for models is usually restricted to information surfaces such as rainfall, geology, and surface topography, and hence the complexity of modelling approaches need to match the complexity of the available data.

This paper presents a comparison of two recently developed catchment-scale models which predict the impact of land-use change on water and salt generation from upland areas to streams. Both models consider a surface water balance, incorporate groundwater processes, and generate water and salt export to streams. BC2C is an annual time-step model which uses a simple water balance approach, and groundwater response time theory to estimate the impact of changes in forest cover on stream volume and salt load. 2CSalt differs from BC2C in that it uses the results of daily time-step 1D modelling to provide the water balance, and includes both a hill-slope and an alluvial groundwater store. It produces monthly stream flow and salt load estimates.

We compare results from three sub-catchments in the mid-Murrumbidgee, NSW, Australia, using both the BC2C and 2CSalt models. This highlights differences between the two approaches, and allows inspection of their relative merits for catchment management issues.

The two models (BC2C and 2CSalt) provide complementary approaches to aspects of investigating the impact of land-use change on generation of water and salt. While there is an overlap in the scale of applicability, the two models are quite different and provide answers to different questions.

BC2C is intended for regional prioritisation across large catchments, and for examining the variation in possible impacts of afforestation scenarios between catchments.

2CSalt operates at a scale finer than BC2C, and is computationally more intensive. Its strengths are in providing access to a broader range on land-use options, providing output to examine seasonal impacts, the ability to calibrate to measured gauged data, and output which can feed into river routing models.

# 1. INTRODUCTION

## 1.1. Background

Land-use change is recognised as a management action that can affect water and salt generation from upland areas. The impacts of land-use change can be highly variable, and depend upon many factors such as rainfall, geology, soil, magnitude of land-use change, hydrogeology, etc. This variability makes it hard to predict impacts across large areas ( >1000 $km^2$ ).

In order to predict impacts of land-use change across large catchments, with limited availability of fine-scale measured data, models are a useful tool. Computer models allow for systematic assessment of data, and provide a framework for applying conceptual models across the landscape.

Groundwater processes affect the timing of the impact of land-use change on stream flow, as well as the salt generation (resulting from discharge of saline shallow groundwater). Two recently developed catchment models have used the Groundwater Flow Systems (GFS) approach (Coram *et al.* 2000, Walker *et al.* 2003), as a way of bringing together groundwater information in a simple but structured manner.

Two models have been developed within the CRC Catchment Hydrology to help understand the impacts of land-use change on upland water and salt generation. The first is BC2C, which is essentially a top-down approach that uses generalised relationships to estimate the impact of afforestation. The second is 2CSalt, which obtains its water balance by aggregating the individual results from more detailed 1D water balance modelling. Superficially, these models appear to be very similar, and this paper sets out to explain the different roles and rationale for deciding between which of these two models to use.

## 1.2. Objective of this paper

The objective of this paper is to investigate the use of two recently developed catchment models (BC2C and 2CSalt) for estimating the impacts of land-use change on generation of water and salt from upland catchments. Importantly, this paper seeks to clarify the differing roles of these superficially similar models in order to explain the rationale for a particular choice of modelling approach.

# 2. MODELLING APPROACHES

This section provides a brief overview of BC2C and 2CSalt. Both models are used to investigate the impacts of land-use change on catchment water and salt balance, however they operate at different time-scales, require different input data, and provide different types of output.

## 2.1. BC2C Model

The BC2C (Biophysical Capacity to Change) Model (Dawes *et al*. 2004) was developed to provide a systematic spatial approach to investigating the impact of afforestation/clearing on generation of water and salt. This paper describes the use of the graphic-user interface version of BC2C, available from the Catchment Modelling Toolkit (www.toolkit.net.au/bc2c), which is documented in Gilfedder *et al*. (2005).

BC2C divides the modelled area into sub-catchments, based on a user-identified area threshold, applied to land-surface topography information . These Groundwater Response Units (GRUs) are the fundamental modelling unit within BC2C. Water and salt generation from each of the GRUs is then summed to the area of interest (e.g. a gauging station). Each modelled area is likely to be made up of many tens or hundreds of individual GRUs.

BC2C uses the mean annual water balance relationship developed by Zhang *et al*. (2001). The excess water is then partitioned into “quick” and “slow” flow components. The “quick” flow component is directed into the stream, while the “slow” flow is delayed according to a groundwater response function. Groundwater Flow Systems (GFS) maps are used to map hydrogeological parameters across the modelled area. Variability in aquifer slope, transmissivity, and flow length affects the timing of groundwater discharge to stream.

BC2C uses mean annual water balance input, and its output shows the change in mean annual water and salt using an annual time-step. Figure 1 shows a simplified version of the conceptual model for a GRU.

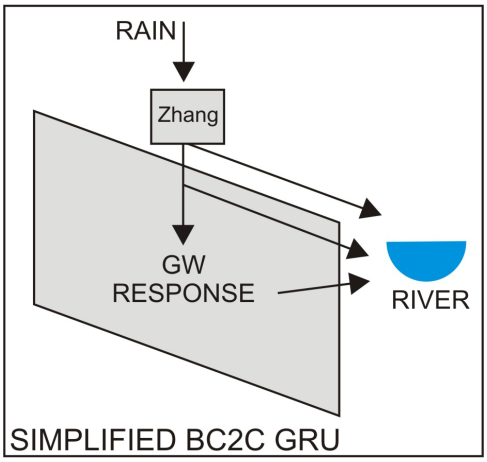


**Figure 1**.Simplified diagram of the basic structure of each groundwater response unit (GRU) in the BC2C model.

BC2C is intended to be a relatively simple model, using only broadly available data. Modelled area would typically be the upland areas of large catchments (e.g. Murrumbidgee, Lachlan), or across large basins (e.g. Murray-Darling Basin). As such, BC2C is useful for exploring variation between catchments at a coarse scale.

### 2.2. 2CSalt Model

2CSalt (Stenson *et al*. 2006) was developed by the CRC Catchment Hydrology to provide water and salt inputs to regulated river models such as IQQM (NSW DLWC 1999). The 2CSalt model results in this paper are from Littleboy (2006). 2CSalt is more complex than the BC2C model, and requires more detailed input data.

2CSalt uses a monthly time-step water balance, derived from multiple runs of daily time-series 1D Water Balance model (the PERFECT model (Littleboy *et al*., 1992) has been used here). Groundwater Flow Systems (GFS) maps are also used to estimate and distribute hydrogeological parameters across the modelled area. The output from 2CSalt is a monthly time series of water and salt generation to stream.

In a similar manner to BC2C, 2CSalt divides the modelled area into sub-catchments, based on a user-identified threshold. These Groundwater Response Units (GRUs) are the fundamental modelling unit within 2CSalt. Each GRU is then divided into two components: 1) hillslope; 2) flat "alluvial" area. This is done using the MRVBF terrain-analysis technique of Gallant and Dowling (2003). Water and salt generation from each of the GRUs is then summed to the area of interest (e.g. a gauging station). Figure 2 shows a simplified conceptual diagram of a GRU in the 2Csalt model.

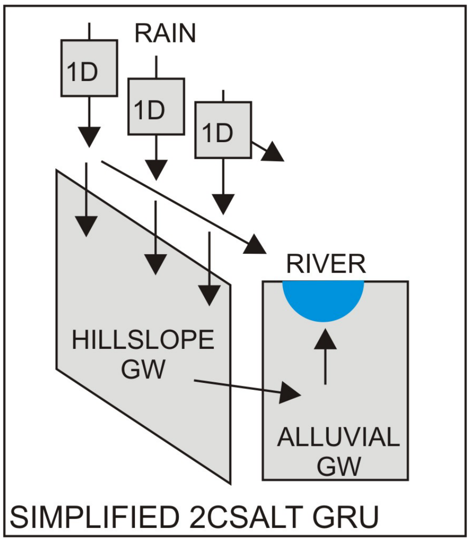


**Figure 2**.Simplified diagram of the basic structure of each groundwater response unit (GRU) in the 2CSalt model.

2CSalt is aimed at exploring seasonal impacts of land-use change. Modelled area is typically at a catchment scale (e.g. Kyeamba, Tarcutta) rather than a large catchment scale (e.g. whole Murrumbidgee).

### 2.3. Similarities / Differences

This section lists some of the key similarities and differences between BC2C and 2CSalt models.

Key similarities are:

- Both assume a gaining stream, with no ability to drain water back into the groundwater system. This restricts the scope of the model to upland areas where this assumption is more likely to be valid.
- Overlap in applicability for modelled areas for catchments of 1000-2000km$^{2.}$

Key differences are:

- Time-step for the water balance is mean annual (BC2C), vs monthly (2CSalt)
- 2CSalt has two groundwater stores, and allows for the buffering action of flat alluvial areas near the river.
- 2CSalt requires calibration against streamflow and stream EC data at the catchment outlet

- BC2C is applicable for modelled areas 1000 – 50 000 km$^2$, 2CSalt is typically less than 2000 km$^2$.
- BC2C uses more generalised data and is typically much quicker to prepare (days vs weeks), and less computationally intensive than 2CSalt (minutes vs hours).

## 3. IMPACT OF AFFORESTATION ON CATCHMENT FLOW AND SALT LOAD

This section compares the use of the two models in three sub-catchments of the Murrumbidgee Catchment.

### 3.1. Study area

Kyeamba, Tarcutta and Jugiong Creeks are catchments within the Murrumbidgee in the NSW Murray-Darling Basin (see Figure 3). They are located in the mid-Murrumbidgee, and flow into the main stream between Burrinjuck Dam and Wagga Wagga.

**Table 1**. Summary data for three study catchments.

| | Gauged size km$^2$ | Current woody cover | Rainfall range mm/yr |
|---|---|---|---|
| Kyeamba@ Ladysmith | 538 | 8% | 620-740 |
| Tarcutta@ Old Borambola | 1630 | 32% | 580-1200 |
| Jugiong@ Jugiong | 2170 | 3% | 600-900 |

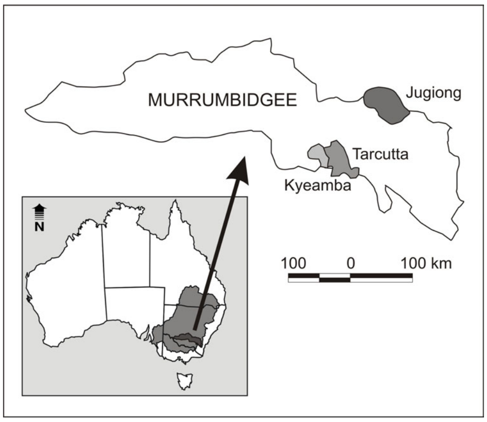


**Figure 3**. Location of the three study catchments within the Murrumbidgee catchment, NSW [Inset shows location within Murray-Darling Basin].

### 3.2. Steady-State Results

The impacts of different levels of afforestation were modelled for each of the three study catchments. BC2C aims to predict variation in impact, rather than absolute values, and as a result we have compared the models' results in terms of the change from modelled current conditions.

Changes in woody cover was implemented in the models by making new woody vegetation maps derived from a *Promod* (Battaglia and Sands, 1997) derived plantation productivity surface (for *Pinus radiata*; Trevor Booth, ensis, *pers. comm.*). By using different productivity thresholds, a series of new woody cover layers were produced which were then run through both models in steady state.

Results in Figures 4 and 5 show the modelled percentage change in total flow and total salt load, as a result of these different levels of woody cover. The results have been normalised to modelled totals under current conditions.

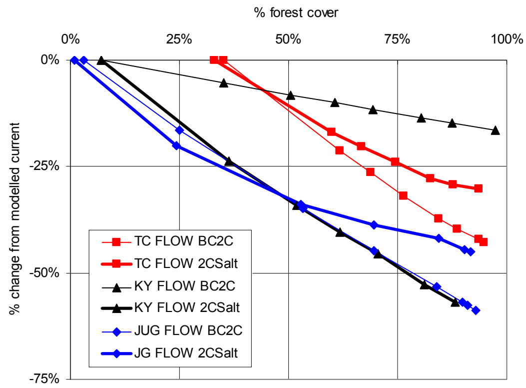


**Figure 4**. Modelled impact of afforestation on stream flow in Kyeamba, Tarcutta and Jugiong.

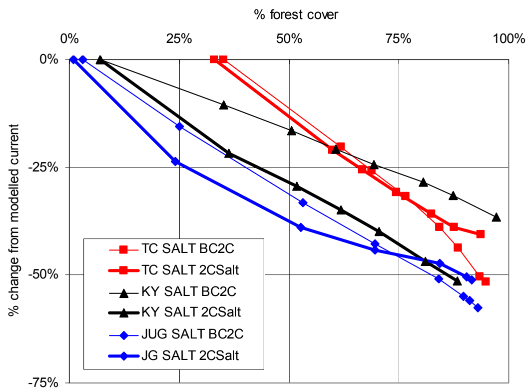


**Figure 5**. Modelled impact of afforestation on stream salt load in Kyeamba, Tarcutta and Jugiong.

Given the differences in complexity of the two models, their results compare reasonably well in Tarcutta and Jugiong for both the impact on flow and the impact on salt. The results for Kyeamba are not a good match though – with 2CSalt predicting over three times the impact on flows that BC2C predicts.

Given the lack of measured data for impact of land-use change at this 1000-2000 km$^2$ catchment size, there is little to pick between models. As such, to answer questions at the level of detail shown in Figures 2 and 3, there seems little reason to go to additional computational complexity present in the 2CSalt model. The relatively simple BC2C model gives a similar result. But if the questions being asked involve small areas (<1000 km$^2$?), with more complex land-use options, and perhaps a finer temporal detail (i.e. seasonal), then simple models such as BC2C are no longer most appropriate.

## 4. REGIONAL FOCUS

If the scope of the question being asked is broad, then models will need to be run across very large areas (i.e. across uplands of MDB). The size of the modelled area implies that there will be minimal detailed measured data, which in turn limits the types of input data to those which are generally available. As a result, relatively simple models, such as BC2C, which use generalised relationships are a sensible starting point. Figure 6 gives an example of such broad-scale BC2C results, which presents modelling results showing the variation in impact of afforestation across a large area.

The BC2C results in Figure 6 give a sense of the variability which can be expected in a systematic and consistent way. While such scenarios could also be run using 2CSalt, the computational overhead is likely to be at least 20 times greater and would involve months rather than days to produce.

The aim of modelling over such a large area is to provide results which give a general guide to the impacts expected, and provide a focus for selecting smaller areas where more detailed models can be used to achieve greater confidence in the outcomes.

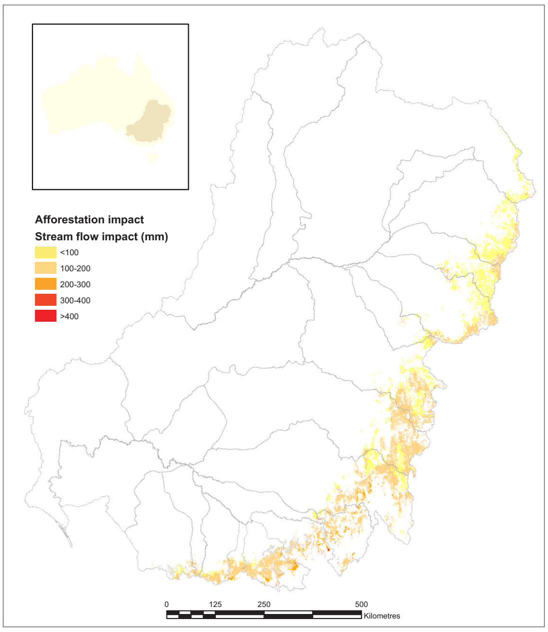


**Figure 6**. Example BC2C output: Modelled impact of afforestation on water yield to streams, for all areas > 500mm/yr rainfall, with plantation productivity >15m$^3$/ha/yr. (Gilfedder *et al.* 2006)

## 5. SUB-CATCHMENT FOCUS

As the size of the modelled area decreases, the extra effort involved in 2CSalt modelling can provide additional details. While BC2C operates at an annual scale using mean annual input, the monthly time-step of 2CSalt allows for the impact on flow seasonality to be explored. Figure 7 shows an example of this, by showing the flow duration curves (FDC) for "current" and "fully-afforested" scenarios in the Jugiong catchment.

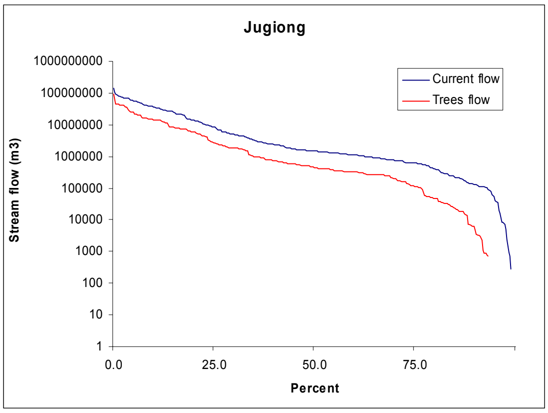


**Figure 7**. Modelled impacts of afforestation on flow duration curves for Jugiong Creek (from Littleboy in review).

2CSalt also provides estimates of the various pathways of water and salt to stream. These pathways vary considerably due to climate, topography, geomorphology, groundwater systems soil type and land use. As an example, the estimated pathways of water to stream for Jugiong Creek is shown in Figure 8. In this example, water to stream is dominated by hillslope hydrology (surface runoff, sub-surface lateral flow and surface discharge).

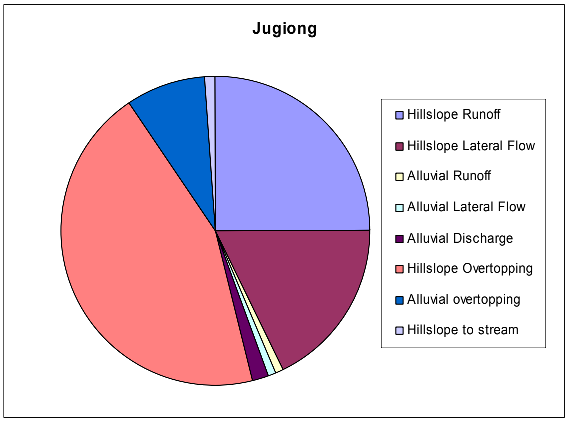


**Figure 8**. 2CSalt modelled pathways of water to stream for Jugiong Creek (from Littleboy in review).

2Csalt can also simulate more detailed land use scenarios than BC2C. Table 2 shows an average annual summary of the reduction is salt export to stream based on the conversion of cropping land to either perennial pasture or lucerne. For the three catchments, lucerne reduced salt export (expressed as t/ha reduction is salt load per hectare of land use change). Large differences between the three catchments are also evident with Jugiong Creek having the largest benefits for conversion of cropping land to either pasture or lucerne.

**Table 2**. Summary of 2CSalt results for cropping land use change scenarios in the three catchments

| | **Reduction in salt export t/yr/ha** | |
|---|---|---|
| | Cropping to Perennial pasture | Cropping to Lucerne |
| Kyeamba | 0.07 | 0.09 |
| Tarcutta | 0.10 | 0.16 |
| Jugiong | 0.51 | 0.64 |

## 6. DISCUSSION AND CONCLUDING REMARKS

The two models described briefly in this paper (BC2C and 2CSalt) provide complementary approaches to aspects of investigating the impact of land-use change on generation of water and salt from upland areas.

Both models assume a gaining stream, and are therefore limited to upland areas where this assumption is most likely to be valid. As the modelled area becomes larger, more complex processes of feedbacks in groundwater / surface water interaction are likely to occur. Neither BC2C nor 2CSalt can currently model the effects of losing streams.

While there is an overlap in their scale of applicability, the two models are quite different and provide answers to different questions.

- BC2C is intended for regional prioritisation across large catchments, and for examining the variation in possible impacts of afforestation scenarios between catchments.
- 2CSalt operates at a scale finer than BC2C, and is computationally more intensive. Its strengths are in providing access to a broader range on land-use options, providing output to examine seasonal impacts, the ability to calibrate to measured gauged data, and output which can feed into river routing models.

## 7. ACKNOWLEDGMENTS

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