rrl
rainfall runoff library

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www.toolkit.net.au/rrl

USER GUIDE

catchment MODELLING TOOLKIT
supported by the CRC for Catchment Hydrology

COOPERATIVE RESEARCH CENTRE FOR CATCHMENT HYDROLOGY

Document History

Date	Author	Revision	Description of Change
03/11/2003	Geoff Podger	1.0.0b	First version of the User Guide

Acknowledgements

This User Guide has been written and edited by Geoff Podger[1].The conversion of the User Guide to on-line help was done by Nick Murray[2]. The User guide was reviewed by Tanya Jacobson.

The software was developed by Jean Michel Perraud[2]. Rainfall runoff models included in the library were provided by Walter Boughton, Francis Chiew[3], and Geoff Podger[1]. The software graphic images were prepared by Susan Daly[4].

The Product Manager for the Rainfall Runoff Library is Geoff Podger[1].[5]

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[1] Department of Infrastructure, Planning and Natural Resources; CRC for Catchment Hydrology

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Rainfall Runoff Library User Manual

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1 Introduction

This Chapter introduces you to the Rainfall Runoff Library (RRL) and this User Guide. It describes the

- purpose of this User Guide,
- the structure and content of the User Guide,
- features of the RRL,
- the data requirements for using the RRL, and
- where to locate other documentation available on the RRL.

1.1 The user guide

1.1.1 Purpose

This User Guide describes how you interact with the Rainfall Runoff Library (RRL). It describes what you can do with the system, and how you do it.

While the RRL can be applied to other catchments, this User Guide uses several example catchments, to provide examples for setup, navigation, interrogation, calibration and analyses of model results.

This User Guide also describes how the model works that includes optimisation methods and the algorithms used in rainfall runoff models.

1.1.2 Structure

This User Guide has 10 Chapters which are ordered by the way that a typical user would work through the system. Chapters cover:

1 Introduction (User Guide and RRL)

2 Installation

3 Using RRL (a description of the menus and dialogues)

4 Description of models

5 Description of optimisers

6 Description of optimisers

7 Saving results

8 Data storage and file formats

9 Reference

10 Glossary

1.2 RRL

1.2.1 Overview

The RRL uses daily time series rainfall and evapotranspiration data to generate daily catchment runoff. The generator provides several commonly used lumped rainfall-runoff models, calibration optimisers and display tools to facilitate model calibration.

1.2.2 Features

The RRL currently contains 6 rainfall-runoff models, 8 calibration optimisers, a choice of 10 objective functions and 3 types of data transformation for comparison against observed data. There is a graphical user interface that comprises menus, dialogues and graph display tools.

The rainfall-runoff models included in the library are:

- AWBM
- Sacramento
- Simhyd
- SMAR
- SWAT core
- TANK

The calibration optimisers included in the library are:

- Uniform random sampling
- Pattern search
- Multi start pattern search
- Rosenbrock search
- Rosenbrock multi-start search
- Genetic algorithm
- Shuffled Complex Evolution (SCE-UA)
- AWBM custom optimisers

The objective functions and data transformations that are provided include:

- Nash-Sutcliffe criterion (Coefficient of efficiency)
- Sum of square errors
- Root mean square error (RMSE)
- Root mean square difference about bias
- Absolute value of bias
- Sum of square roots
- Sum of square of the difference of square root
- Sum of absolute difference of the log
- Runoff difference in %
- Flow duration curve
- Base flow method 2

1.2.3 Audience

The RRL is intended for a specific audience of users, comprising hydrologists in consulting firms, government agencies and students learning about rainfall runoff models. It is also intended as an adjunct to provide data for other catchment management tools.

1.3 Data requirements

1.3.1 Input data

The major inputs to the RRL are as follows:

- **Rainfall** - a continuous time series of rainfall data that represents the rainfall across the catchment.
- **Evapotranspiration** – a continuous time series of potential evapotranspiration or actual evapotranspiration data that represents the evapotranspiration across the catchment.
- **Flow gaugings** - daily runoff values for the gauging station that is to be modelled. This data are used for model calibration and checking.
- **Catchment area** – this is used to convert inputs and outputs between flow and depth of runoff.

1.3.2 Predicted data

The model outputs daily and monthly flow or depth of runoff.

		Units	Time scale
Climate			
	Rainfall	mm/d	Daily
	Evapotranspiration	mm/d	Daily
Flow			
	Observed flow	mm/d ML/d, m3/s	Daily
	Simulated flow	mm/d ML/d, m3/s	Daily or monthly

Table 1Data available for interrogation

1.4 Product components

The RRL package includes:

- the **RRL** software and sample data ,
- User Guide, and
- Sets of workshop exercises.

1.5 References and training

The RRL is a product developed by the CRC for Catchment Hydrology (CRCCH).

As part of the product delivery, the CRCCH runs training workshops. Details of workshops are posted on the Toolkit web site (www.toolkit.net.au) in the news and events sections. References for relevant conference papers and journal articles are also available at the Toolkit web site, in the RRL member's area.

2 Installation

This Chapter of the User Guide covers:

- hardware and software requirements to run the RRL
- the contents of the distribution disk or download file, including the licence agreement
- the directories created by the installation
- the installation procedure for the RRL and its data
- how you access RRL once it is installed on your computer
- how to uninstall RRL from your computer

2.1 Technical specifications

Minimum Requirements	
Processor	• 133-megahertz (MHz) Intel Pentium-class processor
Operating System	The RRL is supported on the following platforms: • Microsoft Windows® Server 2003* (.NET Framework 1.1 is installed as part of the operating system) • Windows XP Professional* • Windows XP Home Edition • Windows 2000* • Windows Millennium Edition (Windows Me) • Windows 98 • Microsoft Windows NT® 4.0 Service Pack 6a The RRL cannot be installed on 64-bit computers
Memory	• 128 megabytes (MB) of RAM, 256 MB recommended
Hard Disk	120 MB of hard disk space required, 40 MB additional hard disk space required for installation (160 MB total)
Display	800 x 600 or higher-resolution display with 256 colours
Input Device	Microsoft mouse or compatible pointing device
Other	• Microsoft Internet Explorer 5.01 or later is required. • The .net framework 1.1 redistributable or later is required.

Table 2 System requirements

The person installing the software must have local administrator access on the computer.

2.1.1 Framework

The .NET Framework is a component of the Microsoft Windows® operating system used to build and run Windows-based applications. The RRL is built using the .NET Framework and consequently requires that the .NET Framework redistributable be installed prior to running the RRL. The .NET Framework Redistributable will install the .NET Framework onto your machine and is downloadable from:www.msdn.microsoft.com/netframework/downloads/redist.aspx.

You can check to see if you already have the .NET Framework installed by clicking **Start** on your Windows desktop, selecting **Control Panel**, and then double-clicking the **Add or Remove Programs** icon. When that window appears, scroll through the list of applications. If you see Microsoft .NET Framework 1.1 listed, the latest version is already installed and you do not need to install it again.

2.2 Distribution media

The RRL is distributed via the Toolkit web site and can be downloaded by:

1. Going to the Toolkit web site (www.toolkit.net.au)
2. Registering as a toolkit user
3. Once a registered toolkit user, then going to the users download area and selecting RRL.
4. Press the **Submit** button to commence the download

2.2.1 Licence agreement

Acceptance of the licence agreement is part of the installation procedure. You must acknowledge that you have read, understood and agree to be bound by the RRL software licence agreement to be able to proceed with the installation. The licence agreement can be viewed when using the RRL by selecting **Help |About** and selecting the **Licence agreement** button.

2.2.2 Data

At present the install shield creates a data directory that contains:

1. The rainfall runoff software
2. Documentation (User Guide, help and training material)
3. Example data sets
4. Example project files

2.3 Directories

The RRL installation creates three sub-directories within the RRL directory (location of which is defined by the user during installation):

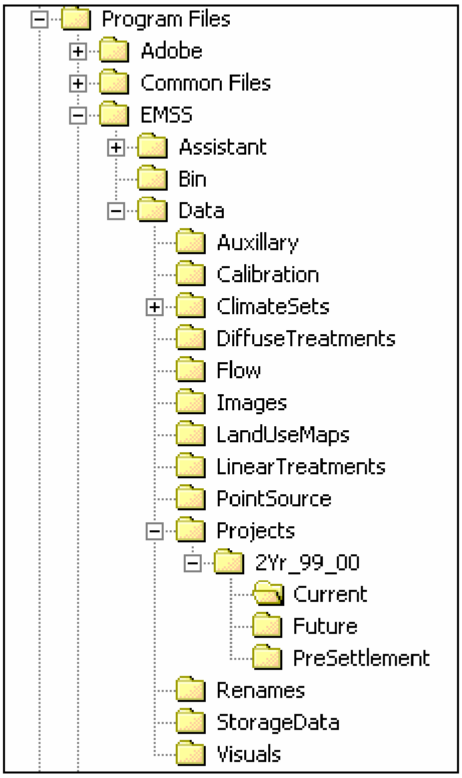
Help – contains the .html and .hlp files for RRL Help.

Documentation – contains two subdirectories User Guide and Training. The User Guide subdirectory contains this document and the Training subdirectory contains training documentation

Projects – contains 6 project files, one for each rainfall runoff model in the RRL.

Data – contains project data. This contains 6 subdirectories, one associated with each of the 6 projects in the project directory.

The subdirectory structure of the installed RRL software is discussed in section 8.1.



2.4 Installation

2.4.1 Stand-alone PC

After downloading the software to a local directory, double clicking **setup.exe** will initiate an install wizard which leads you through the install procedure. Once again, you must indicate that you have read, understood and agree to be bound by the RRL licence agreement. There is only one decision that needs to be made during the installation and that is the name of the install directory:

(default is C:\Program Files\toolkit\Rainfall Runoff Library)

Potential Problems
If your computer doesn't have enough space to install the data, the install procedure will give you an out of disk space message. Select Cancel to exit the installation procedure. You will need to find a larger disk drive.

If the .net framework is not installed on your machine, the install procedure will give you a warning message. Select cancel the installation procedure. You will need to install the .NET redistributable software as described in Section 2.1.1.

2.4.2 File server/network

The RRL is not designed to be used on a file server/network. It is intended that it be used on a stand-alone PC.

2.5 User Interface

2.5.1 Windows

TIME uses standard Microsoft Windows® windows as shown in Figure 1. The features in the window are the:

- Title bar that includes the Toolkit icon followed by the product name and a version number.
- The standard windows minimise, maximise/restore and close icons.
- Optional top level menu.

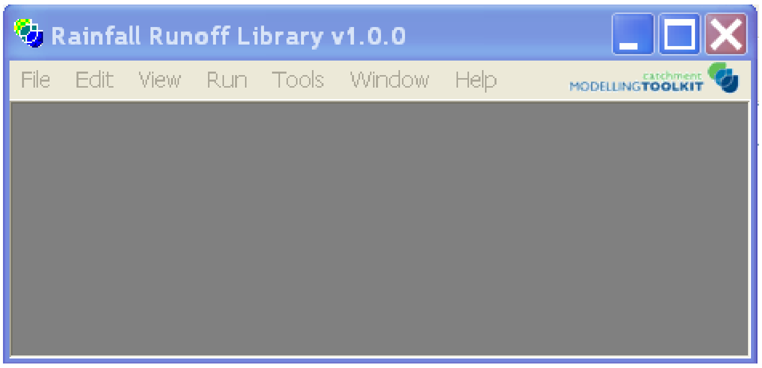
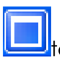


Figure 1 Example of standard window

To minimise or maximise a window or restore it to its previous size

Click the appropriate button in the upper-right corner of the window:

- Click  to minimise the window to a taskbar button. To restore the minimised window to its previous size, click its taskbar button.
- Click  to maximise the window so it covers the full screen.
- After maximising a window, click  to restore the window to its previous size.

Note:

1 You can also double-click the window's title bar to maximize it or restore it to its previous size.

2 You can click on the Toolkit icon on the left of the title bar or right click on the title bar to display a menu to restore, move, size, minimise, maximise or close the window.

The title line contains the name of the software followed by a version number. The version number is in three parts; **x.y.z** where:

x Major Version indicator (integer starting at 1)

y Minor Version indicator (integer starting at 0; may go to any number but rest on a major version change)

z Bug fix indicator (integer starting at 0; may go to any number but reset to zero on a minor or major version change.

The suffix **b** may be added to a version number to denote that the software is a beta release.

Major version increment

This indicator is incremented following a substantial change to the way the software operates, and is usually associated with a significant change to documentation and training material. An example of a major version change would be the port of EMSS from Tarsier to TIME.

Minor Version increment

This indicator is incremented when a new feature is included in the model. An example is adding a new rainfall-runoff model or optimisation method to this library. It is likely that a minor version upgrade would require adjustments to documentation, data examples and training material.

Bug Fix Version increment

This indicator is incremented after minor corrections to code and is not associated with any changes to documentation, data examples or training material. In some cases, users will be notified of the implications of particular bug fixes.

2.5.2 Menus

TIME uses standard Microsoft Windows® menus as shown in Figure 1. The features in the menu are the:

- Top level menu items
- Menu drop down lists
- Popup lists

Top level menu

Top level menu items may be selected by clicking the mouse on the required text or by using hot keys to select the menu option. Note on some versions of word hot keys are identified by underlining the relevant character in the menu item string. The hot key is essentially the alt key in combination with the underlined letter.

Drop down menu list

If a selected top level menu item contains a drop down list the list will be displayed as shown in Figure 2.

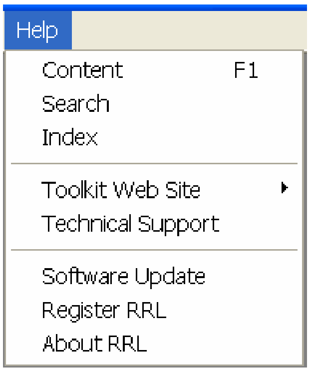


Figure 2 Drop down menu list

Drop down list items may be selected by clicking the mouse on the menu line of text, hot keys or ctrl keys. If ctrl keys are provided these keys will be listed to the right of the menu item e.g. F1 after Content in Figure 2.

Popup lists

If a selected drop down menu item has an associated popup list, signified by  on the right hand side of the menu item. The popup list will be displayed, as shown in Figure 3, when the cursor is moved over the menu item line of text.

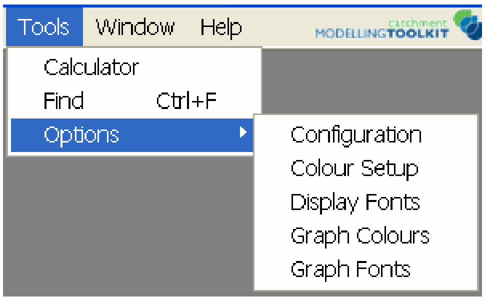


Figure 3 Popup list

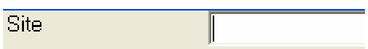
Popup menu items may be selected by clicking the cursor on the menu line of text, hot keys and ctrl keys.

2.5.3 Toolbar buttons

There is no toolbar in the RRL window.

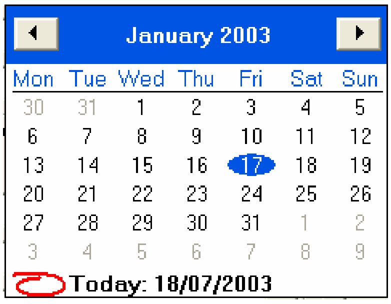
2.5.4 Fields

TIME uses standard Microsoft Windows® and purpose built fields that are assembled together to create user interfaces for products. The components used to create these interfaces include combinations of dialogues, tabs, TIME specific display windows and fields. The common TIME fields and control features are described in Table 3.



String fields – The string field can either be edited or replaced. To edit the field click near the text you want to enter then use the standard edit keys (del, back space and left/right arrows) to edit the text. Alternatively double clicking on the text will highlight the text and then any subsequent typing will overwrite the entire text.

Integer fields – There are two types of integer fields i.e. either with or without spinners. If a spinner is provided by clicking on the up arrow the number will increase by one and clicking on the down arrow the number will decrease by one. Alternatively an integer can be entered in the field. If range checking is activated in the field and the number is outside of the specified bounds then the field will be cleared and set to the closest bound.



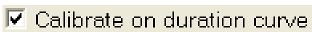
Date fields – There are two ways that a date can be entered:

The date field is divided into three parts separated by '/', day/month/year. You can enter the day month or year by typing the required number in each field. Note the month is entered as a number not a string.

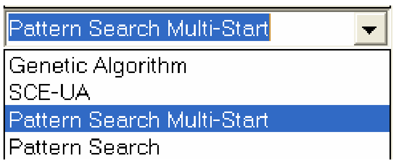
Clicking on the ▼ displays a date picker. The date picker displays a month and any day within the month can be selected by clicking on that day. The ◄ and ► arrow keys move down or up one month respectively.

Real fields – There are two types of real fields i.e. either with or without spinners. If a spinner is provided by clicking on the up arrow the number will increase and clicking on the down arrow the number will decrease. Alternatively a real number can be entered in the field. If range checking is activated in the field and the number is outside of the specified bounds then the field will be cleared and set to the closest bound.

Radio button - used to make an exclusive selection from a range of actions



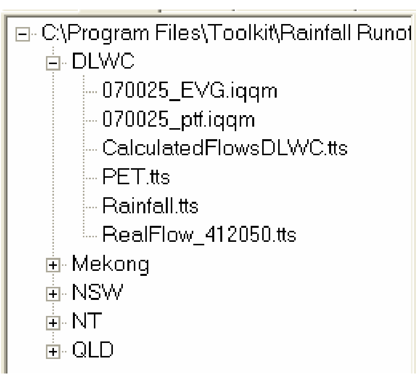
Checkbox – Used to accept or decline an option. When ticked the option is accepted.



Drop-down list box – clicking on the ▼ drops down a list box from which any one or several entries can be selected by moving the cursor over the entry and pressing the left mouse button

Slider bars – The slider bars in the RRL are used to select dates. By moving the slider bar the associated date will be updated to the new date

Colour bar – Clicking on the colour bar will display a colour selection dialogue. When a new colour is selected the colour bar and associated parameter colours will be changed to the new colour



Directory tree – This field is used to browse and select files. This field operates in a similar manner to windows explorer.

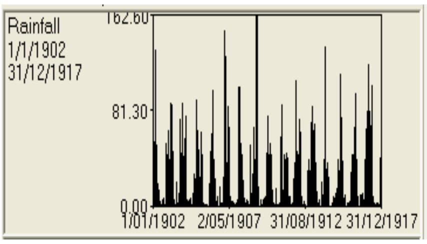
	Time series data field. In the top left hand corner the type and time span of data is displayed. To the left of this is a graph of the time series data with time on the x axis and times series data units on the y axis.

Table 3 TIME fields

2.5.5 Graph Windows

TIME provides a module to plot specific information as graphs. Figure 4 shows an example of the basic form of graphs provided in TIME. The graph is displayed in a window and contains:

- Title text
- X and Y axes with optional labels
- Graphed data points
- Optional graticules
- Optional legend

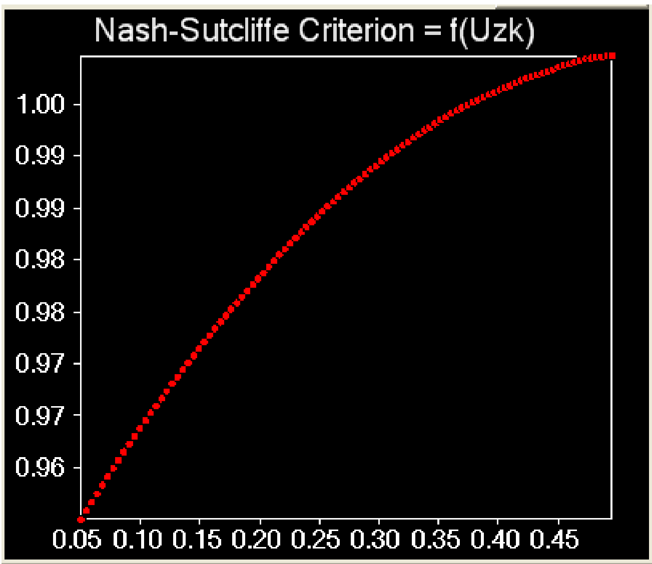


Figure 4 Graph window

By right clicking the mouse in the graph window the graph menu popup is displayed, as shown in Figure 5.

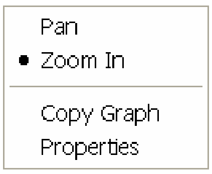


Figure 5 Graph popup

Four menu options are provided in the graph popup:

- Pan
- Zoom In
- Copy Graph
- Properties

The graph screen operates in two control modes, pan or zoom in. The current graph control mode can be determined by viewing the graph menu popup and is signified by a dot to left of the menu item. Alternatively the graph control mode can be identified by the cursor shape a cross indicates Zoom In and a cross with arrows indicates Pan Control mode. Figure 5 shows that Zoom In is the current control mode. To change the graph control model click the mouse on the appropriate text.

Pan

When the graph window is in the Pan Control mode the graph may be paned in any direction by holding down the left mouse key, moving the mouse and releasing the mouse key. The graph will then be redisplayed. As an example to scroll the graph to the left position the mouse to the right of the graph, hold the left mouse button down, move the mouse to the left of the graph and then release the mouse button.

Zoom In

When the graph window is in the Zoom In control mode the graph may be enlarged in a particular area by positioning the mouse near the edge of the area to be enlarged, holding the left mouse button down, a window will appear, then move the mouse to the other edge of the area to be enlarged and release the mouse button. The graph will be redisplayed for the zoomed in area.

Copy Graph

Clicking on the Copy Graph menu item will copy the contents of the graph to the clipboard The graph may then be placed into other Windows® applications.

Properties

Clicking on the Properties menu item displays the graph properties tabbed dialogue as shown in Figure 6. This dialogue allows the user to adjust the text, colours and fonts of the title, axis labels, axis and graphed parameters. The decorators that are available are dependent upon what is currently displayed in the graph but typically include:

- View title
- X Axis label
- Y Axis label
- Axis
- Graphed variable 1 (etc)

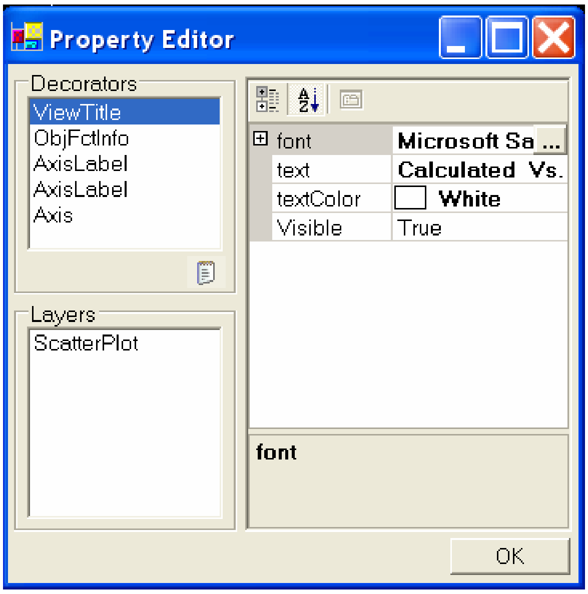


Figure 6 Graph properties dialogue

Each of the decorators allows the user to adjust different properties dependent up on the decorator. Table 4 lists the properties that can be changed on each tab.

Tab	Text	Font	Text colour	Text postion	Line colour	Axis
Title	Yes	Yes	Yes	No	No	No
x-axis	Yes	Yes	Yes	No	No	No
y-axis	Yes	Yes	Yes	No	No	No
Axis	Yes	Yes	Yes	Yes	Yes	Yes
Variable	No	No	No	No	Yes	No

Table 4 Configurable graph properties

Text fields can be modified by clicking on and editing the text string.

Clicking the mouse on the font field button will display a standard Microsoft Windows® font dialogue. The required font, font style and size can be specified in this dialogue.

Clicking the mouse on the text or line colour field will display a colour selection tab dialogue as shown in Figure 7. This tab dialogue provides three colour selection tabs; custom, web and system. The custom tab displays the standard Microsoft Windows® colour selector. The web and system tabs allow selection from an existing set of colours.

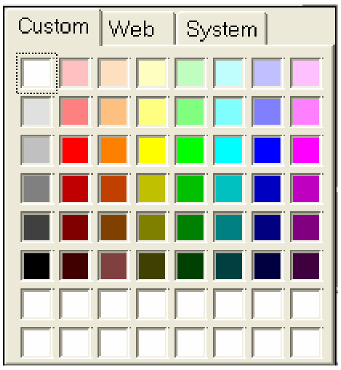


Figure 7 Colour picker

Clicking the mouse on the text position field will display a drop down list box that allows the user to position the axis label to the top, left, bottom or right of the graph. Top and bottom are valid options for the x-axis while left and right are valid options for the y-axis.

The axis properties that the user may change include:

- Background colours

- Border colours
- Axis ticks (spacing, length and colour)
- Tick labels(Type, precision, font, colour)
- Graticules (on/off, colour and line style)

There are number of options for specifying background colours that include:

- Background filled (true or false)
- Background begin colour
- Background end colour
- Background colour transition angle

The background colour may be turned on or off by changing the backwallfilled drop down list field. The background is filled by a transition of colour from the begin colour (backwallbegincolor) to the end colour (backwallendcolor). The colours are set with the colour setting dialogue as shown in Figure 7. The transition of colours is relative to the lower left corner of the graph. The backwallgradientangle specifies the angle (in degrees) for the transition e.g. angle 0 is left to right while 270 is bottom to top.

The border, tick, font and graticule colours can all be specified with the colour dialogue as show in Figure 7.

The tick length on the x and y axis can be changed by clicking the mouse on the appropriate field and typing in a new value (0.0-1.0).

The number of ticks on the x and y axis can be changes by clicking the mouse on the appropriate files and typing in a new value.

The labels for the axis are dependent upon the type of variable that is being displayed. Currently there are only two types of variables supported, real numbers and dates. For real numbers the precision can also be specified. The font used for the label can also be specified with the standard Microsoft Windows® font selection dialogue.

The graph graticules may be turned on and off for either the x or y axes. This is done by clicking the mouse on either true or false in the drop down list of the appropriate parameter. The line style can also be selected via a drop down menu. The available options are shown in Figure 8.

Figure 8 Line style selections

2.5.6 Mouse & Keyboard Controls

This User Guide assumes that you have a standard mouse and keyboard configuration. The left mouse button is commonly used under Windows to access the normal select or normal drag function. The right mouse button is normally used to access context sensitive menus and drag functions. These buttons have the same usage in the RRL.

You may prefer to use keyboard hotkeys or a glide pad.

2.6 Uninstalling RRL

You uninstall RRL via Settings | Control Panel | Add/Remove Programs. Removing the RRL software is only a matter of seconds.

To ensure complete removal of the software use Windows explorer to browse to the RRL install directory and then remove this directory. Caution: all existing data and project files that may have been saved in the RRL subdirectories will also be deleted if this action is taken.

3 Using RRL

3.1 Getting started

3.1.1 Starting the RRL

To run the rainfall runoff library click on the RRL icon on the desktop or select start |programs |Toolkit |Rainfall Runoff Library.

The RRL introduction splash screen will appear for approximately 5 seconds or until a mouse button or key is pressed. The RRL menu will then appear.

3.1.2 RRL Menu

The RRL top level menu is a standard Microsoft Windows® menu as shown in Figure 9. The menu options and associated hot keys are:

- File (alt+f)
- Edit (alt+e)
- View (alt+v)
- Run (alt+r)
- Tools (alt+t)
- Window (alt+w)
- Help (alt+h)

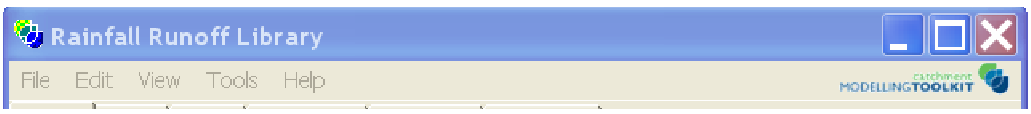


Figure 9 RRL top level menu

The right hand side of the menu contains the Catchment Modelling Toolkit logo.

File drop down menu

The File drop down menu is shown in Figure 10. This menu allows users to:

- Create, open, view, print, save, save as and close RRL project files.

- Setup the printer.
- Change the working directory.
- Select from up to 4 previously opened files.
- Exit the RRL.

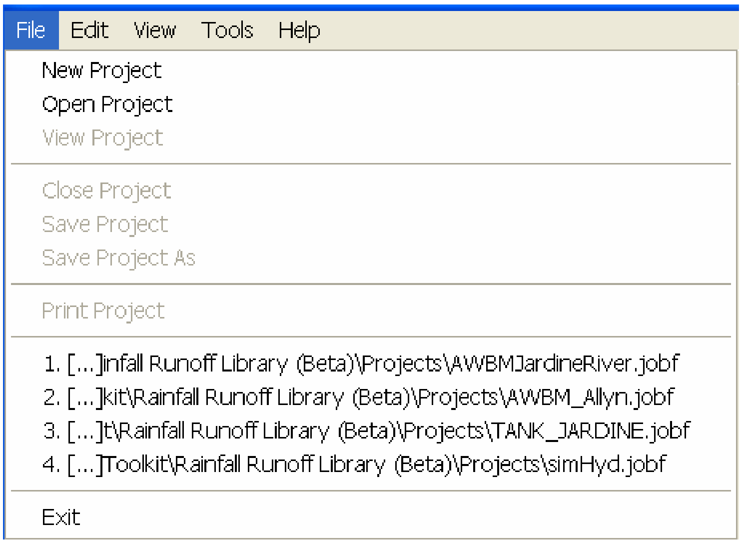


Figure 10 File drop down menu

An RRL project file is a text file that contains information about the configuration of a rainfall runoff model including:

- Model type
- Location
- Input data
- Parameter
- Calibration dates and methods
- Data scaling factors

Note:

1 The close project, save project, save project as and print project options will be greyed until a project file is created or opened.

2 The previously opened file option will only display if previously opened files were specified and still exist. If no files exist then no menu options will be displayed.

Edit drop down menu

The Edit drop down menu is shown in Figure 11. This menu allows users to edit the RRL project file and set default preferences.

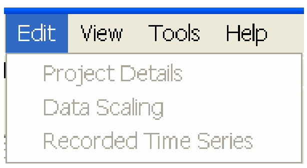


Figure 11 Edit drop down menu

Note that all options will be greyed if a project file has not been opened or created.

View drop down menu

The View drop down menu is shown in Figure 12. This menu allows users to view the RRL project file and default preferences.

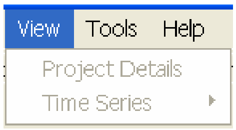


Figure 12 View drop down menu

Note that all options will be greyed if a project file has not been opened or created.Tools drop down menu

The Tools drop down menu is shown in Figure 13. This menu allows users to configure RRL display options such as colours, display fonts, graph colours and graph fonts. It also allows the user to specify the path to the default data directory.

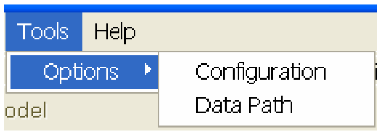


Figure 13 Tools drop down menu

Help drop down menu

The Help drop down menu is shown in Figure 14. This menu allows users to browse and search the RRL help file, link to the Toolkit web site for information, downloads and technical support and find out about the RRL. The about screen lists the organisations and people that have contributed to the development of this product as well as a button that displays the licence agreement.

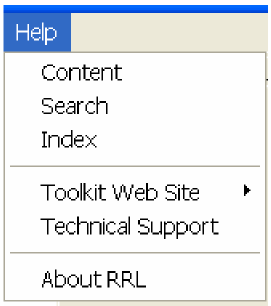


Figure 14 Help drop down menu

3.1.3 RRL Dialogues

The RRL contains a single tabbed dialogue as shown in Figure 15. The tab dialogue allows the user to rapidly move between model options and parameters. There are six dialogues that specify:

- Model: The model type to be used.
- Input: The daily time series inputs of rainfall, evapotranspiration and flow.
- Dates: Calibration and verification start, warm up and end dates.
- Calibration: Model parameters, calibration method, optimisation method and a graph display window.

- **Sensitivity:** Model parameter, parameter limits and objective function. Also includes a sensitivity graph display window.
- **Simulation:** Simulation start and end dates, output file and flow graph display window.

Figure 15 RRL Tabbed dialogue

Model dialogue

The model dialogue, as shown in Figure 16 allows the user to select the model type that is to be used for rainfall runoff modelling. The user may chose from the following models:

- AWBM
- Sacramento
- Simhyd
- SMAR
- SWAT core
- Tank

This dialogue has three fields the model select, schematic and description. When a model is selected the model schematic and description fields will be updated.

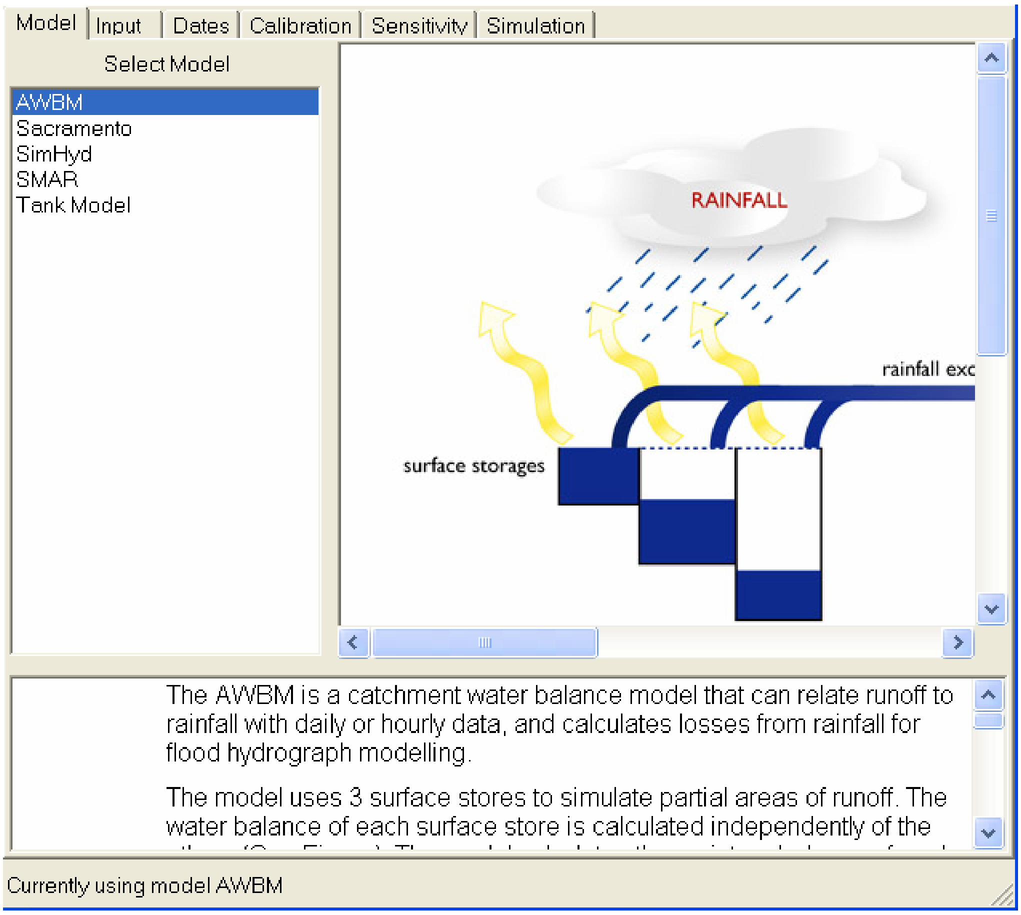


Figure 16 Model selection dialogue

Input dialogue

The input data dialogue, as shown in Figure 17, allows the user to specify the times series files to be used for rainfall runoff modelling. The dialogue has six fields:

1 File browser

2 Time series rainfall

3 Time series evapotranspiration (ET)

4 Time series flow

5 Input statistics button

6 Reset all inputs button

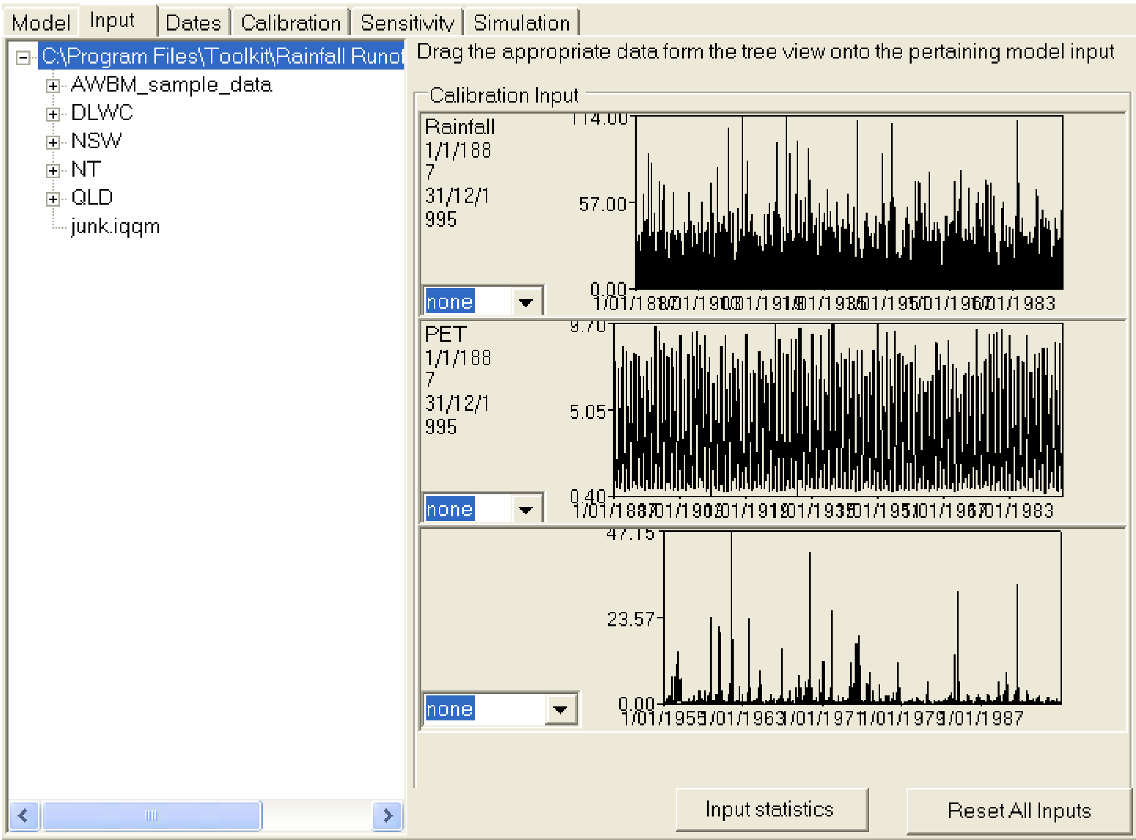


Figure 17 Input dialogue

The file browser is used to locate a file that may then be dragged and dropped onto the appropriate time series field. The file that is selected must be in a valid times series format as discussed in Chapter 8. The units of the data must be compatible with the field that the data is dropped on. The rainfall and evaporation fields are expecting height units while the flow field is expecting flow or height units. The units of the flow input data can be specified by the drop down menu in the flow input field.

Note that both rainfall and evapotranspiration data must be entered as millimetres.

When an appropriate time series data file is dropped on the time series field then the data will be displayed in that field.

The input statistics button displays summary statistics for each set of time series dataWhen the reset all inputs button is selected all of the time series data fields will be cleared.

Dates dialogue

The dates dialogues, as shown in Figure 18, allows the user to:

1 Locate the wettest and driest annual flow periods within the data.

2 Specify a calibration period

3 Specify and optional verification period

4 Find appropriate warm up periods for calibration and verification periods.

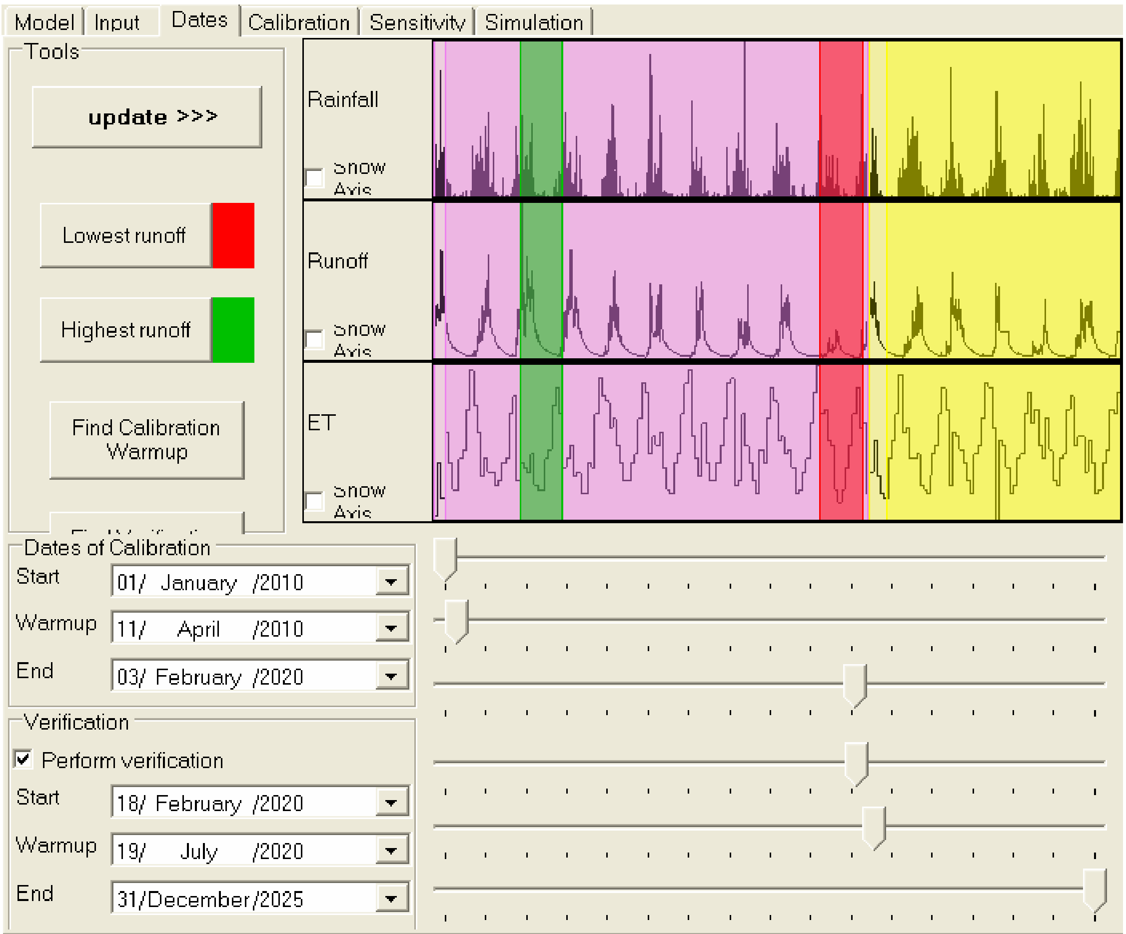


Figure 18 Dates dialogue

Upon entering this dialogue no time series information is displayed. To display the time series data click the mouse on the **update** button. The time series flow, rainfall and evaporation will then be displayed. Note all other buttons and date fields will be greyed until this button is selected.

Clicking the mouse on **show driest year** or **show west year** buttons will display the annual driest and west periods in the respective suffixed transparent colours. The displayed periods can be toggled by clicking on the respective buttons. The colours for wettest and driest periods can be changed by clicking the mouse on the colour bar following the buttons. This will display a colour palette selection window. Note the calibration and verification period colours can be modified in a similar manner.

The calibration start, end and warm-up date fields and associated date sliders allow the user to manually specify the respective calibration dates. Note the end date must be after the start date and the warm up period must be between the two dates. Alternatively the warm up period may be approximated by clicking the mouse on the **find appropriate calibration warm-up**. The model determines this by identifying a period where the contents of the storages reach a storage depth that is within 1% irrespective of the value of the model parameters. Note under certain conditions the model cannot determine this period in which case a warning message as shown in Figure 19 is displayed and this period needs to be specified manually.

Figure 19 Warm up period estimation error dialogue

The perform verification date fields remain greyed until the **perform verification** check box is checked. The operation of these fields as well as **find appropriate verification warm-up** work in a similar manner to the calibration fields. Note there are no constraints for overlapping of calibration and verification periods; however it is good modelling practice that these periods do not overlap.

Calibration dialogue

The calibration dialogue, as shown in Figure 20, allows the user to calibrate the rainfall runoff model both automatically and manually. The dialogue has five areas:

1 Boundaries and fixed parameters button

2 Calibration tab

3 Calibrate button

4 Graph window

5 Viewing results buttons

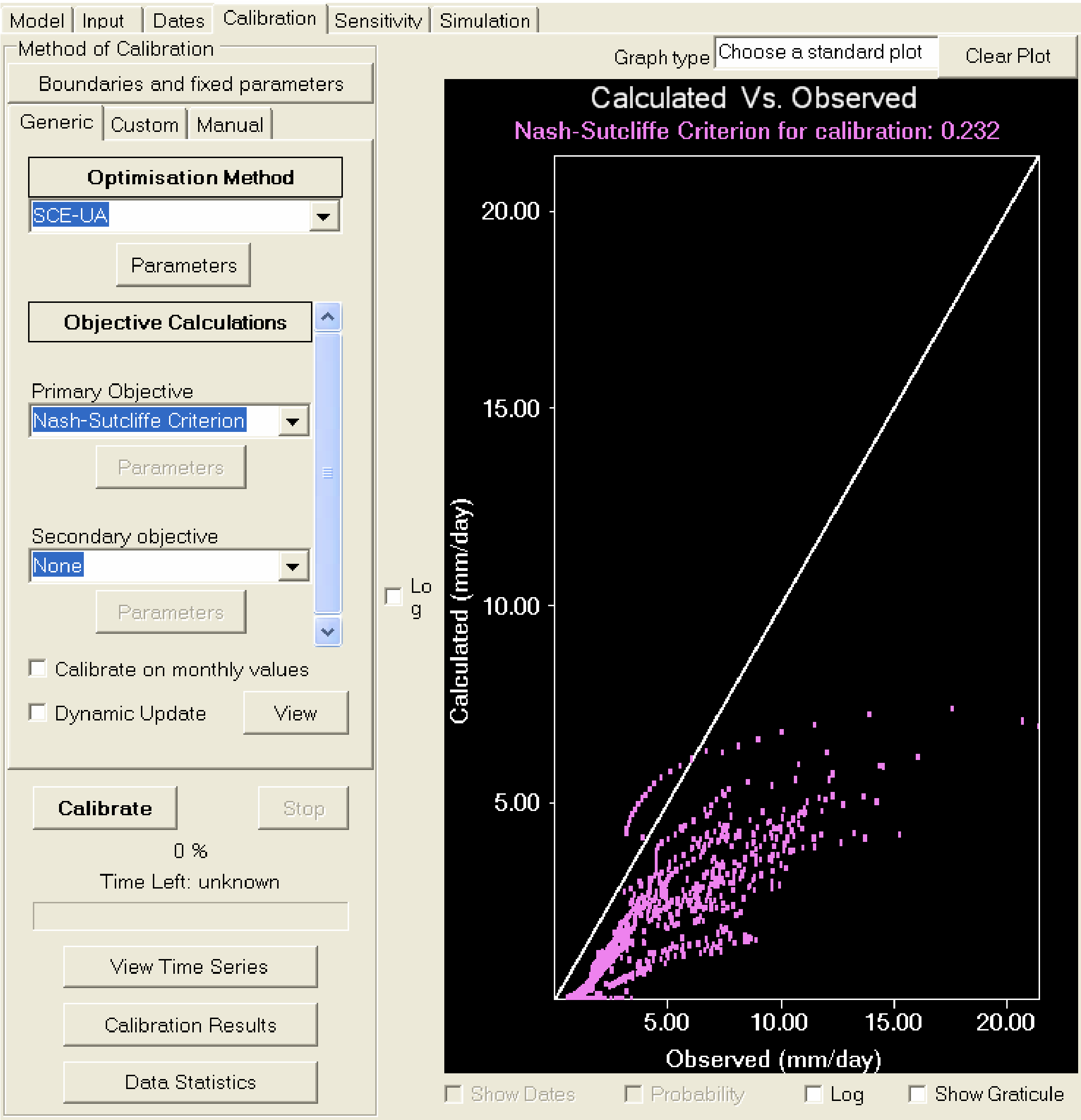


Figure 20 Calibration dialogue

Clicking the mouse on the **boundaries and fixed parameter** button displays the calibration parameters dialogue as show in Figure 21. The dialogue displays each of the model parameters, upper and lower bounds to each parameter and check box fixing that can optional fix the parameter in optimised calibration. Note the parameters that are displayed in this dialogue are dependent on the rainfall-runoff model selected.

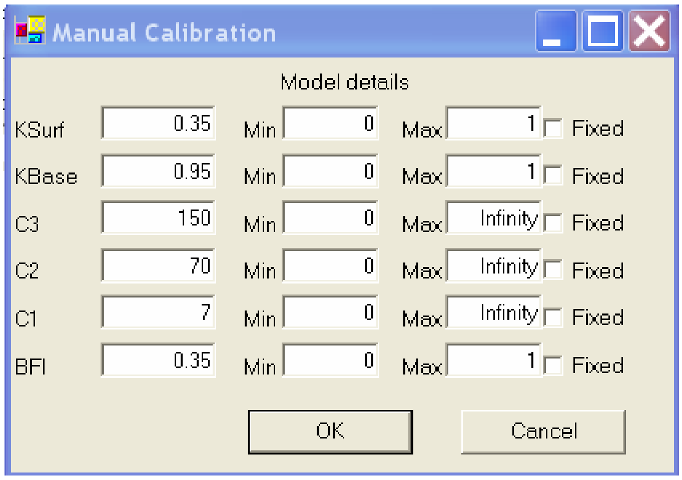


Figure 21 Calibration parameters

There are three tabs on the calibration tab dialogue. The three tabs are:

1 Generic

2 Custom and

3 Manual

The **generic** tab contains drop down menus and buttons to access options for the automatic calibration of model parameters. The user can select optimisation method, primary and secondary objective functions, and data transformation.

By clicking the mouse on the optimisation method drop down list the user can select from the following optimisation methods:

- Uniform random sampling
- Pattern search
- Multi start pattern search
- Rosenbrock search
- Rosenbrock multi-start search
- Genetic algorithm
- Shuffled Complex Evolution (SCE-UA)

The optimisation parameters can be set by clicking on the **parameter**. Note the parameters that are displayed are dependent on the optimisation method that is specified.

By clicking the mouse on the primary objective function drop down list the user can select from the following objective functions:

- Nash-Sutcliffe criterion (Coefficient of efficiency)
- Sum of square errors
- Root mean square error (RMSE)
- Root mean square difference about bias
- Absolute value of bias
- Sum of square roots
- Sum of square of the difference of square root
- Sum of absolute difference of the log
- Runoff difference in %

- Flow duration curve
- Base flow method 2

There are three data transformation options:

- Daily time series (no transformation)
- Monthly volumes (daily flows summed over the month)
- Flow duration (Sorted daily values from highest to lowest)

The **custom** tab is available for rainfall runoff models that have internal calibration algorithms. Currently the only model with this capability is the AWBM model, as shown in Figure 22. For all other models this tab is greyed. This tab displays a drop down list that allows the user to choose internal calibration method, for the AWBM model there is only one option to choose from.

Figure 22 Custom tab

The **manual** tab is provided for manual calibration of the selected rainfall runoff model. There are three sections to this tab:

1 Dynamic update check box

2 Model parameters

3 Update graph button

When the **Dynamic Update** check box is checked any changes in model parameters will cause the rainfall runoff model to be run and the currently specified graph to be updated. This can be a time consuming process if the calibration period is long in which case the user can turn this option off and use the **Update Graph** button as required.

The model parameters that are displayed are dependent upon the model that is selected and consequently the list of parameters will vary for each rainfall runoff model. The user can simply type in the new value or use the spinner for the parameter to be changed. Note range checking is performed based on the boundaries specified in the calibration parameters dialogue that is displayed by clicking on the **boundaries and fixed parameter** button.

The **Update Graph** button allows the user to control when the rainfall runoff model is run and the graph is updated for the current set of model parameters.

Clicking on the **Calibrate** button will cause the program to calibrate the selected rainfall model using the specified optimisation method subject to the selected objected function and data transformation. Progress of the optimisation is displayed at the bottom of the calibrate tab dialogue. If the **Update Objective** check box is checked then the Objective function values will be displayed in the graph window and progressively update for each model run.

The **graph window** has a selection of options for displaying observed and simulated flows as well as the option to display the value of the objective function. This is discussed in more detail in section 2.5.5.

The **view time series** button opens a graph window as shown in Figure 23 that allows the user to graph observed flow and model outputs. The parameters that are output are selectable from the **Edit | Recorded Time Series** menu option.

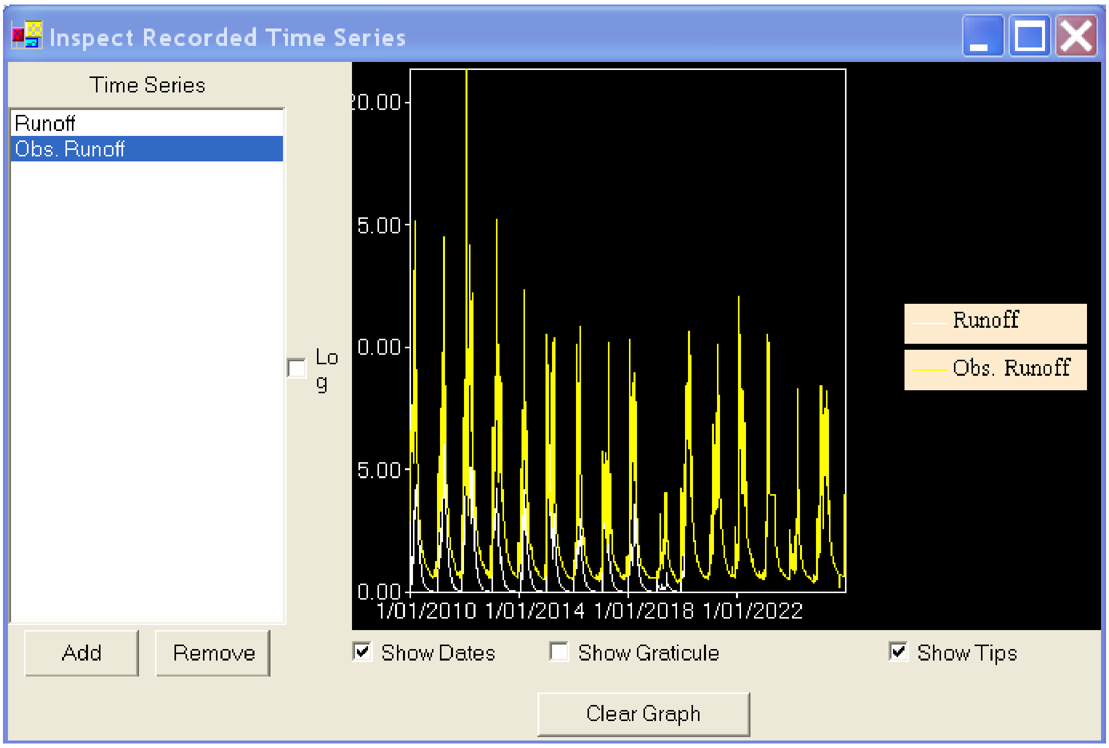
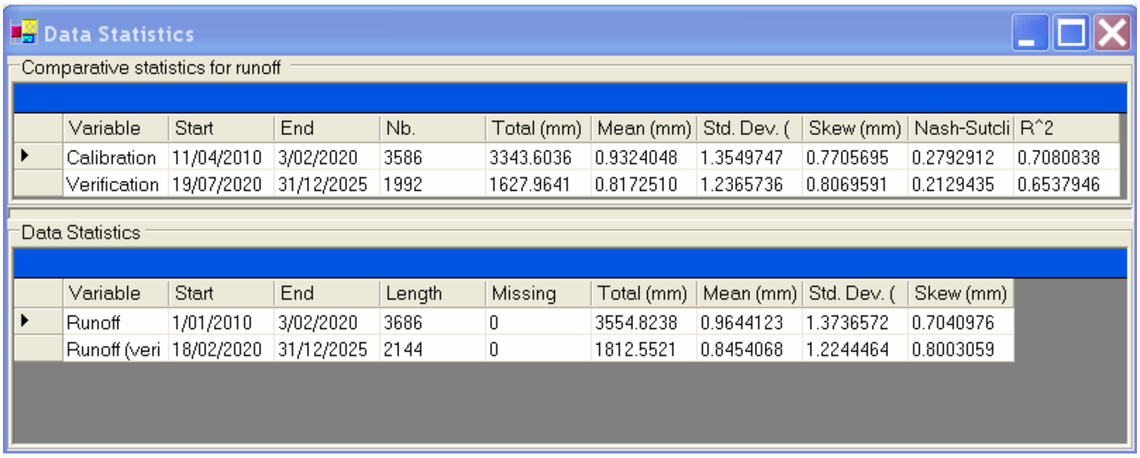


Figure 23 Model output graph window

The **calibration results** button display a list of the optimization results for the latest optimized calibration.

The **data statistics** button displays a statistical comparison between observed and simulation runoff for the calibration and validation period. An example statistical comparison is shown in Figure 24.



Variable	Start	End	Nb.	Total (mm)	Mean (mm)	Std. Dev. (	Skew (mm)	Nash-Sutcli	R^2
Calibration	11/04/2010	3/02/2020	3586	3343.6036	0.9324048	1.3549747	0.7705695	0.2792912	0.7080838
Verification	19/07/2020	31/12/2025	1992	1627.9641	0.8172510	1.2365736	0.8069591	0.2129435	0.6537946

Variable	Start	End	Length	Missing	Total (mm)	Mean (mm)	Std. Dev. (	Skew (mm)
Runoff	1/01/2010	3/02/2020	3686	0	3554.8238	0.9644123	1.3736572	0.7040976
Runoff (veri	18/02/2020	31/12/2025	2144	0	1812.5521	0.8454068	1.2244464	0.8003059

Figure 24 Observed and simulated data comparison

Sensitivity dialogue

The sensitivity dialogue, as shown in Figure 25, allows the user to analyse the sensitivity of a particular model parameter with regard to a selected objective function. There are four sections to this area:

1 Model parameter selection drop down list box,

2 Parameter bounds fields,

3 Objective function selection drop down list box, and

4 Plot curve response button.

The sensitivity dialogue has two areas a sensitivity analysis parameter area and a graph window.

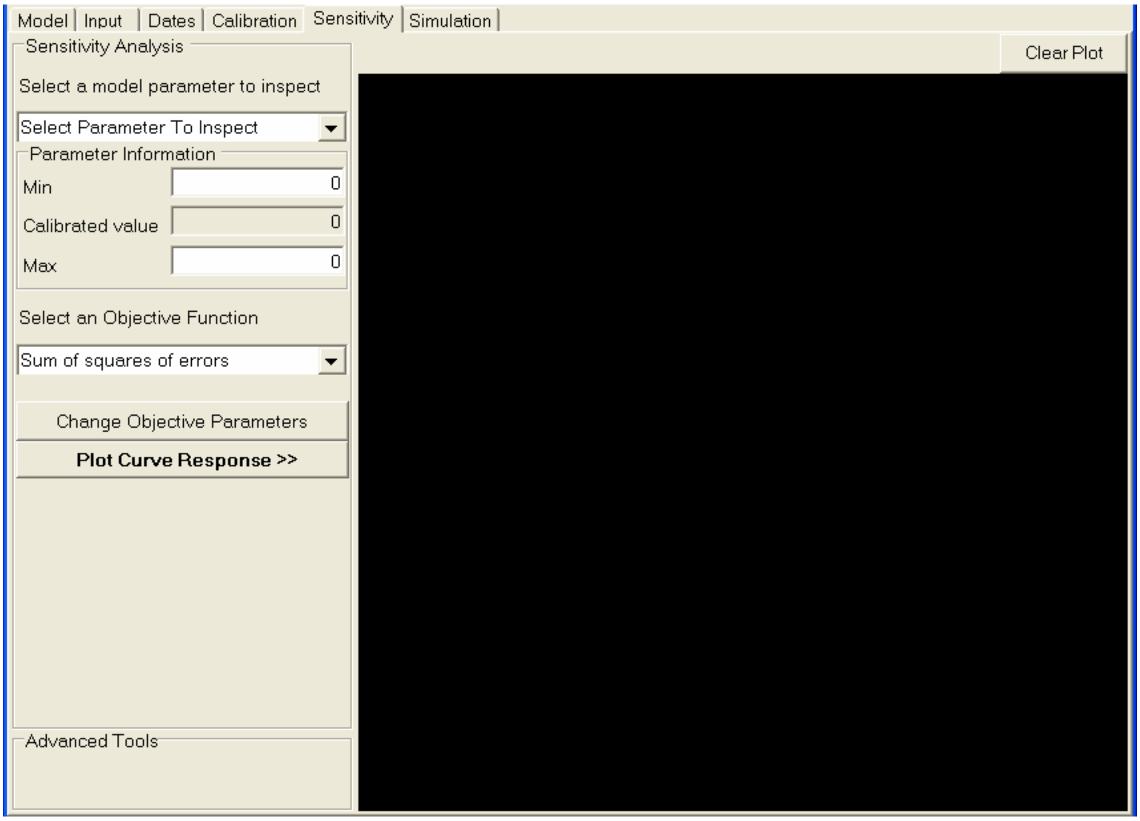


Figure 25 Sensitivity dialogue

The model parameter selection drop down list box allows the user to select the model parameter to be analysed. Note the parameters displayed in this list are dependent upon the rainfall-runoff model selected.

The parameter information section displays the selected parameter bounds and current value. The current bounds can be modified by typing the new bound in the appropriate field.

By clicking the mouse on the objective function drop down list the user can select from the following objective functions:

- Nash-Sutcliffe criterion (Coefficient of efficiency)
- Sum of square errors
- Root mean square error (RMSE)
- Root mean square difference about bias
- Absolute value of bias
- Sum of square roots
- Sum of square of the difference of square root
- Sum of absolute difference of the log

Clicking the mouse on the Plot Curve Response >> button runs the model with all other model parameters fixed and varies the selected parameter within the specified bounds and displays the result of the objective function in the graph area.

Simulation dialogue

The Simulation dialogue, as shown in Figure 26, allows the user to run the model for a specified period and output the results. The simulation dialogue has four areas output period fields, run button, output buttons and a graph window.

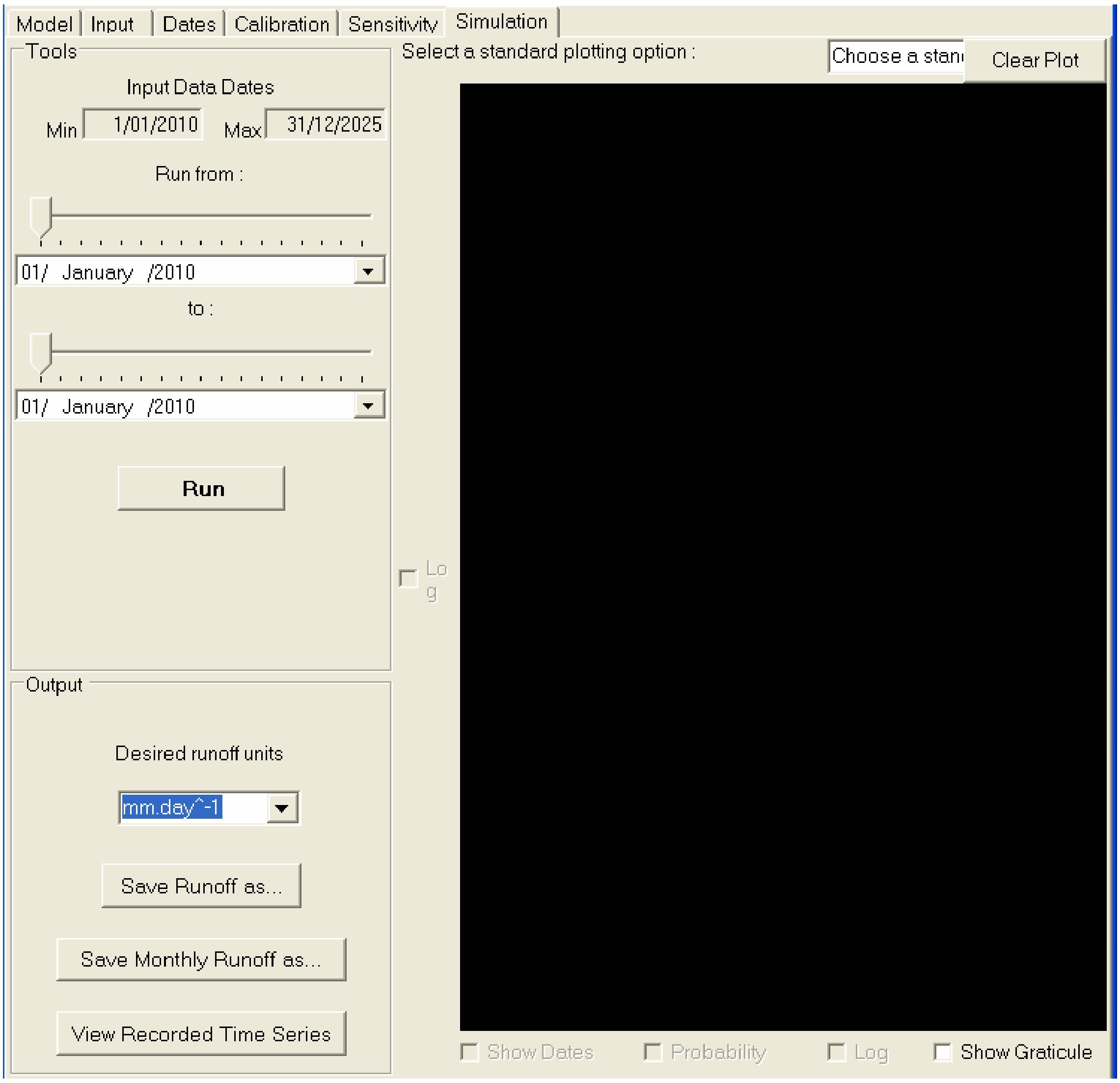


Figure 26 Simulation dialogue

The output period fields show the earliest and latest dates that are possible to run the model over. This is constrained by the period of input data specified in the input dialogue. There are also two date fields and date sliders to specify the period that the model is to be run over. Note the start and end dates will be constrained to the earliest and latest dates.

Clicking the mouse on the run button will run the rainfall runoff model with the current set of parameter values for the period specified in the output period fields. If a graph type is selected in the graph area a graph of the model flow result will be displayed.

The desired runoff units allow the user to choose the output units that the data are to be saved as. There currently three options available mm/d, m3/s and ML/d.

The output buttons allow the user to save the results of a model run to either a monthly or daily output file. Clicking on an output button displays a file save as window as shown in Figure 27. This window allows the user to save the model results in one the TIME supported output formats as described in Chapter 8.

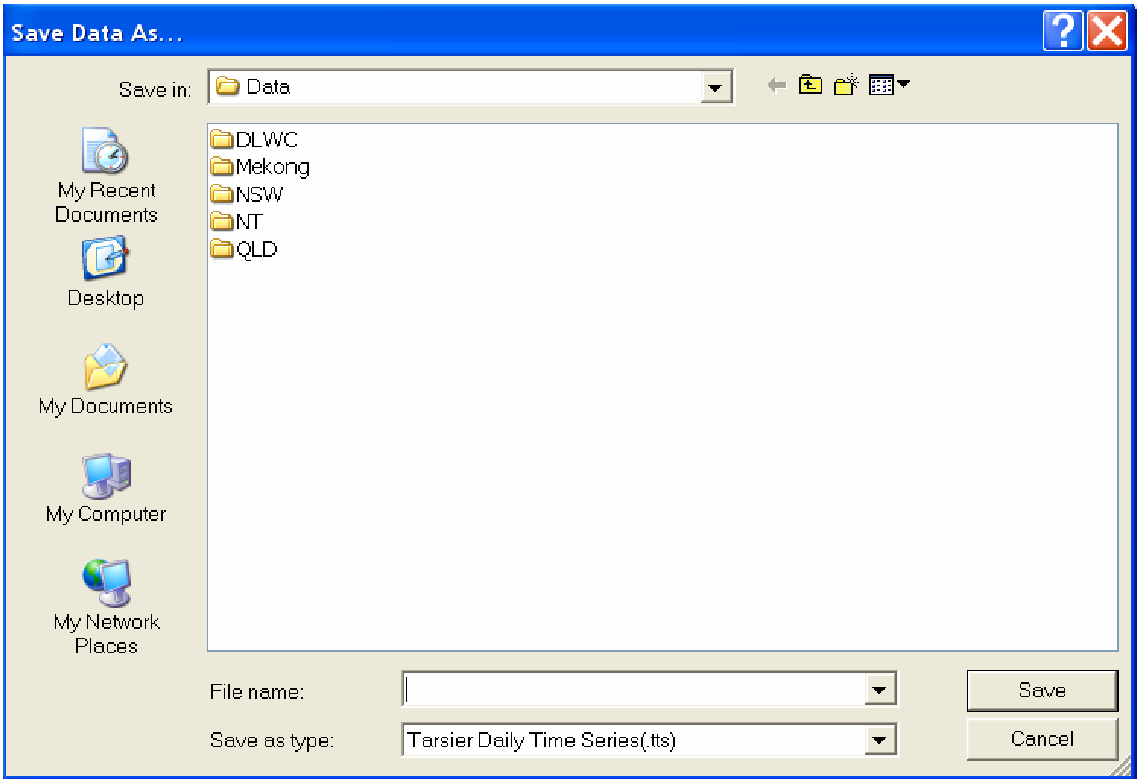


Figure 27 File save as window

The **view recorded time series** button opens a graph window as shown in Figure 23that allows the user to graph observed flow and model outputs. The parameters that are output are selectable from the **Edit | Recorded Time Series** menu option.

3.1.4 RRL Graphs

The RRL contains three graph windows in the **Calibration**, **Sensitivity** and **Simulation** tabs. These graphs are slightly different in each tab but function as described in section 2.5.5.

Calibration Graph

The calibration graph, as shown in Figure 28, allows the user to plot the results of the objective function used for optimised calibration or compare observed and simulated data. The graph can be configured such that it updates with each change of parameters or update by clicking on the update button which is discussed above.

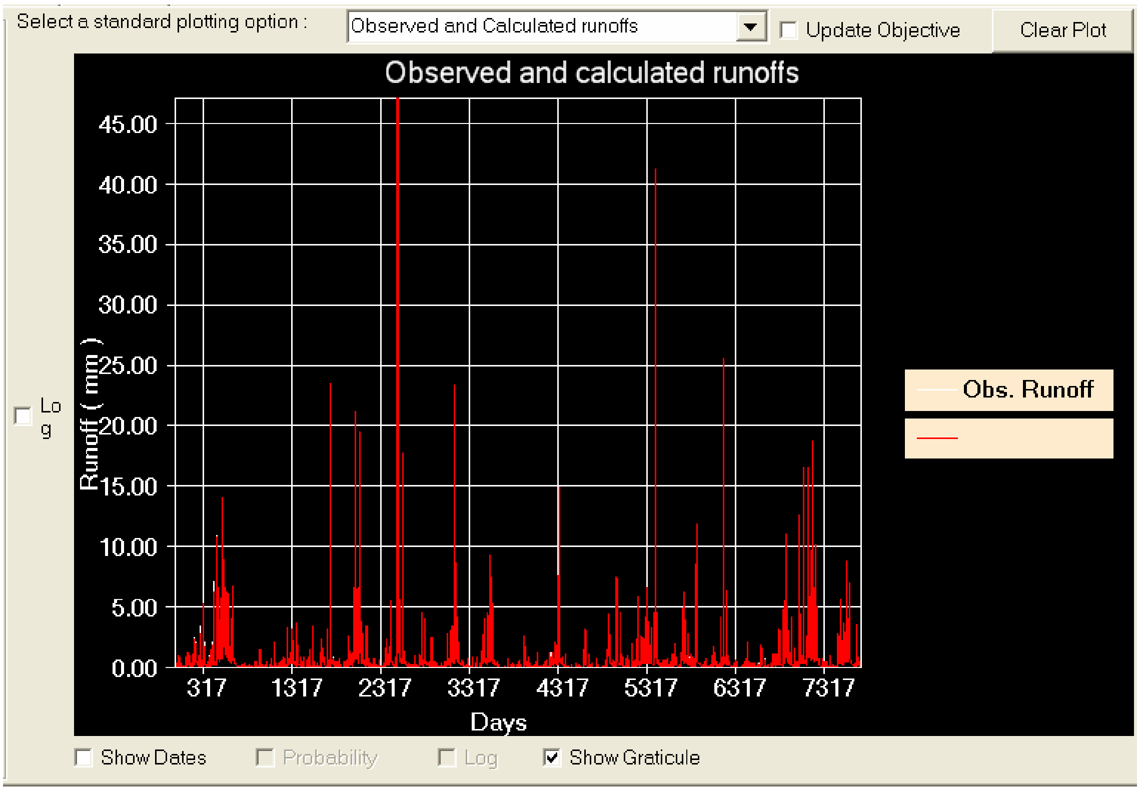


Figure 28 Calibrate graph

The specific options and features that are available on the calibration graph include:

- Update objective function
- Different graph types
- Log/linear y axis
- Days/date/linear/log/probability x axis
- Graticules (on/off)
- Clear plot

When an optimised calibration is being carried out from the calibration tab the user can choose to display the objective function for successive model runs. The graph will be updated for each successive run and is selected by clicking on **Update Objective** check box.

All graph fields except the Update Objective and Show Graticule check boxes, and Clear Plot button will be greyed until the model is run either as an optimised calibration or manual calibration. Once the model is run the graph type fields will be activated and the required graph type can be displayed by selecting from the list of graph types in the **Select a standard plotting option** drop down list. The graph plotting options are:

- Daily Scatter
- Monthly scatter
- Daily time series (calibration and validation periods)
- Daily difference (calibration and validation periods)
- Daily flow duration (calibration and validation periods)

The graph axis options are dependent upon the graph type that is selected and are listed in Table 5.

Graph type	x date	x log	x probability	y log
Daily Scatter	No	Yes	No	Yes
Monthly scatter	No	Yes	No	Yes

Graph type	x date	x log	x probability	y log
Daily time series	Yes	No	No	Yes
Daily difference	Yes	No	No	Yes
Flow duration	Yes	No	Yes	Yes

Table 5 Calibration graph axis options

The x date when checked displays dates on the x axis and when not checked it is days since start date.

The x log when checked plots a log x axis and when not checked it is a linear x axis.

The x probability when checked plots a probability x axis when not checked it is a 0-100% sale x axis.

The y log when checked plots a log y axis and when not checked it is a linear y axis.

The current graph can be cleared by clicking the mouse on the **clear plot** button.

Sensitivity Graph

The sensitivity graph, as shown in, allows the user to plot the sensitivity of the calibration of a particular model parameter with respect to a specified objective function. The x axis is the number of iterations and the y axis is the value of the objective function. The graph is updated by clicking on the **plot curve response** button which is discussed above.

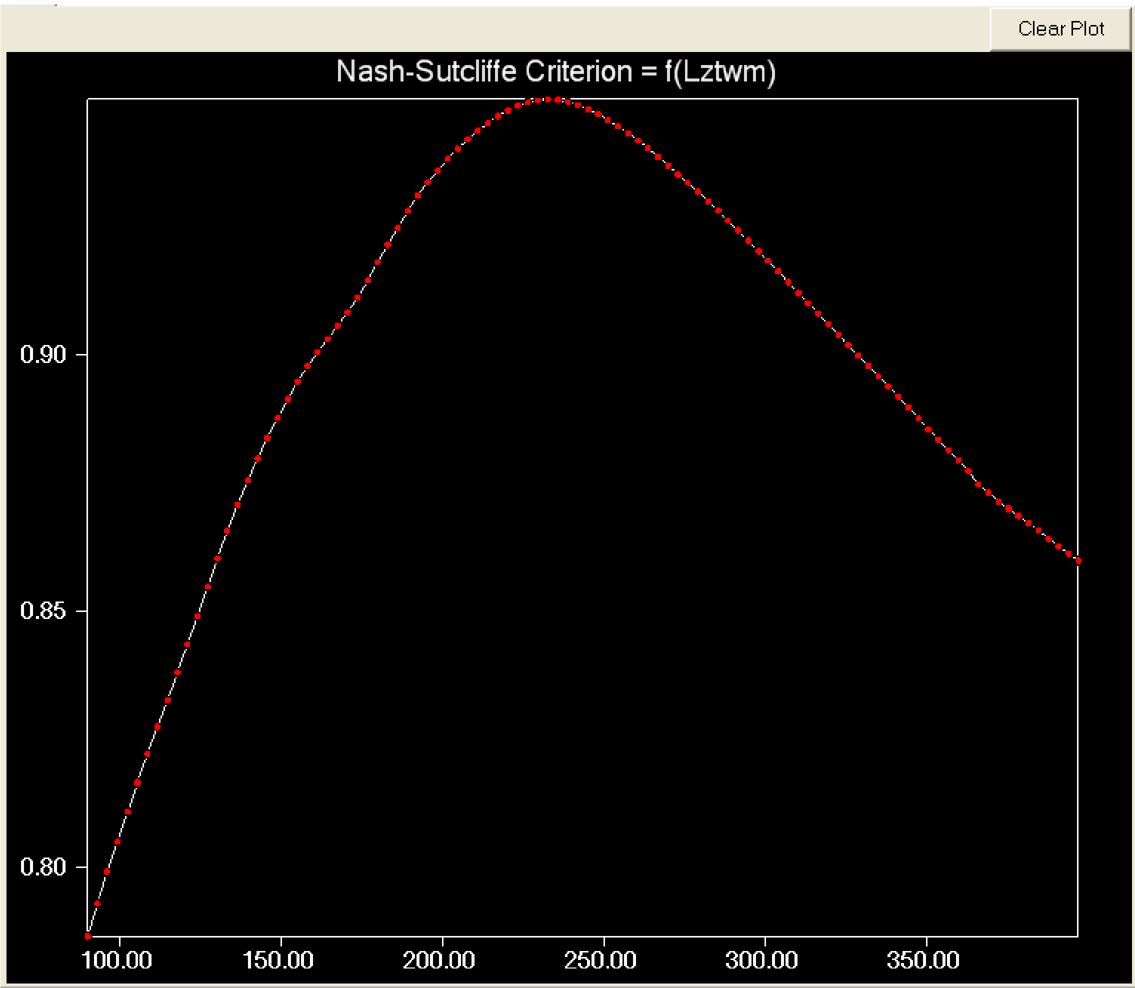


Figure 29 Sensitivity graph

The current graph can be cleared by clicking the mouse on the **clear plot** button.

Simulation Graph

The calibration graph, as shown in Figure 30, allows the user to plot the simulated results of the model. The graph can be configured to display the simulated results as daily time series, monthly time series or daily flow duration.

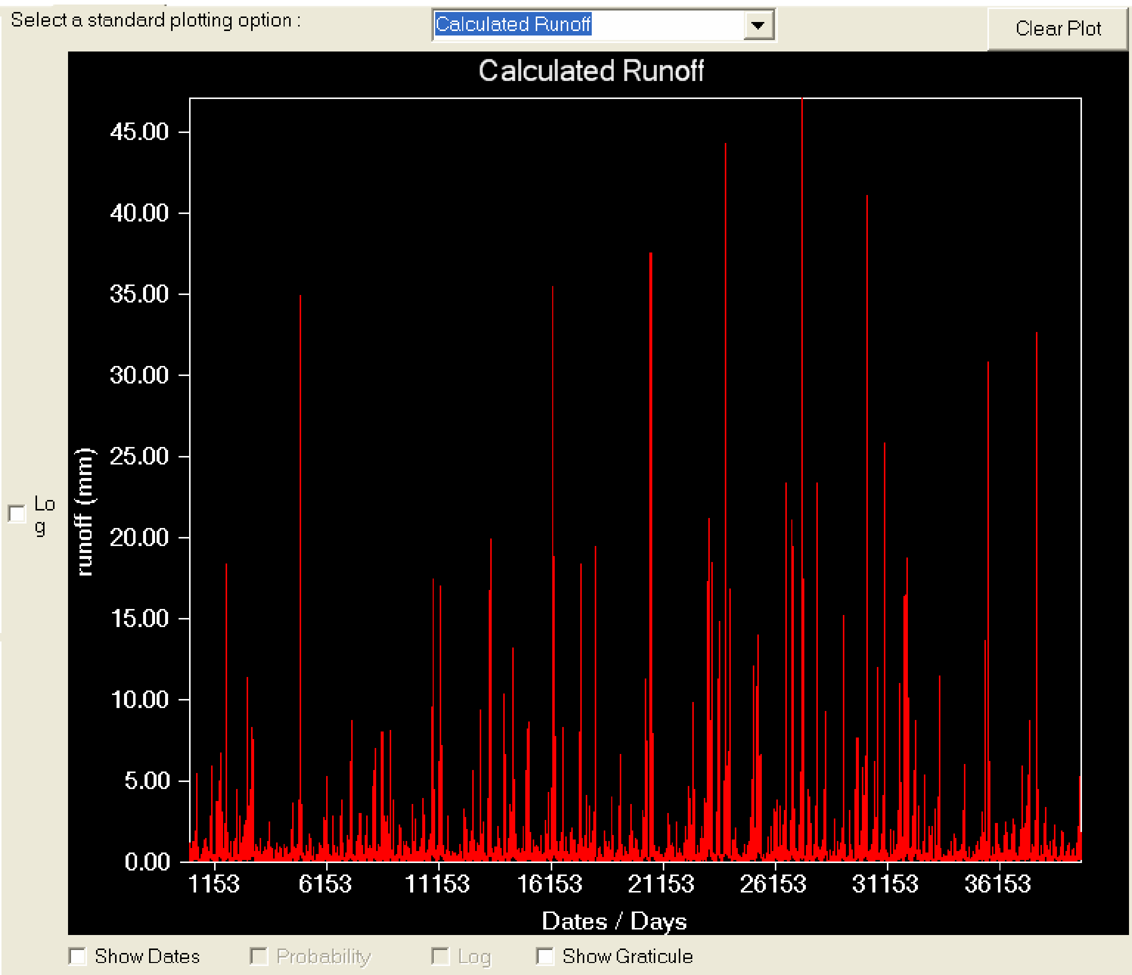


Figure 30 Simulation graph

The specific options and features that are available on the simulation graph include:

- Different graph types
- Log/linear y axis
- Days/date/linear/log/probability x axis
- Clear plot

All graph fields except the Show Graticule check box, and Clear Plot button will be greyed until the model is run. Once the model is run the **Select a standard plotting option** field will be activated and the required graph type can be displayed by selecting from the list of graph types in the drop down list. The graph plotting options are:

- Daily time series
- Monthly time series
- Daily flow duration

The graph axis options are dependent upon the graph type that is selected and are listed in Table 6.

Graph type	X date	X log	X probability	Y log
Daily time series	Yes	No	No	Yes
Monthly time series	Yes	No	No	Yes
Flow duration	Yes	No	Yes	Yes

Table 6 Calibration graph axis options

The x date when checked displays dates on the x axis and when not checked it is days since start date.

The x log when checked plots a log x axis and when not checked it is a linear x axis.

The x probability when checked plots a probability x axis when not checked it is a 0-100% sale x axis.

The y log when checked plots a log y axis and when not checked it is a linear y axis.

The current graph can be cleared by clicking the mouse on the **clear plot** button.

3.2 Creating a new project

To create a new project select **File|New Project** and a Create new project a catchment information dialogue will be displayed as shown in Figure 31.

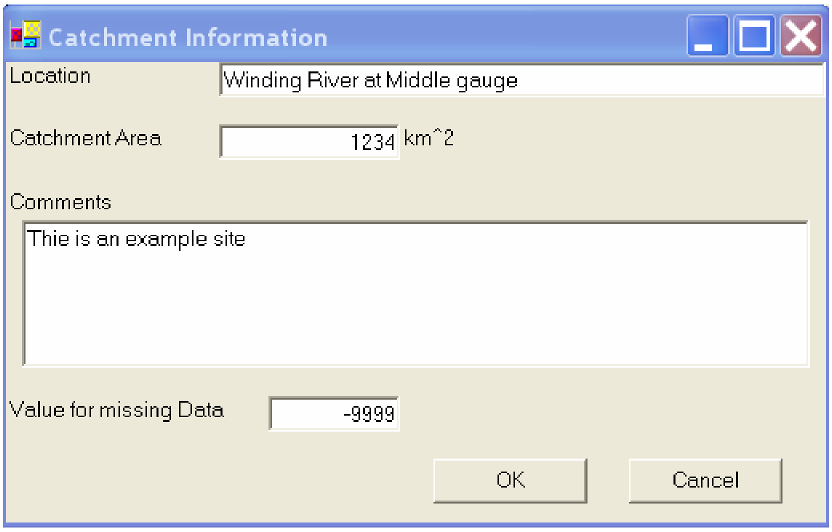


Figure 31 Catchment information dialogue

There are 4 fields that may be entered in this dialogue:

1 Location,

2 Catchment area,

3 Comments, and

4 Missing data value.

The location is a text string that describes the location that is to be modelled by the RRL. This field may be left blank.

The catchment area is a real field that specifies the size of the catchment in km^2. A value must be entered in this field before the **ok** button is selected. This value is used to convert between depth of runoff and flow.

The missing data value is used to identify missing data in the input data.

Note these parameters can be adjusted within the rainfall runoff menus via Edit | Project details

When all of the information has been entered the user can click the mouse on the OK field.

3.3 Loading an existing project

To load an existing project select File | Open Project and a standard windows browse window will appear. By default this file will open up in the RRL project directory. Once a job file is selected the RRL tab dialogues will be loaded with the saved parameters for the project. The time series data will only be loaded if the data exists in the specified directories in the correct format.

4 Description of models

4.1 AWBM

The AWBM is a catchment water balance model that can relate runoff to rainfall with daily or hourly data, and calculates losses from rainfall for flood hydrograph modelling. Data needs and formats are described in Chapter 1 and Chapter 8 respectively.

The model uses 3 surface stores to simulate partial areas of runoff. The water balance of each surface store is calculated independently of the others (Figure 32). The model calculates the moisture balance of each partial area at either daily or hourly time steps. At each time step, rainfall is added to each of the 3 surface moisture stores and evapotranspiration is subtracted from each store. The water balance equation is:

$$store_n = store_n + rain - evap \quad (n = 1 \text{ to } 3) \qquad (1)$$

If the value of moisture in the store becomes negative, it is reset to zero. If the value of moisture in the store exceeds the capacity of the store, the moisture in excess of capacity becomes runoff and the store is reset to the capacity.

When runoff occurs from any store, part of the runoff becomes recharge of the base flow store if there is base flow in the stream flow. The fraction of the runoff used to recharge the base flow store is BFI*runoff, where BFI is the base flow index, i.e. the ratio of base flow to total flow in the stream flow. The remainder of the runoff, i.e. (1.0 - BFI)*runoff, is surface runoff. The base flow store is depleted at the rate of (1.0 - K)*BS where BS is the current moisture in the base flow store and K is the base flow recession constant of the time step being used (daily or hourly).

The surface runoff can be routed through a store if required to simulate the delay of surface runoff reaching the outlet of a medium to large catchment. The surface store acts in the same way as the base flow store, and is depleted at the rate of (1.0 - KS)*SS, where SS is the current moisture in the surface runoff store and KS is the surface runoff recession constant of the time step being used.

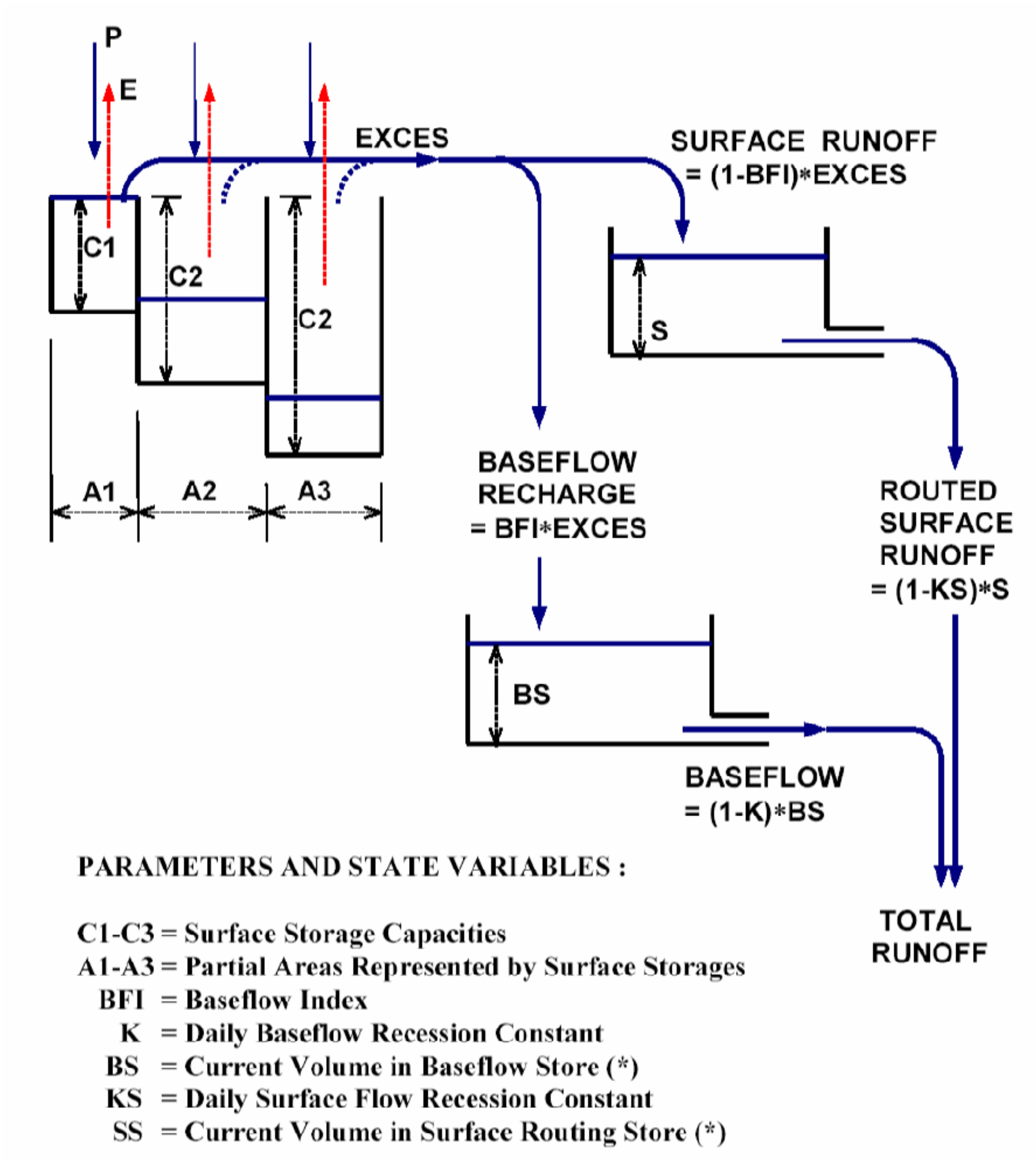


Figure 32 Structure of the AWBM rainfall-runoff model

4.2 Sacramento

The SAC-SMA model represents the moisture distribution in a physically realistic manner within hypothetical zones of a soil column. The model attempts to maintain percolation characteristics to simulate stream flow contributions from a basin. The components of the SAC-SMA are tension water, free water, surface flow, lateral drainage, evapotranspiration (ET), and vertical drainage (percolation). The SAC-SMA model is very often represented graphically as illustrated in Figure 33below.

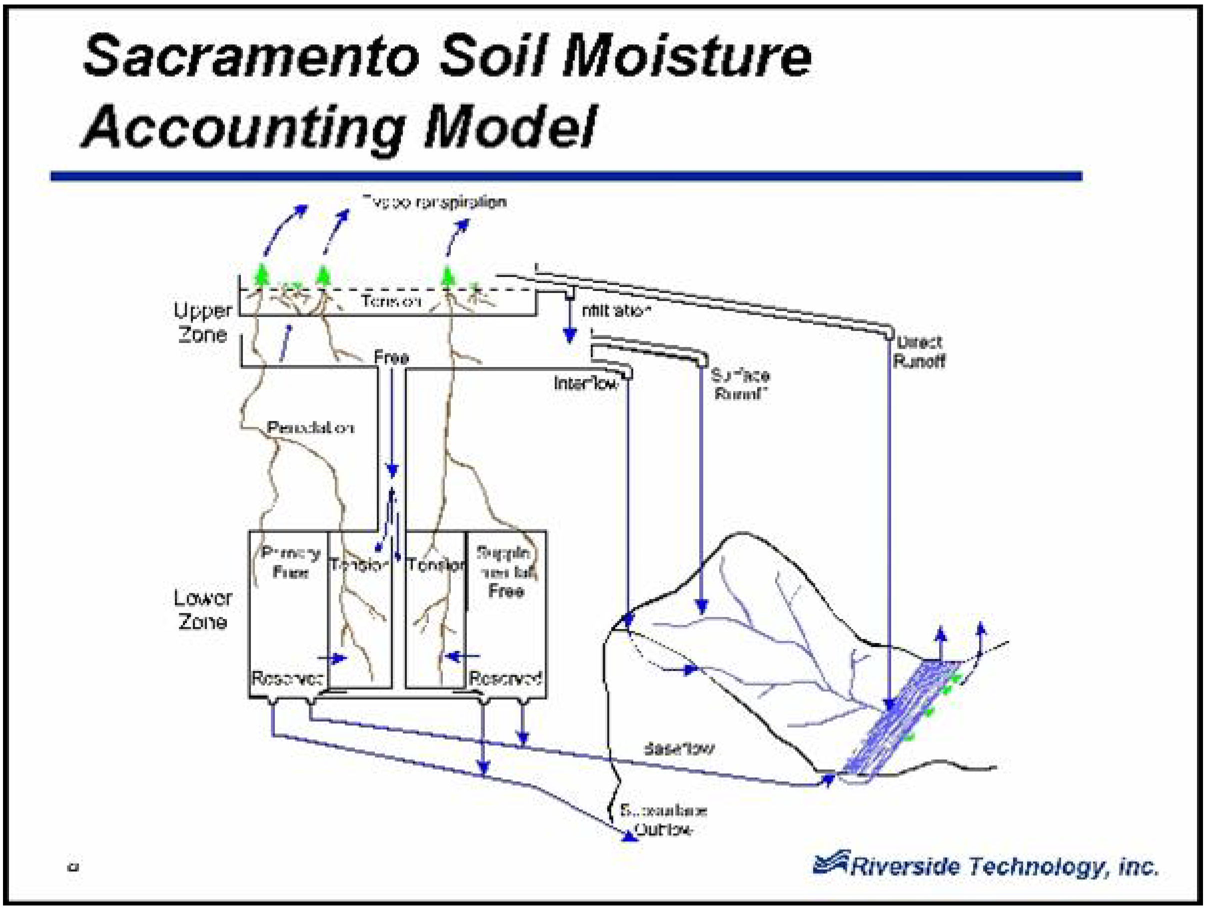


Figure 33 Structure of the Sacramento rainfall runoff model

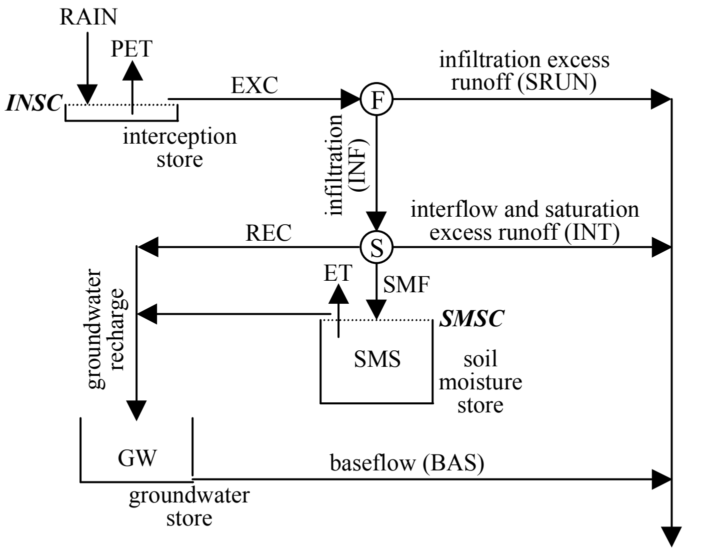
4.3 Simhyd

SIMHYD is a daily conceptual rainfall-runoff model that estimates daily stream flow from daily rainfall and areal potential evapotranspiration data. Data formats are described in Chapter 1 and Chapter 8 respectively.

SIMHYD is a simplified version of the daily conceptual rainfall-runoff model, HYDROLOG, that was developed in 1972 (see Porter, 1972; and Porter and McMahon, 1975, 1976) and the more recent MODHYDROLOG (Chiew and McMahon (1991)). The SIMHYD model has 7 parameters as compared to the 17 parameters required for HYDROLOG and the 19 for MODHYDROLOG.

The structure of the simple lumped conceptual daily rainfall-runoff model, SIMHYD, is shown in Figure 34, with its seven parameters highlighted in bold italics.

In SIMHYD, daily rainfall first fills the interception store, which is emptied each day by evaporation. The excess rainfall is then subjected to an infiltration function that determines the infiltration capacity. The excess rainfall that exceeds the infiltration capacity becomes infiltration excess runoff.



PET = areal potential evapotranspiration (input data)
EXC = RAIN - ***INSC***, EXC > 0
INF = lesser of { COEFF exp (-***SQ*** x SMS/***SMSC***) , EXC }
SRUN = EXC - INF
INT = ***SUB*** x SMS/***SMSC*** x INF
REC = ***CRAK*** x SMS/***SMSC*** x (INF - INT)
SMF = INF - INT - REC
ET = lesser of { 10 x SMS/***SMSC*** , PET }
BAS = ***K*** x GW

Model parameters

INSC	interception store capacity (mm)
COEFF	maximum infiltration loss (mm)
SQ	infiltration loss exponent
SMSC	soil moisture store capacity (mm)
SUB	constant of proportionality in interflow equation
CRAK	constant of proportionality in groundwater recharge equation
K	baseflow linear recession parameter

Figure 34 Structure of the SIMHYD rainfall-runoff model

Moisture that infiltrates is subjected to a soil moisture function that diverts the water to the stream (interflow), groundwater store (recharge) and soil moisture store. Interflow is first estimated as a linear function of the soil wetness (soil moisture level divided by soil moisture capacity). The equation used to simulate interflow therefore attempts to mimic both the interflow and saturation excess runoff processes (with the soil wetness used to reflect parts of the catchment that are saturated from which saturation excess runoff can occur). Groundwater recharge is then estimated, also as a linear function of the soil wetness. The remaining moisture flows into the soil moisture store.

Evapotranspiration from the soil moisture store is estimated as a linear function of the soil wetness, but cannot exceed the atmospherically controlled rate of areal potential evapotranspiration. The soil moisture store has a finite capacity and overflows into the groundwater store. Base flow from the groundwater store is simulated as a linear recession from the store.

The model therefore estimates runoff generation from three sources – infiltration excess runoff, interflow (and saturation excess runoff) and base flow.

4.4 SMAR

The soil moisture and accounting model (SMAR) is a lumped conceptual rainfall run-off water balance model with soil moisture as a central theme (O'Connell *et al.*, 1970; Kachroo, 1992; Tuteja and Cunnane, 1999). The model provides daily estimates of surface run-off, groundwater discharge, evapotranspiration and leakage from the soil profile for the catchment as a whole. The surface run-off component comprises overland flow, saturation excess run-off and saturated through-flow from perched groundwater conditions with a quick response time.

The SMAR model consists of two components in sequence, a water balance component and a routing component. A schematic diagram of the SMAR model is shown in **Error! Reference source not found.**. The model utilises time series of rainfall and pan evaporation data to simulate stream flow at the catchment outlet. The model is calibrated against observed daily stream flow.

The water balance component divides the soil column into horizontal layers, which contain a prescribed amount of water (usually 25 mm) at their field capacities. Evaporation from soil layers is treated in a way that reduces the soil moisture storage in an exponential manner from a given potential evapotranspiration demand. The routing component transforms the surface run-off generated from the water balance component to the catchment outlet by a gamma function model form (Nash, 1960), a parametric solution of the differential routing equation in a single input single output system. The generated groundwater run-off is routed through a single linear reservoir and provides the groundwater contribution to the stream at the catchment outlet. The SMAR model contains five water balance parameters and four routing parameters. The routed surface and the groundwater run-off from the SMAR model are used in the salt mobilisation and wash-off component of CATSALT to estimate the associated salt load.

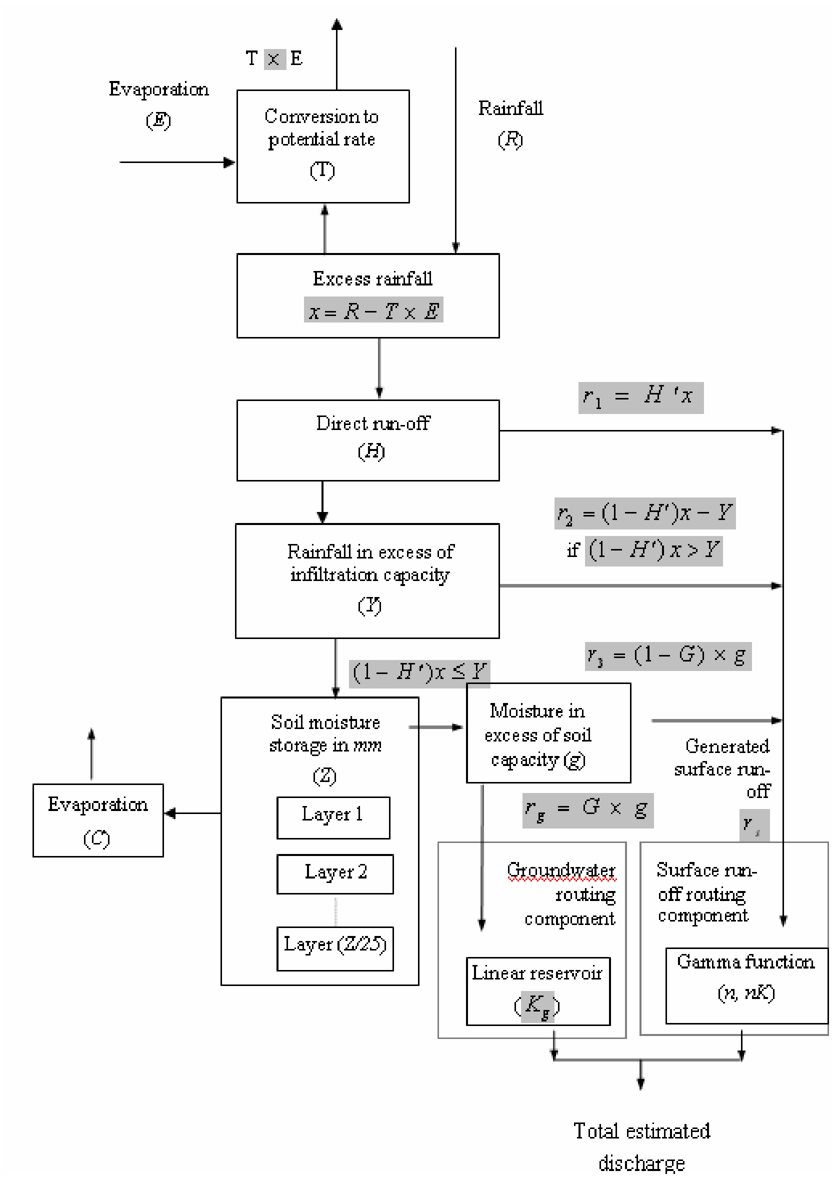


Figure 35 SMAR schematic diagram

4.4.1 Water balance

The water balance component uses five parameters to describe the movement of water into and out of a generalised soil column under conditions of atmospheric forcing: C, Z, H, Y and T.

- The dimensionless parameter C regulates evaporation from the soil layers. Evaporation is assumed to vary as an exponential function of the form C^{i-1}, where C lies between 0 and 1 and i = 1,2,3… refers to the successive soil layers. That is, for a given potential evaporation the first layer can meet that demand at the potential rate, the second layer at a rate C, the third layer at C^2 etc, resulting in a reduction in the soil moisture store in an approximately exponential manner. The potential evapotranspiration rate from the top layer conceptually represents evapotranspiration from the interception storage and from the topsoil during periods of negligible capillary resistance.
- The parameter Z (mm) represents the effective moisture storage capacity of the soil contributing to the run-off generation mechanisms. Each layer holds 25 mm at field capacity.

- The dimensionless parameter H is used to estimate the variable H', the proportion of rainfall excess contributing to the generated run-off as saturation excess run-off or the Dunne run-off. H' is obtained as a product of H, rainfall excess and soil saturation. Soil saturation is defined as the ratio of available soil moisture in mm at time *t* (days) and 125 mm, representing the maximum soil moisture content of the first five layers.
- The parameter Y ($mm \cdot d^{-1}$) represents the infiltration capacity of the soil and is used for estimating the infiltration excess run-off (Hortonian run-off).
- The dimensionless parameter T is used to calculate the potential evaporation from pan evaporation (E).

Generated surface run-off is calculated from the excess rainfall (rainfall minus potential evaporation) as saturation excess run-off (shallow sub-surface flow) plus the Hortonian run-off and plus a proportion (1-G) of moisture in excess of the effective soil moisture storage capacity (g) (i.e. through flow). The remaining proportion (G) of the latter, i.e. the deep drainage component discharged from the groundwater system to the stream, is routed through a linear reservoir, and the total generated surface run-off is routed using a gamma function model form to obtain the daily total estimated discharge at the catchment outlet.

4.4.2 Routing

Groundwater and surface run-off, generated from the water balance component, are routed to simulate the associated lags between rainfall events and flow out of the catchment. The governing equations used in routing component of the SMAR model are presented as follows (Kachroo and Liang, 1992).

The surface runoff routing component

The surface run-off generated from the landscape is routed (attenuation and lag) to the catchment outlet using the linear cascade model of Nash (1960). The model was obtained as a general solution relating a given input of unit volume to a given output as in equation 1.

$$h(t) = \frac{1}{t}\int_{t-1}^{t} \frac{1}{K\,\Gamma(n)} \exp\left(\frac{-\tau}{K}\right)\left(\frac{\tau}{K}\right)^{n-1} d\tau \qquad (1)$$

where, $t =$ simulation time step (d), $\tau =$ time (s), $K_1 = K_2 = \ldots\ldots = K_n = K$ are the storage coefficients of n linear reservoirs in cascade, $h(t) =$ ordinates of the pulse response function (d^{-1}) and and $\Gamma(n) = \int_0^{\infty} \exp(-\tau)\,\tau^{n-1} d\tau$ is the in complete Gamma function (dimensionless).

It was shown by Nash (1960), that under constraints of conservation, stability, high damping and the absence of feedback, this two-parameter equation with n an integer and K positive, is almost as general a model as the differential equation of unlimited order. With additional flexibility obtained by allowing n to take fractional values, the impulse response of this equation has the ability to represent, adequately, almost all shapes commonly encountered in the hydrological context.

The generated run-off (r_s $mm \cdot d^{-1}$)) and the routed run-off (Q_T^r $mm \cdot d^{-1}$) can be time-averaged, as in equations (2) and (3), to represent the daily values.

$$r_s(t) = \frac{1}{t}\int_{\tau-t}^{t} r_s(\tau)\,d\tau \tag{2}$$

$$Q_T^r(t) = \frac{1}{t}\int_{\tau-t}^{t} Q_T^r(\tau)\,d\tau \tag{3}$$

The linear model described by equation 4 is the simplest representation of a causal, time-invariant, relationship between an input function of time (generated run-off) and the corresponding output function (routed run-off). It is used in conceptual modelling, as a component, representing the routing or diffusion, effects of the catchment on those components of the rainfall hyetograph contributing to the outflow.

$$Q_T^r(t) = \sum_{j=1}^{m} h(j)\, r_s(t-j+1) \tag{4}$$

where, $m =$ memory of the pulse response function (d).

The parameter pair n and nK are chosen for optimisation, rather than n and K separately, because n is a 'shape' parameter and nK is the scale parameter. Expressed in this way, the two parameters are likely to be more independent than would be n and K separately, both of which contribute to the scale and to the shape, although in different ways.

Groundwater routing component

The mass balance equation for the groundwater system can be written as in equation 5.

$$Q_T^{rech}(\tau) - Q_T^g(\tau) = \frac{dS(\tau)}{dt} = D\,S(\tau) \tag{5}$$

where, $Q_T^{rech} =$ recharge to the groundwater system ($mm \cdot s^{-1}$), $Q_T^g =$ discharge from the groundwater system ($mm \cdot s^{-1}$), $\tau =$ time (s), $S(\tau) =$ storage of the groundwater system (mm), and $D = d/d\tau$ is the differential operator (s^{-1}).

There are three basic components of discharge from the groundwater system:

- Discharge to the stream until a maximum threshold, after which discharge to land occurs following shallow watertable development.
- Discharge to the land surface that is locked in the landscape and is eventually lost to the atmosphere.
- Inter-basin transport, from the local groundwater system to the regional groundwater system.

Two assumptions are made in treating the groundwater-routing components as a single linear reservoir:

- Discharge to the land that does not eventually reach the river is negligible.
- Inter-basin transport from the local flow system to a regional groundwater system is substantially less than the discharge to the stream (Bear, 1979)

Therefore, $Q_T^g(\tau)$ is comprised mainly of the groundwater discharge to the stream and to the land surface that eventually reaches the stream. The lag times between natural replenishment and groundwater discharge are substantial, and the groundwater system behaves like a highly damped system. This mechanism can be visualised as one of displacement whereby water from episodic drainage events is continually added at the bottom of the root zone and is removed from the groundwater system at a very slow rate. This process can be expressed by a single linear reservoir with a large storage coefficient K_g.

The pulse-response function for the groundwater component can be obtained in a manner analogous to equation 1 as in equation 6.

$$h^g(t) = \frac{1}{t}\int_{t-1}^{t} \frac{1}{K_g} \exp\left(\frac{-\tau}{K_g}\right) d\tau \tag{6}$$

The recharge $Q_T^{rech}(t)$ and the discharge $Q_T^g(t)$ can be time averaged to mm·d^{-1} in an analogous manner, as in equations 2 and 3.

4.5 SWAT core

The model works by solving the following water balance equation:

$$SW_1 = SW_0 + \sum_{i=1}^{t}\left(R_{day} - Q_{surf} - E_0 - w_{seep} - Q_{gw}\right) \tag{1}$$

where SW_1 is the final soil water content (mm H_20), SW_0 is the initial soil water content (mm H2O), Q_{surf} is the amount of surface runoff on day i (mm H_20), E_0 is the amount of evapotranspiration on day i (mm H_20), w_{seep} is the amount of percolation and bypass flow exiting the soil profile bottom on day i (mm H_20), and Q_{gw} is the amount of return flow on day i (mm H_20).

The swat code is not discussed in this document. A full explanation of the SWAT model is supplied in the SWAT reference manuals.

4.6 Tank

The tank model is a very simple model, composed of four tanks laid vertically in series as shown in Figure 36.

Precipitation is put into the top tank, and evaporation is subtracted sequentially from the top tank downwards. As each tank is emptied the evaporation shortfall is taken from the next tank down until all tanks are empty.

The outputs from the side outlets are the calculated runoffs. The output from the top tank is considered as surface runoff, output from the second tank as intermediate runoff, from the third tank as sub-base runoff and output from the fourth tank as base flow.

Despite this simple conceptualisation the behaviour of the tank model is not so simple. The behaviour of the model is strongly influenced by the content of each of the stores. Under the same rainfall and different storage volumes the runoff generated is significantly different.

The tank model is applied to analyse daily discharge from daily precipitation and evaporation inputs. The concept of initial loss of precipitation is not necessary, because its effect is included in the non-linear structure of the tank model.

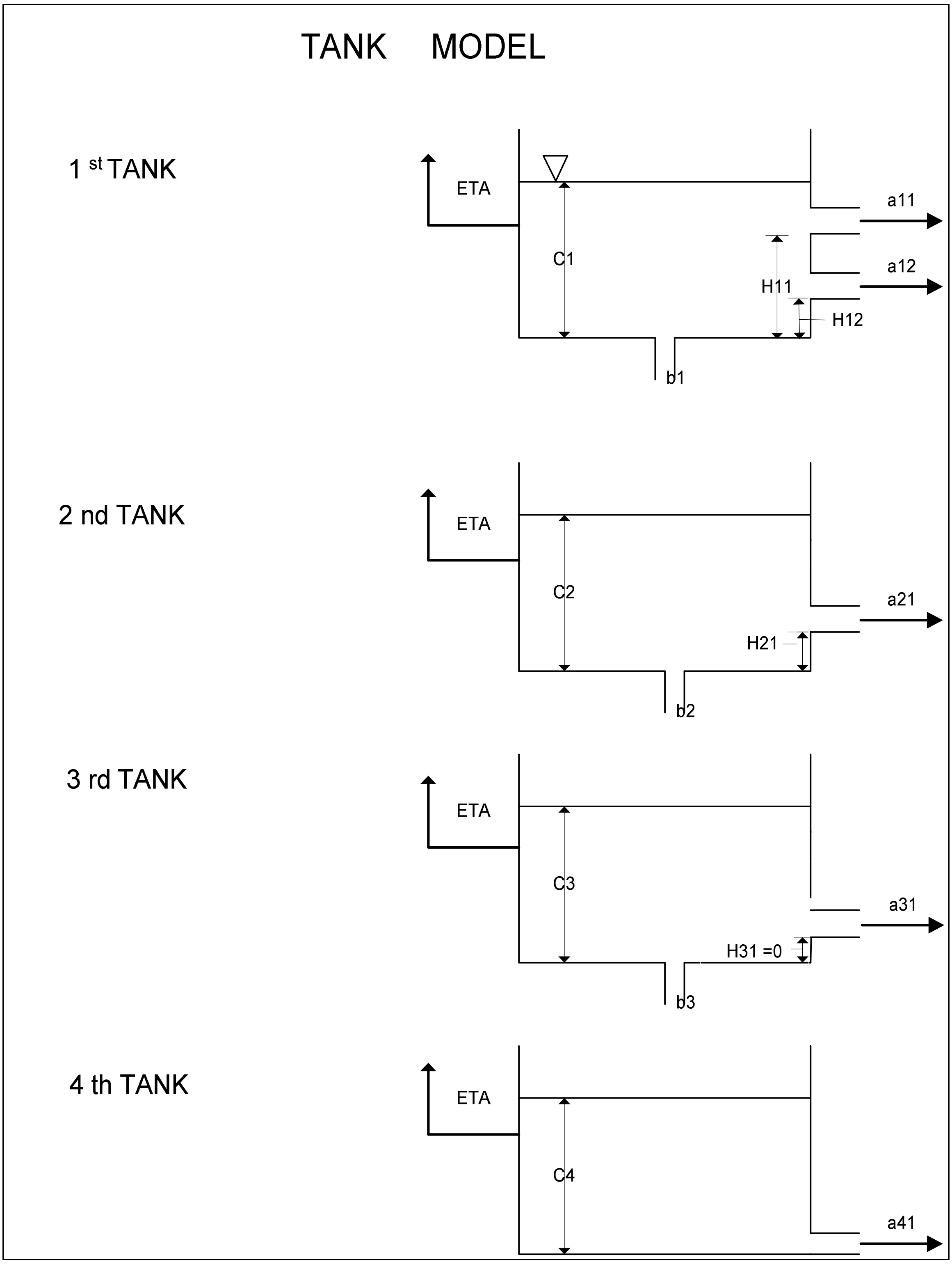


Figure 36 Structure of the TANK model

4.6.1 Runoff

The total runoff is calculated as the sum of the runoffs from each of the tanks. The runoff from each tank is calculated as

$$q = \sum_{x=1}^{4} \sum_{y=1}^{nx} \left(C_x - H_{xy}\right) a_{xy} \qquad (1)$$

Where q is the runoff depth in mm, C_x the water level of tank x, H_{xy} the outlet height and a_{xy} is runoff coefficient for the respective tank outlet. Note if the water level is below the outlet no discharge occurs.

4.6.2 Evapotranspiration

The evapotranspiration is calculated using Beken's (1979) equation.

$$ETA = \sum_{x=1}^{4} 1 - \exp\left(-\alpha C_x\right) \qquad (2)$$

Where ETA is the evapotranspiration in mm, α the evapotranspiration coefficient (0.1) and C_x the water level of tank.

4.6.3 Infiltration

The infiltration in each tank is calculated using:

$$I_x = C_x B_x \qquad (3)$$

Where I_x is the infiltration in mm, C_x the water level of tank x and B_x the infiltration coefficient tank x.

4.6.4 Storage

The amount of water in each tank affects the amount of rainfall, infiltration, evaporation and runoff. The storages are calculated from the top to the bottom tank. The evaporation is initially deducted from the first storage up to a maximum of the potential rate. The remaining potential evapotranspiration is taken from each of the lower tanks until the potential rate is reached or all of the tanks have been evaporated.

After evaporation has been taken from the tanks rainfall is added to the top tank and based on the revised level runoff and infiltration is estimated. This is subsequently deducted from the storage level. The next tank subsequently receives the infiltration from the tank above. The process continues down through the other tanks.

5 Description of optimisers

5.1 Uniform random search

This is a very simple optimisation method where by the parameter space for each parameter is divided up into a specified number of intervals between the minimum and maximum bound. The optimisation proceeds by randomly selecting from the available options for each parameter then running the model and assessing the objective function. This repeat for a specified number of times and the option with the best objective function value is taken as the optimum solution.

5.2 Pattern search

The pattern search is the simplest of all the search methods and has the advantage that it is quick but can suffer from finding local optimums rather than global optimums. This is particularly the case when models are strongly non-linear. The problems of reaching local optimums can be overcome by using a multi-start on the search as discussed in the following section.

The search works by the following method:

1. Start with an initial value and search increment for each of the parameters.
2. Evaluate the objective function for an incremental increase and decrease in current value.
3. If the objective function improves in one direction set the parameter to that value.
4. Increment each of the parameters in the optimum direction and evaluate the objective
5. Repeat to step 4 until there is no improvement in any of the parameters
6. Halve the incremental and go to step 2 until the number of specified interval halvings is reached.

Note if at any stage a parameter reaches a boundary the parameter is limited to the specified boundary value.

5.3 Multi start pattern search

The initial sampling of the parameter space provides the potential for locating the global optimum without being biased by pre-specified starting points. This method works by dividing the parameter values into a specified number of increments between the specified bounds. For each of these possible starting points a pattern search is carried out. The best optimum of the pattern searches is taken as the global optimum.

5.4 Rosenbrock method

The Rosenbrock method (Rosenbrock, 1960; Lewis, 2000) is a local search method bearing some similarities with the Pattern Search method described in the preceding section. This search method returns at each step a point at least as good as the previous one in the parameter space. It was originally designed in order to optimise an industrial process in chemical engineering, and to handle response curves with peculiar features such as functions with narrow curved valleys (e.g. Rosenbrock's banana function detailed in this section). The two main improvements over the pattern search are a better use of the local information from the response curve surrounding the point in the parameter space, and an adaptive step size.

This search method proceeds in a series of so-called stages. A stage is the search in the parameter space following successive directions along an orthonormalised set of vectors (base) of the same dimension as the parameter space. To illustrate the idea behind the algorithm, we will step through the first few iterations of a Rosenbrock search on the aforementioned "banana function", rather than a set of equations. This two-parameter function is defined as:

$$z = (1-x)^2 + 100(y - x^2)^2 \qquad (1)$$

The global minimum is found at $x = y = 1$, and is in a long and narrow valley, as illustrated by Figure 37.

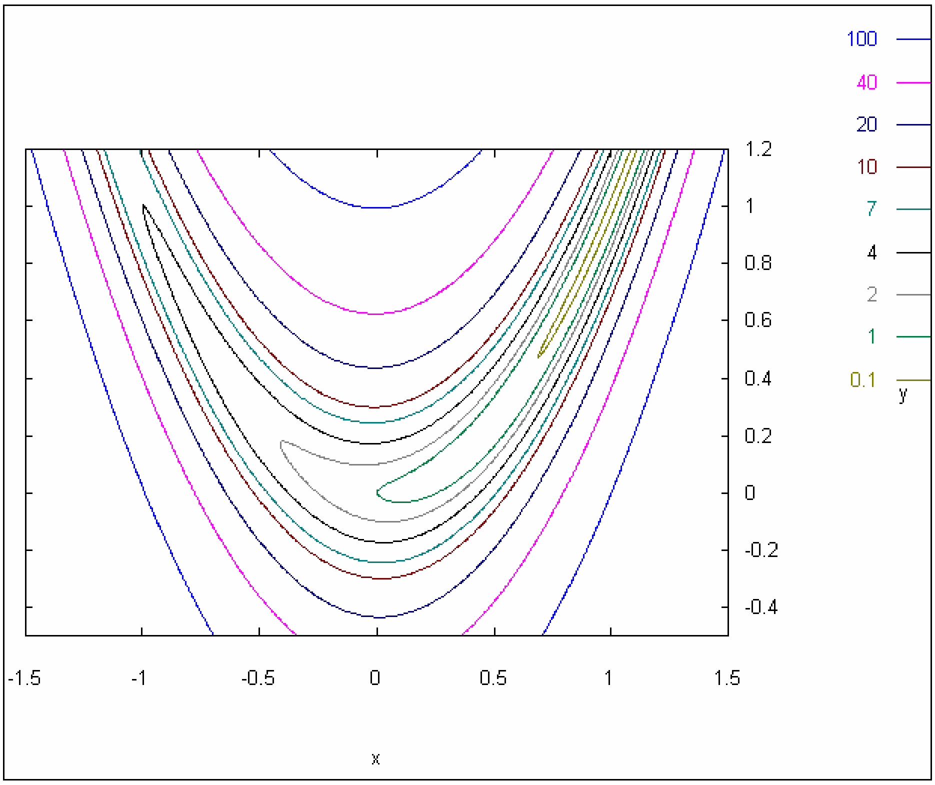


Figure 37 Rosenbrock function

Let us start the search at the point:

$$x = -1,\ y = 0.6. \tag{2}$$

The search starts by initialising the base along the coordinate directions of the parameter space, as shown by Figure 38.

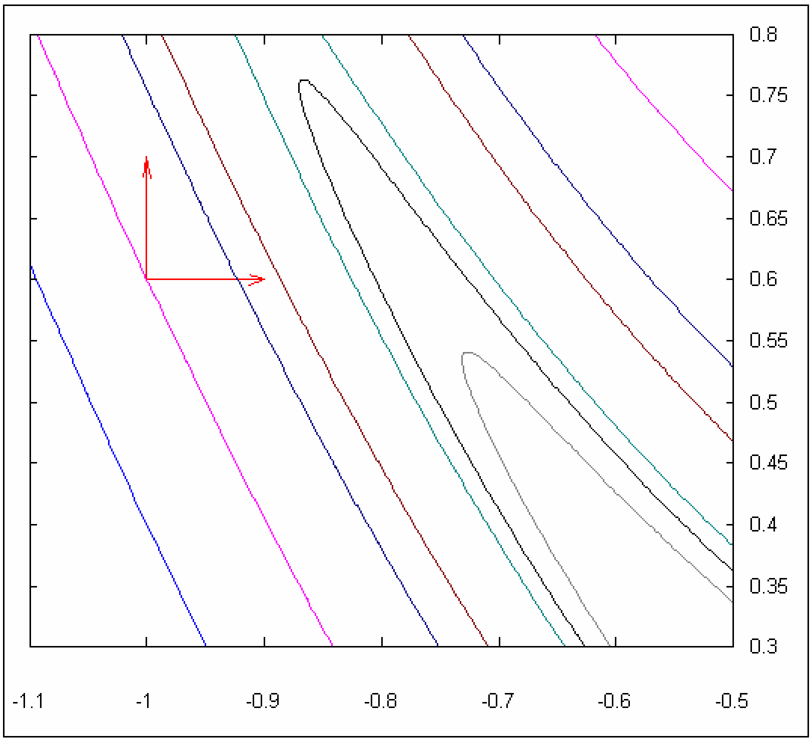


Figure 38 Initial base in the parameter space

The algorithm then searches along these directions. Figure 39 shows the successive successful steps in blue lines. Each time a step in a direction is successful, the step size is increased by a factor $\alpha > 1$ for the next search in that direction. If the attempted step is unsuccessful, the step size is multiplied by a factor $-1 < \beta < 0$. Note that is, going in the other direction. The unsuccessful steps are not shown in the figure, but they are taken into account to define the end of the stage. A stage is completed once there has been at least one successful step and unsuccessful step in each direction.

When the stage is finished, the base is rotated (via a Gram-Schmidt orthonormalisation procedure) in order to have one vector collinear to the overall change achieved by the stage just completed. The motive for this rotation is that the overall direction just obtained is likely to be promising. Note that in the case of **Error! Reference source not found.**Figure 39 this happens not to be true because we optimised into the narrow valley. However the 'second' vector of the new base is promising.

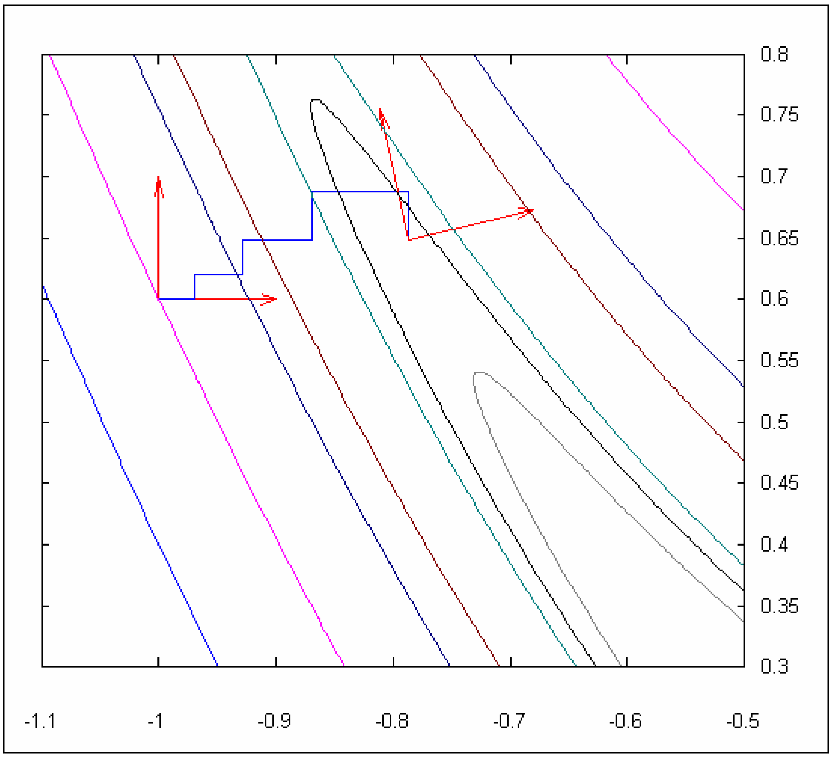


Figure 39 First orthonormalisation of the base

The second stage proceeds in a similar manner to the first one. Note in Figure 40 that within two stages, the new base does have a vector almost collinear with the steepest slope in the narrow valley.

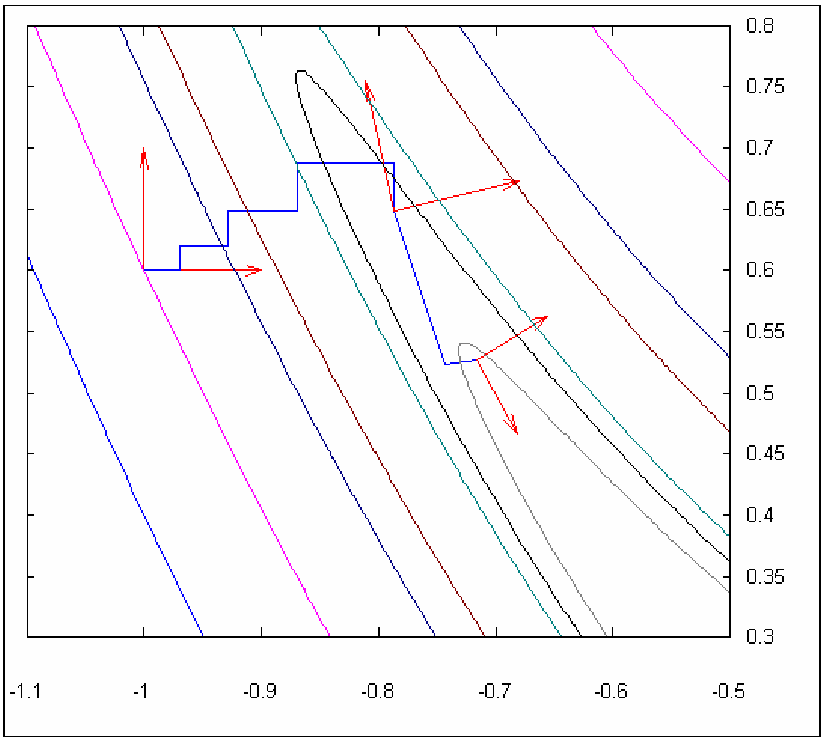


Figure 40 Second orthonormalisation of the base

5.5 Multi start Rosenbrock search

The initial sampling of the parameter space provides the potential for locating the global optimum without being biased by pre-specified starting points. This method works by dividing the parameter values into a specified number of increments between the specified bounds. For each of these possible starting points a Rosenbrock search is carried out. The best optimum of the Rosenbrock searches is taken as the global optimum.

5.6 Genetic algorithm

The genetic algorithm is a search procedure based on the mechanics of natural selection and natural genetics, which combines an artificial survival of the fittest with genetic operators abstracted from nature [Holland, 1975].

The genetic algorithm searches among a population of points and works with a coding of the parameter set rather than the parameter values themselves. It uses probabilistic transition rules.

A population of m (100) points are chosen initially at random in the search space. The objective function values are calculated at all points and compared. From these points two points are selected at random. The selected points are subsequently used to generate a new point in a certain random manner with occasionally added random disturbance. This is repeated until m (100) new points are generated. The generated points are expected to be concentrated in the vicinity of the optima than the original points. The new population points, which can again be used to generate another one and so on, yielding more and more points in the vicinity of the optima.

5.6.1 Parameter coding

The genetic algorithm works with parameter coding. The method of parameter coding that has been used is called binary coding. An l-bit binary variable is used to represent one parameter xi. The integer of the decoded binary variable ranges from 0 to 2l-1 and can be mapped linearly to the parameter range [ai,bi]. The parameter range is discretised into 2l points and the discretisation interval is

$$\Delta x_i = \frac{b_i - a_i}{2^l - 1} \tag{1}$$

For example, when l= 7, the mapping is shown in Table 7. Connecting the codings of all parameters forms the coding for each point in the space to be searched

Table 7 Example of parameter coding for *l*= 7

Binary Code	Integer Value	Parameter Value
0000000	0	Ai
0000001	1	Ai+dxi
0000010	2	Ai+2dxi
…..	…..	…..
1111110	126	Ai+126dxi
1111111	127	Ai+127dxi=bi

5.6.2 Search method

The search is carried out in the following steps:

1. Locate m points randomly in the search space (m = 100 can be used)
2. Find the objective function value at each point
3. Rank the objective function values in descending order.
4. Assign a probability value pj to each point j=1,2,…..,m, giving higher probability to points with a lower function value. The worst point after ranking is j= 1, and its probability value pi will be the smallest. The best point is j= m, and its probability value pm will be the largest. The probability values for other points are linearly interpolated as:

$$p_j = p_1 + \frac{p_m - p_1}{m-1}(j-1) \tag{2}$$

5. The summation of probability values for all points should be equal to unity. The average of probability values for all points is then 1/m. A value C/m can be assigned to pm so that the probability value for the best point is C time the average, where C>1. The corresponding probability value for the worst point p1 is then (2-C)/m. To ensure that all probability values are nonnegative, C <= 2. C=2 was used.
6. Select two points A and B from the m points at random according to the probability distribution pj, j=1,2,…,m.
7. Select two bit positions, k1 and k2, along the overall coding of the parameter set at random, giving each bit position the same chance. If k1>k2, their vales are exchanged.
8. Form a new point by taking the values of the bits from k1 to k2-1 of the A point coding and the values of the bits k2 to the and from 1 to k1-1 of the B point coding.
9. Occassionally change some of the bits of the newly formed point. A bit value 0 will become 1 and vice versa. This occurs to each bit only ata a very small probability pm (pm= 0.01 was used).
10. Repeat steps 5-8 m times so that m new points are produced. The original m points are then replaced by the new ones, forming a new data base for further search.
11. Repeat steps 2-9. The best point found so far is always recorded. Termination of the search is specified by a total number of function evaluations.

Steps 6 and 7 form the core of the method. Better points have a better chance to be chosen to form new points. This is analogous to the survival of the fittest in the theory of natural selection. The better performing individuals produce more offspring. A new point is formed by taking different blocks of bits from the codings of the two original points. This is analogous to crossover in the theory of genetics. An offspring takes some of the genes from one parent and some from the other one. Fit parents are likely to produce fit offspring. The combination of selection and reproduction improves the performance level of the population as the process move on. The occasional change of bit values in step 8 is analogous to mutation in the theory of genetics. It provides some background variation.

5.7 Shuffled complex evolution

The shuffled complex evolution (SCE-UA) method is based on a synthesis of four concepts:

1. Combination of deterministic and probabilistic approaches,
2. Systematic evolution of a 'complex' of points spanning the parameter space, in the direction of global improvement,

3 Competitive evolution, and

4 Complex shuffling.

A general description of the steps of the SCE-UA method is given below (a more detailed presentation of the theory underlying the SCE-UA algorritthm has been given by Duan st al. (1992,1993):

1 Generate *s* sample points randomly in the feasible parameter space and compute the objective function value at each point.

2 Rank the *s* points in increasing objective function value such that the first point represents the smallest objective function value (assuming that the goal is to minimise the objective function).

3 Partion the *s* points into *p* complexs, each containing *m* points. The complexes are partioned such that the first complex contains every $p(k-1)+1$ ranked point, the second complex contains every $p(k-1)+2$ ranked point, and so on, where $k=1,2,\ldots..,m$.

4 Evolve each complex according to the competitive complex evolution (CCE) algorithm as detailed below.

5 Shuffle complexes by combining the points in the evolved complexes into a single sample population; sort the sample population in order of increasing objective function value; shuffle the sample population into *p* complexes according to the procedure specified in Step 3.

6 Check for convergence by checking if any of the pre-specified convergence criteria are met, stop; otherwise, continue.

Check the reduction in the number of complexes, if the minimum number of complexes required in the population, p_{min}, is less than *p*, remove the complex with the lowest ranked points; set $p=p-1$ and $s=pm$; return to Step 4. If $pmin=p$, return to Step 4.

6 Model Calibration

This Chapter discusses the things that need to be considered when calibration a rainfall runoff model. The chapter covers:

1 Data preparation

2 Calibration and validation periods

3 Manual calibration of models

4 Automatic calibration of models

5 Sensitivity of parameters

6.1 Data preparation

The most important step in calibrating a rainfall runoff model is data preparation. Time spent in ensuring that the best possible data set is used will greatly speed up the calibration process. The rainfall runoff models require four important data sets:

1 Catchment characteristics,

2 Rainfall,

3 Evapotranspiration, and

4 Flow.

6.1.1 Catchment characteristics

Generally the only catchment characteristic required by lumped rainfall runoff models is the catchment area. However, in some cases models e.g. SWAT need to know slope, land use, soil profile, soil depth, and hydraulic conductivity.

The models operate in mm and to convert the model output from runoff depth to runoff volume catchment area is required. The catchment area is usually an easy parameter to obtain but should be used with caution. The area is dependent on the scale of maps or DEMs that it was derived from and in flatter areas there can be large uncertainty with regard to where catchment boundaries are. A small error in cathment area can cause a large error in the estimated volume that runs off the catchment.

Although slope, land use, soil profile, soil depth and hydraulic conductivity may not be used by a model this information is also worth considereing. The type of land use will influence surface runoff characteristics, evpotranspiration rates and interception losses. The soil characteristics will influence the size of soil stores and seepage rates. This sort of information is invaluable for setting realistic bounds on model parameters as well as sanity checking the fluxes out of the model.

6.1.2 Rainfall data

The calibration of a rainfall runoff model is most sensitive to the rainfall data that is provided. If the volume of rainfall is incorrect or the rain days are not representative of the peaks in flow then calibration may be difficult with very poor results.

There are several things that need to be considered in the preparation of rainfall data:

- Catchment average rainfall.
- Selection of appropriate rainfall sites.

Catchment average rainfall

The catchment average rainfall can be estimated by many different methods, two of the more common methods are discussed here. The first method is to draw a isoheytal map across the catchment and the second method is sum grid squares from a rainfall surface (spline).

An isoheytal map is basically a contour map, of typically, average annual rainfall. Drawing an isoheytal map is a relatively easy process when there are a number of gauges in and surrounding the catchment. Care should be taken to ensure all rainfall sites are gap filled and that the period selected is common to all sites.

Climate databases such as SILO have splined surfaces that cover Australia. These surfaces take into account location, distance from coast and elevation to derive average annual rainfall across grid squares. This can be summed for the grid squares in a catchment and averaged.

Rainfall site selection

There are several things that need to be considered in selecting rainfall sites:

- Difference in average annual rainfall as compared to the catchment average annual rainfall.
- Proximity to the catchment.
- Correlation with flow peaks.
- The number of sites used.

If the difference in average annual rainfall is great (e.g. more than 20%) then the rainfall process for the catchment and selected site are probably quite different and this is not a good station to use. The RRL provides a data scaling dialogue, as shown in Figure 41, that allows monthly or annuall factors to be applied to rainfall data to adjust for catchment average rainfall.

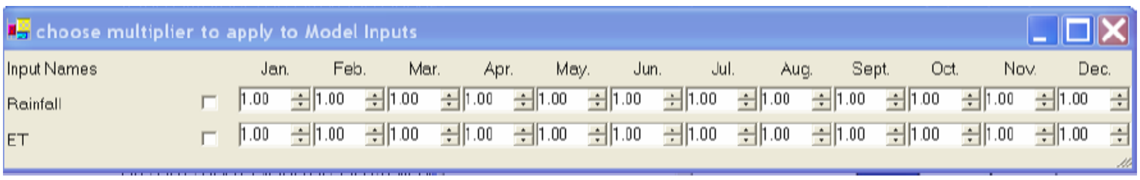


Figure 41 Rainfall and evaporation data scaling

Unfortunately studies have shown that rainfall decorrelation distance is approximately 10km and there are not many places in Australia where rainfall stations are this close together. In most cases stations in the catchment should have priority over ones outside the catchment. However in quite a lot of cases there may not be any long term stations in the catchment. In cases like this short term stations in the catchment may be used to assess which long term stations are most representative.

A good method for assessing how well a rainfall station represents the flow from the catchment is to plot the rainfall and flow on similar scales. The rainfall peaks can then be checked against the flow peaks to see if the size of peaks correlates with the amount of rainfall and that the peaks occur at about the same time.

The number of sites is a very important issue when multiple rainfall sites are available. Typically Theissen weightings are used to associate a protion of the catchment with each rainfall station. There are a few things to consider:

- More is not always better. The more stations you have the more raindays that will occur on the catchment. Care should be taken to makes sure that the number of rain days per month is similar to the number of flow peaks per month.
- When generating long flow records it is tempting to have Theissen weightings that vary as rainfall sites cut in and out. This approach should be used with extreme caution, as calibrating models to different groups of stations generally leads to different calibration parameters. Consequently, you will have no idea how robust the model is when the number of rainfall sites is considerably different to the period when the model was calibrated.
- Be very careful when using rainfall surface data for the reasons mentioned above. It is not recommended that rainfall be used for every grid square that is available in the catchment. A better approach is to use the monthly surfaces at each grid square to estimate the average rainfall on the catchment each month and then disaggregate this data to daily data with selected Theissen weighted rainfall sites.

6.1.3 Evapotranspiration data

There are many different methods of estimating evapotranspiration. A few of the common methods are listed below:

- Evaporation pan (Class A, sunken tank, sunken tank with bird gard),
- Lysimeter,
- Priestely Taylor equation,
- Morton equation,
- Penman equation, and
- Penman Monteith equation.

The important issue with evaporation data is that all of these different methods will provide a different estimate of evaporation. It is important that whatever source is used that it is consistent with what the model requires. There are typically two different types of evapotranspiration data required by models, potential evapotranspiration (E_0) and actual evapotranspiration (E_a).

There are factors that can be applied to each of these data sources to convert to the appropriate type of evapotranspiration. The RRL has a data scaling dialogue that allows annual or monthly factors to be applied to evaporation data.

6.1.4 Flow data

The flow data is what the rainfall runoff model is calibrated against and in calibrating against the flow data the assumption is made that this data has no errors. This is not the case and consequently care should be taken to ensure that the flow data is of good quality. There are several things that need to be considered:

- How height data is collected

- How stable is the rating at the site
- The relationship between height i.e. how sensitive is a flow estimate to a change in height.
- Looped ratings i.e. where the rating on the rising and falling limbs of hydrographs are different.
- Sticking gauge i.e. how believable is it at low flows.
- The highest rated flow.

After assessing the flow data it may be appropriate to remove unrealistic data from the record prior to calibration. It is also important to know what part of the flow range has the least error.

6.2 Calibration and validation period

There are two ways of approaching a rainfall runoff model calibration:

1. Considering the entire period of record, and
2. Considering a proportion of the record for calibration and the other proportion for verification.

6.2.1 Calibrating over the entire period

The main advantage of doing this is that the most optimum calibration for the available data can be achieved. The problems with this is that you have no indication of how the model is likely to perform outside of the calibration period, i.e. how robust is the model. For this reason this is not the recommended approach for calibrating a model.

In some circumstances where there is only a small amount of data available then there may be no other option but to use the entire period for calibration. If this is the case then it is important that the robustness of the model be checked by assessing:

- How representative the rainfall period is i.e. is it wet, dry or average. How close are the extremes of wet and dry to the extremes in the long term record.
- Are there periods when the soil stores are fully saturated and fully dry.
- Are the proportions of surface flow, interflow and base flow appropriate given the catchment size, catchment shape, soil type and land use.

How representative the rainfall period is can be checked by plotting up the annual rainfall volumes of each year in an exceedance plot. The extremes of rainfall during the period of flow record can be checked to see it they lie within the bottom and top thirds of the the annual rainfall excedence. The mean annual rainfall for the calibration period can be checked against the mean annual rainfall for the entire period of record.

If the dry extreme is above the lower third of rainfall and/or the mean of the calibration period is one standard deviation above the mean of the entire period of record then it is likely the calibration will have a bias toward wet periods. This will mean that the model wil perform well during wet periods but is likely to overestimate flows during dry periods.

If the wet extreme is below the higher third of rainfall and/or the mean of the calibration period is one standard deviation belowthe mean of the entire period of record then it is likely the calibration will have a bias toward dry periods. This will mean that the model wil perform well during dry periods but is likely to underestimate flows during wet periods.

When the model has been calibrated it is worth checking how robust the model calibration is by assessing if soil stores reach the extremes of fully saturated or fully dry. This will give some indication of how the model operates under fully saturated surface flow and pure base flow. If the runoff match during fully saturated conditions is good then the model will perform reasonably well during wet periods. If the baseflow recessions match reasonably well during an extended dry period then the model is likely to perform well in dry periods.

Quite often during optimised calibrations it is possible for storages to be calibrated to operate incorrectly with too much baseflow coming out fo interflow stores and vice versa. It is worth checking that the relative proportions of flow coming out of these stores and the recessions are appropriate. Check that the interflow store empties quicker than the base store. Check that the volumes of interflow and base flow are appropriate for the type of catchment.

6.2.2 Calibration and validation

Given a suitably long period of flow record this is the preferred method for calibrating rainfall runoff models. This method gives a way of assessing the robustness of the model for periods outside of the calibration period.

When using calibration and validation periods it is important that an appropriate calibration period be selected. The model should be preferably calibrated in a period that has both wet and dry extremes and has an average annual flow similar to the average annual flow for the whole period of record. The RRL provides two buttons in the date dialogue that will show the wettest and driest annual flow periods (Section 3.1.2).

When selecting a continuous calibration period it is not always possible to get both wet and dry extremes in the calibration period. In most cases it is more important to include the dry extreme as this will better set the size and discharge rates of the soil stores.

If possible the validation and calibration periods should be of similar length. However to include sufficient climatic variability in the calibration period it may be possible to have the validation period only cover one third of the period of record.

There are several other issues that should be taken into consideration when selecting a calibration period:

- The intended use of the model. Is the model to be used for yield analysis, water allocation or flood prediction?
- Over the period of flow record has there been any change to the methods of measuring flow (height recorders and rating curves)?
- Has there been any significant change in land use over the period of flow record.

If the model is to be used for yield analysis or water allocation then selecting a calibration period that represents average or dry conditions is important. If the model is to be used for flood predictions then choosing a wet period for calibration is important.

Quite often over long flow records the type of instrument used to record river level will vary. In the early records daily read staff gauges or Bristol recorders may have been used. It is probably a better option in such cases to calibrate during periods of more accurate flow records and assess how well the model performs during the other periods. For example you would be expecting the model to over estimate flows as compared to a daily read staff gauge. You may also find a smoother shape in recessions compared to a Bristol recorder.

There may be significant changes in ratings at a site. This can be caused by a change in control at that site. The selection of the calibration period should be a period of reasonable stable ratings that best represents the intended period of use for the model.

Land clearing can have a significant effect on the flow characteristics of a catchment particularly during dry periods. The clearing of vegetation generally reduces evapotranspiration rates and increases the proportion of surface runoff. The calibration period should be selected based on the land-use that is most appropriate for the intended use of the model.

6.2.3 Model warm up

When rainfall runoff models start some estimate of the contents of each of the soil moisture stores needs to be made. This can be done by assessing the rainfall conditions prior to the start of the model or by selecting a warm up period such that the soil store will be at a known level. If the warm up period is wet then all of the soil stores may be full or if the warm up period is dry then the stores may be empty.

The RRL provides a tool for automatically setting the model warm up period for both calibration and validation (Section 3.1.2). The RRL estimates the warm up period by starting the model at different initial condtions and determining where the answers converge. If there is no convergence found a warning message is displayed and the warm up period is not set.

6.2.4 Setting the periods

Having chosen appropriate periods for calibration and validation these periods can be set by entering the appropriate dates in the date fields or by using the slider bars.

6.3 Manual calibration of models

The RRL provides many different types of optimisers for calibrating models. However manual calibration is also an important aspect of model calibration. Manual calibration can be used to investigate how the different parameters change the shape of the simulated hydrograph and also to refine an optimised calibration.

The RRL provides a manual calibration tab in the calibration dialogue (Section 3.1). This tab contains:

- A dynamic update checkbox,
- List of calibration parameters, and
- An update graph button.

6.3.1 Dynamic update

The dynamic update check box allows the user to decide whether the graph is updated each time a calibration parameter is changed or not. If checked the graph is updated when a parameter is changed.

This is an extremely useful facility for investigating how the model behaves as different parameters are changed. It also gives the user an idea of how sensitive the model is to changing each of the parameters.

This can be quite slow if the calibration period is long and the model is complex. In such cases the calibration period could be shortened for investigation purposes and then increased when full calibration is required.

6.3.2 List of calibration parameters

This list will vary depending on which model has been selected. The parameter values can be incremented by using the spinner next to the parameter or for fine tuning the parameter can be typed in.

6.3.3 Update graph

If the run time of the model is quite long it can take some time for the graph to update if dynamic update has been set. If dynamic update has not been set activating this button will run the model with the current parameters and update the graph.

6.4 Automatic calibration of models

There are two tabs in the calibration dialogue that allow for automatically calibrating models, Generic and Custom. The generic tab as the name suggest applies to all models while the Custom facility is a pupose built calibrator for a particular model. At present there is only one custom calibration tool and that is for the AWBM model. For all other models custom calibration is not available.

6.4.1 Custom calibration of AWBM

The AWBM custom calibration is a specific facility written to automatically calibrate the AWBM model. To use this facility:

1 Select the custom tab in the calibration dialogue.

2 In the custom method drop down menu select AWBM automatic calibration (currently the only option).

3 Select the **parameters** button to display the optimiser parameters dialogue. There are two optimisation parameters that can be set, convergence criterion and maximum average capacity. Note the default settings are a good place to start.

4 Press the calibrate button to start the model.

The calibratin results can be reviewed by pressing the calibration results button. Depending on how well the optimiser is converging the optimisation may need to be adjusted and then recalibrate the model.

6.4.2 Generic calibration

There are seven optimisation algorithms available (Chapter 5):

1 Uniform random sampling

2 Pattern search

3 Pattern serach multi start

4 Rosenbrock

5 Rosenbrock multi start

6 Genetic algorithm

7 SCE-UA

There are options of having both a primary and secondary objective function. There are 8 primary objective functions available:

1 Nash-Sutcliffe criterion (Coefficient of efficiency)

2 Sum of square errors

3 Root mean square error (RMSE)

4 Root mean square difference about bias

5 Absolute value of bias

6 Sum of square roots

7 Sum of square of the difference of square root

8 Sum of absolute difference of the log

There are four secondary objective function options:

1 None

2 Runoff difference in %

3 Flow duration curve

4 Base flow method 2

The weightings and parameter values for the secondary objective function can be set by clicking on the parameter button below the drop down menu.

This will display a functions parameter dialogue where specific objective function parameters can be set, including the weighting to be applied to the second objective function.

The user can also decide to apply the objective function to either daily or monthly time steps. If the calibrate on monthly values checkbox is checked the objective function will be evaluated based on the monthly aggregate of the daily data.

Objective functions

Objective functions

The equations for each of the objective functions are detailed below. The modelled value number i in the time series is noted $m(i)$, and the observed value is noted by the letter 'o',

Nash-Sutcliffe

The Nash-Sutcliffe criterion, also known as efficiency, is a common mesure of fit in rainfall-runoff modelling, interpreted as how much better the fit is as if one was using the average of the observed data to represent it. The objective function used in the RRL is a slight variation of the standard one:

$$1-\frac{\sum(m(i)^{\lambda}-o(i)^{\lambda})^2}{\sum(o(i)^{\lambda}-mean\_obs^{\lambda})^2}$$

where λ is between 0 and 2. This simple box-cox transform allows giving more weight to the lower flows (if less than 1) or to the high flows (more than 1) in the calibration process.

Sum of the squares of error

$$\sum(m(i)-o(i))^2$$

Root mean squared error

$\dfrac{\sqrt{\sum(m(i)-o(i))^2}}{n}$ where n is the length of the time series

RMS about the bias

The biais is defined as $bias = \frac{\sum(m(i) - o(i))}{n}$ and the root mean squared about the bias as

$$\frac{\sqrt{\sum(m(i) - o(i) - bias)^2}}{n}$$

Sum of the square roots

$$\sum\sqrt{|m(i) - o(i)|}$$

Sum of squares of difference of square roots

$$\sum\left[\sqrt{|m(i)|} - \sqrt{|o(i)|}\right]^2$$

Sum absolute value of the difference of the log

$$\sum\left|Log_{10}(m(i)) - Log_{10}(o(i))\right|$$

Dual Objective

Generic calibration can be performed optionally on several objectives. As of November 2003 there are three ways to have a secondary objective. The background programming logic already allows a much more sophisticated approach and for full multi-objective calibration, but the current interface has been kept relatively simple on purpose. More options are likely to be available in future versions or other Toolkit products.

Constraint on the total runoff

This dual objective penalises the primary objective when the relative total runoff depth difference between the observed and calculated data goes beyond a threshold expressed in percentage. Note that since there is in general no certainty that the model is structurally capable of respecting this constraint, the result of the calibration may still give results beyond the specified threshold.

Dual calibration on the flow duration curve

This option uses the same objective as the one selected as the primary objective, with the same parameters (e.g. lambda Box-Cox), but applies it to a sample of the duration curve (100 values are taken from the curve for each percentile). Since there is a loss of information (i.e. the dates) between the time series and the duration curve, it is wise to keep an intermediate value for the weighing of the two objectives, this weighing parameter can be accessed via the Parameter button of the second objective.

Dual calibration on the baseflow

This option uses the same objective as the one selected as the primary objective, but is applied to the baseflow output of the model. The baseflow calibrated against is derived from the observed runoff depth by the use of a baseflow filter (Grayson (1996)). There are two parameters controlling this filter, plus a weighing parameter for the weighing of the two objectives, accessible via the Parameter button of the second objective. The calculated Baseflow is either taken from the appropriate model output, or filtered from the calculated runoff if the model does not define any Baseflow as an output.

Selection of the objective function

The selection of the objective function will give the calibration a bias toward the range of flows that the objective function determines as most significant. The intended use of the model should be taken into consideration when selecting the objective function. The selected object should give a bias towards the flow characteristics that are of greatest importance such as overall volume, monthly volume, surface runoff and base flow.

Running the optimiser

Once an optimiser has been chosen and a combination of objective functions selected the optimised calibration can begin. The user can check the dynamic update check box to display the current value of the objective function in the graph window. This facility does add some overhead to the model run time and for long calibration periods with slow models this option can be turned off to speed up the optimisation process.

To start the optimisation the calibration button should be clicked. A progress percentage, optimisation time and progress bar will show the progress of the optimisation. Note the optimisation can be stopped at any time by clicking on the stop button.

When completed the graph can be viewed by selecting a graph display option. The progress of the optimiser can be viewed by clicking on the calibration results button. The stats of the calibration can be viewed by clicking on the data statistics button.

The view button recalls the latest graph of objective functions following a generic calibration. Note that if the Dynamic Update option was previously not selected, checking it will also display the latest recorded graph if any is present.

6.5 Parameter sensitivity

It is important to understand how sensitive a model is to certain parameters. This is useful to understand how the model functions and also what parameters need more attention than others. If the model is significantly affected by a particular parameter than the focus of calibration should be on that parameter. The uncertainty of the model will also be closely related to the uncertainty in estimating the most sensitive parameters. The RRL provides a facility to investigate the sensitivity of all model parameters.

Note that in most rainfall runoff models the behaviour of many parameters is related to the values of other parameters i.e. the models are non-linear. Consequently the sensitivity of particular parameters may be different depending upon the values of other parameters.

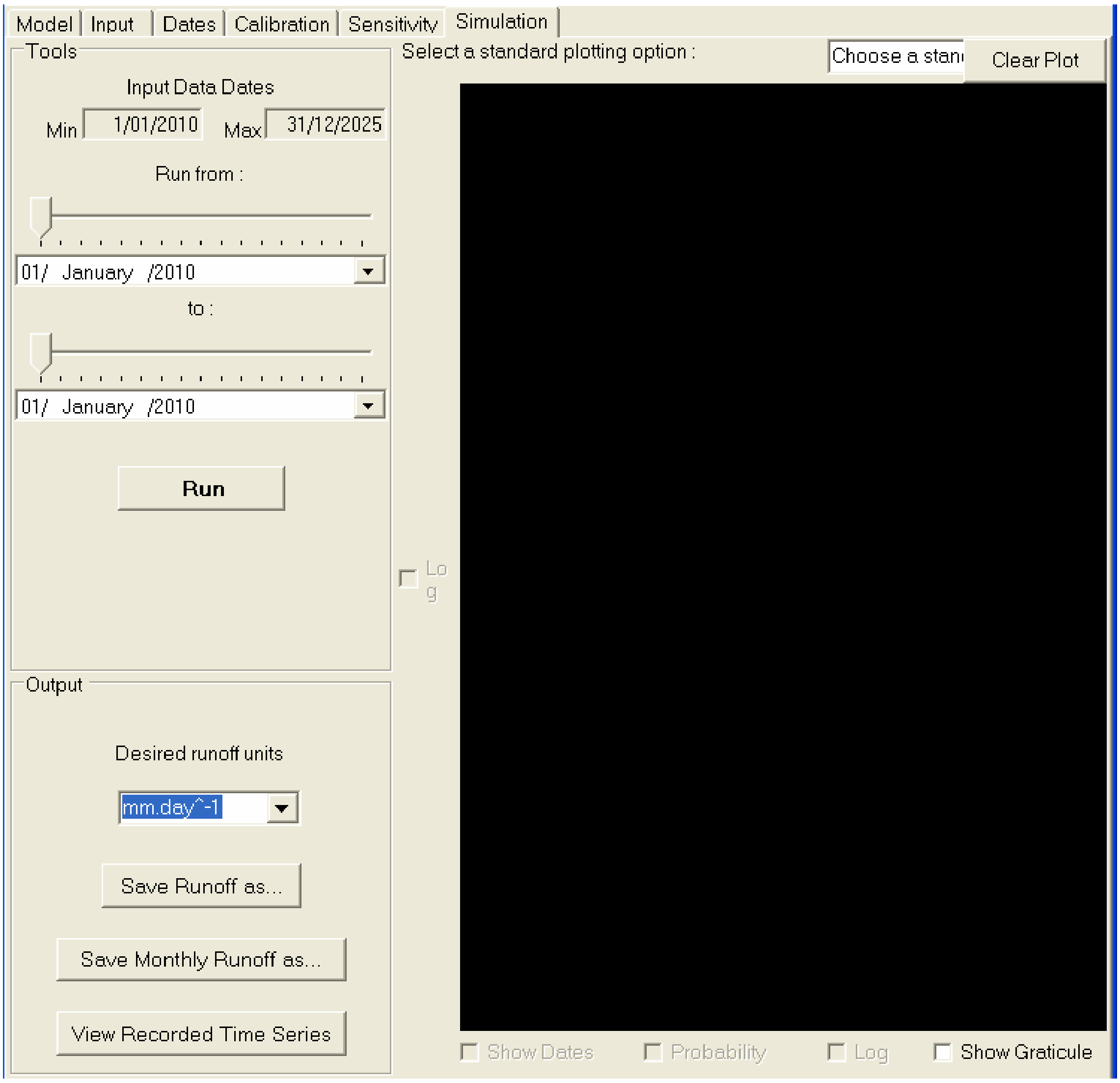
7 Saving results

This chapter discusses saving results of the model calibration and the project file.

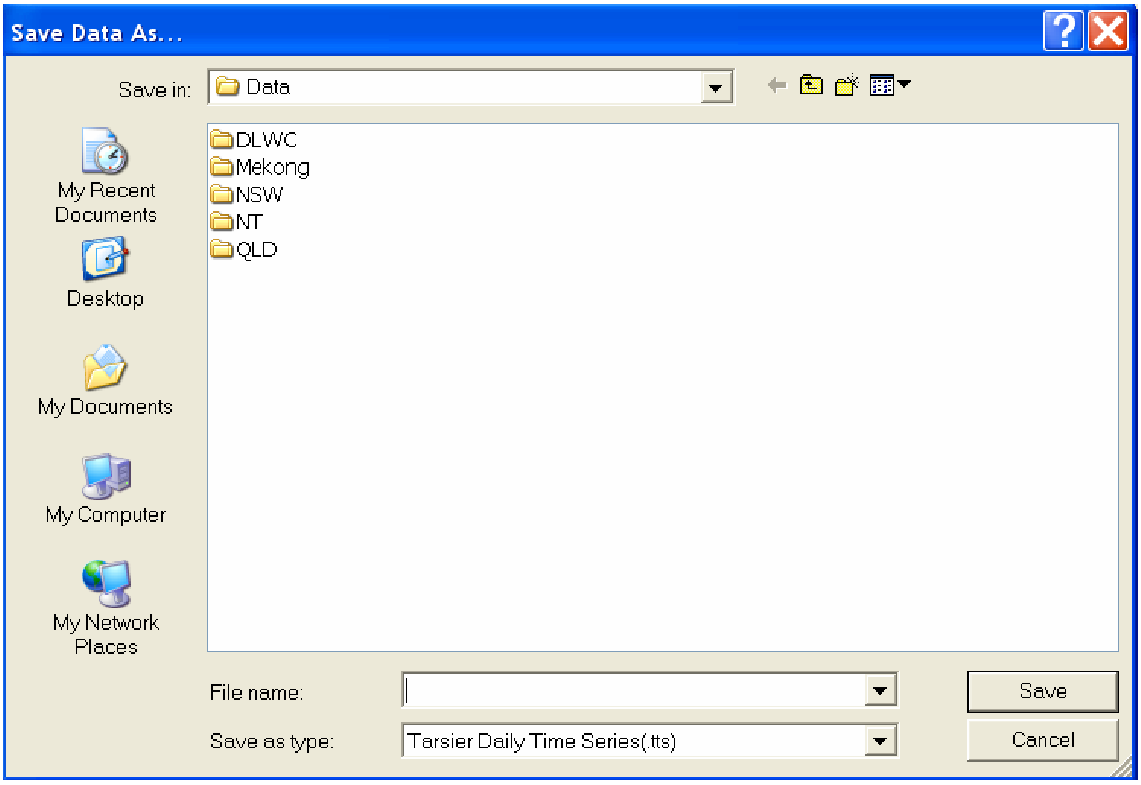
7.1 Saving model calibration results

To save model results:

1 Select the simulation tab dialog as shown below.



2. Specify the period of time that you want model results by sliding the start and end date sliders
3. Select the run button
4. From the desired runoff units select what ouput units required.
5. To save as daily or monthly data, select the appropriate button.
6. The Windows save as dialogue will be displayed



Note the default directory for saving data is the RRL data directory. The Save as type lets the use save the uutput in various formats.

1 Select the output format required

2 Enter a file name without an extension

3 Select the save button.

7.2 Saving the project file

To save the project file for future use:

1 Select the **File** | **Save** or **File** |**Save as** menu option

2 The standard windows save dialogue will be displayed

Note the default directory for saving project files is the RRL project directory. The save as option lets the user save the file under a different name.

8 Data storage and file formats

8.1 Data storage

The directory structure of the RRL is organized relative to the installation directory (root). The default root directory is c:\program files\toolkit\ rainfall runoff library. The data storage structure is:

Installation directory

- Projects

Data

  - Example AWBM
  - Example Sacramento
  - Example Simhyd
  - Example SWAT
  - Example SMAR
  - Example Tank
  - Rainfall
  - Evaporation
  - Flow

Help

Documentation

  - User Manual
  - Training

8.1.1 Installation directory

The installation directory contains the executable code and associated dll's required to run the RRL.

8.1.2 Projects sub directory

The project sub directory is the default directory used to store the RRL project files. Initially this directory contains a project file for each of the rainfall runoff models.

8.1.3 Data sub directory

The data sub directory contains an example directory for each of the rainfall runoff models. These example directories contain the input data files necessary to run and calibrate the models. They are also associated with the example project files contained in the project directory.

The data directory also includes three data directories for rainfall, evaporation and flow data collected from various sources.

8.1.4 Help

The help directory contains a version of the User Manual converted into a windows help file. This file can be viewed by double clicking on the file. The file is also used by the RRL to display help via the help menu.

8.1.5 Documentation directory

The documentation directory has two sub directories one which contains a PDF version of the User Manual and the other contains training material.

8.2 File formats

8.2.1 AWBM daily time series format

An AWBM daily time series format file is an ASCII text file that contains daily time series data. There is no header line in the file. The data is organized in rows of one month of data seperated by the spaces. The first entry in a row is the number of days in the month. This is followed by data values for each day in the month. The data values are followed by the year and month of the data. An example of this format is show in Figure 42.

```
31 0 0 0 0 0 0.....0 0 0 0 1.2 0 0 0 0 0.08 0.8 15.28 0.88 0.08 0 0 0 2001 1

28 0 0 0 0 0 0.....1.68 0 0 0 0 0 0.24 0.56 3.28 0.88 0.4 0 1.28 3.12 2001 2

31 0.08 0 0 0..... 0 0.08 0.8 0 2.48 0.8 3.28 1.28 0.08 0.24 0 0.88 2001 3
```

Figure 42 Example ofAWBM daily time series format

8.2.2 Chiew and Siriwadena daily rainfall time series format (.rain)

An Chiew and Siriwadena daily rainfall time series format file is an ASCII text file that contains daily time series rainfall data. There is no header line in the file. The data is organized as date followed by data value. The date is in year (4 characters), month (2 characters) and day (2 characters) format. The data value is specified to 3 decimal places (10 characters). An example of this format is shown in Figure 43.

```
20011228     0.000
20011229     0.000
```

```
20011230     0.000
20011231    10.200
2002 1 1     0.000
2002 1 2     0.000
2002 1 3     0.000
2002 1 4    16.000
```

Figure 43 Example of Chiew Siriwadena daily rainfall time series format

8.2.3 Chiew and Siriwadena monthly flow time series format (.flow)

An Chiew and Siriwadena monthly flow time series format file is an ASCII text file that contains monthly time series flow data. There is no header line in the file. The data is organized as date followed by data value. The date is in year (4 characters) and month (2 characters). The data value is specified to 2 decimal places (12 characters). An example of this format is shown in Figure 44.

```
197410    46623.00
197411     7366.00
197412     1819.00
1975 1     1168.00
1975 2     1305.00
1975 3     1780.00
```

Figure 44 Example of Chiew and Siriwadena monthly flow times series format

8.2.4 Comma seperated value (CSV) daily time series format (.csv)

A comma separate value (CSV) daily time series format file is an ASCII text file that contains daily time series data. There is no header line in the file. There are two columns of data the first column is a date string in day/month/year format followed by the time series value. The two values are separated by a comma. An example of this format is show in Figure 45.

```
1/01/1900,7
2/01/1900,11
3/01/1900,19
4/01/1900,5
5/01/1900,0
6/01/1900,19
```

Figure 45 Example of CSV daily time series format

8.2.5 IQQM daily time series format (.iqqm)

An IQQM daily time series format file is an ASCII text file that contains daily time series data. The file has a five line header followed by annual tables of daily data.

The five lines of information contained within the header are:

1 The title line, which is a 40-character string of information detailing how, the file was created. It is suffixed with a date and time of creation;

2 The site name which is a 40 character string specifying the site for which the data applies;

3 The type which is a 15 character string specifying the data type within the file, eg. precipitation, evaporation or gauged flow;

4 The unit line which is a 10 character string specifying the units of data, eg. mm, mm*0.1, ML/d; and

5 The data line which specifies the time span of the time series data and the time interval of data stored within the file.

In daily IQQM format files the daily data is grouped in tables of yearly data with 31 columns representing each day in a month and 12 rows for each month of the year. At the end of each row of daily data is a monthly total and at the end of each table is a yearly total. These tables are repeated for the number of years of time series data. An example of a daily IQQM format file is shown in Figure 46.

The first line of each table specifes the year related to the data within the table. This year may be optionally followed by "factor=". Where the number following the factor is a factor that is applies to the whole of the table. If this factor does not exist then no factor is applied to the table.

The time series data values may be suffixed by a special character, which modifies the time series data value. The special characters and their function is described below:

1 '*' Indicates the time series value is to be multiplied by 1000;

2 'e' Indicates the time series value is estimated;

3 'E' Indicates the time series value is estimated and is to be multiplied by 1000;

4 'n' Indicates the time series value is negative. Note negative numbers not followed by a 'n' are assumed to be missing;

5 'N' Indicates the time series value is negative and is to be multiplied by 1000 Note negative numbers not followed by a 'N' are assumed to be missing; and

6 '?' Indicates that the time series value is missing. Note typically missing values are flagged as "-1?". A negative value not suffixed with a "n" or "N" is also considered as missing e.g. "-1 " is considered as a missing value.

```
Title: Winding Rivere at Middle Gauge                Date:30/07/2003
Time:17:47:24.66
Site : Winding River
Type : Flow
Units: ML/d
Date : 01/01/1985 to 31/12/2000    Interval : Daily

Year:1985                    Factor= 0.1E-01
    -----------------------------------------       ----------------------
      01     02     03     04     05     06            30     31     Total
    -----------------------------------------       ----------------------
Jan      0      0      0      0   165e     97          3070   2509     10956
Feb   2040   1666   1337   1081    -1?    870                            -1?
Mar    545    450    358    286    217    216          1987   7309     45937
Apr   6910   5528   4520   4818   4947   3982          9081           219146

Dec     33* 32558  31655  30729  29827  29154         19364  19051    767745
    -----------------------------------------       ----------------------
                                                                  14627179
```

Figure 46 Example of IQQM daily time series format

8.2.6 Rainfall-runoff library project file (.jobf)

The RRL project file is aimed at facilitating the reproducibility of the results obtained during a calibration. They are readable ASCII text files with a dual purpose. The software uses it to store important settings to keep from one session to another. They can also be printed for inclusion in a technical report. They should not be edited by a text editor as this is likely to prevent the software from read the file correctly. From a technical point of view, a text format (as opposed to a binary format) has been chosen to facilitate the backward compatibility in future versions.

A project file as shown in Figure 47 is organised in a series of sections identified by an identify,cation string contained between brackets (*[…]*). The header information describes the filename and path, the creation date and time, and user name of the last person creating this project. Note comment lines begin with a colon.

The file has 11 sections:

1 Model,

2 Location,

3 Input,

4 Null value,

5 Parameter,

6 Calibration dates,

7 Validation dates,

8 Calibration type,

9 Recorders,

10 Data scaling, and

11 Comments.

Model

The model section contains a string identificating of the type of model used and its version.

Location

The location section contains information about the catchment. The name is purely informative, while the area, in square kilometres, is used for automatic conversion between flow in ML/day or cubic meters per seconds to runoff depth in mm/day.

Input

The input section stores the filename and relative path to the loaded inputs for the model associated with this project. This approach was adopted to account for current practices, data formats, and to avoid duplication of the same input data. Note that this means that moving a project file and/or data from one location to another may make those relative paths obsolete.

NullValue

This value is used to identify records in data files that are missing. Any records thaqt have this value will be assumed to be missing.

Parameter

The parameter section stores the parameter name, value, lower bound, upper bound and fixed flag. Note the parameter list varies dependent upon the model type specified. The fixed flag is used to identify whether the model parameter is changed during an optimisation.

Calibration dates

Specifies the minimum and maximum possible dates for a calibration. It also specifies the start, end and warm up period for the calibration.

Verification dates

Specifies the minimum and maximum possible dates for a validation. It also specifies the start, end and warm up period for the validation.

CalibrationType

The calibration type section has exactly the same format and is used to identy the optimisation method used in the calibration. Note that most calibration tools are initialised randomly consequently no extra information about the calibration process is stored as it would not allow the reproduction of results.

Recorders

All models developed within TIME can be 'tagged' as 'State' variables, that is variables which without having to be considered as primary outputs play a role in the production of the primary outputs. The recorders section specifies what state of the output variable. If the line contains the word 'True' the variable is output. Each line also contains the number of significant digits specified by the user, to be optionally used for display purposes. Note that the RRL will always enforce the runoff as being recorded.

Data scaling

The data scaling section specifies the monthly multipliers to apply to the model inputs rainfall and evpotranspiration inputs.

Comments

The comments are stored at the very end of the file. Comments should be updated through the user interface. The software does not extract any information from it apart from making it available to read or edit.

```
: Rainfall Runoff Library Job File, version 20020726
:
: Original File Name :
C:\src\TIME\Applications\RainfallRunoff\Projects\AWBMJardineRiver.jobf
: Created on: 7/3/2003 11:19:43 AM
: IMPORTANT: you should not modify anything before the section starting with
an '*'
: otherwise it is likely that the file will not be readable.
: Please include any comment after the '*'.

[Model]
TIME.Models.AWBM.AWBM

[Location]
Site:
Area:
Area Units:

[Input]
evapotranspiration
.\..\\bin\Debug\Data\QLD\JardineRiver\JardineRiver_evapotranspiration_daily.
tts
runoff .\..\\bin\Debug\Data\QLD\JardineRiver\JardineRiver_runoff_daily.tts
```

```
rainfall
.\..\\bin\Debug\Data\QLD\JardineRiver\JardineRiver_rainfall_daily.tts

[NullValue]
-9999

[Parameter]
:parameter name || value || Min. || Max. || is fixed
KBase 0.973797280616433 0 1 False
KSurf 0.157963349455041 0 1 False
A2 0.437898762571088 0 0.5 False
A1 0.480340269624826 0 1 False
BFI 0.991380037523361 0 1 False
C1 122.021687079944 0 200 False
C3 7573.96082041227 0 10000 False
C2 78.4608507255025 0 3000 False

[CalibrationDates]
calibrationMinDate 1/01/1902 12:00:00 AM
calibrationStartDate 1/01/1902 12:00:00 AM
calibrationWarmupToDate 3/01/1903 12:00:00 AM
calibrationEndDate 28/03/1905 12:00:00 AM
calibrationMaxDate 31/12/1917 12:00:00 AM
validationMinDate 1/01/1902 12:00:00 AM
validationStartDate 31/12/1917 12:00:00 AM
validationWarmupToDate 31/12/1917 12:00:00 AM
validationEndDate 31/12/1917 12:00:00 AM
validationMaxDate 31/12/1917 12:00:00 AM

[CalibrationType]
TIME.Tools.Optimisation.ShuffledComplexEvolution

[DataScaling]
evapotranspiration panFactor 1 1 1 1 1 1 1 1 1 1 1 1
rainfall panFactor 1 1 1 1 1 1 1 1 1 1 1 1


***COMMENTS***
```

Figure 47 Example of rainfall-runoff library job file format

8.2.7 QDNR SILO daily time series format (.txt)

An QDNR SILO daily time series format file is an ASCII text file that contains daily time series data. There is no header line in the file. The data is organized in five columns seperated by spaces. The first four columns are the date in year, month, day and julian day format. The fifth column is the data value. An example of this format is shown in Figure 48.

```
2001 12 29 363 0
2001 12 30 364 0
2001 12 31 365 10.2
2002 1 1 1 0
2002 1 2 2 0
2002 1 3 3 0
2002 1 4 4 16
```

Figure 48 Example of QDNR SILO daily time series format

8.2.8 XML times series format (.tsx)

The XML time series format is not described. An example of the XML format is shown in Figure 49.

```
<SOAP-ENV:Envelope xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:xsd="http://www.w3.org/2001/XMLSchema" xmlns:SOAP-
ENC="http://schemas.xmlsoap.org/soap/encoding/" xmlns:SOAP-
ENV="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:clr="http://schemas.microsoft.com/soap/encoding/clr/1.0" SOAP-
ENV:encodingStyle="http://schemas.xmlsoap.org/soap/encoding/">
```

```
<SOAP-ENV:Body>
<a1:TimeSeries id="ref-1"
xmlns:a1="http://schemas.microsoft.com/clr/nsassem/TIME.DataTypes/DataTypes%
2C%20Version%3D1.0.1392.28588%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D5
9b30b0da8a82a84">
<state href="#ref-4"/>
<_name id="ref-5">precip.tts</_name>
<_nullValue>-9999</_nullValue>
<minCacheValid>true</minCacheValid>
<minCache>0</minCache>
<maxCacheValid>true</maxCacheValid>
<maxCache>73.84</maxCache>
<_categories href="#ref-6"/>
<_lastAllocatedKey>0</_lastAllocatedKey>
<_silence>false</_silence>
<Data_x002B__name href="#ref-5"/>
<Data_x002B__nullValue>-9999</Data_x002B__nullValue>
<Data_x002B_minCacheValid>true</Data_x002B_minCacheValid>
<Data_x002B_minCache>0</Data_x002B_minCache>
<Data_x002B_maxCacheValid>true</Data_x002B_maxCacheValid>
<Data_x002B_maxCache>73.84</Data_x002B_maxCache>
<Data_x002B__units href="#ref-7"/>
<Data_x002B__categories href="#ref-6"/>
<Data_x002B__categoryKeys href="#ref-8"/>
<Data_x002B__lastAllocatedKey>0</Data_x002B__lastAllocatedKey>
<Data_x002B__silence>false</Data_x002B__silence>
<Subject_x002B__silence>false</Subject_x002B__silence>
</a1:TimeSeries>
<a1:TimeSeriesState id="ref-4"
xmlns:a1="http://schemas.microsoft.com/clr/nsassem/TIME.DataTypes/DataTypes%
2C%20Version%3D1.0.1392.28588%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D5
9b30b0da8a82a84">
<_timeStep href="#ref-9"/>
<values href="#ref-10"/>
<_count>6209</_count>
<_start>0001-01-01T00:00:00.0000000+11:00</_start>
<_end>0017-12-31T00:00:00.0000000+11:00</_end>
</a1:TimeSeriesState>
<a2:Hashtable id="ref-6"
xmlns:a2="http://schemas.microsoft.com/clr/ns/System.Collections">
<LoadFactor>0.72</LoadFactor>
<Version>0</Version>
<Comparer xsi:null="1"/>
<HashCodeProvider xsi:null="1"/>
<HashSize>11</HashSize>
<Keys href="#ref-11"/>
<Values href="#ref-12"/>
</a2:Hashtable>
<a3:CompoundUnit id="ref-7"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_units href="#ref-13"/>
<_prefix href="#ref-14"/>
<_label id="ref-15"></_label>
<_hasCustomLabel>false</_hasCustomLabel>
<Unit_x002B__dimensions href="#ref-16"/>
<Unit_x002B__label href="#ref-15"/>
<Unit_x002B__hasCustomLabel>false</Unit_x002B__hasCustomLabel>
</a3:CompoundUnit>
<a2:Hashtable id="ref-8"
xmlns:a2="http://schemas.microsoft.com/clr/ns/System.Collections">
<LoadFactor>0.72</LoadFactor>
<Version>0</Version>
<Comparer xsi:null="1"/>
<HashCodeProvider xsi:null="1"/>
<HashSize>11</HashSize>
<Keys href="#ref-17"/>
<Values href="#ref-18"/>
</a2:Hashtable>
<a1:EventTimeStep id="ref-9"
xmlns:a1="http://schemas.microsoft.com/clr/nsassem/TIME.DataTypes/DataTypes%
2C%20Version%3D1.0.1392.28588%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D5
9b30b0da8a82a84">
<_span>P0Y0M1DT0H0M0S</_span>
```

```
</a1:EvenTimeStep>
<SOAP-ENC:Array id="ref-10" SOAP-ENC:arrayType="xsd:double[6209]">
<item>0</item>
<item>0</item>
<item>0</item>
<item>10.2</item>
<item>0</item>
<item>0</item>
<item>16</item>
</SOAP-ENC:Array>
<SOAP-ENC:Array id="ref-11" SOAP-ENC:arrayType="xsd:anyType[0]">
</SOAP-ENC:Array>
<SOAP-ENC:Array id="ref-12" SOAP-ENC:arrayType="xsd:anyType[0]">
</SOAP-ENC:Array>
<a2:ArrayList id="ref-13"
xmlns:a2="http://schemas.microsoft.com/clr/ns/System.Collections">
<_items href="#ref-19"/>
<_size>2</_size>
<_version>2</_version>
</a2:ArrayList>
<a3:UnitPrefix id="ref-14"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_symbol href="#ref-15"/>
<_name href="#ref-15"/>
<_factor>1</_factor>
</a3:UnitPrefix>
<a3:DimensionLess id="ref-16"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_name id="ref-20">Dimensionless</_name>
<Dimension_x002B__name href="#ref-20"/>
</a3:DimensionLess>
<SOAP-ENC:Array id="ref-17" SOAP-ENC:arrayType="xsd:anyType[0]">
</SOAP-ENC:Array>
<SOAP-ENC:Array id="ref-18" SOAP-ENC:arrayType="xsd:anyType[0]">
</SOAP-ENC:Array>
<SOAP-ENC:Array id="ref-19" SOAP-ENC:arrayType="xsd:anyType[16]">
<item href="#ref-21"/>
<item href="#ref-22"/>
</SOAP-ENC:Array>
<a3:CompoundUnit_x002B_PoweredUnit id="ref-21"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_u href="#ref-23"/>
<_p>1</_p>
</a3:CompoundUnit_x002B_PoweredUnit>
<a3:CompoundUnit_x002B_PoweredUnit id="ref-22"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_u href="#ref-24"/>
<_p>1</_p>
</a3:CompoundUnit_x002B_PoweredUnit>
<a3:CompoundUnit id="ref-23"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_units href="#ref-25"/>
<_prefix href="#ref-14"/>
<_label href="#ref-15"/>
<_hasCustomLabel>false</_hasCustomLabel>
<Unit_x002B__dimensions href="#ref-16"/>
<Unit_x002B__label href="#ref-15"/>
<Unit_x002B__hasCustomLabel>false</Unit_x002B__hasCustomLabel>
</a3:CompoundUnit>
<a3:CompoundUnit id="ref-24"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_units href="#ref-26"/>
<_prefix href="#ref-14"/>
```

```
<_label href="#ref-15"/>
<_hasCustomLabel>false</_hasCustomLabel>
<Unit_x002B__dimensions href="#ref-16"/>
<Unit_x002B__label href="#ref-15"/>
<Unit_x002B__hasCustomLabel>false</Unit_x002B__hasCustomLabel>
</a3:CompoundUnit>
<a2:ArrayList id="ref-25"
xmlns:a2="http://schemas.microsoft.com/clr/ns/System.Collections">
<_items href="#ref-27"/>
<_size>1</_size>
<_version>1</_version>
</a2:ArrayList>
<a2:ArrayList id="ref-26"
xmlns:a2="http://schemas.microsoft.com/clr/ns/System.Collections">
<_items href="#ref-28"/>
<_size>1</_size>
<_version>1</_version>
</a2:ArrayList>
<SOAP-ENC:Array id="ref-27" SOAP-ENC:arrayType="xsd:anyType[16]">
<item href="#ref-29"/>
</SOAP-ENC:Array>
<SOAP-ENC:Array id="ref-28" SOAP-ENC:arrayType="xsd:anyType[16]">
<item href="#ref-30"/>
</SOAP-ENC:Array>
<a3:CompoundUnit_x002B_PoweredUnit id="ref-29"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_u href="#ref-31"/>
<_p>1</_p>
</a3:CompoundUnit_x002B_PoweredUnit>
<a3:CompoundUnit_x002B_PoweredUnit id="ref-30"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_u href="#ref-32"/>
<_p>-1</_p>
</a3:CompoundUnit_x002B_PoweredUnit>
<a3:SimpleUnit id="ref-31"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_dimensions href="#ref-16"/>
<_refUnit href="#ref-33"/>
<_scalingFactor>0.001</_scalingFactor>
<_offset>0</_offset>
<_label id="ref-34">mm</_label>
<_hasCustomLabel>false</_hasCustomLabel>
<Unit_x002B__dimensions href="#ref-16"/>
<Unit_x002B__label href="#ref-34"/>
<Unit_x002B__hasCustomLabel>false</Unit_x002B__hasCustomLabel>
</a3:SimpleUnit>
<a3:SimpleUnit id="ref-32"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_dimensions href="#ref-16"/>
<_refUnit href="#ref-35"/>
<_scalingFactor>86400</_scalingFactor>
<_offset>0</_offset>
<_label id="ref-36">day</_label>
<_hasCustomLabel>false</_hasCustomLabel>
<Unit_x002B__dimensions href="#ref-16"/>
<Unit_x002B__label href="#ref-36"/>
<Unit_x002B__hasCustomLabel>false</Unit_x002B__hasCustomLabel>
</a3:SimpleUnit>
<a3:RefUnit id="ref-33"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_baseUnit href="#ref-37"/>
<_dimensions href="#ref-38"/>
<_refUnit href="#ref-33"/>
<_scalingFactor>1</_scalingFactor>
<_offset>0</_offset>
```

```
<_label id="ref-39">m</_label>
<_hasCustomLabel>false</_hasCustomLabel>
<SimpleUnit_x002B__dimensions href="#ref-38"/>
<SimpleUnit_x002B__refUnit href="#ref-33"/>
<SimpleUnit_x002B__scalingFactor>1</SimpleUnit_x002B__scalingFactor>
<SimpleUnit_x002B__offset>0</SimpleUnit_x002B__offset>
<SimpleUnit_x002B__label href="#ref-39"/>
<SimpleUnit_x002B__hasCustomLabel>false</SimpleUnit_x002B__hasCustomLabel>
<Unit_x002B__dimensions href="#ref-16"/>
<Unit_x002B__label href="#ref-39"/>
<Unit_x002B__hasCustomLabel>false</Unit_x002B__hasCustomLabel>
</a3:RefUnit>
<a3:RefUnit id="ref-35"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_baseUnit href="#ref-40"/>
<_dimensions href="#ref-41"/>
<_refUnit href="#ref-35"/>
<_scalingFactor>1</_scalingFactor>
<_offset>0</_offset>
<_label id="ref-42">s</_label>
<_hasCustomLabel>false</_hasCustomLabel>
<SimpleUnit_x002B__dimensions href="#ref-41"/>
<SimpleUnit_x002B__refUnit href="#ref-35"/>
<SimpleUnit_x002B__scalingFactor>1</SimpleUnit_x002B__scalingFactor>
<SimpleUnit_x002B__offset>0</SimpleUnit_x002B__offset>
<SimpleUnit_x002B__label href="#ref-42"/>
<SimpleUnit_x002B__hasCustomLabel>false</SimpleUnit_x002B__hasCustomLabel>
<Unit_x002B__dimensions href="#ref-16"/>
<Unit_x002B__label href="#ref-42"/>
<Unit_x002B__hasCustomLabel>false</Unit_x002B__hasCustomLabel>
</a3:RefUnit>
<a3:BaseUnit id="ref-37"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_dimensions href="#ref-16"/>
<_refUnit href="#ref-33"/>
<_scalingFactor>1</_scalingFactor>
<_offset>0</_offset>
<_label id="ref-43">m</_label>
<_hasCustomLabel>false</_hasCustomLabel>
<SimpleUnit_x002B__dimensions href="#ref-16"/>
<SimpleUnit_x002B__refUnit href="#ref-33"/>
<SimpleUnit_x002B__scalingFactor>1</SimpleUnit_x002B__scalingFactor>
<SimpleUnit_x002B__offset>0</SimpleUnit_x002B__offset>
<SimpleUnit_x002B__label href="#ref-43"/>
<SimpleUnit_x002B__hasCustomLabel>false</SimpleUnit_x002B__hasCustomLabel>
<Unit_x002B__dimensions href="#ref-16"/>
<Unit_x002B__label href="#ref-43"/>
<Unit_x002B__hasCustomLabel>false</Unit_x002B__hasCustomLabel>
</a3:BaseUnit>
<a3:BaseDimension_x002B_Length id="ref-38"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_name id="ref-44">Length</_name>
<BaseDimension_x002B__name href="#ref-44"/>
<ElementaryDimension_x002B__name href="#ref-44"/>
<Dimension_x002B__name href="#ref-44"/>
</a3:BaseDimension_x002B_Length>
<a3:BaseUnit id="ref-40"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_dimensions href="#ref-16"/>
<_refUnit href="#ref-35"/>
<_scalingFactor>1</_scalingFactor>
<_offset>0</_offset>
<_label id="ref-45">s</_label>
<_hasCustomLabel>false</_hasCustomLabel>
<SimpleUnit_x002B__dimensions href="#ref-16"/>
<SimpleUnit_x002B__refUnit href="#ref-35"/>
<SimpleUnit_x002B__scalingFactor>1</SimpleUnit_x002B__scalingFactor>
```

```
<SimpleUnit_x002B__offset>0</SimpleUnit_x002B__offset>
<SimpleUnit_x002B__label href="#ref-45"/>
<SimpleUnit_x002B__hasCustomLabel>false</SimpleUnit_x002B__hasCustomLabel>
<Unit_x002B__dimensions href="#ref-16"/>
<Unit_x002B__label href="#ref-45"/>
<Unit_x002B__hasCustomLabel>false</Unit_x002B__hasCustomLabel>
</a3:BaseUnit>
<a3:BaseDimension_x002B_Time id="ref-41"
xmlns:a3="http://schemas.microsoft.com/clr/nsassem/TIME.Core.Units/TimeCore%
2C%20Version%3D1.0.1390.33501%2C%20Culture%3Dneutral%2C%20PublicKeyToken%3D1
7de1c0433b5448b">
<_name id="ref-46">Time</_name>
<BaseDimension_x002B__name href="#ref-46"/>
<ElementaryDimension_x002B__name href="#ref-46"/>
<Dimension_x002B__name href="#ref-46"/>
</a3:BaseDimension_x002B_Time>
</SOAP-ENV:Body>
</SOAP-ENV:Envelope>
```


Figure 49 Example of XML times series format

8.2.9 SWAT daily rainfall time series format (.pcp)

An SWAT daily rainfall time series format file is an ASCII text file that contains daily time series rainfall data. The file has a four line header followed by daily data values.

The four lines of information contained within the header are:

1 The swat file description header

2 'Lati' followed by the latitude of the site in degrees

3 'Long' followed by the longitude of the site in degrees

4 'Elev' followed by the elevation of the site in metres

The data is organized in three columns. The first column is the year (4 characters), followed by the julian day (3 characters). The third column is the data value to one decimal place (5 characters). An example of this format is shown in Figure 50.

```
Precipitation Input File pcp.pcp    20030225 AVSWAT2000 - SWAT interface MDL
Lati   14.77
Long   102.7
Elev     167
1985001000.0
1985002000.0
1985003000.0
1985004000.0
1985005000.0
```

Figure 50 Example of SWAT daily rainfall time series format

8.2.10 Tarsier daily time series format (.tts)

An Tarsier daily time series format file is an ASCII text file that contains daily time series data. The file has a 21 line header followed by daily data values.

The four lines of information contained within the header are:

1 The Tarsier version number header

2 Reference to author of Tarsier

3 File path and name

4 Name of software used to crete the file

5 Date and time file was created

6 Tarsier timer series data class (TTimeSeriesData)

7 File version number

8 Number of header lines (set to 1)

9 1.

10 Number of daily data entries in the file

11 'Xlabel' is always Date/Time for time series data

12 'Y1Label Y1' fixed field

13 'Y2Label Y2' fixed field

14 Data units

15

16 Grid position east in metres

17 Grid position north in metres

18 'Latitude' followed by the latitude of the site in degrees

19 'Longitude' followed by the longitude of the site in degrees

20 'Elevation' followed by the elevation of the site in metres

21 Header character

The data is organized in four columns separated by spaces. The first column is the year, followed by the julian day. The third column is the data value. The fourth column is a data quality code '.' Is ok and '-' is missing. An example of this format is shown in Figure 51.

```
Tarsier modelling framework, Version 2.0.
: Created by Fred Watson.
: File Name : C:\tmp\TSFormat\precip.tts
: Generated from TIME Framework
: Date : 24/10/2003 3:21:30 PM
: File class: TTimeSeriesData.
FileVersion unknown
HeaderLines 1
 1.
NominalNumEntries 6209
XLabel Date/Time
Y1Label Y1
Y2Label Y2
Units mm.day^-1
Format 1
Easting 0.000000
Northing 0.000000
Latitude 0.000000
Longitude 0.000000
Elevation 0.000000
*
2001 363 0 .
2001 364 0 .
2001 365 10.2 .
2002 1 0 .
2002 2 0 .
2002 3 0 .
2002 4 16 .
```

Figure 51 Example of Tarsier daily time series format

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10 Glossary

10.1 Surface water/Hydrology

Acronym/Term	Definition
Baseflow	The component of streamflow that originates from groundwater, and supports streamflows during long periods of no rainfall.
Catchment	The area of land drained by a water course that could range from a small runnel to a creek or a river. In hydrologic terms every point in the landscape is the outlet of a catchment of some description. As the term has a wide range of applicability it gets used very broadly (and loosely). The equivalent term in the US is "watershed".
Critical drought	The duration in time that resulted in the either the lowest dam levels, aquifer levels or pressures, or longest duration of restricted water access
Deep drainage	Water in the soil that percolates down below the root zone of plants (ie a component of infiltration water), and therefore cannot be transpired by plants. (see also "infiltration" and "recharge" – in Groundwater list)
End-of system flow	Streamflow at the end of a given river system; eg Murrumbidgee River at Balranald
En-route storage	A water storage (weir or lake) located either instream or off-stream in the middle or lower part of a river system (eg Hay Weir on the Murrumbidgee)
Flow duration curve	A graphical representation of a ranking of all the flows in a given period, from the lowest to the highest, where the rank is the percentage of time the flow value is equalled or exceeded. These curves may be derived for flows in any time interval, such as daily flows, monthly flows or annual flows.
Flow percentile	The percentage of time for which a given flow is equalled or exceeded. (see also "percentiles" in Salinity list)
Flow routing	The change in magnitude, speed and shape (height and duration) of a flow hydrograph as it moves downstream, due to channel and floodplain storage and frictional effects.
GL (gigalitre)	One thousand million litres (also equal to 1 million cubic metres)
Hydrologic cycle	The circulation of water from the oceans through the atmosphere to the land and ultimately back to the ocean.
Hydrograph	The trace which describes the change in stream flow (or water level) over time at a given location in a river system.
Infiltration	The process by which water soaks into the soil from rainfall, snowmelt or

Acronym/Term	Definition
	irrigation. (see also "deep drainage" and "recharge")
Influent stream	An influent stream is one which gains water from groundwater (also known as a "gaining stream")
Lateral throughflow	Relatively rapid subsurface flow through cracks, pipes, macropores in the soil – also referred to as lateral subsurface flow and interflow.
Natural development conditions	This term denotes a scenario that comprises conditions in a river system without any water resources development (dams, water supply infrastructure, irrigation development). Catchment land use changes that have occurred over the years, such as land clearing, are ignored in this definition. This term is relevant to hydrologic modelling for water management purposes and Water Sharing Plans.
Overland flow	Surface runoff, which is caused either because the underlying soil is saturated and cannot accommodate any more water or because the intensity of rainfall is greater than the soil's capacity to infiltrate it.
Precipitation	Rain, snow, hail, sleet, dew.
Probable Maximum Flood (PMF)	The flood resulting from PMP, and where applicable snow melt, coupled with the worst flood-producing catchment conditions that can be realistically expected in the prevailing meteorological conditions.
Probable Maximum Precipitation (PMP)	The theoretical greatest depth of precipitation for a given duration that is physically possible over a particular catchment area, based on generalised methods.
Quickflow	The component of streamflow that has travelled through the catchment as interflow or across the surface as overland flow.
Regulated river	The section of river that is downstream of a major storage from which supply of water to irrigators or other users can be regulated or controlled. In NSW these storages and rivers are operated by State Water and the regulated rivers are designated by legislation.
Regulated flow	Water that is released from storage to meet downstream requirements
Riparian zone	The zone adjacent to streams and rivers; usually there is some exchange of water and nutrients between this zone and the stream.
River diversion	Water diverted (by pump or gravity) from a stream
Seepage	The movement of water downwards through soils or permeable rock. This water can originate from a very wide range of sources, including all water bodies and most land surfaces. Seepage water may percolate far enough to reach groundwater.
Subcatchment	Area of land within a catchment; used in specific contexts to distinguish components of a larger catchment (see also "catchment").
Transmission loss	The flow volume that is 'lost' from a river or stream as water travels downstream. It includes seepage to groundwater, overbank flow that goes into floodplain depressions, wetlands and billabongs and never returns to the river, and evaporation from the water surface. It also includes the effects of uncertainty in river flow gauging measurements and unaccounted water usage.
Unregulated rivers	All rivers that are not regulated, including rivers where the flow is controlled by dams or weirs constructed by urban water suppliers or private users.

10.2 Groundwater/Hydrogeology

Acronym/Term	Definition

Acronym/Term	Definition
Alluvium	Sediments (clays, sands, gravels and other materials) deposited by flowing water. Streams can make Deposits on riverbeds, floodplains, and alluvial fans). Examples: Shepparton, Calivil and Renmark Formations in the Lower Murrumbidgee Valley.
Aquifer	Rock or sediment in a formation, which is saturated and sufficiently permeable to transmit and release water. Examples of major alluvial systems include the Shepparton, Calivil and Renmark aquifers in the Lower Murrumbidgee Valley. These lie underneath the major irrigation areas of southern NSW.
Aquifer, confined	An aquifer that is sandwiched between two layers of impervious materials.
Aquifer, unconfined	Also known as water table or phreatic aquifer. The water table is the upper boundary of unconfined aquifers.
Aquitard	A low-permeability layer that can store groundwater and also transmit it slowly from one aquifer to another.
Artesian water	Groundwater which rises above the ground surface under its own pressure by way of a spring or when accessed by a bore.
Bedrock	A general term for the rock, usually solid, that underlies soil or other unconsolidated material.
Bore (well)	Drilled or dug below the surface to access water in an aquifer system.
Discharge	The process by which water leaves the aquifer.
Drawdown	A lowering of the water table of an unconfined aquifer or a reduction of the water pressure in a confined aquifer. Drawdown is the result of pumping of groundwater from wells.
Fractured rock aquifer	These occur in hard rocks that have been subjected to disturbance, deformation or weathering, creating joints, bedding planes and faults which water can flow through. These are a major source of dryland salinity in the tablelands and slopes of NSW.
Groundwater	The water contained in interconnected pores in rock and alluvium, below the water table in unconfined aquifers and anywhere in confined aquifers.
Groundwater system	Another term for an "aquifer"
Hydraulic conductivity	The rate at which water flows from one point to another through an aquifer.
Hydrogeological	Those factors that deal with subsurface waters and related geological aspects of surface waters.
Impermeable layer	A layer of material which does not allow water to pass through.
Observation well (bore)	A non-pumping well used to observe the elevation of the water table or the potentiometric surface. Also known as a piezometer.
Overburden	The loose soil, silt, sand gravel or other unconsolidated material overlying bedrock. Also known as regolith.
Perched aquifer/ watertable	A watertable above the main watertable level where impermeable soil or rock prevents the water from percolating through it to the main groundwater body.
Permeability	The property or capacity of a porous rock, sediment or soil for transmitting water. Sand, for example, is said to have high permeability.
Piezometer	see Observation well (bore)
Production bore (pumping well)	A bore equipped with a pump to extract groundwater from an aquifer system.
Recharge	The component of deep drainage that reaches the groundwater table. (see also "deep drainage" and "infiltration" – both in Surface Water list)
Regolith	see Overburden
Safe yield	The volume of water that can be taken from an aquifer at any given

Acronym/Term	Definition
	location regardless of impacts, which is largely dependent on the type of bore and capacity of pump that can be installed. This definition assumes the recharge of the aquifer is limitless which, of course, it is not in reality, so it can encourage mining of the resource and lead to environmental damage. Increasingly, the usage of the term "safe yield" is being modified to take into account that recharge is finite.
Static water level	The level of water in a well that is not being affected by withdrawal of groundwater.
Unsaturated zone	The zone between the land surface and the water table. Also known as the zone of aeration or the vadose zone.
Water table	The upper water level of unconfined groundwater, where the water pressure is equal to that of the atmosphere and below which the soils or rocks are saturated.
Waterlogging	Waterlogging occurs when the watertable rises into the root zone, saturating the soil surface with water from rising groundwater or surface run-off collecting in low areas. It results in anaerobic (absence of free oxygen) conditions which reduce plant growth.

10.3 Soils

Acronym/Term	Definition
Soil hydraulic properties	These soil properties control the storage and movement of water, salts and chemical through soils. They are critical in understanding and predicting runoff, recharge and movement of water and salts in catchments.
Soil landscape	An area of land that has recognisable and specifiable topography and soils, that is capable of being represented on maps and of being described by concise statements. A soil landscape will contain a range of soil types in a defined pattern.
Soil profile	A vertical section of earth from the soil surface to parent material, that shows the different soils' horizons.
Soil type	A general term used to describe a group of soils that can be managed similarly and which exhibit similar features and properties.