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www.toolkit.net.au/rrl
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</thead>
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Legal Information

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

The Product Manager for the Rainfall Runoff Library is Geoff Podger.

1 Department of Infrastructure, Planning and Natural Resources; CRC for Catchment Hydrology
2 CSIRO Land and water, CRC for Catchment Hydrology
3 Melbourne University, CRC for Catchment Hydrology
4 CRC for Catchment Hydrology
# Rainfall Runoff Library User Manual

## CONTENTS

1 Introduction

1.1 The user guide

1.1.1 Purpose

1.1.2 Structure

1.2 Software

1.2.1 Overview

1.2.2 Features

1.2.3 Audience

1.3 Data requirements

1.3.1 Input data

1.3.2 Output data

1.4 Product components

1.5 References and training

2 Installation

2.1 Technical specifications

2.1.1 Framework

2.2 Distribution media

2.2.1 Licence agreement

2.2.2 Data

2.3 Directories

2.4 Installation

2.4.1 Stand-alone PC

2.4.2 File server/network

2.5 User Interface

2.5.1 Windows

2.5.2 Menus

2.5.3 Toolbar buttons

2.5.4 Fields

2.5.5 Graph Windows

2.5.6 Mouse & Keyboard Controls

2.6 Uninstalling RRL

3 Using RRL

3.1 Getting started
3.1.1 Starting the RRL ................................................................. 19
3.1.2 RRL Menu ........................................................................ 19
3.1.3 RRL Dialogues ................................................................. 22
3.1.4 RRL Output ...................................................................... 36
3.1.5 RRL Data viewers ............................................................. 37

3.2 Creating a new project .......................................................... 44
3.3 Loading an existing project .................................................... 45
3.4 Viewing and printing project files ............................................. 45

4 Description of models .............................................................. 47

4.1 AWBM ................................................................................ 47
4.1.1 Model description ............................................................. 47
4.1.2 Default values ................................................................. 49

4.2 Sacramento .......................................................................... 49
4.2.1 Model Description ........................................................... 49
4.2.2 Principle of the Sacramento Model .................................... 49

4.3 Stores .................................................................................. 50
4.3.1 Flow generation ............................................................... 51
4.3.2 Evapotranspiration .......................................................... 51
4.3.3 Percolation ..................................................................... 51
4.3.4 Time delay tools ............................................................. 52
4.3.5 Other factors ................................................................. 52
4.3.6 Default values ............................................................... 54

4.4 Simhyd ................................................................................. 54
4.4.1 Default values ............................................................... 56

4.5 SMAR .................................................................................. 56
4.5.1 Water balance ............................................................... 57
4.5.2 Routing ......................................................................... 57
4.5.3 Default values ............................................................... 61

4.6 Tank .................................................................................... 61
4.6.1 Runoff ........................................................................... 63
4.6.2 Evapotranspiration ........................................................ 63
4.6.3 Infiltration ..................................................................... 63
4.6.4 Storage ......................................................................... 63
4.6.5 Default values ............................................................... 63

5 Description of optimisers ........................................................ 65

5.1 Uniform random search ...................................................... 65
5.2 Pattern search ................................................................. 65
5.3 Multi start pattern search .................................................. 66
8.2 File formats

8.2.1 AWBM daily time series format (.awb) .................................................. 87
8.2.2 Comma delimited column daily time series format (.cdt) ..................... 87
8.2.3 IQ Q M daily time series format (.iqqm) ........................................... 87
8.2.4 Rainfall-runoff library project file (.jobf) ......................................... 88
8.2.5 Q D N R SILO daily time series format (.silo5) ................................... 91
8.2.6 Space delimited column daily time series format (.sdt) ..................... 92
8.2.7 SWAT daily rainfall time series format (.pcp) ................................... 92
8.2.8 Tab delimited column daily time series format (.tdt) ........................ 93
8.2.9 Tarsier daily time series format (.tts) ............................................. 93

9 Reference .................................................................................................. 95

10 Glossary .................................................................................................. 97

10.1 Surface water/Hydrology ..................................................................... 97
10.2 Groundwater/Hydrogeology ................................................................. 98
10.3 Soils ...................................................................................................... 100
# TABLE OF FIGURES

| Figure 2.1 RRL directory structure | 7 |
| Figure 2.2 Example of standard window | 9 |
| Figure 2.3 Drop down menu list | 10 |
| Figure 2.4 Popup list | 11 |
| Figure 2.5 Graph window | 13 |
| Figure 2.6 Graph popup | 13 |
| Figure 2.7 Graph properties dialogue | 15 |
| Figure 2.8 Colour picker | 16 |
| Figure 2.9 Line style selections | 17 |
| Figure 2.10 Graph colour specification dialogue | 17 |
| Figure 3.1 RRL top level menu | 19 |
| Figure 3.2 File drop down menu | 20 |
| Figure 3.3 Edit drop down menu | 21 |
| Figure 3.4 View drop down menu | 21 |
| Figure 3.5 Tools drop down menu | 21 |
| Figure 3.6 Help drop down menu | 22 |
| Figure 3.7 RRL Tabbed dialogue | 22 |
| Figure 3.8 Model selection dialogue | 23 |
| Figure 3.9 Input dialogue | 24 |
| Figure 3.10 Setting RRL data directories | 25 |
| Figure 3.11 Input data statistics dialogue | 25 |
| Figure 3.12 Dates dialogue | 26 |
| Figure 3.13 Warm up period estimation error dialogue | 27 |
| Figure 3.14 Calibration dialogue | 28 |
| Figure 3.15 AWBM calibration parameters | 29 |
| Figure 3.16 Setting optimiser parameters | 30 |
| Figure 3.17 Custom tab | 31 |
| Figure 3.18 Setting parameter precision and increment | 31 |
| Figure 3.19 Model output graph window | 32 |
| Figure 3.20 Observed and simulated data comparison | 33 |
| Figure 3.21 Sensitivity dialogue | 34 |
| Figure 3.22 Simulation dialogue | 35 |
| Figure 3.23 File save as window | 36 |
| Figure 3.24 Specify AWBM model variables to be output | 37 |
| Figure 3.25 Time series data output dialogue | 37 |
| Figure 3.26 Time series viewer window | 39 |
| Figure 3.27 Duration curve viewer window | 39 |
| Figure 3.28 Calibrate graph | 40 |
| Figure 3.29 Sensitivity graph | 42 |
1 Introduction

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

- purpose of this User Guide,
- structure and content of the User Guide,
- features of the RRL,
- 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:
1.2 Software

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 5 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
- 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 optimiser

The objective functions provided are:
Introduction

- 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
- There are three options available for calibration based on two objective functions:
  - Runoff difference in %
  - Flow duration curve
  - Base flow method 2 (Boughton, Chapman and Maxwell)

Note when using two objective functions, specified weightings are applied to each objective function and then these weighted functions are combined to create a single objective function that is used by the optimiser.

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. Only data in mm/day should be used.

- **Evaporation** - a continuous time series of potential evapotranspiration (PET) or actual evapotranspiration data that represents the evapotranspiration across the catchment. The type of evaporation data expected will vary from model to model, and only the appropriate data should be used. The evaporation data appropriate for one model may not be appropriate for another. Note the data maybe be converted to the appropriate data by applying monthly factors (Section 6.1.2). Only data in mm/day should be used.

- **Flow gaugings** - daily runoff values for the gauging station that is to be modelled. These data are used for model calibration and checking. The accepted flow units are mm/day, ML/day or m³/s. If data are input as ML/day or m³/s then catchment area is required.

- **Catchment area** - this is used to convert inputs and outputs between flow and depth of runoff.
1.3.2 Output data

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

Table 1.1 Data available for interrogation

<table>
<thead>
<tr>
<th>Time series data</th>
<th>Units</th>
<th>Time scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall</td>
<td>mm/d</td>
<td>Daily</td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>mm/d</td>
<td>Daily</td>
</tr>
<tr>
<td>Flow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observed flow</td>
<td>mm/d, ML/d, m3/s</td>
<td>Daily</td>
</tr>
<tr>
<td>Simulated flow</td>
<td>mm/d, ML/d, m3/s</td>
<td>Daily or monthly</td>
</tr>
</tbody>
</table>

The RRL is also designed to output model specific variables such as fluxes and storage depths. The RRL can be configured to record and save these.

1.4 Product components

The RRL package includes:
- the RRL software and sample data
- User Guide
- 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](http://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

Table 2.1 System requirements

<table>
<thead>
<tr>
<th>Minimum Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor</td>
</tr>
<tr>
<td>133-megahertz (MHz) Intel Pentium-class processor</td>
</tr>
<tr>
<td>Operating System</td>
</tr>
<tr>
<td>The RRL is supported on the following platforms:</td>
</tr>
<tr>
<td>Microsoft Windows® Server 2003 (.NET Framework 1.1 is</td>
</tr>
<tr>
<td>installed as part of the operating system)</td>
</tr>
<tr>
<td>Windows XP Professional* and Home Edition</td>
</tr>
<tr>
<td>Windows 2000</td>
</tr>
<tr>
<td>Windows Millennium Edition (Windows Me)</td>
</tr>
<tr>
<td>Windows 98</td>
</tr>
<tr>
<td>Microsoft Windows NT® 4.0 Service Pack 6a</td>
</tr>
<tr>
<td>The RRL cannot be installed on 64-bit computers</td>
</tr>
<tr>
<td>Memory</td>
</tr>
<tr>
<td>128 megabytes (MB) of RAM, 256 MB recommended</td>
</tr>
<tr>
<td>Hard Disk</td>
</tr>
<tr>
<td>120 MB of hard disk space required, 40 MB additional hard</td>
</tr>
<tr>
<td>disk space required for installation (160 MB total)</td>
</tr>
<tr>
<td>Display</td>
</tr>
<tr>
<td>1024 x 768 or higher-resolution display with 256 colours</td>
</tr>
<tr>
<td>Input Device</td>
</tr>
<tr>
<td>Microsoft mouse or compatible pointing device</td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td>Microsoft Internet Explorer 5.01 or later is required.</td>
</tr>
<tr>
<td>The .NET framework 1.1 redistributable or later is</td>
</tr>
<tr>
<td>required.</td>
</tr>
</tbody>
</table>

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:


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, Login in with your registered user name and password.
4. Select the Products menu.
5. Select the RRL product (RRL icon or more >>).
6. On the RRL menu select Download Software.
7. Read the licence agreement and if it is acceptable select the I agree button.
8. In the Main Download table select the RRL zip file.
9. When the File Download screen appears save the RRL zip file to an appropriate temporary area on your local disk drive.
10. Unzip the RRL zip file. Three files will be extracted:
   a. RainfallRunoffInstaller.msi
   b. Setup.exe
   c. Setup.ini

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 directories that contain:

1. The rainfall runoff executable and associated DLLs.
2. Sample rainfall, evaporation and flow data from across Australia.
3 Documentation (User Guide, Workshop material and Licence agreement)
4 Example project files for each of the rainfall runoff models.
5 Files used by the RRL software.

2.3 Directories

The RRL installation creates six sub-directories (Figure 2.1) within the RRL directory (location of which is defined by the user during installation):

Data - contains sample data. This contains 4 state subdirectories and within each state directory are subdirectories for each flow gauging station that sample data are provided for.


Help - contains the .chm files used for RRL help.

Licence - contains the RRL software licence agreement.

Projects - contains 5 project files, one for each rainfall runoff model in the RRL. These have all been configured for the Jardine River, for model comparison purposes.

Resources - contains files used by the RRL software.

![Figure 2.1 RRL directory structure](image)

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 and unzipping the RRL zip file, double clicking `setup.exe` to 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 are only two decisions that need to be made during the installation. Firstly, the name of the install directory:

(Default is C:\Program Files\Toolkit\Rainfall Runoff Library.)

Secondly whether the software is to be accessed by just you or everyone that accesses your computer. The default is just you.

**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 or remove some unwanted files.

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

If the intended user of the software does not have write access rights for the RRL data directories i.e. the repository for sample data and project files. Then results and project files cannot be saved in these directories. The user will need to copy the Data and Project directories to a directory where the user has access rights (e.g. My Documents\ToolKit\Rainfall Runoff Library). When the software is first started you will need to point RRL to this directory (Section 3.1.3 and Section 7.2).

### 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 2.2. 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.
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 resets to zero
   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 2.2. 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 Windows 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 2.3.

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 2.3.

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 2.4, when the cursor is moved over the menu item line of text.
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 2.2.

#### Table 2.2 Time fields

<table>
<thead>
<tr>
<th>Field Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>String fields</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Integer fields</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Date fields</strong></td>
<td>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 &lt; and &gt; arrow keys move down or up one month respectively.</td>
</tr>
<tr>
<td><strong>Real fields</strong></td>
<td>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</td>
</tr>
</tbody>
</table>
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 drop down 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.

2.5.5 Graph Windows

TIME provides a module to plot specific information as graphs. Figure 2.5 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

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. On the bottom left corner is a units field that either displays the units of the data or in the case where the units are unknown allows the user to choose from a drop down list of options.
By right clicking the mouse in the graph window the graph menu popup is displayed, as shown in Figure 2.6.

Five menu options are provided in the graph popup:

- Pan
- Zoom In
- Draggable
- 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 the 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 2.6 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 panned 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.

Draggable

When activated the Draggable option allows data to be dragged from one graph view to another. This feature is toggled on and off by clicking on the draggable popup menu option.

This facility may be used to drag model results from the calibration view to the time series viewer or duration curve viewer discussed in Section 3.1.5.

Reset to full screen

To reset the graph back to full display after zooming, double click on the graph with the left mouse button.

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 dialogue as shown in Figure 2.7. 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)
Each of the decorators allows the user to adjust different properties dependent on the decorator. Table 2.3 lists the properties that can be changed on each tab.

Table 2.3 Configurable graph properties

<table>
<thead>
<tr>
<th>Tab</th>
<th>Text</th>
<th>Font</th>
<th>Text colour</th>
<th>Text position</th>
<th>Line colour</th>
<th>Axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>x-axis</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>y-axis</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Axis</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Variable</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

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 2.8. 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.
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 2.8. 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 shown in Figure 2.8.

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 changed 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
The line style can also be selected via a drop down menu. The available options are shown in Figure 2.9.

The graph colours may also be adjusted by selecting Tools | options | configuration. When this is selected the interface options dialogue as shown in Figure 2.10 will be displayed. The colours for graphs are changed in similar manner as described above.

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 | Rainfall Runoff Library.

The RRL introduction splash screen will appear for a few seconds while the RRL software configures and loads. 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 3.1. The menu options and associated hot keys are:

- File (alt+f)
- Edit (alt+e)
- View (alt+v)
- Tools (alt+t)
- Help (alt+h)

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 3.2. This menu allows users to:

- New (Section 3.2), Open (Section 3.3), View (Section 3.4), Close, Save (section 7.2), Save As (section 7.2) and Print (Section 3.4) RRL project files
• Select from up to 4 previously opened files
• Exit the RRL

Figure 3.2 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
• Verification dates
• Recorded parameters
• Data scaling factors

Note:
1. The View Project, 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 list 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 3.3. This menu allows users to edit:
• RRL project details (Section 3.2)
• Scale rainfall and evaporation data (Section 6.1.2)
• Set the variables to be recorded (Section 3.1.4)
Figure 3.3 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 3.4. This menu allows users to view:

- RRL project details (Section 3.2)
- Time series data values (Section 3.1.4)

Figure 3.4 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 3.5. This menu allows users to:

- Configure graph colours (Section 2.5.5)
- Specify data paths (Section 3.1.3)
- Compare time series data (Section 3.1.5)
- Compare duration curves (Section 3.1.5)

Figure 3.5 Tools drop down menu

Help drop down menu

The Help drop down menu is shown in Figure 3.6. 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 RRL menu option displays an about screen that lists the organisations and people that have contributed to the development of this product as well as a button that displays the licence agreement.
3.1.3 RRL Dialogues

The RRL contains a single tabbed dialogue as shown in Figure 3.7. 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 simulated flow graph display window.

![Figure 3.7 RRL Tabbed dialogue](image)

**Model dialogue**

The model dialogue, as shown in Figure 3.8 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
- Tank

This dialogue has three fields:

- **Model select**
- **Schematic**
- **Description**

When a model is selected the model schematic and description fields will be updated.
Input dialogue

The input data dialogue, as shown in Figure 3.9, 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 or PET depending on the model)
4. Time series flow
5. Input statistics button
6. Reset all inputs button
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 mm/day units while the flow field is expecting mm/day, m³/s or ML/day units. The units of the flow input data can be specified by the drop down menu in the flow input field.

The root data directories that appear in the file browser window may be modified by selecting **Tools | options | data path**. When this is selected the data directories dialogue as show in Figure 3.10 will be displayed. To remove a data path select the path in the data path window and click on the **Remove** button. To add a new data path click on the **Add** button and a standard windows folder browser will appear. Browse the desired folder and select the **OK** button. The data path will be added to the data path window and will also appear as a root directory in the file browser window on the input dialogue. When completed adding new data paths then select the **OK** button to exit.

- **Note** Depending on the directory that was specified when installing the RRL the initial data directory will be relative to this directory. IF the user does not have access rights in this directory then this will need to be changed. This facility allows the user to point to a directory that has write access rights.
Using RRL

Figure 3.10 Setting RRL data directories

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 as show in Figure 3.11 for each set of time series data. The information displayed includes:

- Start and end date of the time series data
- Number of missing values
- The sum of all values
- Mean
- Standard deviation
- Skew

Figure 3.11 Input data statistics dialogue

When 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 3.12, 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
Find appropriate warm up periods for calibration and verification periods

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 wettest year buttons will display the annual driest and west periods in the respective suffixed transparent colours. 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.

The calibration and verification period colours can be modified in a similar manner. To remove the driest and wettest year displays click on the update button.

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. Under certain conditions the model cannot determine this period in which case a warning message as shown in Figure 3.13 is displayed and this period needs to be specified manually.

Figure 3.13 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 3.14, 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 and stop buttons
4. Graph window
5. Viewing time series, calibration results and data statistics buttons
Figure 3.14 Calibration dialogue

Clicking the mouse on the **boundaries and fixed parameter** button displays the calibration parameters dialogue as show in Figure 3.15. The dialogue displays each of the model parameters, upper and lower bounds to each parameter and check box that can optionally fix the parameter in optimised calibration. Note the parameters that are displayed in this dialogue are dependent on the rainfall-runoff model selected.
There are three tabs on the calibration tab dialogue. The three tabs are:

1. **Generic**
2. **Custom**
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** button. Note the parameters that are displayed are dependent on the optimisation method that is specified. The setting optimiser parameters for the genetic algorithm are shown in Figure 3.16.
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

The secondary objective function drop down lists the following objective functions:

- None
- Runoff difference in %
- Flow duration curve
- Base flow method 2

The *calibrate on monthly values* check box, if checked, specifies that the objective function should be based on monthly volumes (daily flows summed over the month).

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 3.17. 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.
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.

If you right click on the parameter name a **parameter summary and options** dialogue will be displayed as show in Figure 3.18. This allows the significant digits and increment for the spinner to be varied.

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 objective 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. If you wish to stop the calibration then the **Stop** button can be selected.

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 3.19 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 (section 3.1.4).

![Model output graph window](image)

**Figure 3.19 Model output graph window**

The **calibration results** button displays 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 3.20.
Sensitivity dialogue

The sensitivity dialogue, as shown in Figure 3.21, 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 dialogue:

1. Model parameter selection drop down list box
2. Parameter bounds fields
3. Objective function selection drop down list box
4. Plot curve response button
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
Using RRL

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 3.22, allows the user to run the model for a specified period and output the results. The simulation dialogue has four areas:

1. output time period
2. run button
3. output buttons
4. graph window

The output time 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.

Figure 3.22 Simulation dialogue
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 drop down list allows the user to choose the output units that the data are to be saved as. There are 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 3.23. This window allows the user to save the model results in one the TIME supported output formats as described in Chapter 8.

![Figure 3.23 File save as window](image)

The view recorded time series button opens a graph window as shown in Figure 3.19 and 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 (Section 3.1.4).

### 3.1.4 RRL Output

#### Specifying output variables

The RRL allows the user to record various model output. By default the runoff is always output however many of the other model fluxes and storage depths can also be configured to be output. The RRL output variables are set by selecting Edit | Recorded Time Series menu option. The dialogue for the AWBM model is shown in Figure 3.24. The variables are output by selecting the check box associated with the variable. The precision of the output variable can also be specified in the significant digits spinner.
Using RRL

3.1.5 RRL Data viewers

The RRL provides two tools for viewing data in both time series and duration formats. These time series viewers are accessed via Tools | Compare time series and Tools | Compare Duration Curves, respectively. These viewers allow previously saved results from
model calibrations to be compared against each other, as well as the observed data. The graph functions are described in Section 2.5.5.

Data is added to the graph by either:

1. Pointing to the legend of the data in a graph view, holding the left mouse button down and dragging the mouse across to the data viewer graph. Note the draggable option must be turned on in the graph for this to be allowed.

2. Dragging and dropping a valid time series file from Windows Explorer.

Once added to the viewer the data will be displayed and will be listed in the left hand browser window. The data display can be toggled by clicking on the check box in the left hand browser for that data source. The data can be deleted from the view by highlighting it in the browser and selecting the delete icon on the bottom left of the window. The data may also be promoted or demoted in the viewer by clicking on the arrows in the bottom left corner.

Examples of the two viewers are shown in Figure 3.26 and Figure 3.27.

The data viewer also provides a statistics tab that provides statistical comparisons between the data displayed in the viewer. Note there must be at least two variables in the viewer for any statistics to be displayed. The statistics provided are:

1. Correlation coefficient
2. Root mean square error
3. Nash Sutcliffe coefficient
RRL Graphs

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

The calibration graph, as shown in Figure 3.28, 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 previously.

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 the Update Objective check box.

All graph fields except the Update Objective and Show Graticule check boxes, and the 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 3.1.

<table>
<thead>
<tr>
<th>Graph type</th>
<th>x date</th>
<th>x log</th>
<th>x probability</th>
<th>y log</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Scatter</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Monthly scatter</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Daily time series</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Daily difference</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Flow duration</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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 and when not checked it is a 0-100% scale 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 Figure 3.29, 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.
The current graph can be cleared by clicking the mouse on the clear plot button.

Simulation Graph

The simulation graph, as shown in Figure 3.30, 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.
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 3.2.

<table>
<thead>
<tr>
<th>Graph type</th>
<th>X date</th>
<th>X log</th>
<th>X probability</th>
<th>Y log</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily time series</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Monthly time series</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Flow duration</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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 and when not checked it is a 0-100% scale 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 3.31.

![Figure 3.31 Catchment information dialogue](image)

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

1. Location
2. Catchment area
3. Comments
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 km². 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.

### 3.4 Viewing and printing project files

The project file may be viewed or printed by selecting File | View Project or File | Print Project respectively. If view project file is selected the Current Project Dialogue will be displayed as shown in Figure 3.32. When finished viewing the project file this dialogue is exited by selecting the Close button.

![Figure 3.32 View project dialogue](image)

If print project file is selected then the standard windows print dialogue as shown in Figure 3.33 is displayed
Figure 3.33 Print project file dialogue
4 Description of models

4.1 AWBM

4.1.1 Model description

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. Note however that the RRL is currently geared towards modelling at a daily time step and AWBM is not run on hourly data. AWBM requires evapotranspiration as an input whereas most models will take PET as input.

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 4.1). 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:

\[ \text{store}_n = \text{store}_{n-1} + \text{rain} - \text{evap} \ (n = 1 \text{ to } 3) \]  

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

The three parameters \( A_1, A_2, \) and \( A_3 \) representing the proportions of the areas of the catchment are constrained; thus only \( A_1 \) and \( A_2 \) can be set. The default pattern is \( A_1 = 0.134, A_2 = 0.433, A_3 = 0.433 \) and this pattern is fixed (i.e. calibration tools will not modify it). When \( A_1 \) and/or \( A_2 \) are changed, \( A_3 \) will be adjusted to respect the constraint. If the user increases \( A_1 \), and \( A_3 \) cannot compensate, then \( A_1 \) is reduced to still respect the constraint.

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 \( \text{BFI} \times \text{runoff} \), 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. \( (1.0 - \text{BFI}) \times \text{runoff} \), is surface runoff. The base flow store is depleted at the rate of \( (1.0 - K) \times \text{BS} \), 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 \( (1.0 - \text{KS}) \times \text{SS} \), 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.
PARAMETERS AND STATE VARIABLES:

C1-C3 = Surface Storage Capacities
A1-A3 = Partial Areas Represented by Surface Storages
BFI = Baseflow Index
K = Daily Baseflow Recession Constant
BS = Current Volume in Baseflow Store (*)
KS = Daily Surface Flow Recession Constant
SS = Current Volume in Surface Routing Store (*)

Figure 4.1 Structure of the AWBM rainfall-runoff model
4.1.2 Default values

The RRL is configured with a set of default values for each model parameter. These default values specify the initial parameter value plus the upper and lower bounds for that parameter. Table 4.1 lists the default values for the AWBM model.

Table 4.1 Default AWBM model parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default value</th>
<th>Default minimum</th>
<th>Default maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.134</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>A2</td>
<td>0.433</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>BFI</td>
<td>0.350</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>C1</td>
<td>7</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>C2</td>
<td>70</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>C3</td>
<td>150</td>
<td>0</td>
<td>500</td>
</tr>
<tr>
<td>KBase</td>
<td>0.950</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>KSurf</td>
<td>0.350</td>
<td>0.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

4.2 Sacramento

4.2.1 Model Description

The Sacramento model is a continuous rainfall-runoff model used to generate daily streamflow from rainfall and evaporation records. The conceptual layout of the model is shown in Figure 4.2. River basin scale simulation studies such as those implemented in models such as IQ Q M require long-term continuous streamflow records, which are generally unavailable. However, long-term rainfall records are more available, and this can be combined with evaporation data to calibrate a Sacramento model against short term stream flow data, and thus extend or fill periods of missing stream flow.

Selecting streamflow data to use in a river basin scale simulation study needs information about the reliability of the data. Ultimately, the data which is most representative of the streamflow from the catchment. Observed data would normally be selected, except where the data is of poor quality or of unknown reliability.

As with any modelling, the accuracy and reliability of the results from the Sacramento model are determined by how representative the model is of the catchment particularly as the Sacramento model is lumped; and also by the quality of the rainfall, evaporation and streamflow data used. The accuracy and reliability of the model can be assessed using the results of comparisons with observed data.

As a rule, the calibrated parameter values of a specific catchment should not be transposed to other catchments, unless the reliability of this transposition can be assessed. The parameter set is unique to the climate, topography, size, geology, soil and vegetation type of the catchment on which it was calibrated. There is no proven methodology to adjust these parameters to other catchments, including subcatchments, of the calibrated catchment.

4.2.2 Principle of the Sacramento Model

The Sacramento Model uses soil moisture accounting to simulate the water balance within the catchment. Soil moisture storage is increased by rainfall and reduced by evaporation and by flow of water out of the storage. The size and relative wetness of the storage then determines the depth of rainfall absorbed, actual evapotranspiration, and the amount of water moving vertically or laterally out of the store.

Rainfall in excess of that absorbed becomes runoff and is transformed through an empirical unit hydrograph or similar device. Lateral water movements from the soil moisture stores are superimposed on this runoff to give streamflow.
The Sacramento model uses a total of 16 parameters to simulate the water balance. Of these:

- 5 define the size of soil moisture stores,
- 3 calculate the rate of lateral outflows,
- 3 calculate the percolation water from the upper to the lower soil moisture stores,
- 2 calculate direct runoff
- 3 calculate losses in the system

These parameters are listed and described in Table 4.2.

Table 4.2 Sacramento parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>UZTWM</td>
<td>mm</td>
<td>Upper Zone Tension Water Maximum. The maximum volume of water held by the upper zone between field capacity and the wilting point which can be lost by direct evaporation and evapotranspiration from soil surface. This storage is filled before any water in the upper zone is transferred to other stores.</td>
</tr>
<tr>
<td>UZFWM</td>
<td>mm</td>
<td>Upper Zone Free Water Maximum, this storage is the source of water for interflow and the driving force for transferring water to deeper depths.</td>
</tr>
<tr>
<td>LZTWM</td>
<td>mm</td>
<td>Lower Zone Tension Water Maximum, the maximum capacity of lower zone tension water. Water from this store can only be removed through evapotranspiration.</td>
</tr>
<tr>
<td>LZFSM</td>
<td>m</td>
<td>Lower Zone Free Water Supplemental Maximum, the maximum volume from which supplemental baseflow can be drawn.</td>
</tr>
<tr>
<td>LZFPM</td>
<td>mm</td>
<td>Lower Zone Free Water Primary Maximum, the maximum capacity from which primary base flow can be drawn.</td>
</tr>
<tr>
<td>UZK</td>
<td>1/day</td>
<td>The ratio of water in UZFWM, which drains as interflow each day.</td>
</tr>
<tr>
<td>LZSK</td>
<td>1/day</td>
<td>The ratio of water in LZFSM which drains as baseflow each day.</td>
</tr>
<tr>
<td>LZK</td>
<td>1/day</td>
<td>The ratio of water in LZFPM, which drains as baseflow each day.</td>
</tr>
<tr>
<td>PFREE</td>
<td>-</td>
<td>The minimum proportion of percolation from the upper zone to the lower zone directly available for recharging the lower zone free water stores.</td>
</tr>
<tr>
<td>REXP</td>
<td>-</td>
<td>An exponent determining the rate of change of the percolation rate with changing lower zone water storage.</td>
</tr>
<tr>
<td>ZPERC</td>
<td>-</td>
<td>The factor applied to PBASE to define maximum percolation rate.</td>
</tr>
<tr>
<td>SIDE</td>
<td>-</td>
<td>The decimal fraction of observed base flow, which leaves the basin, as groundwater flow.</td>
</tr>
<tr>
<td>SSOUT</td>
<td>m^3/s/km^2</td>
<td>The volume of the flow which can be conveyed by porous material in the bed of stream.</td>
</tr>
<tr>
<td>PCTIM</td>
<td>-</td>
<td>The impervious fraction of the basin, and contributes to direct runoff.</td>
</tr>
<tr>
<td>ADIMP</td>
<td>-</td>
<td>The additional fraction of pervious area, which develops impervious characteristics under soil saturation, conditions.</td>
</tr>
<tr>
<td>SARVA</td>
<td>-</td>
<td>A decimal fraction representing that portion of the basin normally covered by streams, lakes and vegetation that can deplete streamflow by evapotranspiration.</td>
</tr>
</tbody>
</table>

4.3 Stores

There are five stores in the Sacramento Model:

1. Upper zone tension water (UZTW)
2. Upper zone free water (UZFW)
3. Lower zone tension water (LZTW)
4. Lower zone primary free water (LSFWP)
5. Lower zone supplementary free water (LZFWS)

The tension water stores represent the volume of water that is held in the soil matrix by surface tension. Water can only be removed from tension stores by evapotranspiration. In the free water stores water can move through the soil vertically to other stores, or laterally as interflow (upper zone) or as baseflow (lower zone).
Water movement through the stores is determined by rules, where the UZTW store receives the rain first, and when this is filled water will go to the UZF store. The UZF store then supplies water to the lower stores simultaneously, with a user determined split between the free water and tension water stores. When the LZFS is filled water will go to the tension water stores.

4.3.1 Flow generation

Streamflow generated with the Sacramento model is made up of three flow components:
1. Surface runoff
2. Interflow
3. Baseflow

The generation of these components depends on the amount of water in each store relative to that store's capacity, and the rate at which water moves into and out of the stores.

Surface runoff is either direct or occurs when UZTWS is full and the rainfall exceeds the sum of the percolation rate and the maximum interflow drainage capacity.

Interflow is generated from the UZFWS as the product of the volume of water in the store, and a drainage rate parameter, UZK. Baseflow is calculated in a similar manner to interflow, using the volume of water in the lower zone free stores with their corresponding drainage rate parameters, LZPK and LZSK. The baseflow is then reduced by channel loss parameters, SIDE and SSOUT.

4.3.2 Evapotranspiration

Evapotranspiration can only take place from upper and lower tension water stores and upper free water stores, and directly from the streams. The upper limit of evaporation is the evaporative demand, and is the product of the pan evaporation modified by the (user-specified) pan factor. Evaporation occurs firstly from the UZTWS, then from the UZFWS, and lastly from the LZTWS. Evaporation can also occur directly from the stream as set by SARVA.

4.3.3 Percolation

The percolation to the lower stores is a key process of the Sacramento Model. The driving force for percolation is the relative wetness of the UZFWS as moderated by the relative wetness of the lower zone stores.

Percolation increases when either the storage in the UZF store increases or the storage in the lower zone stores decrease. This is equivalent to supply increasing and demand increasing respectively. Conversely, percolation decreases when the lower stores start becoming full.

The lower limit of percolation, \(P_{base}\), occurs when the lower zones are saturated, and is determined by the rate at which the lower zones drain (Equation 1). The maximum rate of percolation occurs when the lower zones are dry, and \(P_{base}\) is factored up using the \(ZPERC\) parameter (Equation 2).

\[
P_{base} = LZFSM \times LZSK + LZFPM \times LZPK \quad (1)
\]

\[
P_{PERC\text{MAX}} = P_{base}(1 + ZPERC) \quad (2)
\]

The actual percolation is moderated by the relative saturation of the lower and upper zones, which is the ratio of actual storage to maximum storage in these stores, to give an estimate of percolation (Equation 3).
\[ \text{Perc} = P_{\text{base}} \left[ 1 + Z_{\text{perc}} \left[ 1 - L_{Z_{r3}} \right]^{\text{Re}_{xp}} \right] \times U_{Z_{r3}} \]  

(3)

Normally, the lower zone tension store would fill before water goes to the lower zone free water store. However, variations in soil types cause deviations from average conditions and therefore in the Sacramento Model a fraction of the percolation (PFREE) is made available for lower zone free water stores.

4.3.4 Time delay tools

The direct runoff and interflow can be delayed to better represent streamflow hydrographs. The Sacramento Model uses a unit hydrograph for this purpose. Each ordinate represents the proportion of flow which will reach the channel outlet in successive time periods. The Sacramento Model also uses a layered routing process.

4.3.5 Other factors

Other inputs that can also be altered in the calibration process include the parameter RSERV (Fraction of lower zone free water unavailable for transpiration).
Figure 4.2: Structure of the Sacramento rainfall runoff model

Description of models
4.3.6 Default values

The RRL is configured with a set of default values for each model parameter. These default values specify the initial parameter value plus the upper and lower bounds for that parameter. Table 4.3 lists the default values for the Sacramento model.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default value</th>
<th>Default minimum</th>
<th>Default maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adimp</td>
<td>0.01</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Lzfpm</td>
<td>40</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>Lzfsm</td>
<td>23</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>Lzpk</td>
<td>0.009</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Lzsk</td>
<td>0.043</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Lztwm</td>
<td>130</td>
<td>0</td>
<td>400</td>
</tr>
<tr>
<td>Pctim</td>
<td>0.01</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Pfree</td>
<td>0.063</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Rexp</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Rserv</td>
<td>0.3</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Sarva</td>
<td>0.01</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Side</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Ssout</td>
<td>0.001</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Uzfwm</td>
<td>40</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>Uzk</td>
<td>0.245</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Uztwm</td>
<td>50</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Zperc</td>
<td>40</td>
<td>0</td>
<td>80</td>
</tr>
</tbody>
</table>

4.4 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 8.

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 4.3.

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.
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.

The fundamental equations of the model are:

\[
\text{imperviousET} = \min(\text{pet}, (1-\text{perviousFraction}) \times \text{perviousThreshold}, \text{imperviousIncident})
\]

\[
\text{interceptionET} = \min(\text{imperviousIncident}, \text{pet}, \text{rainfallInterceptionStoreCapacity})
\]

\[
\text{infiltrationCapacity} = \text{perviousFraction} \times \text{infiltrationCoefficient} \times \exp(-\text{infiltrationShape} \times \text{soilMoistureFraction})
\]

\[
\text{infiltration} = \min(\text{throughfall}, \text{infiltrationCapacity})
\]

\[
\text{interflowRunoff} = \text{interflowCoefficient} \times \text{soilMoistureFraction} \times \text{infiltration}
\]
infiltrationAfterInterflow = infiltration - interflowRunoff;
recharge = rechargeCoefficient * soilMoistureFraction * infiltrationAfterInterflow
soilInput = infiltrationAfterInterflow - recharge

4.4.1 Default values

The RRL is configured with a set of default values for each model parameter. These default values specify the initial parameter value plus the upper and lower bounds for that parameter. Table 4.4 lists the default values for the SimHyd model.

Table 4.4 Default parameters values for the SimHyd model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default value</th>
<th>Default minimum</th>
<th>Default maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseflow Coefficient</td>
<td>0.3</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Impervious Threshold</td>
<td>1</td>
<td>0.0</td>
<td>5</td>
</tr>
<tr>
<td>Infiltration Coefficient</td>
<td>200</td>
<td>0.0</td>
<td>400</td>
</tr>
<tr>
<td>Infiltration Shape</td>
<td>3</td>
<td>0.0</td>
<td>10</td>
</tr>
<tr>
<td>Interflow Coefficient</td>
<td>0.1</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Pervious Fraction</td>
<td>0.9</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Rainfall Interception Store Capacity</td>
<td>1.5</td>
<td>0.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Recharge Coefficient</td>
<td>0.2</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Soil Moisture Store Capacity</td>
<td>320</td>
<td>1</td>
<td>500</td>
</tr>
</tbody>
</table>

4.5 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 Figure 4.4. 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 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.

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

(1)
where, $t =$ simulation time step ($d$), $\tau =$ time ($s$), $K_1 = K_2 = \ldots = K_n = K$ 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 incomplete 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.

4.5.1 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 $i = 1,2,3\ldots$ 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·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.

4.5.2 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 generated run-off ($r_s$ mm·d$^{-1}$) and the routed run-off ($Q'_T$ mm·d$^{-1}$) can be time-averaged, as in equations (2) and (3), to represent the daily values.

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

$$Q'_T(t) = \frac{1}{t} \int_{t-t}^{t} Q'_T(\tau) d\tau$$  \hspace{1cm} (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.

$$Q'_T(t) = \sum_{j=1}^{m} h(j) r_s(t - j + 1)$$  \hspace{1cm} (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.

$$Q'^{rech}_T(\tau) - Q'_T(\tau) = \frac{dS(\tau)}{dt} = D S(\tau)$$  \hspace{1cm} (5)

where, $Q'^{rech}_T$ = recharge to the groundwater system (mm·s$^{-1}$), $Q'_T$ = discharge from the groundwater system (mm·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, $Q^g_T(\tau)$ 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.

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

(6)

The recharge $Q^{rech}_T(t)$ and the discharge $Q^g_T(t)$ can be time averaged to mm·d⁻¹ in an analogous manner, as in equations 2 and 3.
Figure 4.4 Structure of the SMAR rainfall-runoff model
### 4.5.3 Default values

The RRL is configured with a set of default values for each model parameter. These default values specify the initial parameter value plus the upper and lower bounds for that parameter. Table 4.5 lists the default values for the SMAR model.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default value</th>
<th>Default minimum</th>
<th>Default maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>G</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>H</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Kg</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>N</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>NK</td>
<td>1.00</td>
<td>0.01</td>
<td>1.00</td>
</tr>
<tr>
<td>T</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Y</td>
<td>0</td>
<td>0</td>
<td>5000</td>
</tr>
<tr>
<td>Z</td>
<td>200</td>
<td>0</td>
<td>5000</td>
</tr>
</tbody>
</table>

### 4.6 Tank

The tank model is a very simple model, composed of four tanks laid vertically in series as shown in Figure 4.5.

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 4.5 Structure of the TANK rainfall runoff 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

\[ q = \sum_{x=1}^{4} \sum_{y=1}^{n} (C_x - H_{xy}) a_{xy} \]

(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.

\[ ETA = ETP \times \left(1 - \exp\left(-\alpha \sum_{x=1}^{4} C_x\right)\right) \]

(2)

Where \( ETA \) is the evapotranspiration in mm, \( \alpha \) 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:

\[ I_x = C_x B_x \]

(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.

4.6.5 Default values

The RRL is configured with a set of default values for each model parameter. These default values specify the initial parameter value plus the upper and lower bounds for that parameter. Table 4.6 lists the default values for the Tank model.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default value</th>
<th>Default minimum</th>
<th>Default maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>H11</td>
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<td>0</td>
<td>500</td>
</tr>
<tr>
<td>a11</td>
<td>0.2</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Parameter</td>
<td>Default value</td>
<td>Default minimum</td>
<td>Default maximum</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------</td>
<td>-----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>a12</td>
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<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>a21</td>
<td>0.2</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>a31</td>
<td>0.2</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>a41</td>
<td>0.2</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>alpha</td>
<td>0.1</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>b1</td>
<td>0.2</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
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<td>0.2</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>b3</td>
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<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>C1</td>
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<td>0</td>
<td>100</td>
</tr>
<tr>
<td>C2</td>
<td>20</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>C3</td>
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<td>0</td>
<td>100</td>
</tr>
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</tr>
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<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>H41</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

Note that the Cx parameters are initial store values only, not the store capacities.
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. This method is rarely used in practice but may be used as a reference to compare the performance of optimisation methods for a given problem.

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 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:

\begin{equation}
    z = (1 - x)^2 + 100(y - x^2)^2
\end{equation}

The global minimum is found at \( x = y = 1 \), and is in a long and narrow valley, as illustrated by Figure 5.1.
Let us start the search at the point:

$$x = -1, \quad y = 0.6.$$  (2)

The search starts by initialising the base along the coordinate directions of the parameter space, as shown by Figure 5.2.
The algorithm then searches along these directions. Figure 5.3 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, 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 Figure 5.3 this happens not to be true because we optimised into the narrow valley. However, the ‘second’ vector of the new base is promising.

The second stage proceeds in a similar manner to the first one. Note on Figure 5.4 that within two stages, the new base does have a vector almost collinear with the steepest slope in the narrow valley.
Description of optimisers

Figure 5.3 First orthonormalisation of the base

Figure 5.4 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

\[ \Delta x_i = \frac{b_i - a_i}{2^l - 1} \]  

(1)

For example, when \( l = 7 \), the mapping is shown in Table 5.1. Connecting the codings of all parameters forms the coding for each point in the space to be searched

<table>
<thead>
<tr>
<th>Binary Code</th>
<th>Integer Value</th>
<th>Parameter Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000000</td>
<td>0</td>
<td>Ai</td>
</tr>
<tr>
<td>0000001</td>
<td>1</td>
<td>Ai+dxi</td>
</tr>
<tr>
<td>0000010</td>
<td>2</td>
<td>Ai+2dxi</td>
</tr>
<tr>
<td>..</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>1111110</td>
<td>126</td>
<td>Ai+126dxi</td>
</tr>
<tr>
<td>1111111</td>
<td>127</td>
<td>Ai+127dxi=bi</td>
</tr>
</tbody>
</table>

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 $p_j$ to each point $j = 1, 2, \ldots, m$, giving higher probability to points with a lower function value. The worst point after ranking is $j = 1$, and its probability value $p_1$ will be the smallest. The best point is $j = m$, and its probability value $p_m$ will be the largest. The probability values for other points are linearly interpolated as:

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

(2)

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 $p_m$ 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 $p_1$ is then $(2-C)/m$. To ensure that all probability values are nonnegative, $C \leq 2$. $C = 2$ was used.

5 Select two points A and B from the $m$ points at random according to the probability distribution $p_j, j = 1, 2, \ldots, m$.
6 Select two bit positions, $k_1$ and $k_2$, along the overall coding of the parameter set at random, giving each bit position the same chance. If $k_1 > k_2$, their values are exchanged.
7 Form a new point by taking the values of the bits from $k_1$ to $k_2-1$ of the A point coding and the values of the bits $k_2$ to the end from 1 to $k_1-1$ of the B point coding.
8 Occasionally 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 at a very small probability $p_m$ ($p_m = 0.01$ was used).
9 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.
10 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 algorithm has been given by Duan et 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. Partition the $s$ points into $p$ complexes, each containing $m$ points. The complexes are partitioned 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 $k = 1, 2, ..., m$.

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

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 $p_{min} = p$, return to Step 4.
6 Model Calibration

This Chapter discusses what needs to be considered when calibrating 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

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 catchment 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 considering. The type of land use will influence surface runoff characteristics, evapotranspiration 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:

1. Catchment average rainfall.
2. 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 isohyetal map across the catchment and the second method is sum grid squares from a rainfall surface (spline).

An isohyetal map is basically a contour map, of typically, average annual rainfall. Drawing an isohyetal 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:

1. Difference in average annual rainfall as compared to the catchment average annual rainfall.
2. Proximity to the catchment.
3. Correlation with flow peaks.
4. 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 6.1, that allows monthly or annual factors to be applied to rainfall data to adjust for catchment average rainfall.

Figure 6.1 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 portion of the catchment with each rainfall station. There are a few things to consider:

1. More is not always better. The more stations you have the more rain days that will occur on the catchment. Care should be taken to make sure that the number of rain days per month is similar to the number of flow peaks per month.

2. 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.

3. 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:

1. Evaporation pan (Class A, sunken tank, sunken tank with bird gard),
2. Lysimeter,
3. Priestely Taylor equation,
4. Morton equation,
5. Penman equation, and
6. 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 (E₀) and actual evapotranspiration (Eₐ).

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 (Figure 6.1).

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:
1. How height data is collected
2. How stable is the rating at the site
3. The relationship between height i.e. how sensitive is a flow estimate to a change in height.
4. Looped ratings i.e. where the rating on the rising and falling limbs of hydrographs are different.
5. Sticking gauge i.e. how believable is it at low flows.
6. 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:
1. 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.
2. Are there periods when the soil stores are fully saturated and fully dry.
3. 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 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 if they lie within the bottom and top thirds of the annual rainfall exceedence. 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 will 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 below the 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 will 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
Model Calibration

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 of 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:

1. The intended use of the model. Is the model to be used for yield analysis, water allocation or flood prediction?
2. Over the period of flow record has there been any change to the methods of measuring flow (height recorders and rating curves)?
3. 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 conditions 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:

1 A dynamic update checkbox,
2 List of calibration parameters, and
3 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 purpose 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 calibration 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 search 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
Objective functions

The equations for each of the objective functions are detailed below.

Nash-Sutcliffe

\[ 1 - \frac{\sum (m(i)^2 - o(i)^2)^2}{\sum (o(i)^2) - \text{mean}_o obs^2)^2} \]

Sum of the squares of error

\[ \sum (m(i) - o(i))^2 \]

Root mean square error

\[ \sqrt{\sum (m(i) - o(i))^2} \]

Bias

\[ \text{bias} = \frac{\sum (m(i) - o(i))}{n} \]

RMS about the bias

\[ \sqrt{\sum (m(i) - o(i) - \text{bias})^2} \]

Sum of the square roots

\[ \sum \sqrt{m(i) - o(i)} \]

Sum of squares of difference of square roots

\[ \sum (\sqrt{m(i)} - \sqrt{o(i)})^2 \]
Model Calibration

Sum abs diff log

\[ \sum |\log_{10}(m(i)) - \log_{10}(o(i))| \]

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.

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 the required output units.
To save as daily or monthly data, select the appropriate button. 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 user save the output in various formats (Section 8.2).

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 project files directory is relative to the directory specified during the installation of the RRL. If the user does not have access rights in this directory then this will need to be changed to be able to save project files. When a project file is saved to a new directory this directory will become the default project file directory.
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
Data
- NSW
- NT
- QLD
- VIC

Documentation
- User Manual
- Training

Help
Licence
Projects
Resources

8.1.1 Installation directory

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

8.1.2 Data sub directory

The data sub directory contains example rainfall, evaporation and flow data from four states.
NSW

The New South Wales subdirectory contains one subdirectory which is for the Abercrombie catchment (412050). The catchment data details are presented in Table 8.1.

Table 8.1 Catchment data Abercrombie River

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment area</td>
<td>2770 km²</td>
</tr>
<tr>
<td>Flow sites</td>
<td>Abercrombie River at Abercrombie</td>
</tr>
<tr>
<td>Flow Units</td>
<td>ML/d</td>
</tr>
<tr>
<td>Flow Period</td>
<td>09/02/1931 to 10/01/1996</td>
</tr>
<tr>
<td>Rainfall sites</td>
<td>060232 * 0.75, 070080 * 0.25</td>
</tr>
<tr>
<td>Rainfall units</td>
<td>mm/d</td>
</tr>
<tr>
<td>Rainfall period</td>
<td>01/01/1897 to 31/12/1998, Gap filled</td>
</tr>
<tr>
<td>Evaporation sites</td>
<td>Generated based on rainfall</td>
</tr>
<tr>
<td>Evaporation data</td>
<td>mm/d</td>
</tr>
<tr>
<td>Evaporation type</td>
<td>Based on pan data</td>
</tr>
<tr>
<td>Evaporation period</td>
<td>01/01/1897 to 31/12/1998</td>
</tr>
</tbody>
</table>

NT

The Northern Territory subdirectory contains one subdirectory which is for the Magel Ck catchment (8210007). The catchment data details are presented in Table 8.2.

Table 8.2 Catchment data Magel Ck

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment area</td>
<td>260 km²</td>
</tr>
<tr>
<td>Flow sites</td>
<td>Magela Ck upstream Bower Bird water hole</td>
</tr>
<tr>
<td>Flow Units</td>
<td>mm/d</td>
</tr>
<tr>
<td>Rainfall site</td>
<td>Magel Ck</td>
</tr>
<tr>
<td>Rainfall units</td>
<td>mm/d</td>
</tr>
<tr>
<td>Rainfall period</td>
<td>01/01/1901 to 31/12/1998, Gap filled</td>
</tr>
<tr>
<td>Evaporation sites</td>
<td>Generated</td>
</tr>
<tr>
<td>Evaporation data</td>
<td>mm/d</td>
</tr>
<tr>
<td>Evaporation type</td>
<td>Potential evapotranspiration</td>
</tr>
<tr>
<td>Evaporation period</td>
<td>01/01/1901 to 31/12/1998</td>
</tr>
</tbody>
</table>

QLD

The Queensland subdirectory contains two subdirectory which are for the Oxley Ck (143019) and Jardine River (927001). The catchment data details are presented in Table 8.3 and Table 8.4 respectively.

Table 8.3 Catchment data Oxley Ck

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment area</td>
<td>155 km²</td>
</tr>
<tr>
<td>Flow sites</td>
<td>Oxley Ck SE Queensland</td>
</tr>
<tr>
<td>Flow Units</td>
<td>mm/d</td>
</tr>
<tr>
<td>Flow Period</td>
<td>01/01/1990 to 31/12/1991</td>
</tr>
<tr>
<td>Rainfall site</td>
<td>Oxley Ck</td>
</tr>
<tr>
<td>Rainfall units</td>
<td>mm/d</td>
</tr>
<tr>
<td>Rainfall period</td>
<td>01/01/1990 to 31/12/1991, Gap filled</td>
</tr>
<tr>
<td>Evaporation sites</td>
<td>Oxley Ck</td>
</tr>
<tr>
<td>Evaporation data</td>
<td>mm/d</td>
</tr>
<tr>
<td>Description</td>
<td>Details</td>
</tr>
<tr>
<td>----------------------</td>
<td>----------------------------------------------</td>
</tr>
<tr>
<td>Evaporation type</td>
<td>Actual Evapotranspiration</td>
</tr>
<tr>
<td>Evaporation period</td>
<td>01/01/1990 to 31/12/1991</td>
</tr>
</tbody>
</table>

Table 8.4 Catchment data Jardine River

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment area</td>
<td>2500 km²</td>
</tr>
<tr>
<td>Flow sites</td>
<td>Jardine River in Northern Queensland</td>
</tr>
<tr>
<td>Flow Units</td>
<td>mm/d</td>
</tr>
<tr>
<td>Flow Period</td>
<td>01/01/1902 to 31/12/1917</td>
</tr>
<tr>
<td>Rainfall site</td>
<td>Jardin River</td>
</tr>
<tr>
<td>Rainfall units</td>
<td>mm/d</td>
</tr>
<tr>
<td>Rainfall period</td>
<td>01/01/1902 to 31/12/1917 Gap filled</td>
</tr>
<tr>
<td>Evaporation sites</td>
<td>Generated based on rainfall</td>
</tr>
<tr>
<td>Evaporation data</td>
<td>mm/d</td>
</tr>
<tr>
<td>Evaporation type</td>
<td>Actual evapotranspiration</td>
</tr>
<tr>
<td>Evaporation period</td>
<td>01/01/1902 to 31/12/1917</td>
</tr>
</tbody>
</table>

VIC

The Victorian subdirectory contains one subdirectory which is for the Bass River catchment (227219). The catchment data details are presented in Table 8.1.

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment area</td>
<td>52 km²</td>
</tr>
<tr>
<td>Flow sites</td>
<td>Bass River</td>
</tr>
<tr>
<td>Flow Units</td>
<td>mm/d</td>
</tr>
<tr>
<td>Flow Period</td>
<td>01/01/1974 to 31/12/1983</td>
</tr>
<tr>
<td>Rainfall sites</td>
<td>Bass River</td>
</tr>
<tr>
<td>Rainfall units</td>
<td>mm/d</td>
</tr>
<tr>
<td>Rainfall period</td>
<td>01/01/1974 to 31/12/1983 Gap filled</td>
</tr>
<tr>
<td>Evaporation sites</td>
<td>Bass River</td>
</tr>
<tr>
<td>Evaporation data</td>
<td>mm/d</td>
</tr>
<tr>
<td>Evaporation type</td>
<td>Actual evapotranspiration</td>
</tr>
<tr>
<td>Evaporation period</td>
<td>01/01/1974 to 31/12/1983</td>
</tr>
</tbody>
</table>

8.1.3 Documentation directory

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

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 Licence

The licence directory contains a copy of the RRL Licence agreement in rich text format (Licence.rtf).
8.1.6 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.

8.1.7 Resources directory

The resources directory contains two files that are used by the RRL software one is the toolkit mabnner and the the other is the toolkit icon.

8.2 File formats

8.2.1 AWBM daily time series format (.awb)

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 separated 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 8.1.

```
31 0 0 0 0 0 0 ... 0 0 0 0 1.2 0 0 0 0 0.08 0.8 15.28 0.8 0.8 2001 1
28 0 0 0 0 0 0 ... 1.68 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 0.24 0.88 2001 3
```

Figure 8.1 Example of AWBM daily time series format

8.2.2 Comma delimited column daily time series format (.cdt)

A comma delimited column 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 8.2.

```
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 8.2 Example of comma delimited column daily time series format

8.2.3 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 IQ M 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 IQ M format file is shown in Figure 8.3.

The first line of each table specifies 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 River 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

<p>| | | | | | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>Jun</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>165e</td>
<td>97</td>
<td>3070</td>
<td>2509</td>
<td>10956</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feb</td>
<td>2040</td>
<td>1666</td>
<td>1337</td>
<td>1081</td>
<td>-1?</td>
<td>870</td>
<td>-1?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mar</td>
<td>545</td>
<td>450</td>
<td>358</td>
<td>286</td>
<td>217</td>
<td>216</td>
<td>1987</td>
<td>7309</td>
<td>45937</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apr</td>
<td>6910</td>
<td>5528</td>
<td>4520</td>
<td>4818</td>
<td>4947</td>
<td>3982</td>
<td>9081</td>
<td>219146</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dec</td>
<td>33*</td>
<td>32558</td>
<td>31655</td>
<td>30729</td>
<td>29827</td>
<td>29154</td>
<td>19364</td>
<td>19051</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 8.3 Example of IQ M daily time series format

8.2.4 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 8.4 is organised in a series of sections identified by an identifying 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
11. Comments

---

**Data storage and file formats**

---

: Original File Name : C:\tmp\TestRRL\Projects\awbmJardine.jobf
: Created 21/06/2004 14:35:18
: Computer Name CLT225-BU
: User Name per202
: 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 only after the ‘***COMMENTS***’ section.

[Model]
TIME.Models.AWBM.AWBM, AWBM, Version=1.0.1633.27964, Culture=neutral, PublicKeyToken=null

[Location]
Name: Jardine river
Area: 2500 km^2

[Input]
evapotranspiration
.:\..\..\..\src\Program1\Applications\RainfallRunoff\Data\QLD\927001\JardineRiver.evapotranspiration_daily.tts
runoff
.:\..\..\..\src\Program1\Applications\RainfallRunoff\Data\QLD\927001\JardineRiver.runoff_daily.tts
rainfall
.:\..\..\..\src\Program1\Applications\RainfallRunoff\Data\QLD\927001\JardineRiver.runoff_hourly.tts

[NullValue]
-9999

[Parameter]
A1 0.134 0 1 True 3
A2 0.433 0 1 True 3
BFI 0.62 0 1 False 3
C1 3.4697162571238 0 44.7761194029851 False 1
C2 35.4343771108579 0 457.274826789838 False 1
C3 70.8687542217158 0 914.549653579677 False 1
KBase 0.992 0 1 False 3
KSurf 0.68 0 1 False 3

[CalibrationDates]
Minimum 1/01/1902 12:00:00 AM
Start 1/01/1902 12:00:00 AM
WarmupTo 13/05/1903 12:00:00 AM
End 2/02/1909 12:00:00 AM
Maximum 31/12/1917 12:00:00 AM
Model

The model section contains a string identifying 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 that 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 identify 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 evapotranspiration 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.

8.2.5 Q DNR SILO daily time series format (.sil05)

An Q DNR 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 separated 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 8.5.

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Day</th>
<th>Julian Day</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>12</td>
<td>29</td>
<td>363</td>
<td>0</td>
</tr>
<tr>
<td>2001</td>
<td>12</td>
<td>30</td>
<td>364</td>
<td>0</td>
</tr>
<tr>
<td>2001</td>
<td>12</td>
<td>31</td>
<td>365</td>
<td>10.2</td>
</tr>
</tbody>
</table>
8.2.6 Space delimited column daily time series format (.sdt)

A space delimited column 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 space. An example of this format is show in Figure 8.6.

```
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 8.6 Example of space delimited column daily time series format

8.2.7 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 8.7.

```
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 8.7 Example of SWAT daily rainfall time series format
8.2.8 Tab delimited column daily time series format (.tdt)

A tab delimited column 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 tab. An example of this format is shown in Figure 8.8.

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

8.2.9 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 create the file
5. Date and time file was created
6. Tarsier data 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
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 8.9.

Figure 8.9 Example of Tarsier daily time series format
9 Reference


## 10 Glossary

### 10.1 Surface water/Hydrology

<table>
<thead>
<tr>
<th>Acronym/Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseflow</td>
<td>The component of streamflow that originates from groundwater, and supports streamflows during long periods of no rainfall.</td>
</tr>
<tr>
<td>Catchment</td>
<td>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”.</td>
</tr>
<tr>
<td>Critical drought</td>
<td>The duration in time that resulted in the either the lowest dam levels, aquifer levels or pressures, or longest duration of restricted water access</td>
</tr>
<tr>
<td>Deep drainage</td>
<td>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)</td>
</tr>
<tr>
<td>End-of system flow</td>
<td>Streamflow at the end of a given river system; eg Murrumbidgee River at Balranald</td>
</tr>
<tr>
<td>En-route storage</td>
<td>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)</td>
</tr>
<tr>
<td>Flow duration curve</td>
<td>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.</td>
</tr>
<tr>
<td>Flow percentile</td>
<td>The percentage of time for which a given flow is equalled or exceeded. (see also “percentiles” in Salinity list)</td>
</tr>
<tr>
<td>Flow routing</td>
<td>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.</td>
</tr>
<tr>
<td>GL (gigalitre)</td>
<td>One thousand million litres (also equal to 1 million cubic metres)</td>
</tr>
<tr>
<td>Hydrologic cycle</td>
<td>The circulation of water from the oceans through the atmosphere to the land and ultimately back to the ocean.</td>
</tr>
<tr>
<td>Hydrograph</td>
<td>The trace which describes the change in stream flow (or water level) over time at a given location in a river system.</td>
</tr>
<tr>
<td>Infiltration</td>
<td>The process by which water soaks into the soil from rainfall, snowmelt or irrigation. (see also “deep drainage” and “recharge”)</td>
</tr>
<tr>
<td>Influent stream</td>
<td>An influent stream is one which gains water from groundwater (also known as a “gaining stream”)</td>
</tr>
<tr>
<td>Lateral throughflow</td>
<td>Relatively rapid subsurface flow through cracks, pipes, macropores in the soil – also referred to as lateral subsurface flow and interflow.</td>
</tr>
<tr>
<td>Natural development</td>
<td>This term denotes a scenario that comprises conditions in a river system</td>
</tr>
</tbody>
</table>
### Acronym/Term Definition

**conditions**
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

<table>
<thead>
<tr>
<th>Acronym/Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium</td>
<td>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.</td>
</tr>
<tr>
<td>Aquifer</td>
<td>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.</td>
</tr>
<tr>
<td>Aquifer, confined</td>
<td>An aquifer that is sandwiched between two layers of impervious materials.</td>
</tr>
<tr>
<td>Aquifer, unconfined</td>
<td>Also known as water table or phreatic aquifer. The water table is the upper boundary of unconfined aquifers.</td>
</tr>
<tr>
<td>Aquitard</td>
<td>A low-permeability layer that can store groundwater and also transmit it.</td>
</tr>
<tr>
<td>Acronym/Term</td>
<td>Definition</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Artesian water</td>
<td>Groundwater which rises above the ground surface under its own pressure by way of a spring or when accessed by a bore.</td>
</tr>
<tr>
<td>Bedrock</td>
<td>A general term for the rock, usually solid, that underlies soil or other unconsolidated material.</td>
</tr>
<tr>
<td>Bore (well)</td>
<td>Drilled or dug below the surface to access water in an aquifer system.</td>
</tr>
<tr>
<td>Discharge</td>
<td>The process by which water leaves the aquifer.</td>
</tr>
<tr>
<td>Drawdown</td>
<td>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.</td>
</tr>
<tr>
<td>Fractured rock aquifer</td>
<td>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.</td>
</tr>
<tr>
<td>Groundwater</td>
<td>The water contained in interconnected pores in rock and alluvium, below the water table in unconfined aquifers and anywhere in confined aquifers.</td>
</tr>
<tr>
<td>Groundwater system</td>
<td>Another term for an “aquifer”</td>
</tr>
<tr>
<td>Hydraulic conductivity</td>
<td>The rate at which water flows from one point to another through an aquifer.</td>
</tr>
<tr>
<td>Hydrogeological</td>
<td>Those factors that deal with subsurface waters and related geological aspects of surface waters.</td>
</tr>
<tr>
<td>Impermeable layer</td>
<td>A layer of material which does not allow water to pass through.</td>
</tr>
<tr>
<td>Observation well (bore)</td>
<td>A non-pumping well used to observe the elevation of the water table or the potentiometric surface. Also known as a piezometer.</td>
</tr>
<tr>
<td>Overburden</td>
<td>The loose soil, silt, sand gravel or other unconsolidated material overlying bedrock. Also known as regolith.</td>
</tr>
<tr>
<td>Perched aquifer/ watertable</td>
<td>A watertable above the main watertable level where impermeable soil or rock prevents the water from percolating through it to the main groundwater body.</td>
</tr>
<tr>
<td>Permeability</td>
<td>The property or capacity of a porous rock, sediment or soil for transmitting water. Sand, for example, is said to have high permeability.</td>
</tr>
<tr>
<td>Piezometer</td>
<td>see Observation well (bore)</td>
</tr>
<tr>
<td>Production bore (pumping well)</td>
<td>A bore equipped with a pump to extract groundwater from an aquifer system.</td>
</tr>
<tr>
<td>Recharge</td>
<td>The component of deep drainage that reaches the groundwater table. (see also “deep drainage” and “infiltration” - both in Surface Water list)</td>
</tr>
<tr>
<td>Regolith</td>
<td>see Overburden</td>
</tr>
<tr>
<td>Safe yield</td>
<td>The volume of water that can be taken from an aquifer at any given 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.</td>
</tr>
<tr>
<td>Static water level</td>
<td>The level of water in a well that is not being affected by withdrawal of groundwater.</td>
</tr>
<tr>
<td>Unsaturated zone</td>
<td>The zone between the land surface and the water table. Also known as the zone of aeration or the vadose zone.</td>
</tr>
<tr>
<td>Water table</td>
<td>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.</td>
</tr>
<tr>
<td>Waterlogging</td>
<td>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.</td>
</tr>
</tbody>
</table>
### 10.3 Soils

<table>
<thead>
<tr>
<th>Acronym/Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil hydraulic properties</td>
<td>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.</td>
</tr>
<tr>
<td>Soil landscape</td>
<td>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.</td>
</tr>
<tr>
<td>Soil profile</td>
<td>A vertical section of earth from the soil surface to parent material, that shows the different soils’ horizons.</td>
</tr>
<tr>
<td>Soil type</td>
<td>A general term used to describe a group of soils that can be managed similarly and which exhibit similar features and properties.</td>
</tr>
</tbody>
</table>