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DEPARTMENT OF CIVIL ENGINEERING

Water Resources Research Group

Software Profile

A User Manual for TFCAL

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TFCAL
(Transfer Function CALibration)

A program for the identification and calibration of a simple linear transfer function model using a recursive least squares algorithm.

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Software Profile

A User Manual for TFCAL

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by

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Contents

List of Figures

1. Introduction

This manual is a report in a series of Technical Reports produced by the Water Resources Research Group at the Department of Civil Engineering, University of Salford.

The manual is a reference to the software package known as TFCAL (Transfer Function CALibration), a program for identifying and calibrating a simple transfer function model for rainfall-runoff modelling. The report begins by stating the software specification and goes on to discuss the input files required. After a brief conceptual introduction to the transfer function model and its calibration, the structure of TFCAL is described and illustrated with a flowchart. An example run-time session is described. Annotated samples of the input datafiles are included.

The Appendices provide a source listing of the program together with a hard copy listing of example input and output datafiles. The datafiles accompany the program on the distribution disk and may be used to replicate the run-time example in the report main body. User input datafiles should exactly replicate the format of the example datafiles.

This manual is not a definitive guide to transfer function models. Further information can be found in the references listed in the bibliography.

The Water Resources Research Group would welcome any comments on this Software Profile. Please contact Professor Ian Cluckie at the address at the front of the report.

2. Typography and Flow Chart Symbols

The body of this manual is printed in a normal (Times font) typeface; other typefaces have special meanings.

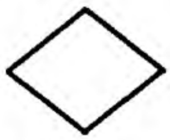
`Courier` is used for the listings of the program, datafiles and screen output. **`Bolded courier`** represents interactive user keyboard input whilst annotated comments of source code and datafile listings are made in **bolded times**.

The program structure is illustrated by a flowchart and described (summarised) textually. Algorithms are described in terms of steps such as input, output and computations. Decisions are made by testing Boolean expressions that are evaluated to be true or false. The flowchart symbols for these processes, along with a symbol to indicate beginning and end are:

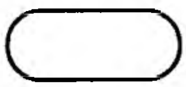
Assignments or computations

Input or output

Boolean expressions



Start or stop



3. Software Specification and System Requirements

TFCAL (Transfer Function CALibration) is an interactive, graphically based FORTRAN program for the identification and calibration of a simple linear transfer function model.

The software is coded in ANSI FORTRAN 77 and has been developed on a Digital Electronic Company (DEC) MicroVAX II minicomputer using VMS V5.0 and FORTRAN 77 V5.0. The code does not use any non-standard VAX FORTRAN 77 implementations (extensions) and is easily ported to a wide range of FORTRAN environments.

Graphics play an integral role in TFCAL and are facilitated by UNIRAS Graphics Software[1] package (Version 5.01, RASPAK module) and these are required in order to run the software. UNIRAS graphics modules are machine independent and can be implemented on a wide range of machines, and are also upwardly compatible with subsequent upgrade releases. A menu of devices for which the graphics elements of the software have already been implemented prompt the user to indicate the device on which the software is running enabling the correct device driver to be software selected. Implementation for new devices is straightforward if a UNIRAS driver for the device is available.

[1] UNIRAS A.S.,376 Gladsaxevej, DK-2860 Søborg, DENMARK
UNIRAS Ltd, Ambassador House, 181 Farnham Road, Slough, SL1 4XP, UNITED KINGDOM.

4. The Transfer Function Model

This section briefly describes the lumped transfer function rainfall-runoff model developed by the Water Resources Research Group. The model is parametrically efficient, structurally compact and robust to data loss or error. It is well suited to the real-time operational environment and is currently being implemented in the U.K by the Water Industry.

4.1. Introduction

The lumped transfer function rainfall-runoff model is a structurally simple model which can be used for real-time flood forecasting. In a forecasting mode the model uses present and past observed rainfall and flow data to forecast future river flow; model updating allowing the model to update the percentage runoff it represents thereby facilitating an input of total rainfall. The features implicitly introduce robustness into the model, the self-correction buffering inaccurate forecasts. The feedback of recently observed rainfall/flow data ensures maximum utilisation of telemetry data. Calibration of the model is carried out off-line using historical storm/flood event data.

4.2. Basic Structure

The transfer function model comprises essentially of two components: the flow part (a parameters), and a rainfall component (b parameters) and has a memory for past rainfall and flow values. The structure of the transfer function model is shown in eq. 1:

$$y_t = a_1 y_{t-1} + a_2 y_{t-2} + \dots + a_p y_{t-p} + b_1 u_{t-1} + b_2 u_{t-2} + \dots + b_q u_{t-q} \qquad \text{(eq. 1)}$$

where:

a_i , b_i = model parameters.

y_t = runoff forecasted for time t.

u_t = total observed rainfall between time t-1 and time t.

y_t = instantaneous runoff observed at time t (y_{t-n} = instantaneous observed runoff for time t-n).

The block diagram representation of the transfer function model highlights the structure of the model and is shown in figure 1 (where z is a backward difference operator such that $u_t z^{-n} = u_{t-n}$).

$$\text{Rainfall Input } u_t \longrightarrow \boxed{\frac{\Delta\left[b_1 z^{-1} + b_2 z^{-2} + , \ldots , + b_q z^{-q} \right]}{1 - a_1 z^{-1} - a_2 z^{-2} - , \ldots , - a_p z^{-p}}} \longrightarrow \text{Runoff Output } y_t$$

FIGURE 1: Block Diagram Representation of the Transfer Function Model

4.3. Stage or Flow ?

The model utilises a rainfall-runoff relationship to forecast riverflow. If the river data are in the form of stage measurements, these are converted to flow using the rating equation for the gauging station (see eq. 2).

$$Q = a\,(H - h)^{b} \qquad \text{(eq. 2)}$$

where:

Q = river discharge
H = river stage
h = gauging station correction factor for stations where Q is not zero when the stage H=0.
a,b = rating parameters.

4.4. Baseflow

The model forecasts runoff i.e. that part of the rainfall that has, by surface or subsurface flow, entered the river channel. Baseflow (assumed as minimum riverflow immediately before the event) is subtracted from the riverflow data before forecasts are made and is added for graphic presentation and results output.

4.5. Catchment Lag

In some catchments there may be some delay between rainfall and resultant flow and the incorporation of a pure time delay (τ) in the model may be appropriate (eq. 3).

$$y_t = a_1 y_{t-1} + a_2 y_{t-2} + \ldots + a_p y_{t-p} + b_1 u_{t-1-\tau} + b_2 u_{t-2-\tau} + \ldots b_q u_{t-q-\tau} \qquad \text{(eq. 3)}$$

The time delay effectively lags the rainfall by τ model intervals delaying its input to the model and thus the resulting output.

4.6. Real-Time Updating

The model utilises on-line parameter scaling to change the state of the model through an event. The procedure adapts the magnitude of the model unit input response by scaling the rainfall component of the model (using a factor delta, Δ). One-step ahead forecast errors are used to update delta in an attempt to adapt the percentage runoff of the model in order to minimise the one-step ahead forecast error. The form of transfer function model including on-line updating and a time delay is:

$$y_t = a_1 y_{t-1} + a_2 y_{t-2} + \ldots + a_p y_{t-p} + \Delta \left[b_1 u_{t-\tau-1} + b_2 u_{t-\tau-2} + \ldots + b_q u_{t-\tau-q} \right] \qquad \text{(eq. 4)}$$

A number of constraints are applied to Δ in the updating algorithm. The updating of delta (eq. 5) also incorporates a smoothing factor μ, ($0 \leq \mu \geq 1$, usually $\mu = 0.5$).

$$\Delta_t = \mu\, \Delta_{t-1} + (1-\mu) \frac{y_t - \left[a_1 y_{t-1} + a_2 y_{t-2} + \ldots + a_p y_{t-p} \right]}{b_1 u_{t-1} + b_2 u_{t-2} + \ldots + b_q u_{t-q}} \qquad \text{(eq. 5)}$$

An advantage of on-line updating is that it facilitates an input of total rainfall simultaneously providing a means of coping with events which have a percentage runoff which differ from the (initial) percentage runoff represented by the model.

4.7. Steady State Gain/Unit Step Response

The steady-state gain of a transfer function model is the ratio of (steady) output to a constant input of unit magnitude i.e. a measure of model amplification. In this context steady-state gain is directly analogous to the percentage runoff and it is this which is adjusted through the event by the updating procedure. The steady state gain may be determined directly from the model parameters as shown in eq. 6.

$$SSG = \frac{y_t}{u_t} = \frac{B(z)}{A(z)} = CF.\left\{\frac{(b_1 + b_2 + ... + b_q)}{1 - (a_1 + a_2 + ... + a_p)}\right\} \quad \text{(eq. 6)}$$

where CF is a unit conversion factor used to ensure that the SSG is dimensionless (eq. 7).

$$CF = \frac{0.06 \cdot \text{model interval (min)}}{\text{catchment area (sq km)}} \quad \text{(eq. 7)}$$

4.8. Stability

A transfer function model should be implicitly stable i.e. a finite input produces a finite output (the so called BIBO rule - bounded-input bounded output) and the model output should decay with time when there is no rainfall. Stability of transfer function model is a complex issue and the conditions which must be satisfied to guarantee stability are beyond the scope of this report (instead see Box and Jenkins, 1976). However in the vast majority of cases if the condition shown in eq. 8 is satisfied , the model will be stable.

$$\left| \sum_{i=1}^{p} a_i \right| < 1.0 \quad \text{(eq. 8)}$$

TFCAL applies this check and warns the user should a violation occur.

4.9. Model Interval, Structure and Order

These model properties of structure, order and interval are inter-related. The model order is defined as the total number of parameters in the model, the structure is the number of a parameters and b parameters and lag, and the model interval is the time interval that the model uses during operation.

The aim of model order determination carried out during calibration is to identify the optimal model structure i.e. that model structure which combines the desirable attributes of parametric economy and forecasting accuracy. In addition to the fact that it is unrealistic to estimate a large number of model parameters from a limited (and noisy) data set, parametric economy is also desirable because the model structure influences;

- the time spent computing forecasts (especially significant when a number of catchment models are running simultaneously in real-time),
- the number of past data items required (model memory) for forecasting, i.e. model demand for past data,

The optimal model structure can only be identified if the optimal model interval for the catchment is used. Deviation from the optimal interval either way may significantly influence model forecasting performance. Using a smaller interval than this will necessitate an increased number of parameters and a potentially poorer model (due to superfluous additional information), whilst a larger interval will result in fewer parameters and poorer model (due to significant information being lost or missed). In the rainfall-runoff process the optimal model interval is governed by catchment response dynamics and will vary from catchment to catchment.

Invariably a transfer function model will have fewer **a** parameters than **b** parameters, or an equal number of **a** and **b** parameters. The number of **b** parameters is a function of catchment lag and model interval, so that, for example, a catchment with a time to peak of ten hours will require approximately ten **b** parameters if a model with an interval of one hour is used, but only five parameters if the model interval be increased to two hours. This rule is a general guideline only.

4.10. Conclusions

This section has briefly described the lumped transfer function rainfall-runoff model. A great deal of more detailed documentation exists and is listed in the bibliography.

5. Model Calibration

The lumped transfer function model relates an input of areally averaged (causal) total rainfall to (resultant) runoff via an empirically derived input-output relationship determined by off-line calibration. Calibration consists of three parts: determination of the optimal model interval; identification of the optimal model structure (combining the ability to best describe the rainfall-runoff process with as few parameters as possible); and parameter estimation.

5.1. The Parameter Estimation Algorithm

At the core of the calibration program is a recursive least squares procedure which is used to estimate the model parameters for a specified model structure (i.e. the number of a and b parameters and lag). The algorithm sequentially steps through the rainfall and flow data pairs updating the parameter estimates at each, attempting to minimise the sum of the squares of the convolution error as it does so[2]. Typically the parameter estimates fluctuate initially, stabilising and converging to optimal estimates as process information is progressively extracted from the data.

5.2. Selection of Model Interval

The importance of model time interval is discussed in section 4.9. TFCAL can use any data interval (though the time interval for river and rainfall must be the same), and can estimate a model having any time interval (as long as this is a whole multiple of the data). Before the model parameters can be estimated a model interval is chosen. TFCAL incorporates an objective technique whereby the optimal model interval is determined by application of classical signal information theory. The technique used is a modified form of sample rules proposed by Isermann (1981), and subsequently extended to hydrological applications by Powell (1985); the optimal interval being determined from the summation of the unit impulse responses of a suite of (ten) transfer function models calibrated from the data.

The process need only be carried out once for each catchment calibration series (though should be repeated as the historic database develops), and for this reason the model interval determination algorithm is an option which

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[2] In order to test the adequacy of a model, the calibrated model is used to simulate the calibration flow sequence using the calibration rainfall data as model input. No observed flow data are fed back so that the convolution process provides a good indication of the representativeness of the model. This process can be likened to the unit hydrograph technique of flow simulation.

can be 'switched' on and off within the options menu of TFCAL (by default the option is switched off).

5.3. Determination of Optimal Model Structure

A crucial part of model calibration is determining the optimal model structure for the data: i.e. the model structure combining parametric economy (parsimony) with forecasting accuracy. Parsimonious models have a number of advantages, particularly in an operational environment where a large number of catchment models may be operating simultaneously on the same computer. Determination of optimal structure is intrinsically linked with the selection of model time interval described in section 5.2.

The recommended technique is the equal model order search which combines objective statistical measures and subjective interpretation with physical meaning in a hydrological context.

In the search, parameters are sequentially estimated for a 2,2 model structure then a 3,3 model and so forth until an increase in model order no longer results in a significant improvement in model accuracy. The process rarely has to be repeated beyond a 6,6 structure most catchments being adequately modelled with a model order less than eight.

A number of evaluation criteria are used:

- error statistics for the model convolution of the calibration data.
- model unit pulse response: physically viable in a hydrological context i.e. positive and stable.
- parameter redundancy, i.e. an unnecessarily high (over-specified) model order is indicated by very small parameters which have little influence on model output.

Once the optimal equal order model has been found an attempt can be made to reduce the model order further. Using the same subjective criteria applied in the equal model order search the number of a parameters is further reduced until the reduction results in an increase in modelling error. Usually the optimal structure has p<q, so that only the number of a parameters are reduced.

5.4. An Average Response Model

The calibrated model represents an average response model having a percentage runoff corresponding to the average percentage runoff of all the events used for calibration. It is inevitably a compromise. As the number of events used for calibration increases the models ability to produce high accuracy forecasts on average increases, whilst its performance in less typical flood conditions (i.e. those where the antecedent catchment condition or the rainfall profile, distribution or intensity departs significantly from the 'norm') falls.

As the number of historic events archived increases it may possible to calibrate a suite of models for use in specific catchment/storm conditions negating the need to continually manually 'tune' models as they forecast. successful implementation will be dependent on the timely recognition of storm and catchment characteristics which would be greatly aided by a decision support (expert) system incorporating pattern recognition procedures for radar images. This work is actively being researched at present within the Water Resources Research Group and preliminary results should emerge during 1990 and will be included in a future Technical Report.

6. Program Structure and Data Requirements

The determination of a good rainfall-runoff forecasting model is dependent on evolutionary calibration and periodical performance verification. TFCAL enables a transfer function model to be easily calibrated; first by identifying the optimal model structure and then by estimating the model parameters. This chapter describes the theoretical basis of the program, its structure, and the input and output files it uses.

6.1. Structure

The program has a simple structure and the code executes sequentially. The first part is an initialisation segment which is followed by an options block and a graphics modules. Before termination the results are written to an output file. An option to write a results summary to the screen during run-time exists. All graphics code is contained in subroutines and are called from the main program body. A full source code listing of TFCAL is provided in Appendix 1. The program flowchart in figure 2 illustrates the program structure which is also outlined below (for parameter estimation only):

- Character and array initialisation
- Welcome message
- Runtime options
- Determination of current device type (for UNIRAS graphics modules)
- Storm selection
- Read input data
- Selection of model structure
- Parameter estimation
- Graphical presentation model convolution and unit pulse response.
- Writing of results to output file and generation of .mod file (if required).

The hydrometric and gauging station/catchment data are read from the three input datafiles. The program then recursively estimates model parameters for the model structure selected by the user.

6.2. Input Data Files

The program uses three input data files, example listings of which are given in Appendices 2, 3, 4 and 5. Annotated diagrams of example rainfall and river (stage) datafiles showing the header block and the first few lines of data are shown in figures 5 and 6 and for the gauging station rating equations in figures 3 and 4.

The primary requirements are rainfall and river data for a given period. Care should be taken to ensure the validity of the data and that the datafiles are the same length, in phase, and spaced at a constant time interval.

The rainfall and river data files have an identical format. Essential information i.e. identification title, catchment name, gauging station name, data type (i.e. whether the data are rainfall, stage or flow), data time interval (minutes), number of events, end of event indicators, event times and durations are held in the header block. The data are read in 'free format' (though a format mirroring the example is recommended for user files). The river data can be stage or flow, the program recognising data type by virtue of the data-type flag in the header block; in the case of the former, the stage data are converted to flow using stage-discharge relationships stored in the third input datafile, the rating equation datafile.

The rating equation file contains the parameters used in the rating equation to convert stage to flow as well as the catchment area. It should be noted that the rating equation is always required even if the river data are already discharge since the catchment area is contained in this file; in this instance 'dummy arguments' are used (see figure 4).

6.3. Presentation of Results

Results presentation is controlled by the 'Options' program block, which controls the way results are presented during run-time and the format of the results output file. The settings contained in the Options Block are (default values in **bold**):

- results output file ? [**yes**/no]
- results summary to screen ? [**yes**/no]
- graphical output ? [**yes**/no]
- write rainfall and river data to the results output file ? [yes/**no**]
- determine optimal model interval ? [yes/**no**].

If required any of these settings can be changed during runtime when the program asks if the program default option settings need to be changed.

The graphic output is in two parts:
- model convolution with the calibration data
- model unit pulse response.

Forecasting results can be optionally written to a textual output results file. A listing of an example output file is provided in Appendix 5. In summary, the following are written to the file.

- catchment and gauging station name
- events used for calibration
- storm event rainfall and river flow data (only if selected in option block)
- calibration storm event characteristics: baseflow; maximum flow; total depth of rain; percentage runoff
- model characteristics: structure; estimated parameters; steady state gain; unit pulse response peak.
- calibration error statistics: mean, absolute mean and root mean square error; residual correlation; root mean square error of convolution.

If the optimal model interval determination option is used, the optimal interval for the data is written directly to screen and no output file is created.

7. Running the Program

The following is summary of the options that confront a user when the program parameter estimation option runs. A run-time listing of the program user-interface during program execution is provided in Appendix 9. A series of prompts sequentially leads the user through a program initialisation phase establishing filenames, reading input data, and opening a results output file (if required). Referral to the program flow chart (figure 2) may aid the reader.

7.1. Device type

At present six devices are explicitly supported by TFCAL (i.e. the device names appear in the program menu). However the machine independency of UNIRAS coupled with the large number of device drivers available means that TFCAL will run on many different device types. If you wish to run TFCAL on a device not displayed on the program menu contact the Water Resources Research Group indicating the UNIRAS (GROUTE) driver name for the device. This will then be incorporated in the code for a subsequent release version. A list of devices currently supported is provided in Appendix 10.

7.2. Output options

If any of the default output options need to be over-ridden or the user wishes to check the settings the user must reply 'yes' when the program prompts 'Do you want to view/change the current output settings'. The Options menu will then appear and can be viewed and amended as desired.

7.3. Individual storms

A model can be calibrated from any combination and number of storms. During run-time information read from the input datafiles is presented as a menu, facilitating storm selection for the calibration sequence.

7.4. Model interval

The data time intervals are read by the program from the input datafiles. TFCAL currently requires the rainfall and river data to have the same time interval and will report a run-time error if they are not. The data time interval forms the basis of the suggested forecasted intervals, and any interval which is a multiple of the data can be used (also see section 5.2. Selection of Model Interval).

7.5. Model time delay

If required a time delay can be incorporated into the model structure. The user is requested to enter the appropriate time delay in multiples of the model interval (i.e. if the model interval is 60 minutes, a lag of 2 corresponds to a lag of 120 minutes).

7.6. Model structure

The model structure i.e. number of a and b parameters is entered by the user.

7.7. Model convolution/unit impulse response plots

The model convolution of the calibration rainfall data can be drawn for comparison with the observed riverflow data. Also, the model unit impulse response of the model can be drawn.

7.8. Example Run-Time Session

An example run-time session (shown in Appendix 9) illustrates the use of TFCAL. The selected options for this run are summarised below.

To summarise the options selected during the example run:
Change option settings so that rainfall and riverflow data are written to output file.
Graphics device driver selected = ReGIS.
Input rating equation datafile = fot.sdc.
Input rainfall datafile = fotheringhay.rai.
Input river datafile = fotheringhay.sta.
4 storm events selected for calibration (storm numbers 1, 2, 3 and 5).
Model interval=240 minutes (4 hours).
No time delay.
2 **a** parameters and 3 **b** parameters.

Generate a .mod file : name=fotheringhay.mod : Header information = Fotheringhay model parameters storms 1, 2, 3 and 5.
Model convolution plot.
Model unit impulse response plot.

STOP

A run-time listing is also provided for the model interval determination mode (Appendix 8). This option is simpler and requires only the input datafile names to be entered by the user.

8. Conclusions

This report is a users guide to the FORTRAN software package TFCAL, a program for the off-line calibration of simple lumped transfer function rainfall-runoff models. The report contains listings of full source code and input and output datafiles; all of which are contained on the software distribution disk.

The transfer function model has been developed over a number of years by Professor Ian Cluckie and his research team, and is currently being implemented for a number of Water Authorities in the U.K. The model structure is well documented elsewhere, and the explanatory notes in the document are kept to a minimum. A bibliography lists references where further information can be sourced.

TFCAL is an interactive, user-friendly program featuring user selected options and a powerful graphics front-end. The structure of the program is described and illustrated with a flowchart. Data requirements are explicitly described. Results may be presented graphically and/or written to a results output file.

A runtime listing is provided and described in the text, and the user options are described.

A bibliography is provided if further information on related topics is required.

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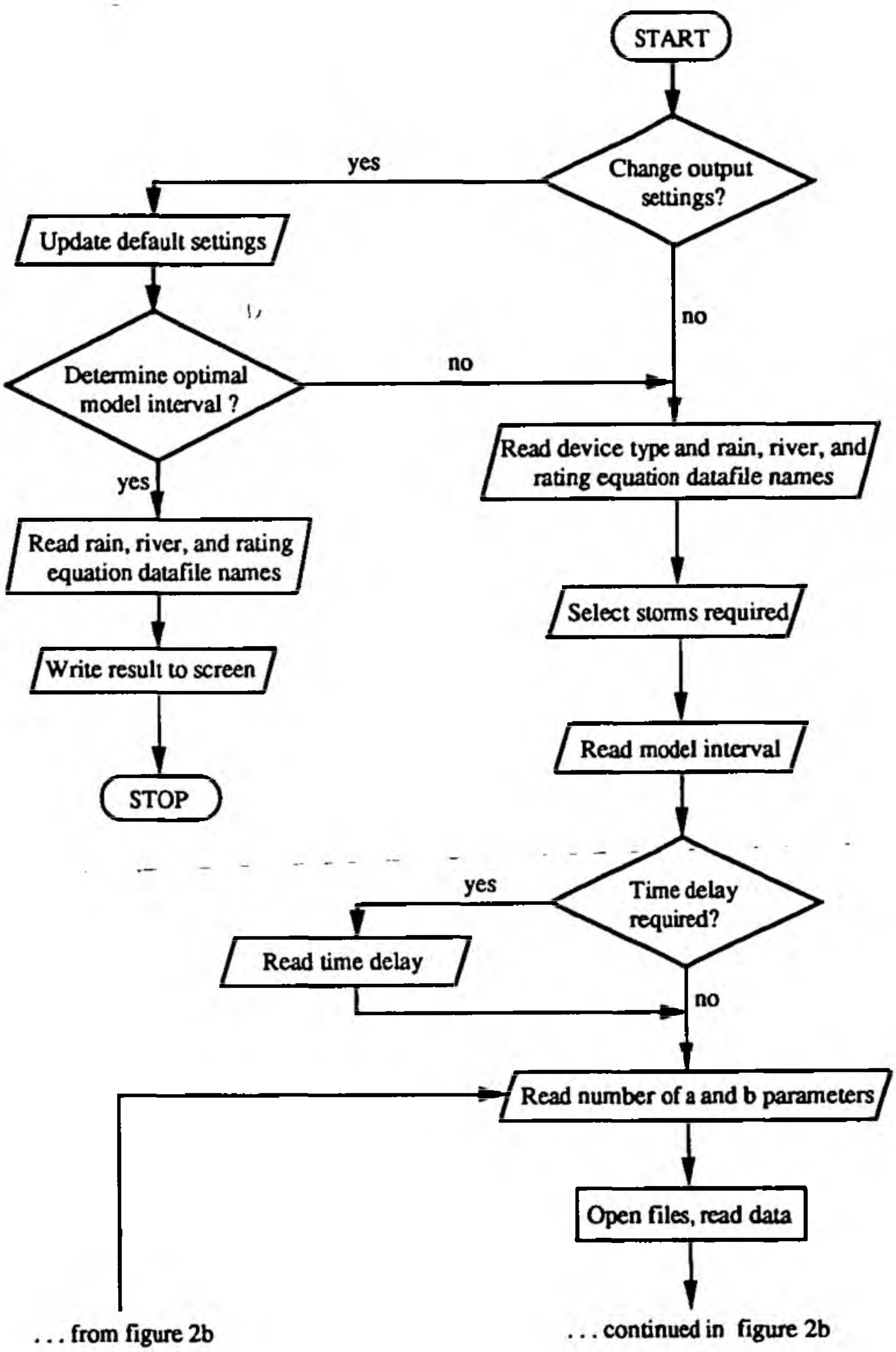


FIGURE 2a: Flow Chart for TFCAL (i)

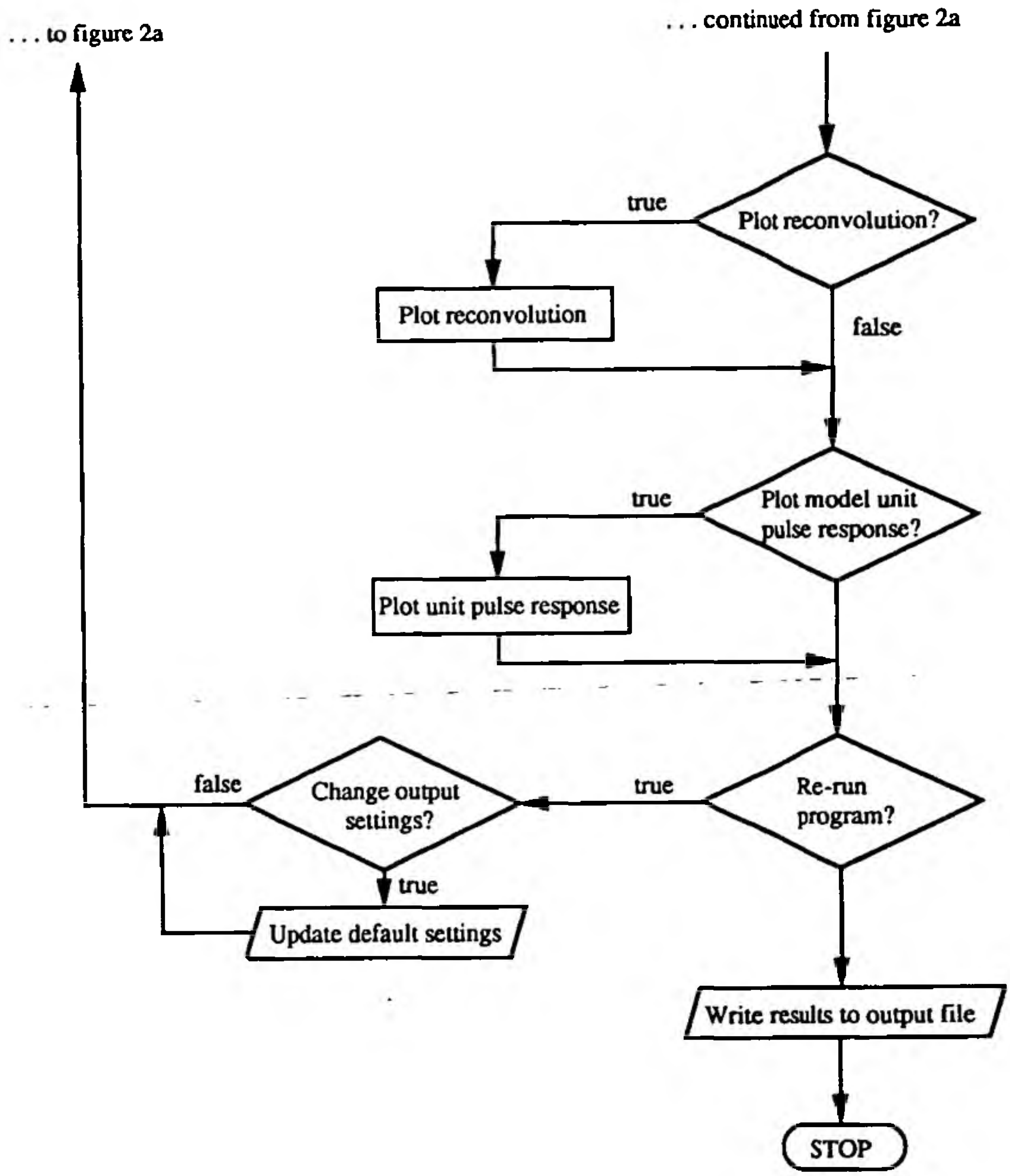


FIGURE 2b: <u>Flow Chart for TFCAL (ii)</u>

Title block (A60): any useful information

Rating Equation for FOTHERINGHAY, Willow Brook

Number of segments in rating equation → 4

Rating equation parameters: Maximum stage (m), a,h and b

0.1370,	3.2142,	0.0012,	1.5413
0.3770,	2.9942,	0.0003,	1.5002
1.2940,	3.0029,	-0.0009,	1.4984
5.0000,	2.9858,	0.0031,	1.5030

Catchment area (sq km) → 89.62

FIGURE 3: Example Rating Equation Datafile: Stage Data

Title block (A60): any useful information

```
Rating Equation for FOTHERINGHAY, Willow Brook
1
0.0,  0.0,  0.0,  0.0
89.62
```

- **'Dummy' number of segments in rating equation** → 1
- **'Dummy' rating equation parameters** → 0.0, 0.0, 0.0, 0.0
- **Catchment area (sq km)** → 89.62

FIGURE 4: Example Rating Equation Datafile: Discharge Data

Data Type Flag (RAIN, STAGE or DISCHARGE) read as 2X, A4

Title block (A60): any useful information

```
All available data (since 1985)
Willow Brook
FOTHERINGHAY
RAIN
15
5
272     06/06/85 04:00 - 08/06/85 23:45    68hrs
792     08/10/87 22:00 - 14/10/87 07:45   130hrs
1240    14/10/87 08:00 - 19/10/87 00:00   112hrs
1432    20/05/86 00:00 - 21/05/86 23:45    48hrs
1616    08/05/88 00:00 - 09/05/88 21:45    46hrs

  0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.005
  0.006    0.009    0.006    0.012    0.016    0.028    0.033    0.033
  0.011    0.011    0.026    0.028    0.054    0.093    0.108    0.162
  0.253    0.344    0.402    0.398    0.400    0.406    0.395    0.416
  0.431    0.370    0.239    0.166    0.127    0.099    0.075    0.061
  0.037    0.022    0.015    0.006    0.000    0.000    0.000    0.001
  0.001    0.000    0.000    0.000    0.001    0.003    0.007    0.004
```

Catchment name, 2x, a31

Gauging station, 2x, a31

Data interval (minutes)

Number of storms

End of storm indicator, event times and duration 2x,i4,a31,i6

First 7 Lines of Data (read in free format)

FIGURE 5: <u>Example Rainfall Datafile</u>

```
All available data (since 1985)
Willow Brook
FOTHERINGHAY
STAGE
15
5
272     06/06/85 04:00 - 08/06/85 23:45     68hrs
792     08/10/87 22:00 - 14/10/87 07:45    130hrs
1240    14/10/87 08:00 - 19/10/87 00:00    112hrs
1432    20/05/86 00:00 - 21/05/86 23:45     48hrs
1616    08/05/88 00:00 - 09/05/88 21:45     46hrs

  0.438    0.440    0.438    0.439    0.440    0.440    0.439    0.439
  0.438    0.439    0.436    0.439    0.437    0.439    0.436    0.435
  0.437    0.433    0.434    0.433    0.433    0.433    0.433    0.432
  0.432    0.431    0.432    0.434    0.432    0.438    0.439    0.441
  0.441    0.443    0.443    0.445    0.448    0.452    0.456    0.458
  0.460    0.465    0.465    0.471    0.476    0.479    0.487    0.489
  0.493    0.496    0.500    0.503    0.507    0.512    0.517    0.522
```

Title block (A60): any useful information (line 1: All available data (since 1985))

Catchment name, 2x, a31 (line 2: Willow Brook)

Gauging station, 2x, a31 (line 3: FOTHERINGHAY)

Data Type Flag (RAIN, STAGE or DISCHARGE) read as 2X, A4 (line 4: STAGE)

Data interval (minutes) (line 5: 15)

Number of storms (line 6: 5)

End of storm indicator, event times and duration 2x,i4,a31,i6 (storm lines 272 to 1616)

First 7 Lines of Data (read in free format) (last seven lines, 0.438 to 0.522)

FIGURE 6: <u>Example River Datafile: Stage Data</u>

Appendices

Appendix 1	TFCAL Source Code Listing
Appendix 2	Example Rainfall Datafile
Appendix 3	Example River Datafile
Appendix 4	Example Rating Equation Datafile: Stage Data
Appendix 5	Example Rating Equation Datafile: Discharge Data
Appendix 6	Example Results Ouput File
Appendix 7	Example .mod Ouput File
Appendix 8	Runtime Listing of TFCAL: Model Interval Determination
Appendix 9	Runtime Listing of TFCAL: Parameter Estimation
Appendix 10	Devices Supported

Appendix 2: Example Rainfall Datafile

```
All available data (since 1985)
Willow Brook
FOTHERINGHAY
RAIN
15
5
272     06/06/85 04:00 - 08/06/85 23:45    68hrs
792     08/10/87 22:00 - 14/10/87 07:45   130hrs
1240    14/10/87 08:00 - 19/10/87 00:00   112hrs
1432    20/05/86 00:00 - 21/05/86 23:45    48hrs
1616    08/05/88 00:00 - 09/05/88 21:45    46hrs

   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.005
   0.006    0.009    0.006    0.012    0.016    0.028    0.033    0.033
   0.011    0.011    0.026    0.028    0.054    0.093    0.108    0.162
   0.253    0.344    0.402    0.398    0.400    0.406    0.395    0.416
   0.431    0.370    0.239    0.166    0.127    0.099    0.075    0.061
   0.037    0.022    0.015    0.006    0.000    0.000    0.000    0.001
   0.001    0.000    0.000    0.000    0.001    0.003    0.007    0.004
   0.005    0.006    0.007    0.018    0.078    0.197    0.272    0.317
   0.247    0.180    0.204    0.157    0.135    0.176    0.335    0.512
   0.710    0.610    0.470    0.345    0.346    0.301    0.225    0.217
   0.160    0.087    0.080    0.126    0.206    0.235    0.247    0.163
   0.202    0.219    0.181    0.181    0.177    0.196    0.176    0.138
   0.226    0.259    0.170    0.113    0.168    0.160    0.123    0.127
   0.120    0.065    0.045    0.051    0.098    0.088    0.054    0.028
   0.012    0.015    0.015    0.022    0.036    0.020    0.058    0.073
   0.130    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.010    0.006    0.005    0.003    0.001
   0.000    0.000    0.000    0.016    0.021    0.009    0.001    0.001
   0.027    0.066    0.082    0.039    0.008    0.007    0.029    0.145
   0.289    0.315    0.295    0.221    0.137    0.061    0.051    0.061
   0.128    0.170    0.136    0.104    0.061    0.016    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.001    0.000    0.000    0.006    0.025    0.004
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.000    0.001    0.001
   0.000    0.013    0.025    0.010    0.008    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.001    0.000    0.000    0.012    0.026    0.012    0.030    0.021
   0.018    0.012    0.005    0.041    0.062    0.058    0.045    0.046
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.002    0.001    0.029    0.179    0.236    0.114    0.002
   0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.006    0.010    0.001
   0.061    0.028    0.129    0.291    0.010    0.000    0.000    0.000
   0.000    0.000    0.001    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.000    0.000    0.004    0.000    0.064
   0.228    0.025    0.004    0.002    0.003    0.005    0.116    0.458
   0.144    0.001    0.000    0.000    0.002    0.000    0.000    0.000
   0.001    0.000    0.000    0.000    0.000    0.000    0.000    0.000
   0.000    0.000    0.000    0.001    0.067    0.268    0.000    0.000
   0.000    0.009    0.069    0.032    0.127    0.746    1.879    2.042
   2.084    0.930    0.335    1.365    2.817    1.220    0.036    0.078
```

0.069	0.058	0.116	0.247	0.187	0.043	0.002	0.000
0.000	0.000	0.044	1.006	0.280	0.497	0.570	0.276
0.925	1.958	2.422	1.135	1.179	1.694	1.420	0.264
0.150	0.186	0.250	0.326	0.605	0.818	0.545	0.240
0.205	0.196	0.119	0.196	0.032	0.032	0.012	0.008
0.005	0.119	0.191	0.173	0.114	0.106	0.075	0.076
0.062	0.027	0.116	0.132	0.124	0.102	0.074	0.161
0.206	0.224	0.238	0.207	0.094	0.026	0.004	0.105
0.101	0.050	0.057	0.109	0.133	0.159	0.078	0.043
0.063	0.028	0.020	0.009	0.006	0.017	0.008	0.019
0.032	0.049	0.030	0.027	0.086	0.066	0.080	0.046
0.031	0.022	0.007	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.001	0.008	0.004	0.001	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.004	0.000	0.002	0.007	0.028
0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.028	0.062	0.065	0.013	0.007	0.014
0.018	0.015	0.025	0.060	0.106	0.162	0.117	0.043
0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.007
0.009	0.001	0.001	0.005	0.001	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.020	0.062	0.011	0.003	0.000	0.000	0.000
0.000	0.026	0.071	0.106	0.000	0.001	0.005	0.028
0.028	0.026	0.050	0.043	0.056	0.039	0.053	0.051
0.151	0.371	0.368	0.302	0.186	0.091	0.002	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.016
0.015	0.065	0.064	0.125	0.207	0.320	0.273	0.194
0.651	0.342	0.781	1.639	1.562	0.151	0.024	0.003
0.000	0.000	0.002	0.020	0.011	0.145	0.158	0.252
1.000	1.471	0.728	0.359	0.002	0.140	0.090	0.004
0.000	0.121	0.308	0.055	0.000	0.000	0.001	0.138
0.157	0.295	0.723	0.018	0.000	0.000	0.011	0.471
1.207	0.420	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.013	0.021	0.024	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.003	0.028	0.025	0.000	0.000	0.001	0.045	0.212
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.037	0.060	0.063
0.180	0.397	0.240	0.275	0.199	0.000	0.000	0.011
0.037	0.059	0.039	0.007	0.069	0.008	0.149	0.266
0.718	0.208	0.727	1.373	0.888	0.632	0.332	0.373
0.999	0.901	0.066	0.009	0.000	0.012	0.001	0.000
0.014	0.032	0.017	0.043	0.101	0.026	0.258	0.156
1.183	0.383	0.075	0.020	0.093	0.029	0.222	0.730
1.359	0.826	0.018	0.000	0.000	0.000	0.000	0.000
0.003	0.073	0.087	0.186	0.496	0.375	0.035	0.002
0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007
0.008	0.006	0.193	0.394	0.311	0.156	0.113	0.104
0.040	0.022	0.002	0.000	0.000	0.000	0.000	0.000

0.031	0.054	0.248	0.249	0.132	0.067	0.011	0.043
0.036	0.004	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.004	0.028	0.084	0.127	0.197	0.315
0.615	0.877	0.935	0.992	1.877	2.914	3.410	2.901
1.025	0.504	0.194	0.096	0.059	0.112	0.160	0.202
0.161	0.037	0.003	0.001	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.029	0.072	0.000	0.042	0.123
0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 3: Example River Datafile

```
All available data (since 1985)
Willow Brook
FOTHERINGHAY
STAGE
15
5
272     06/06/85 04:00 - 08/06/85 23:45     68hrs
792     08/10/87 22:00 - 14/10/87 07:45    130hrs
1240    14/10/87 08:00 - 19/10/87 00:00    112hrs
1432    20/05/86 00:00 - 21/05/86 23:45     48hrs
1616    08/05/88 00:00 - 09/05/88 21:45     46hrs
```

0.438	0.440	0.438	0.439	0.440	0.440	0.439	0.439
0.438	0.439	0.436	0.439	0.437	0.439	0.436	0.435
0.437	0.433	0.434	0.433	0.433	0.433	0.433	0.432
0.432	0.431	0.432	0.434	0.432	0.438	0.439	0.441
0.441	0.443	0.443	0.445	0.448	0.452	0.456	0.458
0.460	0.465	0.465	0.471	0.476	0.479	0.487	0.489
0.493	0.496	0.500	0.503	0.507	0.512	0.517	0.522
0.526	0.531	0.535	0.542	0.546	0.551	0.556	0.561
0.565	0.567	0.574	0.581	0.584	0.590	0.595	0.603
0.606	0.615	0.622	0.631	0.642	0.651	0.663	0.677
0.689	0.701	0.714	0.726	0.737	0.751	0.759	0.772
0.787	0.805	0.820	0.834	0.847	0.863	0.879	0.896
0.912	0.924	0.936	0.946	0.960	0.970	0.988	1.002
1.013	1.027	1.039	1.052	1.066	1.082	1.095	1.109
1.122	1.132	1.144	1.155	1.161	1.167	1.176	1.186
1.190	1.198	1.201	1.206	1.210	1.210	1.212	1.215
1.215	1.217	1.217	1.214	1.213	1.208	1.205	1.199
1.193	1.186	1.180	1.176	1.170	1.161	1.151	1.146
1.139	1.135	1.124	1.115	1.109	1.104	1.095	1.091
1.082	1.077	1.075	1.069	1.065	1.060	1.059	1.050
1.047	1.040	1.037	1.032	1.026	1.023	1.018	1.010
1.007	1.002	1.000	0.995	0.991	0.987	0.985	0.981
0.973	0.969	0.967	0.963	0.959	0.955	0.950	0.946
0.944	0.938	0.935	0.930	0.922	0.923	0.916	0.911
0.909	0.900	0.895	0.888	0.885	0.880	0.874	0.871
0.866	0.858	0.852	0.847	0.842	0.835	0.831	0.827
0.824	0.819	0.815	0.812	0.805	0.799	0.793	0.787
0.783	0.779	0.775	0.772	0.769	0.768	0.765	0.765
0.761	0.759	0.757	0.754	0.749	0.745	0.746	0.741
0.739	0.735	0.734	0.730	0.726	0.724	0.721	0.720
0.716	0.713	0.710	0.707	0.705	0.702	0.698	0.696
0.693	0.689	0.687	0.685	0.680	0.677	0.675	0.672
0.668	0.665	0.664	0.660	0.658	0.655	0.651	0.651
0.648	0.647	0.643	0.640	0.639	0.636	0.633	0.631
0.464	0.463	0.463	0.462	0.460	0.458	0.457	0.456
0.456	0.455	0.455	0.452	0.451	0.450	0.449	0.447
0.446	0.445	0.443	0.443	0.442	0.442	0.441	0.439
0.438	0.437	0.435	0.436	0.438	0.441	0.443	0.439
0.435	0.434	0.433	0.432	0.429	0.427	0.426	0.424
0.422	0.420	0.418	0.415	0.413	0.411	0.409	0.407
0.405	0.403	0.401	0.399	0.397	0.395	0.394	0.391
0.390	0.387	0.386	0.385	0.383	0.383	0.382	0.383
0.383	0.388	0.391	0.402	0.402	0.400	0.402	0.405
0.405	0.403	0.402	0.402	0.403	0.406	0.408	0.410
0.414	0.417	0.422	0.426	0.431	0.437	0.445	0.454

0.463	0.472	0.481	0.488	0.496	0.500	0.504	0.509
0.512	0.515	0.519	0.524	0.526	0.528	0.530	0.533
0.538	0.543	0.548	0.554	0.561	0.570	0.589	0.607
0.616	0.626	0.638	0.653	0.671	0.689	0.709	0.728
0.749	0.772	0.795	0.815	0.840	0.860	0.880	0.901
0.916	0.930	0.945	0.959	0.972	0.988	1.006	1.022
1.036	1.052	1.069	1.087	1.102	1.119	1.136	1.154
1.173	1.189	1.210	1.226	1.244	1.270	1.287	1.301
1.309	1.319	1.329	1.338	1.347	1.355	1.363	1.370
1.381	1.389	1.395	1.402	1.411	1.418	1.424	1.430
1.433	1.438	1.442	1.445	1.446	1.446	1.447	1.447
1.448	1.446	1.445	1.444	1.443	1.440	1.437	1.434
1.429	1.426	1.422	1.414	1.409	1.400	1.394	1.387
1.378	1.370	1.363	1.353	1.346	1.335	1.328	1.319
1.309	1.298	1.289	1.279	1.268	1.256	1.247	1.237
1.226	1.215	1.204	1.193	1.182	1.174	1.162	1.151
1.140	1.130	1.121	1.111	1.102	1.091	1.082	1.075
1.065	1.058	1.050	1.042	1.037	1.030	1.026	1.022
1.018	1.017	1.014	1.013	1.013	1.012	1.011	1.011
1.010	1.010	1.008	1.007	1.006	1.004	1.002	0.999
0.998	0.996	0.994	0.991	0.987	0.984	0.982	0.978
0.974	0.972	0.968	0.965	0.959	0.956	0.952	0.949
0.943	0.940	0.936	0.931	0.927	0.922	0.917	0.912
0.908	0.904	0.899	0.894	0.890	0.885	0.880	0.875
0.871	0.866	0.862	0.858	0.854	0.848	0.843	0.841
0.834	0.830	0.826	0.820	0.815	0.810	0.806	0.801
0.796	0.793	0.787	0.782	0.778	0.774	0.770	0.764
0.760	0.755	0.750	0.747	0.742	0.739	0.733	0.728
0.724	0.719	0.714	0.710	0.705	0.699	0.695	0.691
0.687	0.683	0.678	0.675	0.671	0.666	0.662	0.658
0.654	0.650	0.647	0.642	0.638	0.635	0.630	0.628
0.624	0.621	0.618	0.614	0.611	0.609	0.606	0.603
0.600	0.598	0.595	0.593	0.590	0.588	0.586	0.584
0.582	0.580	0.578	0.575	0.574	0.572	0.569	0.568
0.566	0.564	0.562	0.562	0.559	0.558	0.556	0.554
0.553	0.552	0.550	0.549	0.549	0.547	0.546	0.545
0.544	0.543	0.542	0.542	0.540	0.539	0.538	0.537
0.535	0.534	0.533	0.532	0.530	0.530	0.528	0.527
0.526	0.524	0.523	0.522	0.521	0.520	0.519	0.517
0.516	0.515	0.513	0.512	0.511	0.509	0.509	0.507
0.506	0.504	0.503	0.501	0.501	0.499	0.498	0.497
0.497	0.496	0.494	0.494	0.492	0.491	0.490	0.489
0.489	0.488	0.487	0.486	0.485	0.485	0.485	0.485
0.485	0.485	0.485	0.484	0.483	0.482	0.482	0.482
0.481	0.481	0.480	0.479	0.478	0.477	0.477	0.475
0.475	0.474	0.474	0.473	0.472	0.471	0.471	0.470
0.470	0.469	0.469	0.468	0.468	0.467	0.466	0.466
0.466	0.465	0.465	0.464	0.463	0.462	0.462	0.461
0.461	0.460	0.459	0.458	0.458	0.458	0.457	0.456
0.455	0.455	0.454	0.454	0.453	0.453	0.452	0.451
0.451	0.450	0.449	0.449	0.449	0.449	0.448	0.447
0.446	0.446	0.445	0.445	0.444	0.443	0.442	0.441
0.441	0.440	0.440	0.439	0.438	0.438	0.438	0.438
0.437	0.436	0.435	0.435	0.434	0.434	0.433	0.433
0.432	0.431	0.431	0.430	0.429	0.429	0.428	0.427
0.426	0.425	0.424	0.423	0.422	0.422	0.421	0.420
0.420	0.419	0.419	0.419	0.418	0.418	0.418	0.418
0.418	0.418	0.417	0.417	0.417	0.418	0.418	0.418
0.418	0.419	0.420	0.420	0.420	0.420	0.420	0.420
0.420	0.420	0.420	0.419	0.420	0.419	0.419	0.420
0.420	0.420	0.421	0.421	0.421	0.421	0.419	0.420
0.420	0.420	0.421	0.422	0.424	0.425	0.426	0.426
0.426	0.427	0.427	0.427	0.427	0.429	0.429	0.430

0.430	0.433	0.434	0.436	0.438	0.439	0.442	0.444
0.446	0.447	0.449	0.450	0.453	0.454	0.457	0.459
0.461	0.462	0.465	0.466	0.468	0.470	0.472	0.475
0.478	0.480	0.483	0.485	0.486	0.489	0.490	0.492
0.494	0.497	0.499	0.502	0.505	0.507	0.511	0.515
0.518	0.521	0.525	0.530	0.536	0.542	0.549	0.557
0.564	0.571	0.580	0.589	0.599	0.611	0.625	0.638
0.651	0.663	0.676	0.692	0.709	0.726	0.743	0.760
0.777	0.796	0.811	0.826	0.842	0.858	0.878	0.897
0.922	0.949	0.978	1.006	1.032	1.059	1.083	1.112
1.139	1.166	1.188	1.213	1.236	1.257	1.279	1.301
1.319	1.340	1.355	1.374	1.390	1.404	1.417	1.434
1.449	1.462	1.474	1.485	1.494	1.504	1.513	1.519
1.523	1.533	1.537	1.545	1.550	1.556	1.562	1.571
1.578	1.586	1.593	1.600	1.605	1.612	1.620	1.629
1.635	1.642	1.646	1.651	1.654	1.657	1.660	1.664
1.666	1.667	1.669	1.670	1.671	1.673	1.674	1.675
1.675	1.675	1.675	1.675	1.675	1.674	1.672	1.670
1.667	1.664	1.659	1.653	1.645	1.633	1.620	1.601
1.583	1.568	1.550	1.529	1.510	1.490	1.469	1.449
1.430	1.412	1.394	1.375	1.357	1.338	1.322	1.306
1.290	1.275	1.258	1.244	1.230	1.216	1.202	1.189
1.177	1.166	1.155	1.143	1.133	1.123	1.113	1.103
1.093	1.082	1.074	1.065	1.056	1.049	1.042	1.034
1.028	1.021	1.015	1.007	1.001	0.994	0.987	0.981
0.973	0.968	0.962	0.956	0.951	0.944	0.938	0.932
0.927	0.918	0.911	0.904	0.897	0.890	0.885	0.879
0.874	0.868	0.862	0.857	0.851	0.846	0.840	0.834
0.830	0.825	0.821	0.816	0.811	0.807	0.803	0.799
0.794	0.790	0.786	0.782	0.778	0.773	0.770	0.766
0.763	0.759	0.755	0.752	0.748	0.744	0.741	0.737
0.734	0.730	0.727	0.724	0.720	0.717	0.714	0.710
0.708	0.705	0.702	0.699	0.697	0.694	0.691	0.689
0.686	0.683	0.680	0.678	0.674	0.672	0.670	0.667
0.665	0.662	0.659	0.657	0.654	0.652	0.650	0.648
0.646	0.644	0.642	0.640	0.638	0.635	0.632	0.630
0.629	0.627	0.624	0.622	0.619	0.617	0.615	0.614
0.611	0.610	0.608	0.605	0.603	0.600	0.598	0.596
0.594	0.591	0.590	0.588	0.586	0.585	0.584	0.583
0.581	0.579	0.578	0.575	0.574	0.573	0.571	0.569
0.566	0.566	0.565	0.562	0.561	0.558	0.557	0.556
0.554	0.553	0.551	0.550	0.549	0.548	0.547	0.546
0.545	0.544	0.543	0.542	0.542	0.540	0.540	0.538
0.538	0.537	0.536	0.535	0.535	0.534	0.533	0.533
0.532	0.531	0.530	0.529	0.529	0.528	0.527	0.526
0.526	0.525	0.524	0.524	0.524	0.523	0.522	0.522
0.522	0.521	0.521	0.520	0.520	0.519	0.519	0.518
0.468	0.469	0.472	0.473	0.476	0.479	0.482	0.484
0.484	0.485	0.488	0.492	0.492	0.493	0.494	0.496
0.498	0.502	0.506	0.510	0.523	0.541	0.546	0.542
0.549	0.555	0.556	0.564	0.572	0.594	0.621	0.657
0.711	0.761	0.808	0.870	0.953	1.026	1.071	1.101
1.118	1.128	1.135	1.140	1.147	1.157	1.167	1.181
1.196	1.213	1.232	1.247	1.254	1.260	1.257	1.258
1.261	1.260	1.260	1.266	1.272	1.277	1.284	1.290
1.295	1.300	1.308	1.308	1.314	1.317	1.321	1.322
1.327	1.332	1.332	1.340	1.340	1.341	1.344	1.348
1.350	1.356	1.359	1.362	1.364	1.365	1.363	1.359
1.358	1.357	1.354	1.346	1.342	1.337	1.333	1.327
1.320	1.315	1.309	1.302	1.294	1.285	1.279	1.267
1.261	1.251	1.245	1.234	1.229	1.217	1.213	1.206
1.200	1.193	1.186	1.181	1.178	1.173	1.168	1.165
1.161	1.154	1.150	1.143	1.138	1.132	1.125	1.114

1.108	1.100	1.097	1.085	1.082	1.075	1.069	1.064
1.058	1.054	1.050	1.044	1.039	1.035	1.031	1.025
1.022	1.015	1.010	1.006	1.002	0.996	0.993	0.989
0.986	0.981	0.979	0.973	0.970	0.969	0.964	0.960
0.958	0.956	0.953	0.949	0.946	0.945	0.940	0.939
0.937	0.935	0.934	0.931	0.929	0.928	0.925	0.924
0.922	0.920	0.917	0.917	0.913	0.909	0.906	0.902
0.900	0.898	0.897	0.896	0.894	0.892	0.890	0.889
0.545	0.545	0.545	0.545	0.545	0.545	0.545	0.545
0.545	0.545	0.545	0.545	0.545	0.545	0.545	0.545
0.545	0.545	0.545	0.545	0.545	0.545	0.545	0.545
0.545	0.545	0.545	0.545	0.545	0.545	0.545	0.545
0.545	0.545	0.545	0.545	0.544	0.543	0.543	0.542
0.542	0.543	0.543	0.543	0.545	0.549	0.554	0.559
0.565	0.573	0.583	0.602	0.645	0.733	0.864	0.998
1.110	1.207	1.284	1.340	1.384	1.417	1.442	1.460
1.473	1.481	1.488	1.493	1.497	1.500	1.498	1.492
1.482	1.471	1.456	1.439	1.422	1.404	1.385	1.365
1.346	1.329	1.313	1.297	1.277	1.251	1.219	1.181
1.140	1.100	1.061	1.029	1.001	0.976	0.954	0.936
0.921	0.907	0.895	0.885	0.875	0.867	0.860	0.853
0.849	0.843	0.838	0.833	0.828	0.824	0.820	0.816
0.811	0.807	0.801	0.797	0.791	0.786	0.782	0.776
0.771	0.765	0.760	0.755	0.750	0.745	0.740	0.734
0.729	0.725	0.721	0.716	0.712	0.709	0.705	0.701
0.698	0.694	0.692	0.689	0.686	0.685	0.682	0.681
0.680	0.680	0.679	0.679	0.678	0.678	0.678	0.678
0.677	0.676	0.676	0.674	0.674	0.673	0.671	0.670
0.668	0.667	0.665	0.664	0.661	0.660	0.658	0.656
0.654	0.651	0.649	0.647	0.645	0.642	0.640	0.638
0.636	0.633	0.632	0.629	0.627	0.625	0.623	0.620

Appendix 4: Example Rating Equation Datafile: Stage Data

```
Rating Equation for FOTHERINGHAY, Willow Brook (stage)
4
0.1370,  3.2142,  0.0012,  1.5413
0.3770,  2.9942,  0.0003,  1.5002
1.2940,  3.0029, -0.0009,  1.4984
5.0000,  2.9858,  0.0031,  1.5030
89.62
```

Appendix 5: Example Rating Equation Datafile: Discharge Data

```
Rating Equation for FOTHERINGHAY, Willow Brook (discharge)
1
0.00,  0.00,  0.00,  0.00
89.62
```

Appendix 6: Example Results Output File

```
Estimation of Rainfall-Runoff Model: Output File
------------------------------------------------

River catchment : Willow Brook
Gauging station : FOTHERINGHAY


Events used for calibration :
--------------------------

  06/06/85 04:00 - 08/06/85 23:45
  08/10/87 22:00 - 14/10/87 07:45
  14/10/87 08:00 - 19/10/87 00:00
  08/05/88 00:00 - 09/05/88 21:45


Rainfall, mm
 0.148    3.507    1.649    0.916    5.170    2.774    1.895    0.381
 0.073    1.833    0.615    0.036    0.000    0.000    0.002    0.056
 0.389    0.563    0.017    0.520    0.909    0.148    5.240    9.587
13.670    3.920    1.657    1.834    0.586    0.060    0.000    0.000
 0.004    0.000    0.000    0.000    0.014    0.000    0.000    0.060
 0.000    0.189    0.548    0.000    0.000    0.026    0.000    0.000
 0.000    0.000    0.000    0.000    0.333    1.817    0.000    0.000
 0.018    6.416    4.382    2.298    1.627    0.000    0.000    0.000
 0.000    0.000    0.000    0.000    0.000    0.000    0.000    0.000
 0.000    0.000    0.000    0.000    0.058    0.314    0.755   16.873
 0.202    0.266    0.012    0.000    0.000    0.000    0.000    0.000
 0.000

River discharge, cumecs
 0.860    0.878    1.025    1.260    1.670    2.543    3.502    4.016
 3.679    3.227    2.914    2.608    2.255    2.007    1.832    1.652
 1.503    0.896    0.872    0.778    0.710    0.787    1.089    1.418
 2.565    3.717    4.809    5.220    4.898    4.125    3.342    3.048
 2.900    2.612    2.313    2.003    1.723    1.492    1.338    1.236
 1.180    1.115    1.050    1.013    0.981    0.954    0.923    0.896
 0.869    0.836    0.810    0.816    0.816    0.845    0.932    1.035
 1.246    1.987    3.516    5.149    5.905    6.437    6.472    5.230
 3.888    3.153    2.698    2.284    2.011    1.794    1.634    1.499
 1.380    1.287    1.210    1.167    1.131    1.206    1.206    1.196
 2.990    5.465    3.849    2.363    2.050    1.760    1.674    1.593
 1.464

 89 Data Values



Event Characteristics
--------------------

Event    Baseflow    Max Flow    Total Rain    % Runoff
1)        0.9          4.0         19.4         18.8
2)        0.7          5.2         39.6         16.3
3)        0.8          6.5         16.9         42.2
4)        1.2          5.5         18.4         10.9
```

```
Average    0.9          5.3         23.6         22.0


Model Characteristics
---------------------

Structure  2, 3, 0
Parameters :
a 1)   1.4188
a 2)  -0.4977
b 1)   0.0835
b 2)   0.0964
b 3)  -0.0946

Model percentage runoff =17.36%

Impulse response peak of   0.21 at time  8.00


Error Analysis
--------------

Errors in one step-ahead forecast :
Mean error               =  -0.019
Absolute mean error      =   0.166
Root mean square error   =   0.280

Correlation of residuals :
  95% significance level
   0.214,     0.465,     0.842,     0.854,     0.905,
   0.923,     0.965,     0.996,     1.003,     1.012,
   1.019,     1.027,     1.034,     1.041,     1.353,
  Actual
  -2.287,    -0.349,     0.915,     0.493,    -0.826,
  -0.708,    -0.071,     0.227,     0.035,    -0.117,
  -0.062,    -0.019,     0.238,     6.644,

RMSE of model convolution
  1,  0.45   2,  0.45   3,  1.47   4,  0.67


------------------------  End of output file  -------------------
```

Appendix 7: <u>Example .mod Outputfile</u>

```
Fotheringhay Model Parameters: Storms 1,2,3, and 5.
2  3  0
1.4188 -0.4977  0.0835  0.0964 -0.0946
240
89.62
1
0
4
0.1370  3.2142  0.0012  1.5413
0.3770  2.9942  0.0003  1.5002
1.2940  3.0029 -0.0009  1.4984
5.0000  2.9858  0.0031  1.5030
```

Appendix 8: Runtime Listing of TFCAL: Model Interval Determination

The following is a runtime listing of TFCAL used to determine the optimal model interval for a given catchment, as described in section 7 of the main report.

Bolded text indicates user input.

```
$run  tfcal

  ----------------------------------------------------------------------

                                TFCAL

  A program to identify and calibrate simple linear transfer function
  model for real-time flood forecasting.

  Written by:
     Water Resources Research Group
     University of Salford
     Salford, M5 4WT
     England, U.K.

  ----------------------------------------------------------------------


  Do you want to view/change option settings ? [Y/N]...
y

  Options Menu
  ------------

  Options (default in UPPER CASE)

  1. Results output file              (Y/n)
  2. Results summary to screen        (Y/n)
  3. Graphical output                 (Y/n)
  4. Rain/river data to results file  (y/N)
  5. Determine optimal model interval (y/N)

  To change a default setting enter integer corresponding to the setting
to

  be changed, press return key and enter y or n as appropriate

  [Type a zero (0) to exit]...

5
y

0


  ----------------------------------------------------------------------
                          Program user input
  ----------------------------------------------------------------------
```

```
  Enter name of the stage-discharge file...
fot.sdc

  Enter name of the rain data file...
fotheringhay.rai

  Enter name of the stage data file...
fotheringhay.sta


        ---------------------------------
        |   Please wait - reading data   |
        ---------------------------------



    ------------------------------------------------------
    |   Please wait - determining optimal model interval   |
    ------------------------------------------------------


  10 ...
   9 ...
   8 ...
   7 ...
   6 ...
   5 ...
   4 ...
   3 ...
   2 ...
   1 ...


  ------------------------------------
  Optimum model interval = 345 minutes
  ------------------------------------



 ---------------------------- TFCAL STOP ----------------------------


$
```

Appendix 9: Runtime Listing of TFCAL: Parameter Estimation

The following is a runtime listing of TFCAL to estimate model parameters, as described in section 7 of the main report. Bolded text indicates user input. Graphics are at the end of this Appendix.

The input rating datafile (fot.sdc) is shown in Appendix 4.
The input rainfall datafile (fotheringhay.rain) is shown in Appendix 2.
The input river datafile (fotheringhay.sta) is shown in Appendix 3.
The output results datafile (fotheringhay.out) is shown in Appendix 6.
The output .mod datafile (fotheringhay.mod) is shown in Appendix 7.

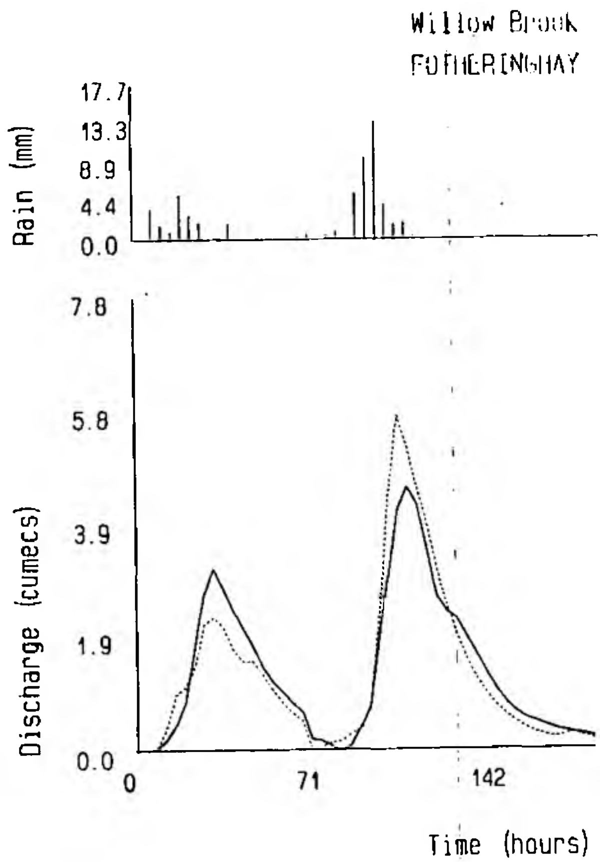
```
$run tfcal

    ---------------------------------------------------------------

    TFCAL

    A program to identify and calibrate simple linear transfer function
    model for real-time flood forecasting.

    Written by:
    Water Resources Research Group
    University of Salford
    Salford, M5 4WT
    England, U.K.

    ---------------------------------------------------------------

    Do you want to view/change option settings ? [Y/N]...
Y

    Options Menu
    ------------

    Options (default in UPPER CASE)

    1. Results output file  (Y/n)
    2. Results summary to screen  (Y/n)
    3. Graphical output     (Y/n)
    4. Rain/river data to results file  (y/N)
    5. Determine optimal model interval (y/N)

    To change a default setting enter integer corresponding to the setting
    to be changed, press return key and enter y or n as appropriate

    [Type a zero (0) to exit]...

4
Y

0

    ---------------------------------------------------------------
    The UNIRAS graphics routines in this program are device independent.
    ---------------------------------------------------------------

    Please type in the integer corresponding to the device you wish
    graphics to be directed to;
    (1) VAXstation    (GPX driver)
    (2) VAXstation    (X11 driver)
    (3) VT Emulator   (ReGIS driver)
    (4) IBM PC  (VGA driver)
    (5) Pen Plotter    (HPGL driver)
    (6) Ink Jet Printer (e.g. HP Inkjet)
```

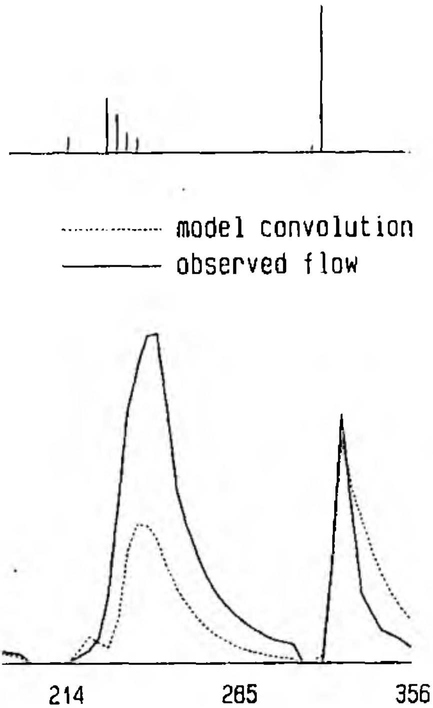
```
   Please type integer [1,2,3,4,5 or   6]...
3


fotheringhay.out

   ------------------------------------------------------------------
   Program user input
   ------------------------------------------------------------------


   Enter name of the stage-discharge file...
fot.sdc

   Enter name of the rain data file...
fotheringhay.rai

   Enter name of the river data file...
fotheringhay.sta

   Enter name of the output file...
fotheringhay.out



   ------------------------    Storm Selection    ----------------------

   The following storm events are on file:

   1)    06/06/85    04:00 -    08/06/85    23:45
   2)    08/10/87    22:00 -    14/10/87    07:45
   3)    14/10/87    08:00 -    19/10/87    00:00
   4)    20/05/86    00:00 -    21/05/86    23:45
   5)    08/05/88    00:00 -    09/05/88    21:45

   To select calibration sequence:
   i)    enter number of storms required [integer], then press return,
   ii)   enter integer(s) corresponding to storms  required, pressing
   return after each,
   iii)  storm sequence must be in ascending order.

4
1
2
3
5

   ------------------------------------------------------------------


   ------------------------    Time Intervals    -------------------------

   Rainfall data interval  15 minutes
   River data interval     15 minutes

   Select a model interval, for example:
   15 minutes;
   30 minutes;
   45 minutes;
   Enter required interval (a multiple of)   15 [integer]...
240

   ------------------------------------------------------------------
```

```
 --------------------------------
 |     Please wait - reading data    |
 --------------------------------
 --------------------     Model Structure Selection     ---------------------


 Is a time delay required in the model ? [Y/N]...
n

 Enter number of flow [a] parameters required [integer]...
2
 Enter number of rain [b] parameters required [integer]...
3

 ----------------------------------------------------------------------




 -------------------------------------------
 |     Please wait - estimating parameters |
 -------------------------------------------




 ------------------------- RESULTS SUMMARY --------------------------

 Model Characteristics
 ---------------------

 Structure   2,     3,     0
 a      1)     1.4188
 a      2)  -0.4977
 b      1)     0.0835
 b      2)     0.0964
 b      3)  -0.0946
 Model percentage runoff =17.36%
 Average event percentage runoff =22.05%

 Error Analysis
 --------------

 Errors in one step-ahead forecast
 Mean error  =      -0.019
 Absolute mean error      =      0.166
 Root mean square error   =      0.280

 RMSE of Model convolution
 1,     0.45  2,     0.45  3,     1.47  4,     0.67

 ----------------------------------------------------------------------



 -------------------------     Graphical Output   ------------------------


 Do you want to plot the model convolution ?     [Y or N]...
Y


 -------------------------------------
 |     Please wait - preparing graph |
 -------------------------------------
```

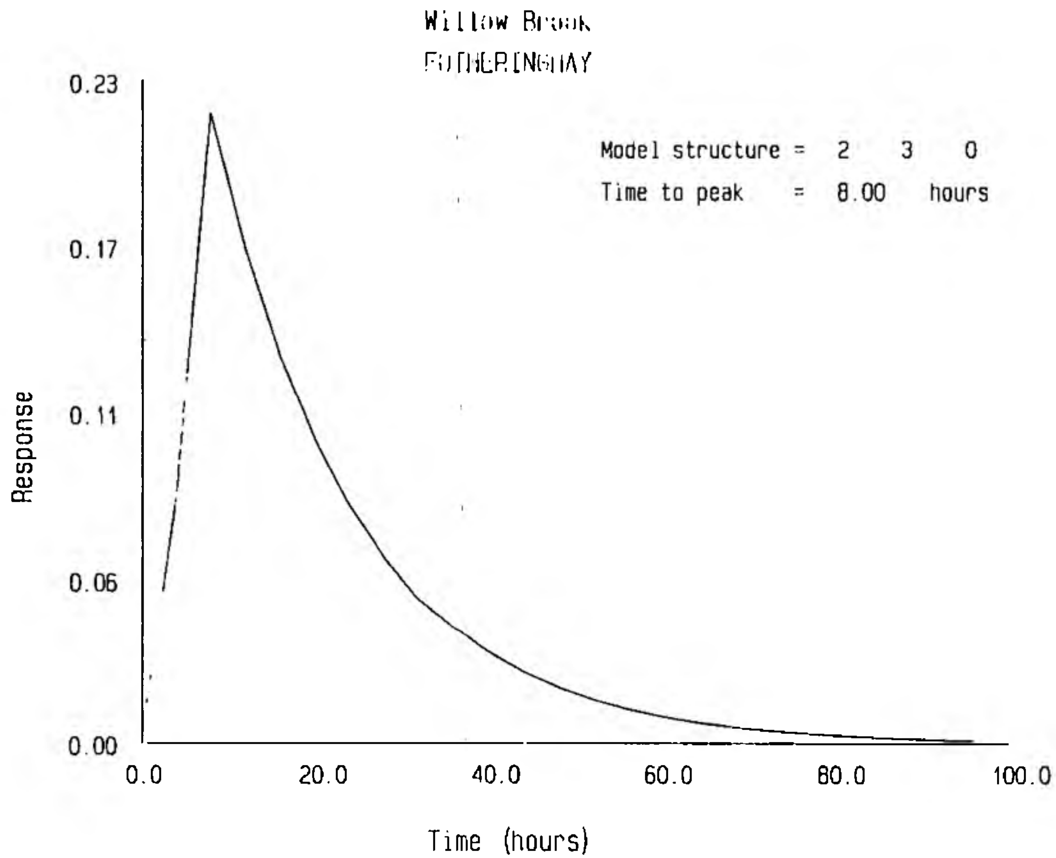
```
   Do you want to plot the model impulse response ?    [Y or N]...
y

   --------------------------------------
   |     Please wait - preparing graph |
   --------------------------------------



   -------------------------------------------------------------------------


   ---------------------- Generation of .mod file ---------------------

   Generate .mod file ? [Y/N]...
y
   Enter name of the .mod output file...
fotheringhay.mod

   Enter title for .mod file header line (max.     60 characters)...
Fotheringhay Model Parameters: Storms 1,2,3, and5.

   -------------------------------------------------------------------------



   -------------------------------------------------------------------------

   Another run ? [Y/N]...
n

  ------------------------------ TFCAL STOP ------------------------------
```

Press return to continue...




model convolution
observed flow
214
285
356

Press return to continue...



Appendix 10: Devices Supported

The following devices are explicitly supported by TFCAL.

DEC VAXstations (GPX driver)
DEC VAXstations (X11 driver)
VAX Terminal Emulators (ReGIS driver)
Pen Plotter (HPGL Driver)
DEC Ink Jet Printer
IBM PC (VGA Driver)