Appendix A1: HYDRO25 model development case study -HYDRO25 Model modules and interfaces

1.1 The main user interface

The main user interface, Figure A1.1 below, supports the code that runs the model and allows the user to link to all the other functions in the model. The user can access more than ten other major user interface forms through the main user interface.
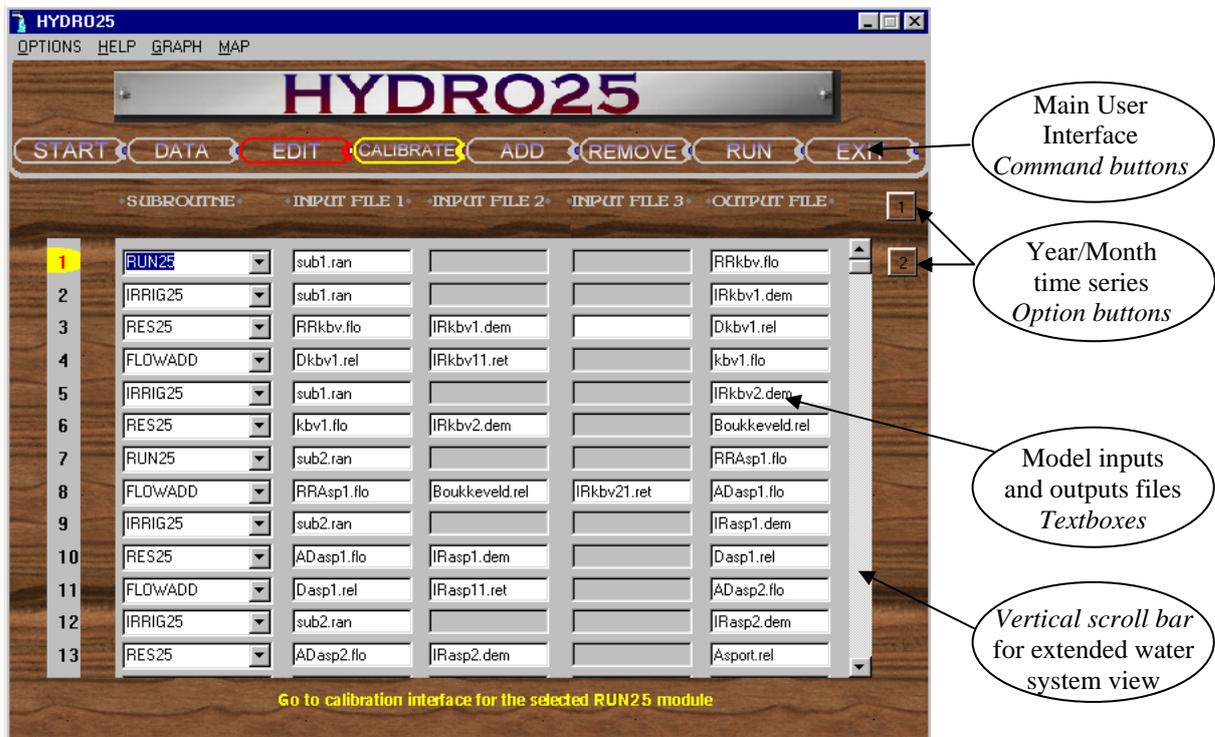

Figure A1.1   The main user interface of the HYDRO25 model.

In the main user interface a water resources network can be loaded by opening an existing network file or by creating a new file. The water resources network is created or edited from the main user interface by accessing and editing inputs via interfacing with input forms, calibrating the model and creating suitably formatted daily and monthly rainfall data. The development of a water resources network involves adding or removing modules, selecting and editing the inputs to the different modules, generating

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suitable rainfall inputs and calibrating the model against recorded data. The main user interface does not support saving of changes to the input file data or any other editing; this is done in the other user interface forms while the main user interface's primary functions are to provide access to other modules, to show modules and file linkages and to run the model. The run procedure in the main user interface runs a network file developed through the use of the other module interfaces.

1.1.2 The main user interface controls

The main user interface has controls that fall under the following broad groups or types:

(1) Menu buttons

(2) Command buttons

(3) Option buttons

(4) Text boxes

(5) Other controls

A number of controls falling under "other controls" are not directly useful to the user's interfacing and will not be dealt with in this discussion. These controls work behind the visible interface and include controls to place timing procedures, to keep the user events in temporary memory and to determine what the user wishes to do. The controls that are important in interacting with the model in the main user interface are as follows:

(1) Menu Buttons

Options: The "OPTION" menu button gives access to the following sub-menus:

"**Edit routines** "

This sub-menu enables editing of the modules and model calibration. On clicking the Combo boxes, a disabled state is changed to an enabled state, so that the user can select from the listed module names and edit the inputs for the module.

"**Run mode** "

> This sets the model into a running mode such that the user can run the model. The Run mode status is lost on accessing other routines that can be used to change the contents of a network file, so as to avoid running an incomplete network file or a network that is in the process of being edited.

"Cut routine"

> The button allows the user to put the "Remove" button into the cutting Status, a state where modules can be completely removed from the network. On clicking the "Cut routine" menu button, a sub-routine number that is highlighted in red with a yellow surrounding, is changed to show a blue surrounding. The blue surround shows that this sub-routine will be completely removed from the network when the "Remove" button is clicked. The network file will be resaved without the sub-routine with the blue background colour when the "Remove" button is clicked. The modified network will then be displayed in the main interface view. This is the only situation where an existing network file can be opened and resaved in the main user interface. In all other cases the network file is saved in the other module parameter interfaces. A short description of the "Remove" button's functions and attributes is displayed when the computer pointer is moved on the "Remove" button. The message displayed will change accordingly when the button's function changes.

"Graph"

> The "Graph" button works in conjunction with the two option buttons captioned 1 and 2. The "Graph" button is used to display a graphical representation of an existing file whose name is displayed on the main user interface. The graph can be for annual values if option 1 is selected or a monthly presentation if option 2 is selected. To use the graph button the user should select the option of annual or monthly graph, and then click in the name of the file to be displayed, then click the graph menu button. Clicking the "Graph" button after clicking the input file 2 text box

of a RES25 module will display plots representing both water supplied and the water demanded if the model has been run.

"Exit "

The "Exit" menu button will end the application and unload all forms associated with the model.

(2) Command buttons:

The command buttons are highlighted with a yellow border on receiving focus, that is when the computer pointer is moved on them, without clicking. A short description of what the button can do when clicked at the moment that they receive focus is displayed at the bottom of the main user interface. On a successful click event the button border is changed to red. The highlighting of the border with different colours gives a user an idea of the processes that he/she will be going through. A button that does not change its border colour on receiving focus or clicking is disabled. Clicking the corresponding menu buttons, discussed under the section on menu controls, changes the button's disabled conditions, in the case of the "Edit" and the "Run" command buttons.

"START": Clicking the "Start" button will load an existing network file for a saved water resources network or an empty network file that already exists. A new network file can also be saved after clicking the "Start" button. The user is given a choice of creating a new file or using an existing network file when he/she clicks the "START" button. The data in the network file are displayed in the main user interface view window when a network file is opened. Editing or calibration is possible only on an active network file whose modules are displayed on the main user interface, while running of a network file does not require that the network be displayed.

"DATA": The "DATA" button allows access to the user interface that facilitates the generation of monthly and daily rainfall inputs. On clicking the "DATA" button a set of choices are made available to the user. Selecting the first option will immediately display the RAIN25 module interface. In this module several monthly rainfall files from a specific catchment being modelled can be used to generate a single file with rainfall expressed in percentages of the catchment's overall MAP. Selecting a second

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option will display the Daily-Rain module interface. This module can be used to generate long-term daily rainfall data. These data are generated from existing records that are in the ACRU single format (Dent, Smithers, Lynch and Schulze, 1995). The single format consists of daily rainfall data in two columns consisting of the date on the left and the rainfall in millimetres separated from the corresponding dates by at least one space. The ACRU single format was chosen here because it is in this format that the author was able to secure most of the daily records in processed form for South African catchments. The ACRU data format can be obtained from the SBEEH at the University of KwaZulu-Natal. The long-term daily rainfall data are useful for estimations of daily water balances in the model from which the monthly model is built. The model does not lump all the rainfall at the end or beginning of a month but identifies the existence of smaller time steps up to a duration of one day. In the absence of the daily rainfall data file a default rainfall distribution pattern is used. The rainfall distribution pattern used in the model's default pattern is discussed in Section 1.2.3 of this Appendix.

"EDIT": The "EDIT" button is disabled on starting an application and when a new network file is opened. The button is enabled when the menu button captioned "EDIT" routines, is clicked. The "EDIT" button gives access to the parameter input module interfaces. A parameter input module can be accessed using the "EDIT" button if the module has been selected and a highlighted module number is showing to its left. To specify the module to edit, the user should click in the box displaying the module name. Pressing the "Enter" key while a module number is highlighted will perform the same function as clicking the "EDIT" button.

"CALIBRATE": The "CALIBRATE" button works with the RUN25 module. This button displays the CAL25 calibration module interface when it is clicked while a RUN25 module has a highlighted number to its left. The calibration will only apply to the RUN25 sub-routine that was highlighted when the "CALIBRATE" button was clicked. Calibration in the HYDRO25 model is important for the rainfall/runoff simulation that takes place in the RUN25 module.

"ADD": The "ADD" button adds a set of dynamic controls at the end of the displayed network. The set of dynamic controls is used to develop the network by

entering the sub-routine name and the names of the input and output files. On clicking the "ADD" button, four text boxes, a number label and a single combo box are added. Note that the inputs in the controls that are added when the "ADD" button is clicked are not saved, and will be lost on reopening of the network file. To save the inputs in the controls, the user should go through the editing procedure and save the appropriate renamed parameter file for the module selected in the newly added control.

"REMOVE": When the "REMOVE" button is clicked, two possible sets of events can occur, depending on whether the "Cut routine" menu button is clicked or not. Information on the event that will take place is displayed at the bottom of the form when the mouse is placed on the "REMOVE" button. The colour surrounding the sub-routine that is currently specified for editing can be used to determine what type of action will take place when the "REMOVE" button is clicked. If the "Cut routine" menu button is clicked the colour surrounding the routine number will be blue, in this state clicking the "REMOVE" button will completely remove the highlighted sub-routine, resave the opened network file without this sub-routine and redisplay the network file. If the "Cut routine" menu button has not been clicked, the colour surrounding the highlighted routine number will be yellow. If the "REMOVE" button is clicked in this situation the last sub-routine in the network is removed from the view irrespective of the position of the highlighting. This is not a permanent removal, as it is not accompanied by saving a new file. Clicking the "START" button and opening the current network file again can re-access the original unmodified system.

"RUN": The "RUN" button is usually disabled and cannot be clicked. To enable this button, the "Run mode" menu button is clicked. On clicking the enabled "RUN" button, any existing network file can be run, including the one currently displayed in the main user interface view if any. It should always be noted that the model will only run a network using files that exist in a single directory, that is the same file location path. The model will only access a single location of files in any single simulation. After a run, the user can run another network file in another directory if that network file has all the required input files in a single directory. Files that do not currently exist in a directory can be specified as inputs for other modules if modules existing earlier in the network will generate these files as outputs. If a file is not

generated, or if an error occurs in an earlier sub-routine that is supposed to generate inputs for later sub-routines, then the sub-routines using the file as input will run with errors. As the simulation progresses, messages of the errors that have occurred will be shown and where they have occurred. A final message will show a summary of the errors as well as the computer location of the outputs that were generated.

"EXIT": Clicking the "EXIT" button will close the application at any time. If the button is clicked and fails to close the application, this could be due to one of the following causes:

(a)   The main interface is not currently the active window.

(b)   The model is currently busy, possibly running a long simulation.

(c)   An error has occurred that still has to be rectified. One possible error that applies to all Windows application is that the application will have failed to respond. If it is only a single application that has failed to respond that application can be stopped by pressing Ctrl + Alt + Del once, then selecting the application that is failing to respond and clicking the button "End Task". It is not advisable to repeatedly press Ctrl + Alt + Del as this will close the Windows application without following the proper Microsoft (MS) Windows "Shut Down" dialogue.

Other Controls:

Combo Boxes: The combo box controls are used to specify the sub-routines in the water resources system network file. The Combo box controls exist in arrays, where up to 50 controls can be displayed in an array if code restrictions are not in place or if computer memory resources are not restricting. If the model being run has no code limitations on the network file length then the user should take precautionary measures when running long networks. Loading several controls on the main user interface with many other open Windows applications strains the computer memory capacity. Some memory problems in the operating system will leave no space for an application to run its error handling procedures, resulting in the computer completely failing to respond to any commands. The ultimate solution will be to restart the computer, a process that involves switching off the computer without following the recommended procedures of switching off the Windows application system.

Text boxes: Four text boxes are made available for each sub-routine. Some of the input file text boxes will not be enabled, depending on the specific sub-routine they are associated with, that is the one in the same row with the text boxes. The text boxes shown in Table A1.1 are available for each of the modules that can be displayed in the main user interface view.

Table A1.1   Input text boxes in the main user interface.

Sub-routine	Number of input file text boxes	Input file 1 (should always be specified)	Number of output files	
			Displayed	*Others
RES25	3	Monthly Inflow file	1	5
RUN25	1	Monthly rainfall file	1	2
CHAN25	1	Monthly flow file	1	1
FLOWADD	3	Monthly data file	1	-
IRRIG25	2	Monthly rainfall file	1	1
FACTORFLOW	1	Monthly data file	1	-

*Others: These are files that are useful for other none key purposes, such as total abstractions, water balance file in RES25 and CHAN25 modules, which are described in Sections 1.4 and 1.5 of this Appendix.

Only the enabled text boxes can have an input file name. At least the input file name for the first entry position captioned "Input file 1" should always be specified. In the case of the rainfall data files that are specified as input, the files must have rainfall data derived from using the module RAIN25 which runs outside the network file.

Other inputs on Main User Interface

Three input files can be specified for the RES25 module. Input file 1 should always be a rainfall file. Input files 2 and 3 are abstraction files, containing data on monthly storage abstraction volumes. The output file in RES25 is a spillage file with details of water releases when a dam is full. If there are no abstractions apart from overflows, then the Input files 2 and 3 can be omitted, that is the boxes are left blank. The other sub-routine with three input boxes is the FLOWADD sub-routine. The files in this routine can be any monthly rainfall or flow files in the HYDRO25 monthly data format.

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All the files specified in the input boxes should either already exist in the working directory or should be created in the modules running earlier in the network. Entry of an input file name can be achieved through one of the following methods:

(a) Typing in the name

(b) Copying and pasting a file name specified as an output in another sub-routine

(c) Double clicking on the input box to display the "Open file" dialogue box.

The first method is not advisable, as errors in typing cannot be detected easily. Method (b) is the best method to specify output files in other sub-routines as inputs to sub-routines coming later in the network. Method (c) is the best way where existing files that have been saved already can be specified. Method (c) should always be used for existing files.

In the model, a file specified as an input file is only accessed for reading purposes, without modifications. A file specified as an output file is destroyed and recreated with new data each time the model is run.

Vertical Scroll bar: The user can scroll up and down the network using this control to see other parts of the network that may not be visible in the main user interface view window.

1.2   RUN25 module

1.2.1   RUN25 general functionality

The module generates the runoff resulting from monthly rainfall input entered as percentage of the catchment MAP. The module, RUN25 is supported by a file that defines the input data and parameters relating to the catchment, as well as the relationships between the modules.

1.2.2 Mathematical structure of the RUN25 module

The Figure A1.2 below shows the schematic structure of RUN25. The structure shows how the module tracks water movement in a water system from rainfall to runoff.

In RUN25 the different processes that take place in the generation of runoff from rainfall were handled in a similar process to the illustration in Figure A1.2. Equation A1.1 shows the water balance equation used in this sub-routine. The theory behind the water balance equation is discussed in Section 1.4.2 of this Appendix.

$$Ro = Pe - Ev - In - Eo - dGw - Se + Sq + dSt$$ …………………….……Equation A1.1

Where

Ro   = runoff (mm)

Pe   = precipitation (mm)

Ev   = evaporation (mm)

In   = interception (mm)

Eo   = evapotranspiration (mm)

dGw   = change of ground water storage (mm)

Se   = seepage (mm)

Sq   = recharge (mm)

dSt   = change of surface water storage (mm)
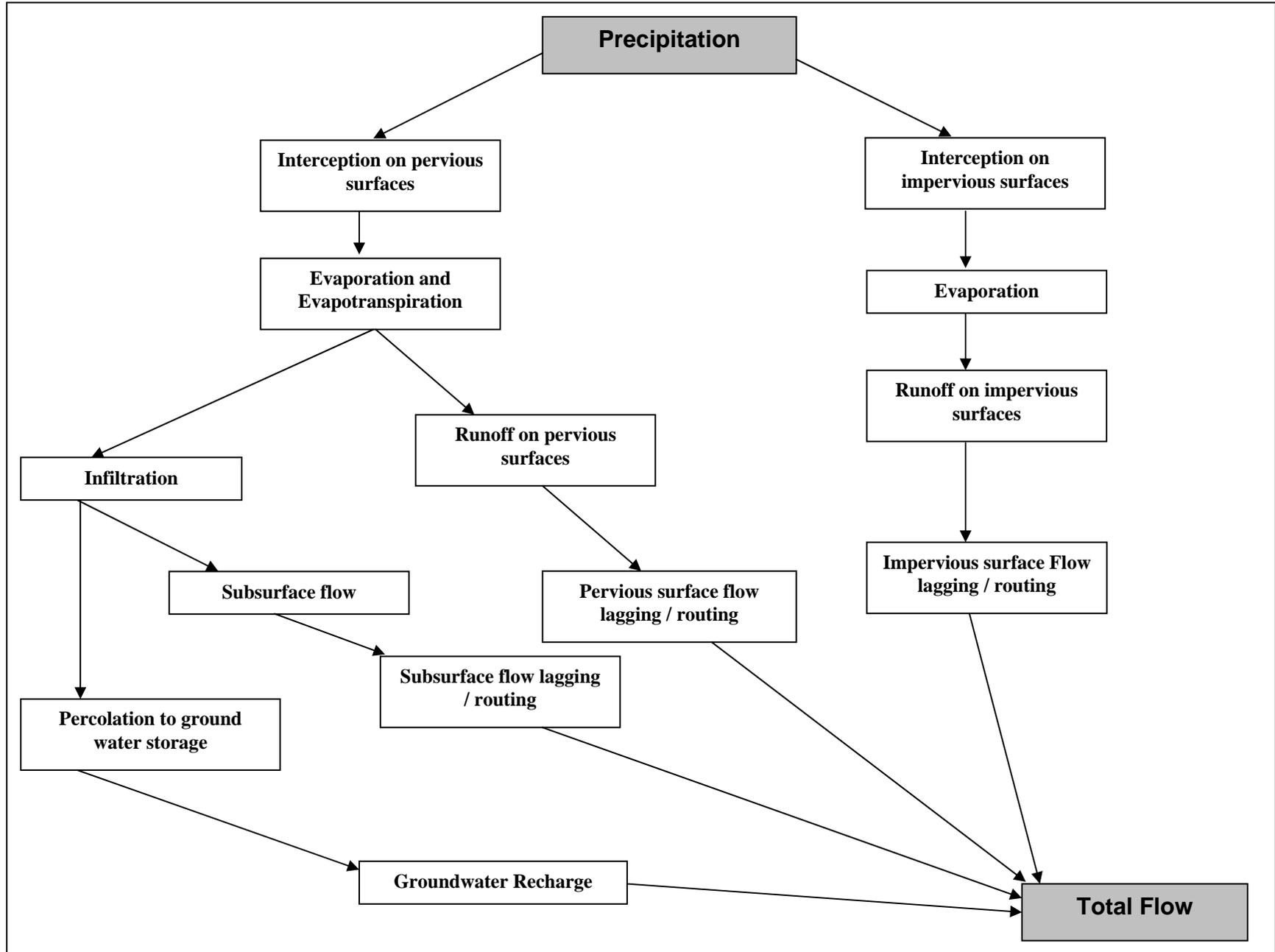
Figure A1.2 Schematic diagram of the RUN25 routine in the HYDRO25 model.

1.2.3 The water balance components in RUN25

Rainfall

The historical rainfall input data are entered in monthly time steps. The monthly figures are the percentage of the MAP that was obtained as an average of a number of records from related rain gauges in the catchment. The module RAIN25 is used to generate monthly rainfall data from a number of rain gauges that are representative of the catchment. The rainfall data, which will be in percentage units, are converted to millimetre units by multiplying percentage values with the catchment MAP. Volumetric quantities in cubic metres are obtained by multiplying the depth measurements with the total area on which the rainfall under consideration fell, usually the area of a catchment, as defined by the contour lines.

In the HYDRO25 model, monthly rainfall is not lumped as a single rainfall event but is distributed over the whole month. Two possible methods are used to spread the rainfall over the month. The method selected depends on whether daily rainfall data are entered or not. If daily rainfall data are not entered a default method based on studies by Pitman (1973) is used. This method is discussed in the following subsection.

Default rainfall distribution

Pitman (1973), made the following important conclusions on rainfall distribution where the actual pattern of rainfall is not known:

(a)   The month's precipitation is equally divided into two parts where each part falls in the approximate half of the month.

(b)   A small rainfall quantity associated with a single day's fall is evenly distributed above and below the line representing uniform rainfall distribution for the month.

The RUN25 sub-routine that simulates the rainfall-runoff relationship divides monthly rainfall into halves with a single peak in each half. A normal distribution is then maintained from the peaks to zero approximately midway for each month.

Long term daily rain

Daily rainfall, if included in the model system, is used to distribute the rainfall pattern on a daily basis in each month. The daily rainfall data do not have to be for the same period as the recorded monthly rainfall data being used in the simulation. The daily rainfall data are used to determine the long-term average rainfall for each day of the year up to 366 days to account for the leap years. In each month, the long-term daily rainfall values are factored such that the total from all the days makes up a single monthly unit. The daily fractions are then applied for each month to generate the amount of rainfall falling on that day of the month. This method, unlike the default method, does not apply a single distribution pattern for all months, but different distribution patterns for each month making it more accurate and flexible.

Interception

Not all rainfall reaches the land surface. Some of the rain is intercepted by foliage and other objects that stop the rain from reaching the ground. In the model intercepted rainfall is varied by adjusting the parameter "PI" which is related to monthly total interception. The Equation A1.2 shown below was used to calculate interception as derived by Pitman (1973):

$$I = x(1 - e^{yp})$$ …………………………………………………….…….Equation A1.2

Where   I = Total interception for the month (mm)

                p = Total precipitation for the month (mm)

                y, x are dimensionless constants derived in Equations A1.3 and A1.4 below:

$$x = 13.08\pi^{1.14}$$ …………………………………………………….....Equation A1.3

$$y = 0.0009\ \pi^{0.75} - 0.011$$ ………………………………………………….Equation A1.4

Surface runoff

In the model surface runoff is considered to be derived from three components:

(a)   runoff from impervious areas;

(b)   "excess" runoff from pervious areas; and

(c)   the contribution of ground water and subsurface flows to runoff.

Pitman (1973) performed several tests on the distribution of infiltration/absorption rates. He concluded that the best approximation of the distribution of the absorption rate could be described by a symmetrical triangle as shown in Figure A1.3.
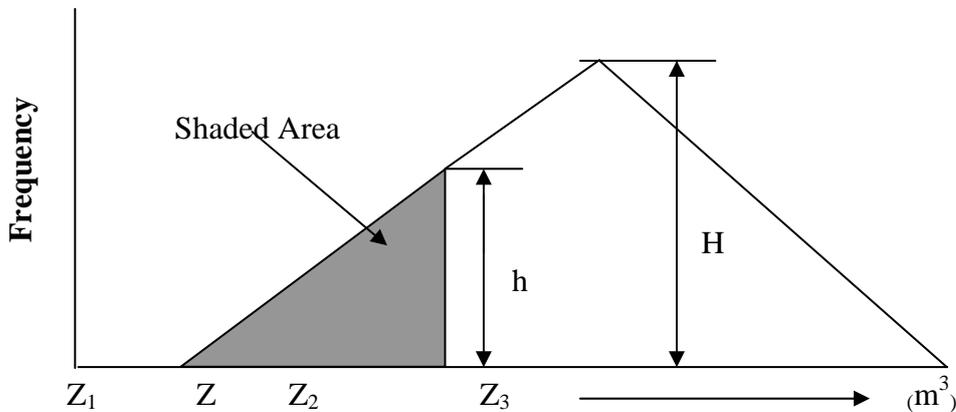

Figure A1.3   Assumed frequency distribution of catchment absorption rate.

Where:

Z =   absorption rate (m^3/month)

Z_1 =   minimum absorption rate (m^3/month)

Z_3 =   maximum absorption rate (m^3/month)

Z_2 =   mean absorption rate (m^3/month)

H =   area of a section of the triangle, such as the shaded part, defines the probability of an absorption rate Z (dimensionless)

For any given rainfall input rate, r, the surface runoff, Q, is given by Equations A1.5 to A1.7 below:

For $Z_1 \leq R$ and $R \geq Z_2$, $Q = \int_{Z_1}^{r} 2(Z - Z_1)^2 / (Z_3 - Z_1)^2 . dz$ …………....Equation A1.5

R   =   runoff rate (m^3/month)

r   =   rainfall input rate (m^3/month)

Q   =   total runoff (m^3/month)

Therefor $Q = \dfrac{2(r - Z_1)^3}{3(Z_3 - Z_1)^2}$ …………………………………………………Equation A1.6

If "r" is smaller than Z_1, there will be no surface runoff.

If "r" = Z_2 Then Q = $(Z_3 - Z_1)$/12 …………………………………………..Equation A1.7

For "r" values between Z_2 and Z_3, Pitman (1973) obtained a volume of runoff that could be described by Equation A1.8 below:

$Q = r - Z_2 + \dfrac{2(Z_3 - r)^3}{3(Z_3 - Z_1)^2}$ ……………………………………………………Equation A1.8

For "r" = Z_3 Q = 0.5 $(Z_3 - Z_1)$ …………………………………………...…Equation A1.9

For r > Z_3,   Q = r - 0.5$(Z_1 + Z_3)$ …………..…………………………….Equation A1.10

The values for Z_1 and Z_3 which determine the surface runoff for any given rainfall input are defined as the parameters Zmin and Zmax in the model. Z_2 is the value given by $\dfrac{1}{2}(Z_1 + Z_3)$.

Evaporation-Soil moisture relationship

Catchment evaporation in the model is assumed to be equal to the potential evaporation, PE in millimetres, when the soil moisture, S in millimetres, is at full capacity, ST. To account for the relationship between the extremes, Pitman (1973) introduced the model parameter R. (The model parameter R is not related to the use of this letter in equations A1.5 to A1.10). The value of R, which is dimensionless, ranges from zero when evaporation ceases, to 1 when soil moisture is at full capacity. Pitman (1973) derived Equation A1.11 to determine catchment evaporation. In the equation, the parameters, PE,

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PEMAX in millimetres, R and the soil moisture content determine the catchment evaporation. PEMAX is the monthly pan evaporation or other evaporation figure entered for each month in the parameter file of the RUN25 module.

$$E = PE \times (\frac{1}{1 - R(1 - PE / PEMAX)} \times (1 - \frac{S}{ST}))$$ …………………..…….Equation A1.11

Runoff-Soil moisture relationship

The relationship between the soil moisture content and runoff was derived by Pitman (1973) who based the relationship on the following four parameters:

ST   = Total soil moisture capacity (m^3)

FT   = Runoff at soil moisture equal to ST (m^3)

SL   = Soil moisture below which no runoff occurs (m^3)

POW = Power of the runoff-soil moisture curve (dimensionless)

Pitman (1973) obtained Equation A1.12 below for this relationship:

$$Q = A (S - SL)^{POW}$$ ………..…………………………………………Equation A1.12

Where A = $\dfrac{FT}{(ST - SL)^{POW}}$ ………..…………..………………………..….…Equation A1.13

Resulting in Q = FT $(\dfrac{S - SL}{ST - SL})^{POW}$ ………..……………………………Equation A1.14

Runoff time lag

The rainfall-runoff time lag and the attenuation of runoff as it flows from the catchment are calculated in the model using the Muskinghum equation. The Muskinghum method uses a linear algebraic relationship between the storage (S), and both the inflow (I), and the outflow (Q), together with two parameters: (K) describing lag of runoff, and (x), a weighting factor. The basic continuity or storage statement is given by Equation A1.15 below.

$$S = \frac{dS}{dt} + I - Q \quad \text{...............Equation A1.15}$$

The total storage is expressed as

$$dS = S_2 - S_1 = K(x(I_2-I_1) + (1 - x)(Q_2 - Q_1)) \quad \text{...........Equation A1.16}$$

The subscripts 1 and 2 refer to the consecutive time steps in this model, a previous month with the subscript 1 and a current month with the subscript 2. A weighting factor of zero was used to account for the lagging of instantaneous runoff as used in the model.

Combining this expression with the continuity equation yields;

$$0.5(I_1 + I_2)dt - 0.5 (Q_1 - Q_2)dt = S_2 - S_1 \quad \text{...............Equation A1.17}$$

An algebraic modification will yield Equation A1.18 below (Raudkivi, 1979).

$$Q_2 - Q_1 = C_1(I_1 - Q_1) + C_2 (I_2 - I_1) \quad \text{...............Equation A1.18}$$

$$\text{Where } C_1 = \frac{dt}{K(1 - x) + 0.5dt} \quad \text{...............Equation A1.19}$$

$$\text{And } C_2 = \frac{0.5dt - Kx}{K(1 - x) + 0.5dt} \quad \text{...............Equation A1.20}$$

The Equation A1.18 relates to a model with the following variables:

Q = monthly runoff total at catchment outlet (m^3)

I_i = Instantaneous monthly runoff (m^3)

dt = routing period (months)

K = lag of runoff (dimensionless)

x = weighting factor (dimensionless)

S   = Storage (m^3)

Two sets of runoff were lagged in the model, with runoff from the soil moisture being accounted for by using a longer lag through higher K values entered in the model as the parameter, GL. The GL values for some parts of the catchment could be as high as three months. The parameter GL should not exceed the maximum ground water contribution to runoff. Surface runoff had shorter time lags defined through the value of K in Equations A1.16 to A1.20, given by the parameter TL in the model. The value of TL can be determined by the model user through repetitive attempts. Values of TL were usually fractions of a month where low values of 0.2 months were used for some parts of the catchment.

1.2.4 RUN25 user interface

The module RUN25 runs in two instances, in the calibration module and in the main model simulation linked to other module routines. In the two instances, the module utilises a parameter file with data structured as shown in Table A1.2 below. The file entries are discussed later in Section 1.2.5 of this Appendix in more detail.

Table A1.2   An example of RUN25 parameter file inputs.

Entry in parameter file	Description
1,"Run5.001"	Name parameter file for the module
2,1	Module location
3,"drn-01.txt"	Rainfall file name
4,"Yes","sub34flow2.101"	Daily rainfall file to use
5,400	Mean annual precipitation
6,2,0,200,30,0,0,180,1.5,.3,0,0	Rainfall-Runoff parameters
7,147,200,241,271,197,178,105,65,46,52,64,91	Symon's pan evaporation
8,.8,1,1,1,1,1,1,1,1,.8,.8,.8	Evaporation factors
9,1920	Rainfall data record start and end year
10,1999	
11,1920	RUN25 module simulation record start and end year
12,1999	
13,2	Number of stages in defining catchment
14,1900,1294,0	Year, pervious catchment area, impervious catchment area
15,1950,2121,0	

The data in the parameter file, such as that shown in Table A1.2, are entered using the RUN25 parameter input interface. Modifications or editing of values in the file will be achieved in the parameter-input interface and the CAL25 interface during calibration. The user can access the RUN25 user interface only when the network file opened in the main interface has a RUN25 module specified. A water resources network can have several sub-catchments where rainfall-runoff simulations are required such that the network file may have a number of the RUN25 modules specified to represent these rainfall-runoff simulations. The user should move the yellow highlighter to the RUN25 module that he/she wishes to edit or enter new parameters. When the sub-routine number corresponding to the RUN25 module is highlighted, clicking the Edit button will open the RUN25 parameter file input interface. New parameter values can then be entered in the parameter input interface, as well as a daily rainfall file (if available) and data on the extent of the pervious and impervious areas in the catchment in any year with data that lie within the simulation period, starting in the simulation start year. Input boxes indicating the start and end of the simulation are shown in the second row of input boxes in Figure A1.4.

Figure A1.4   RUN25 user interface.

1.2.5 The RUN25 module inputs

The inputs in the interface for the RUN25 module consist of text boxes and option buttons. The inputs can be entered by clicking option buttons, typing new values in text boxes that can receive text and, in the case of the disabled input boxes, values are entered through code procedures, triggered by events on the form. Figure A1.4 shows the RUN25 interface with examples of inputs.

The input boxes of RUN25 with parameter file entries as shown earlier in Table A1.2 are discussed here using the captions in the labels on the left of most input boxes and in the top row for monthly inputs and parameter inputs as shown in Figure A1.4.

This file name: The name of the parameter file that is currently opened is displayed in this input box.

Rain file name: The name of the file with the long series of monthly rainfall data in percentages of the mean annual precipitation is entered in this input box. The rainfall file can contain up to 110 years of monthly values. The name of the file is passed to the module interface when the form is loaded. The rainfall file is the input file 1 in the main user interface.

Network file name: The name of the network file defining the water system model structure is entered in this box. The file name is loaded when the form is loaded.

Output file name:The name of the main output file, with the monthly flow values generated from the rainfall is entered in this input box, on form loading. Entry of the output file name is done in the main user interface as the "Input file 4" for the RUN25 module.

MAP : The Mean Annual precipitation in millimetre values is entered in this input box. The value is directly typed into the box. The MAP value works with the rainfall data in percentages of MAP. The rainfall percentages are multiplied by the MAP value to give actual rainfall for each month in millimetre units for use in the model.

Simulation Start Year: This entry is the year in which the RUN25 module will start simulating. The value is entered on pressing the update button.

Simulation End Year: The year in which the simulation will end will be displayed in this text box when the update button is clicked.

Option Buttons: The option buttons work together with the daily rainfall file entries. If a file with the necessary daily rainfall data for the catchment being modelled is available in suitable format in the working directory, then the "Yes" option button is clicked. If no daily rainfall input is to be used for the RUN25 sub-routine being modelled then the "No" option is selected. In both cases, after clicking the appropriate option, the label captioned "Enter Response" is clicked. If the "Yes" option was clicked then the "Open file" dialogue box pops up, where the filter to open files of the extension ".002" can be used to open the daily rainfall file. If the "No" option had been selected then on clicking the "Enter Response" label, the file name box for the daily rainfall file is cleared and the "NO" option is recorded in the parameter file.

Parameters:

POW: Power of soil moisture runoff equation. Equation A1.12 shows how this parameter is used in the model. This parameter has no units.

SL: Soil moisture storage level below which no runoff from the soil occurs. The value is in millimetres.

ST: Maximum soil moisture capacity in millimetre units.

FT: Runoff from soil moisture at full capacity in units of millimetres per month (mm/month).

GW: Maximum groundwater runoff in mm/month.

Zmin: Minimum catchment absorption rate in mm/month. This is Z_1 in the Equations A1.5 to A1.10.

Zmax: Maximum catchment absorption rate in mm/month. In the calculations the value is given as Z_3 as shown in the Equations A1.5 to A1.10

PI: Interception storage in millimetres. The amount of water that does not reach the ground and is considered to be lost through evaporation and evapotranspiration while trapped in leaves or other material covering the ground.

TL: Lag of runoff other than that from soil moisture. TL is the value K in the muskinghum Equation A1.16 for surface runoff.

GL: Lag of runoff from soil moisture. GL is the K value in the muskinghum Equation A1.16 when applied to ground water contribution to surface runoff.

R: The parameter defining evaporation-soil moisture relationship. The Equation A1.11 utilises the parameter R to determine catchment evaporation.

Evaporation:

There are two sets of evaporation inputs: the monthly pan evaporation values in millimetre units in the first interface row with 12 input boxes, and the pan factors in the second row. Monthly evaporation inputs as well as other monthly inputs, including monthly data files, are entered in the model starting in the month of October and ending in September for each year. The period starting in October and ending in September was used in the model to coincide with the hydrological year in South Africa. The South African hydrological year period starts at the beginning of the rainfall season in October and ends at the end of the dry season in September. In the pan evaporation input boxes other monthly evaporation figures, not necessarily pan values, can be entered if the model user considers them more representative of the stream-flow evaporation in the catchment he/she will be working on. The pan factor values are the monthly fractions applied to the evaporation figures to determine the amount of the given evaporation figure that should be applied in the model for the RUN25 module. The pan factor values should be a value of 1 (equal to pan evaporation rate) or less.

Catchment area statistics:

The last set of inputs consists of three arrays of input boxes for entering the state of the catchment over time in years for each year that has available data. The entries should start in the year that the simulation is started or earlier. For each year the total area in square kilometres (km^2) is entered as well as the area of impervious surface. It will be noted that the impervious area, apart from representing the areas that are naturally impervious such as rock formations, will be used to represent the development of paved areas on roads, urban settlements and other infrastructure. This value is usually a very

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small percentage of the total catchment area but steadily increases with time as a result of increasing levels of development in the catchment.

1.3   CAL 25: The calibration routine

The model calibration in HYDRO25 aims to identify and obtain a set of parameters for a particular catchment under particular hydrological and land use conditions, which give the best fit between simulated and observed streamflow for a particular calibration period. The period used in the calibration depends on the record length of observed runoff, measured rainfall, land use and evaporation used in the simulation. The module CAL25, which is basically the RUN25 module with added functionality to improve the input parameters, is used for calibration.

1.3.1 Steps to access CAL25

(1) The model user identifies the RUN25 module that he/she wishes to calibrate by clicking on it in the main user interface. The yellow highlighter will come to the sub-routine number corresponding to this module.

(2) Clicking the "EDIT" button or pressing of the "Enter" key will lead the user to the parameter input interface for the module to be calibrated.

(3) With the RUN25 parameter input interface open, the user can open an existing parameter file if there is one previously saved for this module, or save a new parameter file. To identify the parameter file which was saved for the module, the "View" button is clicked while the module interface is open. A "View" window highlighting the current sub-routine number will appear showing the current parameter file name immediately to the left of the highlighted sub-routine number. Clicking "OK" or pressing the "Escape" key will unload the "View" window.

(4) After editing the parameter file, the parameter file is saved using the "Save" button or the "Save As" button if there is need to specify a new file name.

(5) With the module interface open, pressing the "Escape" key or clicking the "Back" button will take the user back to the main user interface.

At this stage the user will have defined the Runoff inputs, but the parameters in the rainfall-runoff modelling may not be suitable for the catchment characteristics. If recorded runoff for the catchment exists only for a few years, preferably longer than ten years, the user will need to use the naturalised flows to determine the most suitable parameter values, using CAL25. The term naturalised flows used here will refer to the flows at the virgin (undeveloped) state of the catchment, that is before any activities that modify the catchment hydrology have been implemented. The activities responsible for changing catchment hydrology include building of dams, deforestation, afforestation, developing of irrigation schemes and building human settlements.

1.3.2 Using CAL25

a) After editing and saving the parameter file and returning to the main interface as described in (1) to (5) immediately above, clicking the "CALIBRATE" button will open the CAL25 interface for calibration which is shown in Figure A1.5. The module highlighter should be corresponding to the RUN25 routine to be calibrated before the calibration button is clicked.
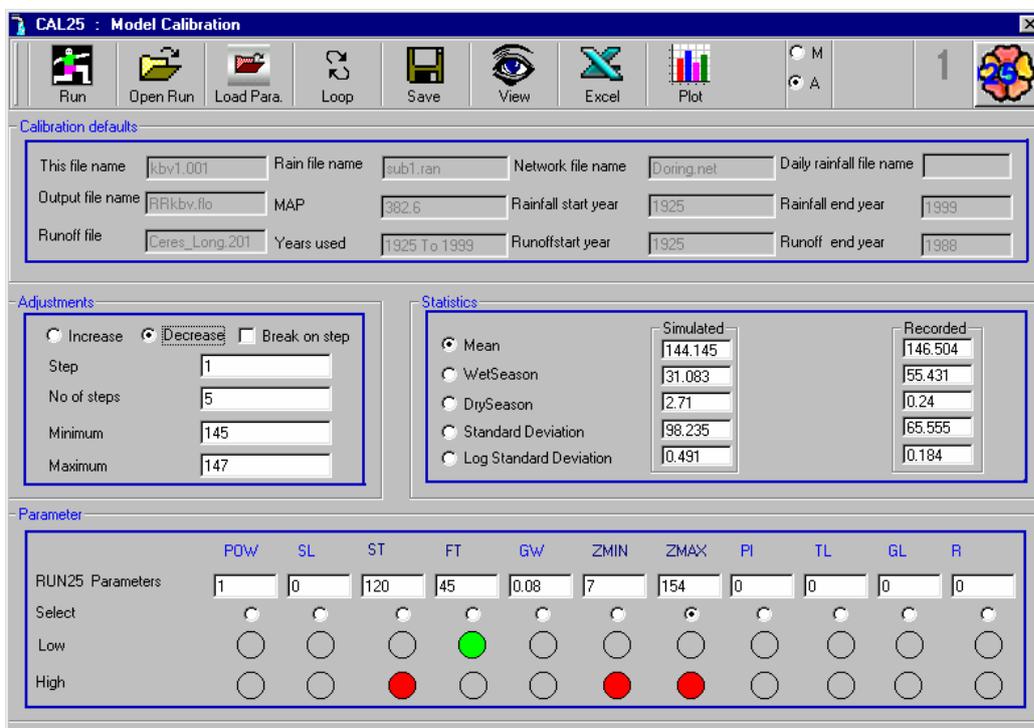

Figure A1.5   CAL25 user interface with examples of inputs.

b) In the Calibration interface, Figure A1.5, the button captioned "Load Para" is clicked to load the parameter file that will be used for calibration.

c) To open the file with the naturalised-recorded runoff the button "Open run" is used. The data file should be of the HYDRO25 monthly data format a sample of which is shown in Figure A2.5 of Appendix 2 as. If the file is not of the correct format an error message is generated which is cleared by clicking its "OK" button.

d) The rainfall-runoff simulation will run on clicking the "Run" button to generate monthly runoff in units of million m^3 per month. A statistical analysis of the simulated runoff is done, as well as a statistical analysis of the recorded runoff. The following statistical results are recorded on the user interface for comparison.

(i)	Mean:	The mean annual runoff for the period
(ii)	Wet Season:	The average of each year's highest monthly value
(iii)	Dry Season:	The average of each year's lowest monthly value
(iv)	Standard deviation:	The standard deviation of annual values
(v)	Log Standard Deviation:	The logarithm of standard deviation of annual values.

It should be noted that the recorded flow data used must lie within the same period as the period being simulated such that simulated monthly flows and recorded data for the same months are compared.

(e) The statistical parameter to be fitted to the recorded data are identified by clicking on the option button behind it. The order in which the statistical values are arranged from top to bottom is the order of importance that the developer attached to each parameter and also relates to the amount of influence the parameter accuracy has on the simulated flows.

(f) On clicking the statistical parameter's caption button, a comparison of the simulated and recorded data's parameters is done and possible changes are suggested for increasing or decreasing values of certain runoff parameters. These will be shown at the bottom of the user interface. A red circle indicator shows that if the value of the parameter is reduced then the statistical indicator of the simulated flow will get

closer to the corresponding recorded flow indicator. If the parameter value is still in a reasonable range, for example, if it is not already zero, then the user is advised to reduce it. The yellow circle indicator shows that if the parameter is increased then the simulated data statistical indicator selected is likely to get closer to the recorded flow statistical indicator.

Using the statistics indicators and parameter box: The suggestions on varying the runoff parameters are not 100 % accurate due to several factors, that include:

(1)   Quality of the input data

(2)   Many factors that are not supported in the model such as soil types, the slope of the terrain, extent and type of plant cover on the land, and type of the rainfall storm.

(3)   The complicated relations between parameters. Each statistical indicator's value depends on a combination of several of the RUN25 parameters.

The model user is advised to concentrate on changing the runoff parameters ST, FT, Zmin and Zmax, which can be identified by the captions in a deeper blue font. Other parameters should only be changed with caution.

The user will notice that when using runoff data that have very little relationship with the catchment, or when starting with unrealistic parameters, then the calibration suggestions will not behave as expected. Direct inputs of parameter values in the boxes is possible if large differences in parameter values need to be tried. In this case one can change all parameters at once, but should not forget to save the changes before running the model. The "looped" run button should not be used when several parameters are being changed, rather a single run is performed by clicking the button captioned "Run".

(g) To run the automatic calibration looped runs, the "Increase" or the "Decrease" option button in the adjustment box is selected to increase or decrease selected parameter

values, respectively. "Break on step" selection box is selected to be able to see the new values of statistical indicators at the end of each simulation step before the set objective is met.

(h) On the left of the text box marked "Step", the extent of the increase or decrease step by which the selected parameter will be varied for each simulation loop is entered. Looped runs should be started with small values to check the sensitivity of the statistical values to the change in the runoff parameter value.

(i) The number of times that the step process will be done is entered in the text box with the label "No of steps". The value should be a positive integer.

(j) The maximum and minimum statistical indicator value is entered to define the range where the user wishes to see the statistical indicator value falling within.

(k) The button captioned "Loop" will start the looped run on clicking.

(l) If the user had selected to "break on step", then the module will run for a single step and display a message indicating that it has completed step 1. Clicking the "OK" button in the dialogue box will allow the looped run to proceed to the next step.

(m) Additional loops can be run by first saving the current parameter values by clicking"Save" to use the file at this stage, or by pressing the "Reload para" button then selecting the statistical indicator to be used, then the parameter to vary and the increase or decrease button. If other values in the adjustment box are not varied, then the previous entries as displayed in the boxes will be used. The user is advised that after a reload, selecting the statistical indicator button will give suggestions on changes related to the previous run with different parameter values to the ones that will be reloaded. Performing a single run after reloading the parameter file is advisable, to ensure that all statistical indicators shown relate to the reloaded parameter file.

Using the adjustment box: The computer will read the value of the decrease and increase option buttons to see what the user wishes to do with a selected parameter. If the user has selected to increase the parameter, then it will use the value defined in the step to increase the selected parameter, for example Zmin. For each new Zmin value the application will simulate the flow using all other values as in the last saved parameter file and include the new Zmin value. For each simulation step, the model will check if the new statistical indicator is within the chosen range as defined by the maximum and minimum values in the adjustment box. If the statistical indicator is within the range for

any time step the model will stop and advise the user that it has found a value within the required range. If the statistical indicator remains outside the range, the model will continue to do the rest of the steps and at the end show the output of the closest match that it simulated as the last output. Parameter values displayed on the form are not saved until the "Save" button is clicked. Only parameter values that have been saved are used to start a simulation. The parameter file has to be saved after a looped run to accept the new value of the parameter and use it for further looping or, if the parameter values displayed are not required, then an existing parameter file is reloaded without changes. Use the button captioned "Load para" to reload the last saved parameter file.

Simulating looped runs: Changing the parameter values by only typing new values without saving and then running a looped run, will result in the use of the last saved parameter file excluding the changes. The displayed values are not changed except for the parameter that is being varied for the looping, such that the parameters displayed and those used in the run will be different. Further complications arise when the user clicks on the statistical indicators. The model will suggest the parameters that need changing but the values displayed will be wrong. The user is advised to avoid the problem by using the "Save" button or the "Reload para" button before any run. A single run will always display the parameter values of the last saved file.

CAL25 has hidden text boxes that display the changes that occur in each of the statistical indicators during a looped run. The text boxes are displayed during a looped run. They will show the changes at each step if the "Break on step" selection box is selected in the adjustment box. If the looping is done without breaking, then the values will be shown at the end of the run after all the looping has been done.

1.3.3 CAL25 tool buttons and other controls

The CAL25 interface, Figure A1.5, has a number of buttons in the toolbar control and on the interface form. The buttons can achieve a number of functions as described below:

(1) "**Back**": allows the user to return to the main user interface. This can also be achieved by pressing the "Escape" key or the flower icon on the top right hand corner of the form.

(2) "**Run**": will perform a single simulation of the runoff and statistically analyse output runoff. If a recorded file has also been opened it will also be analysed such that the two sets of outputs of statistical indicators can be compared.

(3) "**Open Run**": On clicking, a pop-up dialogue box will appear for opening existing files with the extension ".201". This file type should contain the recorded monthly runoff data in million m^3 starting in October and ending in September for all the years in the HYDRO25 monthly data format. The recorded runoff data used for comparison must be naturalised. The comparison takes place between the simulated flows that do not account for developments in the catchment, such that the output flows will be those that describe a virgin catchment.

(4) "**Load para**": this button will load the existing parameter file. If on clicking this button a message box pops up indicating that the file you are using was saved for another RUN25 sub-routine, it is advisable that the user leaves CAL25 and goes to the RUN25 module interface at the same sub-routine that he/she wishes to calibrate. In RUN25 the user should open the file to be calibrated and resave it with a different name, then return to the calibration routine. The parameter file used for calibration should be saved specifically for that RUN25 sub-routine, except in cases where a single runoff gauge is being used in the calibration for all the RUN25 sub-routines that are using the same parameter file. Calibrating a parameter file being used in more than one sub-routine means that all the other sub-routines will also use the parameter values calibrated using recorded flows that may not apply to all of them. It is important that runoff records for each sub-catchment are obtained and used in calibration.

(5) "**loop**": this button allows the model to do a number of runs, changing one of the parameters for each run as defined by the user.

(6) "**Save** ": this button will save two files, a parameter file with all the values as currently displayed, and a network file to include any modifications that the user will have done. The message "Saved" will be displayed in the top tool-bar control for any successful saving. It will be noted that this module does not have a "Save As" facility and thus will not allow the user to change the file name. File name changes can be done in the RUN25 module user interface.

(7) "**View**": On pressing this button or the "Enter" key, a pop-up form will be displayed showing the whole network/system and, most importantly, the parameter file that is currently saved for the sub-routine being calibrated. The current routine is displayed in the "View" window with its routine number highlighted in red, positioned in an accessible location. Immediately on the left of the sub-routine number will be the parameter file being used. To exit from the "View" window click the "OK" button in the window or press the "Escape" Key.

(8) "**EXCEL**": Clicking the button provides a link to the Microsoft Excel application. In Excel the entries of the simulated and the recorded monthly flows are recorded in columns suitable for drawing a graph for visual comparison of the monthly flows. After a simulation that includes the analysis of the recorded flows, clicking the "Excel" button will display an "Open file" dialogue box with a filter to show the Excel files only. The file HYDRO25.xls, which should be in the same directory as the data files, can be opened for updating. The file contains a prepared graph for the recorded and simulated flows. The values in the graph are updated. The model does not make any other changes to the Excel file that is opened except entering recorded and simulated flow values in sheet 1 of the opened file, HYDRO25.xls. A different file name can be used if required. In both cases, the final output file name will have a different name from the file that was opened for update, for example the file name HYDRO25.xls will generate a new file with the name HDRO251.xls. The file will need to be saved if required for later use or if the file chart has to be edited.

(9) "**PLOT**": The button works in co-ordination with the option buttons captioned "A" and "M". After a model run in the CAL25 and the selection of either option "A" for an annual plot or "M" for a monthly plot, clicking on the "Plot" button will load the line graphs of the recorded flow and simulated flow.

(10) The last three boxes in the Tool-bar: On the extreme right is a flower icon with the word "HYDRO25" scrolling. This control can be clicked to return to the main user interface. The box on the second position from right displays the sub-routine number. The third box from right is usually empty but displays the message "Saved "on completion of a successful save and will show the word "Running" when running a looped run if the "Break on step" selection is selected.

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1.4   RES25: Reservoir simulation

1.4.1 General information on RES25

The module RES25 simulates the quantity of water stored in the catchment. The catchment water storage can be an existing dam or a "dummy dam", or a non existent dam that has been proposed for development. The "dummy dam" refers to an imaginary combination of several dams, such as small farm dams that cannot be included easily as single dams in the model. The module RES25 allows the user to enter up to 19 modifications to the storage over the simulation period. Modification can be done on the full supply capacity (FSC), dead storage capacity (DSC) and the dam surface area at FSC. The time-related modifications will allow for the inclusion of structural changes such as raising a dam wall and construction of new farm dams, as well as other time-related changes such as dam siltation and desilting exercises. In RES25 a water balancing process is maintained where inflows and outflows are simulated in relation to changes in the storage volume.

1.4.2 Theoretical and mathematical concepts in RES25

In the module RES25, a water balance equation that is a special case of the general control volume equation is used. This general control volume equation is called the Reynolds Transport Theorem (Chow, 1959).

Reynolds Transport Theorem

Reynolds Transport Theorem states that: "The total rate of change of an extensive property of a fluid, dB/dT is equal to the rate of change of an extensive property stored in the control volume plus the net outflow of the extensive property through the control volume" (De Laat, 1998). Equation A1.21 in Box A1.1 gives this relationship.

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$$\left| \frac{dE}{dt} = \frac{d}{dt} \int \int \int BpdV + \int \int Bp(U.dA) \right.$$ …………………….……..Equation A1.21

Box A1.1   Reynolds Transport Theorem (De Laat, 1998).

In Equation A1.21,

E   = extensive property of the fluid which depends on mass present (kg)

B   = the intensive property of the fluid whose value is not dependent on mass

   (dimensionless)

p   = density of fluid (kg/m^3)

V   = volume (m^3)

U   = velocity vector of the fluid (m/s)

A   = area (m^2)

t   = time (seconds)

U.dA is the vector dot product of the velocity vector of the fluid, U, with length (De Laat, 1998).

The Reynolds Transport Theorem gives the integral equation of continuity from which the water balance equation is derived. The integral equation of continuity was conceived from the following ideas:

If mass is the extensive property being considered then E = m and B = dE/dm = 1. By the law of conservation of mass, dE/dt = dm/dt = 0 because mass cannot be created or destroyed. Substitution in Reynolds Theorem yields the equation of an unsteady flow with variable density as given in Equation A1.22 which gives Equation A1.23 if the flow density remains constant.

$$0 = \frac{d}{dt}\iiint pdV + \iint pU.dA \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots.......\text{Equation A1.22}$$

$$0 = \frac{d}{dt}\iiint dV + \iint U.dA \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\text{Equation A1.23}$$

Box A1.2 Applying the law of conservation of mass to the Reynolds equation (De Laat, 1998).

The integral, $\iiint pdV = S$, the volume of the fluid stored in the control volume, such that the first term in the Equation A1.23 is the rate of change of the storage with time, dS/dt.

The second term in the Equation A1.23 is the net outflow that can be split into inflow, I(t) and outflow, O(t). In the inflow, the direction of the velocity vector U and the area vector, dA, point in different directions such that their dot product is negative. In the case of outflow the vector dot product is positive. As a result Equation A1.23 can be represented as Equation A1.24 below.

$$\frac{dS}{dt} + O(t) - I(t) = 0 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots...\text{Equation A1.24}$$

The Equation A1.24 is the basis for the water budget concept used in the module RES25. The Equation A1.24 is also referred to as the mass balance or water balance equation (De Laat, 1998). In the Equation A1.24

I	=	Inflow (m^3/month)
O	=	Outflow (m^3/month)
$\frac{dS}{dt}$	=	Rate of change of storage with time in (m^3/month) of considered control volume in the system. The control volume in RES25 is the

volume of water in the dam.

Equation A1.24 requires that the system boundaries be well defined; since the boundary will be the region where the water balance is applied. Figure A1.6 gives the schematic illustration of how the water balance is applied in the RES25 module.

In RES25 the inflows, I(t) are:

(1) Direct rainfall (million m^3)

(2) Runoff entering a physical dam or "dummy dam" (million m^3)

The Outflows, O(t) are:

(1) Evaporation (million m^3)

(2) Seepage (million m^3)

(3) Releases (million m^3)

(4) Spillage (million m^3)

(5) IFR: In-stream flow Requirements (million m^3)
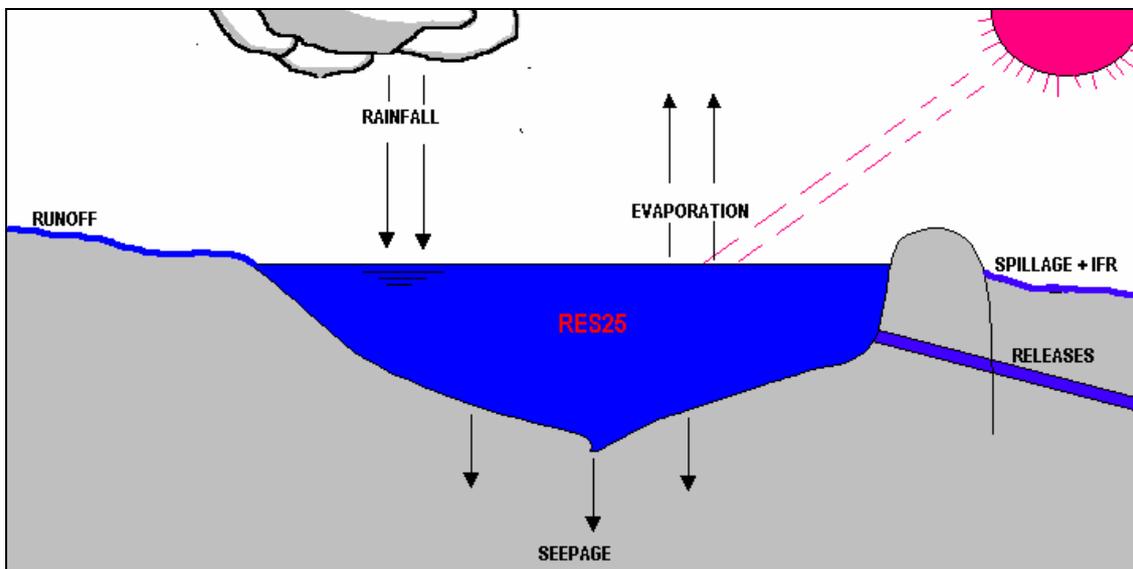

Figure A1.6   Illustration of the RES25 module concepts.

The inflow in the module RES25 are calculated using the Equation A1.25.

$$I = R + P \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\text{Equation A1.25}$$

Where:

I = inflow (million m^3/month)

P = precipitation (million m^3/month)

R = runoff flowing into the dam (million m^3/month)

Calculation of outflows is done using Equation A1.26

$$O = Ev + Sg + Rs + Sp + IFR$$ …………………………………………...Equation A1.26

Where:

O = outflow (million m^3)

Ev = evaporation (million m^3)

Sg = seepage losses into the ground (million m^3)

Rs = controlled releases for downstream users such as irrigation (million m^3)

Sp = dam Spillage (million m^3)

IFR = instream flow requirements (million m^3)

Evaporation

Open water evaporation is calculated in the model using Symon's pan evaporation data figures. The evaporation data are factored using the monthly factor values that are entered. If there is no need to factor evaporation data values then monthly factors of 1.0 should be entered to retain all the original evaporation data. The volumetric evaporation is obtained by multiplying the depth of evaporation and the storage surface area after all the other dam outflows have been deducted in that month. The surface area is determined using the Equation A1.27 based on the work by Tarboton, Lecler, Smithers, Schmidt, and Schulze. (1995).

$$A = bV^c$$ ………………………………………………………..….Equation A1.27

Where:

A = surface area (m^2)

b = coefficient of the surface area/volume relationship (dimensionless)

V = volume at full supply capacity (m^3)

c = exponent of the surface area/volume relationship (dimensionless)

The model user will be able to enter values of b and c, that best describe his or her own catchment storage/surface area relationship. The values for b and c can be obtained by analysing dams with storage and surface area that are similar to the one being modelled. Default values have been provided in the model, these are 7.2 for the coefficient b and 0.77 for the exponent c. The values are based on studies done in the ACRU Model development (Tarboton *et al.*, 1995). A value of 0.6 is recommended for the coefficient c for small farm dams in the Water Resources Simulation Model developed by Pitman and Kakebeeke (1993).

Seepage

The seepage losses for unlined or earth dams can be estimated to give a more realistic overall reservoir yield simulation. In RES25 an estimate of the percentage of the available water volume that seeps out of the dam can be entered as an input value. The value is used in the model to calculate the amount lost as seepage. Tarboton *et al*. (1995), gave an estimate of 0.0006 of the full supply capacity of the dam as the daily seepage which is fixed throughout the simulation period. In the ACRU model seepage is estimated to empty the storage once every five years. In the module RES25 a default value of percentage monthly seepage is given. The default seepage loss value in RES25 can be used in cases where more accurate values that are closely related to the catchment in question cannot be found. In the model, if a zero value is entered or the input box for the percentage seepage is left blank, then the model will use a value of 0.001 % of month end volume as seepage, which is included within the code. This figure is not used if a valid percentage seepage value is entered.

Releases

The model calculates two possible sets of controlled releases from each dam according to the water demand files added to the water system by the model user. Equation A1.28 gives the two controlled release components.

$$Rs = R1 + R2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\text{Equation A1.28}$$

Where

Rs = total controlled releases passing through an outlet pipe or other controlled outflow route (m^3)

R1 = monthly releases due to water demand in "Input file 2" added to the main user interface for the dam (m^3)

R2 = monthly releases due to water demand given in "Input file 3" in the main user interface (m^3)

Total releases are provided when the water is available, after allocating water to the instream flow requirements, IFR. Releases are also restricted by the monthly "Target Draft" values that are entered in monthly input boxes labelled "Target Draft" in the RES25 module interface. If the "Target Draft" values are chosen to be used then the water allocated to "release", Rs, and to "IFR" will not exceed the target draft in each month even if water is spilling. A higher priority of water allocation is given to the IFR flows, such that water is supplied to satisfy all the IFR requirement before it goes to the controlled releases. A selection to use the target draft values can be made by clicking the text reading "Target draft", where the change in the label's background colour indicates that the target draft option will be used. If the "Target Draft" option is not selected the model will try to satisfy the total water demand Rs. Failure to meet the demand will be due to the inadequacy of water as determined in the water balance for the dam.

Spillage

Spillage calculation is done in the model using Equation A1.29

$$S_p = V_p - FSC \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\text{Equation A1.29}$$

V_p = Water volume at the beginning of the month (m^3)

FSC = Full supply capacity of storage (m^3)

S_p = Spillage volume (m^3)

IFR

The National Water Act (Republic of South Africa, 1998) considers the aquatic ecosystem to be an integral part of the (water) resource base from which water is derived for human and environmental use, but "only that water required to meet basic human needs and maintain environmental sustainability will be guaranteed as a right, which is now known as the Reserve" (Jooste and Claassen, 2001). The environmental or ecological aspect of the reserve has been identified in such a way that it must ensure water quantity and water quality which are appropriate to meet these needs. The term "resource quality" is used to include the health of all parts of the water resource, which together make up an ecosystem, including plant and animal communities and their habitat" (DWAF, 1997).

The term in-stream flow requirements (IFR) is used in this study to define the estimate of water required to maintain environmental sustainability of the river system downstream of a reservoir. In the model HYDRO25, IFR is represented by the Equation A1.30 below:

$$IFR = Fy(V) + Fx(I) \ldots\ldots\ldots\text{Equation A1.30}$$

Where:

V = Storage volume at the end of the month, excluding excess water that will be lost as spillage (million m^3/month). V is calculated before all defined water demands such as urban and irrigation demand have been deducted.

Fx = Percentage of available volume that is allocated to IFR even when there is no water flowing into the dam (%)

I = Total monthly volume of water that flowed into the dam (million m^3/month)

Fy = Percentage of monthly total water inflows that is allocated to IFR (%)

The values used for Fx and Fy should be determined on the basis of the catchment's ecological classification giving specific IFR requirements for a river reach or estimates based on other considerations of the aquatic ecosystem. The model has default values of Fx = 10 %, which is based on the work done in the model HYECO (Dube, 1999) and Fy = 20 % which was derived from the average of the IFR rule curve values used in a previous study of the Doring River (McKenzie Schafer and Venter, 1990)

1.4.3 RES25 user interface

The RES25 user interface, shown in Figure A1.7, is used to enter data and parameters that will be used when the model runs the RES25 sub-routine. Most of the input boxes in the interface are text boxes. The boxes that appear with a grey background on the screen cannot have text entered directly by typing in them, but rather rely on coded inputs within the interface to enter specific values.
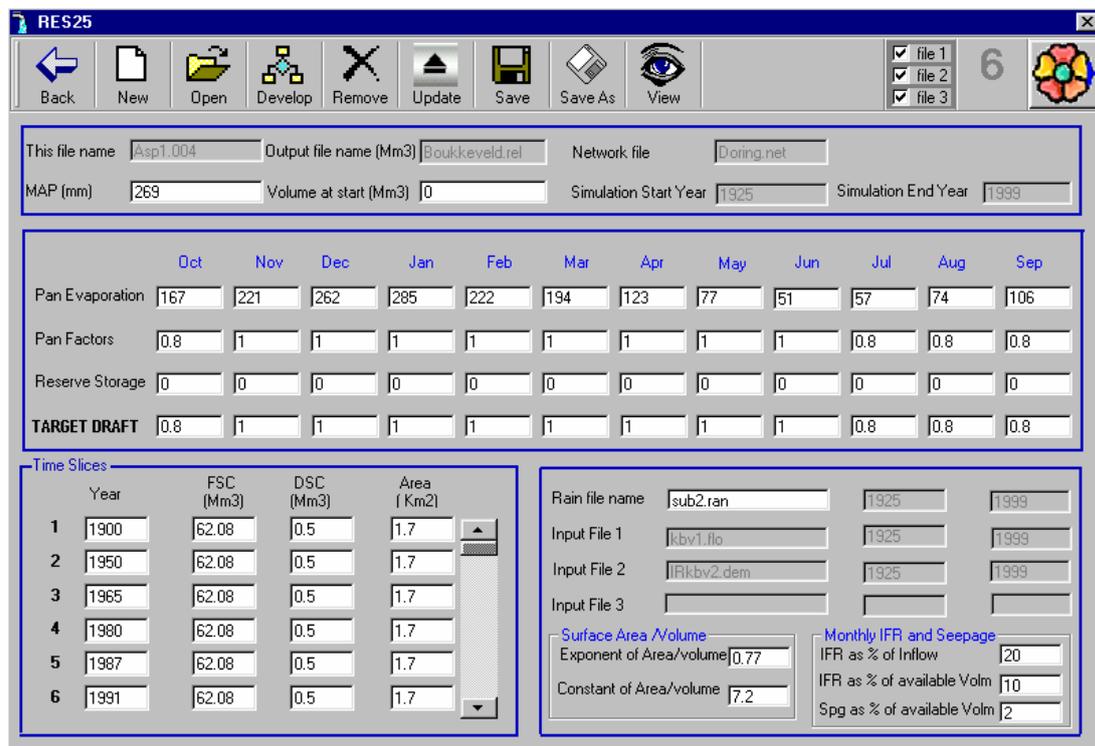

Figure A1.7   RES25 user interface with input examples.

RES25 inputs:

(1) MAP: Mean Annual Precipitation value of the sub-catchment in which the dam is located. The value will be used in conjunction with the average percentage rainfall files to calculate the actual rainfall values in million m^3 per month.

(2) Volume at start: This is the amount of water in million m^3 at the beginning of each simulation. This value will be used once as the starting value in the first October month of the simulation period.

(3) Pan evaporation: The first row of 12 input boxes with the caption "Pan evaporation" on their left are for monthly evaporation inputs. In these input boxes the twelve long-term average monthly Symon's pan evaporation values, starting in October and ending in September, are entered. The values will be used throughout the simulation. The unit of pan evaporation data in the module is millimetres.

(4) Pan factors: These are monthly inputs for factors that will be used to reduce the extent of the evaporation in each month. A value of 1.0 will ensure that the evaporation in that month will be equal to the amount given by the pan evaporation. The pan evaporation gives a potential evaporation in the area. Detailed assessments of actual evaporation in specific catchments have indicated the need to use pan factors lower than 1.0 in some months of the year (Green, 1985; Midgely, Pitman and Middleton, 1994). Values of pan factors obtained for the whole of South Africa by Midgely *et al*. (1994) are recommended for use if Symon's pan evaporation data given in their report titled "Surface Water Resources of South Africa - 1990" are used.

(5) Reserve storage: The 12 monthly inputs define the amount of water in million m^3 that should remain in the dam in any simulation year. A value of zero will ensure that the DSC only is used to define the water remaining in the storage.

(6) Target draft: The monthly target draft values define the upper limit of the possible abstraction in each month. The value consists of releases and the IFR water in million m^3. The target draft values are used only when the caption "Target Draft" is clicked, such that its background is turned to a cyan colour. The model will attempt to satisfy all the targeted draft requirements. If there is not enough water to meet the target draft requirement, then only the available water is sent to (partially) satisfy this requirement.

(7) Time Slices box entries: The box has sets of three input box arrays for entering the different storage states, for up to 19 time "slices" on an annual basis over the simulation period. The time slices will be for the years with data on FSC, DSC and the storage surface area values. If the values are available for most of the years in the simulation, it will be important to spread 19 sets of these values over the whole simulation period. The buttons captioned "Develop" and "Remove" are useful in entering new arrays. If only one set of values is entered say in 1900, then this set of values will be used for all the years that come after 1900. Time "slices" values must start in the first year of simulation.

(8) Rain file name: The name of the file with the monthly rainfall data as percentages of MAP is entered here. In the model, rainfall files are not created within a run and have to be available in the data file when any of the sub-routine interfaces is being used. The RAIN25 module that is accessed from the main user interface is used to generate the appropriate rainfall files. Appendix 2, Section 2.1.2 of this report, gives a description of how the rainfall files are generated in RAIN25. In the rain-file name input box, the user can enter the file by double clicking the input box to display an "Open file" dialogue box that will be used to specify the appropriate file. A better entry method is available, which includes the update function. Using this method, the input files that currently exist in the computer are selected in the selection boxes in the top tool-bar control. Then the update button in the tool-bar control is clicked. A pop up dialogue box for opening the rainfall file will appear where the file will be opened and the update of the rest of the files will immediately follow. Update of files in the model refers to the entering of the start year of data and the end year of data in files as well as entering the start year of the routine simulation and its end year. The "Open file" dialogue filter will favour the opening of a file with the extension ".ran". maintaining this file extension for the rainfall file names improves the file opening process as the "Open file" dialogue box will always suggest to the user the files with the extension ".ran" if he wishes to open a rainfall file. Suggestions in the "Open file" dialogue box ensure that the correct files are opened each time.

(9)Input files: The names of the files in the input boxes captioned "Input file 1" to "Input file 3" are provided from the main user interface. If a file entered for these

input file boxes is not stored in the computer then the user must ensure a file with exactly that file name is generated in an earlier simulation, before this routine is simulated. In such cases an update of data in that file will not be required and this information is conveyed to the computer by not clicking the selection button corresponding to this file in the tool-bar control.

(10) Surface area/Volume: The box is for entering the exponent and the coefficient in the surface area volume equation, Equation A1.27, where default values are provided based on studies done in the development of the ACRU model (Tarboton *et al*., 1995).

(11) Monthly IFR and Seepage: The In-stream flow requirement is defined using two components: (a) a fraction of the total monthly inflow defined by the entry in the topmost input box and (b) a fraction of the end of month storage volume, excluding the amount of water that will spill. Default values for the two IFR components that are used in the simulation if the model user does not specify other values are given in Section 1.4.2 of this Appendix. The third input box is used to enter the fraction of water that will be lost through seepage. The value is entered as a percentage of storage available at the end of each month. The values in this section are based on informed estimates derived from the catchment being simulated.

The tool-bar control commands

Most command buttons in the RES25 user interface are located at the top of the form in the tool-bar with the exception of the "Target Draft" command button. The command buttons are discussed from left to right in the following section, with the caption on each command button being used to distinguish it from its neighbours.

Back   Clicking the "Back" button loads the main interface window to replace the current window as the active window displayed on the computer screen. This function can also be achieved by clicking the flower icon on the right or pressing the "Escape" key. If changes had earlier been made

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in the current RES25 user interface then these changes will be lost when the "Back" button is clicked.

New   Whern clicked, the "New" button will remove the monthly values for the following variables: pan evaporation, pan factors, reserve storage and target draft.

Open   Clicking the "Open" button will display an "Open file" dialogue box where the user can specify which existing file he/she wishes to open. The file will be of the extension ".004". On opening the file, the data in the file and the parameter values will be entered in appropriate input boxes.

Develop   The "Develop" button loads a new array of input boxes for defining storage development over the years of the simulation.

Remove   The time slice array which was added last will be removed when the "Remove" button is clicked. This is the only way to remove the arrays that will have been added to the time slices. Deleting array values and leaving them blank when saving a parameter file gives problems when the application runs. The application will expect values in all dynamically loaded text boxes. Unused dynamic input boxes, such as time slice input points created using the "Develop" button, should be removed using the "Remove" button before running the application.

Update   The "Update" button is used to determine the current start and end year of the data set in the input files that the user will have entered for the sub-routine in the main user interface, as well as the rainfall file. To use the button, the selection boxes corresponding to the input files should be selected by clicking in them, if that file already exists on the computer. Clicking the "Update" button without selecting the files with data will only update the rainfall file. The files labelled "File 1 to 3" may be files generated in another routine of the same simulation, in which case they will not be updated when the "Update" button is clicked. The "Update"

button will also determine the start year and end year of the RES25 simulation routine.

Save   The "Save" button will save a file that has been opened using the "Open" command if it has not been modified. The button will not work if there is no currently open file, or if there have been modifications on the opened file that may require the file to be renamed, or if the program suspects that some changes have been made that require a file to be resaved with a different name. The model will suspect that there is a need for a parameter file name change if the user opens a parameter file that was used for another routine or if he changes the names of other input files such as rainfall and flow files working with the module.

Save As   The "Save As" button allows the user to save a file with a different name or to overwrite an existing file. The values that are currently displayed will be saved through a "Save file" dialogue box. When saving, the model requires that the update button be clicked to ensure that any other changes pertaining to start and end years of the sub-routine simulation are still correct for the files in use.

View   Clicking the "View" button displays the network structure showing all the sub-routines and, most importantly, the parameter file name for the present routine. This file name will be located immediately on the left of the sub-routine number that will be highlighted in red colour. This function can be achieved by pressing the "Enter" key and it works for an existing network file where the current sub-routine exists in the network, which is possible only if the RES25 routine at the current position as defined by the routine number has been previously saved.

1.5   CHAN25: Wetlands routine

The module CHAN25 models water loss from wetlands due to evaporation, evapotranspiration and infiltration into the groundwater as well as the wetland area recharge.

The wetland area in CHAN25 is treated like a simplified RES25 storage. The simulated wetland area has a storage capacity to define the limit of water accumulation, a recharge coefficient to define the fraction of the inflows that contribute to the recharge, and a fixed monthly bed loss for losses due to infiltration. A CHAN25 routine should only be included in a water resources network in cases where there are wetland areas or a wetland area in the catchment in being modelled.

1.5.1 Theoretical and mathematical concepts in CHAN25
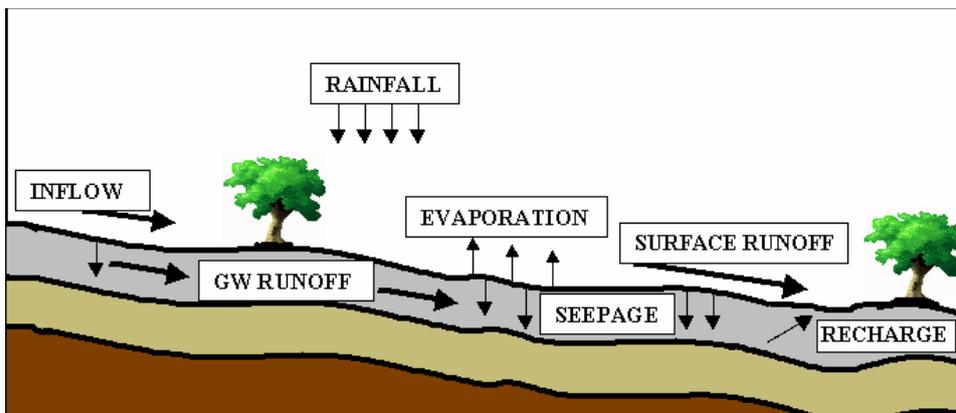
Figure A1.8   Schematic illustration of the CHAN25 sub-routine.

The water balance principles, discussed in Section 1.4.2 of this Appendix for the RES25 module, are used in the CHAN25 module. In CHAN25 the water balance equation, which is illustrated in Figure A1.8, is broken down into inflows and outflows that consist of the following components:

Inflows:

    Rainfall

    Runoff flowing into the wetland area (surface inflow)

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Recharge from groundwater

Outflows:

Evaporation

Bedloss

Runoff flowing out of the wetland area (surface outflow)

Water balance components

Rainfall

A rainfall file is entered in the CHAN25 sub-routine to enable direct rainfall to contribute to the wetland area inflows. The rainfall contributing to the wetland recharge is calculated from Equation A1.31, below.

$$Rc = P \times MAP \times \frac{Aa}{1000}$$ …………………………………….……..Equation A1.31

Where:

Rc   = Direct rainfall contribution to the wetland area recharge (m^3)

P   = Monthly rainfall values in % of MAP (dimensionless)

MAP   = Mean Annual Precipitation (mm)

Aa   = Wetland area (m^2)

In the CHAN25 module all rainfall falling on the wetland area can contribute to recharge.

Runoff into the wetland area

The amount of water available for wetland recharge is determined by factoring the runoff flowing into the wetland using the recharge coefficient (C). A coefficient of recharge is entered for the CHAN25 module as a positive proper fraction in the module's user interface. Equation A1.32 is used to calculate the runoff contribution to the wetland recharge.

$Ri = C \times Rin$ …………………………………………….……….Equation A1.32

Where:

Ri   =   Total wetland area recharge (m^3)

C   =   Recharge coefficient (dimensionless)

Rin   =   Flow from surrounding area to the wetland area (m^3)

Evaporation:

Symon's pan evaporation values are entered in the model for each month in the CHAN25 module interface. Evaporation is determined in a similar way to the method used in the RES25 module with adjustments being made to the pan factors to indicate the difference in the amount of evaporation between open water in the reservoir and the wetland area. Other evaporation figures obtained using other methods which are not Symon's pan figures can be used in the model provided the appropriate evaporation pan factors that will represent the evaporation from the particular wetland are known and are included in the inputs. In cases where factoring of evaporation inputs is not required, a value of 1.0 for the pan factors is entered and if evaporation values that are larger than the Symon's pan evaporation are required pan factors greater than 1.0 are entered. In the model, the factor is simply multiplied by the evaporation figure to get a fraction of the evaporation that will be used for that month in all the years that will be simulated for the sub-routine. Equation A1.33 shows how evaporation is calculated in the CHAN25 module.

$Ev = Ep \times Ef \times Aa$ …………………………………………….....Equation A1.33

Where:

Ev = Evaporation (m^3)

Ep = Pan evaporation (m)

Ef = Evaporation factor (dimensionless)

Aa = Wetland area (m^2)

The surface area of the wetland entered in the determination of evaporation does not vary with volume as with the case of a RES25 module, Equation A1.27. The depth component

of the wetland area is very small such that surface area is usually directly proportional to the wetland volume. There is therefore no need to include a special relationship between the evaporation, the surface area and the depth of the wetland as is done in the case of dams.

Bed Loss

In the module CHAN25 fixed monthly values of Bed Loss are entered in m^3. The values should be determined from physical observations on the catchment or estimates based on previous values measured for similar catchments.

Wetland releases

A water balance is applied to the wetland such that the wetland storage equation, (De Laat and Savenije, 1998) is used to determine the amount of water released from the wetland. The storage equation applied for the CHAN25 module is shown as Equation A1.34.

$$O = I + G_w + \frac{dS}{dt}$$ …………………………………………………...Equation A1.34

Where:

O   = Releases from the wetland outlet (m^3/month)

I   = Surface runoff flowing into the wetland and direct rainfall (m^3/month)

G$_w$ = Ground water inflows (m^3/month)

$\frac{dS}{dt}$ = Rate of change of the wetland volume (m^3/month)

1.5.2   The user interface in CHAN25

Figure A1.9   User interface in CHAN25.

Figure A1.9 shows the user interface for the CHAN25 module. The interface has two sets of input boxes: enabled input boxes where values can be entered directly through typing in the required information, and disabled input boxes where values cannot be typed in. The disabled boxes receive values from code-defined procedures on loading of the user interface, followed by clicking the "Update" button, which opens and then saves a parameter file. The enabled input buttons are discussed in the following section with the names used to identify the boxes in the user interface being used as sub-headings.

(1) **Recharge coefficient:** The recharge coefficient is used in the model to factor the amount of flow entering the wetland area so as to determine the amount of water that will be available to recharge the catchment if wetland storage is not full. The recharge coefficient will be high for highly permeable sandy soils and low for impermeable clay soils.

(2) **Rain file name:** The name of the file with the monthly rainfall data in percentages of the MAP is entered in this input box. The input box is double clicked to select the name of the file through the "Open file" dialogue box that pops up. Rainfall files have to be maintained with the extension ".ran" for easier handling in the model.

(3) **Wetland Storage:** The volume of the wetland storage in million m^3 is entered in this input box. The value used as the catchment area storage is the limit of volume that the area can store, such that any additional inflows will be released without being stored.

(4) **Wetland area:** The value of the total wetland area in km^2 is entered in this input box. The amount identified as wetland area should be excluded from the total catchment area of the module RUN25 such that there is no double counting of runoff from the wetland area.

(5) **MAP**: Mean Annual Precipitation in units of millimetres is entered in this input box. When the model runs the MAP value is multiplied by the monthly rainfall percentages in the rainfall file to get monthly precipitation values in millimetres units.

(6) **Pan Evaporation:** Long-term monthly pan evaporation data are entered in the 12 monthly input boxes provided for evaporation. The values are entered in millimetres.

(7) **Pan Factors:** Twelve pan factor values corresponding to monthly evaporation values are entered in the boxes to calculate the fraction of the pan evaporation that will occur in the wetland area. If the whole depth of evaporation as given in the pan evaporation value will be lost in a month, then a value of 1, is entered for the factor.

(8) **Bed Loss:** Most wetlands lose some water through their beds to recharge ground water reserves such that this water is lost from the surface water system. To account for this water loss, fixed monthly bed loss values in million m^3 are entered for all months from October to September. In cases where such loss is not taking place the "zero" values are entered for bed loss.

The tool-bar controls.

The CHAN25 module uses basically the same buttons as those found in most of the other modules. All the buttons in the CHAN25 tool-bar control, with the exception of two, are

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discussed in earlier sections of this chapter under the user interface controls for the RES25 module, Section 1.4.3 of this Appendix. The two selection boxes, captioned, "Rainfall" and "Inflow" have not been discussed before. These selection boxes are selected for updating the two data files used in CHAN25. The rainfall data file should always be updated. A surface runoff file with the inflows may not be in the working directory at the time this module is saved in the network and its update will therefore not be required. Such a case occurs when the inflows to this module are a result of a simulation in another earlier module such as RUN25. Under these conditions this file will not need to be updated and its selection box should not be selected.

CHAN25 parameter file

Table A1.3 below shows CHAN25 parameter file inputs. The filename should ideally have the extension ".005". File name extensions of this nature were meant to assist the model user in recognising the parameter files that will be used at different stages of the simulation so that he/she will not end up selecting wrong input files for the different modules.

Table A1.3   An example of CHAN25 module parameter file inputs.

Entry in parameter file	Description
1,"channel9.005"	Name of parameter file for the module
2,5	Module location
3,"drn-03.txt"	File with data on inflows to wetland area
4,"DRN-01.ran"	Rainfall file name
5,450	Mean Annual Precipitation
6,1920	Year in which simulation starts
7,1984	Year in which simulation ends
8,1925	First year with rainfall data
9,1992	Last year with rainfall data
10,12,450,0.1	Wetland storage, Wetland area, Recharge coefficient
11,124,146,125,134,123,129,161,171,165, 143,124,161	Long term monthly pan evaporation in millimetres
12,.8,1,1,1,1,1,1,1,1,.8,.8,.8	Pan evaporation factors
13,.1,.2,.7,.12,.43,.13,.15,.6,.5,.7,.8,11	Bed loss in million cubic metres
14,#TRUE#	TRUE means a valid rainfall file name has been specified and is part of the data set

1.6   FLOWADD

The module FLOWADD is useful for the addition of data for up to three files that require summing during the simulation, or where subtractions are required. The data files that are added or subtracted in FLOWADD should be in the HYDRO25 monthly data format. An example of the use of this module is a point in the catchment system where runoff from a catchment has to be added to releases from a dam and outflows from a wetland area. The names of the files with the data, or output files which will have data after a simulation, are entered through typing them in or double clicking the appropriate input boxes in the main user interface as discussed in Section 1.1 of this Appendix. The filenames will be entered in the FLOWADD module when the module is loaded. Direct typing in of the file names is restricted in the module.

1.6.1 FLOWADD user interface

The module FLOWADD has a larger number of disabled input controls, 14 as compared to the enabled input controls, 4 input boxes and 3 selection boxes, as shown in Figure A1.10. The output file generated when FLOWADD is used will span the period covered by all the entry files. This is made possible by obtaining its start year from the input file with the earliest start date and then using the simulation end period taken from the file whose last year of data are most recent. The assumption is that the user will only enter data that he requires to be added up or subtracted, and cut out those data that should not be added or subtracted.
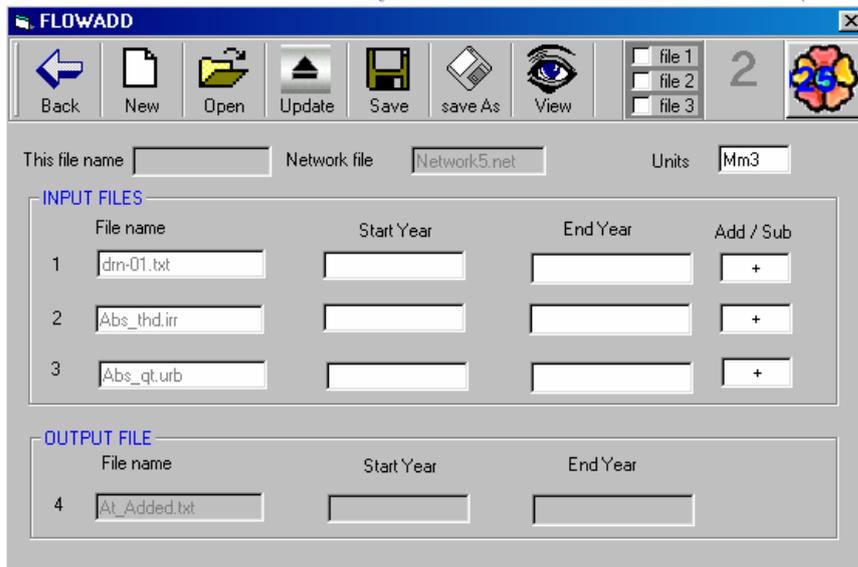
Figure A1.10   FLOWADD user interface with input examples.

An overview of input boxes in the FLOWADD module

A single mathematical equation is applied for each month in FLOWADD. The simplified equation is presented below as Equation A1.35

$$O_T = (O_1 \times F_1) + (O_2 \times F_2) + (O_3 \times F_3)$$ …………………………….....Equation A1.35

Where:

O_T is the resultant flow per month (m^3); O_1, O_2, O_3 are the monthly flows obtained from the input files 1 to 3; and F_1, F_2, F_3 are the factors used in the module code to represent the values entered for the input files 1 to 3 as the input in the corresponding "Add/Sub" input box. If the "+" (plus) value was entered for input file 1, then F_1 will be a "1", if a "-", (minus) is entered in the file 2, then F_2 will be "-1" such that the input file 2 is subtracted and if any other character is entered in the input box for file 3, then F_3 will have a "0", zero value, and will not be added or subtracted.

Disabled Input controls

Disabled input controls, where direct typing of data are not possible, are discussed below for FLOWADD.

This file name: The name of the file that is opened or saved for the current FLOWADD module will be shown in this box. The name is entered in the box on opening of an existing file of the extension ".003" or on saving a file with the inputs for the current FLOWADD module.

Network file: The box will receive the name of the network file that is currently in use for the system being edited. This input box should always have a value, which comes when the interface is loaded.

Input files: The input file names, the start and end years of their data, as well as the add or subtract functions to be used, are entered in the input boxes under the caption "Input files".

The first column of input boxes under the heading "Input files" contain the input file names. The names are entered in the input boxes when the module user interface is loaded. The user should ensure that all the file names specified in the main user interface are shown in the controls before updating and saving the current file. If some boxes have no files then the user should exit the user interface and reload it using the "Enter" key or by pressing the "Edit" button.

The second and third column of input boxes under the "Input files" controls should contain the "Start" and "End" years of the data in each of the files to be added. The values are entered in the input boxes by pressing the update buttons after selecting the selection boxes corresponding to the files that currently have data. If a specified file does not have data, or if the data in the file are to be replaced by outputs from a module running earlier in the network, then this file should not be selected for updating.

Output file

A single output file with monthly data in the HYDRO25 data format is generated as the output file. The file name should be specified in the main user interface. The start and the end years of the output file are displayed on clicking the "Update" button if the files named as file 1 to file 3 contain data.

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Enabled input boxes

The FLOWADD module has four enabled input boxes. There are three controls in the column titled "Add/Sub" which are input files. In these boxes, the following can be entered:

(a) "+" to specify that this file should be added.

(b) "-" to specify that the file should be subtracted

(c) " " a box left blank will not be added or subtracted; it is left out of the calculation. Any other character will also have the same meaning as the 'blank'.

The module FLOWADD has three selection controls. The selections are made by clicking in the selection control corresponding to a file with data. If a file has no data and the file is to be created earlier in the network before this sub-routine, then the selection box corresponding to this file is not selected for update.

An input box for entering units is provided, the units entered will be used for the output file of the sub-routine. A default value of "Mm^3" (million cubic metres) is available for the units box.

1.6.2 The tool-bar control in FLOWADD

The buttons in the tool-bar control are mainly the general buttons used in RUN25 and RES25 as discussed in Section 1.4.3 of this Appendix. Use of the selection boxes explained above is not as critical as its use in the RUN25 and RES25.

1.6.3 FLOWADD parameter file

Table A1.4 below shows an example of a FLOWADD routine parameter file inputs. The file is saved together with a network file every time the "Save" or the "Save As" button is used while the module parameter input interface is being used. The file should ideally have the extension ".002".

Table A1.4   An example of the FLOWADD parameter file inputs.

Entry in parameter file	Description
1,"Add8.002"	Name of parameter file for the module
2,2	Module location
3,"drn-01.txt",1920,1999,"+"	List of names of files whose data are to be added or subtracted, the beginning and end years of the data in the files, the symbol "+" for additions or "-" for subtraction
4,"Abs_thd.irr",1920,1985,"+"	
5,"Abs_qt.urb",1936,1994,"+"	
6,"At_Added.txt",1920,1999	
7,"Mm3"	Units of data in the file (million cubic metres is the default value)

1.7   FACTORFLOW

The module FACTORFLOW allows a single monthly data file to be factored, using monthly factors covering up to ten time steps extended over the duration of the input data file. A typical example of a situation where this module is used is when the abstraction from a reservoir to an urban area, or the inflows from a mining area, have to be increased with time due to growth or expansion. Critical growth stages are determined and factors applied to account for this growth in the output file. The factors are applied in block periods, that is if a factor of 1.2 is entered for October 1920 and the next factor for October, 2.4 is in 1930 then, for the period 1920 to 1929 the 1.2 factor is used and the 2.4 factor will start to be applied in 1930. The start year for entering factors should be smaller or equal to the start year of the data in the data file that is being factored.

1.7.1   FACTORFLOW user interface
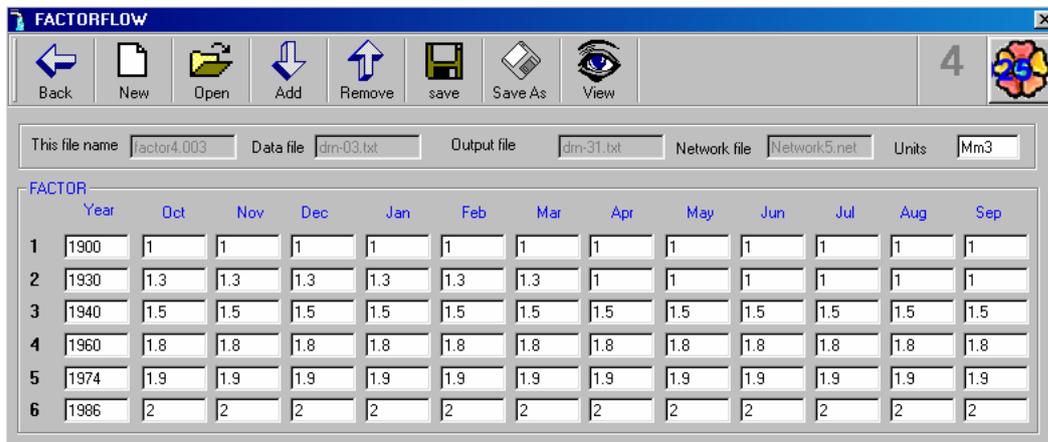
Figure A1.11 FACTORFLOW user interface with examples of module inputs.

An overview of the input boxes

The input boxes shown in the user interface, in Figure A1.11, are discussed below with the captions used in the interface being used as the sub-heading. The input boxes discussed in (1) to (4) below are not enabled; that is, inputs cannot be typed in directly.

(1) **This file name:** The name of the file with the data for the module is entered in the box. The file extension ".003" is supported by the FACTORFLOW module and a file filter to restrict files available for opening uses this extension.

(2) **Data file:** The name of the file with the data that will be factored is entered in this input box. The file should be of the HYDRO25 monthly input data format and is usually a flow data file. The file name is entered in the box on loading of the module "FLOWADD".

(3) **Output file:** The name of the output file that the user will have specified in the main user interface is entered in the input box on loading of the user interface.

(4) **Network file:** The filename of the water resources network, is entered in the box on loading of the user interface. A network file should always be displayed when a

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module is being edited. If the network file input box does not have the name of the network displayed, then the form should be closed and then reloaded.

(5) **Units:** The specific output data units are directly entered into the text box by typing in the value. This value is not used when the module FACTORFLOW is run; it is only displayed in the output file as additional information on that file.

(6) **Factor box:** In the box titled "Factor" an array of input boxes with ten rows and thirteen rows can be created using the "Add" button located in the tool-bar at the top of the user interface. In the array of input boxes the monthly factors to be multiplied by the monthly data in the data file are entered. The button captioned "Remove" is used to remove the last row of input boxes that will have been added to the array of input boxes. Unused rows of input boxes should be removed before saving the module parameter file.

1.7.2 Tool-bar control in FACTORFLOW

The buttons in the tool-bar control are basically the same as those discussed in the module RES25, in Section 1.4.3 of this Appendix. The "Add" and "Remove" buttons have images of arrows to indicate what happens at the end of the arrays of input boxes when the button is clicked. The "Add" button will add a row of input boxes, and the "Remove" button will remove a row of input controls at the end of the array.

1.7.3 FACTORFLOW parameter file

The file that is saved in the FACTORFLOW module user interface is referred to as the FACTORFLOW parameter file. The filename should ideally have the extension ".003" and should contain values as shown in Table A1.5, below. It is not advisable to make changes to the parameter files directly using text applications such as text pad or notepad. Procedures defined in the model will enter changes made to the parameter files into other files required for running the programme, such as the network file, if parameter entries are made in the user interface. If other applications are used to update the parameter files then the updates will remain incomplete. The process of making

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changes will take very little time if done within the model interfaces and will ensure that errors are not carried through to the process of running the model, where errors may waste the model user's time.

Table A1.5   An example of FACTORFLOW parameter inputs.

Entry in parameter file	Description
1,"factor4.003"	Name of parameter file for the module
2,"drn-03.txt"	Name of file whose data are to be split according to specified factors
3,4	Module location
4,"Mm3"	Units of data in the file
5,5	Number of years with data on how flows should be factored
6,1900,1,1,1,1,1,1,1,1,1,1,1,1	
7,1930,1.3,1.3,1.3,1.3,1.3,1.3,1,1,1,1,1,1	
8,1940,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5,1.5	Year and the factors to be used in that year and up to the next year with factors
9,1960,1.8,1.8,1.8,1.8,1.8,1.8,1.8,1.8,1.8,1.8,1.8,1.8	
10,1974,1.9,1.9,1.9,1.9,1.9,1.9,1.9,1.9,1.9,1.9,1.9,1.9	
11,1986,2,2,2,2,2,2,2,2,2,2,2,2	

1.8   IRRIG25: Irrigation module

1.8.1 General functionality

The module IRRIG25 simulates the water use due to irrigation requirements. The module generates monthly irrigation water demand that is received from the water system to meet crop evapotranspiration requirements. The module generates as an output a demand file which is applied as an abstraction from a reservoir using RES25, and from channel flow using FLOWADD and FACTORFLOW modules. The module also simulates return flows from irrigated areas.

1.8.2 IRRIG25 mathematical module structure

Water demand in IRRIG25 is calculated on a monthly basis using the Equation A1.36 below:

$$D = A_r \times P_a \times (fE_o - rR_o) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\text{..Equation A1.36}$$

Where

D   = Volume of Demand (m^3)

A_r = Total irrigation area in that year (m^2)

P_a = Proportion of area irrigated in that month (dimensionless)

f   = Crop factor (dimensionless)

E_o = Evaporation (A-pan evaporation) (m)

r   = Effective rainfall factor (dimensionless)

R_o = Rainfall (m)

The module allows the user to enter the changes in area available for irrigation in hectares over the years, as well as the variation in the fraction of that area which is irrigated each month. Evaporation input data should be A-pan values. However, other evaporation types such as Symon's pan can be used, provided the appropriate crop factors are also used. Another monthly input is the effective rainfall to account for that water which is available for evapotranspiration and excludes the water which is lost before the crops can utilise it.

1.8.3 IRRIG25 user interface

The module IRRIG25 generates a water demand file and a return flow file that is calculated on the basis of the return flow percentage entered by the model user in the text box captioned "Return Flow %". The module uses a parameter file; a copy of the data in one such parameter file is shown as Table A1.6 below.

The parameter file contains the input data that the user enters for use when the module IRRIG25 is simulated. The parameter file data fills the input boxes in the user interface when the file is opened. A description of these entries is given in Section 1.8.4 of this Appendix. To edit or access an IRRIG25 module, the module must exist as part of the network being simulated or must be entered in the main user interface as a new module. After clicking on the IRRIG25 combo box, the "Edit" button is clicked and a new

window, the module interface, will pop up. The IRRIG25 module interface is shown in Figure A1.12.

Table A1.6   An example of 1RR1G25 parameter file inputs.

Entry in parameter file	Description
1,"Ceres3.006"	Name of parameter file for the module
2,6	Module location
3,"23"	Return flow as percentage of irrigation demand
4,"CERES.ran"	Rainfall file name
5,450	Mean annual precipitation
6, 1925	Start year of rainfall data
7, 1999	End year of rainfall data
8,"Return.dat"	Return flow file name
9,"Nola.irr"	Irrigation demand file generated in simulation
10, 224,291,340,369,284,249,161,103,70,80,103, 146,124,161	A-pan monthly evaporation
11,.8,1,1,1,1,1,1,1,1,.8,.8,.8	Crop factors
12,.8,.8,.8,.8,.8,.8,.6,.6,.6,.6,.6,.6	Fraction of total rainfall that is effective rainfall
13,80,80,70,70,40,40,40,50,60,70,70,80	Percentage of total area that is irrigated
14,#TRUE#	True if the specified rainfall file has been found in the data directory
15,4	Number of years with irrigation area data
16,1900	Years with irrigation area data and the corresponding irrigation area below each year.
17,400	
19,1960	
20,1400	
20,1980	
21,1760	
21,1990	
22,1800	

1.8.4   1RR1G25 module inputs

Inputs in IRRIG25 are entered through the use of text boxes and clicking of command buttons in the tool-bar. The Figure A1.12 shows the IRRIG25 module interface with the text boxes and command buttons, as they will appear when the interface inputs are being edited.

Figure A1.12 IRRIG25 module user interface with examples of module inputs.

A discussion of entries to be made in each of the input spaces is discussed in the following sections using the captions that identify each input space as shown on the left of the input boxes and at the bottom of the command buttons in Figure A1.12.

(1) **This file name:** The name of the file with the data for the module is entered in the box. The file with the name extension ".006" is entered in the input box on opening of an existing file or on saving of a new file name for the sub-routine. The user is advised to click the "View" button or press "Enter" to see the file that the model is currently using if this module is not new in the system. If the module is new and has not been saved, then it will not be shown in the "View" window.

(2) **Output file name:** The name of the file that will contain the monthly water demand simulated by the IRR1G25 module.

(3) **MAP (mm):** mean annual precipitation for the area being considered in the irrigation module.

(4) **Return Flow (%):** The percentage that will be applied to the irrigation water demand to generate the return flows.

(5) **Rainfall Start Year**: The year marking the beginning of the records in the rainfall file.

(6) **Rainfall End Year**: The last year with rainfall data. It is noted that the rainfall file must cover the period being simulated. In cases where the period being simulated is

longer than the available rainfall file then the rainfall file must have "zero" values to fill the remainder of the rainfall file so that the rainfall file ends in the same year as the last year of the simulation.

(7) **Rain file name:** The name of the file with the catchment rainfall is entered here. In the model, rainfall files are not created within a run and have to be available in the data file before they are selected for use in network modules.

(8) **Return flow file**: a filename for the file that will contain the return flows isspecified here. The return flows are calculated on the basis of the irrigation demand and the percentage that the user applies as return flow fraction.

(9) **Evaporation and crop factors:** The model development used A-pan evaporation data in all irrigation calculations, and the model user should also use these evaporation values to simulate irrigation. The choice of A-pan evaporation was based on recommendations from previous studies such as (Green, 1985, Pitman and Kakebeeke, 1993; Kunz and Schulze, 1995) where A-pan evaporation was considered to be more accurate at representing crop evaportranspiration. The values are entered on a monthly basis, starting in October. The model user will notice that the A-pan evaporation values are larger than the S-pan evaporation values. If other types of evaporation data are used the crop factors applied must relate to the specific evaporation data in use. The crop factors describe the extent of water required for evapotranspiration by each crop in each month. The model uses average crop factors for more than one crop if a number of crops are grown in the irrigation area. The model user needs to determine the average crop factors for each irrigation area through the use of weighted factors where such factors relate to the area covered by each crop in each month. The crops that use more water in certain months have large crop factor values for those months. As an example, maize has crop factors as high as 1.3 in November in the Western Cape, whilst deciduous fruits in the same area and cabbages have crop factors as low as 0.2 for most months of the year.

(10) **Effective rainfall**: Twelve entry points are available for the model user to enter the fractions of the total rainfall that are available to the crops as effective rainfall in each month. Not all the rainfall recorded by rain gauges will reach the ground in all areas. Processes such as interception reduce the amount of rainfall reaching the ground such that only a certain fraction of the rainfall, referred to as "effective rainfall", is available for evaportranspiration. The model uses factors to calculate the effective rainfall. The factors usually range between 0.8 and 0.6 in most South

African catchments, other values below one can be accommodated by the input boxes.

(11)   **Area irrigated:** the model allows the user to specify the area available for irrigation on an annual basis in hectares. A monthly variation of the actual area irrigated depending on the cropping patterns is entered in the column for the monthly inputs. To enter more values for the years irrigated the user should use the "Add" button to get new entry positions.

(12)   **Tool-bar Control:** The command buttons on the tool-bar control and their functions are discussed in the RES25 module in Section 1.4.3 of this Appendix.

1.9   Graph

The model HYDRO25 has a built-in graph routine and a supporting user interface for the user to obtain a graphical presentation of input data files and output files. The graph routine is accessed from two interfaces, the main user interface and the rainfall-runoff calibration routine, "CAL25 ". The graphs drawn are time series graphs with two possible options of a monthly and an annual series.

1.9.1 Accessing the graph routine from the main user interface

The main user interface allows the user to graph any time series data file with values given in monthly time steps over at least two years of records. The file name should be available in the display on the main user interface as one of the files in the working directory. The following sequence of steps is followed to obtain a graphical illustration of the time series data:

(1)   An option is selected for the type of graph to be drawn by clicking on the option marked "1" for monthly time steps and the second option for an annual plot. Figure A1.1 shows the option buttons on the main user interface.

(2)   The specific file to be plotted is identified by clicking it to give it focus.

(3)   In the task bar, the menu button "Graph" will immediately display the graph on clicking. The data file must be in the format used by the HYDRO25 model for monthly data.

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1.9.2 Accessing the graph routine from CAL25 user interface

Two graphs are always obtained when the CAL25 user interface is used to draw graphs. In this case, the graphs are useful for the rainfall-runoff calibration. A time series graph of the simulated runoff is drawn together with the recorded data for the same period. The following steps are followed to use the CAL25 interface to give the graphical illustrations of simulated and recorded runoff:

(1)   The rainfall-runoff routine, "RUN25", that is to be calibrated in the main user interface is selected by clicking the box with its name followed by the button captioned "Calibrate", to go to the calibration routine.

(2)   In the CAL25 user interface, a single run or looped multiple runs are done as detailed in Section 1.3.2 of this Appendix on "How to use CAL25"

(3)   Clicking the option button labelled "A" will select an annual plot and the option "M" will specify that a monthly plot is required.

(4)   The task bar button captioned "Plot" is then clicked to show a time series graphical plot with default options on how the graph will look.

1.9.3 Graph resetting

The graphs obtained when accessing from the main user interface, and when using the calibration module as described above have the same user interface. This allows the user to change how the graph is shown and how it is printed. The illustration below, Figure A1.13, shows the interaction areas available for the graph and Figure 9.5 shows a typical annual hydrograph of recorded and simulated runoff. Descriptions of the available options are listed below according to the labels shown in Figure A1.13.
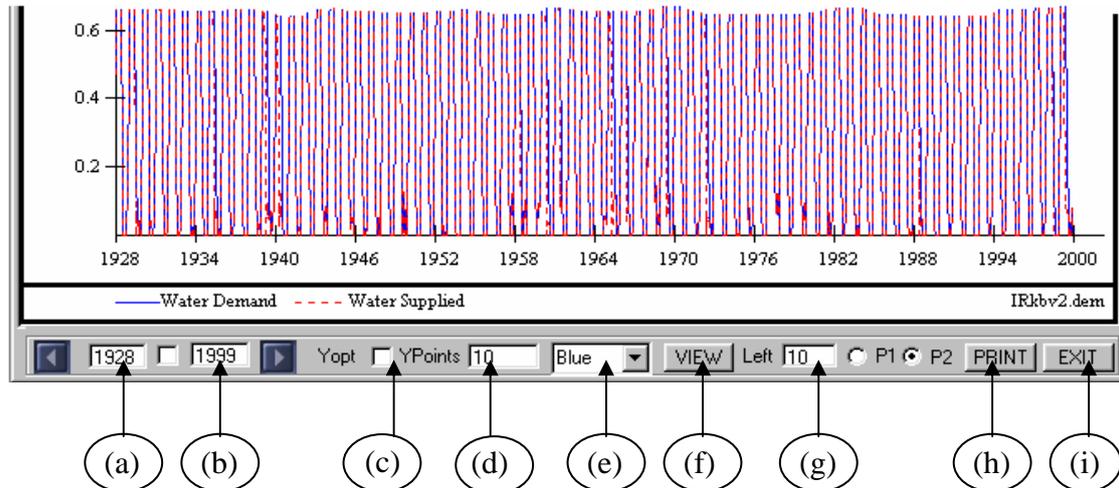
Figure A1.13   **Graph interaction area with points of interaction (described in the text below).**

(a) and (b)   **Start Year and End Year**

These two values give the range of data being plotted as it will be shown on the X-axis. On the left will be the year that the plotting starts and the other value will be the year that plotting ends. The values that are displayed when the graph window pops out give the longest range possible with the data given; that is, the two years will be the first (earliest) year that has data and the most recent year with data. In the case of the CAL25 graph only the years that have data for both recorded and simulated runoff are drawn. The user can select periods shorter than the default values to give better view of certain sections of the graph. If the user selects non-valid periods, the default values are used; these are the values the graph uses when it is loaded for the first time.

(c) and (d)   Yopt and Ypoints

The "Yopt" is a selection box that works with the "Ypoints" value. When the "Yopt" box is selected the user is able to give larger values in the "Ypoints" box which are used as the intervals on the Y-axis. As an example, entering 100 in "Ypoint" will give an interval of 100 on the Y-axis if the "Yopt" is selected. If "Yopt" is not selected then the "Ypoint" value gives the number of points to be given on the Y-axis, with a maximum of approximately twenty points and a minimum of five points. If a value lower than five

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points is selected, the default number of approximately ten Y-axis values is used. In the two cases, that is the case when "Yopt" selection is made and the case when the selection is not made, the maximum number of points on the Y-axis that will be equally distributed over the range of the values in the data files is twenty. Entries that may result in more than twenty points are not displayed. On the other hand the lowest number of points is maintained at approximately five with four and six points occurring if the graph routine finds them most appropriate in giving the best visual display that satisfies the data and options made for "Ypoints" and "Yopt".

(e)   Colour box

The selection of colour uses a combo box with six possible colours. The colours selected apply to the single graph displayed if only one graph is displayed and to the simulated data plot if two graphs are being displayed. The recorded data line and the water supplied line are always dotted red lines.

(f)   View

This view button should be clicked after any changes are made on the graphical interface options. The button refreshes the view with the changes made.

(g)   Left

This text box allows the user to change the left margin alignment, a feature that is most useful when printing the graph. Integer values are entered in the text box followed by clicking the view button to shift the left alignment of the graph. The changes in the left alignment are not reflected in the right alignment, such that the overall effect is either a stretching effect or squashing of the X-axis. When a large left margin is required, a large integer is entered in the text box. The user can use multiples of ten for very large changes.

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(h) and (i) Printer Option Buttons

P1 and P2 refer to the two possible options when printing. The option is selected before the Print button is clicked. The options allow two possible settings of printer outputs that affect the orientation of the axis and how the y-axis values are interpreted by different printers. Most printers use the default selection, but if the printer produces a distorted graph that has a different orientation from the one displayed on the screen, then P2 should be tried.

1.10   HYDMAP: The geographical information interface

1.10.1   General information on HYDMAP

The module HYDMAP allows the use of graphics and maps to edit the model inputs and to illustrate or display the catchment simulation in a way that is closely related to the catchment's physical state. In this module the model user can work with an interface that is closely related to the mental picture of the catchment that he/she creates. The module uses a graphical interface to reinforce the understanding of commands and functions of interface objects, which reduces the requirement of high knowledge levels in model users. The command buttons have suggestive names and images that relate to the command button functions. The HYDMAP module uses graphical options to include some of the functions that are attached to the main user interface, such as organising the network modules, editing module data and drawing graphs of input and output data. In the HYDMAP interface the model user interacts with the model on a "Drawing board" where the catchment map can be included, as well as a drawing of the catchment network with points where the user can interact with the drawing.

The development of the HYDMAP module made it possible for the model to be able to read data from a number of image formats such that maps and graphics in several formats can be loaded to the "Drawing board" of the module. The module supports image formats that includes formats whose filenames have the following name extension ".jpg", ".bmp" and "ico".

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On the map the model modules are represented by image buttons that the user can place at locations of his choice. The modules are linked using lines. Module inputs are edited and data files viewed using click events on the interface. The graphical network as displayed in the HYDMAP interface can be saved for later use.

1.10.2   The use of HYDMAP

The HYDMAP interface was developed with a large work space where the model user can add objects that describe his/her catchment as well as interact with these objects to enter data, edit model parameters and draw graphs of time series data. The interface has menu controls at the top, a button box in the open space, as well as an initial module as shown in Figure A1.14 below. A HYDMAP interface with showing the catchment map and modules is shown in Appendeix 2 as Figure A2.8.
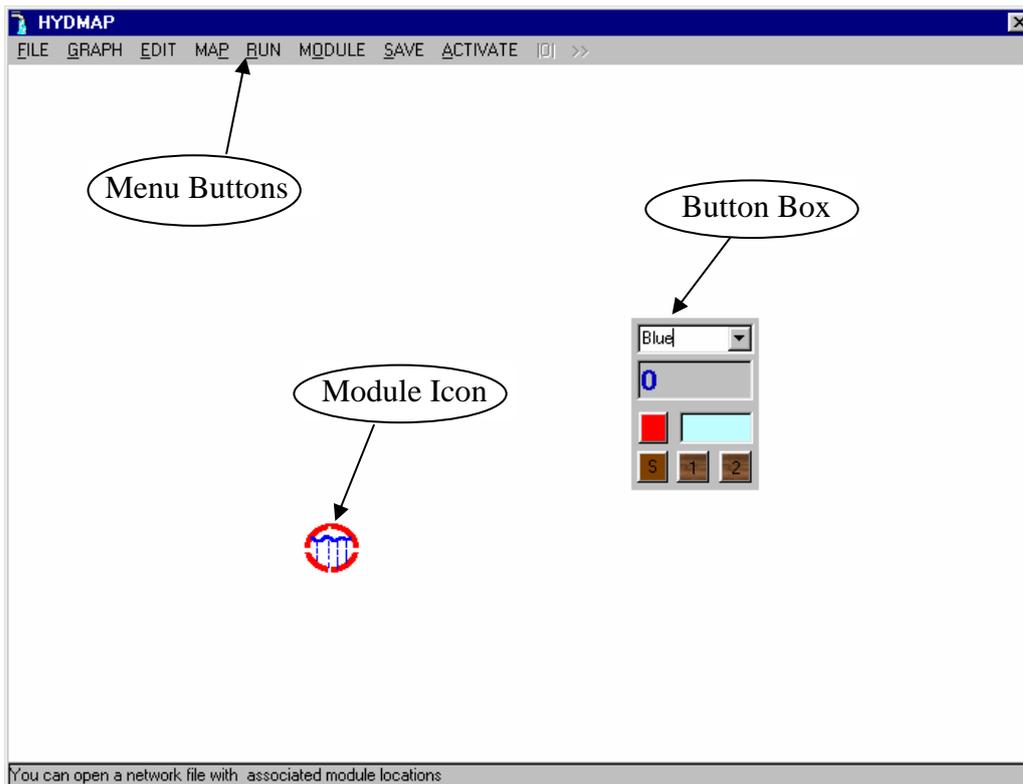
Figure A1.14   HYDMAP user interface before adding catchment modules.

1.10.3   Accessing HYDMAP

Access to the HYDMAP is handled by a menu button titled "MAP" in the main user interface. On clicking the "MAP" button the HYDMAP interface is loaded with a link to the main user interface network data. The link between the HYDMAP data and the data loaded in the main user interface is lost if the model users specifies a new path by opening a file saved in another location that is different from that of the data loaded in the main user interface. In the HYDMAP user interface, a number of menu buttons and a few command buttons are used to pass information from the user to the model. The interface interaction points are discussed in the following section.

1.10.4   HYDMAP FILE menu buttons

An illustration of the "FILE" menu button and its sub-menus is shown in Figure A1.15.
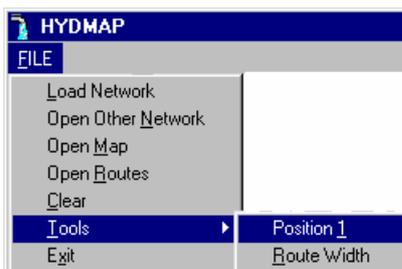
Figure A1.15 File menu buttons in HYDMAP.

The functions of the sub-menus under the "FILE" menu are described under each sub-menu title in the following section. The underlined letters in the names of the menus are used for quick access to the menu functions. To use the quick access the model user presses the "Alt" key of the keyboard and the underlined letter simultaneously.

Load Network : The "Load Network" sub-menu will load the network file that is currently open in the main user interface. If the network file has valid module inputs then the initial module icon is changed to that of the first module in the network. If the catchment network module locations were previously saved in the HYDMAP, then the model user has the option of opening the saved locations of all modules. This option is selected by clicking the "ACTIVATE" menu button. To avoid displaying all the network

modules the "Clear" sub-menu button of the "FILE" menu is clicked. This allows the model user to place the modules at new locations one at a time.

Open Other Network: Clicking the button labelled "Open Other Network" will activate the "Open File" dialogue box where the user can open other network files including the one that may already be loaded in the main user interface. This button can also be used in cases where there is no open file in the main user interface. Clicking the "ACTIVATE" button before using this button allows the associated location file of the modules to be opened such that all the modules will be shown at locations that they were saved, in relation to a catchment map or other diagram that the model user will have loaded.

Open Map: The "Open Map" button allows the user to open a map image where the modules can be placed. It is not a requirement that a map is used for any network. The modules can be displayed in the white space and editing done from there if a map is not available or if the user wishes to develop a schematic catchment that is not related to a map.

Open Routes: Clicking the "Open Routes" button will open the file with data on the catchment routes and display these routes on the user interface.

Clear: The "Clear" button will clear the routes then activate a message asking the user if he wishes to clear the displayed modules as well. If the user answers positively by clicking the option marked "Yes", then the modules will be cleared from the display. If the model user clicks the "No" option, then only the displayed routes will be cleared. Clicking the "Clear" button will also set the file opening and reloading option to open network files without the associated modules and routes locations. Changing this option to allow opening of locations is done through the clicking of the "ACTIVATE" button.

Tool: The tool button handles the access to the sub-menus "Position 1" and "Routes Width"

Position 1: Clicking the "Position 1" button will set the button box to a default position allowing the model user to be able to work on it if it was not within his/her view.

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Routes Width: Clicking the "Routes Width" will change the thickness of the displayed module routes. Only two sizes of widths can be selected by either clicking the button once or twice

Exit: Clicking the button "Exit" will unload the HYDMAP interface to return to the main user interface.

Graph menu button
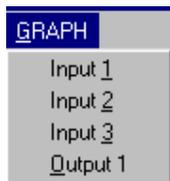
Figure A1.16 HYDMAP Graph menu button.

The "GRAPH" menu button (Figure A1.16)connects the displayed modules to the graph functions. Each module has at most three input files and a single output file whose names are entered in the main user interface. Time series graphs of the data in input files can be plotted on the computer screen or a printer by clicking one of the options, labelled "Input 1", "Input 2" and "Input 3", or the option labelled "Output 1" to print output file data. In the case of the RES25 modules, where the second input file is a water demand file, the graph will also plot the water supply file so that the model user can observe the periods when the simulation failed to supply all the water demanded. This failure to meet water demand usually shows points of water system failure, which is important information for decision-makers.

EDIT menu button

The button labelled "EDIT" allows the model user to access the module editing routines for the module selected before the "EDIT" button is clicked. To select a module and edit its inputs the user clicks the graphical icon representing the module and then clicks the "EDIT" button. A user interface where the module inputs and parameters can be edited will pop up.

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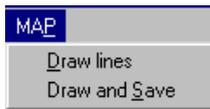
MAP button

Figure A1.17 Map menu button options in HYDMAP.

The "MAP" button (Figure A1.17) provides access to the two sub-menus labelled "Draw lines" and "Draw and Save". On clicking the button "Draw lines" the user will be able to draw lines that can be used to represent map boundaries or routes connecting modules. These lines only exist on the screen and cannot be manipulated using commands such as those for varying the width. Saving of routes and other lines is possible only after the "Draw and Save" button is clicked. The data on the routes and line positions are stored in a file whose name is derived from the network file name with a changed file extension, where ".net" is changed to ".lin"

Module button
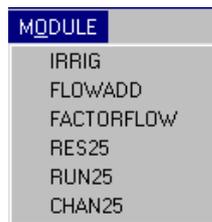
Figure A1.18 Module button options in HYDMAP.

Clicking a sub-option of the "MODULE" button (Figure A1.18) gives a description of the module functions and the module graphical icon at the position clicked by the user on the HYDMAP user interface immediately after clicking the module button. The description of the module function appears in the display control at the bottom of the window. The module icons are displayed only when there is no open network file in the HYDMAP interface. If there is an open network file then only the module description will be displayed.

SAVE button

Clicking the "Save" button will save the module locations. Saving of module locations is possible only if a network file has been opened by clicking either the "Load Network" or

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the "Open other Network" button of the "FILE" menu. The module locations will be saved in a file that has the network file name as well as the file name extension ".dat".

ACTIVATE button

The "ACTIVATE" button works with the two menu buttons with the labels "IOI" and ">>". The button labelled "IOI" is for locating a position on the user interface and the button labelled ">>" is for loading a network module icon to the interface. To change the position of a module icon the computer pointer is used to click the module icon, then the "ACTIVATE" button is clicked, followed by the button labelled "IOI", then the new position for the module is clicked. The module icon will move to this new position immediately. The button labelled "IOI" is also used to position the button box which is illustrated in Figure A1.14. To change the position of the button box the cyan coloured button in the box is clicked such that its colour changes to red which means that the positioning process is active on the button box. The next step is to click the position on the interface where the tool box should go to. Additional clicks on the positioning button in the button box will alternate between making the button box movements possible and allowing movements of the module icon that was clicked on or added last.

Load Button

Clicking the "Load" button with the ">>" label loads modules from the opened network file, one at a time. To load a module the "Load" button is clicked followed by clicking the position where the module will be located. When using the "Load" button the "ACITIVATE" button is clicked if the "Load" button is in a disabled state, that is the state when it cannot be clicked. The "ACTIVATE" button will enable the "Load" button. If the modules in the network are all represented by icons on the user interface then further clicks of the "Load" button will not load more modules, and clicking the "ACTIVATE" button at this stage will disable the "Load" button. The user is able to tell if the "Load" button is active or not from the style of the label, an embossed label means that the label is not active. In Figure A1.14 the "Load" button is shown in a disabled state.

Button box in HYDMAP

| (1) Colour box |
| (2) Module label |
| (3) Position button |
| (4) Shape button |

Blue

1

| (5) Saving indicator |
| (6) Monthly graph option |
| (7) Annual graph option |

S   1   2
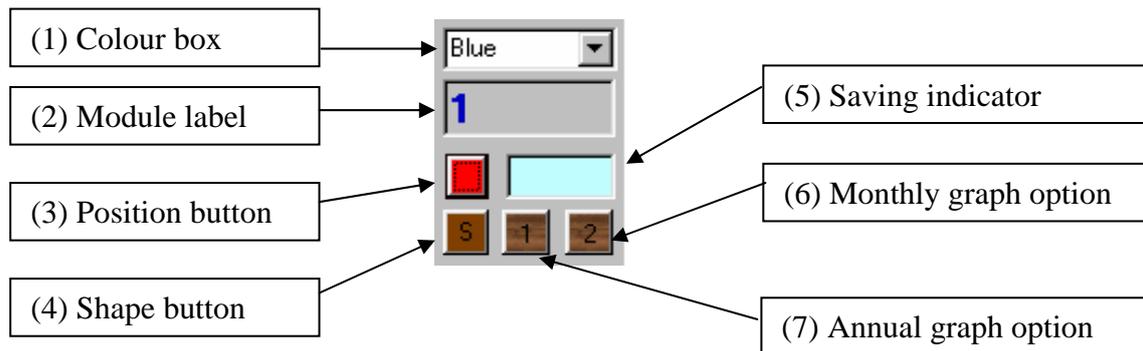
Figure A1.19 HYDMAP button box.

The button box (Figure A1.19) has seven controls to receive information from the model procedures and to convey user actions to the HYDMAP module procedures. The controls in the button box are listed as follows:

Colour box: The "Colour box" is a type of control called the combo box with a list of colours that the user can select by clicking the arrow on the box. The colour selected is used for the drawing of module routes and other lines on the HYDMAP user interface.

Module Label: The "Module label" receives information from the clicking event on the module icons. The label displays the identification number of the clicked module in the network file when the user clicks on a module icon.

Position button: Clicking the "Position button" will allow the user to be able to change the position of the HYDMAP button box. This is useful in cases where the screen position of the button box may obstruct the network view.

Shape button: Clicking the "Shape button" will change the shape of the button box such that it can be fitted in particular locations on the interface to avoid cluttering the interface.

Saving indicator: The "Saving" indicator is a label that shows the user when module routes are being saved. If the button has a cyan colour without the text "Saving" in it,

then the module routes will not be saved. To change the state to allow the saving of the routes the menu button "Draw and save" has to be clicked.

Monthly and Annual graph options: These two option buttons are clicked to select a monthly plot or an annual plot of the time series data of a selected file for the displayed modules.

1.11 HYDRO25 output files

The main output files in the model HYDRO25 have data formatted in the HYDRO25 monthly data format. These files can easily be used by other modules in the catchment system. For example, the flow file from the runoff module can be used as inflow into a reservoir located downstream. The output files are discussed below for each of the HYDRO25 modules.

RES25

The RES25 module generates a total of six output files. Five of these files are overwritten when another RES25 module is run in the same directory. The sixth output file is the file entered in the main user interface inputs as file number four.

The output data in this file are replaced if the user does not specify a different output for subsequent simulations of RUN25. Five of the files use similar names for all the RES25 modules in each network. The five file names are listed in Table A1.7.

Table A1.7   RES25 output files.

Default file name	File contents
SpillsZ.txt	The file will contain data on the monthly volume of water released as spillage, due to the dam being full
IFRZ.txt	The amount of water released to meet "In-stream Flow Requirements" is entered in this file on a monthly basis.
VolumeZ.txt	The volume of water in the storage at the end of each month is entered in this file
ReleaseZ.txt	Amount of water that is released for demands specified as input files 2 and 3 of the main user interface is entered in this file for each RUN25 simulation
BalanceZ.txt	The storage water balance is entered in this file. The file should ideally have zero values for all months if the model is not to end up with "unaccounted for water"
The "**Z**" is the number of the module that will have generated the output and the counting will be applied only to the RES25 modules	

RUN25

The module generates three output files listed as follows:

Output file 1: This file has a name given by the user while building the network file. The file contains the monthly flows generated by the rainfall/runoff simulation. The name of the file is specified in the main user interface under the "Output file" column heading.

Output file 2: The file has the same name as the monthly rainfall file name, except that the extension ".dat" is used. The naming method in "Output file 2" requires that the use of the extension ".dat", be avoided in other modules since such files risk being replaced if the name is the same as that of the rainfall file. "Output file 2" will contain the monthly flows in a format that can be opened to fit in three columns in a spreadsheet programme such as Lotus 1.2.3, Quattro or Excel. This format is suitable for plotting of monthly hydrographs in existing spreadsheet applications.

Output file 3 : The file has a name derived from the input monthly rainfall file name where the text "gr.prn" has been used to replace the file name's extension. This file contains data on the monthly rainfall that have been used as the input in the model. The data are in a format similar to "Output file 2".

CHAN25

The module generates two output files. The first one is the output file that the user will have entered in the main user interface as the output file name. The file contains the result of the channel simulation on a monthly basis. The second file is a water balance file. In this file, the CHAN25 calculations are checked to determine the correctness of the water balance in all months simulated. The water balance output file has the same name as the specified output file with the extension ".bal" replacing the name given by the user.

FACTORFLOW

The module splits flows in terms of fractional proportions that are entered as inputs by the model user. A single file output is produced which will be the result of factoring all monthly flows in the original input file.

FLOWADD

The module generates a single file in the HYDRO25 monthly format. The file name is the same as that specified by the user in the main user interface for the module outputs.

IRRIG25

The irrigation routine generates two files, an irrigation demand file and a return flow file. The irrigation routine should always be run before the water supply source such that the irrigation file generated here is used by the water source such as a dam, channel or addition module to generate a monthly water demand.

1.12 HYDRO25 error handling

Error handlers have been included in the application to avoid situations where the application crashes because an error has occurred. The development of the error handling facility was designed to enable the application to inform the user of the occurrence of such errors and to allow the process to be repeated without having to exit the application. In many cases, some entries that cause errors will not be accepted by input handling procedures that have been included with the application code. While error handlers alone cannot completely assist in correcting problem areas if there is no information on where this error occurred, a system was included to give a guide on identifying the error locations. Table A1.8 shows the labels and numbers used to identify errors in the model.

Table A1.8   Model error location system.

Module	Count letter	User interface error location	RUN button routine error
RAIN25	A	1	-
RUN25	B	2	22
FLOWADD	C	3	33
FACTORFLOW	D	4	44
CHANNEL	E	5	55
RES25	F	6	66
CAL25	J	7	-
DAILYRAIN	-	-	-

In the table, the count letter is used to identify the module within the code. The letter will have the value for the position of the module in the network that will be in current use. In the module parameter input interface, the single digit numbers will appear in the title bar of the error messages for the respective module interface. As an example, the error message boxes will have titles such as "Error at 6.2". The "6" will refer to the RES25 module, and the "2" will refer to a sub-routine in the module RES25.

The running of the network occurs when the "Run" button of the main user interface is clicked. The "Run" button is connected to the code that calls the different modules in the same order as they will be given in the network file, assigns the appropriate parameter files to them, and runs them. If an error occurs in any of the modules then the title bar of

the error message will have a number such as 44 for the CHAN25 module. A typical message will read, "Error at: 22.1: 2". The number "22" is to identify the module RUN25 in the "Run" mode, the "1" identifies a sub-routine of the RUN25 module. The "2" that comes after the semicolons is the number that will be carried by the count letter during the running at the moment of the error. The number "2" means that the model had simulated 1 RUN25 module already and that the error has occurred when the second RUN25 module was being simulated. Using the information given by "22.1:2" and the actual error message giving details on what happened when the programme stopped the user can go straight to the inputs for that particular module to correct the source of the error.

An error with "B6" in the title of the message box refers to an error in the "Run" button outside of the modules. The errors in this location will be mostly associated with the network file.

The RAIN25 module is another area where errors may not easily be accounted for. The errors that are difficult to locate are usually encountered after the "Execute" button is clicked. The RAIN25 module can be used to work on up to ten files at a time. When an error occurs which is associated with a file in the Execution code, the title of the message box will show the name of the last file that is currently being processed or has attempted to be processed.

All buttons that are likely to cause errors have error handlers. Most of the errors did not need any system of numbering as they were directly related to what the user will have done just before the error occurs. These errors usually have no connection to other processes that may make them difficult to correct. The user should deal with such errors by revising the step he/she carried out just before they occurred.

1.13 Common user procedures in network modules

The term "network modules" in this study refers to the modules that are run in a particular sequence determined by the network file when the "Run" command of the main user interface is executed. The network file contains information in text format on

which module should be run at each stage of the simulation and defines the inputs to associate with the different processes. The parameter input interfaces of the network modules, RUN25, CHAN25, RES25, IRRIG25, FLOWADD and FACTORFLOW perform very similar functions. The common steps in the use of the network module interfaces are discussed in the following section.

1) In the main user interface a "Start" button is used to open a new network file or to create a new file.

2) Editing of the module inputs is possible after enabling the edit mode. To enable the edit mode, the menu command is clicked followed by clicking "Edit routines". The module names which previously could not be clicked, that is they were disabled, can now receive focus when the user clicks on them.

3) An existing routine is selected by clicking in the combo box, a control that allows selection from a list of text items, in this case the text items are the module names. If a new module is to be used it is added by clicking on the "Add" button.

4) A yellow highlighter is used to show the model user which module has the focus. To work on the module that has the focus, the "Edit" button is clicked.

5) The user interface for the selected module interface will pop up without opening the associated data files, which are referred to as the parameter files in this model.

In the module interfaces, the following steps apply to all parameter input interfaces.

a) To open an existing parameter file, the "Open" button is clicked while the user is in the edit mode for the module to be edited. In each parameter input interface there are two file filter options in the "Open file" dialogue boxes for the user to either select a file with a default extension for the particular parameter file, or to choose from all files. For example RUN25 parameter files should have the extension ".001". Different file name extensions have been specified for the different parameter files to allow easier referencing and to avoid the use of wrong inputs in the model in cases where the user may be running large models with many input files. The model user is advised to enter the file name only, without the extension, when saving parameter files. The model adds the appropriate extensions.

b) Saving a parameter file is achieved through the use of the buttons "Save As" or "Save". When the module inputs have been edited the "Save As" button has to be

used. This button allows the user to specify a new file name if he/she wishes. The "Save" button is a quick way of saving the inputs without changing the file name.

c) The "View" button or "Enter Key" is used to view the position of the routine in the water resources network.

d) The "New" button is used to clear module inputs. Only inputs that will be tedious to clear individually have been connected to the "New" button.

e) A "Back" button returns the model user to the previous screen. The same can be achieved using the "Escape" key or clicking the flower icon on the right hand top corner of each parameter-input form.

f) The buttons with the caption "Add" and "Develop" will place more form controls at run time. The controls added to the form in this manner are also referred to in this model as dynamic controls. The user will be able to enter time series data in the dynamic controls. The button with the caption "Remove" will remove the last added dynamic control. The "Add", "Develop" and "Remove" buttons apply to the parameter input forms for FACTORFLOW, RES25 and RUN25.

Appendix A2: The Doring River case study:

Data collection, analysis and entry

2.1 Data collection

2.1.1 Introduction

Water resources studies that utilise models mainly rely on time series data and the mathematical formulations in the model. In the simulation of the Doring River catchment, historical time series data were used in the model HYDRO25. It was assumed that for the period considered in the simulation of proposed catchment developments, the rainfall and evaporation patterns would have the same trends as those recorded since 1925.

Several studies on climatic changes have indicated that there is a continuous increase in the concentration of carbon dioxide in the atmosphere creating a "Greenhouse" effect that is responsible for increases in atmospheric temperature, a condition commonly referred to as "Global warming". Atmospheric changes have also been identified to be leading to a series of other climatic changes that differ for different areas (Pittock, 1990; Schulze and Perks, 2000; McCarthy, Canziani, Leary, Dokken, and White, 2001). The other climatic changes include increases in annual precipitation in high and mid latitudes and most equatorial regions, while general decreases in precipitation are believed to be taking place in the sub-tropics of both hemispheres.

Studies in southern Africa using climatic models (Arnell, 1999) have shown that annual precipitation is likely to decrease by at least 10 % and potential evaporation will increase by between 4 and 10 % over the next 100 years due to global warming. On the other hand, increased concentration of carbon dioxide will increase the water use efficiency of plants and stimulate nitrogen fixation (McCarthy *et al.*, 2001). There are considerable uncertainties in trying to predict the magnitude of any effects of global warming, and more particularly, the related regional and local effects on rainfall such that more research is needed to narrow down the uncertainties (Pittock, 1990). In this study it is

noted that climatic changes have an impact on the correctness of water resources simulation results. However, due to the uncertainties surrounding attaching measurable quantities to these effects, an assumption has been made that, for the period projected in the irrigation development proposals, that is the 74 years used in Section 9, the impact of such climatic changes on water availability assessment parameters used in the case studies of this research will be minimal.

The study used time series data stretching from 1925 to 1999 to assess the historical catchment development and to simulate the proposed developments. Section 3.3 covers the general background to the data used in the HYDRO25 modelling case study. In this section the collection and analysis of data used in the Doring River catchment analysis are discussed.

2.1.2 Rainfall data

The rainfall data used in the model came from different sources due to a number of technicalities. The following organisations were approached to provide data and made some data available for this study.

(a) The Computing Centre for Water Research (CCWR)
(b) The Weather Bureau
(c) The Department of Water Affairs and Forestry: Hydrology Directorate

The Hydrology Directorate in DWAF, which has its own rainfall stations in the catchment area, had the most up to date daily records of data. The CCWR had monthly data for a number of the stations, though these data were noted to be shorter than the simulation period with most station records ending in the 1980s and early 1990s. The Weather Bureau was noted to have closed a number of its rainfall gauges such that the study had to rely on data from a few stations, in spite of several stations having been identified as being in the area. The data came in different formats and had to be processed into the HRU format that is used by the patching programme "patchr" where filling of missing and unreliable records was done. The following rain gauges were used in the patching process 42227, 42532, 42669, 66027, 45184, 44286 and 44050 to

generate two patched rainfall files for the two sub-catchments, KBV and Aspoort sub-catchment. The catchment divisions are shown in Figure 9.2 with positions of rainfall stations in the study area.
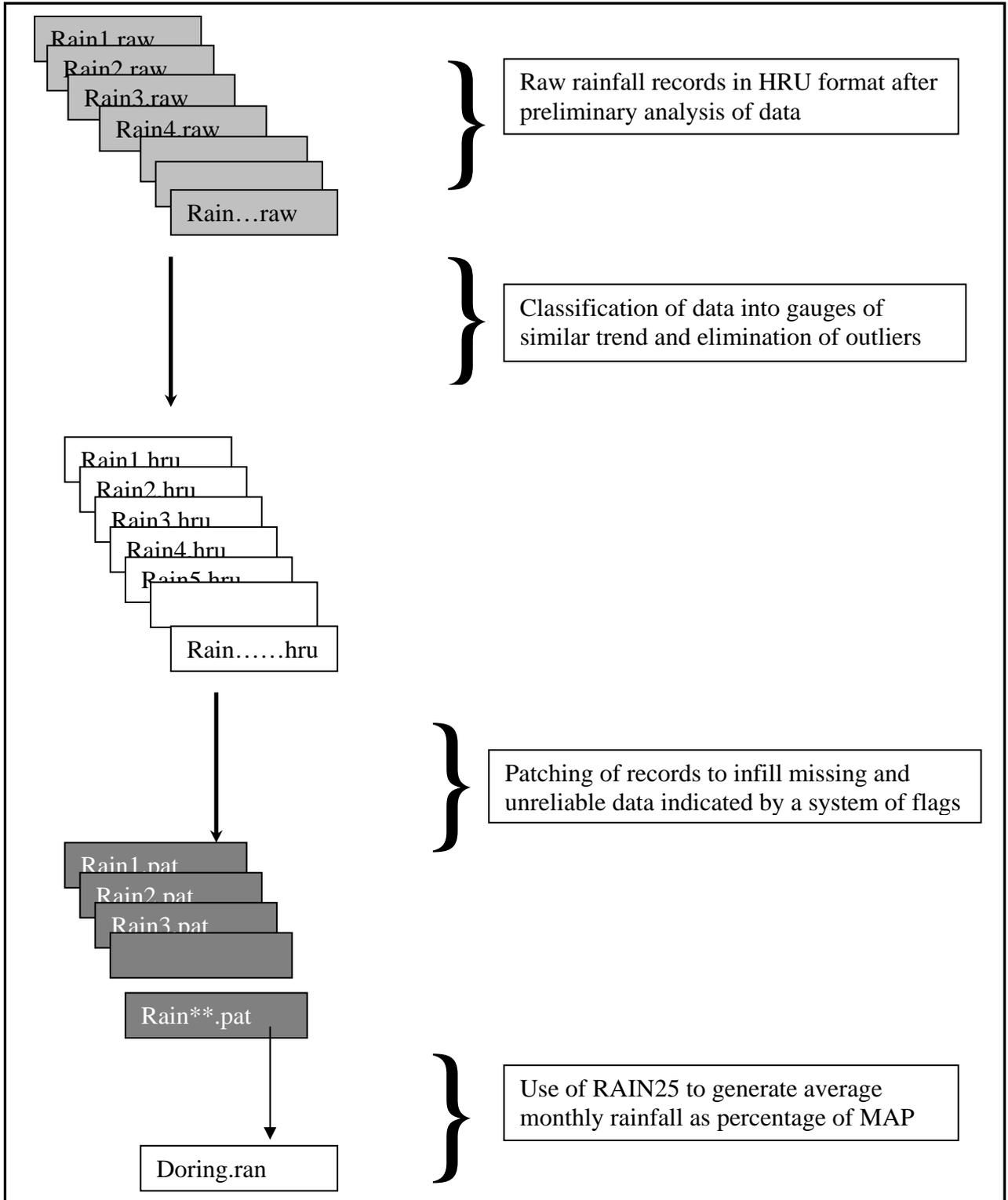

Figure A2.1 Processing of rainfall data.

The model uses monthly rainfall data expressed as a percentage of mean annual precipitation (MAP). The values of MAP were obtained from the WR90 reports (Midgely *et al.*, 1994). Figure A2.1 shows the general process followed to obtain the average monthly rainfall files used in the model.

The module RAIN25 referred to in Figure A2.1 was used to obtain the rainfall files used in the model. In the module RAIN25 a number of rainfall gauge data files (a maximum of ten files) are entered by selecting their names using the module RAIN25's selection list. The file data will be of the "patched" HRU type data (Pegram, 1994) with rainfall data in tenths of millimetres, a method used to exclude the decimal point in the programme "patchr". Three sets of such data for a short period are shown in Figure A2.2 for the stations 42227, 66027 and 42669.

```
                      AVERAGE RAINFALL IN PERCENTAGES FOR THE CATCHMENT: HYDRO
                             DETAILS OF RAINFALL STATIONS USED
                      DATA SOURCE                  PERIOD OF RECORD
                      042227                          1920 TO 1999
                      042669                          1945 TO 1999
                      066027                          1917 TO 1999
                             RAINFALL INPUT AS PERCENT M.A.P.
 Yea  No. of  Oct    Nov    Dec    Jan    Feb    Mar    Apr    May    Jun    Jul    Aug    Sep    Year
      Gauges
 ----------------------------------------------------------------------------------------------------------
 1960  3            1.21   8.58   4.23   0.71   3.86  12.00  14.61  12.39  11.70  10.40  17.23   99.06
 1961  3     1.09   0.00   0.00   2.35   2.39   5.30   7.06   5.03  40.18  11.00  28.23   4.35  106.98
 1962  3    18.69   5.07   0.25   3.78   1.16   1.00   2.80   3.25  14.22  15.24  31.49   2.85   99.80
 1963  3     3.10   8.18   9.71   0.05   1.73   2.70   2.85   5.45  23.84   8.94  14.31  10.26   91.12
```

Rain25 Output

```
 OUTPUT FROM THE INFILLING/EXTENSION PROGRAM – PATCHR
  THE CONTENTS OF THE FILE 042669.PAT
 -----------------------------------------------------------------------
  042669     1945 1999   3678.
 042669   1960        60   235   115    20    85   377   195   505   255   255   710   2837
 042669   1961    0     0     0     0     0    75   170   255  1090   230   775   130   2725
 042669   1962  620   215     0   255     0     0     0   134   505   530  1265   100   3624
 042669   1963  190   150   515     0     0     0  139+  182   680   355   345   327   2883+
```

Gauge 1

```
 OUTPUT FROM THE INFILLING/EXTENSION PROGRAM – PATCHR
  THE CONTENTS OF THE FILE 042227.PAT
 -----------------------------------------------------------------------
  042227     1920 1999   4726.
 042227   1960        95   135   200    25   102   250   375   360   550   665   875   3802
 042227   1961  155     0     0   100   238   655   470   385  1935   760  1355   240   6293
 042227   1962 1125   350    35@   20     0    75    28    70   762   766  1637   150   5018@
 042227   1963  145   505   270     7   161   130   150   475   885   710  1085   405   4928
```

Gauge 2

```
 OUTPUT FROM THE INFILLING/EXTENSION PROGRAM – PATCHR
  THE CONTENTS OF THE FILE 066027.PAT
 -----------------------------------------------------------------------
  066027     1917 1992   2812.
 066027   1960         0   464   150    30   200   575   860   445   465   287   390   3926
 066027   1961    0     0     0   139    60     0   186     0  1405   300   983   125   3198
 066027   1962  433    55     0   112    98    40   220   130   360   425   715    75   2663
 066027   1963   30   275   265     0    50   150    45    38   965    60   298   375   2551
```

Gauge 3

Figure A2.2   Example of patched input data and a section of RAIN25 output.

Figure A2.2 shows an example of the inputs to the RAIN25 module and the rainfall data produced by the model as a percentage of the MAP. The calculation of the rainfall values in RAIN25 uses Equation A2.1, below:

$$R = \sum_{1}^{n} (\frac{R_i}{MAP_i}) \times (\frac{100}{n})$$ …………………………….…………….……Equation A2.1

Where

R   =   Rainfall for a single month for the area expressed as a percentage of MAP for the catchment (mm)

R_i =   Rainfall for a single month from station "i" patched data expressed in tenths of millimetres (mm)

MAP_i =   Mean annual precipitation of station "i" (mm)

n   =   Number of gauges with reliable rainfall data in that month (The user can specify to include flagged unreliable data or to exclude them in the input options of RAIN25)

In the example illustrated in Figure A2.2 for three rainfall gauges, Equation A2.1 is used in RAIN25 as shown in Equation A2.2 for each of the months. In the data shown in Figure A2.2, two months have patched data indicated by the flags "+" and "@". The months with patched data are April 1963 for gauge 1 and December 1962 for gauge 2. In months with flagged data the model user has a choice to include or exclude them from the calculation of the percentage rainfall. When the patched values in Figure A2.2 are excluded, Equation A2.1 will use n = 2 and values from two gauges for the concerned months only. Equation A2.2 shows the rainfall calculation for three data sets.

$$R = ((\frac{R_1}{MAP_1}) + (\frac{R_2}{MAP_2}) + (\frac{R_3}{MAP_3})) \times \frac{100}{3}$$ ………………………………Equation A2.2

To get the value of 2.14 % in October of 1960 shown highlighted in the top section of Figure A2.2 with the heading "RAIN25 Output", the variables in Equation A2.2 had the following values:

$R_1 = 25$; $R_2 = 170$ and $R_3 = 60$, the three being the October 1960 values from each of the gauges highlighted in Figure A2.2 in units of tenths of millimetres. $MAP_1 = 3678$, $MAP_2 = 4726$ and $MAP_3 = 2812$, these being the mean annual precipitation for each of the three rainfall stations for the whole record length being used by RAIN25 in units of tenths of millimetres. When the model runs using the rainfall file in percentage of MAP, the percentage values are multiplied by the MAP of the catchment to determine the rainfall depth for the area. The MAP for a catchment is obtained by calculating the mean of annual rainfall for long series of data from several stations or from isohytal maps of the area. The RAIN25 module has functions to calculate the long-term mean annual rainfall for up to ten rainfall stations using monthly rainfall as inputs.

2.1.3 Evaporation data

In the model long-term average evaporation data for the Doring River catchment were used. The choice to use long-term average evaporation was based on previous studies and earlier work in the model, HYDRO25, where it was noted that the evaporation inputs entered in a similar method as rainfall data, that is using actual monthly records, did not produce significant improvements to the model results. Previous work by Pitman (1973), BKS (1986), Pitman and Kakebeeke (1993) and DWAF (2000) in the simulation of catchments used mean monthly evaporation as inputs in the water resources models they developed. The monthly evaporation data were obtained from the Weather Bureau as well as DWAF's hydrological directorate. The model used average monthly Symon's pan evaporation for the calculation of the water losses from the reservoirs and other open surfaces. The calculation of the amount of water required to irrigate crops after losing water through evapotranspiration was done using A-pan evaporation data. The choice to use the A-pan in the irrigation modules and Symon's pan evaporation in open water losses was based on the requirement to use evaporation figures which are related to crop evaporation, while on the other hand the hydrological viewpoint was to use evaporation that is meaningful in describing evaporative losses from open water bodies such as reservoirs. Kunz and Schulze (1995) and Green (1985) point out that A-pan evaporation is more meaningful in describing evapotranspiration while other methods, including Symon's pan evaporation, are suggested for open water evaporation simulations. The evaporation data supplied by the Weather bureau were for gauges located at different

points in the catchment. To calculate the long-term average Symon's pan evaporation for the entire catchment, the mean annual evaporation of the catchment was estimated on the basis of records from a number of gauges and available information on the average annual evaporation of the catchment using literature such as the report by Green (1985). The average monthly evaporation for the sub-catchment areas considered in the study were determined by calculating the mean monthly evaporation at each gauge as a percentage of the respective mean annual evaporation rates. The percentages for each month from the different gauges were averaged to obtain the monthly distribution of the mean annual catchment evaporation which is shown for the two sub-catchments in Table A2.1 and Table A2.2 below.

Table A2.1   **KBV sub-catchment monthly distribution of evaporation expressed as a percentage of the catchment's annual evaporation.**

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
8.9	12.1	14.5	16.4	11.9	10.7	6.3	3.9	2.8	3.1	3.9	5.5

Table A2.2   **Aspoort sub-catchment monthly distribution of evaporation expressed as a percentage of the catchment's annual evaporation.**

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
9.1	12.0	14.2	15.5	12.1	10.5	6.7	4.2	2.8	3.1	4.0	5.8

2.1.4 Land use data

Land use data were entered in the model as a time series input to account for the process of development that occurs over time. The land use inputs were mainly for irrigation developments. Data on existing irrigation were obtained from a report on the Olifants-Doring system (Theron and du Plessis, 1998). Changes in the catchment's paved areas, (*i.e.* are built up areas and roads which are treated as impervious areas), were estimated on the basis of development trends recorded by Midgeley *et al.*, (1994). These changes in the areas of impervious surfaces have a large impact on the catchment runoff and were included as a time series based catchment development event.

2.1.5 Streamflow data

The model HYDRO25 uses existing records of runoff to calibrate the amount of water flowing in the catchment. DWAF's gauge E2H002 is located on the Doring River at latitude 32° 32' 10" and longitude 19° 32' 09", which is the same location as the proposed Aspoort Dam lying at the downstream end of the study area. This gauge had some missing records in certain months but the data were the best available for this study. Patching of the missing records was done for gauge E2H002 on the daily flow records using a specialised application developed for the patching of Clanwilliam Dam inflows in a study in the same hydrological region as the Doring River (Dube, 2000). Another runoff gauge located further downstream, gauge E2H003, was used as additional input in the patching programme. The most up to date records for gauges E2H002 and E2H003 were obtained from DWAF in daily flow format and had to be processed to generate the monthly records used in the calibration of the model. Apart from missing records, the data had a number of other shortcomings that had to be overcome, for example, suspect values that were not flagged and minimum records that could not be relied on. General data observations as well as statistical and arithmetic calculations directed at determining the trends in the records and excluding outliers were performed on the data before patching could be done. Figure A2.3 shows a typical monthly record of flows as it was when it was supplied by the Hydrology Directorate of DWAF.

```
MONTHLY                        MONTHLY VOLUMES      2000-12-19        Page    1

                    STATION NUMBER-DATA CODE: E2H002-A01              E2H002-A01
                         FLOW GAUGINGS IN: DORING RIVER
                        PLACE/COMMON NAME: ELANDS DRIFT ASPOORT
                       STATION DESCRIPTION: GAUGING WEIR
                                 LOCATION: LAT 32 30 10  LONG 19 32 09
                         CATCHMENT AREA(km2): 6903.00

                    MONTHLY VOLUMES - MILLIONS CUBIC METRES
----------------------------------------------------------------------------------
  YEAR    OCT   NOV   DEC    JAN    FEB    MAR    APR    MAY    JUN    JUL   AUG    SEP   ANNUAL
                                                                                        VOLUME
----------------------------------------------------------------------------------
1923/1924 12.0  3.27  1.32  1.77  0.375  0.587  0.812  1.43  32.3   15.7  56.7   58.0    184
1924/1925 9.85  12.8  2.20  0.451 0.478  0.510  0.647  1.47  +258   +223  48.3   11.7   +570
1925/1926 21.6  13.5  5.05  1.15  0.677  0.810  1.17   12.3  12.7   35.0  40.6   11.7    156
1926/1927 16.9  9.51  1.72  0.442 0.632  0.433  1.74   4.85  11.2   25.0  +58.6  44.6   +175
1927/1928 4.61  5.13  0.991 0.371 0.246  0.473  0.739  0.927 36.0   41.6  18.2   65.8    175
1928/1929 8.20  1.88  0.663 0.171 0.134  0.366  2.78   27.0  +41.1  +142  37.4   57.4   +319
1929/1930 8.45  2.28  1.05  2.82  2.50   0.735  1.32   1.17  2.77   15.8  20.1   +86.8  +145
1930/1931 26.0  3.11  1.88  0.790 0.250  0.308  2.71   34.5  6.62   16.7  +88.5  +80.9  +262
1931/1932 43.5  4.49  1.15  0.784 2.41   1.69   1.76   6.38  45.8   91.8  22.8   15.2    237
1932/1933 12.4  2.75  0.762 0.277 0.259  0.732  0.677  1.94  81.7   +145  44.0   19.5   +310
1933/1934 8.77  5.60  10.4  0.416 0.315  1.87   0.960  4.53  5.35   41.7  16.4   38.6    134
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
1985/1986 10.7  3.83  2.65  0.567 0.200  0.251  0.187  3.05  26.2   35.1  67.7   29.5    179
1986/1987 7.66  2.84  0.890 0.196 0.122  0.150  1.76   9.06* 34.0   41.1  16.3   23.8    137*
1987/1988 10.6  2.64  1.39  0.352 0.019  0.451  5.08   5.32  33.1   19.6  19.7   46.3    144
1988/1989 10.8  2.65  0.868 0.143 0.013* #      0.449* 6.68  15.9   30.0  66.4   +96.8   #
1989/1990 16.9  5.03  1.18  0.210 0.053* 0.641  6.21   +41.0 37.9   +121  46.1   11.3   +288*
1990/1991 3.79  1.52  0.670 0.390 0.275  0.291  0.769  4.07  +45.0  +142  +101   86.3   +387
1991/1992 26.8  10.6  1.60  0.370 0.241  0.644  3.63   9.78  +87.4  63.3  39.1   23.4   +266
1992/1993 +55.2 17.5  2.56  0.597 0.363  0.268  15.7   35.1  42.7   +213  55.3   15.0   +454
1993/1994 4.82  1.34  0.738*0.00* 0.00   0.216  0.676  1.82  +83.8  61.1  15.3   18.9   +188*
1994/1995 14.9  3.31  0.754 0.089 0.002  1.11   0.825  2.89  6.89   38.8  36.4   9.74    115
1995/1996 26.3  8.57  7.48  1.52  0.154  0.249  0.892  1.39  +69.3  +98.1 +101   +139   +455
1996/1997 63.7  50.8  9.50* 2.73* 1.34   4.08   2.75*  4.90  +106   51.9  42.8   26.9   +357*
1997/1998 5.39  4.93  2.53  1.66  0.380  0.667  1.36   +42.8 29.7   30.4  19.5   7.62   +146
1998/1999 5.28  10.8  2.86  0.317 0.122  0.034  0.601  2.14  7.78   18.9  +64.6  +68.7  +182
1999/2000 11.9  2.50  1.45  0.520 0.331  0.724  0.581  1.22  4.79   30.5  18.0   36.6*   109*

* : RECORD INCOMPLETE       # : NO RECORD     m : MINIMUM HEIGHT   $ : RATING LIMIT EXCEEDED AS WELL AS
+ : RATING LIMIT EXCEEDED  *C* : DATA NOT EDITED YET   M : MAXIMUM HEIGHT     MINIMUM / MAXIMUM HEIGHT

RATING(S) USED :
+---------------------------------------------+
| No |        Period         |    Stored    |
+---------------------------------------------+
|003 | 1923/03/27 to date    | 1998/10/16 |
+---------------------------------------------+
NOTE :     Data are continuously evaluated and improved.
```

Figure A2.3   Original version of monthly flow records from the gauge E2H0002 as supplied by DWAF.

2.1.6 Data analysis and patching

Data collection involved searching for all the catchment data that could be used in the model without setting any preference to any one source of data. In the case of rainfall data, records from other rain gauges close to the catchment area were also considered since the record to be used in the model had to represent average rainfall for a large area. Feedback for rainfall data requests from the different institutions reduced the number of possible stations to around twenty gauges. The vast amounts of data required in the

HYDRO25 model are mainly monthly rainfall type of data, such that the data analysis stage focussed on the analysis of rainfall data. The data assessments started with simple observation where a number of stations were excluded after showing major shortcomings when the following considerations were made:

(a) Inadequate record length

(b) Too many zero values or unflagged suspicious values

(c) Presence of negative values in the records

(d) Chronological order not being followed in the records

(e) Too many flags generating suspicion on many records. In some cases some records from the CCWR had flags for all the values for a rain gauge

(f) Records from different data sources with the same rainfall gauge numbers but completely different values

Further data analysis involved the use of mathematical and graphical methods. Mass plots were done to check on data consistency. A typical double mass curve of the rainfall gauges 042669 and gauge 086079 is shown in Figure A2.4.
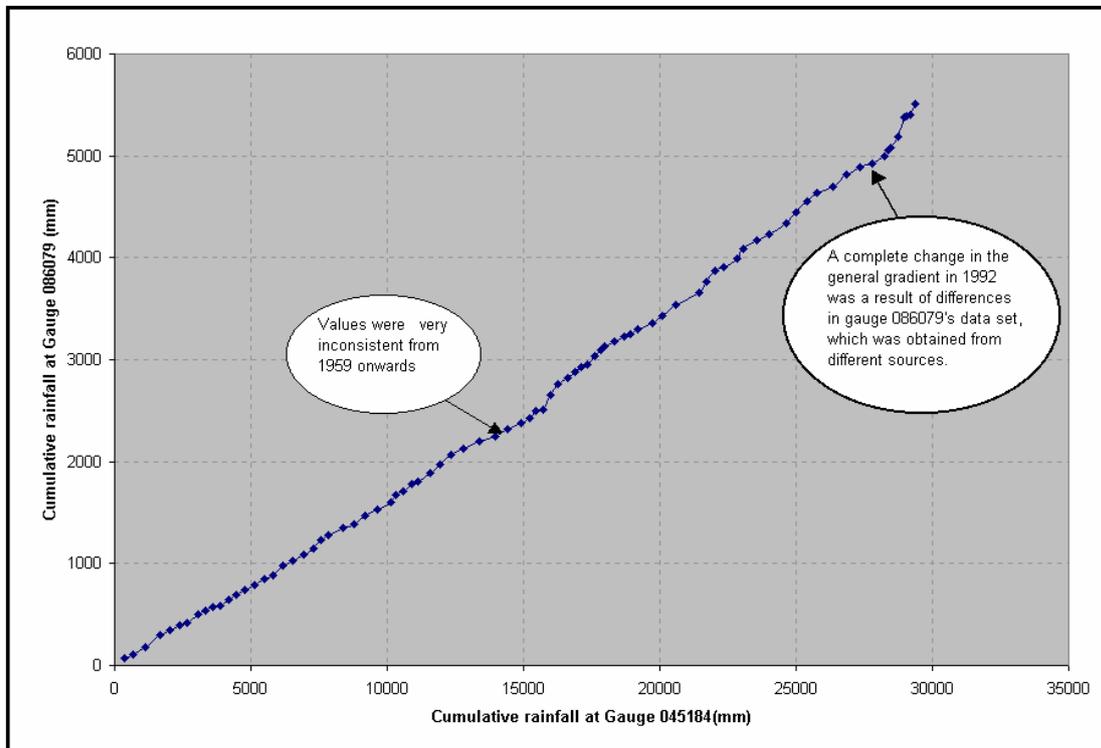

Figure A2.4   Double mass curve of rainfall gauges 042669 and 086079 for the period 1917 to 1999.

The double mass curve of gauge 086079 and 042669, shown in Figure A2.4, gave a number of inconsistencies, some of which are indicated in the figure. Plots of data from the two stations, 086079 and 042669 against that from the other stations in the catchment indicated that gauge 086079 had a number of shortcomings that made it unsuitable for use in the simulation.

Geographical plotting of mean annual precipitation to identify any unusual patterns as well as split sample testing of means and variances were also part of the pre-treatment stage for the data. The software application, Classr (Pegram, 1994) was then used to classify rainfall gauges into groups with a similar trend and for further identification of outliers. The application Classr used a measure of distance to identify gauges of similar nature. The distances or physical locations of the rainfall stations are derived from the naming convention used for rain gauges. In the application statistical calculations were used to identify outliers. Two sets of rainfall data were obtained for the two sub-catchments, the Koue Bookkeveld and the Aspoort sub-catchment. The two sets of data were used in the patching programme to fill in missing or unreliable records. The unreliable records had flags/indicators added at the data source and additional flags placed by the Classr application.

The grouped and flagged rainfall records were patched using the application Patchr (Pegram, 1994). The patching programme used stepwise multi-linear regression based on the EM algorithm. In the EM algorithm, the idea is to recursively substitute regressed data for those that are missing and then re-estimate the regression (Makhuvha, 1988). The EM algorithm has the advantage that the other records that are used to patch the unreliable gauge data can have missing data, a feature which is not possible when the general multi-linear regression method is used. In multi-linear regression the records used to patch another data set must not have missing or unreliable values; such data sets are very rare to find.

2.1.7 Data input formats in HYDRO25 and the output files

The model, HYDRO25 relies on data stored in a system of files to pass information from the user to the model, and from one model module to another. Calculations in the model

rely on values entered in files as inputs. The hydrological data are mainly on a monthly basis. A daily rainfall input for at least one year is needed to determine the best daily rainfall distribution in the model. The actual values in the daily data file are not used by the model. The model uses this input to determine how to distribute a monthly value of rainfall. The other input files are the parameter files with information on what the model should do for each of the component modules. A network file is the first input to building any system, and has details about all the modules and a list of the data files to be used by each module, and the directory locations of where each processing stage should save information for subsequent stages to access in the simulation process.

2.1.7.1   The HYDRO25 monthly data format

Figure A2.5 shows the HYDRO25 monthly data format. The first five lines must contain a description of the file name and the headings for each month. The spacing between columns is not critical.

Figure A2.5   HYDRO25 monthly data format.

The model reads the data in free format, such that the monthly values must be separated by at least a single space. The data do not necessarily have to be in a set of neat columns, though this is important for clear presentation and to identify problems if they do arise while accessing the file. The file has to be created using a simple text editor, such as Notepad or Textpad. The editing of the input data files should avoid the use of specialised word applications such as MS Word or Word perfect. These applications are based on the rich-text software control, which adds formatting to text files and causes access problems when the free format method of reading values is used. How a data file ends is a very important aspect in the HYDRO25 model. There should be no open space at the end of the last data entry. The end of file should be exactly at the last figure typed in the file. The error message "Input past end of file" will be displayed if a file does not end as described. This error results from the computer reading an empty space and attempting to identify that space as a possible input to the model. It will be noted that the same error message is displayed for data read in free format if the data are being distributed to defined variables and it happens that some of the variables expecting to get data assigned to them from a single line fail to get data. An example of such a problem will be encountered if a parameter file is incorrectly altered or if a parameter file from another module is opened in the wrong parameter input interface. In cases such as these, the file end will not be the problem, instead the data format will be the source of the error.

2.1.7.2 HYDRO25 daily data format

The daily data format, if it is available, is used in the RUN25 module. The daily data in this module are rainfall data that are used to distribute the values for monthly flows, interception, evaporation and water seepage into daily components. If the daily data file is not supplied, a default distribution pattern is used that is applied for all the months, and all the years. The distribution pattern obtained from the daily inputs is not varied over the years. The daily rainfall file is obtained using the Daily-Rain module that is accessed by clicking the "Data" button in the main user interface and then selecting the second choice in the selection form that appears. The module uses data in the ACRU (Dent *et al.*, 1995) single data format to generate data in a format that can be used in this model. Figures A2.6 and A2.7 show the HYDRO25 daily data format and the ACRU single format, respectively.

```
File Name :  sub34flow2.101
Units     :  mm
                         AVERAGE  DAILY  RAINFALL
--------------------------------------------------------------------
  DAY   OCT   NOV   DEC   JAN   FEB   MAR   APR   MAY   JUN   JUL   AUG   SEP  DAY
--------------------------------------------------------------------
    1   0.89  1.41  3.09  1.56  2.6   1.97  1.94  1.81  1.29  1.26  1.13  0.92   1
    2   1     1.24  3.2   1.68  2.29  1.97  1.86  1.65  1.29  1.29  1.16  0.89   2
    3   0.78  1.32  2.74  1.71  1.94  2.71  2.36  1.59  1.24  1.26  1.16  0.92   3
    4   0.72  1.38  2.31  1.65  1.66  2.74  2.89  1.7   1.29  1.29  1.13  0.97   4
    5   1.06  1.59  1.86  1.68  1.8   3.06  2.64  1.65  1.39  1.26  1.16  0.89   5
    6   0.86  1.85  1.51  1.76  1.74  2.86  2.56  1.46  1.39  1.24  1.11  0.89   6
    7   0.75  1.65  1.94  1.68  1.63  2.57  2.06  1.38  1.39  1.21  1.13  0.89   7
    8   0.64  1.29  2.86  1.5   2.11  3.54  1.38  1.38  1.32  1.21  1.13  0.86   8
    9   0.67  1.24  2.29  2.18  2.31  2.86  2.03  1.35  1.32  1.21  1.08  1      9
   10   0.75  1.26  2.03  2.15  2.23  2.46  2.03  1.3   1.29  1.21  1.08  1     10
   11   0.75  1.44  1.77  1.68  2.17  2.46  1.92  1.27  1.32  1.21  1.08  1     11
   12   0.94  1.5   1.63  2.32  2.97  3.29  1.83  1.27  1.34  1.21  1.05  1.03  12
   13   0.86  1.38  1.91  2.12  2.86  2.66  1.78  1.27  1.45  1.18  1.03  0.97  13
   14   0.94  1.21  1.91  2     3     2.86  1.92  1.35  1.45  1.18  1.03  0.89  14
   15   0.92  1.29  2.14  1.82  3.2   3.29  1.86  1.35  1.37  1.18  1     1.11  15
   16   0.92  1.21  2.14  2.09  3.26  2.97  1.81  1.32  1.32  1.18  1     0.89  16
   17   1.11  1.38  2.46  2.06  3.8   2.34  1.83  1.38  1.32  1.18  0.97  0.81  17
   18   1.11  1.41  2.34  2.06  3.57  2.43  1.83  1.49  1.32  1.16  0.95  0.78  18
   19   1.56  1.85  2.09  1.85  3.54  2.57  2.11  1.32  1.32  1.18  0.95  0.73  19
   20   1.28  2.24  1.69  1.97  3.17  2.86  1.78  1.27  1.34  1.18  0.97  0.7   20
   21   1.03  2.18  1.66  2.5   3.11  2.6   1.67  1.3   1.42  1.13  1     0.7   21
   22   1.22  2     1.83  2.68  2.57  2.37  1.47  1.46  1.42  1.11  1     0.65  22
   23   1.17  1.65  2.91  3.09  2.37  2.4   1.39  1.43  1.42  1.11  0.97  0.65  23
   24   1.22  1.71  2.34  3.5   2.34  2.49  1.56  1.35  1.39  1.13  0.97  0.62  24
   25   1.53  1.94  2.14  2.94  2.31  2.29  1.97  1.32  1.32  1.13  0.97  0.62  25
   26   1.36  1.97  1.91  2.74  2.51  2.31  1.86  1.54  1.32  1.11  1     0.65  26
   27   1.44  2.06  2.03  2.38  2.49  2.37  1.58  1.57  1.32  1.11  1     0.68  27
   28   1.44  1.97  1.83  2.74  2.17  2.43  1.56  1.51  1.32  1.13  1.08  0.84  28
   29   1.28  2.09  2     2.29  2.17  2.14  1.78  1.38  1.29  1.11  1.03  0.89  29
   30   1.14  2.76  1.63  2.09  -     2.03  1.81  1.32  1.29  1.13  1     0.89  30
   31   1.33  -     1.57  2.21  -     2.03  -     1.3   -     1.13  1     -     31
```

Figure A2.6   HYDRO25 daily data format.

```
B1H004
1963   1   31
  1       .0  -
  2       .0  -
  3       .0  -
  4       .0  -
  5       .0  -
  6       .0  -
  7       .0  -
  8       .0  -
  9       .0  -
 10       .0  -
 11       .0  -
 12      1.6  -
 13       .7  -
 14       .2  -
 15       .1  -
 16       .1  -
 17       .1  -
 18       .1  -
 19       .1  -
 20       .1  -
 21       .1  -
 22       .1  -
 23       .1  -
 24       .1  -
 25       .2  -
 26       .2  -
 27       .1  -
 28       .1  -
 29       .1  -
 30       .1  -
 31       .1  -
B1H004
1963   2   28
  1       .1  -
  2       .1  -
  3       .0  -
  4       .0  -
  5       .0  -
  6       .0  -
  7     -99.9 M
  8     -99.9 M
  9       .0  -
 10       .0  -
 11       .1  -
  1
```

Figure A2.7   An example of ACRU single data format.

2.1.7.3 Parameter files

Appendix 1 discussed the parameter files, for each of the modules that require a parameter file in HYDRO25. The files defined as parameter files in this study do not necessarily have a module's parameters but have details about the module such as the rainfall data file name, the files to add, the evaporation data and all the information required about the module when the model runs.

2.2   Building the model for the Doring River case study

2.2.1 Simulation objectives in the Doring River case study

This study aimed to generate information that could be used to decide on the following development proposals:

(1) The maximum area of irrigated land that can be successfully developed for irrigation in the Koue Bokkeveld (KBV) area without providing additional storage.

(2) The possibility of irrigation at Aspoort using Doring River run-off

(3) The best combination of irrigation options for the KBV and Aspoort areas, with an additional storage at Aspoort. This scenario looks at the size of the irrigation area at Aspoort and the size of the Aspoort Dam then seeks to maximise its irrigation potential.

In this study only the hydrological implications were evaluated using the model HYDRO25. The study also aimed to use the most up to date hydrological inputs including recent developments in the catchment.

2.2.2   Physical conceptualisation

This stage of model development involved recording the physical design of the Doring River water system. The physical design is represented in a network diagram that describes the natural system. The network diagram also gives the relationships between

the modules and how they should be entered in the model. The schematic illustration in Figure A2.8 shows the model schematisation.
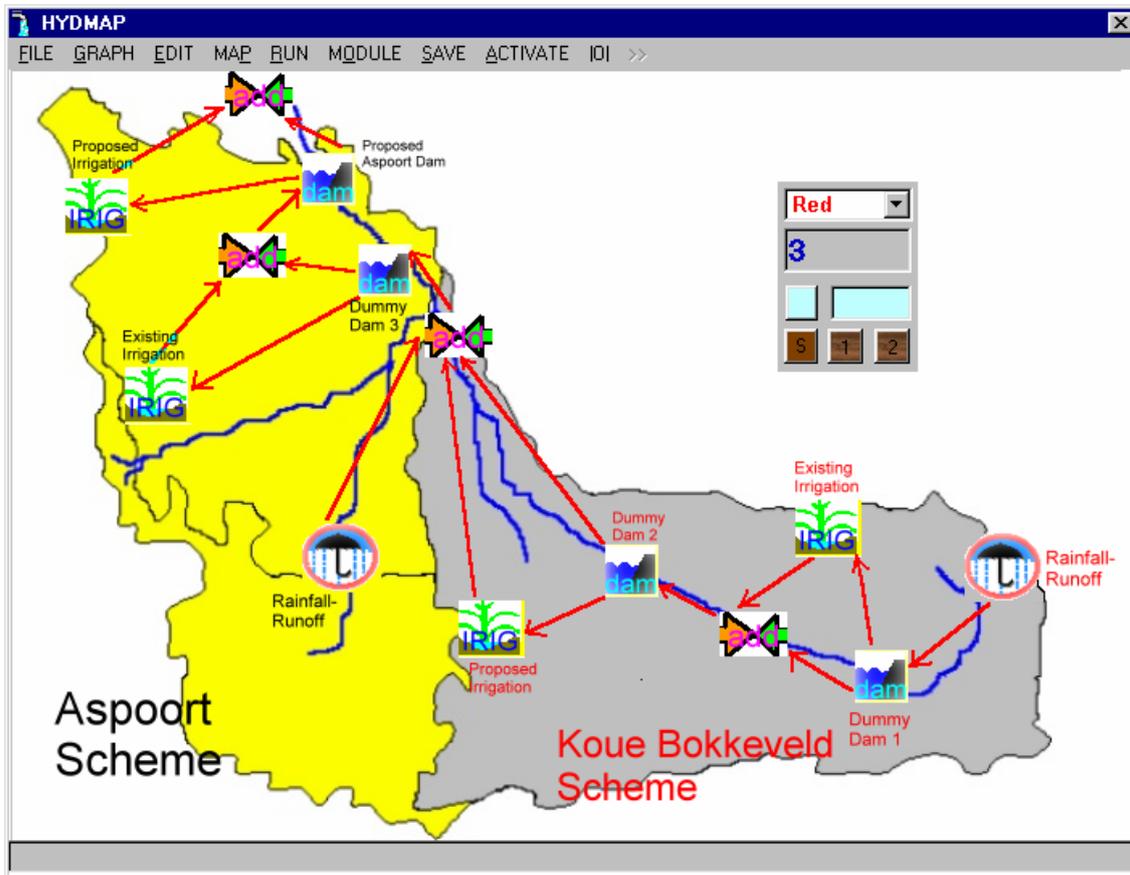

Figure A2.8   Doring River model schematisation.

The physical conceptualisation describes the pathway to a solution in a way that allows the modeller to develop a numerical solution on the computer. It communicates the necessary details of the solution including organisation, structure and relationships between the modules used for creating the elements of the solution. The physical model system was used to enter the electronic network in the computer. The main user interface will display modules in the same order as the sequence in which the network is resolved during a model run.

2.2.3 Model network and module relationships

The model simulated the catchment in a modular approach through component module blocks that described the different events in the catchment. The inter-relationships of the

modules were set in the system network description file and the parameter files that contain information about each module. The parameter files were discussed in Appendix 1 for each of the modules in HYDRO25. Table 6.1 shows the network file contents as they were set up in the main user interface.

The main user interface does not show all the information in the water system's network file. Of major importance are the names of the parameter files associated with each routine. To see the parameter file names used for each module, an additional window is available that is accessed by pressing the enter key while in the module interface. In building up the model for the upper Doring catchment the positioning of the modules had to follow the precise order that allowed them to obtain inputs from other modules in time for the next step of the simulation. In the upper Doring River system two simulation systems were used, one for the calibration and another for determining the irrigation supplies without the dams. In the simulation, the irrigation modules and the runoff modules should be placed before the modules using their inputs. In the case of the upper Doring system, the modules FLOWADD and the RES25 modules used the outputs from runoff and irrigation simulations. The linking of the modules and the transfer of information between the modules, and between the model and the user, is a function of text files. The files are stored in the computer in a single directory for each run and have no effect on subsequent runs of other catchments if their files are stored separately.

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