BC2C Technical Documentation
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# Table of Contents

Acknowledgements ii  

1 Introduction 1  
1.1 Overview 1  
1.2 This Report 2  

2 Model Outline and Description 3  
2.1 Introduction 3  
2.2 Model Direction 4  
2.3 Model Description 5  
2.3.1 Data Sources 5  
2.3.2 Water Partitioning 6  
2.3.3 Discharge and Salinity 7  
2.4 An Example of the User Interface 8  

3 Groundwater Processes And Time Scales 11  
3.1 Groundwater Response 11  
3.2 Time-scales 12  
3.3 Shape of the response curve 12  
3.4 Combining the groundwater time-scales 15  

4 BC2C Theory 16  
4.1 DEM Analysis 16  
4.2 Water Partitioning 16  
4.3 Groundwater Time Delays 17  
4.4 Tree Canopy Time Delays 18  
4.5 Water Salinity 19  

5 Changes to Salt Duration Flow Regime and 20  
5.1 Changes to Salt Duration 20  
5.2 Changes to flow regime 20  

6 Water and Salt Balance Issues 22  
6.1 Mass Balance Considerations 22  
6.2 Climatic Considerations 22  
6.3 Water Partitioning and Salinity 23  
6.4 Mixing and Discharge Processes 23  
6.4.1 Some Example Catchments 24  

7 Little River (sub-regional) Case Study 25  

8 MDB Case Study Report 28  

9 Summary and Discussion 32  

10 References 77
1 Introduction

This report brings together a range of documents (a combination of published and unpublished material) which make up the technical documentation for the BC2C (Biophysical Capacity to Change) model. The report describes some of the background and theory of the model, applications of the model in case studies, and the AML code (rewritten version in September 2004) for the model itself.

1.1 Overview

The BC2C (Biophysical Capacity to Change) model is a prioritisation tool for estimating the changes in catchment salt generation as a result of land-use change. As its name suggests, it deals only with the biophysical, and does not consider social or economic capacities to change. It does however provide a simple biophysical input for use in socio/economic models.

BC2C is a conceptual mass balance model designed to simulate the long-term average salt and water yield of whole catchments. The catchments should have two important features: first they are unregulated, that is man-made structures and flow manipulation should not greatly impact on the actual stream flow, and second they should be large enough so that all rain falling within the boundary is discharged to the surface or stream within the same boundaries. This in general places a lower limit on catchment size of around 1 km².

BC2C predicts two quantities that vary through time:

- The first is the change in water yield from a catchment due to a change in the percentage of forest cover. A time-lag was included to account for the time taken for trees to mature in each catchment, along with the time required for the groundwater system to equilibrate with the new recharge input.

- The second is the amount of salt present in the water yield. Once the water balance is generated this is simply a matter of associating each water quantity with a salinity, and adding them up. (A third output is available, total water salinity, and this is simply a ratio of the amount of salt to the amount of water at any time.)

BC2C is a rapid assessment tool, and therefore it has certain features and associated limitations. It readily allows a user to get a feel for the current situation in terms of water and salt yield, and the relative differences that can be made by changing the percentage of tree cover within individual sub-catchments of the catchment. Far from being an end point, this quickly allows the user to decide where further investigation is warranted, and those areas for which vegetation manipulation will not produce the desired results. BC2C is designed for state extension officers, catchment management groups and planners, policy staff and managers in consultancies and state, regional and local government agencies.
1.2 This Report

This report provides the technical documentation, and brings together several publications and other pieces of work, which contribute towards the documentation of the BC2C model. As such, this BC2C documentation consists of:

1. Overview
2. Model outline and description
3. Groundwater Processes and Time scales
4. Theory behind the model
5. Changes to Salt Duration and Flow Regime
6. Water and Salt Balance issues
7. Little River Case Study
8. MDB Case Study
9. Discussion of Future Work

Appendix 1 The AML code for the model
Appendix 2 Model code for changes to flow regime

There are also four separate publications which help to describe the application of the BC2C model in more detail. These consist of published Technical Reports which give more detail on the application of the model to specific case study examples (Attachment #1, 2), and also more detail on the extension of the theory to include the effects of land-use change on salt duration effects (Attachment #3), and the method for estimating the effect of land-use change on flow regime (Attachment #4).

Companion Publications


2 Model Outline and Description

2.1 Introduction

The Biophysical Capacity to Change (BC2C) model has been developed to help answer some very broad questions. How much difference can planting or clearing trees really make to the area of dryland salinity in a catchment, or the salt load of a stream? How long will it take until we can see the full effects of vegetation change? These are important questions, given current and proposed salinity management strategies that involve broad-scale reafforestation, coupled with the clearing of native vegetation in some areas.

There are certain requirements for a tool that would answer these questions.

- Firstly it must be spatially explicit: able to produce a map at different scales showing areas that improve or degrade after a change.
- Secondly it must be temporally explicit: how much time passes following a change will affect the answer at any given location.
- Thirdly it must produce a number: there is little value producing a risk map with “high” or “low” associated risk, the best solution produces a number in relevant units that indicates the magnitude of change we could expect.

The aim of much catchment modelling work is to reproduce daily flow and salinity records as measured at a stream gauge. Most usefully this will be done under several different conditions, whether they are climate or land-use change related. The clear intention of this type of work is prediction of fine-scale changes as induced by larger-scale influences, and is most appropriate where it is clear that meaningful changes can be made to the system, or where an asset or resource is being threatened.

What is commonly missing from ad-hoc studies, however, is a meaningful framework to place the results within. Thus an experiment examining the near surface processes may not be linked with another focussing on groundwater flow across the same area. Similarly, single discipline analyses of catchments may overly simplify or even ignore inputs and interactions with processes considered less important. The work of Coram et al. (2000) has resulted in such a framework, the Groundwater Flow Systems (GFS). This is based on geology, surface landform and regolith mapping, so it encapsulates much information about the soil and aquifer systems covered. Continental and Basin-scale data is applicable for broad policy setting goals, while sub-regional scale mapping allows finer resolution work prioritising sub-catchments.

The flow and salt load of streams is controlled by a number of factors:

- the relative dominance of surface and subsurface flow paths,
- size and activity of salt stores, and
- rainfall seasonality and other climatic drivers.

Estimation of water-balance components, pathway time delays, potential mixing, and discharge processes are necessary in the Biophysical Capacity to Change model (BC2C). Methods must only use data that is ubiquitous, and as far as possible, not require stepping through each year to arrive at an updated estimate or solution. The work of Zhang et al. (1999) and Dawes et al. (2002) for water balance, Gilfedder et al. (2002a) for time delay, Gilfedder et al. (2002b) and Smitt et al. (2002) for response shape, and Coram et al. (2000) for groundwater flow system linkage, provide the basis for the procedures within the BC2C model. The earlier modelling work of Dawes et al. (2001, 2004b) describes the SALSA model used by ABARE, and not the BC2C model.
Within individual catchments there are two important stream response functions: flow-duration curve, and flow-salinity curve. Either, or both, of these curves may be affected by a land-use change within a catchment. How these change from the pre-clearing or current conditions to new land-use patterns, is both useful information, and a powerful tool for inferring catchment function. Within the BC2C model an annual time step is used, which allows some simplification of process and response representation. While the obvious advantage is that computations are simpler and fewer, there is a total loss of detail at sub-annual time scales.

Using GFS as a basis, available MDB-wide data sets and robust long-term water and salt relationships, it is possible to estimate the salt and water yield from catchments. A graphic-user interface model has been developed for BC2C within the CRCCH Toolkit Project, although variants have used EXCEL spreadsheets (for crude screening work of whole catchments) or GIS systems (for spatial applications and finer work). The data requirements are: annual average rainfall, average rainfall salinity, tree cover, and groundwater flow systems. Within the GFS layer there are several other parameters: groundwater recharge coefficient, groundwater response time and groundwater discharge salinity.

Work is restricted to consideration of unregulated catchments only. The reasons for this are that off-takes of water for domestic and commercial purposes distort the natural flow and salinity patterns. It is often difficult enough to establish the effect of an altered land-use pattern with annual climate variability the only complication. The addition of anthropogenic stream flow and salinity modifications not only makes the task much more difficult, but negates the ability to extrapolate the findings to other catchments.

2.2 Model Direction

BC2C is a conceptual model that links changes in land-use to changes in stream flow and salt load. A tool has been developed implementing this model that will allow the prioritising of areas for tree planting within large catchments. The BC2C tool has two important functions. Firstly, it must be technically sound enough to give confidence that the salt and water balances can be reasonably fitted, and that modelled results following land-use change are believable. Secondly, it must be simple enough that changes can be made and new results displayed quickly, fulfilling an educational role.

There are a number of desirable attributes for any apparently new model, first and foremost not reinventing previous work. In the salinity community though, there are other imperatives, and BC2C has the following features:

- it complements other activities in the various states such as CATSALT, LAMPS, IQQM, REALM, SHAM, etc,
- it builds directly upon the GFS concept and the mapped units at the appropriate scale,
- it explicitly includes timing of impact,
- it links water and salt yield changes,
- it uses ubiquitous data only,
- it can be part of a package that would be flexible enough to incorporate changes and able to be workshopped at a regional level,
- it can be aggregated to provide a basin wide picture.
The model however also comes with these caveats:

- it is only designed for unregulated catchments, or where groundwater extraction and stream diversion is a small proportion of the water balance,
- currently it is most appropriate where there are no internal storages that remove salt from the annual output, or dilute or concentrate the salinity of water,
- the model uses an annual time step and long-term average inputs, thus only total flow and salt load can be estimated,
- it is restricted to catchments where all surface water reaches the outlet within the annual time step to remove the need to route water explicitly,
- short-term effects of clearing or revegetation are not explicitly modelled, e.g. time until canopy closure, travel time of recharge to deep aquifers, surface soil changes.

The current BC2C model is designed to answer the question “how much difference can planting trees make to the flow and salt load of a stream?” We can look from either the point of view of the catchment manager looking at what can potentially be achieved, e.g. if we replanted everything would it reduce salt export enough, or of the land owner deciding how much change to make, e.g. “if I fenced off the whole of paddock 4 and plant trees, what is the effect”.

2.3 Model Description

2.3.1 Data Sources

The BC2C model uses the following readily available data sources:

1. digital elevation model (DEM),
2. groundwater flow system (GFS) attributes,
3. average annual rainfall,
4. current tree cover.

Digital Elevation Model

The DEM provides the basic information for a topographic analysis of surface water catchments based on streams derived by a minimum catchment size. It is important to recognise that while groundwater processes drive landscape salinisation, it is manifest at readily identifiable surface features, such as streams, low-lying areas, and breaks of slope. Land management is also most conveniently aimed at surface water catchments and streams rather than geological or groundwater maps, so these become the basic unit within which changes are made.

Groundwater Flow Systems

A GFS map produced by the Catchment Characterisation project or Regional Workshop is required to determine the driving groundwater gradients, flow rates, and time lags within catchments. The properties within each GFS are hydraulic conductivity, storage coefficient, aquifer thickness, groundwater salinity, and recharge fraction. Within each surface catchment defined from the DEM, the individual properties of each GFS are averaged to provide an integrated estimate of each component. Currently, this is a simple arithmetic average of each property weighted by area.
Average Annual Rainfall

An interpolated rainfall surface has two purposes. Firstly it is required to provide estimates of transpired and excess water, and secondly it determines the total amount of salt brought into the catchment each year. Within each catchment, the excess water is partitioned into different pathways, which attract delays in reaching the outlet, and which have the capacity to accumulate different amounts of salt. All the salt that falls in the annual rainfall is delivered to the catchment outlet with surface runoff each year. The water that becomes recharge gains the salinity of the GFS in the catchment and is pushed out using a discharge function and added to the surface flow volume.

Current Tree Cover

The current tree-cover data provides a binary map where each pixel is classified as either covered in trees or not. The proportion of tree cover in each catchment is then simply a sum of all tree pixels within the catchment divided by the number of pixels in the catchment. It is changes to tree cover that drive the BCC output since other input data are not within the domain of land management plans and practices. Total tree cover also governs the partitioning of the “fast” water components: overland flow and through-flow.

2.3.2 Water Partitioning

The work of Zhang et al. (1999, 2001) is used for partitioning rainfall into transpired and non-transpired, or excess, water. Their work examined the data produced from nearly 300 catchment experiments world-wide, and produced a robust equation for predicting the proportion of rainfall that could be used under native and cleared conditions. Using this envelope of response and knowledge of the proportion of catchment with trees, considered to be native vegetation, an average amount of transpired water can be estimated.

This sets the amount of excess water that is available to become stream flow, either as fast flow that goes directly to the catchment outlet within a year, or slow flow that becomes recharge to a groundwater system and may take many years to be discharged. This secondary partitioning is done with the use of a recharge fraction, an attribute of each GFS. This parameter can be fitted, estimated from baseflow separation of stream flow records, or from bore hydrographs and similar average net recharge estimators.

The final step is to partition the fast flow (that water that makes it to the catchment outlet within the annual time step) into overland flow and lateral flow through the soil matrix. Tree-cover determines this partitioning in the BC2C model. Where native trees and grass have been extensively cleared, the soil tends to be wetter and can form shallow water tables that travel laterally to the stream or are discharged back to the land in surface seeps. The less the tree cover the greater the proportion of fast flow that is deemed to travel as through-flow. The remaining fast flow water is deemed to travel as overland flow to the stream or outlet, and carries with it the salt that fell in the rainfall. As the tree cover increases conversely, a greater proportion of water that appears as fast flow must be overland flow, since most of the rainfall that infiltrates will be used up by the trees in increased transpiration.

The effect of rainfall seasonality as it modifies annual excess water is an area where future research may allow for better representation of estimating evapotranspiration and excess water. In the GIS version of BC2C this can be handled using an optional latitude correction factor.
2.3.3 Discharge and Salinity

The water partitioning provides two sets of numbers: the overland flow, through-flow and recharge under current conditions, and the same components with a changed amount of tree cover. These numbers are valuable in themselves as the long-term average water balance of a catchment, or series of sub-catchments, at equilibrium. However, groundwater processes are much slower than surface water flows, so time lags are introduced in changing from current to future conditions.

The next step is to estimate a time constant associated with tree planting, and one for the groundwater discharge response. It is assumed that the new values of overland flow, through-flow and recharge will take effect gradually as the tree canopy closes or immediately trees are removed to the new proportion of tree cover within a catchment. This time delay is inversely related to average rainfall, i.e. as annual rainfall increases the tree canopy grows faster and the time delay decreases, and vice versa as rainfall decreases resulting in longer delays for canopy closure.

The time constant relevant to the groundwater discharge process can be estimated directly from the properties of the GFS and the aquifer itself. The value is related to the rate of flow through the system, volume of water stored in the aquifer, and how much recharge is being added annually. The aquifer properties are determined from the GFS map layer that contains the relevant information, the recharge rate is found from the water partitioning routines, and the topographic analysis that broke the region into sub-catchments yields information on flow length and slope. Of these factors the groundwater time delay increases with an increase in total stored water, flow length or recharge rate, and decreases with an increase in flow rate or slope.

There are now three water components and two time delays. To get a salt export, a salinity value is associated with each flow component as they change through time.

- **Groundwater discharge** has the salinity calculated from the GFS in each sub-catchment, which has been estimated from values measured in bores across the region.

- **Overland flow** has the salinity of rainfall plus the salt load from the evaporated component. Rain salinity has been assumed to be a constant value of 5 mg/L (although this value can be changed if required).

- **Through-flow** has rainfall salinity, plus an additional constant salinity value related to the groundwater salinity (default value has been set at 20% of the groundwater salinity).

With the water balance components estimated, time lags in place, and salinity for each flow path set, the annual total water flow and salt load can be estimated for any time into the future following the prescribed land-use change.
2.4 An Example of the User Interface

In addition to the research tool which is run as AMLs within a GIS system (Appendix 1), the BC2C model is also part of the CRCCH Catchment Modelling Toolkit. Initially this model was coded into the Tarsier-environment. The Toolkit no longer supports this environment, deciding to use the TIME-environment (using dot.net). This example uses the old version, but still provides a good example of what BC2C is.

An example is presented using the Little River in the Macquarie River catchment in central NSW. The basic interface is shown in Figure 2.1. Looking around the window we see buttons for selecting which variables to display as lines and spatially in the map window, what level to integrate results at, and the input location for changing tree cover.

![Figure 2.1: Old version: BC2C Interface](image-url)
The first step in running through the example is to perform the basic topographic analysis. To do this we click on the “Inputs” button highlighted in Figure 2.1, and are presented with a sub-menu, shown in Figure 2.2. Here we can specify the four different input data layers and look at their distributions in pop up windows. The most important field for the user to fill is the one marked “Stream Threshold”, which controls where the topographic analysis believes a stream starts and therefore the stream density and size of sub-catchments used as the fundamental groundwater units in the model.

![Figure 2.2: Old version: BC2C Topographic Analysis Menu](image)

To edit the properties of individual GFS, use the “Edit Properties” button. The sub menu in Figure 2.3 allows the user to enter new values for all the properties, add and remove GFS types, or just examine what is already entered. Text files containing these data are saved on disk and they may be edited manually in any text editor, but this must not be done while running the program!

![Figure 2.3: Old version: BC2C Groundwater Flow System Input Menu](image)
Once BC2C has run its topographic analysis, the “Average Hillslope” panel will be filled with a number derived during processing, and a map of the entire area and the calculated sub-catchments will be displayed. By clicking in individual sub-catchments the area currently with tree cover is displayed and it may be edited manually on screen. When any of the tree cover values are changed, the graphs in Figure 2.4 are calculated and displayed. The user can continue to make changes to sub-catchments with updated results displayed after each step.

![Biophysical Capacity to Change](image-url)

**Figure 2.4**: Old version. The BC2C interface, showing the response of the whole catchment to planting the dark-green coloured sub-catchments from 3% to 20% tree cover. The area shown is Little River in the Macquarie catchment, NSW.

In Figure 2.4 we see a land-use change involving planting trees that produces an outcome for the whole catchment. The display is done “by node”, with the catchment outlet selected in this case (not shown). There is a steady reduction in salt export through the first 5 to 10 years, followed by a slow equilibration to a new level. The water reduction is not as large as the salt export however and the proportions of overland flow and through-flow have been altered, thus the salinity is reduced by less than half the percentage change in salt. These particular areas that were replanted have already been identified as areas where landholders were willing to plant trees for an improvement in both local and whole catchment conditions.
3 Groundwater Processes And Time Scales

3.1 Groundwater Response

Apart from the salt balances, other biophysical considerations include the time lag between implementation of a land use change and the salinity response. In addition to the time delays imposed by planting/harvesting schedules and by tree growth times, groundwater systems can also impose significant time delays between management action, and salinity outcome.

While a change in groundwater recharge will eventually lead to a corresponding change in groundwater discharge, the amount of time taken to reach this new state of equilibrium will vary considerably. We define a groundwater response function, $D(t)$, as:

$$D(t) = \frac{\text{Change in groundwater discharge at time } t \text{ after land use change}}{\text{Change in catchment recharge}}$$

This "groundwater response function" will differ across catchments, depending on many factors such as flow-length, groundwater slope, recharge rate, and hydrogeological properties. However, it must start at zero, as there will be no immediate salinity impact, and must go to 1, as what water goes in must come out.

The need to use only readily available data places a strong constraint on the type of approach in defining $D(t)$. Across large areas, data that are more readily available include topographic (sub-catchment disaggregation, gradient, flow-length); climate, soils and land use (recharge); and stream gauging (yield). Rarely will detailed hydrogeological and aquifer geometry information be known for any particular groundwater flow system (GFS), yet this is precisely the information which would be required to drive complex computer models such as MODFLOW (McDonald and Harbaugh 1988). It would be useful to relate groundwater response times to characteristics such as flow length, permeability, specific yield, aquifer thickness and slope, without needing specific spatial information within each and every GFS. This will allow differences in groundwater response time to be estimated across large areas in a consistent manner.
3.2 Time-scales

Dimensional analysis is a classical physical technique, which has been frequently used in other areas of physics and fluid mechanics for exploring scaling relationships between time and other parameters. This technique can be used to derive response time-scales, which relate to different groundwater processes from the flow equations. Such a methodology allows the estimation of the time-scales associated with groundwater response for a range of different GFS with different geologies, slopes, flow lengths.

A scaling argument is used to relate time-scale of groundwater response to key parameters (hydraulic conductivity, specific yield, aquifer thickness, flow-length, catchment gradient, and recharge rate). Three different processes contribute to the overall groundwater response:

1. vertical filling: 
\[ t_1 = d' \frac{S}{\Delta R} \]  
(3.1)

2. lateral movement: 
\[ t_2 = S \frac{L^2}{K d} \]  
(3.3)

3. gradient driven lateral movement: 
\[ t_3 = S \frac{L^2}{K h} \]  
(3.2)

where:
- \(d'\) unsaturated zone representative thickness (m)
- \(d\) representative aquifer thickness (m)
- \(S\) representative storativity (specific yield)
- \(\Delta R\) change in recharge rate (m/yr)
- \(L\) flow length of the GFS (m)
- \(K\) representative hydraulic conductivity of the aquifer (m/yr)
- \(h\) The change in groundwater elevation along the flow length (m)

3.3 Shape of the response curve

While a dimensional analysis does provide relevant time-scales for the processes involved, it does this at the expense of not providing information on, for example, areas at risk of salinisation (to predict areas at risk will require solving equations, such as those in more complex models such as MODFLOW (McDonald and Harbaugh, 1988) or FLOWTUBE (Dawes et al., 2000)). Dimensional analysis in itself does not provide measures of fluxes, only the time to go from one equilibrium state to another. Nor does it provide the functional form in going from one equilibrium state to another e.g. exponential decay, log-normal function or a logistic function. However, knowing such shapes from solving the flow equations in MODFLOW or equivalent usually will show a narrowly defined number of shapes. For example, Figure 3.1 shows output from FLOWTUBE analyses of the case studies from the National Land and Water Resources Audit and the MDBC case studies: Brymaroo (QLD: Smitt et al. 2003), Popes catchment (Wanilla, SA: Dawes et al. 2002), Whipstick (Kamarooka, VIC: Hekmeijer et al. 2001).
The FLOWTUBE outputs in Figure 3.1a shows a wide range in groundwater response as a result of land use change (2-300 years). This relates to the variety of catchment sizes, difference in permeability and gradients. However, using a dimensionless time on the X-axis, most of the curves can be seen to collapse into similar functions (response between 1 and 6). In the absence of the groundwater information used in the modelling studies, a simple function, which had a similar shape to those in Figure 3.1b, captures most of the key information.

The S-shaped logistic curve (Figure 3.2) gives a reasonable approximation for a response to an INCREASE in recharge, particularly where the aquifer starts to discharge to the land surface in addition to the stream at the aquifer outlet. This simple model of response to change weights changes in recharge to changes in discharge, according to a time scale and rate of change.

\[ D(t) = \frac{1}{1 + e^{4 - (4t/t_{\text{half}})}} \]  

(3.4)

where \( t_{\text{half}} \) is the time until 50% of the recharge has passed through the system. This function is a convenient one, although any functional shape could be used in its place if it was considered more suitable.
**Figure 3.2** Example showing the smooth shape of the response (from 0=no change, to 1=fully responded) of the logistic function (Eqn. 3.4).

For a DECREASE in recharge, the aquifer response is better represented by a classical exponential decay curve. The BC2C model uses:

\[
D(t) = 1 - e^{\left(-\frac{t \ln(2)}{t_{\text{half}}}ight)}
\]  

(3.5)

where the \( \ln(2) \) is included to allow the response function to pass through a response time of 0.50 for a given \( t_{\text{half}} \).

**Figure 3.3** Example showing the shape of the response (from 0=no change, to 1=fully responded) of the exponential function (Eqn. 3.5).
3.4 Combining the groundwater time-scales

The minimum of the three time-scales will tend to dominate the overall response. In considering a range of catchments where the relative importance of the three processes may vary, a function is needed which can approximate this behaviour in a smooth manner. Using a value equal to the “harmonic mean” is a simple way of approximating this behaviour, as it combines the time-scales in such a way that it allows the minimum time-scale to dominate the response when that given process is the fastest:

For an INCREASE in recharge, the harmonic mean of the three time-scales is:

\[
\frac{1}{t_{\text{harmonic mean}}} = \frac{1}{t_1} + \frac{1}{t_2} + \frac{1}{t_3}
\]  

(3.6a)

For a DECREASE in recharge, the timescale relating to aquifer filling \( (t_1) \) is not relevant, and so the harmonic mean of the two lateral time-scales are used.

\[
\frac{1}{t_{\text{harmonic mean}}} = \frac{1}{t_2} + \frac{1}{t_3}
\]  

(3.6b)

The time taken for a 50% response \( (t_{\text{half}}) \) can be approximated using a value of one third of the harmonic mean \( (t_{\text{half}} = \frac{1}{3} t_{\text{harmonic mean}}) \). This provides an approximation of a 50% time-response over a range of conditions. It provides a simple way of combining the three time-scales smoothly, and in the absence of more detailed modelling, can be used to parameterise a simple functional relationship which exhibits appropriate behaviour.
4 BC2C Theory

This section describes the algorithms in the BC2C model. There are four input layers to the BC2C model: a land surface DEM grid, an annual rainfall grid, a tree cover grid, and a GFS grid. These individual grids must be all the same pixel resolution, and projected into the same space so that they exactly overlay each other. All subsequent operations rely on the four grids stacked in this manner, so it is quick and easy to interrogate the properties of any pixel.

4.1 DEM Analysis

The land surface is broken into catchments controlled by a user-defined tolerance. The user enters a value of contributing area that will initiate a stream. The larger this number, the more area that must lie upslope of a point before it is considered to have a stream running through it. Once stream pixels are found within the DEM grid, each stream is searched from the top end until a confluence is found with another stream. At these points, actual catchments are defined for each stream link upslope of the confluence. This process is repeated downwards until the outlet is reached.

This analysis is relatively straightforward in a computational sense, but it does mean that the user must understand that they are not specifying a catchment size. Some trial and error is required to get the appropriate catchment size for a particular problem, although a useful rule of thumb is that average catchment size is roughly double the stream threshold value.

4.2 Water Partitioning

Within each catchment unit, three different values are required to partition annual rainfall. First is the average annual rainfall, second is the total proportion of tree cover, and third is the average recharge coefficient from the GFS layer. From the work of Zhang et al. (1999), the evapotranspiration from a catchment is estimated:

\[
ET = \frac{P}{1 + \frac{w \times Z}{P} + \frac{P}{Z}}
\]

where \(ET\) is average annual evapotranspiration (mm), \(P\) is average annual rainfall (mm), \(w\) is a dimensionless water storage parameter, and \(Z\) is a rainfall scaling parameter (mm). For mature mixed age forests, \(w=2.0\) and \(Z=1410\) mm, while for fully cleared catchments covered in annual species, \(w=0.5\) and \(Z=1100\) mm. To estimate actual catchment evapotranspiration:

\[
AET = F \times ET(\text{forest}) + (1 - F) \times ET(\text{cleared})
\]

where \(AET\) is the actual catchment evapotranspiration (mm), \(F\) is the proportion of forest cover in the catchment, and \(ET\) is calculated as appropriate from Eq. (4.1). Finally, we can estimate annual average recharge:
\[ AR = RF \times (P - AET) \]  \hspace{1cm} (4.3)

where \( AR \) is the annual recharge (mm), and \( RF \) is the recharge coefficient. This water is considered to travel immediately to the aquifer underlying the catchment, and is transferred through the groundwater response function to the stream.

The remaining excess water is that amount that quickly (within one annual time step) enters the stream via overland flow and subsurface through-flow. This quantity can again be partitioned since overland flow is generally quite fresh, i.e. at the salinity of rainfall, while water that travels laterally near the surface can become saline due to salt stored in the soil. Currently the proportion of water that flows overland is dependent on the amount of tree cover. With more trees in the landscape, the surface soil tends to be drier and so a greater proportion of water travels overland compared to through the soil. Conversely, where shallow rooted plants are dominant, there is greater scope for developing shallow water tables and transmitting more water in this pathway. In BC2C this is represented by:

\[
SF = 0.25 + \frac{F}{2} \hspace{1cm} (4.4)
\]

\[
OV = SF \times (P - AET - AR) \hspace{1cm} (4.5)
\]

\[
TF = (1 - SF) \times (P - AET - AR) \hspace{1cm} (4.6)
\]

where \( SF \) is the surface flow partitioning factor, \( OV \) is the amount of overland flow (mm), and \( TF \) is the amount of subsurface through-flow (mm). This combination of equations means that the amount of water in each of the three pathways change non-linearly as tree cover is manipulated. This implies that the salinity of a stream changes over time after a land-use change.

### 4.3 Groundwater Time Delays

The water that is passed along each pathway attracts different time delays. The data required to estimate groundwater system time lags are: average annual rainfall, average aquifer transmissivity, average aquifer porosity, and average path length and elevation difference, computed during the DEM analysis of each catchment. Recent work by Gilfedder & Walker (pers. comm.) estimates a characteristic time response of an aquifer as 1/3 of the harmonic mean of the relevant characteristic time scales (see Section 3.2):

\[
\text{Increased Recharge:} \quad t_{\text{half}} = \frac{1}{3} \times t_{\text{harmonic mean}} = \frac{1}{3} \times \frac{3}{K \frac{h}{L^2} \frac{d}{S} + \frac{\Delta R}{d'} S} \hspace{1cm} (4.7a)
\]

\[
\text{Decreased Recharge:} \quad t_{\text{half}} = \frac{1}{3} \times t_{\text{harmonic mean}} = \frac{1}{3} \times \frac{2}{K \frac{h}{L^2} \frac{d}{S} + \frac{\Delta R}{d'} S} \hspace{1cm} (4.7b)
\]

where \( t_{\text{half}} \) is the time for 50\% of the response to change (years), \( K \) is representative hydraulic conductivity (m/year), \( h \) is head difference from top to bottom of the flow path (m), \( L \) is the...
groundwater flow length (m), $S$ is effective specific yield, $d$ is aquifer thickness (m), $d'$ is unsaturated zone thickness (m) (approximated by $d$ in this case), and $\Delta R$ is the change in recharge rate (m/year).

Gilfedder et al. (2002b) and Smitt et al. (2002) discuss the shapes of response with a recharge increase or decrease, and suggest that they are different. When recharge increases there can be a delay while storage changes occur before there is a large change to the new equilibrium state, thus the use of an S-shaped logistic curve such as Eq. (4.8). However, a classical exponential response is applicable for when total available water decreases, such as increasing tree cover to reduce recharge and eventually groundwater discharge (Eq. 4.9). The aquifer response function is either a logistic function or an exponential, depending on the change in recharge:

Increased Recharge:

$$D(t) = \frac{1}{1 + \exp\left(4 - \left(4t/t_{\text{half}}\right)\right)}$$

(4.8)

Decreased Recharge:

$$D(t) = 1 - \exp\left(-\frac{t \times \ln(2)}{t_{\text{half}}}\right)$$

(4.9)

where $D(t)$ is the relative response of the aquifer from zero to one, $t$ is the actual time passed (years).

### 4.4 Tree Canopy Time Delays

BC2C also incorporates an estimate of the final time delay associated with increasing tree cover. This allows for the time required for the canopy to close and the full impact of new plantations to be felt on runoff. This is a complex function of many variables, which has been reduced to an inverse relationship with annual rainfall, i.e. as annual rainfall increases, the time to canopy closure decreases, and vice versa. BC2C currently estimates the time to canopy closure by:

$$CC = 1 + \frac{3000}{P}$$

(4.10)

where $CC$ is the time until the canopy closes (years), and $P$ is mean annual rainfall (mm). An exponential function (Eqn 4.11) is used to attenuate the change excess water signal to this timescale, scaled so that the $CC$ time gives a response of 95%.

For the case of increasing tree cover, there is no groundwater induced time-lag, so the overland/through flow components respond according to the canopy closure function (Eqn 4.11):

$$F(t) = 1 - \exp\left(-\frac{3t}{CC}\right)$$

(4.11)
The canopy closure function ($D(t)$: Eqn 4.11) provides the input to the groundwater response function ($F(t)$: Eqn 4.9). Thus it is necessary to use a function which combines both responses into a single function. The resultant combined response ($C(t)$: Eqn 4.12a) is:

\[
C(t) = 1 + \frac{(3 / CC)}{(\ln(2)/ t_{\text{half}}) - (3 / CC)} \exp\left(\frac{-\ln(2)t}{t_{\text{half}}}\right) + \frac{(\ln(2)/ t_{\text{half}})}{(3 / CC) - (\ln(2)/ t_{\text{half}})} \exp\left(-\frac{3t}{CC}\right)
\]  

(4.12a)

If $(\ln(2)/ t_{\text{half}}) - (3 / CC) = 0$, the solution becomes:

\[
C(t) = 1 - \exp\left(\frac{-\ln(2)t}{t_{\text{half}}}\right) - \ln(2)t \exp\left(-\frac{\ln(2)t}{t_{\text{half}}}\right)
\]  

(4.12b)

where $CC$ is given in Eqn 4.10, $t_{\text{half}}$ is given in Eqn 4.7b.

### 4.5 Water Salinity

Currently the salinity of each pathway is constant, derived from the GFS present within each catchment. The groundwater salinity is a property of the GFS, and is averaged for each catchment derived by the topographic analysis. Groundwater salinity thus varies by catchment, and is affected by catchment size, so isolating highly saline GFS may require smaller catchments from the topographic analysis. The salinity of rainfall has been set at 5 mg/L (although this can be changed if required). The salinity of the through-flow pathway is set as the rainfall salinity plus a salinity equal to 20% of the groundwater salinity in the catchment.

In some catchments the main salt stores may currently be in the near surface regolith, and this must be taken into account. The addition of a soil water salinity parameter to complement the groundwater salinity parameter in each GFS would allow these circumstances to be modelled more directly, replacing the default 20% value.
5 Changes to Salt Duration Flow Regime and

Changes in land-use not only change the mean annual yield (Zhang et al. 2001), but have the potential to change the distribution of yield over the year (i.e. changes to the flow duration curve) (Best et al. 2003). The distribution of salt in this yield is also affected.

5.1 Changes to Salt Duration

Dawes et al. (2004a) found that for small upland catchments, there was no clear evidence that the flow duration curve and salinity duration curve will be different, except by a linear constant that converts between the units of interest. They concluded that separate flow duration and flow salinity modelling was unnecessary, and that with appropriate handling of the flow duration curve and known representative discharge salinity, small upland catchments are well described.

This means that if the mean annual yield change is known for a particular catchment, the effect of a land-use change on changes in the flow duration curve (FDC) are sufficient to describe the change in salt-load duration curve (SLDC).

5.2 Changes to flow regime

A model for predicting the changes in flow duration curves (FDC) due to altered land use conditions has been developed by Best et al. (2003). Their method uses five parameters to describe a FDC:

- the median flow of the days when flow occurs ($P_{50}$),
- the cease to flow point ($CTF$) or the percentage of days when flow occurs, and
- three curve fitting parameters ($c_1$: upper exponent, $a$: slope at origin, and $c_2$: lower exponent).

To predict the changes in FDC due to vegetation change, the parameters of the FDC model need to be adjusted in accordance with the estimates of changes in mean annual water yield. This can be done in one of two ways, depending on whether gauging data are available for the catchment. Where no gauging data are available, regional relationships are developed between the mean annual flow and the parameters of the FDC model. Where flow records are available, the existing flow records, combined with knowledge of catchment properties, can be used to develop catchment specific relationship between the annual flows and the model parameters.

The changes in the FDC were calculated for the Ten Mile Creek catchment in NSW (see Cresswell et al. in press). The changes were based on regional relationships for catchments in the Murrumbidgee Basin. Empirical relationships between the mean daily flow and the FDC model parameters were developed using the method of Best et al. (2003). These relationships allow FDCs at the outlet of Ten Mile Creek to be predicted for current land use and for an integrated revegetation strategy (described in Cresswell et al. in press). This approach was adopted as existing flow data are not available at the catchment outlet. The regional relationships developed proved adequate in describing the FDC for Billabong Creek @ Aberfeldy which is considered to be the closest gauging station with good quality records. Figure 5.1 shows the predicted FDCs for the current land use and the integrated revegetation strategy. Under current land use, Ten Mile Creek flows 90% of the time and the model predicts this will be reduced to 85% under the integrated revegetation scenario.
Figure 5.1 Modelled changes in Ten Mile Creek’s FDC due to the integrated revegetation strategy (from Cresswell et al. in press).

Best et al.’s (2003) model code is in Appendix 2. This mean annual yield change from BC2C is used as the median flow parameter ($P_{50}$), while the remaining parameters can be estimated based on information about the geology, rainfall intensity, and rainfall seasonality in order to estimate changes to FDC. The method of Dawes et al. 2004a can then used to estimate the changes to the SLDC.
6 Water and Salt Balance Issues

In this section, some of the concepts and considerations that must be reckoned with when constructing salt and water balances are introduced. Aspects of real-world salt and water behaviour are discussed, and examples of how variation within and between catchments are shown.

6.1 Mass Balance Considerations

It is well accepted that changes in land-use, particularly when perennial and annual vegetation are exchanged, have consequences for the water and salt balance of catchments. In general, replacing perennial vegetation with annual species will decrease the total volume of evapotranspiration with a corresponding increase in the volume of “excess water” (see for example Zhang et al., 1999). The reverse is also true. There are three main pathways for excess water: overland flow, subsurface through-flow, and groundwater flow. Each of these are different processes, which have different residence times, i.e. how long it takes for a parcel of water to pass along the pathway, and assign a different salinity level to the water passing through.

Knowledge of the factors that control excess water partitioning critically affects the calculation of a catchment water balance. Further, how much water is passed through each of the different pathways gathering and losing salt, controls how much salt appears in the stream. In combination, this will determine if the flow regime within a catchment changes when a land-use change brings about a change in the amount of excess water. It also leads onto the larger question of whether the same salt stores remain active, or if other sources are activated and begin contributing to stream salinisation.

6.2 Climatic Considerations

A major complication in estimating the water balance is intra-annual climate variability. This relates to whether the rainfall distribution is summer-dominant, relatively uniform or winter-dominant. In the Murray-Darling Basin the main rainfall gradient is approximately east-west, with less rainfall as you travel from the Great Dividing Range inland, and the seasonality gradient is north-south, with the southern part of the MDB experiencing most rainfall in winter while the north has rainfall mainly in summer. These differences raise several issues.

Summer-dominant rainfall tends to occur in higher intensity storms. This can lead either to an increased amount of runoff compared to an equal storm at a lower intensity, or more episodic behaviour where storms below a certain size generate no runoff or stream flow response.

Rainfall and evaporation demands can either be in-phase, i.e. rainfall and evaporation peak at the same time of year as in summer-dominant conditions, or out-of-phase, i.e. rainfall is greatest when evaporation is least and vice versa in winter-dominant conditions. If two locations had the same annual amount of rainfall but different seasonality, we might expect there to be a different amount of water evaporated, and therefore differences in the amounts of runoff and recharge to groundwater. In the GIS version of BC2C, this is handled by allowing for a reduction in excess water based on the catchment’s latitude. Since the main seasonality gradient runs south to north this is an effective method in eastern Australia. Finding a more robust method based on monthly rainfall and potential evaporation data is future work.
6.3 Water Partitioning and Salinity

Rainfall is readily partitioned into evapotranspiration and “excess water” (Zhang et al., 1999). The excess water can follow a number of pathways over, through and under the catchment to get to the stream outlet. These include overland flow across the land surface to a stream channel, subsurface flow through the near surface soil layers to a stream, and recharge to a groundwater aquifer with a delay of months up to hundreds of years before being discharged into a drainage feature.

There are two ways of looking at how the excess water is partitioned through these various pathways. The first and simplest is to assume that fixed proportions of water can be partitioned off; as more water is generated proportionally more is assigned to the various water balance buckets. The second method is to estimate proportions of excess water in each pathway that depend on external factors, e.g. the total amount of excess water, climatic variability, land cover type, catchment geometric properties, thresholds derived from aquifer and soil hydraulic properties.

It is likely that the fixed-proportion method will work adequately for a percentage of real catchments, and is most likely to apply where rainfall is plentiful and streams run perennially. The most important result of such a strategy is that unless the salinity of the different pathways changes over time by some other process, the salinity of the resulting water mixture will always be reasonably constant. In effect, this says that the flow-salinity relationship is fixed, and the stream salt load only varies with the amount of excess water. Again there will be a certain proportion of catchments where this is a valid assumption on an annual basis.

Other situations exist however, where stream flow only occurs on a seasonal basis, or where storm intensity is so great that most of the rainfall runs off and avoids slower and deeper pathways, or where the hydraulic properties of the surface soil layers tightly control the amount of water that can penetrate to groundwater aquifers or travel laterally through the soil. Further, not all subsurface through-flow or groundwater is discharged directly to a stream. There may be an intermediate storage body that concentrates or dilutes flow, and may even attenuate the discharge signal.

6.4 Mixing and Discharge Processes

In practical terms, there are four distinct possibilities for changes to the annual salt and water balance:
- both water partitioning and pathway salinity are constant;
- partitioning changes but salinity is constant;
- partitioning is constant but salinity changes; or
- both partitioning and salinity change following a land-use change.

In small local flow systems (terminology after Coram et al., 2000) there is a reasonable expectation that discharge of all excess water occurs directly to a stream or surface drainage feature, with little if any mixing between surface and sub-surface pathways. This results in a simple conceptual model of a catchment that is easy to implement numerically. If both the partitioning of excess water and pathway salinities remain constant, this results in a stream that does not get more or less saline after equilibration with changing vegetation cover, and where salt load is a simple linear function of flow. This may be representative of high elevation upland catchments with high annual rainfall (e.g. greater than 800 mm) that yield large amounts of water.
As catchments and flow systems become larger, there is a much greater opportunity for water to mix, and for individual pathways to concentrate or dilute the salinity of the flow passing along it. One such system is an alluvial fill aquifer that a stream runs through. Historically a higher energy stream has cut down through the landscape, but in more recent times fine grained material has been deposited to create a floodplain and a buffer between the stream and other aquifers. Groundwater that previously discharged directly to the stream now passes into the alluvial aquifer, and surface runoff and through-flow may also pass into this zone. The result is mixing of the different water sources and may cause either dilution of saline flows, or concentration of incoming fresh water before discharging to the stream. This situation may occur in local flow systems, and is likely to be the general case in intermediate and larger flow systems. Changes in flow partitioning are also likely in larger systems, and those with moderate to low annual rainfall. This represents a complex mixture of processes that leads to both salinity and flow regime changes following land-use change.

6.4.1 Some Example Catchments

Jolly et al. (1997) reported the gauging station at Walbundrie on Billabong Creek as exhibiting the greatest rate of increase in stream salinity in NSW. Baker et al. (2001) performed a case study of the Billabong Creek catchment under the NLWRA Program 3. Groundwater modelling of the upland catchment found that average recharge was small, and occurred in well-defined areas where subsurface clay layers were thinnest. There was no mapped dryland salinity in the uplands catchment, and either land-use change in the recharge zones, or strategic pumping of groundwater, could control the slowly rising groundwater levels. The cause of rising stream salinity was found to be a shallow surficial clay aquifer that Billabong Creek flowed through on the plains. During periods of above average rainfall, the bed of the main creek and its tributaries could cut down through the clay layer and expose new sources of salt. As these were mobilised and began leaching into the stream, the salinity increased. Here the flow-duration curve might be constant but the flow-salinity relationship is not.

Kyeamba Creek is in western NSW south of Wagga Wagga, and is the highest salt yielding catchment per square kilometre in the mid-Murrumbidgee catchment. Work reported in Cresswell et al. (2003) indicates the catchment has both intermediate and local-scale flows. Due to the aquifers currently being relatively full, the catchment acts as though it were only local flows. At a previous time when the recharge regime was much less, the intermediate system may have dominated and therefore both the flow and salinity regime may have been very different. New salt stores in the local systems may have been activated as the intermediate system filled, leading to a marked increase in stream salinity and salt load. Different catchment equilibrium states in Kyeamba Creek may result in distinct flow and salt load characteristics.

The stream flow and salt export behaviour of the Axe Creek catchment, in central Victoria, has been described by Dyson (various; pers. comm.). The balance between overland flow and groundwater discharge processes changes seasonally. In winter when there is most of the annual rainfall in the area, relatively fresh water recharges the surface stores and near surface aquifers and runoff provides much of the stream flow. In the drier summer months, the salt in the surface aquifer is concentrated by evaporation, and it is this more saline water that discharges to the stream as baseflow. Both the flow-duration and flow-salinity relationships change seasonally.
7 Little River (sub-regional) Case Study

As part of a consultancy for the NSW Department of Agriculture, the BC2C model was applied to the Little River catchment (2325 km²), part of the Macquarie catchment in NSW, near Dubbo (Evans et al. 2004) (Figure 7.1). The Little River catchment has an average annual rainfall of 700 mm, and is approximately 75% cleared for cropping/grazing.

![Map of the Little River Catchment](image)

**Figure 7.1** Map of the Little River Catchment (from Evans et al. 2004)

The aim was to provide estimates of groundwater response time across the many individual GFSs in the Little River, as a tool to help prioritise possible management actions. The first step was to determine the location and size of the GFSs in the Little River catchment. This catchment has been mapped as consisting of several different Local scale GFS types (<5 km in hydraulic length). Local GFS are generally coincident with surface topography, so a Digital Elevation Model (DEM) could be used to break up the catchment, and for estimating the stream network. Sub-catchments were constructed from the DEM by extending the stream-network upstream until minimum stream contributing area of 1000 ha was reached. The minimum contributing area parameter was used to achieve stream networks that matched with local knowledge of the distribution of groundwater flow across the broader Little River catchment. Sub-catchment boundaries were then defined using this generated stream-network (Figure 7.2).
The second step was to obtain parameters for each GFS, and use these to estimate groundwater response times for each GFS. Groundwater response times were calculated using the timescales described in Section 3.2. For each sub-catchment:

1. Proportions of each Salinity Province were calculated
2. Area-weighted values of aquifer properties (hydraulic conductivity: $K$; aquifer thickness: $d$, aquifer storage term: $S$), were calculated using the salinity province map.
3. Topographic properties (height drop: $h$; and flow length: $L$) were calculated; unsaturated thickness was approximated as being equal to aquifer thickness.
4. The time (in years) for 50% of the groundwater response to occur (half time = $t_{half}$) was calculated (Figure 7.3).
Figure 7.3 Estimated variation in groundwater response times estimated by BC2C for each sub-catchment area in the Little River (see Figure 7.1 for location). The model predicts that darker (black = t_{1/2} of 11 years) areas will respond more slowly than the lighter (white = t_{1/2} of 1 year) areas (from Evans et al., 2004).

The distribution of the groundwater response estimates for each of the sub-catchments in the Little River is shown in Figure 7.3. The information contained within the figure can be used to help incorporate groundwater information into an overall prioritisation of areas for land use changes, in terms of effect on stream salt load. This information has already been used by NSW Agriculture to provide groundwater information for their farm-scale economic model (Andrew Bathgate, pers. comm.). Interpretation of this type of information is best used as an initial tool to investigate relative differences across the catchment, rather than as a precise or accurate prediction of the exact response time.
8MDB Case Study Report

The BC2C Model has been used to help understanding areas for prioritisation at the MDB scale. Investors may be interested in which catchments to approach to gain maximum salinity benefits. However, it should be noted that data at the MDB scale will generally be too coarse for land use decisions. These results are published in full in a technical report by Dowling et al. (2004).

A modification of BC2C was implemented on a GIS system. For each GIS cell, a scenario was considered where the cell was transformed from the current state to 100% forest cover. While this is generally not going to be a practical scenario, it does allow us to compare the impacts of different cells on the same scenario. Generally, it is a simple matter to estimate what impact that a change in land use over part of the cell coverage would have. Three different impacts were considered: water yield (mm), salt load (t/km²/yr) and in-valley flow-weighted mean salinity (before diversions in µS/cm/km²).

Because this information can be portrayed spatially, one gets the sense where full afforestation will make the largest impacts on water yield and salt loads. The mean flow-weighted salinity methodology relies on using a target stream site, but provides a picture of whether the benefit will be positive or negative, and the magnitude of the change. While finer-scale information will be required to provide absolute numbers, it is clear that:

- Large areas will have no significant impact on stream salinity within the timeframe of 30 years
- Some areas will have a negative impact on salinity
- Where the benefit is positive, it is not necessarily clear that plantations will be cost-effective.

As an example of the results of applying BC2C at this scale, maps are presented in Figures 8.1-8.3 (from Dowling et al., 2004).
Figure 8.1 illustrates the change in modelled yield if all current land-use was changed to trees. The only areas with zero change are those that already have 100% trees present, and although a forest appears as a coherent mass, these patches are scattered across the MDB. Obviously the greatest differences in total water yield are found in the high rainfall areas, with values quickly dropping from east to west and the lower rainfall inland areas.

**Figure 8.1** Examples of the types of maps of BC2C output for the MDB: water yield change from current cover to forest cover (from Dowling et al., 2004).
While it is possible to model the effects of any conceivable vegetation cover scenarios at any time into the future with the technique presented, but Figure 8.2 shows estimate of the effect of replanting the entire basin to trees and see how salt generation changes in 15 years time (crosshatched areas are Regional-scale GFS and the methods applied are not appropriate to properly describe them or the irrigation areas they contain).

**Figure 8.2** Examples of the types of maps of BC2C output for the MDB: salt reduction after 15 years with change from current cover to forest cover (from Dowling et al., 2004).
In–valley EC impact in 50 years time is shown in Figure 8.3. This scenario was derived by converting current land-use to forest everywhere; effectively a return to native conditions. The change in EC induced by the land-use change is expressed in units relative to the in-valley EC of the stream. Areas seen as white are those that are currently forested, and therefore will not impose a change into the future, or where it would take the planting of 1000 km² of trees to create a reduction of 1 µS/cm. Areas coloured in blue indicate a negative change, or decrease, to in-valley stream salinity, while those coloured orange are areas expected to increase salt delivery and salinity, or reduce water yield more than salt output, if converted to trees (again, crosshatched areas are Regional-scale GFS and the methods applied are not appropriate to properly describe them or the irrigation areas they contain).

Figure 8.3 Examples of the types of maps of BC2C output for the MDB. in-valley impact on stream EC after 50 years with change from current cover to forest cover (from Dowling et al., 2004).

The methodology allows us to focus quickly on those areas, where benefits are positive and the greatest and to understand why this is the case. It points to those areas, where further data needs to be collated. The collation of the datasets for BC2C will generally necessarily use the only available groundwater data over large areas. The same dataset will be required for any other modelling study, e.g. the CRC-CH 2C project. The spatial platform used for running BC2C enables users to come to grips with the groundwater data before moving to more complex models.
9 Summary and Discussion

The BC2C Model has been described with the internal calculation methods detailed down to the level of individual equations. Much robust science and empirical summary underpin the methods used in BC2C, but further research could be conducted to improve individual aspects of its operation. Of particular interest is the dichotomy between fixed salinity and variable water pathways compared to well-defined pathways and variable discharge salinity.

BC2C uses GFS directly as a data layer with the information attached to each system used in water and salt balance modelling. The operation of BC2C can also help refine GFS data attributes and definition. Comparing model outputs with current stream flow and salinity data allows refinement of individual GFS data values, while the prediction of changes through time allows BC2C model structure and GFS extents to be examined. A number of issues have been raised in describing the BC2C system. These are discussed in no particular order, along with their possible inclusion into a revised BC2C model.

Rainfall seasonality as it modifies annual excess water

This is a definite area where future research may allow for better representation of estimating evapotranspiration and excess water. In the GIS version of BC2C this is handled using a latitude correction. For small enough catchments, the addition of the catchments latitude in eastern Australia would allow a suitable correction to be made, but this is not generally applicable. More information on rainfall seasonality would be required along with an appropriate method of using it. A seasonality factor would be a whole-of-catchment property, rather than a distributed one.

Changes in stream flow-salinity relationship

This is more directed toward the End-of-Valley prediction exercise, rather than general simulation of gross water and salt budgets as in BC2C. However, there is information that could potentially be passed between BC2C and an estimator of salt and flow regime, e.g. gross water balance changes under different vegetation scenarios, or time delays expected before a new groundwater discharge equilibrium is established. For the present time, BC2C is not designed to process or estimate flow duration curves, and as such any changes to the model to incorporate these are not planned.

Changes in rainfall salinity across large areas

The assumption of a uniform and constant value of rainwater salinity is a simplification that is reasonable over small enough catchments away from the south-west of the MDB. For other parts of Australia this will be different. It is possible to derive rainfall salinity maps, and one has been used with GIS BC2C. The addition of average rainfall salinity over a catchment is a reasonable advance on the current fixed value, and would be a whole catchment value.

Changes in soil salinity affecting through-flow within GFS

As with the GFS data layer, the information to characterise the soil salinity in, or across, a catchment is generally not available quantitatively. Hard data is traded for expert opinion, but when setting values of groundwater and through-flow salinity, the user necessarily constrains the model outcomes. As with the groundwater recharge factor, soil through-flow salinity would probably be best described as a value for each GFS, since surface landform is a factor when determining GFS.
Changes in proportions of overland flow and through-flow

This is linked with the previous point, regarding salinity of through-flow, and the user constraining a model with choices made about parameter values. For example if the through-flow salinity were set to a value ten times higher than the groundwater discharge salinity, it would be a surprise if it was found that groundwater was the greatest contributor to stream salinity and needed to be controlled. It is difficult to find good data that describes just rainfall and excess water, thus hard data on the proportion of excess water that becomes runoff or through-flow is even harder to find. It is this area where intensive small-scale computer modelling may provide a response surface or simple rule that could be incorporated into BC2C.

Delineating and modelling alluvial buffers around streams

This issue relates mainly to a changing of the salinity of water discharged into a stream over time, but may also be connected with the previous topic. There are two ways to approach a change in salinity: (1) the pathway salinities remain constant but the proportions change significantly (see previous topic), or (2) the pathway salinities are constant and a large enough buffer is contaminated or freshened over time due to changing volumes of incoming water. If the second model holds true, then estimating the characteristics of such a buffer become critical to explaining observed changes in stream salinity. Methods developed by Gallant and Dowling (2003) have promise to provide the extra information needed. Such data would then be required at the stage of calculating individual catchments so that appropriate storage buffers could be attached to sub-catchments before calculations proceed. Using an analytic solution this could be incorporated into BC2C.
Appendix 1
Revised AML to run BC2C

The original AMLs which formed the BC2C model were published in Dowling et al. (2004). The BC2C model code has now been completely rewritten, to form a much more user-friendly AML which can be run in batch mode if required.

The revised (September 2004) BC2C AML code is printed out below.

/* ************
/* BC2C Model *
/* ************

/* AML by Matt Stenson mailto: matthew.stenson@csiro.au
/* Version 1.2
/* Started 14/05/2004 on Terrain Analysis module
/* Continued work 03/06/2004 on Zone statistics stuff
/* Started on the recharge section 07/06/2004 after looking at the AML's written by Trevor Dowling and updated by Jenet Austin
/* Started working on menus and adding comments 14/06/2004
/* Finished Terrain Module 18/06/2004
/* Back into it again 01/07/2004
/* Finished recharge module 05/07/2004
/* After discussions with Mat Gilfedder we decided to change the processing from mostly raster to mostly vector; oh the pain ;-) 20/07/2004
/* I decided to separate the GRU parameterisation from the scenario modelling 20/07/2004
/* Finished GRU Module 20/07/2004
/* * Added a Vegetation module to allow the modeller to add a raster vegetation GRIDS to their working GRU map 21/07/2004
/* Added a Rainfall module to allow the modeller to add a raster rainfall and/or latitude correction GRIDS to their working GRU map 21/07/2004
/* * Continued work on the scenario module 22/07/2004
/* Finished water balance part of scenario module 23/07/2004
/* Finished the salt balance part of the scenario module 23/07/2004
/* Fixed a bug in the salt balance calcs and added some more comments 28/07/2004
/* Started testing with Little River Data, fixed a bug in t-half calcs 04/07/2004
/* Fixed a bug in the terrain module 18/08/2004
/* * Added manual way of adding pour points for catchment disaggregation
/* * Added manual polygon merging
/* * Added tree canopy closure code /28/09/2004
/* Split quickflow into lateral and overland and recalculated salt 29/09/2004
/* * Fixed a nasty bug that caused the geometry data to be assigned to the wrong GRU's 14/10/2004
/* * Made a minor change to the logistic curves 15/10/2004
/* * Improved the eliminate function by doing two passes

/* To run this AML simply type 'fr bc2c' from the arc prompt. You must have GRID installed but not running.
/* This AML assumes that the map units are in metres

/* A word on the output table
/* *******************************************************************************************************************
/* The output table will contain fields for each time step up to and including the total run length variable as
/* long as the timestep does not stride over it.
/* Units:
/* CUR_EXCESS, NEW_EXCESS, cur_rc and new_rc are reported in millimetres per year
/* cur_rc_ML AND new_rc_ML are reported in ML
/* delt_rc_ML is reported in Mega Litres per year
/* VERT_FILL, LAT_MOVE and GRAD_LAT are reported in years.
/* CUR_QK_DIS and NEW_QK_DIS are your quick discharge components for both your current and proposed scenario in
/* Mega Litres per years. Due to their quick nature they are assumed to be available as discharge immediately and
/* suffer no delay. They are further split into lateral flow (LAT_FLOW) and overland flow (OV_FLOW).

/**************Main Output**************/
/* T_HALF is half the time in years for the groundwater to reach a new equilibrium after a change in recharge.
/* TOT_DIS_Y* is total discharge for each GRU reported in Mega Litres in a particular timestep year
/* TOT_SALT_Y* is the total salt in tonnes for each GRU in a particular timestep year
/* *******************************************************************************************************************

/* Global variables for the USER to set if required
Further reading

- **CSIRO Land & Water:** Murray-Darling Basin with respect to salinity benefits from afforestation. CLW Technical Report 15/04.
* catchment scale, Water Resources Research 37, 701-708.
*/
* *******************************************************************************************************************
* Preamble
* *******************************************************************************************************************
* Cleanup from any previous runs
&call terrain_cleanup
&call GRU_cleanup

/*Define some variables
&setvar answer? = ' ' 
&setvar break = ' '
&setvar rainflag = 0
/* Set the projection compare to full so users input data sets have to match
/* Turn off at your own risk
projectcompare none
* *******************************************************************************************************************
* Main Menu and entry point for AML
* *******************************************************************************************************************

/* Sets a re-entry spot for the main menu
&label main-menu
/* This is the main menu from here the user can select at what point in the model they wish to start
&do &until %answer% eq 1 or %answer% eq 2 or %answer% eq 3 or %answer% eq 4 or %answer% eq 5
&call clearscreen

&type ***********************
&type &Type *BC2C* 1.2
&Type the Biophysical Capacity to Change Model
&Type Dawes, W.R(1), Gilfedder, M.(1), Walker, G.R.(1) and Evans, W.R[2], 2004
&Type
&Type AML Version
&Type by Matt Stenson(1) based on work by Trevor Dowling(1) and Jenet Austin(1)
&Type June 2004
&Type
&Type Main Menu
&Type
&Type Please Select an Option:
&Type 1 - Start from scratch on a new model area by processing a DEM to a GRU map
&Type 2 - GRU Parameterisation Module to add parameters to an existing GRU map
&Type 3 - Add a current or scenario vegetation raster GRID to a GRU coverage
&Type 4 - Add a rainfall and/or a latitude correction GRID to a GRU coverage
&Type 5 - Process a completed GRU coverage containing vegetation scenarios to
determine major outputs including salt in kg and water in ML
&Type 6 - Quit the BC2C AML
&Type
&Type (1) CSIRO Land and Water (2)Salient Solutions Australia
&Type

&setvar answer [response' ']
&if %answer% eq 6 &then
&do
&call terrain_cleanup
&call GRU_cleanup
&call clearscreen
&return
&end
&end

/* Jump to appropriate module depending on the users choice
&setvar rainflag = 0
&call clearscreen
&if %answer% eq 1 &then &goto terrain
&if %answer% eq 2 &then &goto GRU
&if %answer% eq 3 &then &goto Vegetation
&if %answer% eq 4 &then &goto Rainfall
&if %answer% eq 5 &then &goto Scenarios

Terrain Analysis module for delineating sub-catchments from a Digital Elevation Model (DEM) and calculating all the zonal information

Sets a entry spot for the terrain module

label terrain

Start GRID

grid

&call terrain_cleanup

Set the mask variable to nothing for starters

&setvar mask_grid = ' '

Get the input DEMs name from the user

&do &until %in_dem% ne ' ' and [ exists %in_dem% -grid ]

&call clearscreen

&type  *********************************************************************************
&type                                 Terrain Module
&type  The DEM will be used to disaggregate the catchment into smaller sub-catchments
&type  It is assumed that these sub-catchments are coincident with
&type  Groundwater Response Units (GRUs). These GRUs will then be the cornerstone
&type  on which all future calculations will rely.
&type  It is recommended that you either clip you DEM to a major catchment boundary
&type  or that you apply a mask GRID that represents a major catchment boundary
&type  Please Select an Option:
&type  Input DEM GRID Name - To set the input DEM
&type  M - To set an analysis Mask GRID first
&type  Q - Quit to the main menu
&type  *********************************************************************************

&setvar in_dem [response ' ']

/* The user want to quit

&if %in_dem% eq 'q' or %in_dem% eq 'Q' &then

&do

quit

&call terrain_cleanup

&call clearscreen

&goto main-menu

&end

/* The user want to set a mask

&if %in_dem% eq 'm' or %in_dem% eq 'M' &then

&do &until [ exists %mask_grid% -grid ] or %mask_grid% eq 'q' or %mask_grid% eq 'Q'

&call clearscreen

&type  *********************************************************************************
&type                                 Terrain Module
&type  The Analysis Mask GRID will be used to determine which areas of the input DEM,
&type  on a pixel by pixel basis, will be used in the analysis. The Analysis Mask GRID
&type  should have a value of NODATA for pixels not to be included in the analysis
&type  Please enter the name of your DEM GRID when returned to the previous menu.
&type  Q - Quit to the previous menu
&type  *********************************************************************************

&setvar mask_grid [response ' ']

&if [ exists %mask_grid% -grid ] &then

&do

setmask %mask_grid%

&setvar in_dem = ' '

&end

&end


/* Set the cell size to the same as the input DEM */
setcell %in_dem%

/* Retrieve all the DEMs attributes */
describe %in_dem%

/* Set the display windows */
display 9999 %screen%

/* Set the map extent to be the same as the input DEM */
mapextent %in_dem%

/* Draw the input DEM in the map window for the user to view */
gridpaint %in_dem% value linear nowrap gray

&do &until %answer1% eq 'y' or %answer1% eq 'Y' or %answer1% eq 'n' or %answer1% eq 'N'
&call clearscreen

*************** BC2C Terrain Module ***************

Do you wish to remove areas of internal drainage in the input DEM making it
a depressionless DEM?

This is a very important step. In order for proper delineation of
sub-catchments to occur spurious areas of internal drainage/depressions in the
DEM need to be filled. It is recommended that you say yes to this option unless
you have already processed the input DEM to remove depressions and would like to
save processing time now.

Please Select an Option:

Y - To fill areas of internal drainage in the input DEM
N - Not to fill areas of internal drainage in the input DEM
Q - Quit to the main menu

*************** BC2C Terrain Module ***************

&setvar answer1 [response ' ']
/* The user want to quit */
&if %answer1% eq 'Q' or %answer1% eq 'q' &then
&do
quit
&call terrain_cleanup
&call clearscreen
&goto main-menu
&end

&end

&call clearscreen

/* If the answer is yes then fill the DEM */
&if %answer1% eq 'y' or %answer1% eq 'Y' &then
&do
fill %in_dem% fill_xxx sink
/* Copy the newly filled DEM to the working DEM */
dem1 = fill_xxx
mapextent dem1
/* Redraw the DEM */
gridpaint dem1 value linear nowrap gray
/* Ask the user if they wish to save a copy of the newly calculated depressionless DEM */
&do &until %answer2% eq 'y' or %answer2% eq 'Y' or %answer2% eq 'n' or %answer2% eq 'N'
&call clearscreen

*************** BC2C Terrain Module ***************

Do you wish to save a copy of the depressionless DEM?

Saving a copy is not necessary but will save you processing time if
you wish to run the analysis again for the same area.

Please Select an Option:
&type Y - To save a copy of the Depressionless DEM
&type N - To discard to depressionless DEM once the analysis is finished
&type Q - Quit to the main menu

*******************************************************************************
&setvar answer2 [response ' ']
/* The user want to quit
&if %answer2% eq 'q' or %answer2% eq 'Q' &then
  quit
  &call terrain_cleanup
  &call clearscreen
  &goto main-menu
&end

/* The user want to save a copy of the depressionless DEM
&if %answer2% eq 'y' or %answer2% eq 'Y' &then
  &call clearscreen

*******************************************************************************
&setvar depdem [response ' ']
if [ exists %depdem% -grid ] &then kill %depdem% all
%depdem% = fill_xxx
&end
&call clearscreen

&if %answer1% eq 'n' or %answer1% eq 'N' &then
  /* If the user chose not to process the input DEM, likely because they have previously done so,
  * copy the input DEM to working DEM
  dem1 = %in_dem%
&end

if [ exists fill_xxx -grid ] then kill fill_xxxx all
/* Calculate the flow direction of the working DEM
dir_xxx = flowdirection(dem1)
/* Calculate flow accumulation from the flow direction GRID
accum_xxx = flowaccumulation(dir_xxx)
/* Sets a re-entry spot to restart the catchment delineation should the user not be happy with it
&label catch-delin
/* Asks the user if they wish to select the pour points for catchment disaggregation manually
&do &until %answer20% eq 'y' or %answer20% eq 'Y' or %answer20% eq 'n' or %answer20% eq 'N'
&call clearscreen
&type ***********************************************
&type &type Do you wish to select the pour points for catchment disaggregation
&type &type interactively or use a catchment threshold value
&type &type
&type &type Please Select an Option:
&type &type Y - To select the pour points interactively using the mouse
&type &type N - To set a catchment threshold value (this is the more common way
&type &type to run BC2C)
&type &type Q - Quit to the main menu
&type *********************************************************************************
&setvar answer20 [response ' ']
/* The user wants to quit
@if %answer20% eq 'q' or %answer20% eq 'Q' &then
  do
    quit
    &call terrain_cleanup
    &call clearscreen
    &goto main-menu
  &end
&end
&call clearscreen
@if %answer20% eq 'y' or %answer20% eq 'Y' &then
  do
    /* Asks the user to provide a snap distance for the pour points
    &do &until %snap% gt 0

    &call clearscreen
    &type *********************************************************************************
    &type                                      *BC2C*
    &type                                    Terrain Module
    &type                                     *BC2C*
    &type Please set a snap distance in Metres that will be used to snap the pour points
    &type you add interactively to the flow accumulation GRID. If for example you set the
    &type snap distance value to 100m, when you add a pour point it will snap to the
    &type highest value cell in the flow accumulation GRID within a 100m search radius
    &type If after adding the pour points and disaggregating the catchment your resulting
    &type sub-catchment map doesn't look as you expected try changing this value and
    &type re-adding the pour points.
    &type                                     *BC2C*
    &type Please Select an Option:
    &type Add a Snap Distance in Metres - Add a distance
    &type 1 - Quit to the main menu
    &type
    &type *********************************************************************************
    &setvar snap [response ' ']
    /* The user wants to quit
   @if %snap% eq 1 &then
      do
        quit
        &call terrain_cleanup
        &call clearscreen
        &goto main-menu
      &end
    &end
    &call clearscreen

    &setvar catch_thresh = ( ( %grd$ncols% * %grd$nrows% ) * 0.01 )
    /* Delineate streams
    stream_xxx = con (accum_xxx > %catch_thresh%, 1)
    /* Draw the input DEM in the map window for the user to view
    gridpaint stream_xxx value
    link_xxx = snappour(*, accum_xxx, %snap%)
  &end
  &else
    &do
      &setvar x = %grd$dx%
      &setvar y = %grd$dy%
      &setvar cell_area = ( %x% * %y% )
      &setvar cell_area_hectares = ( %cell_area% / 10000 )
      /* Gets the user to input the number of cells that will be used to delineate a catchment
      &do &until %catch_thresh% > 0

      &call clearscreen
      &type *********************************************************************************
      &type                                      *BC2C*
      &type                                    Terrain Module
      &type                                     *BC2C*
      &type Please enter the minimum number of cells that define a sub catchment
      &type
This will define the minimum area for each sub-catchment used during disaggregation of the major catchment.

To calculate the number of cells needed:

- **Cell Area in m²** = %cell_area%
- **Cell Area in Hectares** = %cell_area_hectares%

**Number of columns** = %grd$ncols%  
**Number of rows** = %grd$nrows%

1 - Quit to the main menu

*********************************************************************************

```plaintext
&setvar catch_thresh [response ' ']
/* The user wants to quit */
&if %catch_thresh% eq 1 &then
  &do &until %catch_thresh% eq 1 &then
    &do &until %catch_thresh% eq 0 or %catch_thresh% eq 0
      &call clearscreen
      /* Delineate streams */
      stream_xxx = con (accum_xxx > %catch_thresh%, 1)
      /* Find stream link points, these will be used as pour points to delinate catchment */
      link_xxx = streamlink(stream_xxx, dir_xxx)
      /* Clean up any old version of the zones grid if it exists as we will recreate it */
      if [ exists zones -grid ] &then kill zones all
      /* This gives us our catchments */
      zones = watershed(dir_xxx, link_xxx)
      /* Clean up temporary data sets */
      kill stream_xxx all
      kill link_xxx all
  &end
  quit
  &call terrain_cleanup
  &call clearscreen
  &goto main-menu
&end
&end
&call clearscreen
/* Gets the user to input a weed tolerance that will be used in converting the raster zones coverage to a polygon coverage */
&do &until %weed_multi% > 0 or %weed_multi% eq 0
  &call clearscreen
  &type
  &type *********************************************************************************
  &type                                     *BC2C*
  &type                                 Terrain Module
  &type  Please enter a weed tolerance value between 0 and 2
  &type  The weed tolerance for generalization of arcs specifies the distance between vertices in map units. The default is 0.0. Arcs are generalized using the Douglas-Peuker algorithm. At a value 0.0 no generalisation is done.
  &type  A good all round value to use here is 1.
  &type
  &type 3 - Quit to the main menu
  &type
  &type *********************************************************************************
  &type &setvar weed_multi [response ' ']
  /* The user wants to quit */
  &if %weed_multi% eq 3 &then
    &do &until %weed_multi% > 0 or %weed_multi% eq 0
      &call clearscreen
      &if %weed_multi% eq 3 &then
        &do &until %weed_multi% > 2 &then
          &type Value too large using 2
          &setvar %weed_multi% = 2
        &end
      &end
    &end
&end
&call clearscreen
```

---

CSIRO Land and Water
&setvar weed = %grd$dx% * %weed_multi%
sub_catcxxx = gridpoly(zones, %weed%)
/* Quit GRID
quit
&if %answer20% eq 'n' or %answer20% eq 'N' &then
&do
&setvar sub_area = ( ( %x% * %y% ) * %catch_thresh% )
call clearsreen
&type ******************************************************
&type ****Pass One***
&type Program control is about to be passed to a sub-program called 'Eliminate'
&type Eliminate will help you remove any artefact polygons which may be left over
&type from the disaggregation process. To use Eliminate type the following commands
&type followed by hitting return. Commands are in inverted comma's.
&type The program will make two passes through Eliminate.
&type "res area < $minimum area$" (where $minimum area$ is the area below which
&type polygons will removed. This value is in m^2. So the command will most likely
&type look like this: "res area < %sub_area%"
&type " " (Here you just press return)
&type "n" (Here you are saying no)
&type "n" (Here you are saying no)
&type ******************************************************
&tty eliminate sub_catcxxx sub_catchx nokeepedge poly # border
/* Clean our new coverage
clean sub_catchx sub_catchx # poly
&call clearsreen
&type ******************************************************
&type ****Pass Two***
&type Program control is about to be passed to a sub-program called 'Eliminate'
&type Eliminate will help you remove any artefact polygons which may be left over
&type from the disaggregation process. To use Eliminate type the following commands
&type followed by hitting return. Commands are in inverted comma's.
&type The program will make two passes through Eliminate.
&type "res area < $minimum area$" (where $minimum area$ is the area below which
&type polygons will removed. This value is in m^2. So the command will most likely
&type look like this: "res area < %sub_area%"
&type " " (Here you just press return)
&type "n" (Here you are saying no)
&type "n" (Here you are saying no)
&type ******************************************************
&tty eliminate sub_catchx sub_catchxx nokeepedge poly # area
&end
&else
&do
&call clearsreen
&type ******************************************************
&call clearscreen
/* Clean our new coverage
*/ Add a field and populate with the area in Hectares
dropitem sub_catchx.pat sub_catchx.pat hectares tables
additem sub_catchx.pat hectares 10 10 i
quit
ae
eec sub_catchx
ef poly
sel all
calculate hectares = ( area / 10000 )
save
quit
/* Start ArcPlot
arcpplot
/* See if the user wants to refine the sub catchment map by hand
&do &until %answer22% eq 'n' or %answer22% eq 'N'
&call clearscreen
&type *********************************************************************************
&type                                     *BC2C*
&type                                 Terrain Module
&type  Do you wish to interactively select and merge sub-catchments to refine your
&type  GRU coverage?
&type  To use you will be presented with a map window, simply select with the mouse
&type  all the polygons you wish to merge and when you are finished press ‘9’
&type  *Only select polygons with adjacent boundaries to merge*
&type  You can loop through merging polygons as many times as you like until you are
&type  happy with the results
&type  Please Select an Option:
&type            Y - To merge polygons by interactively
&type            N - To continue without merging polygons
&type            Q - Quit to the main menu
&type *********************************************************************************
&setvar answer22 [response ' ']
/* The user wants to quit
&if %answer22% eq 'q' or %answer22% eq 'Q' &then
&do quit
&call terrain_cleanup
&call clearscreen
&goto main-menu
&end
&if %answer22% eq 'y' or %answer22% eq 'Y' &then
&do
/*. Into Arcedit
quit
ae
ec sub_catchxx
ef poly
polygons sub_catchxx
sel many
merge select
save
quit
/* Clean our new coverage
  clean sub_catchxx sub_catchxx # # poly
/* Add a field and populate with the area in Hectares
dropitem sub_catchxx.pat sub_catchxx.pat hectares
tables
additem sub_catchxx.pat hectares 10 10 i
quit
ae
ec sub_catchxx
ef poly
sel all
calculate hectares = ( area / 10000 )
save
quit
/* Start ArcPlot
arcplot
mapextent sub_catchxx
polygons sub_catchxx
/*Draws the sub-catchment area on each polygon. Can look very messy.
textcolor red
polygontext sub_catchxx hectares
&end
&end
&call clearscreen
quit
/* Clean our new coverage
clean sub_catchxx sub_catchxx # # poly
/* Add a field and populate with the area in Hectares
dropitem sub_catchxx.pat sub_catchxx.pat hectares
tables
additem sub_catchxx.pat hectares 10 10 i
quit
ae
ec sub_catchxx
ef poly
sel all
calculate hectares = ( area / 10000 )
save
quit
kill sub_catcxxx all
/* Start ArcPlot
arcplot
mapextent sub_catchxx
polygons sub_catchxx
/*Draws the sub-catchment area on each polygon. Can look very messy.
polygonext sub_catchxx hectares

&do &until %answer5% eq 'y' or %answer5% eq 'Y' or %answer5% eq 'n' or %answer5% eq 'N'

&call clearscreen
&type *********************************************************
&type Terrain Module
&type Happy with the sub-catchment delineation?
&type Y - If you are happy with the sub-catchment delineation
&type N - If you would like to re-delineate the catchment
&type Q - Quit to the main menu
&type *********************************************************

&setvar answer5 [response ' ']
/* The user wants to quit
&if %answer5% eq 'q' or %answer5% eq 'Q' &then
&do
quit
&call terrain_cleanup
&call clearscreen
&goto main-menu
&end
&end

&if %answer5% eq 'y' or %answer5% eq 'Y' &then
&do
/* Quit ArcPlot
quit

&do &until %answer6% ne ' '

&call clearscreen
&type *********************************************************
&type Terrain Module
&type Please enter the name you wish to save the sub-catchment coverage under
&type These sub-catchments will now represent Groundwater Response Units (GRU’s) and
&type are the underlying unit of a BC2C analysis
&type Please Select an Option:
&type Input sub-catchment name - Input filename
&type Q - Quit to the main menu
&type
&type

**********************************************************
&setvar answer6 [response ' ']

/* The user wants to quit
&if %answer6% eq 'q' or %answer6% eq 'Q' &then
  &do
    &call terrain_cleanup
    &call clearscreen
    &goto main-menu
  &end
&end

&else &do

  /* Leave ArcPlot
  quit
  kill sub_catchxx
  grid
  describe dem1
  mapextent dem1
  gridpaint dem1 value linear nowrap gray
  &goto catch-delin

&end

/* Back into GRID
display 0
grid

/* Save our sub-catchment coverage
&if [ exists %answer6% -cover ] &then kill %answer6%
copy sub_catchxx %answer6%
quit

/* Add all the fields we will need to sub-catchment tables
additem %answer6%.pat value 10 10 i
additem %answer6%.pat GRU 10 10 i
additem %answer6%.pat length 8 8 f 2
additem %answer6%.pat height 8 8 f 2
quit
arcedit
ec %answer6%
ef poly
sel all

calculate value = %answer6%#
calculate GRU = value
copy %answer6% save
quit

/* Set the display windows change from 1 to 3 if you require a larger window
display 9999 %screen%
grid
describe dem1
&if [ exists zones -grid ] &then kill zones
zones = polygrid(%answer6%, gru, #, #,%grd$dx%)

/* The user wants to set a mask
&if %mask_grid% ne ' ' &then
  &do
    setmask %mask_grid%
  &end

mapextent zones
/* cleanup old grids
&if [ exists zone_length -grid ] &then kill zone_length all
&if [ exists zone_height -grid ] &then kill zone_height all
kill sub_catchxx
kill dir_xxx all
kill accum_xxx all
kill dem1 all
mapextent zones
gridshades zones
ellipse_xxx = zonalgeometry (zones, ellipse)
shadeset color.shd
gridnodatsymbol transparent
drawshapes info ellipse_xxx # zoneid
dem_int = int(%in_dem%)
zone_median = zonalmedian(zones, dem_int, data)
zone_min = zonalmin(zones, dem_int, data)
zone_height = (zone_median - zone_min) * 2
kill zone_min all
kill zone_median all
kill dem_int all
arc joinitem zones.vat ellipse_xxx zones.vat value
zone_length = ((zones.Majoraxis + zones.Minoraxis) / 2)
arcedit

/* Time to add the height and length data to the table
length-xxx = zonalstats(zones, zone_length, mean, data)
quit
display 0
dropitem %answer6%.pat %answer6%.pat count
dropitem %answer6%.pat %answer6%.pat mean
joinitem %answer6%.pat length-xxx %answer6%.pat value
arcedit
ec %answer6%
ef poly
sel all
calculate length = mean
save
quit
killinfo length-xxx

grid
height-xxx = zonalstats(zones, zone_height, mean, data)
quit
dropitem %answer6%.pat %answer6%.pat count
dropitem %answer6%.pat %answer6%.pat mean
joinitem %answer6%.pat height-xxx %answer6%.pat value
arcedit
ec %answer6%
ef poly
sel all
calculate height = mean
save
quit
killinfo height-xxx
dropitem %answer6%.pat %answer6%.pat mean count

/* A bit more cleaning up
kill zone_length all
kill zone_height all

&do &until %answer7% eq 'c' or %answer7% eq 'C'
&call clearscreen
	&type **************************** ****************************************************
&type &type "BC2C"
&type &type Terrain Module
&type &type The terrain analysis section of BC2C is now complete. The output coverage
&type %answer6% has been saved to your working directory. It contains the field
&type GRU which is your unique GRU/Zone identifier derived from the catchment
&type disaggregation. It also contains the fields length and height which
&type were derived from the geometry of each GRU and will be used to run scenarios
&type Press C to continue with your analysis and move to the GRU Parameterisation
&type module of BC2C or Q to quit to the main menu.
&type &type Please Select an Option:
&type &type C - To continue with the analysis
&type &type Q - Quit to the main menu
&type &type **************************** ****************************************************
&type &setvar answer7 [response' ']
/* The user want to quit
&if %answer7% eq 'q' or %answer7% eq 'Q' &then
&do
&call terrain_cleanup
&call clearscreen
&setvar answer7 = ' ' &goto main-menu
&end
&end
/* Carry the zones information to the GRU Parameterisation Module
grid
zone_xxx = zones
kill zones all
&setvar sub_catchxx = %answer6%

/* GRU Parameterisation Module for taking and spatially averaging aquifer parameters from a Groundwater Flow Systems
coverage and adding them to a GRU coverage

/* Sets a re-entry spot for the GRU module
&label GRU
display 0
&if %answer7% eq ' ' &then
&do /* Enter GRID
grid /* The user wants to set a mask
&if %mask_grid% ne ' ' and [ exists %mask_grid% -grid ] &then
&do
setmask %mask_grid%
&end /* The GRU coverage contains the zone information from the catchment
&type The GRU coverage also contains geometry information about each GRU such as
&type height and length
&type Please Select an Option:
&type Input GRU Coverage - To set the input Zone Dataset
&type Q - Quit to the main menu
&type
&setvar sub_catchxx [response ' ']
/* The user want to quit
&if %sub_catchxx% eq 'q' or %sub_catchxx% eq 'Q' &then
&do
quit
&call terrain_cleanup
&call clearscreen
&setvar answer7 = ' '
&goto main-menu
&end
&end
&call clearscreen

/* Just incase the input GRU coverages value field does not contain the same values as their zone/GRU field
quit
dropitem %sub_catchxx%.pat %sub_catchxx%.pat value
tables
additem %sub_catchxx%.pat value 10 10 i
quit
arcedit
ec %sub_catchxx%
ef poly
sel all
calculate value = gru
save
/* Get the cell size from the user */
do &until %cell_size% > 0
&call clearscreend

*** GRU Parameterisation Module ***
Please enter the Cell Size you wish to use for the Analysis

Please Select an Option:
Input Cell Size - To set the input cell size
0 - Quit to the main menu

*** GRU Parameterisation Module ***

@setvar cell_size [response ' ']
/* The user want to quit */
@if %cell_size% eq 0 &then
  quit
  &call terrain_cleanup
  &call clearscreend
  @setvar answer? = ' ' @goto main-menu
@end

&call clearscreend

/* Create the zones grid */
@if [ exists zone_xxx -grid ] &then kill zone_xxx
zone_xxx = polygrid(%sub_catchxx%, gru, #, #, %cell_size%)
@end

/* First we'll area weight all the input parameters */
&call clearscreend

/* Get the input GFS (Groundwater Flow System) Polygon Coverage name from the user */
do &until %gfs% ne ' ' and [ exists %gfs% -cover ]
&call clearscreend

*** GRU Parameterisation Module ***
The Groundwater flow systems Coverage should have an attached attribute:
table containing:
Aquifer Thickness - in metres
Unsaturated Zone Thickness - in metres
Specific Yield as a Fraction - 0 to 1
Hydraulic Conductivity - in metres per year m/yr
Recharge Leaching Fraction - 0 to 1
Groundwater Salinity in mg/l or microsiemens (Set Switch)

Please Select an Option:
Input GFS Coverage Name - To set the input Groundwater Flow Systems Dataset
Q - Quit to the main menu

@setvar gfs [response ' ']
/* The user want to quit */
&if %gfs% eq 'q' or %gfs% eq 'Q' &then
&do
quit
&call terrain_cleanup
&call GRU_cleanup
&setvar answer7 = ' '
&call clearscreen
&goto main-menu
&end
&end
&call clearscreen

;/* Get the aquifer thickness field name from the user */
do &until %aq_thickness% ne ' '
do &call clearscreen

&setvar aq_thickness [response ' ']

/* The user want to quit */
&if %aq_thickness% eq 'q' or %aq_thickness% eq 'Q' &then
&do
quit
&call terrain_cleanup
&call GRU_cleanup
&setvar answer7 = ' '
&call clearscreen
&goto main-menu
&end
&end
&call clearscreen

;/* Get the unsaturated zone thickness field name from the user */
do &until %unsat_thickness% ne ' '
do &call clearscreen

&setvar unsat_thickness [response ' ']

/* The user want to quit */
&if %unsat_thickness% eq 'q' or %unsat_thickness% eq 'Q' &then
&do
quit
&call terrain_cleanup
&call GRU_cleanup
&setvar answer7 = ' ' &call clearscreen &goto main-menu &end &end &call clearscreen /* Get the specific yield field name from the user */ &do &until %specific_yield% ne ' ' &call clearscreen &type ********************************************************************************* &type                                     *BC2C* &type                           GRU Parameterisation Module &type Please enter the name of the specific yield field as it appears in the &type attribute table of the Groundwater Flow Systems coverage &type Specific Yield as a Fraction - 0 to 1 &type Please Select an Option: &type Input specific yield field name - To set the input field name &type Q - Quit to the main menu &type ********************************************************************************* &type &setvar specific_yield [response] ' ' /* The user want to quit */ &if %specific_yield% eq 'q' or %specific_yield% eq 'Q' &then &do &call terrain_cleanup &call GRU_cleanup &setvar answer7 = ' ' &call clearscreen &goto main-menu &end &end &call clearscreen /* Get the hydraulic conductivity field name from the user */ &do &until %hydraulic% ne ' ' &call clearscreen &type ********************************************************************************* &type                                     *BC2C* &type                           GRU Parameterisation Module &type Please enter the name of the hydraulic conductivity field as it appears in the &type attribute table of the Groundwater Flow Systems coverage &type Hydraulic Conductivity - in metres per year m/yr &type Please Select an Option: &type Input hydraulic conductivity field name - To set the input field name &type Q - Quit to the main menu &type ********************************************************************************* &type &setvar hydraulic [response] ' ' /* The user want to quit */ &if %hydraulic% eq 'q' or %hydraulic% eq 'Q' &then &do &call terrain_cleanup &call GRU_cleanup &setvar answer7 = ' ' &call clearscreen &goto main-menu &end &end
&call clearscreen
/* Get the recharge fraction field name from the user
&do &until %rech_fract% ne ' '
&call clearscreen
&type *********************************************************************************
&type                                     *BC2C*
&type                           GRU Parameterisation Module
&type Please enter the name of the recharge fraction field as it appears in the
&type attribute table of the Groundwater Flow Systems coverage
&type Recharge Fraction - 0 to 1
&type Please Select an Option:
&type Input recharge fraction field name - To set the input field name
&type Q - Quit to the main menu
&type *********************************************************************************
&type
&setvar rech_fract [response ' ']
/* The user want to quit
&if %rech_fract% eq 'q' or %rech_fract% eq 'Q' &then
&do
&call terrain_cleanup
&call GRU_cleanup
&setvar answer7 = ' ' 
&call clearscreen
&goto main-menu
&end
&end
&call clearscreen

/* Get the groundwater salinity field name from the user
&do &until %gw_salinity% ne ' '
&call clearscreen
&type *********************************************************************************
&type                                     *BC2C*
&type                           GRU Parameterisation Module
&type Please enter the name of the groundwater salinity field as it appears in the
&type attribute table of the Groundwater Flow Systems coverage
&type This field should have a single salinity value for each Groundwater Flow System
&type Please Select an Option:
&type Input groundwater salinity field name - To set the input field name
&type Q - Quit to the main menu
&type *********************************************************************************
&type
&setvar gw_salinity [response ' ']
/* The user want to quit
&if %gw_salinity% eq 'q' or %gw_salinity% eq 'Q' &then
&do
&call terrain_cleanup
&call GRU_cleanup
&setvar answer7 = ' ' 
&call clearscreen
&goto main-menu
&end
&end
&call clearscreen

/* Set map extent
mapextent zone_xxx
/*Set the cell size to the same as the input DEM
setcell zone_xxx
/* Retrieve all the DEMs attributes
**Create hydrogeologic parameter GRIDS from GFS GRID**

unsat_thick_g = polygrid(%gfs%, %unsat_thickness%, #, #, %grd$dx%)
aq_thick_g = polygrid(%gfs%, %aq_thickness%, #, #, %grd$dx%)
SY_g = polygrid(%gfs%, %specific_yield%, #, #, %grd$dx%)
K_g = polygrid(%gfs%, %hydraulic%, #, #, %grd$dx%)
fract_g = polygrid(%gfs%, %rech_fract%, #, #, %grd$dx%)
gw_sal_g = polygrid(%gfs%, %gw_salinity%, #, #, %grd$dx%)

/* Remove the old fields if they exist */
arc dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
arc dropitem %sub_catchxx%.pat %sub_catchxx%.pat count
arc dropitem %sub_catchxx%.pat %sub_catchxx%.pat Un_thick
arc dropitem %sub_catchxx%.pat %sub_catchxx%.pat Aq_thick
arc dropitem %sub_catchxx%.pat %sub_catchxx%.pat Spec_Yield
arc dropitem %sub_catchxx%.pat %sub_catchxx%.pat zone-K
arc dropitem %sub_catchxx%.pat %sub_catchxx%.pat Rech_Frac
arc dropitem %sub_catchxx%.pat %sub_catchxx%.pat GW_Sal

/* Re-add the fields we'll be using */
quit
tables
additem %sub_catchxx%.pat Un_thick 8 8 f 2
additem %sub_catchxx%.pat Aq_thick 8 8 f 2
additem %sub_catchxx%.pat Spec_Yield 8 8 f 2
additem %sub_catchxx%.pat zone-K 8 8 f 2
additem %sub_catchxx%.pat Rech_Frac 8 8 f 2
additem %sub_catchxx%.pat GW_Sal 8 8 f 2
quit
grid

/* Time to add the unsaturated thickness data to the table */
unsat-xxx = zonalstats(zone_xxx, unsat_thick_g, mean, data)
quit
dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
dropitem %sub_catchxx%.pat %sub_catchxx%.pat count
joinitem %sub_catchxx%.pat unsat-xxx %sub_catchxx%.pat value
arcedit
ec %sub_catchxx%
ef poly
sel all
calculate Un_thick = mean
save
quit
killinfo unsat-xxx
dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
dropitem %sub_catchxx%.pat %sub_catchxx%.pat count

/* Time to add the aquifer thickness data to the table */
aq-xxx = zonalstats(zone_xxx, aq_thick_g, mean, data)
quit
dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
dropitem %sub_catchxx%.pat %sub_catchxx%.pat count
joinitem %sub_catchxx%.pat aq-xxx %sub_catchxx%.pat value
arcedit
ec %sub_catchxx%
ef poly
sel all
calculate Aq_thick = mean
save
quit
killinfo aq-xxx
dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
dropitem %sub_catchxx%.pat %sub_catchxx%.pat count

/* Time to add the specific yield data to the table */
SY-xxx = zonalstats(zone_xxx, SY_g, mean, data)
quit
dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
dropitem %sub_catchxx%.pat %sub_catchxx%.pat count
joinitem %sub_catchxx%.pat SY-xxx %sub_catchxx%.pat value
arcedit
ec %sub_catchxx%
ef poly
sel all
calculate Spec_Yield = mean
save
quit
killinfo SY-xxx
dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
dropitem %sub_catchxx%.pat %sub_catchxx%.pat count
/* Time to add the hydraulic conductivity data to the table
grid
K-xxx = zonalstats(zone_xxx, K_g, mean, data)
quit
dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
dropitem %sub_catchxx%.pat %sub_catchxx%.pat count
joinitem %sub_catchxx%.pat K-xxx %sub_catchxx%.pat value
arcedit
ec %sub_catchxx%
se poly
sel all
calculate zone-K = mean
save
quit
killinfo K-xxx
dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
dropitem %sub_catchxx%.pat %sub_catchxx%.pat count
/* Time to add the recharge fraction data to the table
grid
fract-xxx = zonalstats(zone_xxx, fract_g, mean, data)
quit
dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
dropitem %sub_catchxx%.pat %sub_catchxx%.pat count
joinitem %sub_catchxx%.pat fract-xxx %sub_catchxx%.pat value
arcedit
ec %sub_catchxx%
se poly
sel all
calculate Rech_Frac = mean
save
quit
killinfo fract-xxx
dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
dropitem %sub_catchxx%.pat %sub_catchxx%.pat count
/* Time to add the groundwater salinity data to the table
grid
gwsal-xxx = zonalstats(zone_xxx, gwsal_g, mean, data)
quit
dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
dropitem %sub_catchxx%.pat %sub_catchxx%.pat count
joinitem %sub_catchxx%.pat gwsal-xxx %sub_catchxx%.pat value
arcedit
ec %sub_catchxx%
se poly
sel all
/* Check if the input units for groundwater salinity are in TDS-mg/l or microsiemens
/* if they are already in TDS (flag = 1) then leave alone. If not then convert them
&if %gwsal_units% eq 1 &then
&do
calculate GW_Sal = mean
&end
&else
&do
calculate GW_Sal = ( mean * %gw_ms2tds% )
&end
save
quit
killinfo gwsal-xxx
dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
dropitem %sub_catchxx%.pat %sub_catchxx%.pat count
/* Clean up temporary GRIDS
kill unsat_thick_g all
kill aq_thick_g all
kill SY_g all
kill K_g all
kill fract_g all
kill gwsal_g all
&do &until %answer9% eq 'q' or %answer9% eq 'Q'
&call clearscreen
&type ================================================================================
&type  BC2C*
&type  GRU Parameterisation Module
&type  The GRU parameterisation section of BC2C is now complete. The output coverage
&type  $sub_catchxx% now contains the extra field Un_thick representing the
&type  spatially averaged value of unsaturated zone thickness for each GRU. It also
&type  contains the field Aq_thick representing aquifer thickness, Spec_Yield representing
&type  specific yield as a percentage, zone-K representing hydraulic conductivity in
&type  metres per year and Rech_Frac representing the fraction of excess water
&type  from rainfall that will be partitioned as recharge. All fields are spatially
&type averaged for each GRU.
&type
&type Press Q to return to the main menu
&type
&type ******************************************************************************
&type
&setvar answer9 [response: ' ']
&if %answer9% eq 'q' or %answer9% eq 'Q' &then
   &do
      &call terrain_cleanup
      &call GRU_cleanup
      &call clearscreen
      &setvar answer7 = ''
      &goto main-menu
   &end
&end

/* ************************************************************************************
/* Vegetation Module for taking raster vegetation GRIDS representing either present or proposed scenarios spatially
/* averaging them and adding the results as a value between 0 and 1 where 1 is 100% trees and 0 is 100% grass
/* ************************************************************************************
/* Sets a re-entry spot for the Scenario module
&label Vegetation

display 0
grid
/* Get the input sub-catchment coverage name from the user
&do &until %sub_catchxx% ne ' ' and [ exists %sub_catchxx% -cover ]
   &call clearscreen
   &type ******************************************************************************
   &type
   &type         *BC2C*
   &type        Vegetation Module
   &type        Please enter the name of the input GRU (zones/sub-catchment) Coverage
   &type        The GRU coverage contains the zone information from the catchment
   &type        disaggregation. These zones function as Groundwater Response Units or GRU's
   &type        The GRU coverage also contains geometry information about each GRU such as
   &type        height and length
   &type        Please Select an Option:
   &type        Input GRU Coverage - To set the input Zone Dataset
   &type        Q - Quit to the main menu
   &type        ******************************************************************************
   &type
   &setvar sub_catchxx [response: ' ']
   &if %sub_catchxx% eq 'q' or %sub_catchxx% eq 'Q' &then
      &do
         quit
         &call terrain_cleanup
         &call clearscreen
         &goto main-menu
      &end
   &end
&end

&call clearscreen

/* Just in case the input GRU coverages value field does not contain the same values as their zone/GRU field
quit
dropitem %sub_catchxx%.pat %sub_catchxx%.pat value tables
additem %sub_catchxx%.pat value 10 10 i
quit
arcedit
ec %sub_catchxx%
ec poly
sel all
calculate value = gru
save
quit
grid

/* Get the cell size from the user
&do &until %cell_size% > 0
 &call clearscreen
 &type ******************************************************************************
 &type
 &type     Vegetation Module
 &type
 &type     Please enter the Cell Size you wish to use for the Analysis
 &type
 &type
 &type     Please Select an Option:
 &type
 &type     Input Cell Size - To set the input cell size
 &type     0 - Quit to the main menu
 &type
 &type ******************************************************************************
 &type
 &setvar cell_size [response' ']
 /* The user want to quit
 &if %cell_size% eq 0 &then
 &do
 &call terrain_cleanup
 &call clearscreen
 &goto main-menu
 &end
 &end
 &call clearscreen

 /* Create the zones grid
 &if [ exists zone_xxx -grid ] &then kill zone_xxx
 zone_xxx = polygrid($sub_catchxx%, gru, #, #, %cell_size%)
 /* Set map extent
 mapextent zone_xxx
 /*Set the cell size
 setcell zone_xxx
 /* Retreive all the GRIDs attributes
 describe zone_xxx
 /* Leave GRID for the 100th time
 quit
 &do &until $answer10% eq 'q'
 &call clearscreen

 &type ******************************************************************************
 &type
 &type     Vegetation Module
 &type
 &type     This module will take the name of a raster GRID representing vegetation
 &type     and spatially average it based on the zonal information in a GRU coverage.
 &type     The vegetation coverage can represent a) the current breakup of grass and trees
 &type     or b) a proposed scenario such as planting or removing trees in one of the GRU's
 &type     The values contained within the vegetation GRID should be between 0 and 1.
 &type
 &type     ***You can add as many vegetation scenarios to your GRU coverage as you like.
 &type     This allows you to batch process many different scenarios***
 &type
 &type     A value of 1 = 100 percent trees, 0 percent grass for that cell
 &type     A value of 0 = 0 percent trees, 100 percent grass for that cell
 &type     A value of 0.5 = 50 percent trees 50 percent grass for that cell
 &type
 &type     The input GRID name will be used as the new field name
 &type
 &type     Please Select an Option:
 &type     Input the name of the Vegetation GRID
 &type     Q - Quit to the main menu
 &type
 &type ******************************************************************************
&setvar answer10 [response ' ']
/* Take the user back to the main menu
&if %answer10% eq 'q' or %answer10% eq 'Q' &then
  &do
    &call terrain_cleanup
    &call GRU_cleanup
    &call clearscreen
    &goto main-menu
  &end
&if %answer10% ne ' ' and [ exists %answer10% -grid ] &then
  &do
    /* Remove the old fields if they exist
    dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
    dropitem %sub_catchxx%.pat %sub_catchxx%.pat count
    dropitem %sub_catchxx%.pat %sub_catchxx%.pat %answer10%
    /* Re-add the fields we'll be using
    tables
      additem %sub_catchxx%.pat %answer10% 8 8 f 2
      quit
    grid
    /* Time to add the unsaturated thickness data to the table
    veg-xxx = zonalstats(zone_xxx, %answer10%, mean, data)
    quit
    joinitem %sub_catchxx%.pat veg-xxx %sub_catchxx%.pat value
    arcedit
      ec %sub_catchxx%
      ef poly
      sel all
      calculate %answer10% = mean
      save
      quit
    killinfo veg-xxx
    dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
    dropitem %sub_catchxx%.pat %sub_catchxx%.pat count
  &end
&end

/* *******************************************************************************************************************
/* Rainfall Module for taking raster rainfall and/or latitude correction GRIDS and spatially averaging them and
/* adding the results to a new field in the pat table of the input GRU coverage
/* *******************************************************************************************************************
/* Sets a re-entry spot for the Rainfall module
&label Rainfall

display 0
grid
/* Get the input sub-catchment coverage name from the user
&do &until %sub_catchxx% ne ' ' and [ exists %sub_catchxx% -cover ]
  &call clearscreen
  &type
    &type  *******************************************************
    &type        Rainfall Module
    &type
    &type          Please enter the name of the input GRU (zones/sub-catchment) Coverage
    &type
    &type      The GRU coverage contains the zone information from the catchment
    &type
    &type    disaggregation. These zones function as Groundwater Response Units or GRU's
    &type
    &type      The GRU coverage also contains geometry information about each GRU such as
    &type
    &type    height and length
    &type
    &type      Please Select an Option:
    &type
    &type    Input GRU Coverage - To set the input Zone Dataset
    &type
    &type Q - Quit to the main menu
    &type
    &type  *******************************************************
  &type
  &setvar sub_catchxx [response ' ']
/* The user want to quit
&if %sub_catchxx% eq 'Q' or %sub_catchxx% eq 'q' &then
  &do
    quit
&call terrain_cleanup
&call clearscreen
&goto main-menu
&end
&end clearscreen

/* Just in case the input GRU coverages value field does not contain the same values as their zone/GRU field */
dropitem %sub_catchxx%.pat %sub_catchxx%.pat value
tables
additem %sub_catchxx%.pat value 10 10 i
quit
arcedit
ec %sub_catchxx%
ef poly
sel all
calculate value = gru
save
quit
grid

/* Get the cell size from the user */
do &until %cell_size% > 0
&call clearscreen
&atype ************************************************************
&atype
&atype        *BC2C*
&atype Rainfall Module
&atype
&atype Please enter the Cell Size you wish to use for the Analysis
&atype
&atype
&atype Please Select an Option:
&atype
&atype Input Cell Size - To set the input cell size
&atype
&atype 0 - Quit to the main menu
&atype
&atype ************************************************************
&atype
&setvar cell_size [response' ']
/* The user want to quit */
if %cell_size% eq 0 &then
&do
quit
&call terrain_cleanup
&call clearscreen
&goto main-menu
&end
&end clearscreen

/* Create the zones grid */
if [ exists zone_xxx -grid ] &then kill zone_xxx
zone_xxx = polygrid(%sub_catchxx%, gru, #, #, %cell_size%)
/* Set map extent */
mapextent zone_xxx
/* Set the cell size */
setcell zone_xxx
/* Retrieve all the GRIDs attributes */
describe zone_xxx
/* Leave GRID */
quit
&label Rainfall-again

/* Get the rainfall or lai grid name from modeller */
do &until %answer11% ne ' ' and [ exists %answer11% -grid ]
&call clearscreen
&atype ************************************************************
&atype
&atype        *BC2C*
Rainfall Module
Please enter the name of a GRID representing mean annual rainfall in mm or a latitude correction GRID
The input GRID name will be used as the new field name
***You can add as many rainfall scenarios to your GRU coverage as you like. This allows you to batch process many different scenarios***
Please Select an Option:
Input mean annual rainfall GRID name - To set the input GRID name
Q - Quit to the main menu

If $\text{answer11}$ is 'q' or $\text{answer11}$ is 'Q' then
&do
  &call terrain_cleanup
  &call GRU_cleanup
  &call clearscreen
  &goto main-menu
&end

If $\text{answer11}$ or exists $\text{answer11}$ -grid then
&do
  /* Take the user back to the main menu
  if $\text{answer11}$ eq 'q' or $\text{answer11}$ eq 'Q' then
    &do
      &call terrain_cleanup
      &call GRU_cleanup
      &call clearscreen
      &goto main-menu
    &end
  &endif

  /* Remove the old fields if they exist
  dropitem ${\text{sub\_catchxx}}$.pat ${\text{sub\_catchxx}}$.pat mean
  dropitem ${\text{sub\_catchxx}}$.pat ${\text{sub\_catchxx}}$.pat count
  dropitem ${\text{sub\_catchxx}}$.pat ${\text{sub\_catchxx}}$.pat $\text{answer11}$

  /* Re-add the fields we'll be using
  additem ${\text{sub\_catchxx}}$.pat $\text{answer11}$ 8 8 f 2
  quit grid

  /* Add the rainfall data to the table
  rain-xxx = zonalstats(zone_xxx, $\text{answer11}$, mean, data)
  quit
  jointxx = $\text{sub\_catchxx}$ $\text{answer11}$ rain-xxx $\text{sub\_catchxx}$
  quit
  arcedit ec $\text{sub\_catchxx}$
  ef poly
  sel all
  calculate $\text{answer11}$ = mean
  save
  quit
  killinfo rain-xxx
  dropitem $\text{sub\_catchxx}$ $\text{answer11}$ $\text{sub\_catchxx}$ count
&end

if $\text{rain\_sal}$ eq 0 and $\text{trainflag}$ ne 1 then
&do
  /* Get the rainfall salinity grid name from modeller
  &do until $\text{answer12}$ ne ' ' and [ exists $\text{answer12}$ -grid ]
    &call clearscreen
    &type ************************************************************
    &type
    &type ***BC2C***
    &type Rainfall Module
    &type Please enter the name of a GRID representing rainfall salinity in mg/l
    &type
    &type Please Select an Option:
    &type
    &type Input rainfall salinity GRID name - To set the input GRID name
    &type
    &type Q - Quit to the main menu
    &type
    &type
&end
;&type; ***************************************************************************** &type;
;&setvar answer12 [response ' ']
;/* Take the user back to the main menu */
;&if %answer12% eq 'q' or %answer12% eq 'Q' &then
;&do
;&call terrain_cleanup
;&call clearscreen
;&goto main-menu
;&end;
;&if %answer12% ne ' ' and [ exists %answer12% -grid ] &then
;&do
;/* Remove the old fields if they exist */
dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
dropitem %sub_catchxx%.pat %sub_catchxx%.pat count
dropitem %sub_catchxx%.pat %sub_catchxx%.pat rain_sal
;/* Re-add the fields we'll be using */
tables
additem %sub_catchxx%.pat rain_sal 8 8 f 2
quit
grid
;/* Add the rainfall data to the table */
rain-xxx = zonalstats(zone_xxx, %answer12%, mean, data)
quit
joinitem %sub_catchxx%.pat rain-xxx %sub_catchxx%.pat value
arcedit
ee %sub_catchxx%
ef poly
sel all
calculate rain_sal = mean
quit
killinfo rain-xxx
dropitem %sub_catchxx%.pat %sub_catchxx%.pat mean
dropitem %sub_catchxx%.pat %sub_catchxx%.pat count
;&setvar rainflag = 1
;&end
;&end
;&else
;&do
;
dropitem %sub_catchxx%.pat %sub_catchxx%.pat rain_sal
;/* Re-add the fields we'll be using */
tables
additem %sub_catchxx%.pat rain_sal 8 8 f 2
quit
arcedit
ee %sub_catchxx%
ef poly
sel all
calculate rain_sal = %rain_sal%
save
quit
;&setvar rainflag = 1
;&end
;&end
;&do
;&call clearscreen
;&goto Rainfall-again

/* ***************************************************************************** */
/* Scenario Module */
/* ***************************************************************************** */
/* Sets a re-entry spot for the Scenario module */
&label Scenarios
/* Time to tackle the recharge */
display 0
/* Get the user to give the scenario a name */
&do &until %scenario% ne ' '
;&call clearscreen
;&type; ***************************************************************************** &type;
;&type; *BC2C*
;&type; Scenario Module
;&type;
&type Please enter the name for the current scenario
&type A copy of the input Groundwater Response Unit (GRU) coverage will be made using
&type this name. This new coverage will contain the results of the scenario
&type Please Select an Option:
&type Input scenario name - To set the input a name for the current scenario
&type Q - Quit to the main menu
&type
&setvar scenario [response' ']
/* The user want to quit
if %scenario% eq 'q' or %scenario% eq 'Q' &then
&do
    &call terrain_cleanup
    &call clearscreen
    &goto main-menu
&end
&end
&call clearscreen

/* Get the user the number of years of analysis
&do &until %years% > 0
&call clearscreen
&setvar years [response' ']
/* The user want to quit
if %years% eq 0 &then
&do
    &call terrain_cleanup
    &call clearscreen
    &goto main-menu
&end
&end
&call clearscreen

/* Get the input sub-catchment coverage name from the user
&do &until %sub_catchxx% ne ' ' and [ exists %sub_catchxx%-cover ]
&call clearscreen
&setvar sub_catchxx [response' ']
/* The user want to quit
if %sub_catchxx% eq ' ' &then
&do
    &call terrain_cleanup
    &call clearscreen
    &goto main-menu
&end
&end
&call clearscreen

/* The scenario will be run for the number of years input here using the user
 defined time step.
Please Select an Option:
Input number of years - To set the number of years for the current scenario
0 - Quit to the main menu

*********************************************************************************
*********************************************************************************
*BC2C* Scenario Module
Please enter the number of years for the current scenario
The scenario will be run for the number of years input here using the user
defined time step.
Please Select an Option:
Input number of years - To set the number of years for the current scenario
0 - Quit to the main menu

*********************************************************************************
*********************************************************************************
*BC2C* Scenario Module
Please enter the name of the input GRU (zones/sub-catchment) Coverage
The GRU coverage contains the zone information from the catchment
disaggregation. These zones function as Groundwater Response Units or GRU's
The GRU coverage also contains geometry information about each GRU such as
height and length
Please Select an Option:
&type &type Input GRU Coverage - To set the input Zone Dataset
&type Q - Quit to the main menu
&type
&type *************************************************************************************
&type
&setvar sub_catchxx [response' ']
/* The user want to quit
&if %sub_catchxx% eq 'q' or %sub_catchxx% eq 'Q' &then
&do
  &call terrain_cleanup
  &call clearscreen
  &goto main-menu
&end
&end
&call clearscreen

/* Just in case the input GRU coverages value field does not contain the same values as their zone/GRU field
dropitem %sub_catchxx%.pat %sub_catchxx%.pat value tables
additem %sub_catchxx%.pat value 10 10 i
quit
arcedit
ec %sub_catchxx%
ef poly
sel all
calculate value = gru
save
quit
grid

/* Get the cell size from the user
&do &until %cell_size% > 0
&call clearscreen
&type *************************************************************************************
&type                        *BCIC*
&type Scenario Module
&type Please enter the Cell Size you wish to use for the Analysis
&type
&type Please Select an Option:
&type
&type Input Cell Size - To set the input cell size
&type 0 - Quit to the main menu
&type
&type *************************************************************************************
&type
&setvar cell_size [response' ']
/* The user want to quit
&if %cell_size% eq 0 &then
&do
  quit
  &call terrain_cleanup
  &call clearscreen
  &goto main-menu
&end
&end
&call clearscreen

/* Create the zones grid
&if [ exists zone_xxx -grid ] &then kill zone_xxx
zone_xxx = polygrid(%sub_catchxx%, gru, #, #, %cell_size%)
/* Set map extent
mapextent zone_xxx
/* Set the cell size
setcell zone_xxx
/* Retreive all the GRIDs attributes
describe zone_xxx
/* Leave GRID
quit
/* Make a copy of our input GRU coverage for use in the analysis */
@if [ exists %scenario% -cover ] &then kill %scenario% all copy %sub_catchxx% %scenario%
end

call clearscreen

/* Get the current tree cover field name from the user */
do &until %currveg% ne ' ' 
call clearscreen
&setvar currveg [response ' ']
/* The user want to quit */
@if %currveg% eq 'q' or %currveg% eq 'Q' &then 
do &call terrain_cleanup &call GRU_cleanup &call clearscreen &goto main-menu &end
end

call clearscreen

/* Get the tree cover scenario field name from the user */
do &until %newveg% ne ' ' 
call clearscreen
&setvar newveg [response ' ']
/* The user want to quit */
@if %newveg% eq 'q' or %newveg% eq 'Q' &then 
do &call terrain_cleanup &call GRU_cleanup &call clearscreen &goto main-menu &end
}
/* Get the mean annual rainfall field name from the user
&do &until %rain% ne ' ' 
&call clearscreen
&call clearscreen
&type ************************************************** Scenario Module
&type Please enter the field name in the GRU coverage representing mean annual rainfall in mm per year that you wish to use for this scenario run
&type
&type Please Select an Option:
&type
&type       Input mean annual rainfall field name - To set the input field name
&type
&type *********************************************************************************
&type
&setvar rain [response' ']
&do &if %rain% eq 'q' or %rain% eq 'Q' &then &call terrain_cleanup &call GRU_cleanup &call clearscreen &goto main-menu &end 
&end
&call clearscreen

/* Get the optional latitude correction field name from the user
&do &until %answer% eq 'y' or %answer% eq 'Y' or %answer% eq 'n' or %answer% eq 'N'
&call clearscreen
&call clearscreen
&type ************************************************** Scenario Module
&type Do you wish to use latitude correction?
&type
&type Please Select an Option:
&type
&type       Y - To input a latitude correction field name
&type
&type       N - To continue not using latitude correction
&type
&type *********************************************************************************
&type
&setvar answer [response' ']
&do &if %answer% eq 'q' or %answer% eq 'Q' &then quit &call terrain_cleanup &call GRU_cleanup &call clearscreen &goto main-menu &end
&end

/* The user wants to use latitude correction
&do &if %answer% eq 'y' or %answer% eq 'Y' &then &call clearscreen
   /* Get the optional latitude correction field name from the user
   &do &until %lat% ne ' ' or %break% eq 'y'
      &call clearscreen
Scenario Module

Please enter the name of a field in the input GRU coverage representing latitude correction

Please Select an Option:

Input optional latitude correction field name - To set the input field name
Q - Quit to the previous menu

Please enter the name of a field in the input GRU coverage representing latitude correction

Please Select an Option:

Input optional latitude correction field name - To set the input field name
Q - Quit to the previous menu

Please enter the name of a field in the input GRU coverage representing latitude correction

Please Select an Option:

Input optional latitude correction field name - To set the input field name
Q - Quit to the previous menu

Please enter the name of a field in the input GRU coverage representing latitude correction

Please Select an Option:

Input optional latitude correction field name - To set the input field name
Q - Quit to the previous menu

Please enter the name of a field in the input GRU coverage representing latitude correction

Please Select an Option:

Input optional latitude correction field name - To set the input field name
Q - Quit to the previous menu

Please enter the name of a field in the input GRU coverage representing latitude correction

Please Select an Option:

Input optional latitude correction field name - To set the input field name
Q - Quit to the previous menu

Please enter the name of a field in the input GRU coverage representing latitude correction

Please Select an Option:

Input optional latitude correction field name - To set the input field name
Q - Quit to the previous menu

Please enter the name of a field in the input GRU coverage representing latitude correction

Please Select an Option:

Input optional latitude correction field name - To set the input field name
Q - Quit to the previous menu

Please enter the name of a field in the input GRU coverage representing latitude correction

Please Select an Option:

Input optional latitude correction field name - To set the input field name
Q - Quit to the previous menu
additem %scenario%.pat ov_salt 8 8 f 2
additem %scenario%.pat lat_salt 8 8 f 2

quit
/* Time to get to the guts of the model, and yes I know I could have done this in tables but ArcEdit
/* writes more stuff to the screen and so looks more impressive to the user ;-) 
arcedit
ec %scenario%
ef poly
sel all
/* Calculate excess rainfall using Zhang Curves
if %lat% eq ' ' then
  /* No latitude correction
  /* Calculate excess rainfall
  calculate cur_excess = %train% - ( ( %train% * ( ( 1 + 0.5 * 1100 / %train% ) / ( 1 + 0.5 * 1100 / %train% + %train% / 1100 ) ) * ( 1 - %curveg% ) ) + ( %train% * ( ( 1 + 2.0 * 1410 / %train% ) / ( 1 + 2.0 * 1410 / %train% + %train% / 1410 ) ) * %curveg% ) )
calculate new_excess = %train% - ( ( %train% * ( ( 1 + 0.5 * 1100 / %train% ) / ( 1 + 0.5 * 1100 / %train% + %train% / 1100 ) ) * ( 1 - %newveg% ) ) + ( %train% * ( ( 1 + 2.0 * 1410 / %train% ) / ( 1 + 2.0 * 1410 / %train% + %train% / 1410 ) ) * %newveg% ) )
else
  /* Fine, use latitude correction see if I care
  /* Calculate excess rainfall
  calculate cur_excess = %train% - ( ( %train% * ( ( 1 + 0.5 * 1100 / %train% ) / ( 1 + 0.5 * 1100 / %train% + %train% / 1100 ) ) * ( 1 - %curveg% ) ) + ( %train% * ( ( 1 + 2.0 * 1410 / %train% ) / ( 1 + 2.0 * 1410 / %train% + %train% / 1410 ) ) * %curveg% ) )
calculate new_excess = %train% - ( ( %train% * ( ( 1 + 0.5 * 1100 / %train% ) / ( 1 + 0.5 * 1100 / %train% + %train% / 1100 ) ) * ( 1 - %newveg% ) ) + ( %train% * ( ( 1 + 2.0 * 1410 / %train% ) / ( 1 + 2.0 * 1410 / %train% + %train% / 1410 ) ) * %newveg% ) )
end
*/
/* Calculate canopy closure
calculate cc = ( 1 + ( 3000 / %rain% ) )
*/
/* Calculate recharge by applying our recharge fraction
calculate cur_rc = cur_excess * Rech_Frac
calculate new_rc = new_excess * Rech_Frac
calculate cur_rc_ML = ( ( ( cur_rc / 1000 ) * area ) / 1000 )
calculate new_rc_ML = ( ( ( new_rc / 1000 ) * area ) / 1000 )
*/
/* Calculate quick discharge in ML per year
calculate cur_qk_dis = ( ( ( cur_excess - ( cur_excess * Rech_Frac ) ) / 1000 ) * area ) / 1000 )
calculate new_qk_dis = ( ( ( new_excess - ( new_excess * Rech_Frac ) ) / 1000 ) * area ) / 1000 )
*/
/* Partition quick flow into overland and lateral flow components
calculate ov_flow = ( ( 0.25 + ( %newveg% / 2 ) ) * new_qk_dis )
calculate lat_flow = ( ( 1 - ( 0.25 + ( %newveg% / 2 ) ) ) * new_qk_dis )
*/
/* Calculate salt load from ET portion of precipitation, this will be added to overland flow
calculate ET_loss_ML = ( ( ( %rain% / 1000 ) * area ) / 1000 )
calculate ET_salt = ( ( ET_loss_ML * rain_sal ) / 1000 )
*/
/* Calculate salt in overland and lateral flow components
calculate ov_salt = ( ( ov_flow * rain_sal ) / 1000 )
calculate lat_salt = ( ( lat_flow * rain_sal ) / 1000 )
*/
/* Calculate the change in recharge and convert from mm/y to m/y
calculate delt_rc = ( new_rc - cur_rc ) / 1000
calculate delt_rc_ML = ( ( delt_rc * area ) / 1000 )
*/
/* Select any delt_rc fields with a value of 0 and make them a very small number. Oh how computers hate to divide by 0
severity &error &ignore
select for delt_rc eq 0
calculate delt_rc = 0.00000001
arcedit
select all
*/
/* Here we need to account for negative recharge vs positive recharge
select for delt_rc gt 0
*/
/* Calculate time scales for positive recharge case
calculate vert_fill = ( ( %Un_thick * Spec_Yield ) / delt_rc )
calculate lat_move = ( ( Spec_Yield * ( length ** 2 ) ) / ( ZONE-K * Aq_thick ) )
calculate grad_lat = ( ( Spec_Yield * ( length ** 2 ) ) / ( ZONE-K * height ) )
calculate t_half = ( ( 1 / ( 1 / vert_fill ) + ( 1 / lat_move ) ) )
*/
/* Calculate time scales for negative recharge case
select for delt_rc lt 0
calculate lat_move = ( ( Spec_Yield * ( length ** 2 ) ) / ( ZONE-K * Aq_thick ) )
calculate grad_lat = ( ( Spec_Yield * ( length ** 2 ) ) / ( ZONE-K * height ) )
calculate t_half = ( ( 2 / ( 1 / lat_move ) ) )
select all
severity &error &fail
grid
&if [ exists delt_rc -grid ] &then kill delt_rc all
&if [ exists cc -grid ] &then kill cc all

/* Create the GRIDS needed for our calculations */
t_half = polygrid(%scenario%, t_half, #, #, %cell_size%)
delt_rc = polygrid(%scenario%, delt_rc, #, #, %cell_size%)
cc = polygrid(%scenario%, cc, #, #, %cell_size%)
t_half-xxx = zonalstats(zone_xxx, t_half, mean, data)
quit
dropitem %scenario%.pat %scenario%.pat count
dropitem %scenario%.pat %scenario%.pat mean
joinitem %scenario%.pat t_half-xxx %scenario%.pat value
arcedit
ec %scenario%
ef poly
sel all
/* Calculate t-half
calculate t_half = mean
save
quit
killinfo t_half-xxx

&setvar n = 0

/* calculate discharge and salt for n number of years. This is our main timestep loop */
do n = 0 &to %years% &by %timestep%
    /* Remove the old fields if they exist */
    dropitem %scenario%.pat %scenario%.pat mean
dropitem %scenario%.pat %scenario%.pat dis_Y%n%
dropitem %scenario%.pat %scenario%.pat salt_Y%n%
dropitem %scenario%.pat %scenario%.pat lat_temp
    /* Re-add the fields we'll be using */
    additem %scenario%.pat dis_Y%n% 8 8 f 2
    additem %scenario%.pat salt_Y%n% 8 8 f 2
    additem %scenario%.pat lat_temp 8 8 f 2
    quit

    /* Nice one, why no multi variable exp() function in Tables or ArcRedit? */
    grid
    &if [ exists alpha -grid ] &then kill alpha all
    &if [ exists beta -grid ] &then kill beta all
    &if [ exists time -grid ] &then kill time all
    &if [ exists gw-disch -grid ] &then kill gw-disch all
    &if [ exists disch-xxx -info ] &then arc killinfo disch-xxx
    &if [ exists lat-disch -grid ] &then kill lat-disch all
    &if [ exists lat-xxx -info ] &then arc killinfo lat-xxx
    alpha = (3 / cc)
    beta = (ln(2) / t_half)
    /* Calculate groundwater discharge for each timestep */
    if ( delt_rc >= 0 )
        gw-disch = ( 1 + ( (alpha / (beta - alpha) ) * ( exp( -1 * beta * %n% ) ) ) )
    else if ( ( delt_rc < 0 ) && (alpha != beta) )
        gw-disch = ( 1 + ( (alpha / (beta - alpha) ) * ( exp( -1 * beta * %n% ) ) ) ) + ( (beta / (alpha - beta) ) * ( exp( -1 * alpha * %n% ) ) )
    else if ( ( delt_rc < 0 ) && (alpha eq beta) )
        gw-disch = ( 1 - (exp( -1 * alpha * %n% ) ) ) - (alpha * %n% * exp( -1 * alpha * %n% ) )
    endif
    disch-xxx = zonalstats(zone_xxx, gw-disch, mean, data)
    lat-disch = con ( ( delt_rc < 0 ), ( 1 - exp ( ( -%n% / ( cc / 3 ) ) ) ) ), 1)
    lat-xxx = zonalstats(zone_xxxx, lat-disch, mean, data)
    quit
    joinitem %scenario%.pat lat-xxx %scenario%.pat value
    arcedit
ec %scenario%
ef poly
    sel all
    calculate lat_temp = mean
    save
    quit
dropitem %scenario%.pat %scenario%.pat mean
dropitem %scenario%.pat %scenario%.pat count
    joinitem %scenario%.pat disch-xxx %scenario%.pat value
    arcedit
ec %scenario%
ef poly
**Total discharge in ML**

\[
\text{dis}_{Y} = \left( \text{cur}_{rc} + (\text{delt}_{rc} \times \text{mean}) + (\text{cur}_{qk} - (\text{new}_{qk}) \times \text{lat}_{temp}) \right)
\]

**Total salt in tonnes**

\[
\text{salt}_{Y} = \left( \left( \frac{(\text{cur}_{rc} + (\text{delt}_{rc} \times \text{mean})) \times \text{GW}_{Sal}}{1000} \right) + \text{ov}_{salt} + \text{lat}_{salt} \right)
\]

This bit is to account for areas that had no veg change so should already be in equilibrium.

```
&severity &error &ignore
select for delt_{rc} eq 0.00000001
calculate dis_{Y} = \left( \left( \frac{(\text{new}_{rc} / 1000) \times \text{area}}{1000} \right) + \text{new}_{qk} \right)
calculate salt_{Y} = \left( \left( \left( \left( \frac{(\text{new}_{rc} / 1000) \times \text{area}}{1000} \right) / 1000 \right) \times \text{GW}_{Sal} \right) / 1000 \right)
&severity &error &fail
save
quit
```

/* Clean up

```
dropitem %scenario%.pat %scenario%.pat mean
dropitem %scenario%.pat %scenario%.pat count
dropitem %scenario%.pat %scenario%.pat lat_{temp}
```

/* Restore the value of delt_{rc} back to 0 for areas with no change

```
&severity &error &ignore
arcedit
ec %scenario%
ef poly
select for delt_{rc} eq 0.00000001
calculate delt_{rc} = 0
save
quit
&severity &error &fail
```

/* The end :)

```
&call terrain_cleanup
&call GRU_cleanup
&goto main-menu
&return
```

/*

******************************************************************************
**
**routine GRU_cleanup
*/

```
&if [ exists t_half -grid ] &then kill t_half all
&if [ exists delt_{rc} -grid ] &then kill delt_{rc} all
dropitem %scenario%.pat %scenario%.pat cur_{rc}
dropitem %scenario%.pat %scenario%.pat new_{rc}
dropitem %scenario%.pat %scenario%.pat delt_{rc}
```

```
/* Cleanup any grids or coverages left from failed previous runs
&if [ exists new_excess -grid ] &then kill new_excess all
&if [ exists current_R -grid ] &then kill current_R all
&if [ exists current_R_m -grid ] &then kill current_R_m all
&if [ exists delta_r -grid ] &then kill delta_r all
&if [ exists new_R -grid ] &then kill new_R all
&if [ exists fract -grid ] &then kill fract all
&if [ exists unsat_thick_g -grid ] &then kill unsat_thick_g all
&if [ exists aq_thick_g -grid ] &then kill aq_thick_g all
&if [ exists SY_g -grid ] &then kill SY_g all
&if [ exists K_g -grid ] &then kill K_g all
&if [ exists fract_g -grid ] &then kill fract_g all
&if [ exists new_rc -grid ] &then kill new_rc all
&if [ exists cur_rc -grid ] &then kill cur_rc all
&if [ exists unsat-xxx -info ] &then arc killinfo unsat-xxx
&if [ exists aq-xxx -info ] &then arc killinfo aq-xxx
&if [ exists SY-xxx -info ] &then arc killinfo SY-xxx
&if [ exists K-xxx -info ] &then arc killinfo K-xxx
&if [ exists fract-xxx -info ] &then arc killinfo fract-xxx
```

```
&if [ exists unsat_thick_g -grid ] &then kill unsat_thick_g all
&if [ exists aq_thick_g -grid ] &then kill aq_thick_g all
&if [ exists SY_g -grid ] &then kill SY_g all
&if [ exists K_g -grid ] &then kill K_g all
&if [ exists fract_g -grid ] &then kill fract_g all
&if [ exists veg-xxx -grid ] &then kill veg-xxx all
&if [ exists veg-xxx -info ] &then arc killinfo veg-xxx
&if [ exists rain-xxx -info ] &then arc killinfo rain-xxx
&if [ exists rain-xxx -grid ] &then kill veg-xxx all
&if [ exists t_harmonic -grid ] &then kill t_harmonic all
&if [ exists gw-disch -grid ] &then kill gw-disch all
&if [ exists disch-xxx -info ] &then arc killinfo disch-xxx
&if [ exists t_half -grid ] &then kill t_half all
&if [ exists delt_rc -grid ] &then kill delt_rc all
&if [ exists t_half_old -grid ] &then kill t_half_old all
&if [ exists cc -grid ] &then kill cc all
&if [ exists t_half-xxx -info ] &then arc killinfo t_half-xxx
&if [ exists quick -grid ] &then kill quick all
&if [ exists lat-disch -grid ] &then kill lat-disch all
&if [ exists lat-xxx -info ] &then arc killinfo lat-xxx
&if [ exists t_half_new -grid ] &then kill t_half_new all
&if [ exists alpha -grid ] &then kill alpha all
&if [ exists beta -grid ] &then kill beta all
&return
/*
***************************************************************************************
********
&routine terrain_cleanup
/* Cleanup any grids or coverages left from failed previous runs
&if [ exists dir_xxx -grid ] &then kill dir_xxx all
&if [ exists accum_xxx -grid ] &then kill accum_xxx all
&if [ exists stream_xxx -grid ] &then kill stream_xxx all
&if [ exists link_xxx -grid ] &then kill link_xxx all
&if [ exists deml -grid ] &then kill deml all
&if [ exists subCatchxx -cover ] &then kill subCatchxx
&if [ exists zone_min -grid ] &then kill zone_min all
&if [ exists zone_median -grid ] &then kill zone_median all
&if [ exists dem_int -grid ] &then kill dem_int all
&if [ exists ellipse_xxx -info ] &then arc killinfo ellipse_xxx
&if [ exists length_xxx -grid ] &then kill length_xxx all
&if [ exists height_xxx -grid ] &then kill height_xxx all
&if [ exists zone_xxx -grid ] &then kill zone_xxx all
&if [ exists unsat_thick -grid ] &then kill unsat_thick all
&if [ exists aq_thick -grid ] &then kill aq_thick all
&if [ exists SY -grid ] &then kill SY all
&if [ exists K -grid ] &then kill K all
&if [ exists fill_xxx -grid ] &then kill fill_xxx all
&if [ exists zone_length -grid ] &then kill zone_length all
&if [ exists zone_height -grid ] &then kill zone_height all
&if [ exists zones -grid ] &then kill zones all
&if [ exists length-xxx -info ] &then arc killinfo length-xxx
&if [ exists height-xxx -info ] &then arc killinfo height-xxx
&if [ exists subCatxxx -cover ] &then kill subCatxxx
&if [ exists subCatx -cover ] &then kill subCatx
&return
/*
***************************************************************************************
********
&routine clearscreen
/* System call to clear the screen
*/ &system cls
&system %os%
*/ &system clear
&return
/
Appendix 2
Changes to Flow Duration Curve for Land-Use Change

This appendix contains the modelling code developed by Best et al. (2003).

MAIN CODE

clear all
close all
Flow_File = 'Redhill.txt';
Rainfall_File = 'Tumut_Rain.txt';
Monthly_PET = 'Monthly_PET.txt';
Start_Date_Cal = '01/01/1990';
End_Date_Cal = '12/31/1993';
Start_Date_Equil = '01/05/1997';
End_Date_Equil = '04/30/1999';
Flow_All = read_text_file(Flow_File);
Start_WY = start_water_year(Flow_File);
T_V = threshold_value(Flow_File);
Rainfall_all = read_text_file(Rainfall_File);
PET_all = get_daily_PET(Monthly_PET, Flow_All);
[Flow, Rain, PET] = cut_file_length(Flow_All, Rainfall_all, PET_all, datenum(Start_Date_Cal), datenum(End_Date_Cal));
Mean_Annual_Rainfall = Daily2MeanAnnual(Rain(:,2));
Water_Years = Daily2wateryears(Flow(:,1), Flow(:,2), Start_WY);
for i = 1:length(Water_Years(1,:))
  FDC_Parameters(i,:) = fit_FDC_curve(Water_Years(:,i), T_V);
end
percent_current = 0.0;
percent_new = 1;
ET_current = ET_Mean_Annual_Water_Balance(Mean_Annual_Rainfall, percent_current);
ET_new = ET_Mean_Annual_Water_Balance(Mean_Annual_Rainfall, percent_new);
ET_change = ET_new - ET_current;
k = 0.95
Input(:,1) = Rain(:,2);
Input(:,2) = PET(:,2);
timestep = 5;
mean_current = mean(Flow(:,2)).*365.25;
mean_new = mean_current - ET_change;
mean_new_daily = mean_new./365.25;
H = bucket_optimisation(Input, k, timestep, percent_current, Flow);% adjust CTF for change in ET
New_S_min = New_S_min(H(1), H(2), Input, k, timestep, percent_current, percent_new, ET_change, Flow);
if New_S_min < -30
  New_S_min = -30;
end
Bucket_old = CTF_Bucket_Model(H(1), H(2), 0, -log(k),...
  Rain(:,2), PET(:,2), timestep, H(2), percent_current);
Bucket_new = CTF_Bucket_Model(H(1), New_S_min, 0, -log(k),...
  Rain(:,2), PET(:,2), timestep, H(2), percent_new);
CTF_old = 1- (length(find(Bucket_old(640:end,5) == 0))./length(Bucket_old(640:end,5)));
CTF_new = 1- (length(find(Bucket_new(640:end,5) == 0))./length(Bucket_new(640:end,5)));
mean_daily_conditional = mean_new_daily./CTF_new;
[Median, Regression_Median] = new_Parameters(log(FDC_Parameters(:,9)), log(FDC_Parameters(:,3)),
  log(mean_daily_conditional), 1);
Median = exp(Median);
% quality control on fit if CofE < 0.95 remove the results
j = 1;
for i = 1:length(FDC_Parameters(:,7))
  if FDC_Parameters(i,7) > 0.95
    Y(j,1) = FDC_Parameters(i,4);
    X(j,1) = FDC_Parameters(i,9);
    j = j + 1;
  end
end
end
end

[Slope, Regression_Slope] = new_Parameters (log(X), (Y), log(mean_daily_conditional), 1);

if CTF_new < 1
  % lower curve must go through
  RHS = (1./Slope).*log10(T_V./Median);
  options = optimset('Display','off','MaxIter',10000,'TolX',1.0e-005, 'TolFun',1.0e-005);
  Lower_Exponent = fminsearch(@(LHS_Lower_Exponent_less_95, mean(FDC_Parameters(:,6)), options, RHS);
else
  [ninty_five, Regression_Lower] = new_Parameters ((FDC_Parameters(:,9)), (FDC_Parameters(:,end)),
            (mean_daily_conditional), 1);
  RHS = (1./Slope).*log10(ninty_five./Median);
  options = optimset('Display','off','MaxIter',10000,'TolX',1.0e-005, 'TolFun',1.0e-005);
  Lower_Exponent = fminsearch(@(LHS_Lower_Exponent_greater_95, mean(FDC_Parameters(:,6)), options, RHS);
end

FDC_Param(1,1) = Median;
FDC_Param(1,2) = CTF_new;
FDC_Param(1,3) = Slope;
FDC_Param(1,4) = Lower_Exponent;
FDC_Param(1,5) = T_V;

Initial_Estimate_Upper = mean(FDC_Parameters(:,5));
options = optimset('fminsearch');
options = optimset('Display','iter');
Upper_Exponent = fminsearch(@Min_Difference_area_V2, Initial_Estimate_Upper, options, FDC_Param,mean_new);
FDC_Param(1,5) = Upper_Exponent;
FDC_Param(1,6) = T_V;

FDC_Predicted_new = FDC_Predicted (FDC_Param);
[Flow, Rain, PET] = cut_file_length (Flow_All, Rainfall_all, PET_all,
                      datenum(Start_Date_Equil),datenum(End_Date_Equil));
FDC_OBS = percentile(Flow(:,2),99,1,1);
hold on;
plot(FDC_OBS(:,1),FDC_OBS(:,2),'r')

Cease to flow - Bucket Model Code

function CTF_Bucket_Model= CTF_Bucket_Model(S_max, S_min, S_base, k, Rainfall, PET, timestep, Initial_Storage,
          percent_forest)
%CTF_bucket Model takes the inputs of Rainfall and PET (daily) and divides the rainfall up into runoff and ET.
%Can be run at various timesteps by specifying the timestep (1 = daily, 5 = 5 daily etc);
%Created: Alice Best
%Date: 13 Nov 2003
%Modified: 20 Feb 2004
%Modification involves dividing the storage into upper and lower sections,
%the upper sections as ET at PET and fills first after a rainfall event. Lower section has ET only if upper storage is
%empty and at a fraction of PET depending on saturation level.
if nargin < 6
  error('require inputs of S_max, S_min, S_base, k, Rainfall and PET')
else nargin == 6
  timestep = 1;
  Initial_Storage = S_min;
else nargin == 7
  Initial_Storage = S_min;
end
%adjust data for appropriate number days
if timestep == 1
  Rainfall_to_use = Rainfall;
  PET_to_use = PET;
else
  LengthOfDataToUse = floor(length(Rainfall)./timestep);
  for i=1:LengthOfDataToUse
    Rainfall_to_use(i,1) = sum(Rainfall(((i.*timestep)-timestep+1):(i.*timestep),1));
    PET_to_use(i,1) = sum(PET(((i.*timestep)-timestep+1):(i.*timestep),1));
  end
end

%Initial_Storage = S_min;
Size_S_Upper = (0.005+0.395.*percent_forest).*S_max*S_min;
if S_min > S_base
  Size_S_Lower = (S_max-S_base)*Size_S_Upper;
else
  Size_S_Lower = (S_max-S_min) - Size_S_Upper;
end
Total_Storage = Size_S_Upper + Size_S_Lower;

for i = 1: length(Rainfall_to_use);
    if i == 1
        S_Upper(1,1) = 0.4.*Initial_Storage ;
        S_Lower(1,1) = 0.6.*Initial_Storage;
        S_Upper(1,1) = S_Upper(1,1) + Rainfall_to_use(1,1);
        if S_Upper(1,1) > Size_S_Upper
            P_Lower = S_Upper(1,1) - Size_S_Upper;
            S_Upper(1,1) = Size_S_Upper;
        else
            P_Lower = 0;
        end
        S_Lower(1,1) = S_Lower(1,1) + P_Lower;
        if S_Lower(1,1) > Size_S_Lower
            P_Excess = S_Lower(1,1) - Size_S_Lower;
            S_Lower(1,1) = Size_S_Lower;
        else
            P_Excess = 0;
        end
    else
        S_Upper(i,1) = S_Upper(i-1,1) + Rainfall_to_use(i,1);
        if S_Upper(i,1) > Size_S_Upper
            P_Lower = S_Upper(i,1) - Size_S_Upper;
            S_Upper(i,1) = Size_S_Upper;
        else
            P_Lower = 0;
        end
        S_Lower(i,1) = S_Lower(i-1,1) + P_Lower;
        if S_Lower(i,1) > Size_S_Lower
            P_Excess = S_Lower(i,1) - Size_S_Lower;
            S_Lower(i,1) = Size_S_Lower;
        else
            P_Excess = 0;
        end
    end
end

for i = 1: length(Rainfall_to_use);
    if i == 1
        a = 1
    else
        a = a + 1
    end
end

%Add Rainfall to storage
for i = 1: length(Rainfall_to_use);
    if i == 1
        S_Upper(i,1) = 0.4.*Initial_Storage ;
        S_Lower(i,1) = 0.6.*Initial_Storage;
        S_Upper(i,1) = S_Upper(i,1) + Rainfall_to_use(i,1);
        if S_Upper(i,1) > Size_S_Upper
            P_Lower = S_Upper(i,1) - Size_S_Upper;
            S_Upper(i,1) = Size_S_Upper;
        else
            P_Lower = 0;
        end
        S_Lower(i,1) = S_Lower(i,1) + P_Lower;
        if S_Lower(i,1) > Size_S_Lower
            P_Excess = S_Lower(i,1) - Size_S_Lower;
            S_Lower(i,1) = Size_S_Lower;
        else
            P_Excess = 0;
        end
    else
        S_Upper(i,1) = S_Upper(i-1,1) + Rainfall_to_use(i,1);
        if S_Upper(i,1) > Size_S_Upper
            P_Lower = S_Upper(i,1) - Size_S_Upper;
            S_Upper(i,1) = Size_S_Upper;
        else
            P_Lower = 0;
        end
        S_Lower(i,1) = S_Lower(i-1,1) + P_Lower;
        if S_Lower(i,1) > Size_S_Lower
            P_Excess = S_Lower(i,1) - Size_S_Lower;
            S_Lower(i,1) = Size_S_Lower;
        else
            P_Excess = 0;
        end
    end
end

S_Total(i,1) = min(S_min,S_base) + S_Upper(i,1) + S_Lower(i,1);
S_Total_Lower(i,1) = min(S_min,S_base) + S_Lower(i,1);

Threshold_Max_ET = 1;

calculate ET
if S_Upper(i,1) > 0
    ET(i,1) = PET_to_use(i,1);
    if P_Excess > 0
        BT_Soil = ET(i,1)-P_Excess;
        if BT_Soil > 0
            if S_Total_Lower(i,1) - BT_Soil < S_min
                Percent_saturation = (S_Total_Lower(i,1) - S_min) ./ ((S_max- S_min) - Size_S_Upper);
                if Percent_saturation > 0
                    ET_Lower = (BT_Soil - S_Upper(i,1)).* Percent_saturation ./ Threshold_Max_ET;
                    ET_Lower_potential = max(0,ET_Lower);
                    ET(i,1) = min(S_Upper(i,1)+BT_Lower_potential+P_Excess, ET(i,1));
                else
                    ET(i,1) = min(S_Upper(i,1)+P_Excess, ET(i,1));
                end
            end
        end
    else
        if S_Total_Lower(i,1) - ET(i,1) < S_min
            Percent_saturation = (S_Total_Lower(i,1) - S_min) ./ ((S_max- S_min) - Size_S_Upper);
            if Percent_saturation > 0
                ET_Lower = (ET(i,1) - S_Upper(i,1)).* Percent_saturation ./ Threshold_Max_ET;
                ET_Lower = min(ET_Lower, S_Total_Lower(i,1) - S_min);
                ET_Lower_potential = max(0,ET_Lower);
                ET(i,1) = min(S_Upper(i,1)+ET_Lower_potential+P_Excess, ET(i,1));
            else
                ET(i,1) = min(S_Upper(i,1)+P_Excess, ET(i,1));
            end
        end
    end
else
    ET(i,1) = 0;
end
elseif S_Total_Lower(i,1) < S_min
    ET(i,1) = 0;
elseif S_Total_Lower(i,1) > S_min
    Percent_saturation = (S_Total_Lower(i,1) - S_min) ./ ((S_max- S_min) - Size_S_Upper);
    if Percent_saturation > Threshold_Max_ET
        ET(i,1) = PET_to_use(i,1);
    else
        ET(i,1) = PET_to_use(i,1).* Percent_saturation ./ Threshold_Max_ET;
    end
else
    ET(i,1) = 0;
%if P_Excess > ET(i,1)
    Q_direct(i,1) = P_Excess - ET(i,1);
%else
    Q_direct(i,1) = 0;
    ET_from_soil = ET(i,1) - P_Excess;
end

S_Total(i,1) = S_Total(i,1) - ET_from_soil;

%calculate baseflow
if S_Total(i,1) >= S_max
    Q_base(i,1) = (S_max - S_base) .* k;
elseif S_Total(i,1) > S_base + 0.002
    Q_base(i,1) = (S_Total(i,1) - S_base) .* k;
else
    Q_base(i,1) = 0;
end

%if ET(i,1) > PET_to_use(i,1);
%    ET(i,1) = PET;
%elseif S(i,1) - ET(i,1) - Q_base(i,1) < S_min
%     ET(i,1) = S(i,1) - S_min - Q_base(i,1);
%     if ET(i,1) < 0
%        ET(i,1) = 0;
%     end
% end

%calculate Q_direct
%if P_Excess > ET(i,1)
%     Q_direct(i,1) = P_Excess - ET(i,1);
%     ET_from_soil = 0;
%else
%     Q_direct(i,1) = 0;
%     ET_from_soil = ET(i,1) - P_Excess;
% end

Q_base_upper = S_Upper(i,1) - ET_from_soil;
if Q_base_upper > Q_base;
    ET_upper = ET_from_soil;
    ET_lower = 0;
    Q_base_upper = Q_base(i,1);
    Q_base_lower = 0;
else
    Q_base_upper = max(Q_base_upper,0);
    Q_base_lower = Q_base(i,1) - Q_base_upper;
    ET_upper = min(ET_from_soil,S_Upper(i,1));
    ET_lower = ET_from_soil - ET_upper;
end

%Calculate S_Upper
S_Upper(i,1) = S_Upper(i,1) - Q_base_upper - ET_upper;
S_Lower(i,1) = S_Lower(i,1) - Q_base_lower - ET_lower;
S(i,1) = min(S_min, S_base) + S_Upper(i,1) + S_Lower(i,1);
S_Total(i,1) = min(S_min, S_base) + S_Lower(i,1);

end

Q_total = Q_direct + Q_base;
CTF_Bucket_Model = S;
CTF_Bucket_Model(:,2) = ET;
CTF_Bucket_Model(:,3) = Q_base;
CTF_Bucket_Model(:,4) = Q_direct;
CTF_Bucket_Model(:,5) = Q_total;

Cease to flow - Bucket Optimisation Code

function bucket_optimisation = bucket_optimisation(Input, k, timestep, percent_forest, Flow)
%used to optimise the bucket model

%Created: Alice Best
%Date: 14 Nov 2003
%Modified: 16 April 2004
%Modified: 3 May 2004
k = -log(k);
Flow_Cumulated = cumulate_Flows(Flow(:,2),timestep);
Initial_Storage = Flow_Cumulated (1)./k;
S_min = percentile(Flow_Cumulated ,70,70,1);
\[ S_{\text{min}} = \frac{S_{\text{min}(2)}}{k}; \]
\[ S_{\text{base}} = 0; \]
\[ S_{\text{max}} = \text{percentile(Flow\_Cumulated, 20, 20, 20)}; \]
\[ S_{\text{max}} = \frac{S_{\text{max}(2)}}{k}; \]

Get input data
\[ \text{Rainfall} = \text{Input(:,1)}; \]
\[ \text{PET} = \text{Input(:,2)}; \]
\[ \text{Flow\_Cumulated} = \text{cumulate\_Flows(Flow(:,2), timestep)}; \]
\[ Y = \text{Flow\_Cumulated}; \]

\[ Y_{\text{predicted\_all}} = \text{CTF\_Bucket\_Model}(S_{\text{max}}, S_{\text{min}}, S_{\text{base}}, k,... \]
\[ \text{Rainfall, PET, timestep, Initial\_Storage, percent\_forest}); \]
\[ Y_{\text{predicted}} = Y_{\text{predicted\_all}(:,5)}; \]
\[ \text{SSE\_whole} = \text{sum}((Y - Y_{\text{predicted}})^2); \]
\[ \text{SSE\_whole\_1} = \text{sum}((Y - Y_{\text{predicted}})^2); \]
\[ \text{SSE\_whole\_2} = 0; \]
\[ k_1 = 1; \]
\[ \text{inc\_1} = S_{\text{max}}.*2; \]
while abs(SSE\_whole - SSE\_whole\_2) > 1
  fit S\_max to ensure mass balance
  if k\_1 == 1
    if SSE\_whole\_2 < SSE\_whole
      SSE\_whole\_best = SSE\_whole;\]
      S\_max\_best = S\_max;\]
      S\_min\_best = S\_min;\]
    else
      S\_max = S\_max\_best;\]
      S\_min = S\_min\_best;\]
    end
  else
    k\_1 = k\_1 + 1;\]
  end
  Y\_predicted\_all = CTF\_Bucket\_Model(S\_max, S\_min, S\_base, k,... \]
  \[ \text{Rainfall, PET, timestep, Initial\_Storage, percent\_forest}); \]
  Y\_predicted = Y\_predicted\_all(:,5); \]
  Volume\_1 = \text{sum}(Y\_predicted) ./ \text{sum}(Y); \]
  Volume\_2 = 1; \]
  inc\_1 = inc\_1/2; \]
  m = 1; \]
  while or(sum(Y\_predicted) ./ \text{sum}(Y) < 0.99, sum(Y\_predicted) ./ \text{sum}(Y) > 1.01)
    if abs(Volume\_1 - Volume\_2) <= 0.00001
      break
    end
    if m == 1
      inc = -inc\_1; \]
      m = m + 1; \]
    elseif m == 2
      inc = inc\_1; \]
      m = m + 1; \]
    elseif abs(1-Volume\_2) < abs(1-Volume\_1)
      Volume\_1 = Volume\_2; \]
    else
      Volume\_2 = sign(1-Volume\_2) = sign(1-Volume\_1)
      Volume\_1 = Volume\_2; \]
    end
  S\_max\_1 = S\_max + inc;
  Bucket\_1 = CTF\_Bucket\_Model(S\_max\_1, S\_min, S\_base, k,... \]
  \[ \text{Rainfall, PET, timestep, Initial\_Storage, percent\_forest}); \]
  if abs(Volume\_2 - 1) < abs(Volume\_1 - 1)
    if sign(1-Volume\_2) == sign(1-Volume\_1)
      S\_max = S\_max\_1; \]
      inc = -inc\_2; \]
      Volume\_1 = Volume\_2; \]
    else
      S\_max = S\_max\_1; \]
      m = 3; \]
    end
  elseif sign(1-Volume\_2) == sign(1-Volume\_1)
    Volume\_1 = Volume\_2; \]
    S\_max = S\_max\_1; \]
    inc = -inc\_2; \]
    m = 3; \]
  else
    inc = -inc\_2; \]
  end
  Y\_predicted\_all = CTF\_Bucket\_Model(S\_max, S\_min, S\_base, k,... \]
  \[ \text{Rainfall, PET, timestep, Initial\_Storage, percent\_forest}); \]
  Y\_predicted = Y\_predicted\_all(:,5); \]
  end
  SSE\_whole\_1 = \text{sum}((\text{sqrt}(Y) - \text{sqrt}(Y\_predicted))\^2); \]
  SSE\_1 = \text{sum}((\text{sqrt}(Y) - \text{sqrt}(Y\_predicted))\^2); \]
  SSE\_2 = SSE\_whole; \]
  inc = inc\_1; \]
  m = 1; \]
  while abs(SSE\_1 - SSE\_2) > 0.1
if m == 1
    inc = inc_1;
    m = m + 1;
else if m == 2
    inc = -inc_1;
    m = m + 1;
else if SSE_2 < SSE_1
    if abs(1-Volume_SSE) < 0.1
        SSE_1 = SSE_2;
    end
    S_min_1 = S_min + inc;
    S_max_1 = S_max + inc;
    Bucket_1 = CTF_Bucket_Model(S_max_1, S_min_1, S_base, k,...
                              Rainfall, PET, timestep, Initial_Storage, percent_forest);
    SSE_2 = sum((sqrt(Y) - sqrt(Bucket_1(:,5))).^2);
    if SSE_2 < SSE_1
        Volume_SSE = sum(Bucket_1(:,5))./sum(Y);
        if abs(1-Volume_SSE) < 0.1
            S_min = S_min_1;
            S_max = S_max_1;
            m = 3;
        else
            inc = -inc./2;
        end
    else
        inc = -inc./2;
    end
end

Y_predicted = Bucket_1(:,5);
SSE_whole_1 = sum((sqrt(Y) - sqrt(Y_predicted)).^2);
Volume_1 = sum(Bucket_1(:,5))./sum(Y);
Volume_2 = 1;
inc = S_max.*2;
m = 1;
while or(sum(Y_predicted)./sum(Y) < 0.99,sum(Y_predicted)./sum(Y)>1.01)
    if abs(Volume_1 - Volume_2) <= 0.00001
        break
    end
    if m == 1
        inc = -inc_1;
        m = m + 1;
    elseif m == 2
        inc = inc_1;
        m = m + 1;
    elseif abs(1-Volume_2) < abs(1-Volume_1)
        Volume_1 = Volume_2;
    elseif sign(1-Volume_2) ~= sign(1-Volume_1)
        Volume_1 = Volume_2;
    else
        inc = -inc./2;
    end
    S_max_1 = S_max + inc;
    Bucket_1 = CTF_Bucket_Model(S_max_1, S_min, S_base, k,...
                              Rainfall, PET, timestep, Initial_Storage, percent_forest);
    Volume_2 = sum(Bucket_1(:,5))./sum(Y);
    if abs(Volume_2-1) < abs(Volume_1-1)
        if sign(1-Volume_2) ~= sign(1-Volume_1)
            S_max = S_max_1;
            inc = -inc./2;
            %Volume_1 = Volume_2;
        elseif sign(1-Volume_2) ~= sign(1-Volume_1)
            S_max = S_max_1;
            m = 3;
        else
            inc = -inc./2;
        end
    else
        sign(1-Volume_2) = sign(1-Volume_1)
        Volume_1 = Volume_2;
    end
    elseif sign(1-Volume_2) = sign(1-Volume_1)
    end
Y_predicted_all = CTF_Bucket_Model(S_max, S_min, S_base, k,...
                              Rainfall, PET, timestep, Initial_Storage, percent_forest);
Y_predicted = Y_predicted_all(:,5);
end
SSE_whole_2 = sum((sqrt(Y) - sqrt(Y_predicted)).^2);
end

Cease to flow – Adjust CTF Point

function New_S_min = New_S_min(S_max, S_min, Input, k, timestep, percent_current, percent_new, ET_change, Flow)
k = -log(k);
Flow_Cumulated = cumulate_Flows(Flow(:,2),timestep);
Rainfall = Input(:,1);
PET = Input(:,2);
S_base = 0;
Initial_Storage = Flow_Cumulated (1)/k;

Y_predicted_all = CTF_Bucket_Model(S_max, S_min, S_base, k,...
Rainfall, PET, timestep, Initial_Storage, percent_current);
ET_current = (sum(Y_predicted_all(:,2))./length(Y_predicted_all(:,2))./timestep).*365;

ET_new_required = ET_current + ET_change;
Y_predicted_all = CTF_Bucket_Model(S_max, S_min, S_base, k,...
Rainfall, PET, timestep, Initial_Storage, percent_new);
ET_new = (sum(Y_predicted_all(:,2))./length(Y_predicted_all(:,2))./timestep).*365;
if round(ET_new) > round(ET_new_required)
    New_S_min = S_min;
else
    inc = 50;
    while abs(ET_new - ET_new_required) > 1
        S_min = S_min - inc;
        Y_predicted_all = CTF_Bucket_Model(S_max, S_min, S_base, k,...
            Rainfall, PET, timestep, Initial_Storage, percent_new);
        ET_new_2 = (sum(Y_predicted_all(:,2))./length(Y_predicted_all(:,2))./timestep).*365;
        if and(ET_new_2 > ET_new_required, ET_new > ET_new_required)
            inc = inc;
        elseif ET_new_2 > ET_new_required, ET_new > ET_new_required
            inc = -inc/2;
        elseif ET_new_2 < ET_new_required
            inc = inc;
        elseif ET_new_2 < ET_new_required
            inc = inc/2;
        else
            inc = -inc/2;
            ET_new = ET_new_2;
        end
        New_S_min = S_min;
    end
end

Y_predicted_all = CTF_Bucket_Model(S_max, New_S_min, S_base, k,...
Rainfall, PET, timestep, Initial_Storage, percent_new);

Parameter regression code

function [new_value, R_square] = new_Parameters (X_variable, Y_variable, X_required, plot_mark)
if nargin == 3
    plot_mark = 0;
end
X = (X_variable);
X(:,2) = 1;
Y = (Y_variable);

if plot_mark == 1
    figure;
    plot(X(:,1),Y,'o');
end
MC = X\Y;
new_value = (MC(1).*(X_required) + MC(2));
R_squared = corrcoef(X(:,1),Y);
R_square= R_squared(2).^2;
FDC ADJUSTED FOR LAND USE

function FDC_Predicted = FDC_Predicted (FDC_Param, Upper, Lower, Interval)

if nargin == 1
    X(1,1) = 0.1;
    X= [0.1:0.1:99.9]';
    X(2:length(X_2)+1) = X_2;
else
    X = [Lower:Interval:Upper]';
end

Median = FDC_Param(1);
CTF = round(FDC_Param(2).*100);
Slope = FDC_Param(3);
Lower = FDC_Param(4);
Upper = FDC_Param(5);
Threshold_value = FDC_Param(6);

for i = 1:length(X);
    if round(X(i).*100)/10 == CTF
        Y(i) = Threshold_value;
    elseif X(i) > CTF
        Y(i) = 0;
    elseif X(i) <= CTF/2
        Y(i) = Median.* (10.^ ((Slope./Upper).*exp(invcdfn(X(i)/CTF).*Upper)- (Slope./Upper)));
    else
        Y(i) = Median.* (10.^ ((Slope./Lower).*exp(invcdfn(X(i)/CTF).*Lower)- (Slope./Lower)));
    end
end

plot (X, Y);
FDC_Predicted = X;
FDC_Predicted_Y = Y';

FDC_Predicted(1:length(FDC_Predicted_Y),2) = FDC_Predicted_Y;
10 References


