# IHACRES

## Catchment-scale rainfall - streamflow modelling
## (PC version)

**Version 1.0**
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This User Guide was produced by the

Centre for Ecology and Hydrology, Wallingford (formerly the Institute of Hydrology) with input from the Integrated Catchment Assessment and Management Centre (ICAM), Australian National University, Canberra.



PC-IHACRES v1.02 was developed jointly by the Centre for Ecology and Hydrology, Wallingford (a component organisation of NERC) and the Integrated Catchment Assessment and Management Centre (ICAM), Australian National University, Canberra.

The software, its 97-page User Guide and set-up details are available free of charge via the online Reference Manual of the Hydrological Operational Multipurpose System (HOMS) maintained by the World Meteorological Organization (WMO). PC-IHACRES v1.02 is Component K22.2.11 and can be downloaded from the HOMS website at http://www.wmo.ch/web/homs/homshome.html. It is also downloadable from the CEH website at http://www.ceh.ac.uk/.

The HOMS and CEH websites are the only sources of PC-IHACRES v1.02 material recognised by CEH or ICAM. It is recommended that each user downloads the software and its documentation to their PC separately.

From 2003, no person or organization should pay money for obtaining the PC-IHACRES v1.02 software or its documentation. Any payment made or received for results and /or reports involving application(s) of PC-IHACRES v1.02 by parties other than CEH or ICAM is a matter between the parties involved. Neither CEH nor

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# 1. INTRODUCTION

## 1.1 Identification of unit hydrographs and component flows from rainfall, evaporation and streamflow data (IHACRES)

IHACRES is a catchment-scale rainfall-streamflow modelling methodology developed collaboratively by the Institute of Hydrology (IH), United Kingdom and the Centre for Resource and Environmental Studies, Australian National University (CRES at ANU), Canberra. Its purpose is to assist the hydrologist or water resources engineer to characterise the dynamic relationship between basin rainfall and streamflow. Possible applications include:

- identification of unit hydrographs
- continuous time series streamflow modelling
- environmental change - hydrological regime studies
- runoff event modelling
- hydrograph separation (for example, to assist with water quality investigations)
- derivation of a Slow Flow Index (SFI)
- derivation of Dynamic Response Characteristics (DRCs)
- investigation of relationships between DRCs and Physical Catchment Descriptors (PCDs)
- teaching unit hydrograph theory and its applications
- hydrometric data quality assurance/control (QA/QC)
- infilling missing streamflow data

The only field-data required are time series of rainfall and streamflow, and a third variable by which evapotranspiration effects can be approximated. The third variable can be air temperature but pan evaporation, or potential evaporation (PE) derived from hydrometeorological measurements, can also be used as alternatives if they are available. Data time steps from six minutes to one month have been employed successfully by IHACRES for catchments varying in size from 490 $m^2$ (in China) to nearly 10,000 $km^2$ (in the UK). The methodology yields a unit hydrograph (UH) for *total* streamflow. This can often be resolved into separate unit hydrographs that characterise the quick and slow components of streamflow. This feature allows hydrographs to be separated into their dominant quick and slow flow components and provides a Slow Flow Index (SFI) analogous to the well-known Baseflow Index (BFI).

No guarantee can be given that PC IHACRES will work well in every situation, even if the data being used are of good quality. For example, a flow regime might be affected by large artificial abstractions and discharges or it might be atypically complex if the site in question is immediately downstream of a confluence of tributaries which exhibit very different flow characteristics. The technique may not be suitable for modelling streamflow in catchments that experience highly variable groundwater imports to, or exports from, adjacent topographically defined basins. Also, version 1.0 of PC IHACRES makes no attempt to model snowmelt or conditions where ice or other severe hydroclimatological factors affect the hydrograph. Future versions of the package may include a snowmelt module.

However, a sufficient number of real datasets from different sizes and types of catchment in different hydroclimatic zones of the world have been analysed successfully by the IHACRES rainfall-runoff modelling methodology to warrant making it available to the general hydrological community as a PC package. IH and CRES (ANU) will continue to develop the methodology and the PC package. Reports of experience with the package (good or otherwise) and suggestions for improvements are, therefore, welcome at either of the addresses given in Section 8 of this User Guide.

Neither IH nor CRES accept responsibility for how any results obtained with PC IHACRES are used. The IHACRES methodology continues to be developed and applied for special studies, employing very powerful computing facilities at IH and ANU. We welcome enquiries about the use of such facilities to undertake the type of work programme which may not be so easily addressed with PC IHACRES and with the resources at the ready disposal of the operator, e.g., regional studies involving multiple analyses of many long datasets.

## 1.2 IHACRES in a PC Windows environment

The program reads information from five files and writes to either eleven or twelve files depending on whether the operation is one of model calibration or simulation. Many of the files written by the program are for graphics. The package provides an extensive range of screen displays which can be included in reports (e.g., observed and modelled streamflow, effective rainfall, a catchment wetness index, unit hydrographs, hydrograph separation, etc.). The operator does not have to create or edit any files manually except for two field-data files, one containing rainfall and streamflow data and the other containing temperature data (or some other surrogate variable for evapotranspiration effects). Menu sequences provide facilities for all file handling necessary for modelling. *New users of PC IHACRES are strongly advised to work through the tutorials in Section 7 of this User Guide*.

## 1.3 Structure and content of the User Guide

Section 2 describes the background to the IHACRES modelling methodology in sufficient detail for users of the PC package. Some readers may wish to leave this Section until they have gained a little experience with using the package, in which case they may proceed to Sections 3 to 7 and return to Section 2 later. The methodology and several of its applications are well documented in the scientific literature (see the bibliography in Section 9).

Section 3 describes how to install the package on a PC.

Section 4 gives a reference operational overview of the package.

Section 5 describes the program control file <**filename.ctl**>. This file contains details of all the other files which are either read, or written, by the package.

Section 6 describes the field-data (input) and modelling results (output) files.

Section 7 gives several tutorials based on real case studies.

Section 8 gives contact details for the Institute of Hydrology (UK) and the Centre for Resource and Environmental Studies, Australian National University.

Section 9 is a selected bibliography of published descriptions and applications of the IHACRES rainfall-runoff modelling methodology.

Section 10 acknowledges those who have played an important part in the development of IHACRES.

# 2. THE IHACRES MODELLING METHODOLOGY

## 2.1 The model

The emphasis is on modelling identifiable catchment-scale rainfall-runoff *behaviour* rather than the small-scale hydrological processes by which rainfall causes streamflow. Nevertheless, in order to have physical appeal, the model structure employed in IHACRES incorporates a sound conceptualisation of relevant large-scale catchment processes. The model comprises two modules, in series, as shown in Figure 1.

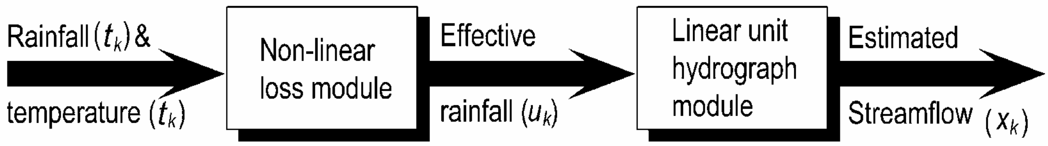


*Figure 1*

It is assumed that there is a linear relationship between effective rainfall and streamflow (effective rainfall $u_k$ for time step $k$ is that part of rainfall $r_k$ which eventually leaves the catchment as streamflow $x_k$). This allows the application of well-known unit hydrograph theory which conceptualises the catchment as a configuration of linear storages acting in series and/or parallel. All of the *non*-linearity that is commonly observed between rainfall and streamflow is accommodated, therefore, in the module which converts rainfall to effective rainfall. The underlying conceptualisation in this part of the model is that catchment wetness varies with recent past rainfall and with evapotranspiration. A 'catchment wetness index' (ideally, $0 < s_k < 1$) is computed at each time step on the basis of recent rainfall and temperature (employing this variable for evapotranspiration effects for introductory purposes). The percentage of rainfall which becomes effective rainfall in any time step varies linearly between 0% and 100% as the catchment wetness index ($s_k$) varies between zero and unity. An alternative conceptualisation of the catchment wetness index ($s_k$) is that it represents the proportion of the catchment area at time step $k$ which contributes, eventually, to streamflow, but it is important not to stretch the physical interpretation of the catchment wetness index ($s_k$) too far. Conceptualisation of spatially distributed processes in both the non-linear and linear modules of the IHACRES model is restricted. An advantage of the spatially 'lumped' approach, however, is that the model requires only a small number of parameters. Indeed, results of applying the methodology have confirmed that only a small number of model parameters *can* be identified solely from time series of basin rainfall, streamflow and temperature data. Typically there are three parameters in the non-linear loss module and another three in the linear module, making a total of just six parameters overall. Despite its structural simplicity, the IHACRES methodology performs well for many types of catchment.

The following outline of the methodology is complementary to detailed descriptions of IHACRES in the scientific literature (see the bibliography at Section 9) and is in a style more suitable for a User Guide. Unless stated otherwise, the measurement units of rainfall and streamflow in the following outline are assumed to be millimetres, and temperature is in $^{o}$C.

### 2.1.1 The linear (UH) module

Consider the simple discrete-time hydrograph such that *unit* effective rainfall over one data time step produces streamflow $b$ ( < 1) over the same time step (effective rainfall and flow have been zero in all preceding time steps and effective rainfall is zero in all subsequent time steps). In each subsequent time step, streamflow is a fixed proportion ($a < 1$) of what it was in the previous time step and thus the flow decays exponentially (at a rate determined by $a$). This scheme, including the resultant unit hydrograph, is shown in Figure 2.

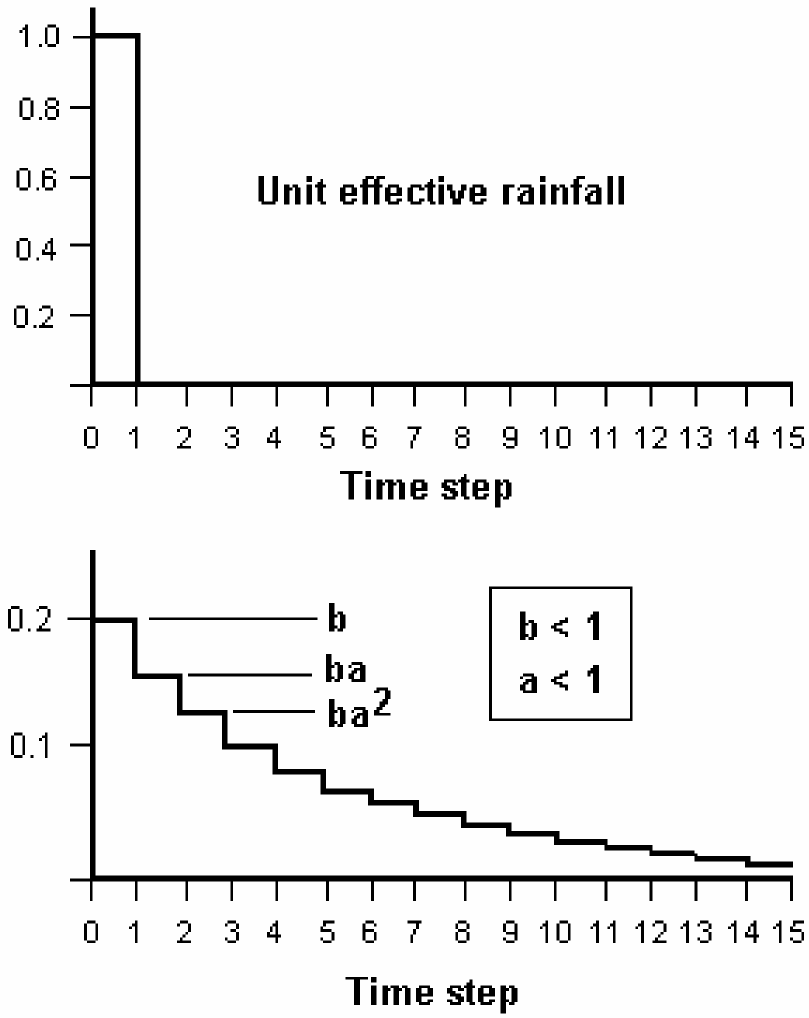


*Figure 2*

The area under the resultant UH (volume of flow) is given by the sum of the infinite geometric series ($b + ab + a^2b + a^3b + ...$) and, by definition, this is one unit (1mm over the catchment). With $0 < a < 1$, this infinite geometric series sums to $b/(1 - a)$, as given by equation (1), and equation (2) follows. The shape of this simple UH is completely defined, therefore, by one parameter (either $a$ or $b$).

$$b(1 + a + a^2 + a^3 + \ldots) = \frac{b}{1-a} \quad (1)$$

$$b = 1 - a \quad (2)$$

Convolution of the UH with effective rainfall excess ( ..., $u_{k-2}$, $u_{k-1}$, $u_k$, $u_{k+1}$, $u_{k+2}$, ... ), to give an estimate of streamflow ( ..., $x_{k-2}$, $x_{k-1}$, $x_k$, $x_{k+1}$, $x_{k+2}$, ... ), can be executed by recursive application of equation (3). Although $b = 1 - a$, it is helpful (as will be seen) to retain both parameters explicitly as in equation (3).

$$x_k = ax_{k-1} + bu_k \tag{3}$$

In principle, any number of these simple UHs in series and/or parallel can be configured to represent the catchment-scale rainfall-runoff process. PC IHACRES allows three configurations: single; two in series; and two in parallel. In practice, subject to data quality and a suitable data time step, the IHACRES methodology indicates usually that two such UHs in parallel is the optimal configuration identifiable from basin rainfall, streamflow and air temperature data (see later). In this case, the rates of exponential decay for the two simple UHs are relatively 'quick' ($q$) and 'slow' ($s$), and the separate UHs sum to give a UH for *total* streamflow which has a mixed-exponential decay. In this instance equation (4) applies and the linear module has just three parameters (any three of $a^{(q)}$, $b^{(q)}$, $a^{(s)}$ and $b^{(s)}$).

$$\frac{b^{(q)}}{1-a^{(q)}} + \frac{b^{(s)}}{1-a^{(s)}} = 1 \tag{4}$$

Estimates of the quick and slow components of streamflow are given by recursive application of equations (5) and (6) respectively. Estimated total streamflow $x_k$ is given by equation (7).

$$x_k^{(q)} = a^{(q)} x_{k-1}^{(q)} + b^{(q)} u_k \tag{5}$$

$$x_k^{(s)} = a^{(s)} x_{k-1}^{(s)} + b^{(s)} u_k \tag{6}$$

$$x_k = x_k^{(q)} + x_k^{(s)} \tag{7}$$

This 'two UHs in parallel' structure accords well with the observation that, usually, streamflow hydrographs for essentially natural flow regimes (i.e., insignificant artificial abstractions and discharges) are basically the superposition of (a) baseflow which is most noticeable as long (slow) recessions during periods of zero effective rainfall, and (b) (quick) runoff responses caused by effective rainfall events.

Indeed, as will be seen later, convolution of a slow flow component UH with effective rainfall using equation (6) can give an intuitively reasonable 'baseflow' hydrograph.

For purposes of illustration, assume that the areas under the quick and slow UHs are 0.4 and 0.6 respectively, and that the values for $a^{(q)}$ and $a^{(s)}$ are 0.6 and 0.8 respectively. It follows from equation (4) that the values for $b^{(q)}$ and $b^{(s)}$ are 0.16 and 0.12 respectively. Note that the area under the slow flow UH ($b^{(s)}/(1 - a^{(s)})$ = 0.6 in this case) is a Slow Flow Index SFI comparable to the well known Base Flow Index BFI, which is also calculated by PC IHACRES.

### 2.1.2 Dynamic Response Characteristics (DRCs) - unit hydrographs

Characteristic decay time constants for the quick and slow UHs can be calculated from equations (8) and (9), where $\Delta$ is the data time step.

$$\tau^{(q)} = \frac{\Delta}{-\ln(a^{(q)})} \tag{8}$$

$$\tau^{(s)} = \frac{\Delta}{-\ln(a^{(s)})} \tag{9}$$

Other DRCs are the relative volumetric throughputs for quick and slow flow ($v^{(q)}$ and $v^{(s)}$) given by equations (10) and (11) respectively (assuming both rainfall and streamflow are in mm – in which case $\nu^{(s)} + \nu^{(q)} = 1$).

$$v^{(q)} = \frac{b^{(q)}}{1 - a^{(q)}} \tag{10}$$

$$v^{(s)} = \frac{b^{(s)}}{1 - a^{(s)}} \tag{11}$$

The dynamic response characteristic (DRC) $v^{(s)}$ is the Slow Flow Index, mentioned already. Peaks of the quick and slow UHs, $I^{(q)}$ and $I^{(s)}$ are given by (12) and (13) respectively.

$$I^{(q)} = b^{(q)} \tag{12}$$

$$I^{(s)} = b^{(s)} \tag{13}$$

### 2.1.3 The non-linear (loss) module

The effective rainfall part of the model (the 'loss' module) accounts for all of the non-linearity in the catchment-scale rainfall - runoff process. A catchment that is already wet will usually generate more streamflow from a given amount of rainfall than it does from the same amount of rainfall when it is initially dry. This observation is employed in the form of a catchment wetness index, $s_k$, (ideally, $0 < s_k < 1$); effective rainfall $u_k$ (the part of the rainfall that leaves as streamflow) is the product of $r_k$ and the catchment wetness index $s_k$, as in equation (14), where the catchment wetness index $s_k$ is given by equations (15) and (16).

$$u_k = r_k s_k \tag{14}$$

$$s_k = C r_k + \left(1 - \frac{1}{\tau_w(t_k)}\right) s_{k-1}, \qquad s_0 = 0 \tag{15}$$

$$\tau_w(t_k) = \tau_w e^{0.062 f (R - t_k)}, \qquad \tau_w(t_k) > 1 \tag{16}$$

Parameter $\tau_w$ (the catchment drying time constant) in (16) is the value of $\tau_w(t_k)$ at a reference temperature $R$ chosen by the operator. In equation (15), $\tau_w(t_k)$ controls the rate at which the catchment wetness index ($s_k$) decays in the *absence* of rainfall. Parameter $f$ (the temperature modulation factor) in (16) controls the sensitivity of $\tau_w(t_k)$ to changes in temperature $t_k$. For time intervals *with* rain, decay of catchment wetness index ($s_k$) still occurs but it is also incremented by a proportion ($C$) of the rainfall ($r_k$). A value for $C$ is selected (i.e., calculated automatically during model calibration) such that the volumes of effective rainfall and observed streamflow over the model calibration period are equal. *It is important, therefore, that model calibration periods are selected by the operator to start and finish at times of low flow (e.g., at suitable times near the end of the regional water-year if modelling with daily data) such that the net change in catchment storage of water over the calibration period can reasonably be assumed to be close to zero.*

Version 1.0 of PC IHACRES allows just the one loss module described above. Subsequent versions may include alternative algorithms for accounting for the non-linearity between rainfall and streamflow, providing the operator with some choice in this matter.

### 2.1.4 Dynamic Response Characteristics (DRCs) - loss module

Parameters $\tau_w$, $f$ and $C$ (the catchment drying time constant, the temperature modulation factor and the volume-forcing constant) are DRCs which apply to the loss module of the overall model.

### 2.1.5 Summary

The whole model usually has six parameters; any three of $a^{(q)}$, $a^{(s)}$, $b^{(q)}$ and $b^{(s)}$ in the linear module plus $f$ (the temperature modulation factor), $\tau_w$ (the catchment drying time constant) and $C$ (the volume-forcing constant) in the non-linear module. A pure time delay $\delta$ (an integer multiple of the data time step $\Delta$) can be applied, in which case all the $u_k$ in equations (3), (5) and (6) become $u_{k-\delta}$.

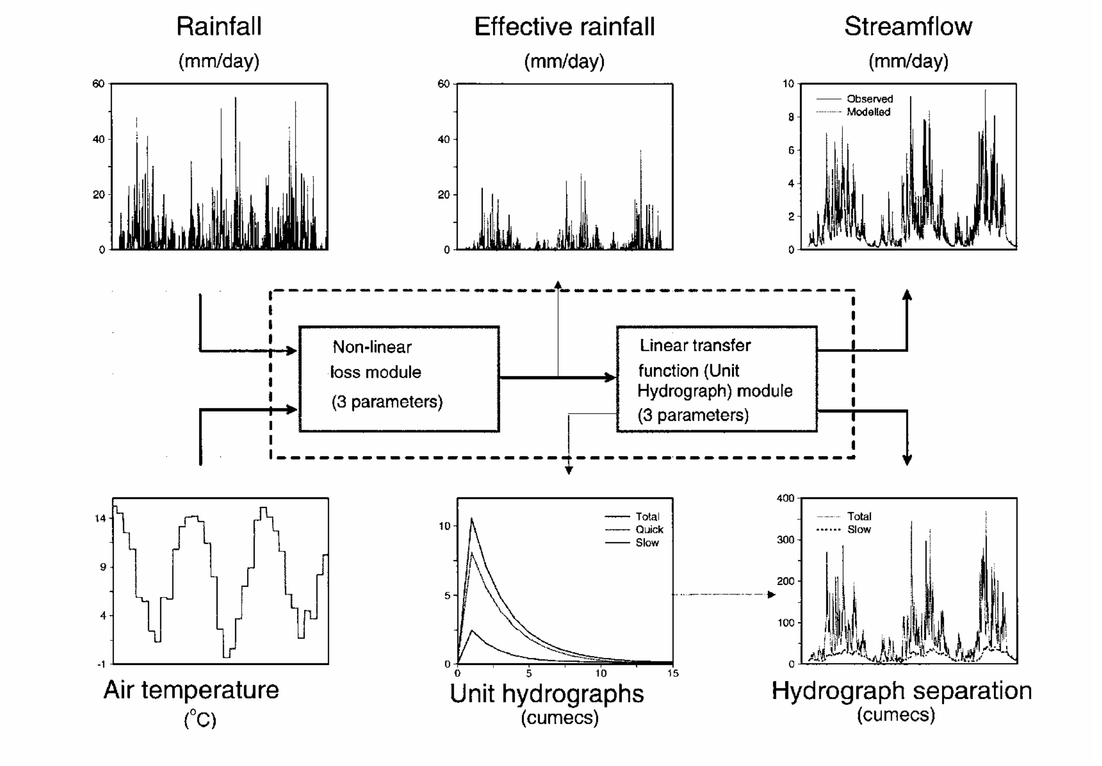


*Figure 3*

Figure 3 is a schematic of the modelling procedure. Note that, as indicated in Figure 3, good results can be obtained using monthly temperatures with daily rainfall and streamflow.

## 2.2 CALIBRATION OF A MODEL

As with many other PC packages, efficient use of PC IHACRES becomes more likely with experience. There are many strategies which can be followed for finding a ‘best’ model but the following is a basic methodology. The procedure will be better understood by new operators after they have worked through the tutorial examples in Section 7.

For a given configuration of simple UH storages in the linear module (usually two in parallel) – and a given pure time delay ♎ (an integer multiple of the data time step ☟), which is usually 0 or 1 for daily data, the operator selects values for the catchment drying time constant ($\tau_w$) and the temperature modulation factor (*f*) in the non-linear module. The parameters in the linear module ($a^{(q)}$, $a^{(s)}$, $b^{(q)}$ and $b^{(s)}$) and parameter *C* (the volume-forcing constant) in the non-linear module are then calculated automatically by the program. The coefficient of determination *D* and a percentage 'average relative parameter error' *%ARPE* (for the parameters in the linear module) are also calculated. A good model is usually one that has a high value for *D* and a low value for *%ARPE* (there are other factors to consider but discussion of these is left to the tutorials in Section 7).

The package allows the operator to select *ranges* for the parameters $\tau_w$ (the catchment drying time constant) and *f* (the temperature modulation factor) in the non-linear loss module. In a single run of the program, *D* (coefficient of determination) and *%ARPE* (percentage average relative parameter error) are then tabulated by the program for each pair of catchment drying time constant ($\tau_w$) and temperature modulation factor (*f*) to enable the operator to scan the results in search of a 'best' pair ($\tau_w$, *f*). Ideally, the maximum value of *D* and the minimum value of *%ARPE* would occur for a single pair of $\tau_w$ and *f*. In practice, the maximum *D* and minimum *%ARPE* will define ranges of the catchment drying time constant ($\tau_w$) and the temperature modulation factor (*f*), and it is necessary, therefore, for the operator to make a subjective trade-off between a high *D* and low *%ARPE* when selecting an optimal ($\tau_w$, *f*) pair.

When an optimal ($\tau_w$, *f* ) pair has been identified by the operator for (a) a given configuration of simple UHs and (b) a given value of the pure time delay $\delta$, different configurations of UH storages in the linear module, and different values for $\delta$, can be applied to check that the optimal combination of these factors has been selected. The model calibration procedure is fairly straightforward when some experience has been gained but *new operators are strongly recommended to work through the tutorial examples given in Section 7 of this User Guide.*

## 2.3 Application of a model in simulation mode

When the model is to be applied in simulation mode (i.e., over a period not used for its calibration), the first step is to calibrate the model again (if this was not the last operation performed), specifying the selected pair of $\tau_w$ and $f$ (catchment drying time constant and temperature modulation factor) rather than ranges for these parameters. The program then automatically makes available the relevant model parameters for a subsequent simulation by that model.

# 3. IHACRES INSTALLATION

This section of the original User Guide (for v1.0) has changed.

To download and install the PC-IHACRES v1.02 package and its documentation to the C: drive of your PC, where it should stay for operational use, follow the instructions given at *http://www.ceh.ac.uk/* , PRODUCTS, Software Products, Hydrology/Freshwater, etc., or at *http://www.wmo.ch/web/homs/homshome.html* (WMO HOMS Component K22.2.11).

# 4. OPERATIONAL OVERVIEW

The program is called by double-clicking on the **IHACRES** icon in the **IH Software** group. This Section describes each of the functions which appear on the menu bar at the top of the IHACRES window (items which are 'greyed-out' are inoperable until some later stage).

## 4.1 File

A single click on **File** at the top-left of the screen initiates file management without leaving the program (see Figure 4), e.g., **Open** to look at an existing file. The default filename **<*.txt>** at the top of the left-hand box of the screen display can be changed by either (a) setting the cursor at the beginning of that character string and typing or (b) highlighting the portion of the name you wish to change (by holding the click and sweeping across) and then entering the replacement character string. (These methods of editing character strings are common in Windows applications and may already be familiar to the operator.) Double-click on the appropriate directory in the right-hand box to list the filename(s) in the left-hand box. Double-click on the chosen filename in the left-hand box to see the file. Options **Print** and **Printer Setup** facilitate production of hard-copy output from modelling with PC IHACRES.

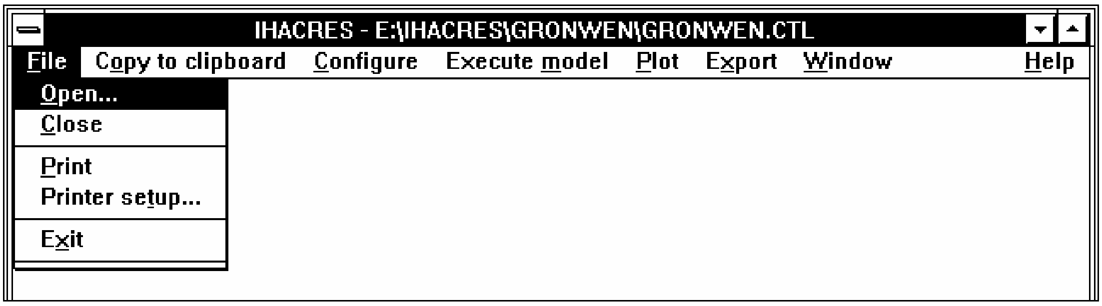


*Figure 4*

## 4.2 Copy to Clipboard

This facility allows output from PC IHACRES (text and plots) to be copied to word processor files. Click on **Copy to Clipboard** (or use **Ctrl + Insert**), then with the cursor in a word processor file at the desired position use the **Shift** + **Insert** keys to copy the clipboard contents into the file.

## 4.3 Configure

This is the function the operator will probably use most frequently. A single click on **Configure** gives the screen shown in Figure 5.

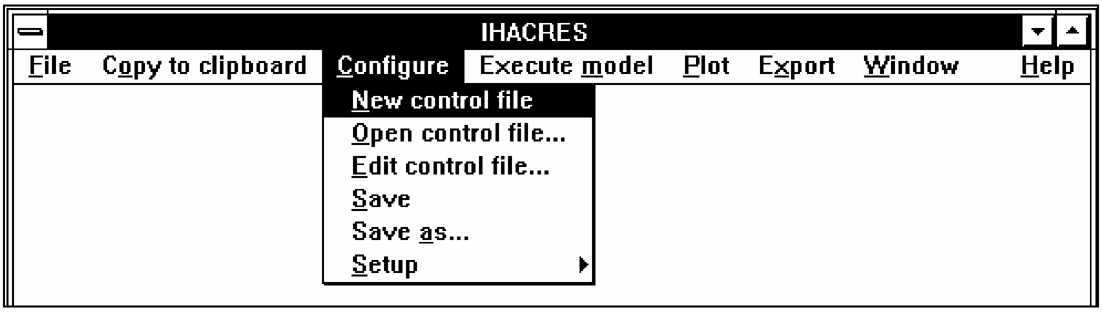


*Figure 5*

### 4.3.1 New control file

The control file **<filename.ctl>** contains the names of other files either read or written (not all of these) by the program:

- a parameter file (**<filename.inb>** – see Section 6.2);
- the rainfall/streamflow data file (**<filename.dat>** – see Section 6.1.1 for format);
- the temperature data file (**<filename.tem>** – see Section 6.1.2 for format);
- a model parameter file (**<filename.sim>** – see Section 0);
- a full results file (**<filename.out>** – see Section 6.4);
- a summary results file (**<filename.sum>** – see Section 6.3).

The operator will want to define these names, e.g., for specific catchments. A single click on **New control file** makes available a template control file **<ihacres.ctl>** ready for customising by the operator. The names of files in **<ihacres.ctl>** can be edited by using the buttons at the end of the filename bars to display a file dialogue panel. By double-clicking on the greyed-out names in the left-hand box the system automatically enters appropriate filenames in the **<filename.ctl>** file (the operator can double-click on any filename). Using **Save As,** the edited **<ihacres.ctl>** file can be saved as **<filename.ctl>**.

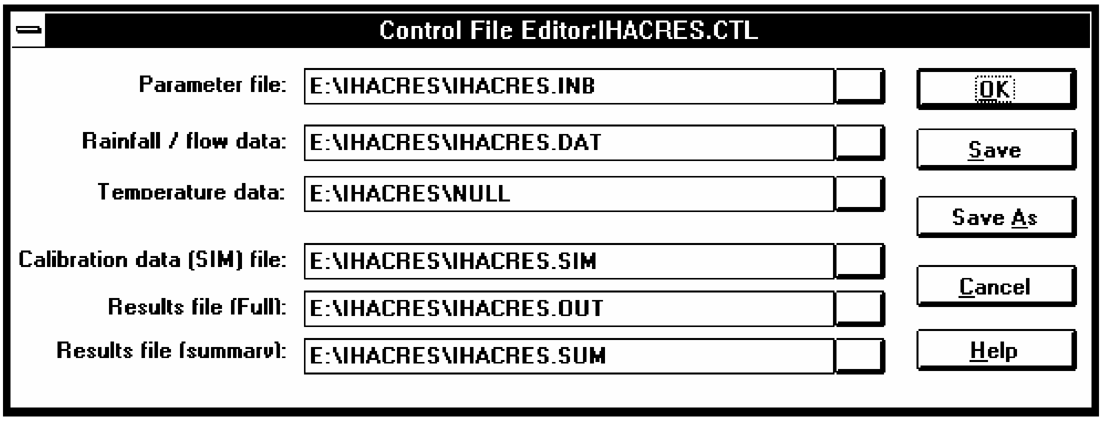


*Figure 6*

## 4.3.2 Open control file

Single-click on **Configure** then on **Open control file**; the operator can then select the control file just created or one created previously. A double-click on a filename in the 'Directories' box will cause the corresponding filename (if it exists) to appear in the 'File name' box. A double-click on this filename automatically puts the operator into the first stage of **Setup** (see 4.3.6), i.e., **Data description**.

## 4.3.3 Edit control file

Single-click to initiate editing of the control file just opened (see 4.3.2).

## 4.3.4 Save

Single-click to overwrite **<filename.ctl>** file created under **Setup** (see 4.3.6).

## 4.3.5 Save as ...

Single-click to write a **<filename.ctl>** file to a differently-named file.

## 4.3.6 Setup

The function of **Setup** is to allow preparation of **<filename.inb>** specified in **<filename.ctl>** currently open. Single-click to see the five stages of this process: **Data description …**; **Runtime options …**; **Subperiods …**; **Uncertainty analysis …**; and **Linear structure …** (see Figure 7). A single click on each of these gives a screen featuring either radio buttons or text boxes (or both) to enable the operator to create an appropriate **<filename.inb>** file.

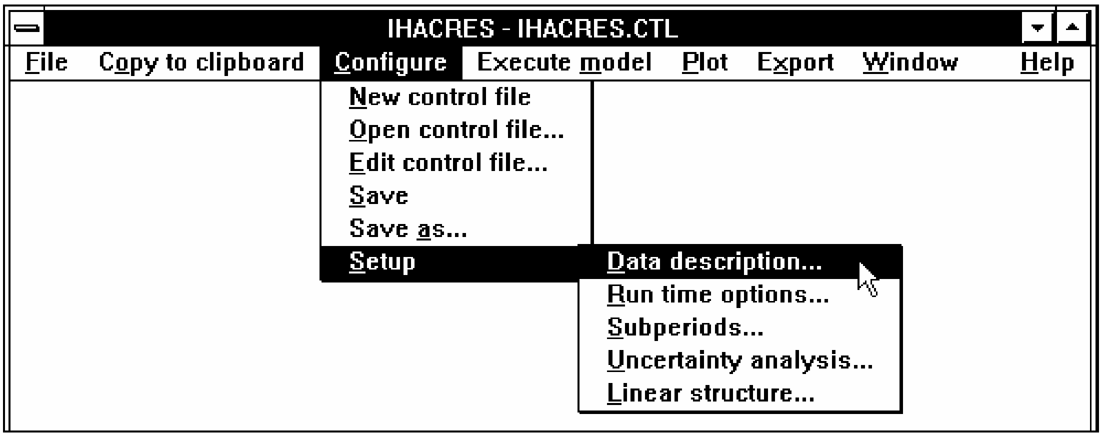


*Figure 7*

### 4.3.6.1 Data description

The operator selects from the options provided:

**Time base (Rain and flow)**

**Rainfall units**

**Streamflow units**

**Time base (temp)**. E.g., the rain and flow data can be daily and the temperature data can be monthly.

**Loss module selection** - 3 options, as follows:
*No rainfall filter* - the data in the first column of the rain/flow data file are assumed to be effective rainfall (i.e., the loss module is bypassed).
*Filter without temperature* - $\tau_w(t_k)$ in equation (15) is

replaced by $\tau_w$ (the catchment drying time constant).
*Filter using temperature* - equations (15) and (16) are invoked.

**Start date in rain/flow file**. The operator enters the date corresponding to the first row in <filename.dat>.

**Start date in temperature file**. date of first row in <filename.tem>.

#### 4.3.6.2 Runtime options

The operator enters values defining the ranges and increments for the **catchment drying time constant** ($\tau_w$) and the **Temperature modulation factor** ($f$) (see Figure 8). IMPORTANT: Wide searches of the $\tau_{w,}\, f$ parameter space using small increments can take a long time and should be avoided unless specifically planned. The operator is also required to enter the **Time delay** ($\delta$ – see Section 2.1.3), a **Reference temperature** and information in **Pre-filter selection** (see the Nant y Gronwen tutorial, Section 7.1.3, for details of the Reference temperature and pre-filters).

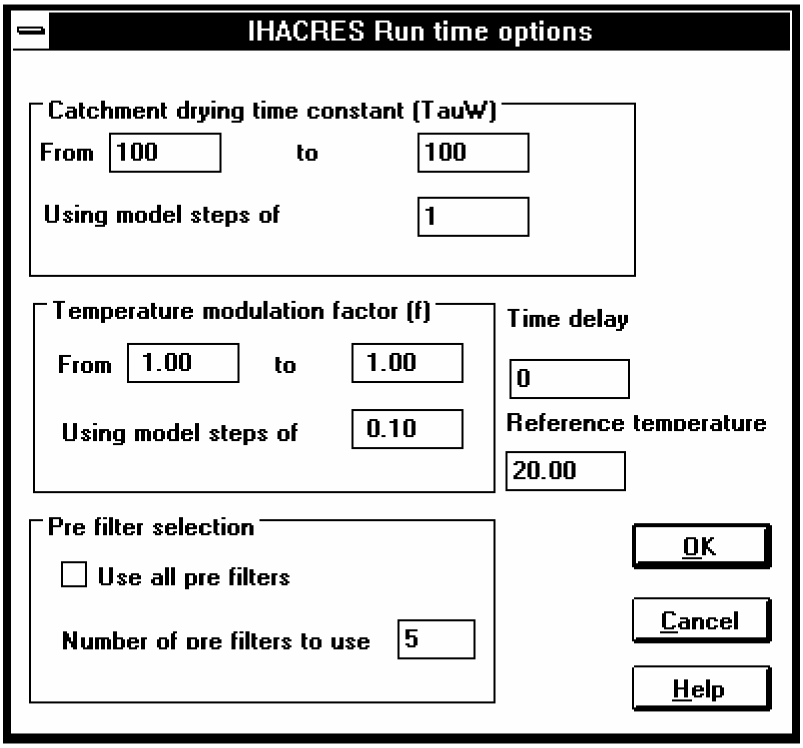


*Figure 8*

### 4.3.6.3 Subperiods

The operator can specify the subperiod of the data file named in **<filename.ctl>** (see Figure 9) required for model calibration or simulation by either (a) editing the **Start** and **End** dates and times or (b) using the **As file offsets** (which refer to row numbers in the **<filename.dat>**. Only one of these methods for specifying sub-periods needs to be used. After the operator uses **Save** the program will automatically ensure that both types of limits for the subperiod are consistent with each other.

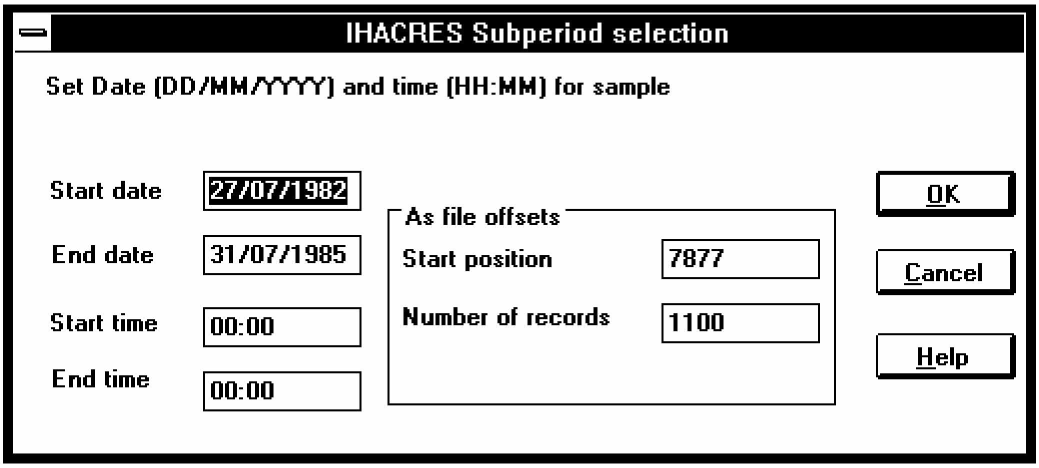


*Figure 9*

### 4.3.6.4 Uncertainty analysis

This allows calculation of specified indicative **Confidence limits** for dynamic response characteristics (DRCs) which relate to the UH part of the model (see Figure 10). The operator specifies the **No. of trials** and the **Confidence limit**s. This facility is generally used only when a 'best' model has been identified and is usually, therefore, set to **Off**. The operator should only set it to **On** when necessary – it can slow the performance of the program. (See the Teifi tutorial, Section 7.2.7, for an application of this facility.)

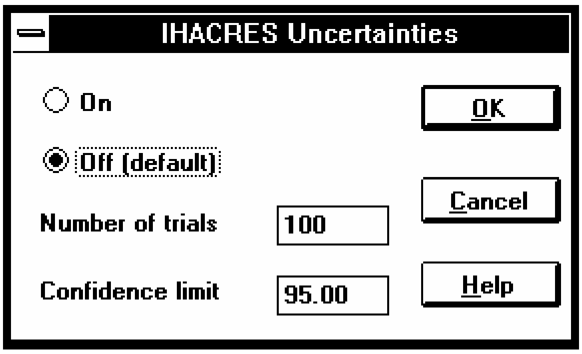


*Figure 10*

### 4.3.6.5 Linear structure

This refers to the configuration of linear UH storages in the model (see Figure 11). Subject to data quality and a suitable data time step (such that the rain/flow series contain useful information about both the quick and slow flow components) the configuration most commonly used will probably be **Two in parallel** (option C).

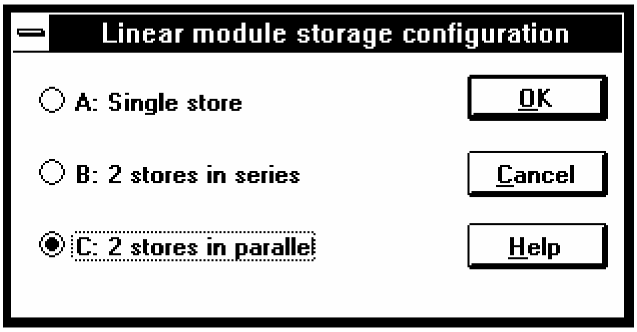


*Figure 11*

## 4.4 Execute model

Single-click on **Execute model** to **Calibrate** or **Simulate**. The process of *calibration* identifies optimal UH module parameters corresponding to all the settings in a **<filename.inb>** created automatically under **Setup**. The process of *simulation* applies a given model over any subperiod of record (which may include, or overlap with, the model calibration subperiod).

### 4.4.1 Calibrate

Single-click to initiate a model calibration. Progress is indicated on screen while the program searches for the optimal set of UH parameters for each pair of catchment drying time constant ($\tau_w$) and temperature modulation factor ($f$) specified in **Runtime options** under **Setup** (it may be just one pair). On completion, the summary results file **<filename.sum>** should be displayed on the screen – if it does not appear try to view it using **File - Open**.

### 4.4.2 Simulation

First, if it was not the last procedural step applied in the current PC IHACRES session, perform a model calibration with the optimal pair of catchment drying time constant and temperature modulation factor ($\tau_w$, $f$) prescribed under **Setup**. Set the subperiod over which the simulation is to be performed (**Setup** and **Subperiods**). Then single-click on **Simulation**. The operator can then select from a wide range of graphical displays using **Plot**.

## 4.5 Plot

A single-click reveals the panel **Observed data**, **Model results** and **Hydrographs**. Each of these deals with self-explanatory groupings of graphical output.

### 4.5.1 Observed data

This menu provides the following three options:

Rainfall

Streamflow

Both

### 4.5.2 Model results

This menu provides the following five options:

Effective rainfall

Effective and observed rainfall

Modelled and observed streamflow

Modelled streamflow and residuals

Catchment wetness index $s_k$

### 4.5.3 Hydrographs

This menu provides the following seven options:

Total

Quick component

Slow component

Total and quick

Total and slow

Quick and slow

Total, quick and slow

There are default titles and axis labels for each plot but these can be edited by the operator. For each plot in the **Hydrographs** group (operable only for option ‘C: 2 stores in parallel’ in **Setup - Linear structure**) there is the facility for plotting (a) the specified hydrograph time series and (b) the corresponding unit hydrographs.

## 4.6 Export

This facility allows modelled streamflow data to be written to a file, e.g., for data infilling purposes. Click on **Export**, then move to the directory of choice. Enter filename to create <**filename.exp**>, then click on OK to execute this step. The file <**filename.exp**> is created with header information (use **File - Open** to view it).

## 4.7 Window

A single-click on **Window** provides four options for managing the file and plot windows created in any one run of the program. The operator can experiment with these.

Tile

Cascade

Arrange icons

Close All

# 5. THE CONTROL FILE <filename.ctl>

## 5.1 Background

The file **<filename.ctl>** is the main control file. It contains information about the files that the package requires during its execution. The package requires the names and appropriate paths for 21 files of which **<filename.inb>**, **<filename.dat>** and (if temperature is applicable) **<filename.tem>** must be accessible before the program is executed. The file **<filename.inb>** is created by the operator using **Configure - Setup** (Section 4.3.6) but it is a binary file and cannot be viewed in the usual way. The files **<filename.sum>**, **<filename.sim>** and **<filename.out>** are created by the program. The file **<filename.pre>** must be one of the five files *ihacresa.pre*, *ihacresb.pre*, *ihacresc.pre*, *ihacresd.pre* and *ihacrese.pre* supplied on disk and loaded automatically when the package is installed. The remaining files in **<filename.ctl>** are created by IHACRES during its execution.

An example of a **<filename.ctl>** file (*teifi.ctl*, which is used in a worked example in Section 7) is given below. The first line is a comment and must start with a $ (it has been used here to advise against editing the file from outside the package). The second and third lines start with 5 and 6 respectively to maintain consistency with a UNIX version of IHACRES. The numbers are file reference numbers (unit numbers). The text enclosed by { } are descriptive comments.

```
$If the contents of this file are edited outside IHACRES - The model may behave unpredictably
5                                                      {KEYBOARD UNIT # (NOT FOR WINDOWS USE)}
6                                                      {SCREEN UNIT #  (NOT FOR WINDOWS USE)}
7  B E:\IHACRES\TEIFI\TEIFI.INB                        {STD INPUT FILE}
8  T E:\IHACRES\IHACRESC.PRE                           {PREFILTER FILE}
9  T E:\IHACRES\TEIFI\TEIFI.OUT                        {OUTPUT FILE}
10 T E:\IHACRES\TEIFI\TEIFI.DAT                        {DATA FILE}
31 T E:\IHACRES\TEIFI\TEIFI.TEM                        {TEMPERATURES}
32 T E:\IHACRES\TEIFI\TEIFI.SIM                        {SIMULN PREFILTS}
33 T E:\IHACRES\TEIFI\TEIFI.SUM                        {SUMMARY FILE}
20 T E:\IHACRES\TEMP\IHACRES.ROB                       {OBSERVED RAIN}
21 T E:\IHACRES\TEMP\IHACRES.REF                       {EFFECTIVE RAIN}
22 T E:\IHACRES\TEMP\IHACRES.FOB                       {OBSERVED FLOW}
23 T E:\IHACRES\TEMP\IHACRES.FEF                       {MODELLED FLOW}
24 T E:\IHACRES\TEMP\IHACRES.IUH                       {UNIT HYDROGRAPHS}
25 T E:\IHACRES\TEMP\IHACRES.UHQ                       {QUICK UH}
26 T E:\IHACRES\TEMP\IHACRES.UHS                       {SLOW UH}
41 B E:\IHACRES\TEMP\IHACRES.UHB                       {TIME BASE FILE}
42 B E:\IHACRES\TEMP\IHACRES.UQB                       {UH BINARY FILE}
43 B E:\IHACRES\TEMP\IHACRES.USB                       {QUICK UH BINFILE}
44 B E:\IHACRES\TEMP\IHACRES.QCK                       {SLOW UH BINFILE}
45 B E:\IHACRES\TEMP\IHACRES.SLW                       {QUICK FLOW BF}
```

## 5.2 Error and warning messages

If any of the files <**filename.inb**>, <**filename.dat**> or <**filename.tem**> are not available a warning message will be displayed. A possible cause of a file not being available is that the path in <**filename.ctl**> is wrong or not present. A similar message will appear if the path for the remaining files is illegal.

## 5.3 The CTL editor

It is advisable to use the CTL file editor to edit <**filename.ctl**>. The editor will display a dialogue box (Figure 12) containing 6 fields. These fields include <**filename.inb**>, <**filename.dat**>, <**filename.tem**>, <**filename.sim**>, <**filename.out**> and <**filename.sum**> and their appropriate paths. An appropriate file name and path can be entered into each field or a standard name and path selected using the button to the right of each of the fields. The **Save** and **SaveAs** facilities save the settings in the current <**filename.ctl**> file or into any other named <**filename.ctl**> file respectively. The contents and format of these files are described in later sections.

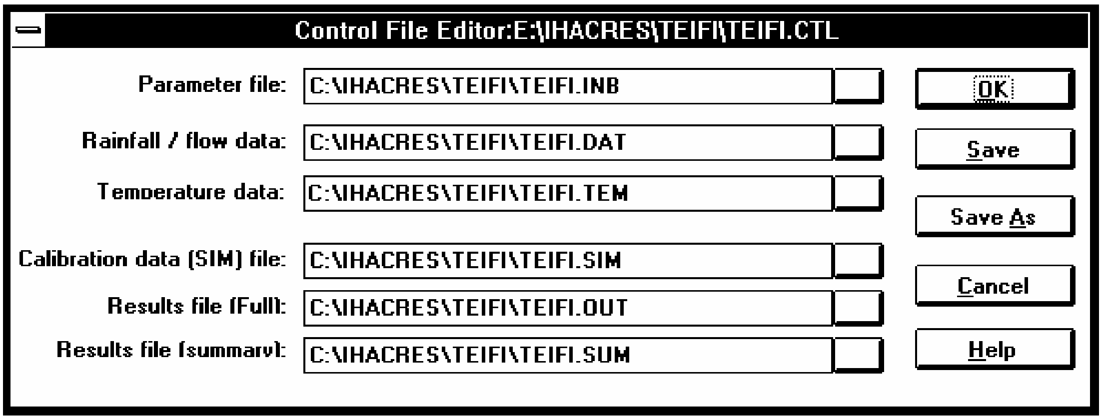
Control File Editor:E:\IHACRES\TEIFI\TEIFI.CTL
Parameter file:
C:\IHACRES\TEIFI\TEIFI.INB
Rainfall / flow data:
C:\IHACRES\TEIFI\TEIFI.DAT
Temperature data:
C:\IHACRES\TEIFI\TEIFI.TEM
Calibration data (SIM) file:
C:\IHACRES\TEIFI\TEIFI.SIM
Results file (Full):
C:\IHACRES\TEIFI\TEIFI.OUT
Results file (summary):
C:\IHACRES\TEIFI\TEIFI.SUM
OK
Save
Save As
Cancel
Help

***Figure 12***

# 6. INPUT AND OUTPUT FILES

## 6.1 Field-data files

The only field-data required are observed basin rainfall and streamflow in <**filename.dat**>, and air temperature (or some other surrogate variable to account for evapotranspiration effects) in <**filename.tem**>. It is possible to run the program without temperature data – see the Nant y Gronwen tutorial in Section 7.1.

### 6.1.1 Observed rainfall and streamflow (<filename.dat>)

Observed rainfall and streamflow are read as the first and second columns respectively of **<filename.dat>**. The example data shown below are from **<gronwen.dat>**. In this case both rainfall and flow are in millimetres and the data are hourly. The program reads the data in 'free format', so the only requirement is that there is at least one space between the rain and flow values in each row. The program reads the first two columns only, so **<filename.dat>** can contain further information in third, fourth, etc. columns which may help the operator to identify the data. For example, in **<teifi.dat>** supplied with the package there are three additional columns: the third column indicates the number of raingauges which were employed to calculate basin rainfall on any given day; the fourth column is day number within the year; and the fifth column is the year.

```
0.0    7.9
0.0    8.6
0.0    7.6
0.0    7.9
0.0    7.6
0.4    7.9
3.6   13.7
5.6   71.8
2.4  113.7
1.6  116.3
2.2  116.3
2.4  152.1
0.6  124.0
0.4  113.7
0.0   91.6
0.0   72.6
0.0   59.1
0.0   51.8
0.0   46.0
0.0   41.7
0.0   34.6
```

### 6.1.2 Observed air temperature (or pan evaporation, etc.) <filename.tem>

The following monthly air temperatures (first column, $^{o}$C) are from <**teifi.tem**> supplied with the package. The program reads from the first column only, so additional columns may be used for other information. In this case, row number, month and year appear in the second, third and fourth columns respectively.

| | | | |
|---|---|---|---|
| 3.18 | 1 | 1 | 1961 |
| 6.18 | 2 | 2 | 1961 |
| 6.98 | 3 | 3 | 1961 |
| 8.72 | 4 | 4 | 1961 |
| 9.70 | 5 | 5 | 1961 |
| 12.54 | 6 | 6 | 1961 |
| 13.40 | 7 | 7 | 1961 |
| 14.04 | 8 | 8 | 1961 |
| 13.74 | 9 | 9 | 1961 |
| 9.70 | 10 | 10 | 1961 |
| 5.74 | 11 | 11 | 1961 |
| 1.80 | 12 | 12 | 1961 |
| 4.04 | 13 | 1 | 1962 |
| 3.94 | 14 | 2 | 1962 |
| 1.94 | 15 | 3 | 1962 |
| 6.38 | 16 | 4 | 1962 |
| 8.80 | 17 | 5 | 1962 |
| 12.02 | 18 | 6 | 1962 |
| 13.30 | 19 | 7 | 1962 |
| 12.86 | 20 | 8 | 1962 |
| 11.56 | 21 | 9 | 1962 |

If a surrogate for evapotranspiration effects is employed other than air temperature, it may be necessary to first apply a scaling factor to those data externally such that the selected value for the reference temperature $R$ in equation (16) is still appropriate (see Section 4.3.6.2, **Setup - Run time options**, and Section 7.1.3).

## 6.2 Input file <*filename.inb*>

When the operator follows the **Configure-Setup** sequence (Section 4.3.6), a binary file <**filename.inb**> is created. The operator needs only to ensure that this file (as named in the <*.**ctl**> file) is accessible before executing a model calibration or simulation. Because it is a binary file it cannot be viewed in the normal way.

## 6.3 Summary of results <*filename.sum*>

The example below is <**teifi.sum**> corresponding to a tutorial given in Section 7.2 where 'linear structure' is set to 'Two in parallel' (option C).

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\TEIFI\TEIFI.SUM
DATE     : 05/12/1996
TIME     : 13:16:06
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 7877 to 8976(1100), Subints= 1,Time Delay= 1
   f    TauW   %Run    D    Bias    x1     u1   %ARPE   1/c    Tq     Ts     Vs
  1.00    4    66.70
  1.00    4    66.70 .868   -.84  163.4  -20.9    .05   75.9 2.17  38.69  .510
  1.00    6    66.70
  1.00    6    66.70 .877   -.57  147.0  -18.2    .04  104.5 2.41  41.37  .424
  1.00    8    66.70
  1.00    8    66.70 .881   -.38  170.2  -20.6    .03  132.1 2.66  42.96  .354
  1.00   10    66.70
  1.00   10    66.70 .882   -.22  188.1  -22.3    .03  158.9 2.87  43.05  .297
  1.00   12    66.70
  1.00   12    66.70 .882   -.08  188.1  -21.8    .03  185.0 3.06  40.54  .251
  1.00   14    66.70
  1.00   14    66.70 .881    .09  114.8  -12.2    .03  210.2 3.15  32.12  .229
  1.00   16    66.70
  1.00   16    66.70 .878    .71  -15.0    4.8   4.86  234.8  .87   5.47  .872
```

The column headings in <*.sum> refer to:

| | |
|---|---|
| f | Temperature modulation factor (*f*) in equation (16) |
| TauW | Catchment drying time constant ($\tau_w$) in equation (16) |
| %Run | {Streamflow volume/rainfall volume} x 100% over selected period. |
| D | Coefficient of determination |
| Bias | Mean of model residuals |
| x1 | cross correlation coefficient between model residuals and modelled streamflow |
| u1 | cross correlation coefficient between model residuals and effective rainfall |
| %ARPE | percentage average relative parameter error (linear module) |
| 1/c | Reciprocal of *C* in equation (15). (*C* is the volume-forcing constant) |
| Tq | $\tau_q$ in equation (8) |
| Ts | $\tau_s$ in equation (9) |
| Vs | $\upsilon_s$ in equation (11) |

## 6.4 Full report <*filename.out*>

The following is the full output report for the Teifi <**teifi.out**> corresponding to a catchment drying time constant ($\tau_w$) and a temperature modulation factor ($f$) of 6 days and 1.4 respectively, as discussed in a tutorial given later in Section 7.2.

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\TEIFI\TEIFI.OUT
DATE     : 23/01/1997
TIME     : 14:33:47
CONTAINS : Model output information.


Run Option     : 3
Method         : Simple Refined IV
# Experiments  : 1


REAL DATA
Subperiod           :     1
# Samples           :  1100
Interval            :     1
Starting Position   :  7877

PREFILTER INFORMATION
All prefilters used?          : NO
Maximum Number Prefilters     :  5


RAINFALL FILTER AND SCALING INFORMATION
Used?             :        YES
Lower Bound       :          6
Upper Bound       :          6
Increment         :          1
Initial Condition :         .0
Scale Factor      :       10.3


Monthly Temperatures are being used.
First Temperature Date     :  1/1961
First Rainfall Date        :  1/ 1/1961

TEMPERATURE MODULATION FACTOR(f) INFORMATION
Used?               :    YES
Lower Bound         :   1.40
Upper Bound         :   1.40
Increment           :  1.000


CALCULATION INFORMATION
Time Delay      :    1
Iterations      :   10
Means           :    N
Least Squares   :    Y
Plots           :    Y
```

```
Reference Temperature =  20.00


RESULTS FOR SUBPERIOD NUMBER  1
Start Date                  : 26/ 7/1982
Number of Days              :          29
End Date                    : 30/ 7/1985
Number of Remaining Months :          36

FIRST 20 DATA VALUES FOR DATA CHECKING
  Temperature       Rainfall
    14.56000          .00000
    14.56000          .00000
    14.56000          .00000
    14.56000          .00000
    14.56000          .00000
    14.56000         2.50000
    13.96000          .90000
    13.96000         5.20000
    13.96000          .00000
    13.96000          .70000
    13.96000         1.60000
    13.96000          .10000
    13.96000          .00000
    13.96000          .00000
    13.96000          .20000
    13.96000         3.40000
    13.96000          .10000
    13.96000         7.80000
    13.96000        15.30000
    13.96000         2.10000


BASE FLOW INDEX FOR OBSERVED STREAMFLOW =    .56



 Temperature modulation factor (f) =  1.40
 Time constant of rainfall filter (tau w)=      6

Subinterval   Percentage (of rain) runoff   Percentage Yield
      1                66.7040                     .6670
     ALL               66.7040                     .6670

Iter        A(1)         A(2)       B(0)        B(1)        D
   0      -1.9500       .9025       .0000       .0000       .0000
   1        .0000       .0000       .0000       .0000       .0000
 PROBLEM ON ITERATION NUMBER:          1

System Residuals      Mean      Median        Minimum     Maximum
Absolute Error        5.266     2.757          .000         2.090
Abs Rel Error          .294      .172          .000          .100




Iter        A(1)         A(2)       B(0)        B(1)        D
   0      -1.6000       .6400       .0000       .0000       .0000
   1      -1.7241       .7269      2.0144     -1.9890       .7933
   2      -1.6869       .6936      2.2256     -2.1551       .8468
   3      -1.6758       .6836      2.2396     -2.1590       .8822
```

```
    4      -1.6721       .6802       2.2399      -2.1558        .8825
    5      -1.6706       .6789       2.2389      -2.1536        .8825
    6      -1.6700       .6782       2.2382      -2.1523        .8825
    7      -1.6696       .6779       2.2378      -2.1516        .8826
    8      -1.6694       .6777       2.2375      -2.1512        .8826
    9      -1.6693       .6776       2.2374      -2.1510        .8826
   10      -1.6692       .6776       2.2373      -2.1509        .8826

Bias of Residuals =    .241E-01
Relative Bias     =   -.117
%(ARPE)          =       .03301


Steady State Gains
                    Quickflow   Slowflow      Total
Non-Normalized       7.080       3.286      10.366
Normalized            .683        .317       1.000

CHARATERISTIC PARAMETERS

                  Quickflow       Slowflow
Time Constants      2.7675         35.8503

Relative
Throughput           .6830           .3170
Volumes

Relative
Contribution         .9596           .0404
To IUH Peak


Maximum value of non-linear store(1/c) =   134.7608

AVERAGES  +/-  Std Devn
Obs Rainfall         3.9017 +/-     6.2012 mm
Obs Streamflow      26.9177 +/-    26.2423 cumecs
Filt Rainfall        2.6026 +/-     4.7750 mm
Mod Streamflow      26.8936 +/-    24.7653 cumecs
Obs Temperature      8.6999 +/-     4.3740 degree

TOTALS
Observed Rainfall     4291.9000   mm
Filtered Rainfall     2862.8671   mm
Observed Streamflow  29609.4680   cumecs
Modelled Streamflow  29582.9703   cumecs
```

## 6.5 Linear module (UH) parameters <filename.sim>

The content of <filename.sim> generated **by Execute model - Calibrate** depends on the configuration of linear storages prescribed in **Setup - Linear structure** for the UH part of the model. The example below corresponds to a calibration with C: 2 stores in parallel for the Teifi when the catchment drying time constant ($\tau_w$), temperature modulation factor ( $f$ ) and $\delta$ (time delay) are 6 days, 1.4 and 1 day respectively. The '2' in the first row specifies the second-order transfer function by which the configuration option C: 2 stores in parallel is represented within the package (see bibliography at Section 9 for further details).

```
2
A 1  -1.66923233
A 2    .67757448
B 0   2.23732690
B 1  -2.15085480
E
   .00742055
```

The values for A1, A2, B0 and B1 are the parameters of this second-order transfer function calculated by the program. In terms of the *a* and *b* parameters in equation (4), the parameters A1, A2, B0 and B1 can be expressed by equations (17) to (20) respectively.

$$A1 = -(a^{(s)} + a^{(q)}) \tag{17}$$

$$A2 = a^{(s)} a^{(q)} \tag{18}$$

$$BO = b^{(q)} + b^{(s)} \tag{19}$$

$$BO = -(b^{(q)} a^{(s)} + b^{(s)} a^{(q)}) \tag{20}$$

The value in the last row of <**filename.sim**> is $C$ in equation (15).

# 7. TUTORIALS

The following tutorials provide a reference for the sequence of operations to calibrate and apply models. They also cover *some* of the more subtle aspects of modelling with IHACRES. The PC Windows environment allows the operator quickly to become familiar with the functionality of the package. When the basic step-by-step sequences of operations have been learned it will be less necessary to refer to this aspect of the tutorials. The first tutorial, for the Nant y Gronwen in Wales, gives the step-by-step sequence the operator will use in most cases. Subsequent tutorials assume that the operator has become familiar with the functionality of the IHACRES PC package and *it is strongly recommended, therefore, that the tutorials are worked through in the order in which they are given before proceeding to entirely new cases.*

## 7.1 The Nant y Gronwen

Dilution gauging was employed to calibrate the streamflow gauging site for a 0.7 $km^2$ catchment of the Nant y Gronwen, an upland stream draining to Llyn Brianne, Wales. Hourly rainfall (mm) and streamflow (L/s) for the period 1 June to 18 September 1987 (the record length is 1914 hours) are supplied with PC IHACRES. During installation (see section 3), these are automatically transferred as a file *gronwen.dat* to the directory:

```
C:\IHACRES\GRONWEN\
```

Other files for the Nant y Gronwen supplied with the program are <gronwen.ctl> and <gronwen.inb>.

### 7.1.1 Selecting the appropriate Control file <filename.ctl>

Select **Configure** then **Open control file**. Select the *gronwen* directory then the *gronwen.ctl* file.

[*Note:* The Gronwen case does not use temperature data and a message will be displayed to remind the user about this. The message can be cleared by clicking on the **OK** button.]

### 7.1.2 Setting the data time step, measurement units, etc.

A dialogue box, *IHACRES Data description*, will be displayed whenever a control file is opened. This dialogue box can also be opened by selecting the menu sequence **Configure** - **Setup** - **Data description**. Set the entries in this dialogue box as follows:

**Time base (Rain & Flow):** hourly
**Rainfall units**: mm
**Streamflow units:** L/sec
**Loss module:** Filter without temperature
**Catchment area:** 0.70 $km^2$
**Start date in rain/flow file:**
    **Date:** 01/07/1987
    **Time:** 00:00

Because this dataset has no temperature data, the dialogue box areas for **Time base (temperature)** and **Start date in temperature file** will be greyed out and are not accessible to the user. The dialogue box with these entries is shown in Figure 13.

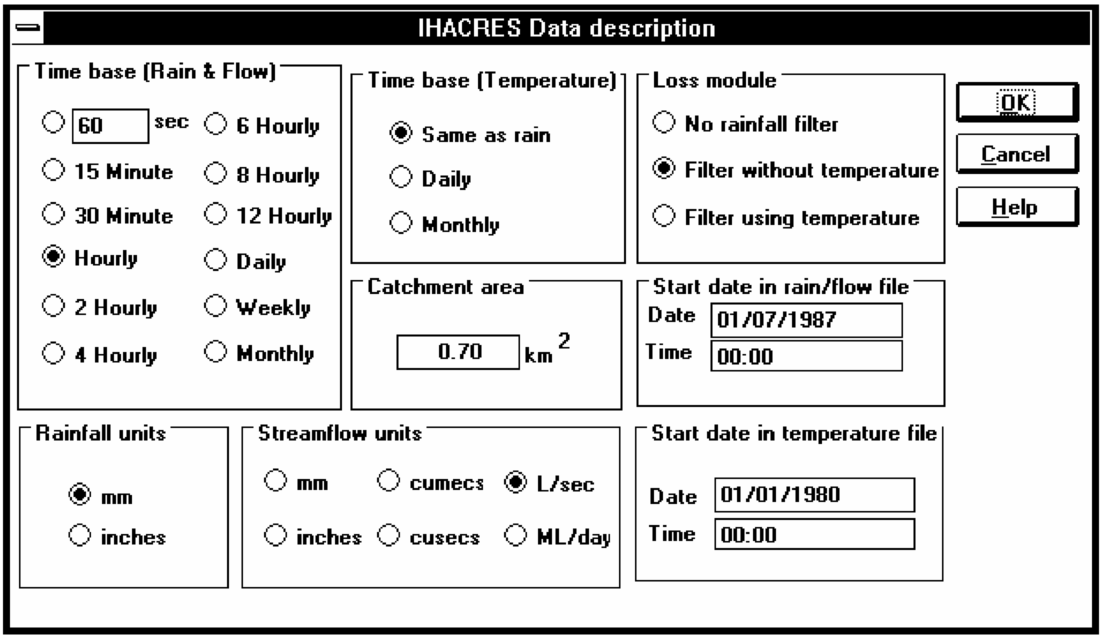


*Figure 13*

### 7.1.3 Setting the parameters in the non-linear loss module

The menu sequence **Configure - Setup - Run time** options produces the dialogue box named *IHACRES Run time options*. Set the entries in this dialogue box as follows:

**Catchment drying time constant**:
- **From:** 100
- **To:** 100
- **Using model steps of:** 1

**Time delay:** 0
**Reference temperature:** 20.00
**Use all pre filters**: Off (i.e. this box is left unchecked)
**Number of pre filters to use**: 5

These settings should be the same as those shown in Figure 14.

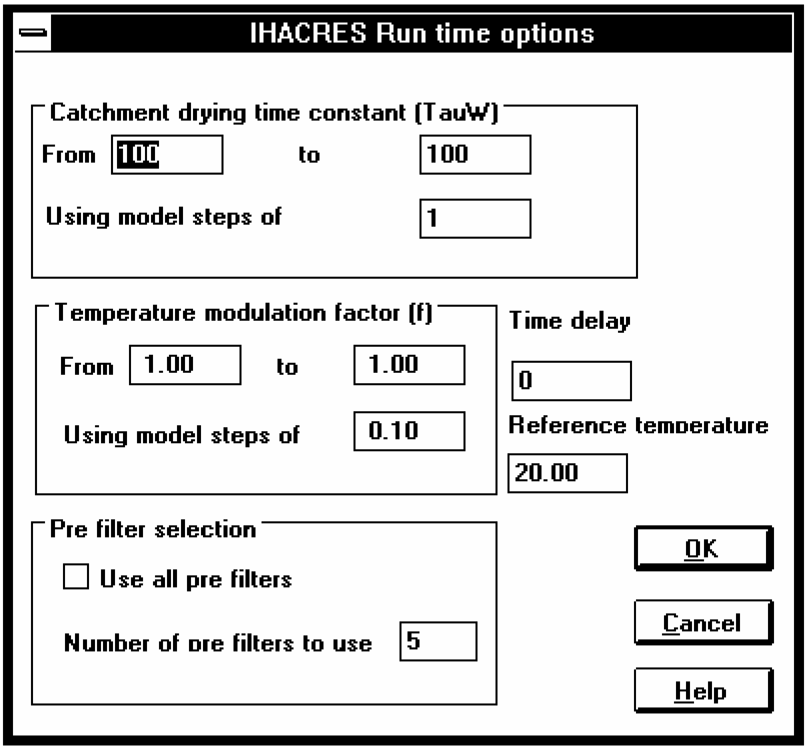


*Figure 14*

Although **Reference temperature** is not relevant to the current tutorial (temperature data are not being used and this section of the dialogue box is therefore 'greyed' out) it is used in the next tutorial (the Teifi catchment; Section 7.2)**.** The **Reference temperature** is $R$ in equation (16) and serves only to enable the input of convenient integer values of the **Catchment drying time constant** (TauW or $\tau_w$) such that the search of its parameter-space can be achieved with sufficient sensitivity using integer **steps** between the specified **From** and **to** values. This becomes clearer by referring to Figure 15 which shows two curves of $\tau_w(t_k)$ versus temperature $t_k$ according to equation (16). Each curve was derived using the same value for $f$ but a different value for $\tau_w$. The parameter $\tau_w$ is the value of $\tau_w(t_k)$ at reference temperature $R$. So, for the case shown in Figure 15, if $R$ was entered as 30°C, an integer search of the $\tau_w$ parameter-space would be more restricted – in terms of the sensitivity with which different curves could be tested – than if a value of -10°C was entered. For the next tutorial (the Teifi catchment; Section 7.2) a value of 20°C has been used but other values may be more suitable for other catchments. The value of $R$ is written to the files

**<filename.sum>** and **<filename.out>** to give a record of this and other settings.

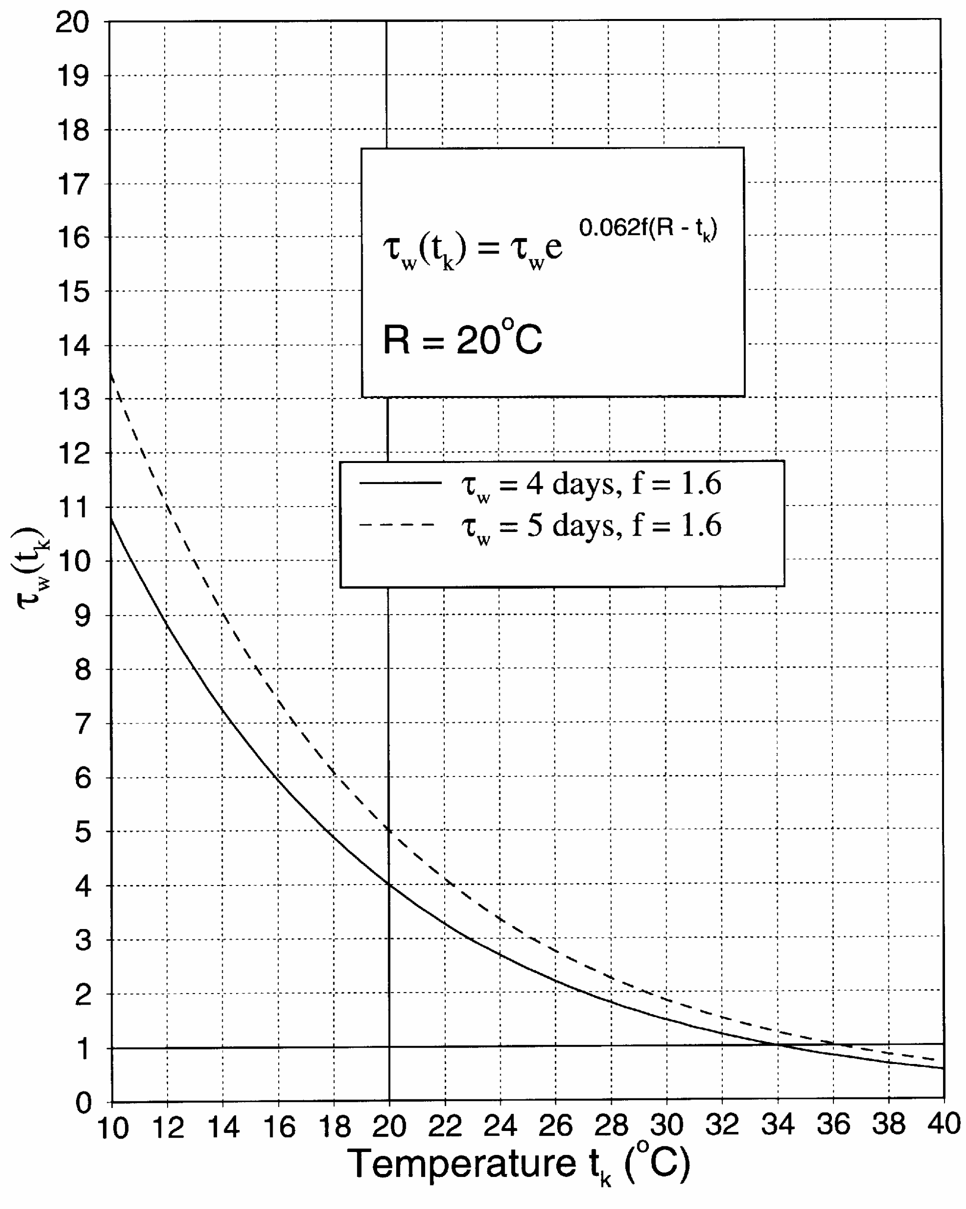


*Figure 15*

**Pre-filter selection** in **Run time options** deals with an aspect of the linear module parameter identification algorithm whereby up to five pre-filters can be used in an attempt to obtain successful convergence (the operator need not be too concerned about the exact nature of this process). When **Number of pre-filters to use** is set to *n*, and **Use all pre-filters** is switched 'off' (the default setting), if the algorithm fails to converge using the first pre-filter it tries the second, and so on until, if necessary, all *n* pre-filters have been applied. The maximum value for *n* in Version 1.0 is 5. With **Use all pre-filters** switched 'on' the program uses all *n* pre-filters, whether or not parameter convergence is successful (see Section 7.1.15 for further discussion of this facility).

### 7.1.4 Setting the sub-period of record for analysis

The menu command sequence **Configure** - **Setup** - **Subperiods** displays the dialogue box named IHACRES Subperiod selection. Set the entries in this dialogue box as follows:

> **Start date**: 01/09/1987
> **End date**: 18/09/1987
> **Start time**: 11:00
> **End time**: 17:00

The '**As file offsets**' area of this dialogue box can be ignored for the moment. The setup should look like that shown in Figure 16.

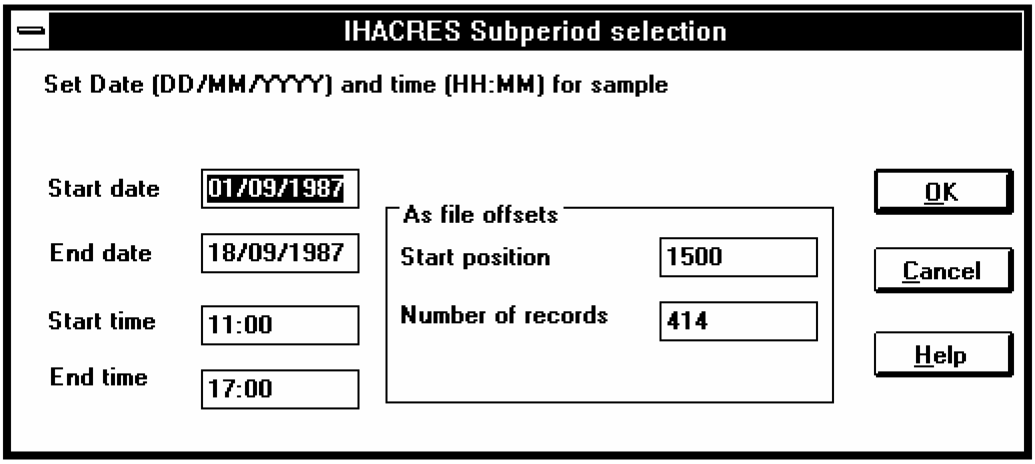


*Figure 16*

### 7.1.5 Uncertainties associated with the linear module parameters

Using the menu command sequence **Configure** - **Setup** - **Uncertainty analysis**, check that the setting is 'Off (default)'.

### 7.1.6 Selecting the configuration of linear UH storages

Using the menu command sequence, **Configure** - **Setup** - **Linear structure**, check that the setting is 'C: 2 stores in parallel'.

### 7.1.7 Saving any changes which have been made in steps 7.1.2 to 7.1.6

Save the configuration and other settings made in 7.1.2 to 7.1.6 by using the menu command sequence **Configure - Save**.

### 7.1.8 To calibrate a model

The model can now be calibrated by using the menu command sequence **Execute model** - **Calibrate**. After about 30 seconds (the time varies with type of PC being used) the summary file **<gronwen.sum>** should appear on the screen. Check the results of this file against those in Figure 17.

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\GRONWEN\GRONWEN.SUM
DATE     : 28/10/1996
TIME     : 14:16:06
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 1500 to 1913( 414), Subints= 1,Time Delay= 0
   f    TauW   %Run    D    Bias    x1     u1  %ARPE   1/c   Tq    Ts    Vs
  1.00  100    53.15
  1.00  100    53.15 .950   -.60 1691.8  -11.6   .02   39.6 4.29  75.52  .608
```

*Figure 17*

### 7.1.9 To see plots

Plots can be viewed by selecting commands from the **Plot** menu. Here are three examples:

**(a)** Select **Plot** - **Model results** - **Modelled & Observed streamflow** - **Plot**. A dialogue box, *IHACRES Time series plot*, allows the operator to change the default plot title and axis labels, and to select the 'file offset' x-axis annotation style rather than the calendar date style. The default setting will produce the plot shown in Figure 18. This sequence can be repeated as often as wished.

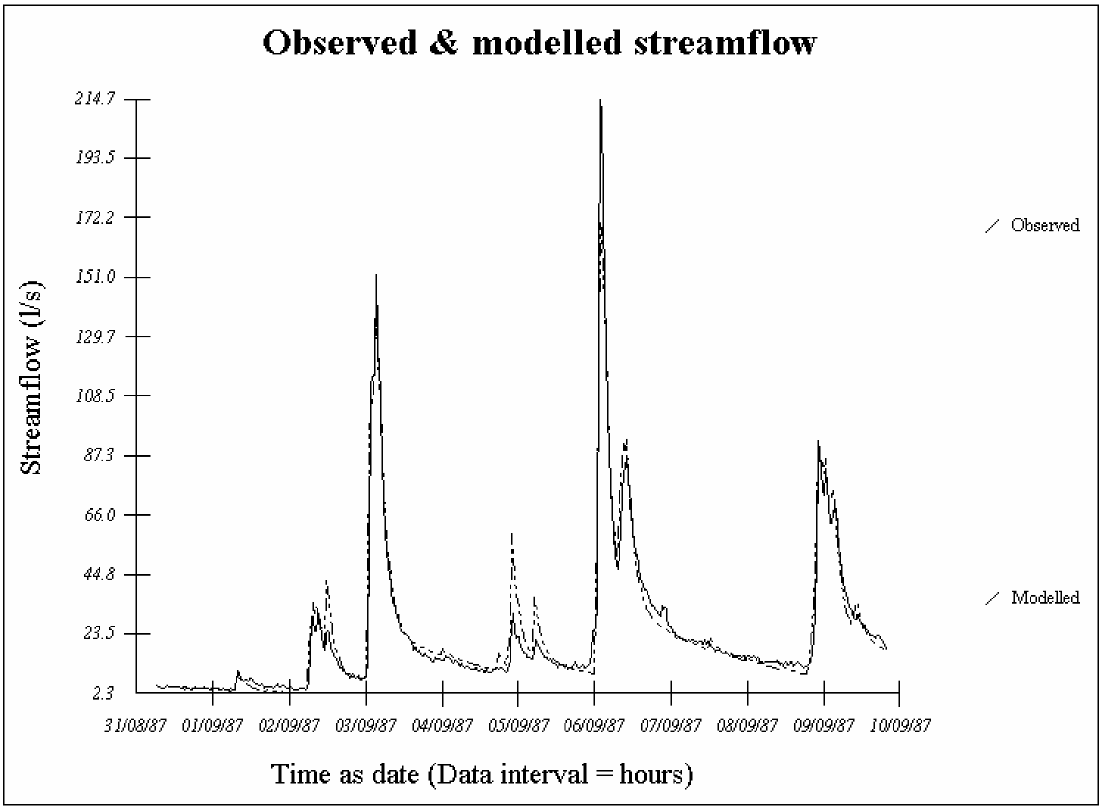


*Figure 18*

(b) The similar procedure, **Plot - Hydrographs - Total & quick & slow,** will produce the plot shown in Figure 19. (Note that the **Hydrograph type** in this dialogue box defaults to **Plot hydrographs**.)

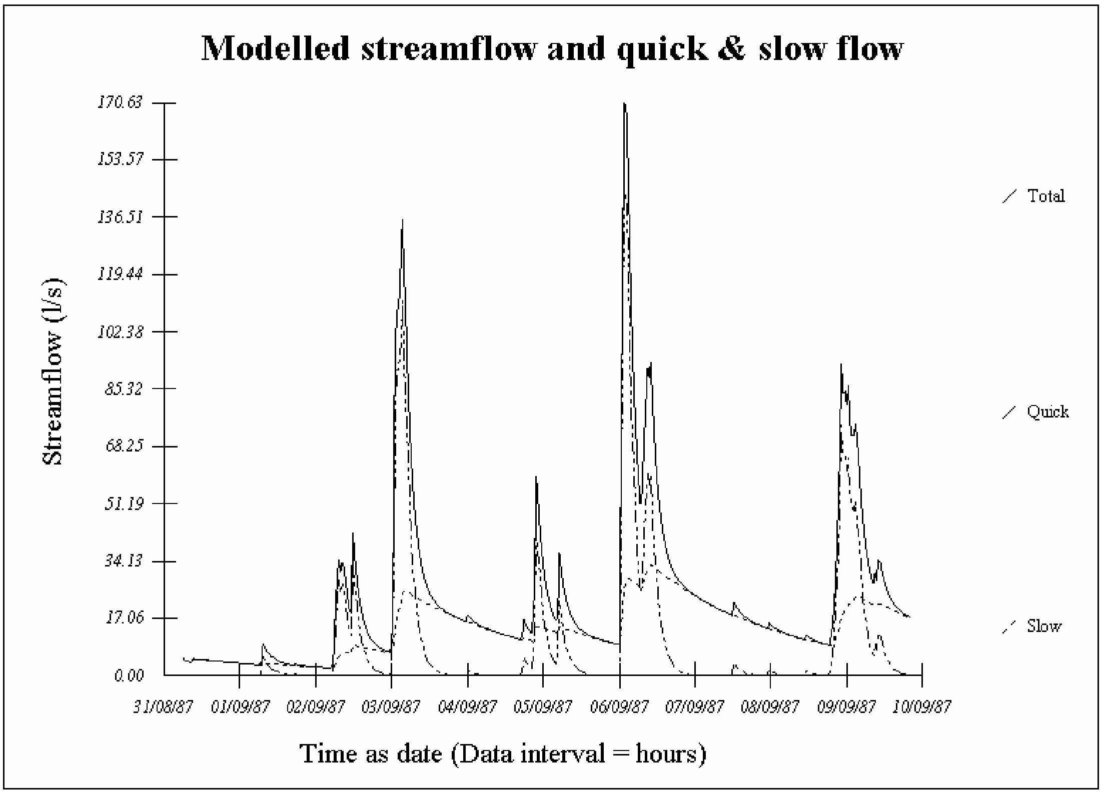


*Figure 19*

(c) Repeat the last procedure, **Plot - Hydrographs - Total & quick & slow,** but select **Plot unit hydrograph** instead of **Plot hydrographs** under **Hydrograph type**. The plot shown in Figure 20 should appear.

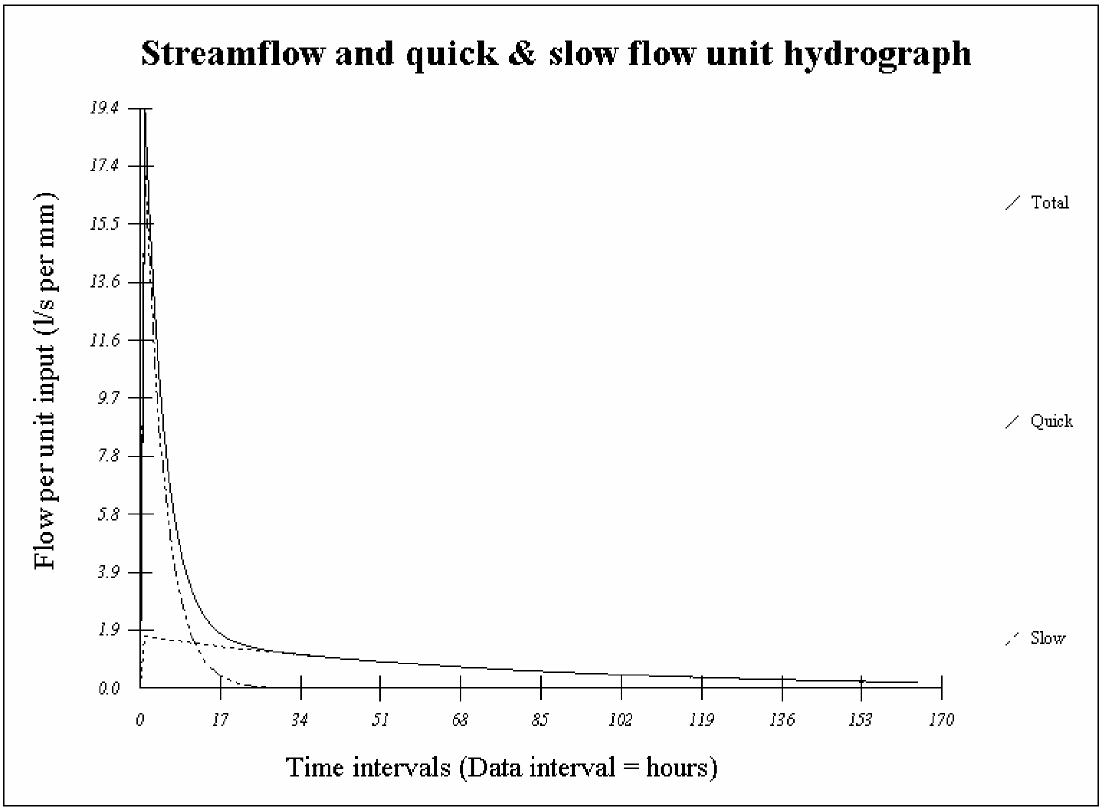


*Figure 20*

There are more than 20 sub-options under **Plot**. The operator can try them all, changing the plot title, axis labels and x-axis time annotation style as wished.

### 7.1.10 To inspect the contents of the main results file (*gronwen.out*)

Select **File** then **Open**. Change **.dat* to **.out*, select *gronwen* then *gronwen.out*. The file **<gronwen.out>** records the details and full results of the analysis which has just been undertaken. In this tutorial (where, so far, only a single value for the catchment drying time constant, $\tau_w$, of 100 hours has been prescribed and effectively there is no temperature modulation factor, *f*) the file **<gronwen.out>** is fairly small.

(For large ranges of both the catchment drying time constant ($\tau_w$) and the temperature modulation factor (*f*), with small steps specified, <filename.out> would become very large and it is unlikely that the operator would be very interested in it – the interest would be in scanning the **<filename.sum>** file (see the Teifi tutorial in Section 7.2). A limit has been set, therefore, such that the main results listings for no more than five catchment drying time constant and temperature modulation factor pairs ($\tau_w$, *f*) appear in **<filename.out>**. A message to this effect is written to that file when appropriate).

The operator should scan **<gronwen.out**> and note the similarities with the contents of the file <teifi.out> given in Section 6.4. Much of the file is self-explanatory, and that which is not immediately meaningful to the operator is not important at this stage on the IHACRES learning-curve. The file **<gronwen.sum>** (see 7.1.8) is a subset of **<gronwen.out>**. Information in **<gronwen.out>** but not in **<gronwen.sum>** which the operator might like to identify is as follows.

Base Flow Index BFI = 0.58. This is BFI calculated by the method given in Institute of Hydrology Report 108.

The non-normalised Steady State Gains (SSGs) for quick flow, slow flow and total streamflow are 84.9, 131.6 and 216.5. Note that a Slow Flow Index SFI, analogous to BFI is given by the non-normalised slow flow SSG divided by the corresponding total flow SSG (in this case 131.6/216.5) – and that this appears as the normalised slow flow SSG and 'Relative throughput volume' for slow flow in **<gronwen.out>** and as 'Vs' in **<gronwen.sum>** (in this case SFI = Vs = 0.608). 'Vs' corresponds to $\nu^{(s)}$ - see equation (11) in Section 2.1.1. *The total normalised SSG in the <filename.out> should always be unity – if it is not, there is something wrong.*

Over the model calibration period:

| | |
|---|---|
| average rainfall | = 0.23 mm/hr |
| average observed streamflow | = 23.4 L/s |
| average modelled streamflow | = 24.0 L/s |

bias of the residuals[1] = -0.596

### 7.1.11 Applying the model in simulation-mode

To run the model which has just been calibrated, but in simulation mode over the whole period 1 July to 19 September 1987, select **Configure** - **Setup** - **Subperiods**. In the 'As file offsets' area of the dialogue box, change '414' to '1914' and '1500' to '1'. Then **Save** followed by **Execute** - **Simulate**. Use **Plot** to view the results. The operator can try model simulations over different subperiods by changing the entries in **Subperiods** as required.

### 7.1.12 To investigate the effect of non-zero pure time delay (parameter $\delta$)

First, re-calibrate the model using the following settings in **Configure - Setup** (as in 7.1.3 and 7.1.4):

**<u>Data description</u>**

- **Time base (Rain & Flow):** hourly
- **Rainfall units**: mm
- **Streamflow units:** L/sec
- **Loss module:** Filter without temperature
- **Catchment area:** 0.70 km$^2$
- **Start date in rain/flow file:**
  - **Date:** 01/07/1987
  - **Time:** 00:00

**<u>Run time options</u>**

- **Catchment drying time constant**:
  - **From:** 100
  - **To:** 100
  - **Using model steps of:** 1
- **Time delay:** 0
- **Reference temperature:** 20.00
- **Use all pre filters**: Off (i.e. this box is left unchecked)

[1]This appears as -0.6 in **<gronwen.sum>.**

**Number of pre filters to use**: 5

**Subperiods**

**Start date**: 01/09/1987
**End date**: 18/09/1987
**Start time**: 11:00
**End time**: 17:00

**Uncertainty analysis**

**Off**

**Linear Structure**

**C: 2 stores in parallel**

Repeat the calibration procedure with Time delay ($\delta$) in **Run time options** set to 1 then 2, then 3. The values for *D* and percentage average relative parameter error (*%ARPE*) obtained should be as follows.

| Pure time delay $\delta$ (hours) | **D** | **Bias** | **%ARPE** |
|---|---|---|---|
| 0 | 0.950 | -0.60 | 0.02 |
| 1 | 0.943 | -0.13 | 0.03 |
| 2 | 0.822 | 0.54 | 0.19 |
| 3 | - | - | - |

Note that the parameters in the linear module do not converge for $\delta = 3$ hours; a blank line appears in **<gronwen.sum>** and inspection of **<gronwen.out>** shows that the parameter convergence failed for each of the five pre-filters applied. Clearly, for the Nant y Gronwen, the best combination of a high coefficient of determination *D* and a low percentage average relative parameter error *%ARPE* is for $\delta = 0$.

### 7.1.13 To confirm that a best value of the loss module parameter catchment drying time constant ($\tau_w$) is about 100 hours

From the **Configure - Setup** menu, set the model parameters as follows:

**<u>Data description</u>**

**Time base (Rain & Flow):** hourly
**Rainfall units**: mm
**Streamflow units:** L/sec
**Loss module:** Filter without temperature
**Catchment area:** 0.70 km$^2$
**Start date in rain/flow file:**
  **Date:** 01/07/1987
  **Time:** 00:00

**<u>Run time options</u>**

**Catchment drying time constant** (TauW or $\tau_w$):
  **From:** 70
  **To:** 130
  **Using model steps of:** 5
**Time delay** *(*$\delta$**:** 0
**Reference temperature:** 20.00
**Use all pre filters**: Off (i.e. this box is left unchecked)
**Number of pre filters to use**: 5

**<u>Subperiods</u>**

**Start date**: 01/09/1987
**End date**: 18/09/1987
**Start time**: 11:00
**End time**: 17:00

**<u>Uncertainty analysis</u>**

**Off**

**<u>Linear Structure</u>**

**C: 2 stores in parallel**

Then **Execute - Calibrate**. The resultant file **<gronwen.sum>** should be as follows:

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\GRONWEN\GRONWEN.SUM
DATE     : 15/01/1997
TIME     : 14:24:56
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 1500 to 1913( 414), Subints= 1,Time Delay= 0
   f    TauW   %Run    D    Bias    x1      u1  %ARPE   1/c   Tq    Ts     Vs
  1.00   70    53.15
  1.00   70    53.15 .943  -1.46 7113.7  -50.2   .02   32.6 4.76 119.99  .614
  1.00   75    53.15
  1.00   75    53.15 .946  -1.24 5314.0  -34.9   .02   33.8 4.50 115.68  .617
  1.00   80    53.15
  1.00   80    53.15 .947  -1.09 4149.0  -27.2   .02   35.1 4.46 104.91  .614
  1.00   85    53.15
  1.00   85    53.15 .948   -.95 3270.1  -21.7   .02   36.3 4.42  94.61  .610
  1.00   90    53.15
  1.00   90    53.15 .947   -.58 -823.4    5.6   .02   37.4 4.30  86.13  .598
  1.00   95    53.15
  1.00   95    53.15 .950   -.62 1065.5   -5.8   .02   38.5 4.27  78.42  .612
  1.00  100    53.15
  1.00  100    53.15 .950   -.60 1691.8  -11.6   .02   39.6 4.29  75.52  .608
  1.00  105    53.15
  1.00  105    53.15 .950   -.50 1409.5   -9.8   .02   40.7 4.26  71.44  .608
  1.00  110    53.15
  1.00  110    53.15 .949   -.42 1204.2   -8.5   .02   41.7 4.22  68.04  .609
  1.00  115    53.15
  1.00  115    53.15 .949   -.34 1053.4   -7.6   .02   42.7 4.20  65.23  .610
  1.00  120    53.15
  1.00  120    53.15 .948   -.27  942.6   -7.0   .02   43.6 4.17  62.89  .611
  1.00  125    53.15
  1.00  125    53.15 .946   -.21  861.3   -6.5   .02   44.6 4.15  60.94  .612
  1.00  130    53.15
  1.00  130    53.15 .945   -.15  802.5   -6.2   .03   45.4 4.12  59.28  .613
```

In this case, it is evident that the goodness of model-fit, in terms of a trade-off between a high value for *D* and a low value percentage average relative parameter error (*%ARPE*), is fairly insensitive to changes in the catchment drying time constant ($\tau_w$) in the non-linear loss module. A value for the catchment drying time constant ($\tau_w$) of about 100 hours seems appropriate. Note that low absolute values of bias and *x1* and *u1*[2] are also desirable features of a good model but

[2] *x1* is the cross correlation coefficient between model residuals and modelled streamflow, and *u1* is the cross correlation coefficient between model residuals and effective rainfall.

minima of these do not occur at the same value of catchment drying time constant, $\tau_w$, (i.e., about 100 hours) selected on the basis of the trade-off between a high value for *D* and low value for the percentage average relative parameter error (*%ARPE*). This illustrates a problem in selecting optimal model-fits; it is unusual for all of the desirable statistical features of a good model to occur at the same value of catchment drying time constant, $\tau_w$, or at a single pair of values for $\tau_w$ and temperature modulation factor (*f*) when more complex loss modules are prescribed (see the Teifi tutorial, Section 7.2). Final selection of a best model to use for any application is greatly facilitated by visual inspection of model-fit plots and must always be the responsibility of the user.

### 7.1.14 To investigate other configurations of simple UHs in the linear module

So far in this tutorial, the operator has used option C in **Configure - Setup - Linear structure**, i.e., ‘C: 2 stores in parallel’. Now, use **Configure - Setup** to set the model parameters as follows:

<u>**Data description**</u>

**Time base (Rain & Flow):** hourly
**Rainfall units**: mm
**Streamflow units:** L/sec
**Loss module:** Filter without temperature
**Catchment area:** 0.70 km$^2$
**Start date in rain/flow file:**
  **Date:** 01/07/1987
  **Time:** 00:00

<u>**Run time options**</u>

**Catchment drying time constant**:
  **From:** 100
  **To:** 100
  **Using model steps of:** 1
**Time delay:** 0
**Reference temperature:** 20.00
**Use all pre filters**: Off (i.e. this box is left unchecked)

**Number of pre filters to use**: 5

**Subperiods**

**Start date**: 01/09/1987
**End date**: 18/09/1987
**Start time**: 11:00
**End time**: 17:00

**Uncertainty analysis**

**Off**

Now, in **Configure - Setup - Linear structure**, select 'A: Single store' then **Execute model - Calibrate**. Repeat using 'B: 2 stores in series' and 'C: 2 stores in parallel' (it will take only a short time to repeat this configuration setting). The results should be as follows.

### A: Single store

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\GRONWEN\GRONWEN.SUM
DATE     : 01/11/1996
TIME     : 12:34:19
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 1500 to 1913( 414), Subints= 1,Time Delay= 0
   f    TauW   %Run    D    Bias    x1     u1  %ARPE  T.C.   A1   B0  Const
  1.00  100    53.15
  1.00  100    53.15 .819   5.50    9.0     .0   .02  8.87 -.893 *****  .025
```

### B: 2 stores in series

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\GRONWEN\GRONWEN.SUM
DATE     : 01/11/1996
TIME     : 12:44:38
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 1500 to 1913( 414), Subints= 1,Time Delay= 0
   f    TauW   %Run    D    Bias    x1     u1  %ARPE   1/c   TC1   TC2
  1.00  100    53.15
  1.00  100    53.15        ONE OF THE TIME CONSTANTS IS NEGATIVE
```

## C: 2 stores in parallel

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\GRONWEN\GRONWEN.SUM
DATE     : 01/11/1996
TIME     : 12:50:09
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 1500 to 1913( 414), Subints= 1,Time Delay= 0
   f    TauW   %Run    D    Bias    x1      u1  %ARPE   1/c    Tq    Ts    Vs
  1.00  100    53.15
  1.00  100    53.15 .950   -.60 1691.8  -11.6    .02   39.6 4.29  75.52  .608
```

Note the message written to the file **<gronwen.sum>** for option **B: 2 stores in series**, "ONE OF THE TIME CONSTANTS IS NEGATIVE", indicating that this model is conceptually unacceptable. When this occurs the model-fit statistics are not written to the **<*.sum>** file − in order to discourage their use. However, values for *D*, bias, etc. can be obtained from the file **<*.out>** in such cases (e.g., *D* = 0.821 for the Nant y Gronwen case). In summary, therefore, the result of this exercise is as follows.

| Linear structure | | D | Bias | %ARPE |
|---|---|---|---|---|
| A: | Single | 0.819 | 5.50 | 0.02 |
| B: | 2 stores in series | 0.821 | 5.33 | 21.7 |
| C: | 2 stores in parallel | 0.950 | -0.60 | 0.02 |

Clearly, in terms of a best trade-off between a high *D* and a low percentage average relative parameter error (*%ARPE*), option 'C: 2 stores in parallel' is the best configuration for the Nant y Gronwen.

### 7.1.15 Checking the convergence of linear module parameters

As mentioned in Section 7.1.3, when **Use all pre-filters** in **Configure - Setup - Run time options** is switched 'On', the package will run the parameter convergence algorithm *n* times – irrespective of success or failure. Perform an **Execute - Calibrate** again with the following settings, as in the previous exercise but with **Linear structure** set to 'C: 2 stores in parallel' and **Use all pre-filters** set to 'On':

**Data description**

**Time base (Rain & Flow):** hourly
**Rainfall units**: mm
**Streamflow units:** L/sec
**Loss module:** Filter without temperature
**Catchment area:** 0.70 $km^2$
**Start date in rain/flow file:**
  **Date:** 01/07/1987
  **Time:** 00:00

**Run time options**

**Catchment drying time constant**:
  **From:** 100
  **To:** 100
  **Using model steps of:** 1
**Time delay:** 0
**Reference temperature:** 20.00
**Use all pre filters**: On
**Number of pre filters to use**: 5

**Subperiods**

**Start date**: 01/09/1987
**End date**: 18/09/1987
**Start time**: 11:00
**End time**: 17:00

**Uncertainty analysis**

**Off**

**Linear structure**

**C: 2 stores in parallel**

The following **<gronwen.sum>** file should be generated, indicating that parameter convergence in the linear module was successful for two of the five pre-filters tried – with encouragingly very good agreement. If, when this procedure is performed for any other cases, quite different results are obtained for different pre-filters, it indicates that the parameter convergence may not be reliable. For the current Nant y Gronwen case, now look in **<gronwen.out>** to see the history of the successful and unsuccessful parameter convergences for the five different pre-filters.

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\GRONWEN\GRONWEN.SUM
DATE     : 01/11/1996
TIME     : 12:54:41
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 1500 to 1913( 414), Subints= 1,Time Delay= 0
   f    TauW   %Run    D    Bias    x1     u1  %ARPE   1/c   Tq    Ts    Vs
  1.00  100    53.15
  1.00  100    53.15 .950   -.60 1691.8  -11.6   .02   39.6 4.29  75.52  .608
  1.00  100    53.15 .950   -.64 2279.1  -15.4   .02   39.6 4.28  75.10  .610
```

The fact that, in the Nant y Gronwen case, only two of the five pre-filters give successful parameter convergence, points to the inherent difficulty of the numerical problem of finding a good model-fit where the underlying mechanism is conceptualised as a mixed exponential decay, quick and slow, response. In subsequent releases of PC IHACRES more pre-filters may be provided in order to deal with difficult cases.

### 7.1.16 Using 'pre filter selection' in simulation mode

**NB**. When running the package in simulation mode with **Use all pre filters** switched on, care must be taken to ensure that **Number of pre filters to use** is not greater than the number of sets of model parameters in the file <**name.sim**> (<**gronwen.sim**> in this case).

Otherwise a message "F6405 ... external I/O illegal beyond end of file" will appear and the program will abort when the user clicks on the **OK** button. It is recommended, therefore, that the model which the operator wants to run in simulation mode is calibrated immediately before the simulation run with **Number of pre filters to use** set to 5 and **Use all pre filters** switched off (the default mode). This will ensure that only one set of model parameters is written to <**name.sim**> and the program is ready to run in simulation mode over a specified subperiod without having to change the settings in **Pre filter selection**.

## 7.2 The Teifi at Glan Teifi

### 7.2.1 The catchment

The Teifi at Glan Teifi is a rural catchment (893.6 km$^2$) in Wales which exhibits an essentially natural flow regime at its outlet. Streamflow is measured by the velocity-area method at a gauging station maintained and operated by the UK Environment Agency. When PC IHACRES is installed (Section 3) a file containing daily mean streamflows for the Teifi (from the National River Flow Archive maintained by the Institute of Hydrology) is automatically created on the user's hard disk as C:\IHACRES\TEIFI*teifi.dat*. File **<teifi.dat>** also contains daily catchment (areal) rainfall and covers the period 1 January 1961 to 31 December 1989. The basin rainfall was calculated from between 8 and 21 sites in and around the catchment – the number varying as different raingauges were in operation through time. Another file, **<teifi.tem>**, containing representative monthly air temperatures is also transferred automatically when IHACRES is installed. The temperatures in **<teifi.tem>** were calculated from values for five 40 km by 40 km cells covering the catchment.

The Teifi tutorial is different to the Nant y Gronwen case study in that it employs the full non-linear loss module given by equations (14) to (16), i.e., there are two parameters in the non-linear loss module, rather than just one, to be optimised by trial-and-error. These two parameters are the catchment drying time constant ($\tau_w$) and the temperature modulation factor (*f*), rather than just $\tau_w$ alone. This means that the search for optimal parameters takes longer but the same basic procedure is adopted. It is possible to set ranges and increments for both the catchment drying time constant ($\tau_w$) and the temperature modulation factor (*f*) simultaneously in **Configure-Setup-Runtime options** but, in practice, it is often better to start by varying $\tau_w$ while keeping *f* constant, as follows. *The following tutorial assumes the operator has become familiar with the functionality of the PC package through the preceding, Nant y Gronwen, case study.*

### 7.2.2 Finding a sub-optimal catchment drying time constant ($\tau_w$)

First, use **Configure-Open control file** to initiate the Teifi case study, and check the entries in **Data description**, **Runtime options** and **Subperiods** against values below (as shown in Figure 21, Figure 22 and Figure 23). **Uncertainty analysis** should be set to 'Off' and **Linear structure** should be 'C:2 stores in parallel'. Note that the catchment drying time constant ($\tau_w$) is set in **Runtime options** to vary from 4 to 16 days in steps of 2 days while the temperature modulation factor (*f*) is being held constant at 1.0.

**Data description**

**Time base (Rain & Flow):** Daily
**Time base (Temperature):** Monthly
**Rainfall units**: mm
**Streamflow units:** cumecs
**Loss module:** Filter using temperature
**Catchment area:** 893.60 km$^2$
**Start date in rain/flow file:**
  **Date:** 01/01/1961
  **Time:** 00:00
**Start date in temperature file:**
  **Date:** 01/01/1961
  **Time:** 00:00

**Run time options**

**Catchment drying time constant (TauW)**:
- **From:** 4
- **To:** 16
- **Using model steps of:** 2

**Temperature modulation factor (f):**
- **From:** 1.00
- **To:** 1.00
- **Using model steps of:** 1.00

**Time delay:** 1
**Reference temperature:** 20.00
**Use all pre filters**: Off (i.e. this box is left unchecked)
**Number of pre filters to use**: 5

**<u>Subperiods</u>**

**Start date**: 27/07/1982
**End date**: 31/07/1985
**Start time**: 00:00
**End time**: 00:00

**<u>Uncertainty analysis</u>**

**Off**

**<u>Linear Structure</u>**

**C: 2 stores in parallel**

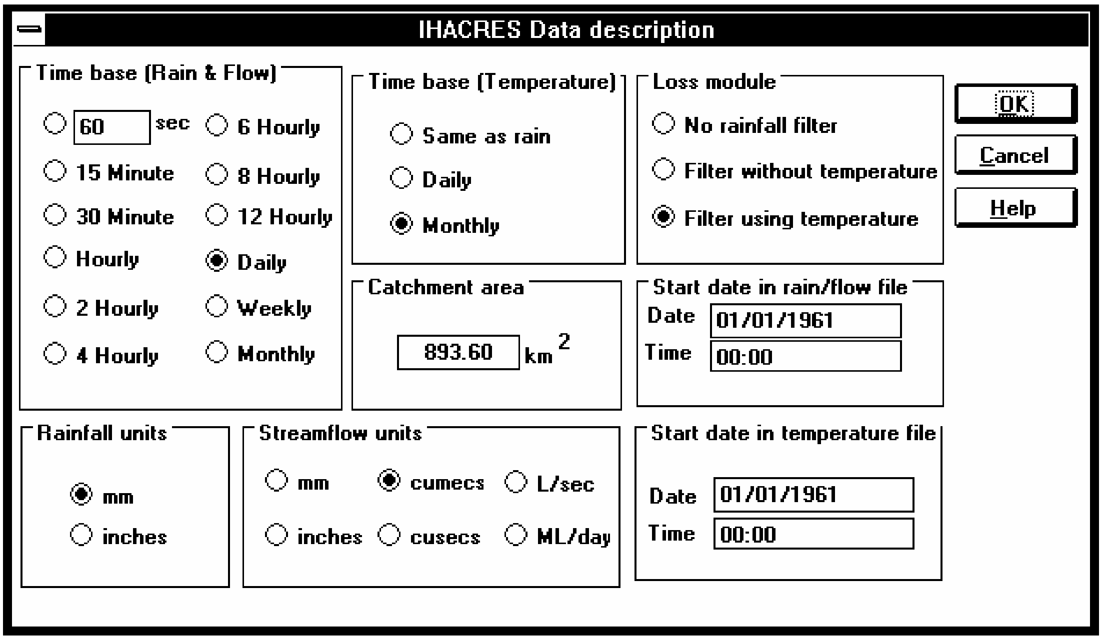


*Figure 21*

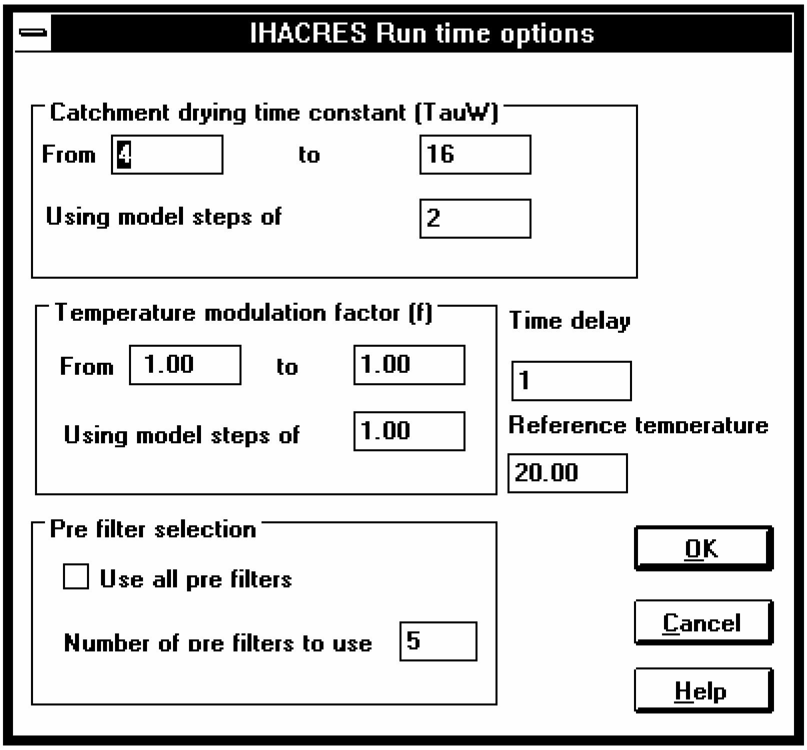


*Figure 22*

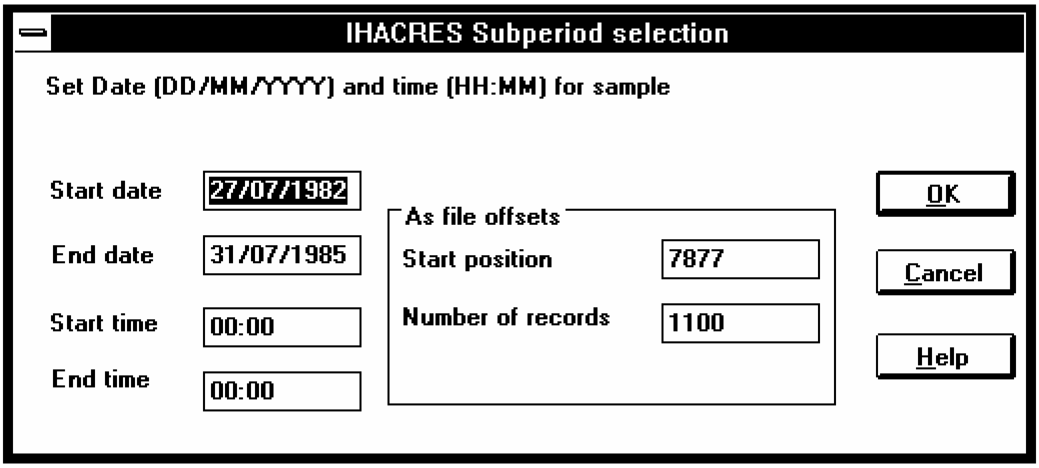


*Figure 23*

Now **Execute model - Calibrate**; on a slow PC it may take several minutes before the file **<teifi.sum>**, which can be checked against Figure 24, appears on the screen. Note that as catchment drying time constant ($\tau_w$) varies from 4 to 16 days:

(a) *D* peaks at a value of 0.882 at about 11 days

(b) bias changes from being negative to positive at about 13 days

and

(c) percentage average relative parameter error (*%ARPE*) decreases from 0.05 to a minimum of 0.03 at about 12 days, then increases sharply to 4.86 at 16 days.

On this basis the optimal value of the catchment drying time constant ($\tau_w$) appears to lie between 8 and 14 days, though *x1* and *u1*[3] are closer to zero at about 15 days. While it is difficult to give firm guidelines, a good strategy often is to choose a value of catchment drying time constant ($\tau_w$) at the lower end of the range for which *D* is at (or just less than) its maximum (say 8 days in this case).

---

[3] *x1* is the cross correlation coefficient between model residuals and modelled streamflow, and *u1* is the cross correlation coefficient between model residuals and effective rainfall.

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\TEIFI\TEIFI.SUM
DATE     : 04/11/1996
TIME     : 09:16:34
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 7877 to 8976(1100), Subints= 1,Time Delay= 1
   f     TauW    %Run    D     Bias     x1      u1  %ARPE   1/c    Tq     Ts     Vs
  1.00    4     66.70
  1.00    4     66.70 .868   -.84  163.4  -20.9    .05   75.9 2.17  38.69  .510
  1.00    6     66.70
  1.00    6     66.70 .877   -.57  147.0  -18.2    .04  104.5 2.41  41.37  .424
  1.00    8     66.70
  1.00    8     66.70 .881   -.38  170.2  -20.6    .03  132.1 2.66  42.96  .354
  1.00   10     66.70
  1.00   10     66.70 .882   -.22  188.1  -22.3    .03  158.9 2.87  43.05  .297
  1.00   12     66.70
  1.00   12     66.70 .882   -.08  188.1  -21.8    .03  185.0 3.06  40.54  .251
  1.00   14     66.70
  1.00   14     66.70 .881    .09  114.8  -12.2    .03  210.2 3.15  32.12  .229
  1.00   16     66.70
  1.00   16     66.70 .878    .71  -15.0    4.8   4.86  234.8  .87   5.47  .872
```

*Figure 24*

Now, in **Runtime options** make the necessary changes to select a single value for the catchment drying time constant ($\tau_w$) of 8 days, then enter the sequence **Execute model - Calibrate - Plot - Model results - Modelled and observed streamflow** to see the corresponding model-fit (shown here in Figure 25).

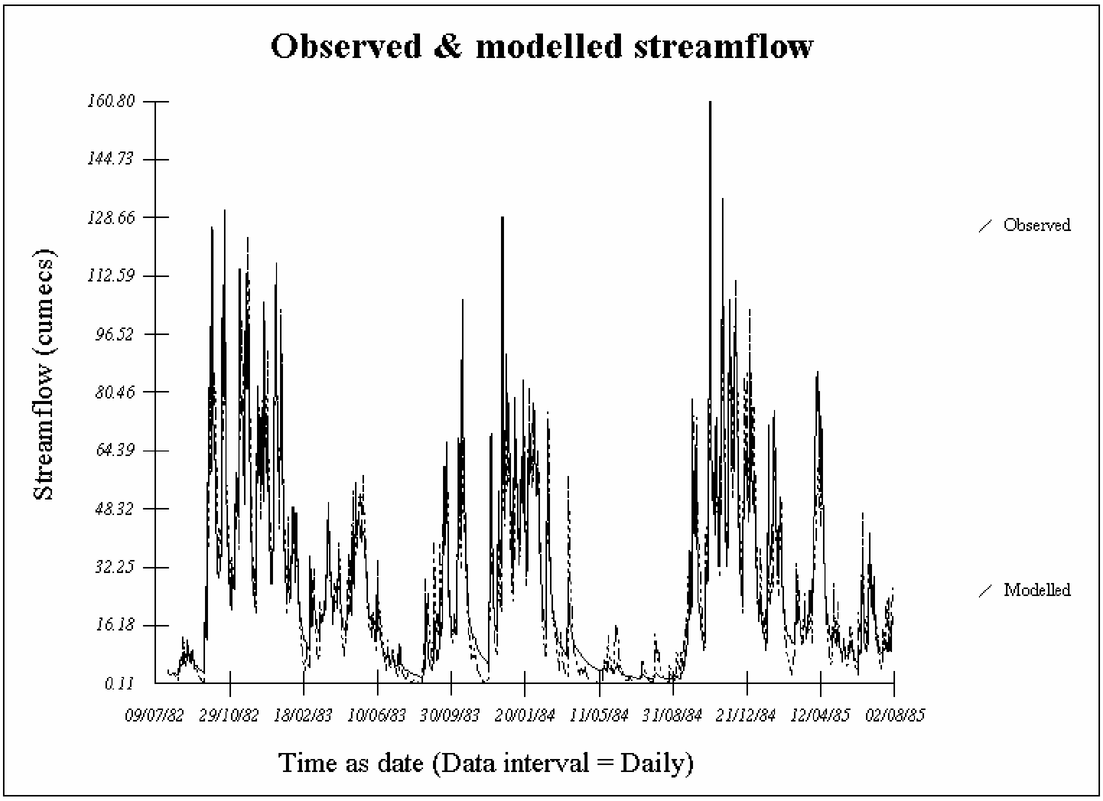


*Figure 25*

At this stage, the operator might judge that the model-fit is adequate for the particular application in hand and decide, therefore, to halt the procedure. However, for detailed work it will be necessary to continue, seeking an optimal *pair* of catchment drying time constant and temperature modulation factor ($\tau_w$, $f$) as described in the next Section. The extra work can be considerable and the law of diminishing returns (in terms of improving on an already good model-fit) means that the operator will have to decide when finally to call a halt to the procedure. In practice, as will be seen, there will usually be a range of catchment drying time constant and temperature modulation factor parameters ($\tau_w$, $f$) over which the quality of model-fits are almost indistinguishably good. The final choice of ($\tau_w$, $f$) is the responsibility of the operator and will probably depend on the wider purpose of the analysis.

### 7.2.3 Finding optimal catchment drying time constant and temperature modulation factor ($\tau_w$, $f$)

With the catchment drying time constant ($\tau_w$) set to 8 days, change the temperature modulation factor ($f$) in **Runtime options** to vary from 0.9 to 1.8 in steps of 0.1. It is clear from the results shown in Figure 26 below that in terms of *D*, percentage average relative parameter error (*%ARPE*) and bias, a good model is obtained using $\tau_w$ = 8 and $f$ = 1.2. This might be about as good as the operator requires, or the search can continue.

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\TEIFI\TEIFI.SUM
DATE     : 16/01/1997
TIME     : 10:56:11
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 7877 to 8976(1100), Subints= 1,Time Delay= 1
   f    TauW   %Run    D    Bias    x1     u1  %ARPE   1/c   Tq    Ts    Vs
   .90    8    66.70
   .90    8    66.70 .879   -.52  176.1  -21.4    .04  124.0 2.56  43.94  .383
  1.00    8    66.70
  1.00    8    66.70 .881   -.38  170.2  -20.6    .03  132.1 2.66  42.96  .354
  1.10    8    66.70
  1.10    8    66.70 .883   -.24  161.7  -19.5    .03  140.8 2.76  41.59  .325
  1.20    8    66.70
  1.20    8    66.70 .883   -.08  148.2  -17.8    .03  150.2 2.86  39.46  .297
  1.30    8    66.70
  1.30    8    66.70 .882    .09  128.0  -15.4    .03  160.3 2.94  35.68  .273
  1.40    8    66.70
  1.40    8    66.70 .881    .30  115.3  -14.4    .04  171.0 2.96  27.57  .265
  1.50    8    66.70
  1.50    8    66.70 .876   1.04  -26.1    6.9   1.87  182.5 1.12   6.04  .819
  1.60    8    66.70
  1.60    8    66.70 .875   1.02  -26.2    6.3   3.70  194.8  .93   5.56  .857
  1.70    8    66.70
  1.70    8    66.70 .872    .98  -26.6    5.8   6.32  207.8  .81   5.30  .878
  1.80    8    66.70
  1.80    8    66.70 .867    .94  -26.5    5.3   9.89  221.5  .72   5.15  .892
  1.90    8    66.70
  1.90    8    66.70 .860    .90  -26.1    4.9  14.59  236.1  .66   5.05  .901
```

*Figure 26*

Wide ranges of both the catchment drying time constant ($\tau_w$) and the temperature modulation factor ($f$) can be set in **Configure - Setup - Run time options.** On a slow PC the following exercise may take about half an hour. Set the catchment drying time constant ($\tau_w$) to vary from 6 to 9 days in steps of 1 day, and the temperature modulation factor ($f$) to vary from 1.1 to 1.5 in steps of 0.1. In the

**<teifi.sum>** results shown in Figure 27 below, the 'best' ($\tau_w$, *f*) in each group where *f* is constant has been highlighted. The best of these, in terms of a high *D*, low percentage average relative parameter error (*%ARPE*), and near-zero values for bias, *x1* and *u1*[4], is for (*f* = 1.4, $\tau_w$ = 6), though similarly good models might be found for other combinations of $\tau_w$ and *f* if the operator chooses to continue with the parameter search. Indeed, there are several combinations of $\tau_w$ and *f* for which the model-fits are practically indistinguishable and the operator is left to make the final choice. A uniquely optimal pair ($\tau_w$, *f*) may be difficult to find but, for the remainder of this tutorial, the 'best' combination is assumed to be 6 days and 1.4 respectively.

[4] x*1* is the cross correlation coefficient between model residuals and modelled streamflow, and *u1* is the cross correlation coefficient between model residuals and effective rainfall.

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\TEIFI\TEIFI.SUM
DATE     : 04/11/1996
TIME     : 09:50:08
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 7877 to 8976(1100), Subints= 1,Time Delay= 1
   f    TauW   %Run    D    Bias    x1     u1   %ARPE   1/c    Tq     Ts     Vs
  1.10    6    66.70
  1.10    6    66.70 .880   -.44  138.8  -17.1    .04  111.2 2.50  40.55  .398
  1.10    7    66.70
  1.10    7    66.70 .882   -.33  150.8  -18.4    .03  126.2 2.63  41.29  .359
  1.10    8    66.70
  1.10    8    66.70 .883   -.24  161.7  -19.5    .03  140.8 2.76  41.59  .325
  1.10    9    66.70
  1.10    9    66.70 .883   -.15  168.1  -20.0    .03  155.3 2.87  41.29  .295
  1.20    6    66.70
  1.20    6    66.70 .882   -.29  131.2  -16.1    .03  118.5 2.59  39.51  .370
  1.20    7    66.70
  1.20    7    66.70 .883   -.18  142.0  -17.2    .03  134.5 2.73  39.86  .331
  1.20    8    66.70
  1.20    8    66.70 .883   -.08  148.2  -17.8    .03  150.2 2.86  39.46  .297
  1.20    9    66.70
  1.20    9    66.70 .883    .01  147.2  -17.5    .03  165.7 2.97  37.91  .269
  1.30    6    66.70
  1.30    6    66.70 .883   -.14  122.5  -15.0    .03  126.3 2.68  38.07  .343
  1.30    7    66.70
  1.30    7    66.70 .883   -.02  129.1  -15.7    .03  143.5 2.82  37.61  .304
  1.30    8    66.70
  1.30    8    66.70 .882    .09  128.0  -15.4    .03  160.3 2.94  35.68  .273
  1.30    9    66.70
  1.30    9    66.70 .882    .21  125.2  -15.0    .03  176.8 3.02  30.89  .253
  1.40    6    66.70
  1.40    6    66.70 .883    .02  111.3  -13.7    .03  134.8 2.77  35.85  .317
  1.40    7    66.70
  1.40    7    66.70 .882    .16  111.8  -13.7    .03  153.1 2.90  33.65  .282
  1.40    8    66.70
  1.40    8    66.70 .881    .30  115.3  -14.4    .04  171.0 2.96  27.57  .265
  1.40    9    66.70
  1.40    9    66.70 .880    .63   19.5   -1.1    .12  188.6 2.43  11.66  .431
  1.50    6    66.70
  1.50    6    66.70 .881    .21   98.6  -12.3    .03  143.8 2.84  32.04  .296
  1.50    7    66.70
  1.50    7    66.70 .880    .37  113.3  -14.6    .04  163.4 2.90  25.27  .279
  1.50    8    66.70
  1.50    8    66.70 .876   1.04  -26.1    6.9   1.87  182.5 1.12   6.04  .819
  1.50    9    66.70
  1.50    9    66.70 .876    .96  -23.3    5.9   3.98  201.2  .91   5.52  .861
```

*Figure 27*

## 7.2.4 Checking the time delay $\delta$

In **Run time options**, select time delays of 0, 1 and 2 days in turn and each time **Execute model - Calibrate** with the catchment drying time constant ($\tau_w$) and the temperature modulation factor (*f*) set to 6 days and 1.4 respectively. A time delay ($\delta$) of 1 day has already been tried but can be repeated quickly for this exercise. (Note that the settings for '**Using model steps of**' have no effect on the model when '**From**' and '**To**' have single values for $\tau_w$ and $f$, which are 6 and 1.4 in this case.) The results shown below indicate that, in terms of a high $D$, low percentage average relative parameter error (*%ARPE*) and small bias, a time delay ($\delta$) of 1 day is best. Note that *x1* and *u1*[5] are much smaller for $\delta = 1$ than for $\delta = 0$. The UH model parameters failed to converge when $\delta = 2$ days (indicated by the blank results line in the corresponding file **<teifi.sum>**).

**$\delta = 0$**

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\TEIFI\TEIFI.SUM
DATE     : 04/11/1996
TIME     : 15:48:09
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 7877 to 8976(1100), Subints= 1,Time Delay= 0
   f    TauW   %Run    D    Bias    x1     u1  %ARPE   1/c   Tq    Ts    Vs
  1.40   6    66.70
  1.40   6    66.70 .865   -.34  543.4  -60.8   .03  134.5 4.65  62.09  .177
```

[5] *x1* is the cross correlation coefficient between model residuals and modelled streamflow, and *u1* is the cross correlation coefficient between model residuals and effective rainfall.

**$\delta = 1$**

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\TEIFI\TEIFI.SUM
DATE     : 04/11/1996
TIME     : 15:55:08
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 7877 to 8976(1100), Subints= 1,Time Delay= 1
   f    TauW    %Run    D     Bias     x1      u1   %ARPE    1/c    Tq     Ts     Vs
  1.40    6     66.70
  1.40    6     66.70 .883     .02   111.3   -13.7    .03   134.8 2.77   35.85   .317
```

**$\delta = 2$**

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\TEIFI\TEIFI.SUM
DATE     : 04/11/1996
TIME     : 15:58:11
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 7877 to 8976(1100), Subints= 1,Time Delay= 2
   f    TauW    %Run    D     Bias     x1      u1   %ARPE    1/c    Tq     Ts     Vs
  1.40    6     66.70
```

### 7.2.5 Checking the configuration of storages in the linear UH module

With the time delay ($\delta$ ) set to 1 day, the catchment drying time constant ($\tau_w$) set to 6 days and the temperature modulation factor (*f*) set to 1.4, select 'A: single store' in **Configure-Setup-Linear structure**, then **Execute model - Calibrate**. Repeat the exercise for 'B: 2 stores in series', (Option 'C: 2 stores in parallel' has already been run but it can be repeated quickly for this exercise). The results shown below indicate that, in terms of a high *D*, low percentage average relative parameter error (*%ARPE*) and a low bias, option 'C: 2 stores in parallel' is the best configuration. Option 'B: 2 stores in series' gives a negative time constant $\tau$ for one of the linear storages and is not, therefore, conceptually valid; inspection of the file **<teifi.out>** for this case reveals that parameter convergence was not successful until the fifth set of pre-filters, when $D = 0.863$ and

*%ARPE* = 0.889 – a poorer combination of these parameters than for option 'C: 2 stores in parallel'.

**'A: Single'**

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\TEIFI\TEIFI.SUM
DATE     : 04/11/1996
TIME     : 11:52:33
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 7877 to 8976(1100), Subints= 1,Time Delay= 1
   f    TauW    %Run    D    Bias    x1     u1  %ARPE  T.C.   A1   B0  Const
  1.40    6    66.70
  1.40    6    66.70 .857   1.78    1.7     .0    .01  4.10 -.784 2.092  .007
```

**'B: 2 stores in series'**

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\TEIFI\TEIFI.SUM
DATE     : 04/11/1996
TIME     : 12:38:34
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 7877 to 8976(1100), Subints= 1,Time Delay= 1
   f    TauW    %Run    D    Bias    x1     u1  %ARPE   1/c   TC1   TC2
  1.40    6    66.70
  1.40    6    66.70        ONE OF THE TIME CONSTANTS IS NEGATIVE
```

**'C: 2 stores in parallel'**

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\TEIFI\TEIFI.SUM
DATE     : 04/11/1996
TIME     : 12:42:39
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 7877 to 8976(1100), Subints= 1,Time Delay= 1
   f    TauW    %Run    D    Bias    x1     u1  %ARPE   1/c    Tq     Ts    Vs
  1.40    6    66.70
  1.40    6    66.70 .883    .02  111.3  -13.7    .03  134.8 2.77  35.85  .317
```

PC IHACRES allows only the three configurations mentioned above. The transfer function approach adopted by IHACRES, however, allows representation of other, more complex, configurations of linear storages (e.g., one storage in parallel with two others in series, or three in parallel) but – given only the information in rainfall, streamflow and temperature time series – the configuration of two in parallel is usually optimal. Fortunately, this configuration leads fairly effortlessly to separation of hydrographs into their dominant quick and slow flow components. In cases of relatively poor data quality, or crude data time step, it may be possible to identify only *one* dominant flow component – in which case option 'A: Single' will give the best results.

### 7.2.6 The main results file <teifi.out>

File **<teifi.out>** contains:

(a) a record of the settings made in **Setup**
(b) various diagnostics
(c) full results of the analysis (see Section 6.4)

Attention to the following is advisable to check that the analysis has run smoothly.

The program performs 10 iterations in the UH parameter identification procedure. Figure 28 (taken from **<teifi.out>** for the case $\tau_w = 6$, $f = 1.4$, $\delta = 1$ and 'C:2 stores in parallel') shows how each parameter, and the coefficient of determination *D*, approaches its final value asymptotically. Note that there is very little change in all of these values after 4 or 5 iterations (the iterations are labelled 'Iter' in the listing). Any deviation from this 'good behaviour' indicates that, for whatever reason, the model calibration has not proceeded in a reliable way and that the parameters should be treated with extreme caution.

| Iter | A(1) | A(2) | B(0) | B(1) | D |
|---|---|---|---|---|---|
| 0 | -1.6000 | .6400 | .0000 | .0000 | .0000 |
| 1 | -1.7241 | .7269 | 2.0144 | -1.9890 | .7933 |
| 2 | -1.6869 | .6936 | 2.2256 | -2.1551 | .8468 |
| 3 | -1.6758 | .6836 | 2.2396 | -2.1590 | .8822 |
| 4 | -1.6721 | .6802 | 2.2399 | -2.1558 | .8825 |
| 5 | -1.6706 | .6789 | 2.2389 | -2.1536 | .8825 |
| 6 | -1.6700 | .6782 | 2.2382 | -2.1523 | .8825 |
| 7 | -1.6696 | .6779 | 2.2378 | -2.1516 | .8826 |
| 8 | -1.6694 | .6777 | 2.2375 | -2.1512 | .8826 |
| 9 | -1.6693 | .6776 | 2.2374 | -2.1510 | .8826 |
| 10 | -1.6692 | .6776 | 2.2373 | -2.1509 | .8826 |

*Figure 28*

The following characteristic parameters (Figure 29) also appear in **<teifi.out>**. These Dynamic Response Characteristics (DRCs) are calculated by equations (8) to (13) in Section 2.

CHARATERISTIC PARAMETERS

| | Quickflow | Slowflow |
|---|---|---|
| Time Constants | 2.7675 | 35.8503 |
| Relative Throughput Volumes | .6830 | .3170 |
| Relative Contribution To IUH Peak | .9596 | .0404 |

*Figure 29*

### 7.2.7 Uncertainties associated with DRCs

When a suitable model has been derived by the operator it may be required to know indicative statistical uncertainties associated with the DRCs. In the dialogue box created by **Setup - Uncertainty analysis …** switch from ‘Off (default)’ to ‘On’, and set the desired **Confidence limit** (95% by default) and **Number of trials** (100 by default), then **Execute model - Calibrate** to generate a revised file **<teifi.sum>** which, as shown in Figure 30 below, has eight extra columns for the lower and upper prescribed confidence limits associated with $\tau_q$, $\tau_s$, $v_q$, and $v_s$ respectively (the extra columns are shown separately in the figure).

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\TEIFI\TEIFI.SUM
DATE     : 17/01/1997
TIME     : 11:15:55
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 7877 to 8976(1100), Subints= 1,Time Delay= 1
   f    TauW   %Run    D    Bias    x1     u1  %ARPE   1/c   Tq     Ts    Vs
  1.40    6    66.70
  1.40    6    66.70 .883    .02  111.3  -13.7    .03  134.8 2.77  35.85  .317
```

```
  Tql   Tqu    Tsl    Tsu   Vql   Vqu   Vsl   Vsu

 2.574 3.024  29.626  45.581  .640  .727  .269  .358
```

*Figure 30*

The file **<teifi.out>** now contains a revised table of DRCs, as shown in Figure 31 below. The pairs of numbers (‘*n.nn*’ to ‘*n.nn*’) below the dynamic response characteristic (DRC) values are the indicative uncertainty limits (95% limits in this case).

```
CHARATERISTIC PARAMETERS

                    Quickflow       Slowflow
Time Constants        2.7675         35.8503
    2.5744 to   3.0242      29.6260 to  45.5812

Relative
Throughput             .6830            .3170
Volumes
     .6405 to    .7272        .2690 to    .3578

Relative
Contribution           .9596            .0404
To IUH Peak

     .9461 to    .9703        .0273 to    .0506
```

*Figure 31*

### 7.2.8 Simulation-mode examples

Use **Configure - Setup** to set the parameters as in Section 7.2.2 but with the catchment drying time constant ($\tau_w$) set to 6 days and the temperature modulation factor (*f*) set to 1.4:

**Data description**

**Time base (Rain & Flow):** Daily
**Time base (Temperature):** Monthly
**Rainfall units**: mm
**Streamflow units:** cumecs
**Loss module:** Filter using temperature
**Catchment area:** 893.60 km$^2$
**Start date in rain/flow file:**
- **Date:** 01/01/1961
- **Time:** 00:00

**Start date in temperature file:**
- **Date:** 01/01/1961
- **Time:** 00:00

**Run time options**

**Catchment drying time constant (TauW)**:
- **From:** 6
- **To:** 6
- **Using model steps of:** 1

**Temperature modulation factor (f):**
- **From:** 1.4
- **To:** 1.4
- **Using model steps of:** 1.00

**Time delay:** 1
**Reference temperature:** 20.00
**Use all pre filters**: Off (i.e. this box is left unchecked)
**Number of pre filters to use**: 5

**Subperiods**

**Start date**: 27/07/1982
**End date**: 31/07/1985
**Start time**: 00:00
**End time**: 00:00

**Uncertainty analysis**

**Off**

## Linear Structure

### C: 2 stores in parallel

Run **Calibration** so that the file **<teifi.sim>** contains the appropriate model parameters. At this stage, and at any other time the operator wishes, it is good procedure to confirm that the model-fit, hydrograph separation (available only when 'C: 2 stores in parallel' is specified in **Linear structure**), etc., are sensible hydrologically by using the extensive **Plot** facilities.

To run the model (which was just calibrated) in simulation-mode over the *previous* approximately 3-year period, change '7877' in **Subperiods** (i.e., **Configure-Setup-Subperiods**) to '6777'. This will change the date ranges from 27/7/1982 - 31/7/1985 to 23/7/1979 - 27/7/1982 (return to the **Setup** menu and re-enter **Subperiods** to check this). Select **Execute model - Simulate** to run the model, then **Plot - Model results - Modelled and observed streamflow**. The results should be as shown in Figure 32.

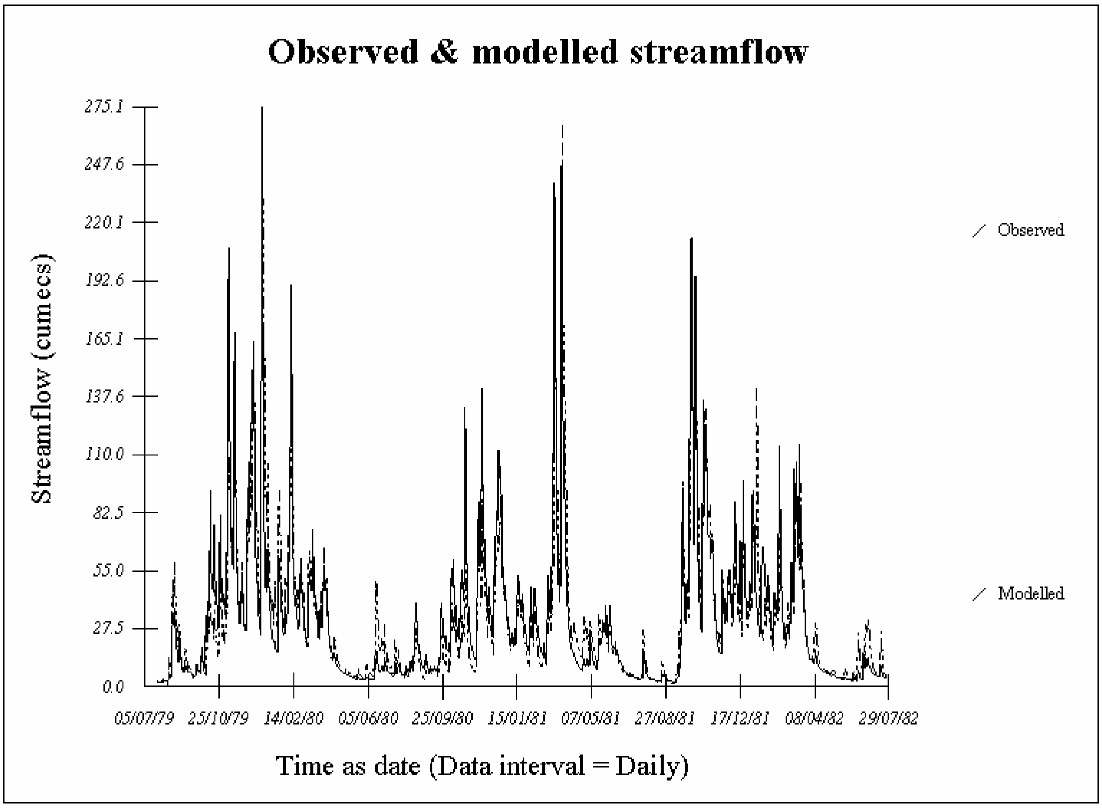


*Figure 32*

It will be seen that the model calibrated over the period 27/7/1982 to 31/7/1985 is a good characterisation of the Teifi catchment in the sense that it performs well over a period immediately before the calibration period. But how well does it perform over periods further removed from the calibration period?

Now, in **Subperiods**, change the dates to read 1/10/1969 to 1/10/1972, then **Execute model - Simulate** (it is not necessary to re-**Calibrate** if the previous operation was as immediately above). The model-fit (**Plot**) is not as good as the previous simulation model-fit but, nevertheless, it indicates approximately how the flow varied in the months of March, April and August of 1970, when observed flows are not available (Figure 33). In **<teifi.sum>**, the low value for *D* of 0.638 is due largely to the missing flow data (indicated as -1 in **<teifi.dat>**). The next section considers how to derive 'best' estimates of these missing flows.

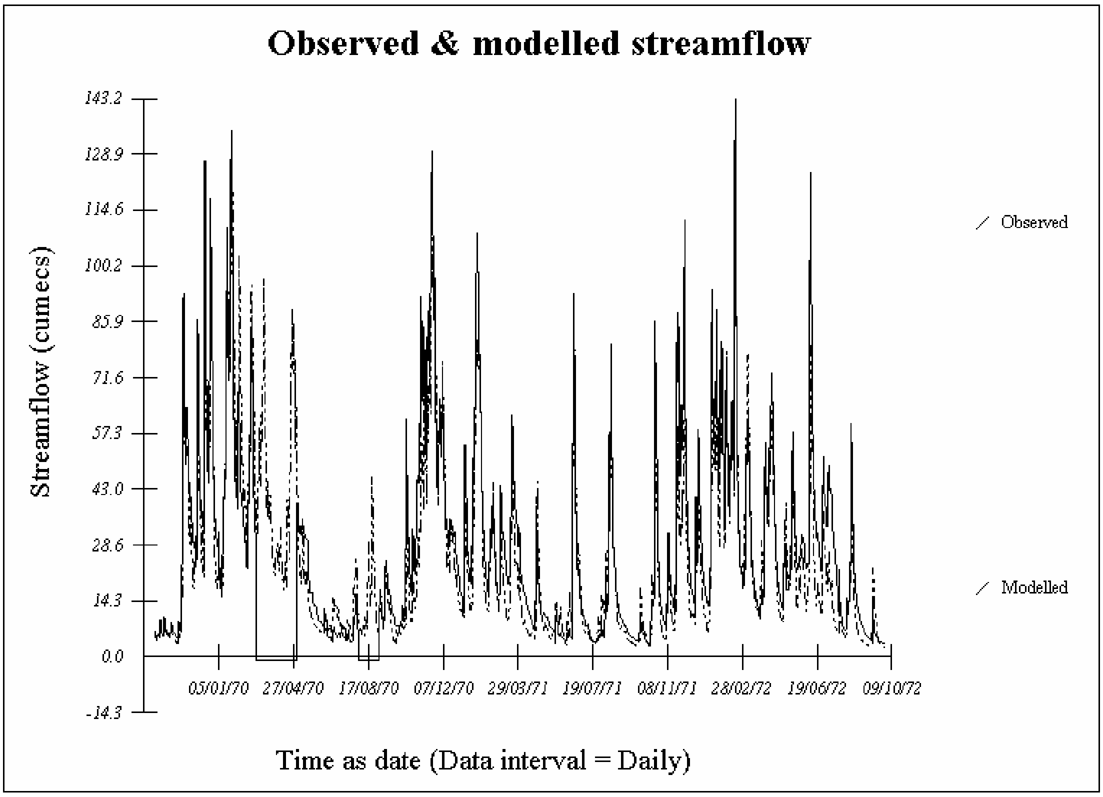


*Figure 33*

### 7.2.9 Infilling missing streamflow data

Although the model calibrated over the period 27/7/1982 to 31/7/1985 performs reasonably well over the period including the missing data in 1970, it may be possible to derive a better model (or models) from periods just before or after the gaps. For example, select 1/10/1970 to 1/10/1973 in **Subperiods** then, in **Runtime options**, set the catchment drying time constant ($\tau_w$) to 6 days, the temperature modulation factor ($f$) to 1.4 and the time delay to 1 day, then **Execute model - Calibrate**. Run **Plot** to check that a reasonable model-fit is obtained. Search the $\tau_w$, $f$ parameter space to find a 'best' model (in terms of $D$, percentage average relative parameter error (*%ARPE*), bias, *x1* and *u1*[6]). In the example $\tau_w$, $f$ parameter search below (using $\tau_w$ = 5 to 9 with model steps of 1, and $f$ = 1.3 to 1.5 with model steps of 0.1), it can be seen that the values of $\tau_w$ and $f$ of 6 days and 1.4 respectively are about right; other combinations of these parameters do not give an improved model and many are worse in terms of combinations of higher values for percentage average relative parameter error (*%ARPE*), *x1* and *u1* and lower values of $D$. (The '******' entries for *x1* indicate very large, i.e., undesirable, values for this statistic.)

[6] *x1* is the cross correlation coefficient between model residuals and modelled streamflow, and *u1* is the cross correlation coefficient between model residuals and effective rainfall.

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\TEIFI\TEIFI.SUM
DATE     : 06/11/1996
TIME     : 11:10:38
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range= 3560 to 4655(1096), Subints= 1,Time Delay= 1
   f     TauW   %Run    D    Bias    x1      u1  %ARPE   1/c   Tq    Ts    Vs
  1.30    5    70.49
  1.30    5    70.49 .864   -.28 1642.6 -204.9   .03   93.2 2.59  56.13  .409
  1.30    6    70.49
  1.30    6    70.49 .870   -.20 1778.0 -218.3   .03  106.6 2.67  57.70  .374
  1.30    7    70.49
  1.30    7    70.49 .872   -.11 1861.4 -224.7   .02  119.8 2.77  58.33  .342
  1.30    8    70.49
  1.30    8    70.49 .871   -.04 2165.3 -252.8   .02  132.6 2.86  58.43  .315
  1.30    9    70.49
  1.30    9    70.49 .862   1.40 ******  164.0   .03  145.3 2.59  36.54  .349
  1.40    5    70.49
  1.40    5    70.49 .868   -.21 1795.2 -222.8   .03   98.8 2.64  58.18  .389
  1.40    6    70.49
  1.40    6    70.49 .872   -.13 1953.0 -236.6   .02  113.2 2.73  59.92  .353
  1.40    7    70.49
  1.40    7    70.49 .872    .00 1888.2 -221.4   .02  127.3 2.84  60.89  .321
  1.40    8    70.49
  1.40    8    70.49 .866   1.30 ******  390.2   .03  141.0 2.77  62.31  .318
  1.40    9    70.49
  1.40    9    70.49 .856   1.68   36.9   -6.0   .22  154.5 1.61   8.48  .613
  1.50    5    70.49
  1.50    5    70.49 .870   -.14 1948.9 -238.5   .02  104.9 2.69  60.76  .370
  1.50    6    70.49
  1.50    6    70.49 .872   -.02 1963.4 -235.8   .02  120.3 2.80  63.29  .332
  1.50    7    70.49
  1.50    7    70.49 .871    .54 -722.2   87.8   .02  135.3 2.87  62.13  .309
  1.50    8    70.49
  1.50    8    70.49 .855   1.78   27.9   -4.3   .18  150.0 1.72   9.16  .579
  1.50    9    70.49
  1.50    9    70.49 .854   1.71   29.1   -4.9   .40  164.3 1.38   7.33  .683
```

With the catchment drying time constant ($\tau_w$) and the temperature modulation factor (*f*) set to the chosen values (6 days and 1.4 respectively), first **Execute model - Calibrate** over the period 1/10/1970 to 1/10/1973 (to make the appropriate UH model parameters available in **<teifi.sim>**), then **Execute model - Simulate** over year 1970. Use **Plot** to see the simulation model-fit and, if required, **Export** (see Section 4.6) to create a file of the modelled flows which include the periods of missing observed flow record (it is essential, of course, that the rainfall record is complete for this type of analysis). The listing below shows the first part of a file **<teifi.exp>** created in this way which can be used as input to any separate analysis the operator wants to undertake.

```
Date created         :11/06/96
Time created         :11:38:13
Record start date    :01/01/1970
Record start time    :00:00
Record end date      :31/12/1970
Record end time      :00:00
Record time interval :     Daily
Number of time steps :       364

  31.30000
  28.12000
  28.18000
  32.18000
  26.18000
  21.20000
  19.54000
  17.51000
  16.48000
  26.23000
  36.69966
  39.78377
  49.47853
  50.21651
  57.80552
  58.85244
  95.10520
  78.94067
  91.28454
     :
     .
```

The choice of which model to use for infilling missing flow data, and whether any of the *observed* flow data are of poor quality and should be replaced, are matters which require careful deliberation on the part of the operator.

## 7.3 The Gwy (Plynlimon) - setting up a new CTL file

The previous tutorials have not required the operator to work from scratch; **<filename.dat>**, **<filename.inb>** and **<filename.ctl>** for the Nant y Gronwen and Teifi were supplied on the installation disk. In the following tutorial, the operator has to create **<gwy.ctl>** and **<gwy.inb>**; only **<gwy.dat>** has been supplied (hourly rain and flow, both in millimetres).

### 7.3.1 Creating the new CTL file (<gwy.ctl>)

Follow the menu command sequence **Configure - New control file** to display the dialogue box for the default control filename, **<filename.ctl>**, on the screen. Change the fields as follows (this example assumes that PC IHACRES is installed on drive C):

Replace the contents of the 1st field with:

```
C:\IHACRES\GWY\GWY.INB
```

Replace the contents of the 2nd field with:

```
C:\IHACRES\GWY\GWY.DAT
```

Replace the contents of the 3rd field with:

```
C:\IHACRES\NULL
```

Replace the contents of the 4th field with:

```
C:\IHACRES\GWY\GWY.SIM
```

Replace the contents of the 5th field with:

```
C:\IHACRES\GWY\GWY.OUT
```

Replace the contents of the 6th field with:

```
C:\IHACRES\GWY\GWY.SUM
```

### 7.3.2 Saving the newly created <filename.ctl>

Press the **SaveAs** button and save the new control file as (C:\IHACRES\GWY\GWY.CTL)

### 7.3.3 Creating the new <filename.inb>

The menu command sequence **Configure - Setup - Data Description** will cause the *IHACRES Data Description* dialogue box to appear with default values. Select **Hourly** using the appropriate radio button in the region ‘Time base (Rain & Flow)’. Enter **3.88** (km$^2$) for the catchment area. Enter **01/01/1980** for the start date in the ‘Rain/Flow file' field. Set the units for both rainfall and streamflow to **mm**. Under ‘Loss module' select ‘Filter without temperature'. Then press the OK button.

Use the menu command sequence **Configure** - **Setup - Run Time Options** to set the ‘Catchment catchment drying time constant’ ($\tau_w$) to run from 3 hours to 3 hours in steps of 1 hour, and set the time delay ($\delta$) to 1 hour.

Use the menu command sequence **Configure** - **Setup** - **Subperiods** to set the Start date field to **01/01/1980** and the End date field to **07/01/1980**. Set the Start time and End times to **00:00**. Then press the OK button. (If **Configure** -**Setup** - **Subperiods** is repeated immediately, the operator should see that the ‘file offset' start position is now 1 and the ‘number of records' is 144.)

Use the menu command sequence **Configure** - **Setup** - **Uncertainty analysis** to ensure that the setting is **Off**. Then press the OK button.

Use the menu command sequence **Configure** - **Setup** - **Linear structure** to set the linear structure to **C: 2 stores in parallel**. Then press the OK button.

Finally, use the menu command sequence **Configure** - **Save** to save the setup in the file **<gwy.inb>**.

### 7.3.4 Model calibration

Use the menu command sequence **Execute model** - **Calibrate** to run the package in calibration mode. On completion, the following file **<gwy.sum>** should appear.

```
IHACRES for WINDOWS, Version 1.0

FILE     : E:\IHACRES\GWY\GWY.SUM
DATE     : 06/11/1996
TIME     : 13:03:26
CONTAINS : Summary of model results.

Reference Temperature =  20.00


Version 1.00,  Subperiod=  1,Range=    1 to  144( 144), Subints= 1,Time Delay= 1
   f    TauW    %Run    D    Bias    x1     u1  %ARPE   1/c   Tq    Ts    Vs
  1.00    3    75.20
  1.00    3    75.20 .981    .00     .4    -.5   .18   14.9 1.02  25.41  .501
```

The operator can now proceed, trying any of the facilities described in other parts of the User Guide.

## 7.4 Summary

The tutorials have covered the entire functionality of PC IHACRES and, with the rest of this User Guide, provide reference material for the analysis of data from other catchments which may be of more direct interest to the operator. Several possible uses of PC IHACRES are listed in Section 1.1; those interested in finding out more about the IHACRES methodology and its applications might like to consult the bibliography in Section 9.

# 8. CONTACT POINT, ADDRESSES, ETC.

Enquiries can be made to either the Centre for Ecology and Hydrology, Wallingford (UK) or the Integrated Catchment Assessment and Management Centre (Australian National University), depending on which is most convenient to the operator (e.g., geographically closest).

Centre for Ecology and Hydrology
Maclean Building
Wallingford
Oxfordshire
OX10 8BB
United Kingdom

*Tel:* +44 (0)1491 838800
*Fax:* +44 (0)1491 692424
*E-mail:* igl@ceh.ac.uk

Integrated Catchment Assessment and Management Centre
Australian National University
Canberra
A.C.T. 0200
Australia

*Tel/Fax:* +61 (0)6 249 4277
*E-mail:* susank@cres.anu.edu.au

# 9. BIBLIOGRAPHY

Development of the IHACRES rainfall - runoff methodology, and reference to its antecedents in the field of systems identification, has been well documented in the scientific literature. The methodology has utility across a wide range of hydrological applications, many of which have also been discussed in the literature. The following selective bibliography is provided for guidance.

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*Discussion*

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# 10. ACKNOWLEDGEMENTS

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| | |
|---|---|
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