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DEPARTMENT OF CIVIL ENGINEERING

Water Resources Research Group

Software Profile

A User Manual for TFUH

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TFUH (Transfer Function Unit Hydrograph)

A program for estimating the parameters of a transfer function model from the ordinates of a unit hydrograph.

Software Profile

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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 TFUH, a program for estimating the parameters of a transfer function model from the ordinates of a unit hydrograph for gauged or ungauged catchments. In the case of the latter a triangular synthetic unit hydrograph is determined by application of Flood Studies Report (FSR) procedures. The report begins by stating the software specification and goes on to discuss the input information required. The structure of TFUH is described and illustrated with a flowchart and an example run-time session described. Annotated samples of input and output datafiles are included.

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

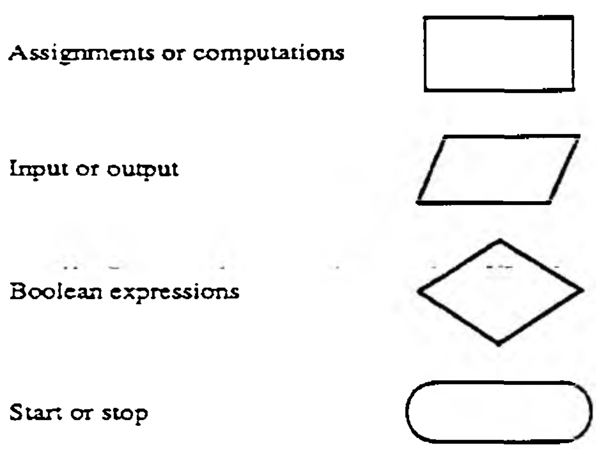
The Water Resources Research Group would welcome any comments on this Software Profile. Please contact Professor Ian Cluckie at the address at the front of the report.

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:



3. Software Specification and System Requirements

TFUH is a FORTRAN program for estimating the parameters of a transfer function model directly from unit hydrograph ordinates. The model parameters are written to an output file together with summary statistics. The forecasting performance of the estimated model can be assessed off-line using the model verification program TFFOR (see Tilford, 1989a).

The software is coded in ANSI FORTRAN 77 and has been developed on a Digital Electronic Company (DEC) MicroVAX II minicomputer using VMS V5.2 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 important role in TFUH and are facilitated by UNIRAS Graphics Software[1] package (Version 6.02). UNIRAS graphics modules are machine independent and can be implemented on a wide range of machines. 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 summarises aspects of the lumped transfer function rainfall-runoff model developed by the Water Resources Research Group, related to unit hydrograph theory and the calibration procedures built into TFUH. The model is parametrically efficient, structurally compact and robust to data loss or error. It is well suited to real-time operational environments and is currently being implemented in the U.K by regions of the National Rivers Authority.

4.1. Transfer Function Models and Unit Hydrographs

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

The unit hydrograph is the most widely applied hydrological model nationally and worldwide and owes this to its simplicity in terms of theoretical basis, ease of derivation, implementation and use. In contrast to the transfer function model, the unit hydrograph is an 'open loop' model and does not use feedback of 'new information' used to improve forecast accuracy (though manual intervention can add a feedback dimension though this may not always be feasible should flooding be widespread and human resources thinly spread). The unit hydrograph technique has been criticised for this shortcoming, the inference being that less than full use is being made from the real-time hydrometric data. A further criticism frequently cited is the number of parameters (ordinates) required: a function of catchment response characteristics and data sample intervals, a unit hydrograph usually has more than fifty ordinates and often approaching one hundred.

The transfer function model has been developed primarily with a weather radar rainfall input in mind. The model utilises an input of total rainfall, a single parameter being used to adjust the percentage runoff the model represents (model gain). The ability of this parameter to update continuously in real-time enables the model to adapt to changes in the physical state of the catchment as ascertained from comparison of model forecasts with observed flows. The total rainfall input avoids the need to define a storm loss (i.e. effective rainfall), a cumbersome and none to exact process thus aiding implementation in real-time, whilst the feedback mechanism possesses the ability to buffer inaccurate forecasts which may be attributable to poor input data.

The FSR (NERC, 1975) procedure for ungauged catchments is an attempt to produce a catchment model directly from physical characteristics easily obtained from maps. It is by definition a great oversimplification of the extremely complex processes of catchment response and storm dynamics. However, in practice synthetic triangular unit hydrographs can work surprisingly well. The reason for this is not obvious unless the mathematical characterisitics of the model are examined more deeply. Powell (1987) did this for a number of different forms of the unit hydrograph (e.g. Clarke, Snyder, US Soil Conservation Service, etc.) and showed that despite differences in shape, all had similar properties in the frequency domain and possessed the characteristics of low pass filters. Hence, despite simplification in derivation and crudity in shape, convolution using the simple triangular form produces an output result which does not differ greatly to the output from other more complex representations.

Information regarding unit hydrograph convolution can be found in any basic hydrological text and is not covered in this manual.

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:

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

where:

a_i , b_i = model parameters.

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

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

y_t = instantaneous observed runoff

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 $u_t z^{-n} = u_{t-n}$).

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

FIGURE 1: Block Diagram Representation of the Transfer Function Model

4.3. Catchment Lag

Unit graph theory proposed by Sherman over half a century ago (Sherman, 1932) prohibits a lag in catchment response. Uniformly distributed rainfall is assumed to occur simultaneously over the whole catchment response therefore being instantaneous. Thus, although a pure time delay (τ) can be easily incorporated into the model structure; in the context of transfer function models being derived from unit hydrographs, a lag will not be required.

4.4. Raingauge and Radar Rainfall Estimates

Existing catchment unit hydrographs will have been obtained by analysis of observed river runoff and catchment averaged rainfall estimates derived from point rainfall measurements. The intrinsic difference between these rainfall data types will influence model simulation/forecasting performance. However, flow forecasts from a model calibrated from raingauge data using radar rainfall estimates will not necessarily be worse than if raingauge data were used. A study of flow forecasts obtained from raingauge and radar rainfall estimates using a non-linear storage model for a limited number of events in the Bristol-Avon District of Wessex Water Authority showed that forecasts could improve when a radar rainfall input was used (Evans, 1987), despite the model being calibrated from raingauge data. However the expectation should be that as an archive of historical event data is established models are recalibrated directly from catchment data and radar rainfall estimates.

4.5. Model Steady State Gain

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) and is directly analogous to the percentage runoff:

$$\text{Model \% runoff} = 100 \text{ (steady state gain)} \qquad \text{(eq. 2)}$$

In this context, unit hydrographs (and consequently the transfer function models derived from them) have a gain of unity, since the output volume is equal to the input volume (because the input is effective rainfall). To overcome this, the b parameters of the transfer function model are scaled by the catchment runoff factor producing a transfer function model which has a percentage runoff directly equivalent to the average catchment runoff for flood events. In the case of synthetic triangular unit hydrographs, standard percentage runoff is estimated from physical catchment characteristics (see section 5.3.4).

The steady state gain may be determined directly from the parameters of the transfer function model as shown in eq. 3.

$$SSG = CF \cdot \left\{ \frac{(b_1 + b_2 + \ldots + b_q)}{1 - (a_1 + a_2 + \ldots + a_p)} \right\} \qquad \text{(eq. 3)}$$

$$CF = \frac{0.06 * \text{model interval (min)}}{\text{catchment area (sq km)}} \qquad \text{(eq. 4)}$$

where CF is a unit conversion factor to ensure that the SSG is dimensionless.

4.6. Model Stability

A transfer function model should be implicitly stable, a finite input producing a finite output (the so-called BIBO rule: bounded-input bounded-output) and the model output decaying 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 the model will be stable if the condition shown below is satisfied.

$$\left| \sum_{i=1}^{p} a_i \right| < 1.0 \qquad \text{(eq. 5)}$$

This condition is applied in TFUH and the user warned if violation occurs.

4.7. Model Order

The model order is defined as the total number of parameters in the model. Invariably a transfer function model will have fewer a parameters than b parameters, the latter being a function of catchment lag and model interval.

For example, a catchment with a lag of ten hours and hourly data (and a model with an interval of one hour) will require approximately ten **b** parameters, but should the model interval be increased to two hours only about five parameters will be necessary. This rule is a general guideline only and in practice fewer **b** parameters will often suffice. Fewer **a** parameters than **b** parameters are usually required.

4.8. 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. In particular the reader is referred to the Software Profiles for the transfer function model calibration and verification packages TFFOR and TFCAL (Tilford 1989a, and Tilford 1989b).

5. Model Calibration

This chapter is sub-divided into several sections. First, the general procedure utilised to obtain the parameters of a transfer function model directly from unit hydrographs are introduced. These are then covered in more detail; firstly for a gauged catchment unit hydrograph determined from classical empirical procedures, and then for the case of synthetic triangular unit hydrograph determined from physical catchment characteristics of an ungauged catchment. Finally a procedure common to both is described, identification of the optimal model structure using an equal order model search technique.

5.1. Procedure to Determine a Transfer Function Model from a Unit Hydrograph

A simple though powerful technique is used to estimate the parameters of a transfer function model from unit hydrograph ordinates.

A (pseudo)-random sequence of numbers is used as an input to the unit hydrograph which convolutes the input to produce an output sequence (in the same way as effective rainfall is convoluted to produce river runoff). The resultant input-output sequence then forms the basis of parameter estimation - model parameters for a selected model structure being estimated by a recursive least squares algorithm (see Tilford, 1989a).

The same input data sequence is then 'fed' into the calibrated transfer function model and the model output compared with that from the unit hydrograph. This relative comparison (statistically summarised by the root mean square error of signal convolution) can be used to assess the degree to which the output of the transfer function model and a unit hydrograph agree for a given input sequence. However meaningful interpretation of the statistic beyond a simple relative comparison is difficult and other criteria aid more fully the calibration procedure.

The unit impulse response of the transfer function model and the unit hydrograph are compared graphically as a further test of model adequacy (the two represent the same thing, i.e. the model response to a finite pulse input of unit duration and magnitude). The important time to peak and peak flow values and the transfer function model and catchment percentage runoff's are summarised at the end of the model run.

The calibration process can be repeated for different model structures until an optimal model structure is found using the search procedure described below.

5.2. Identification of Optimal Model Structure

Determination of optimal model structure is an important part of model calibration attempting to identify the model structure that combines the attributes of parametric economy (parsimony) and forecasting accuracy. Parsimony is important for a number of reasons, most notable of which are:

- 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), i.e. the model demand for past data.

Both are a function of the number of model parameters and hence both will reduce as the model order falls. Moreover, it is unrealistic to have a model with many parameters given the nature of the hydrological data (uncertainty and noise).

Identification of optimal model structures is a difficult subject and no truly satisfactory objective method yet exists: thus two different modellers can (will) produce two different 'optimal structures' for a given input-output sequence. This is not important as long as the model is sufficiently close to the optimum. Careful application of the equal model order search described below will result in a model whose structure satisfactorily approaches that of the optimal model.

The equal order model search technique 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 adequacy (where adequacy is judged using a combination of the measures described in section 5.1).

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 produces a significant increase in model inadequacy. Usually the optimal structure has $p<q$, so only the number of a parameters are reduced.

5.3. Further Aspects of Unit Hydrographs

Using TFUH, transfer functions models can be calibrated directly from existing unit hydrograph ordinates or from physical catchment characteristics (in the case of the latter by application of the procedures for ungauged catchments published in the Flood Studies Report i.e synthetic triangular unit hydrographs). Whilst the calibration procedure itself is identical for both the initial processing prior to calibration differs though all processing is performed transparently.

All information required by TFUH (e.g. unit hydrograph ordinates, catchment areas, etc.) is held in an input datafile described in section 6.2 and in figures 6, 7 and 8.

5.3.1. Gauged catchments

For gauged catchments where unit hydrographs have already been determined from analysis of event data, the calibration procedure is relatively straightforward. The ordinates are used to directly convolute the pseudo-random input data sequence and the model calibrated using the procedures described in section 5.1 and 5.2.

5.3.2. Ungauged catchments

For ungauged catchments, procedures documented in the Flood Studies Report are applied to yield a synthetic triangular unit hydrograph. Hourly ordinates are then used to convolute the pseudo-random sequence as described in section 5.1. The parameters of the unit hydrograph triangle are determined from the following information (except if a direct estimate of catchment lag is available - see later in this section),

S1085 : the stream channel slope measured between two points 10 and 85% of the stream length from the gauge (m/km).
MSL : the length of the main stream (km)
RSMD : a net 1 day rainfall of 5 year return period.
URBAN : the urban fraction of the catchment.

using the following series of equations:

FSR ?

$$T_p = 46.6 MSL^{0.14}\ S1085^{-0.38}\ (1+URBAN)^{-1.99}\ RSMD^{-0.4} \quad \text{(eq. 6)}$$

$$Q_p = \frac{220}{T_p} \quad \text{(eq. 7)}$$

$$T_B = 2.52\ T_p \quad \text{(eq. 8)}$$

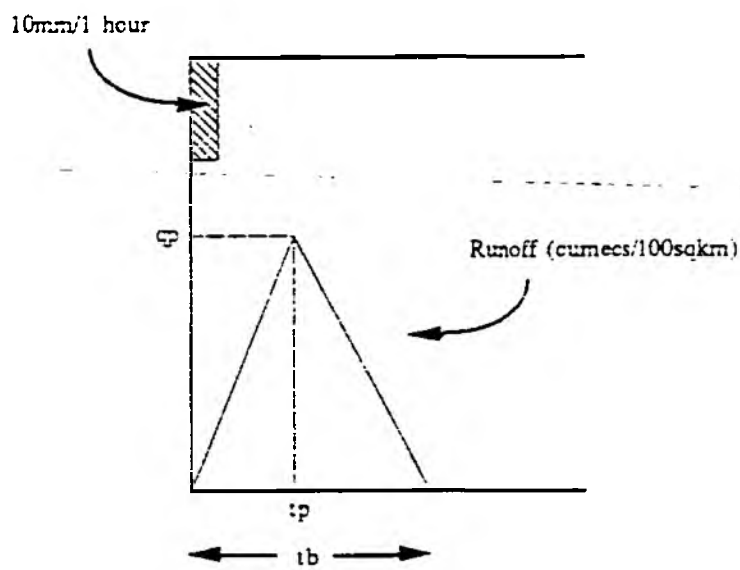
The synthetic triangular unit hydrograph derived has the form shown in figure 2.

Tp, Tb and Qp are calculated preferentially from the catchment lag time if this is available, since this enables more accurate estimation of the triangular unit hydrograph parameters. Catchment lag time can be defined in many different ways, the method preferred in the FSR being the time from the centroid of total rainfall to the peak flow. If catchment lag is available equation 9 is applied in place of equation 6:

$$T_p = 0.9 \text{ LAG} \qquad \text{(eq. 9)}$$

Before convolution the triangle is digitised to yield a finite number of hourly ordinates using simple trigonometric relations. The total number of ordinates is equal to the integer value of the base time (e.g. if t_b=13.7 hours there will be 13 ordinates).

Figure 2: Synthetic Triangular Unit Hydrograph



A problem when estimating a transfer function model from a triangular unit hydrograph is obtaining a model impulse response which is both a realistic shape in a hydrological context having the general characteristics (e.g. time to peak, peak magnitude) of the triangular unit hydrograph. In trying to match the unit hydrograph characteristics the parameter estimation algorithm often produces a model with an impulse response having negative values at or greater than time t_b (see figure 4a). To help overcome this tendency the recession limb of the triangular unit hydrograph is smoothed by the introduction of an exponential decay (see figure 3). The overall effect is to relax constraints on the estimation algorithm stemming from the triangular shape, generally resulting in a more physically meaningful unit impulse response (figure 4b). The refinement was selected for its ability to produce improved impulse responses with minimal changes to the triangle. Further research on this aspect of transfer function estimation from triangular unit hydrographs is required.

5.3.3. Standardised Unit Hydrograph Ordinate Correction

All synthetic triangular unit hydrographs determined by application of the FSR procedure and some catchment averaged unit hydrographs derived by the classic techniques ('by eye' averaging or superposition) are standardised for 10mm rainfall depth over an area of 100sq km. In such cases, a simple correction factor is applied (eq. 10) to produce hydrograph ordinates (and hence a transfer function model) for 1mm rainfall depth over the catchment area of concern.

$$\text{Factor} = \frac{\text{catchment area}}{\text{area of hydrograph}} * \frac{1}{\text{hydrograph depth}} \qquad \text{(eq. 10)}$$

5.3.4. Effective Rainfall, Total Rainfall, Percentage Runoff and Model Gain

The consequence of the different input data used by the models (i.e. total and effective rainfall) is that a transfer model calibrated directly from unit hydrograph ordinates will have a steady state gain of unity (100% runoff). This is resolved by reducing the model **b** parameters by a factor corresponding to the runoff coefficient of the events used to calibrate the unit hydrograph. Hence, if the average percentage runoff of the events used to determine the catchment unit hydrograph was 30%, each of the **b** parameters will be reduced by 0.3, the transfer function model thus having a steady state gain of 0.3 (a percentage runoff of 30%) for delta equals unity. It is consequently essential to know the standard percentage runoff of a catchment.

In the case of an ungauged catchment where the standard percentage runoff may not be known there are two options. In order of desirability:

- calculate the standard percentage runoff from SOIL and URBAN indices according to equation 11.

SESR ?

$$\text{SPR} = 95.5\ \text{SOIL} + 12\ \text{URBAN} \qquad \text{(eq. 11)}$$

- use a value of 15% for the standard % runoff (this value is the lowest attainable from equation 11 i.e.

for a catchment with no urban areas having a SOIL index of 0.15 [SOIL varies between 0.15 and 0.5]).

Figure 3: 'Refined' Synthetic Triangular Unit Hydrograph

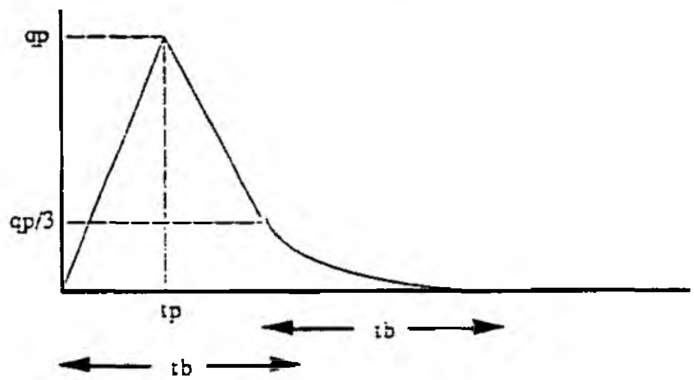
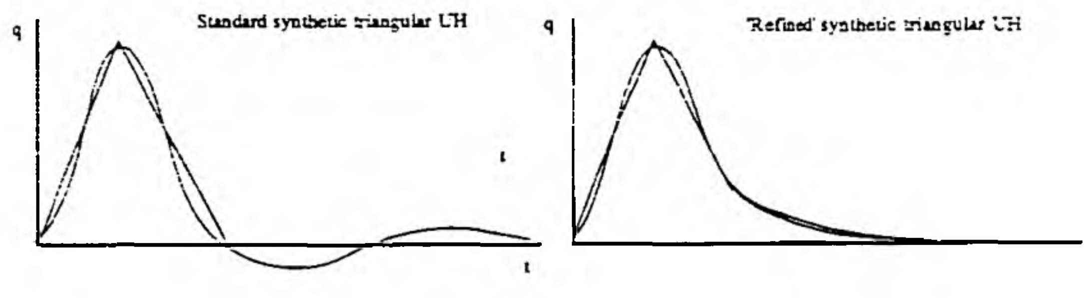


Figure 4: Unit Impulse Response of a Transfer Function Model Derived from Standard and Refined Synthetic Triangular Unit Hydrograph Ordinates



5.3.5. Model Time Interval

The time interval of a calibrated transfer function model will be the same as the time interval of the ordinates of the unit hydrograph: thus if the unit hydrograph intervals have an interval of 2 hours the transfer function will be a 2 hour model. The influence of model interval on model order is discussed in section 4.7.

5.4. Conclusions

This chapter has briefly introduced the procedure to estimate a transfer function model from the a catchment unit hydrograph for gauged and ungauged catchments. The TFUH package performs all data processing and parameter estimation transparently enabling the user to concentrate on obtaining an optimum model structure for which a combined subjective/objective approach is described. The procedure for ungauged catchments entails the determination of a synthetic triangular unit hydrograph by application of procedures published in the FSR, and this is described in some detail. A number of pertinent aspects particular to model estimation from unit hydrographs have been discussed especially regarding the consequences stemming from effective (unit hydrograph) and total (transfer function) rainfall model inputs, ordinate correction and model time intervals.

6. Program Structure and Data Requirements

This chapter briefly describes the structure of TFUH.

6.1. TFUH Structure

A full source code listing of TFUH is provided in Appendix 1. In addition, a program flowchart is shown in figure 1 and a runtime listing is provided in Appendix 4. The program comprises of main block and a number of subroutines which are called from it.

Procedures for opening files, generating pseudo-random number sequences, determining synthetic unit hydrographs, convoluting models with input data, estimating model parameters using a recursive least squares algorithm, drawing unit hydrographs and transfer function model unit impulse responses, and producing program output are all held in subroutines.

Runtime execution can be summarised as:

Character and array initialisation
Welcome message
Determination of current device type (for graphics module)
Output options block
Establishment of input and output datafile names
Read model structure
Read input data
Process unit hydrograph data / Estimate model parameters
Graphical presentation of results
Output of calibration results

All the required information is read from the input datafile (i.e. unit hydrograph details or physical catchment characteristics, catchment area, etc.). Model calibration is a cyclical process since a subjective search procedure is used to determine a suitable model structure, and is only interactive in that the required model structure must be entered by the user.

6.2. Input Datafiles

The program uses one input datafile, example listings of which are given in Appendix 2. The requirement in terms of input information differs according to whether a transfer function model is to be determined from an existing catchment unit hydrograph or for an ungauged catchment. An annotated diagram of a catchment unit hydrograph datafile is shown in figure 2 and of a catchment characteristics/synthetic unit hydrograph datafile in figure 3. Care should be taken to ensure that the input file complies exactly with the stated specification since any deviation may cause calibration error without necessarily causing a runtime error.

6.2.1. Input Datafile for Catchment Unit Hydrographs

A three line header block is ignored by TFUH and can be used to store pertinent information. The next four lines comprise catchment/gauging station information used for the results output: namely, river name, gauging station name, gauging station reference number, and station grid reference. Then follow, each on separate lines, the catchment area, the time interval of the unit hydrograph in hours, the rainfall depth of the unit hydrograph, the catchment area of the unit hydrograph, standard % runoff of the hydrograph calibration events, and the number of ordinates. After a one line space the unit hydrograph ordinates follow, one on each line.

The catchment information is read as A40 and all numerical information is read in free format.

6.2.2. Input Datafile for Physical Catchment Characteristic Data

A three line header block is ignored by TFUH and can be used to store pertinent information. The next four lines comprise catchment/gauging station information used for the results output: namely, river name, gauging station name, station reference number, and grid reference. The next line is the catchment area, a blank line and then the interval of the triangular unit hydrograph in hours. If the catchment lag is known (lag>0.0) it is followed by the catchment standard percentage runoff but if lag is unknown (lag=0.0) the main stream length (MSL), stream gradient (S1085), urban fraction of the catchment (URBAN), and climatic index (RSMD) follow on the next four lines. The last value is the catchment standard percentage runoff.

The catchment information is read as A40 and all numerical infomation is read in free format.

6.3. Presentation of Results

An 'Output Options' program block, 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]
- draw graphics on screen or to a plotter [screen/plotter]
- is a graphics output required (yes/no)

If required these settings can be changed during runtime when the program asks if the program default settings need to be changed. It should be noted that the plotter/screen graphics output toggle is only enabled if a screen output device is selected at the first device selection menu.

The graphic output is a simple line overplot of the unit hydrograph and calibrated transfer function model unit impulse response.

Calibration results can be optionally written to screen and/or a textual output results file. Two example output files are shown in Appendix 3. In summary, the following are written to the output file and a subset of it directed to the screen.

- catchment information (river name, gauge location, gauge code, grid reference)
- adjusted hydrograph ordinates
- calibrated transfer function model information: structure, time interval, parameters, model and event percentage runoff.
- calibration error statistics: RMSE between unit hydrograph and transfer function model reconvolution of random data input sequence.
- model response statistics: unit hydrograph/transfer function model peak flows and time to peaks.

7. Running the Program

The following is summary of the options that confront a user when the program runs. A full run-time listing of the program user-interface during program execution is provided in Appendix 4. A series of prompts sequentially leads the user through a program initialisation phase establishing input and output filenames. Referral to the program flow chart (figure 5) may aid the reader.

The program is invoked by entering RUN TFUH. After each response the return (enter) key is pressed, the display scrolls and the next prompt is displayed. When all the prompts have been answered the program reads and processes the data in the input file, calibrates parameters, produces graphical output (if required) and writes a calibration report to the screen (if required) and to an output file (if required).

7.1. Example Run-Time Session

An example run-time session illustrates the use of TFUH. The selected options are summarised below.

Device driver selected = VT Emulation (ReGIS).
Graphic output directed to a plotter.
Estimation option = calibration from catchment unit hydrograph
Input datafile name = coisterworth.dat
Output filename = results.out
Model structure = 5,6,0

Graphic output.

Calibration results output to screen and to output file.

STOP

If a filename is entered by the user which does not exist (in the case of the input datafile) or already exists (in the case of an output file), an appropriate error message notifies the user and a new filename can be entered. Error traps are also invoked should an incorrect response be made to a program prompt.

8. Example Model Estimation

In this chapter two example transfer function models are calibrated, one for a gauged catchment using existing unit hydrograph ordinates and another for an ungauged catchment from physical characteristics.

8.1. Gauged catchment: River Witham at Colsterworth, NRA Anglian Region, Northern Area.

The reader is referred to Appendix 2i and 3a for the input and output datafiles for this example.

This is a gauged catchment for which a unit hydrograph already exists. The unit hydrograph is for 1mm rainfall depth over the catchment area (51.3sq km) and has 47 ordinates. The catchment lag is approximately nine hours.

Initially parameters were estimated for equal order model structures ranging from 2,2 to 9,9. When completed, the convolution and ordinate/impulse response RMSE's, magnitude and timing of peak flows were compared paying particular attention to the graphical comparison of the unit hydrograph and transfer function impulse responses (figure 9). From these it was notable that the lower model orders (2,2 to 5,5) could not adequately represent the unit hydrograph shape whilst orders of 6,6 upwards could.

From these the 6,6 model order was selected as the optimal equal order model. This order closely reproducing the shape of the unit hydrograph whilst having a significantly smaller convolution error than the lower orders. The slight difference in the magnitude of the peak of the impulse response compared to the unit hydrograph is not important, and would be absorbed in real-time by the transfer function model scaling factor delta.

Reduction in the number of a parameters beyond a 5,6 structure results in degradation in the shape of the impulse response compared to the shape of the unit hydrograph (with a corresponding fall in convolution accuracy).

A 5,6 model structure is selected as optimum.

8.2. Ungauged catchment: River Stour at Kedington, NRA Anglian Region, Eastern Area.

The reader is referred to Appendix 2g and 3b for the input and output datafiles for this example.

This is an ungauged catchment for which no unit hydrograph exists. Thus the FSR procedure for ungauged catchments option is applied. Because the approximate catchment lag is known (nine hours) this is used to directly estimate the parameters of the synthetic triangular unit hydrograph rather than using physical characteristics.

Initially parameters were estimated for equal order model structures ranging from 2,2 to 9,9. When completed, the convolution and ordinate/impulse response RMSE's, magnitude and timing of peak flows were compared paying particular attention to the graphical comparison of the unit hydrograph and impulse responses (figure 10). From these it was notable that the lowest model orders (2,2 and 3,3) could not adequately reproduce the main characteristics of the triangular unit hydrograph. However orders greater than 6,6 did not offer significant advantages over the lower order models.

From these the 5,5 model order was selected as the optimal equal order model. Reduction in the number of a parameters to 4,5 and 3,5 structures results in (small) negative values of the impulse response and were consequently rejected. However the 2,5 order impulse response remains positive and for this reason is selected as optimum.

8.3. Conclusions

The examples illustrate the problems associated from estimation of transfer function models from catchment unit hydrographs or (and in particular) physical catchment characteristics, largely because of the subjective nature of the model order identification process.

It should be recognised that the ungauged catchment procedure is very approximate and the resultant hydrograph a crude approximation of catchment response. Production of a transfer function model closely replicating the synthetic hydrograph is not the object of model estimation and the synthetic unit hydrograph should be viewed as no more then a general guide. For ungauged catchments transfer function models will not benefit from real-time riverflow information and will therefore run in a 'simulation' mode (Cluckie and Tilford, 1989). Despite this the models should provide valuable early information on likely catchment response particularly with quantitative precipitation forecasts.

Derivation from a gauged catchment unit hydrograph is more straightforward. The unit hydrograph should already be a reasonable representation of catchment response and it should be possible to produce transfer function models with an impulse response closely resembling the unit hydrograph. In real-time operation, model updating will enable the transfer model to adapt to observed catchment response in real-time and thus improve upon the performance of the unit hydrograph model.

In both cases it is desirable that the transfer function models be re-estimated with the advent of event data. A procedure for updated calibration of model parameters off-line as such data become available is currently being examined.

9. Conclusions

This report is a users guide to the FORTRAN software package TFUH, a program for estimating the parameters of a simple linear transfer function model from the ordinates of a unit hydrograph. Two examples of model estimation for a gauged and ungauged catchment are included in the text.

The report contains listings of full source code and input and output datafiles; all of which are contained on the software distribution disk. 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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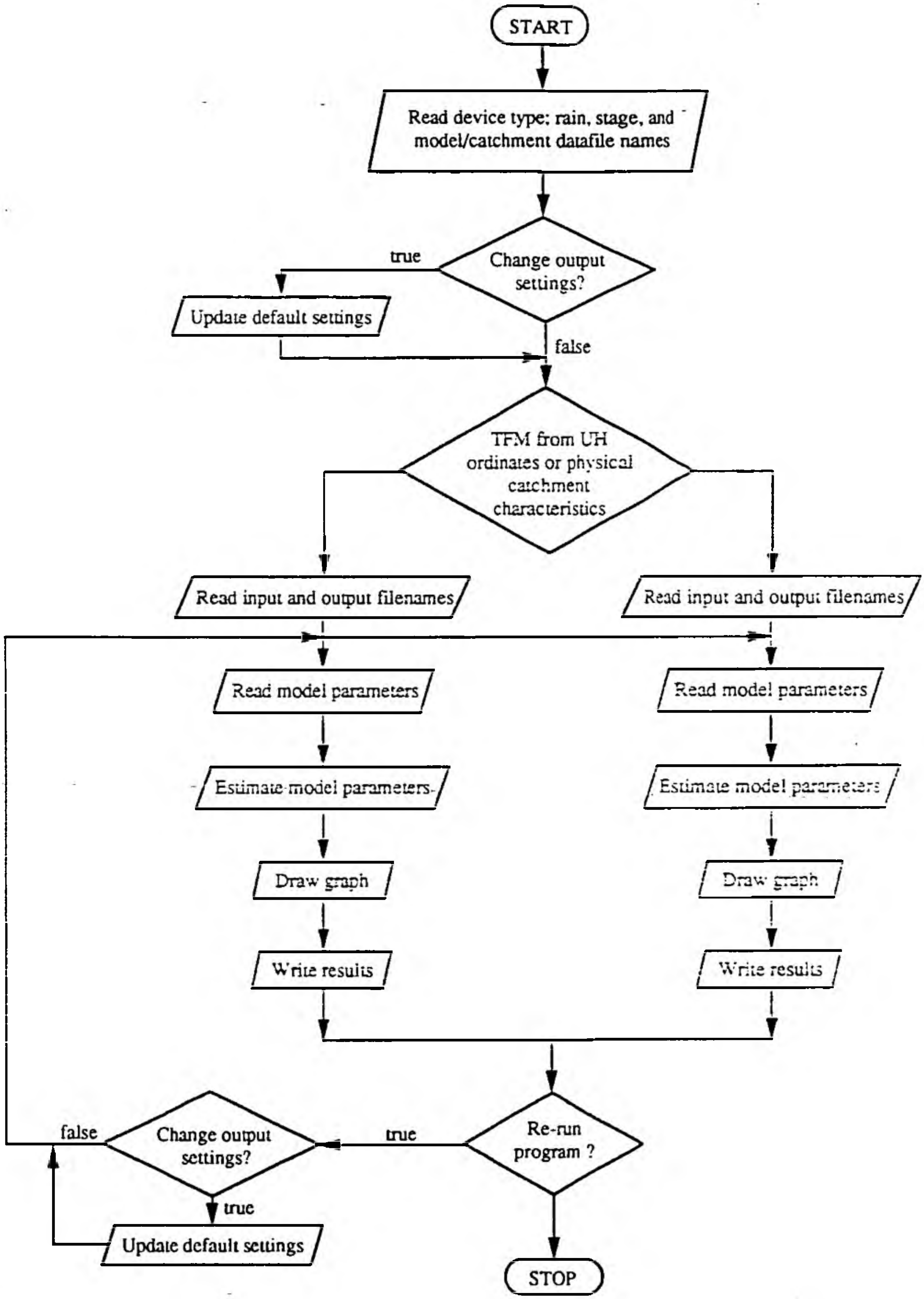


FIGURE 5: Flow Chart for TFUH

3 line title block:
ignored by TFUH

River name (1x, A40)

Gauging station name (1x, A40)

Reference code (1x, A40)

Grid reference (1x, A40)

Catchment area

Interval of unit hydrograph in hours (H)

Rainfall depth of UH ordinates

UH area (either 100.0 or actual catchment area)

Standard % runoff

Number of UH ordinates

Blank line

UH ordinates (first five)

Figure 6: Example Input I.

```
This is uh datafile for Colsterworth, River Witham
Ordinates from Northern Area

River Witham
COLSTERWORTH
30/01 010
SK929246
51.3    ! catchment area
1       ! time interval of UH ordinates in hours
1.0     ! this is depth of uh ie 10mm
51.3    ! uh area
18.4    ! standard % runoff
47      ! number of ordinates

3e-2
8e-2
1.5e-1
2.8e-1
4.5e-1
```

3 line title block: ignored by TFUH	`This is a datafile containing physical catchment characteristics`
	`for the Willow Brook, Fotheringhay catchment.`
	`Source: IH Report, "Flood Hydrology of the River Nene"`
River name (1x, A40) →	`Willow Brook`
Gauging station name (1x, A40) →	`FOTHERINGHAY`
Reference code (1x, A40) →	`32002`
Grid reference (1x, A40) →	`TL067933`
Catchment area →	`89.62 ! catchment area`
Blank line →	
Interval of unit hydrograph in hours (I1) →	`1 ! interval of triangular UH in hours`
Catchment lag (also serves as a flag) →	`0.0 ! catchment lag (0.0 if unknown)`
Physical catchment characteristics (all read in free format) →	`33.98 ! mean stream length in km`
	`2.87 ! stream gradient m/km`
	`0.042 ! proportion of catchment urbanised`
	`22.24 ! RSMD`
Standard % runoff →	`25.3 ! standard % runoff`

Figure 7: <u>Example Input Datafile, Ungauged Catchment Lag Unknown (Physical Characteristics used)</u>

3 line title block: ignored by TFUH	This is a datafile containing physical catchment characteristics for the River Stour, Kedington catchment. Source: Eastern Region
River name (1x, A40) →	River Stour
Gauging station name (1x, A40) →	KEDINGTON
Reference code (1x, A40) →	800
Grid reference (1x, A40) →	TL708450
Catchment area →	76.2 ! catchment area
Blank line →	
Interval of UH in hours (I1) →	1 ! interval of triangular UH in hours
Catchment lag (hours) →	10.0 ! lag
Standard % runoff →	38.2 ! standard % runoff

Figure 8: Example Input Datafile, Ungauged Catchment Lag Known

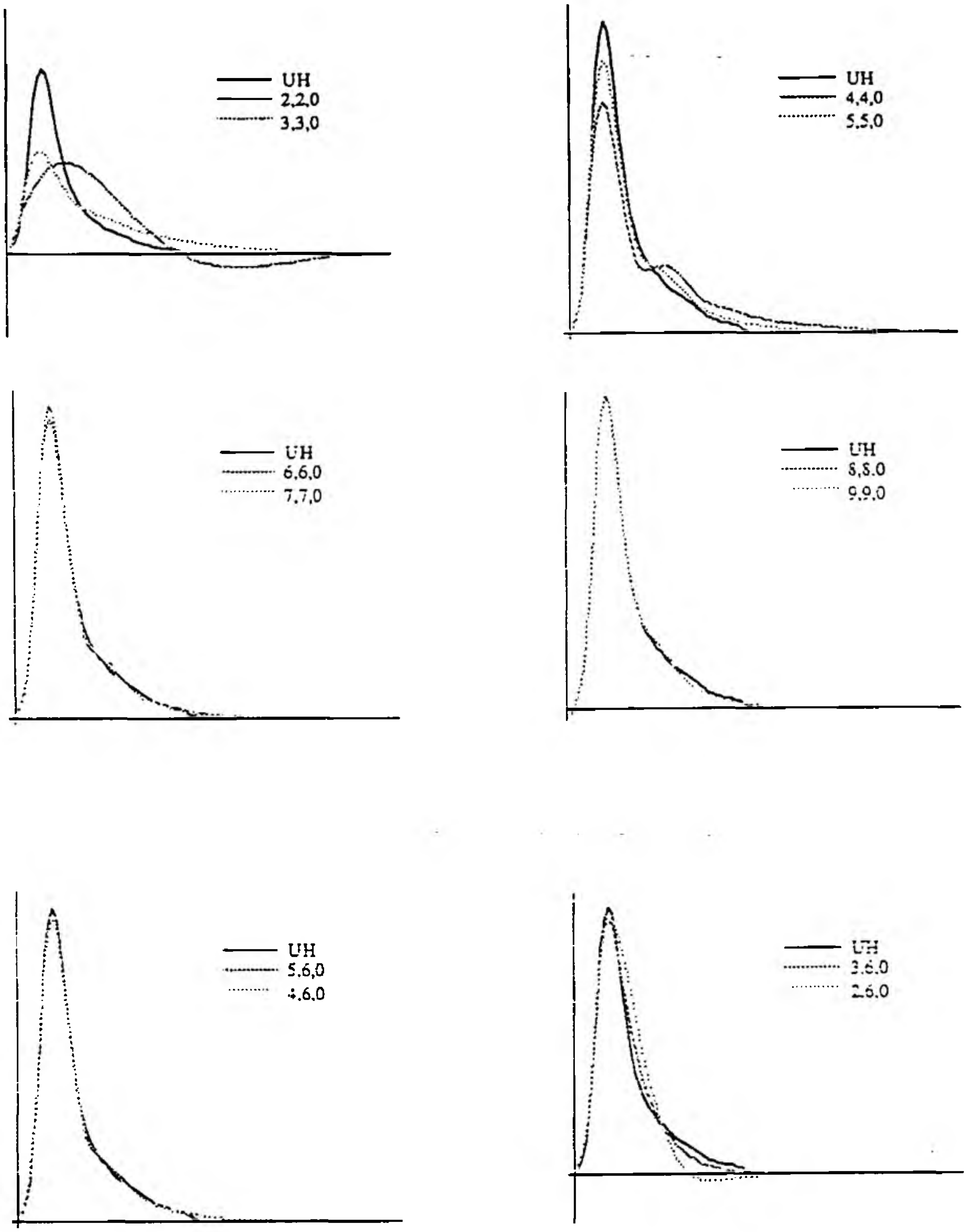


Figure 9: Transfer Function Model Impulse Responses and Unit Hydrograph Ordinates: Model Estimation Example 1.

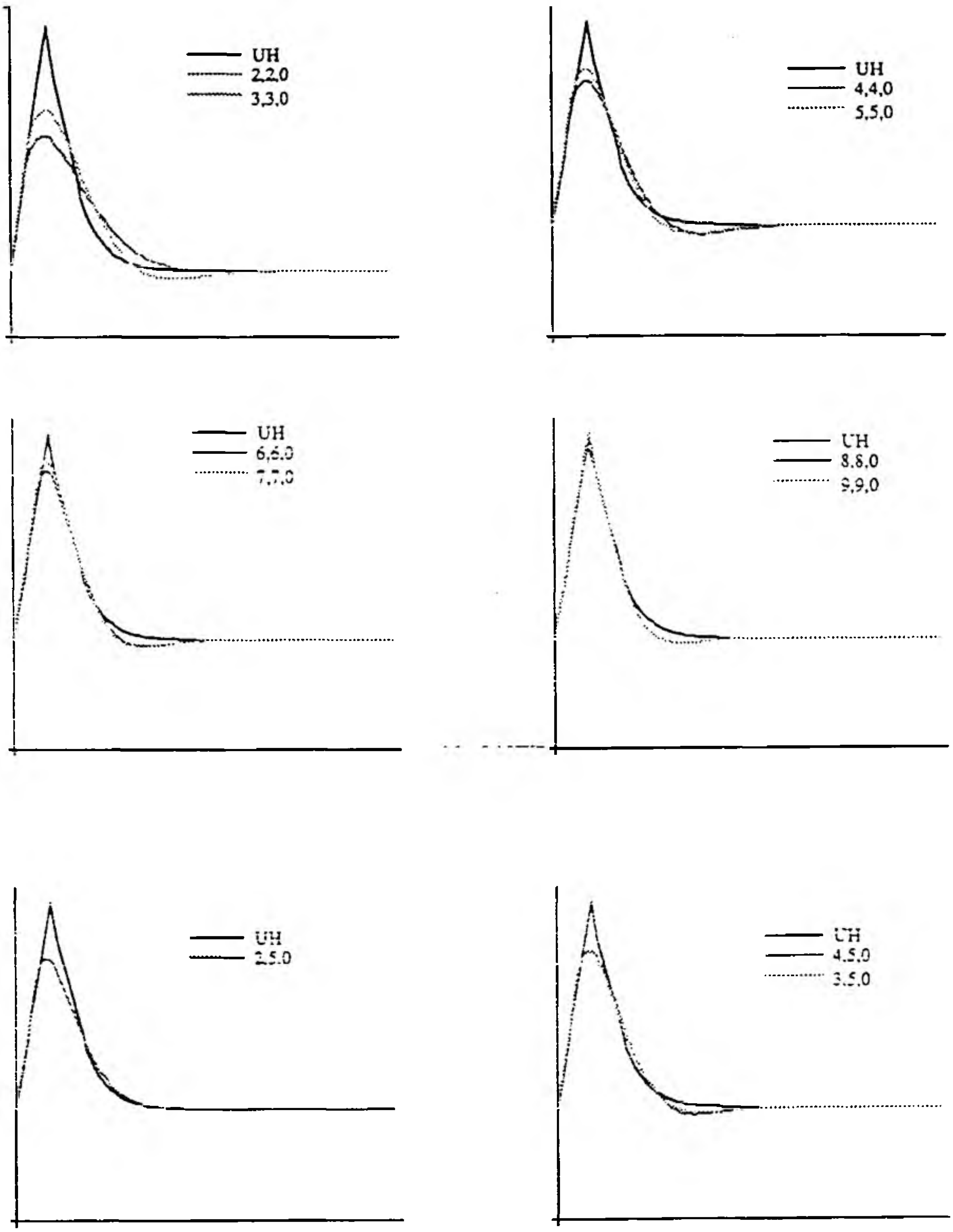


Figure 10: Transfer Function Model Impulse Responses and Unit Hydrograph Ordinates: Model Estimation Example 2.

Appendices

Appendix 1	TFUH Source Code Listing
Appendix 2	Example Input Datafiles (10 examples)
Appendix 3	Example Output Datafiles (2 examples)
Appendix 4	Runtime Listing of TFUH
Appendix 5	Devices Supported

Appendix 1: <u>TFUH Source Code Listing</u>

```
c
c
c   -------------------------------------------------------------------
c
c                 PROGRAM TFUH
c
c   A program to estimate the parameters of a transfer function model
c   from unit hydrograph ordinates or using the FSR procedure for
c   ungauged catchments.
c
c   Water Resources Research Group
c   Department of Civil Engineering
c   University of Salford
c   SALFORD
c   M5 4WT
c
c   For further information contact:
c         Prof. Ian Cluckie
c
c   -------------------------------------------------------------------
c
      dimension a(50),b(0:50)
      dimension random(501),h_recon(501),tf_recon(501)
      dimension h_ord(101)
      real imp_resp(501),impin(501)
c
      integer uhtp.tfmtp
      real msl
c
      character*1 sp
      character*1 ooset1,ooset2,ooset3,view,again
      character*40 g_nam,g_num,g_code,g_ngr
c
 5    format(i2)
 6    format(a1,a40)
 45   format(a1)
c
      num_calc=500
      iuhflag=0
      ifsrflag=0
c
      write(*,*)
      write(*,*)
      write(*,*)' ---------------------------------------------
     $-------------------------'
      write(*,*)
      write(*,*)'        Transfer Function - Unit Hydrograph
     # Program (TFUH)'
      write(*,*)
          write(*,*)'  A program to estimate the parameters of a transfer
     # model from the'
      write(*,*)' ordinates of a unit hydrograph or by application
     # of the Flood Studies '
      write(*,*)' Report procedure for ungauged catchments.'
      write(*,*)
            write(*,*)'  See TFUH Software Profile for further
information.'
      write(*,*)
      write(*,*)'  Water Resources Research Group'
      write(*,*)'  Department of Civil Engineering'
      write(*,*)'  University of Salford'
      write(*,*)'  SALFORD'
      write(*,*)'  M5 4WT'
      write(*,*)
      write(*,*)' ---------------------------------------------
     #-------------------------'
      write(*,*)
      write(*,*)
```

```
      write(*,*)'  $ Press RETURN (ENTER) to continue'
      read(*,*)
      do 211 i=1,4
         write(*,*)
 211       continue
c
c  Establish device name for graphics output
c
      write (*,*)
      write (*,*)'  ----------------------------------------------------
     *--------------------'
      write (*,*)'  The UNIRAS graphic routine in this program is
     * device independent.'
      write (*,*)'  ----------------------------------------------------
     *--------------------'
      write (*,*)'  Please type in the integer corresponding to the
     *device you wish'
      write (*,*)'  graphics to be directed to;'
      write (*,*)
      write (*,*)'  (1) VAXstation       (GPX driver)'
      write (*,*)'  (2) VAXstation       (X11 driver)'
      write (*,*)'  (3) VT Emulator      (ReGIS driver)'
      write (*,*)'  (4) IBM PC           (VGA driver)'
      write (*,*)'  (5) Pen Plotter      (HPGL driver)'
      write (*,*)'  (6) Ink Jet Printer (e.g. HP Inkjet)'
      write (*,*)
          write (*,*)'  Output can be switched between screen and pen
     * plotter output but only if'
      write (*,*)'  a screen option is selected at this stage:
     * selecting a pen plotter'
         write (*,*)'  overides the screen/plotter toggle option.'
 696      write (*,*)
      write (*,*)'  Please type integer (1,2,3,4,5 or 6)'
      read (*,5,err=696)idevice
      if (idevice.gt.6) goto 696
      if (idevice.le.4) iidevice=idevice
      write(*,*)
c
c  Output Options Block
c
 213     cosetl='Y'
         coset2='Y'
         coset3='S'
 214      write(*,*)
      write(*,*)'  Do you want to view/change current output
     * option settings  (Y/N) ?'
      read (*,45,err=214)view
      if (view.ne.'y'.and.view.ne.'Y'.and.view.ne.'n'.and.view.ne.'N')
     * goto 214
      if (view.eq.'y'.or.view.eq.'Y')
     *        call outopt(cosetl,coset2.coset3,idevice,iidevice)
c
      write(*,*)
      write(*,*)
      write(*,*)'  ---------------------------------------------'
      write(*,*)'                    Program user input'
      write(*,*)'  ---------------------------------------------'
      write(*,*)
      write(*,*)
      write(*,*)'  Which option is required ?'
      write(*,*)'     (1) TF model from unit hydrograph ordinates'
      write(*,*)'     (2) TF model from physical catchment
     * characteristics'
      write(*,*)'  Please type integer [1 or 2].'
 10   read(*,5,err=12)istat
      if (istat.eq.1.or.istat.eq.2) goto 151
 12   write(*,*)
      write(*,*)'  Enter an integer corresponding to choice [1 or 2]'
      goto 10
 151      write(*,*)
c
 26   if ((iuhflag.eq.0.and.istat.eq.1).or.
```

```
     #     (ifsrflag.eq.0.and.istat.eq.2)) then
        write(*,*)'  Enter name of input file'
        call openfile(1,iquit)
        if (iquit.eq.999) goto 999
        read(2,*)
        read(2,*)
        read(2,*)
        read(2,6)sp,g_nam
        read(2,6)sp,g_num
        read(2,6)sp,g_code
        read(2,6)sp,g_ngr
        read(2,*)cmtarea
        if (istat.eq.1) then
              read(2,*)int_h
              read(2,*)h_depth
              read(2,*)h_area
              read(2,*)spro
              read(2,*)n_h_ord
              read(2,*)
              do 23 i=1,n_h_ord
                 read(2,*)h_ord(i)
                    h_ord(i)=h_ord(i)*(cmtarea/h_area)*(1.0/h_depth)
 23           continue
           else
              read(2,*)
              read(2,*)int_h
              read(2.*)fsr_lag
              if (fsr_lag.lt.0.1) then
                 read(2,*)msl
                 read(2,*)s1085
                 read(2,*)urban
                 read(2,*)rsmd
              end if
              read(2,*)spro
         end if
      end if
c
c     Establish name of and open output file
c
      if (((iuhflag.eq.0.and.istat.eq.1) .or.
     #     (ifsrflag.eq.0.and.istat.eq.2)).and.
     #     (coset1.eq.'Y')) then
        iout=0
 37     write (*,*)'  Enter name of the results output file'
        call openfile(2.iquit)
        if (iquit.eq.999) goto 999
          end if
c
      write(*,*)
 2    write(*,*)'  Model Structure Input'
      write(*,*)'  ----------------------'
      write(*,*)
 811        write(*,*)'  Enter number of a parameters (max. 30) (integer)'
      read(*,5,err=811)numa
      if (numa.gt.30) goto 811
 812        write(*,*)'  Enter number of b parameters (max. 30) (integer)'
      read(*,5,err=812)numb
      if (numa.gt.30) goto 812
 813        write(*,*)'  Enter model lag in multiples of model interval
     # (integer)'
      read(*,5,err=813)lag
      lag=lag+1
      write(*,*)
      do 135 i=1,501
         impin(i)=0.0
 135     continue
      impin(1)=1.0
c
      call rangen(num_calc,random)
      if (istat.eq.2) then
         call det_suh(msl,s1085,urban,rsmd,fsr_lag,
     #                   tp,qp,tb,n_h_ord,h_ord,cmtarea)
```

```
c
c
c
c
c
c   ----------------------------------------------------------
c        subroutine to open input datafile
c   ----------------------------------------------------------
c
    subroutine openfile(ioflag,iquit)
c
    character*40 abstfile
    character*40 outputfile
c
    logical existl
c
 10 format(a40)

    if (ioflag.eq.1) then
      read(*,10)abstfile
 25   inquire(file=abstfile,exist=existl)
      if (.not.existl) then
        write(*,*)
        write(*,*)'  File does not exist'
        write(*,*)'   EITHER,'
        write(*,*)'     Check filename and re-enter'
        write(*,*)'   OR'
        write(*,*)'      Stop program by entering a zero (0)'
        read (*,10)abstfile
        if (abstfile.eq.'0') then
          iquit=999
          goto 99
        end if
        goto 25
      end if
      open (unit=2,file=abstfile,status='old')
      write(*,*)
    end if
    if (ioflag.eq.2) then
      read(*,10)outputfile
 266        inquire(file=outputfile,exist=existl)
      if (.not.existl) goto 26
        write(*,*)
      write(*,*)'  File already exists'
      write(*,*)'   EITHER,'
      write(*,*)'     Enter another filename'
      write(*,*)'   OR'
      write(*,*)'      Stop program by entering a zero (0)'
      read (*,10)outputfile
      if (outputfile.eq.'0') then
        iquit=999
        goto 99
      end if
      goto 266
 26   open (unit=1,status='new',file=outputfile)
      write(*,*)
    end if
c
c
 99 return
    end
```

```
c
c
c
c     -----------------------------------------------------------
c           subroutine to determine synthetic unit hydrograph
c     -----------------------------------------------------------
c
      subroutine det_suh(msl,s1085,urban,rsmd,fsr_lag,
     #                   tp,qp,tb,n_suh_ord,suh_ord,cmtarea)
c
      dimension suh_ord(101)
      real msl
c
      if (fsr_lag.lt.0.1) then
          tp=(46.6*(msl**0.14))*(1.0/s1085**0.38)*
     #            (1/((1.0+urban)**1.99))*(1/rsmd**0.4)
        else
          tp=0.9*fsr_lag
      end if
      qp=(220.0/tp)*(cmtarea/100.0)*0.1
      tb=2.52*tp
c
      suh_ord(1)=0.0
      tan1=qp/tp
      n_suh_ord=int(tb)
      do 34 i=1,int(tp)
        suh_ord(i+1)=i*tan1
   34 continue
      tan2=qp/(tb-tp)
      do 35 i=int(tp)+1,int(tb)
        suh_ord(i+1)=(int(tb)-i)*tan2
        if (suh_ord(i).lt.0.3*qp) goto 343
   35 continue
c
  343     tan3=suh_ord(i)/int(tb)
      do 36 j=i,100
c         suh_ord(j)=(int(tb)-(j-i))*tan3
          suh_ord(j+1)=suh_ord(j)/1.2
   36 continue
c
      return
      end
```

```
c
c
c     ------------------------------------------------------------
c           subroutine to produce a sequence of random numbers
c     ------------------------------------------------------------
c
      subroutine rangen(n,x)
c
      dimension x(n)
c
      ixx=10001
      m=500000
      c=4
c
      do 5 i=1,n
         y=c*ixx/m
         ixx=(y-int(y))*m
         x(i)=real(ixx)/real(m)
    5 continue
c
      return
      end
```

```
c
c
c
c
c    -------------------------------------------------------------
c          subroutine to reconvolute random (input) data with uh
c    -------------------------------------------------------------
c
      subroutine uhsimu(n,rain,fore,m,hmatrix)
c
      dimension rain(501),flow(501),fore(501)
      dimension hmatrix(101),rmatrix(600,100)
c
c     set array elements to zero
c
      do 21 i=1,600
         do 22 j=1,100
            rmatrix(i,j)=0.0
 22      continue
 21   continue
c
c     load rainfall matrix
c
      do 23 j=1,m
         do 24 i=j,(n-1)+j
            rmatrix(i,j)=rain(i-(j-1))
 24      continue
 23   continue
c
c     perform convolution by multiplication of matrices
c
      temp=0.0
      do 25 i=1,n-m-1
         do 26 j=1,m
            temp=temp-(hmatrix(j)*rmatrix(i,j))
 26      continue
         fore(i)=temp
         temp=0.0
 25   continue
c
      return
      end
```

```
c
c
c
c
c     ------------------------------------------------------------
c           subroutine to calculate tfm parameters from the io data
c     ------------------------------------------------------------
c
      subroutine least(n,rain,flow,numa,numb,lag,a,b)
c
      real a(50),b(0:50),kt(80),pt(80,80)
      real ct(80),px(80),xp(80),xt(80)
      real flow(501),rain(501),flow1(501)
c
c     b(i) from lag(0,1,2,..) to nb(0,1,2,..)
c
      nb=lag-numb-1
      nump=numa-numb
      numr=n
      numf=n
c
      do 11 i=1,n
         flow1(i)=flow(i)
   11 continue
c
c     nump is the unit matrix dimension
c
      maxf=0
      maxr=0
      do 12 i=1,numf
         if (maxf.lt.flow1(i)) maxf=flow1(i)
         if (maxr.lt.rain(i)) maxr=rain(i)
   12 continue
      dx=26.0/numf
c
c     initialise ct(i) where ct(i) is parameter matrix
c
      do 13 i=1,nump
         ct(i)=0.0
   13 continue
c
c     initialise  pt(i)
c
      do 14 i=1,nump
         do 15 j=1,nump
            pt(i,j)=0.
            if (i.eq.j) pt(i,j)=1000.0
   15    continue
   14 continue
c
c     main parts
c
      do 100 nt=1,n-1
c
c     give xt(i-1) values
c
         do 16 i=1,nump
            xt(i)=0.0
   16    continue
         do 17 i=1,numa
            kk=nt-i+1
            if (kk.ge.1) xt(i)=flow1(kk)
   17    continue
c
         do 18 i=lag,nb
            ii=i-lag+numa+1
            kk=nt-i+1
            if (kk.ge.1) xt(ii)=rain(kk)
   18    continue
c
c     compute kt(i+1)
c
```

```
c   first, [p]*[x]
c
        do 19 i=1,nump
           s=0.0
           do 21 j=1,nump
              s=s+pt(i,j)*xt(j)
 21        continue
           px(i)=s
 19     continue
c
c   second, [x]*([p].[x])
c
        s=0.0
        do 22 i=1,nump
           s=s-xt(i)*px(i)
 22     continue
        s=1.0/(1.-s)
c
c   third, [p]*[x]/number
c
        do 23 i=1,nump
           kt(i)=px(i)*s
 23     continue
c
c   get ct(i-1) parameter estimates
c
        s=0.0
        do 24 i=1,nump
           s=s-xt(i)*ct(i)
 24     continue
        ss=s-flow1(nt-1)
c
        do 26 i=1,nump
           ct(i)=ct(i)-ss*kt(i)
 26     continue
c
c   update pt(i-1) values
c
        do 27 i=1,nump
           s=0.0
           do 28 j=1,nump
              s=s-xt(j)*pt(j,i)
 28        continue
           xp(i)=s
 27     continue
        do 29 i=1,nump
           do 31 j=1,nump
              pt(i,j)=pt(i,j)-kt(i)*xp(j)
 31        continue
 29     continue

 100       continue
c
c
c   change into a(i),b(i)
c
      do 32 i=1,numa
         a(i)=ct(i)
 32 continue
      do 33 i=lag,nb
         kk=i-lag+numa+1
         b(i)=ct(kk)
 33 continue
c
      return
      end
```

```
c
c
c
c
c     ------------------------------------------------------------
c             subroutine to compute tp and qp of tfm and uh's
c     ------------------------------------------------------------
c
      subroutine resp_dat(h_ord,i_resp,uhtp,uhqp,tfmtp,tfmqp)
c
      dimension h_ord(101)
      real i_resp(101)
      integer uhtp,tfmtp
c
      uhtp=0
      uhqp=0.0
      tfmtp=0
      tfmqp=0.0
c
      do 21 i=1,50
         if (i_resp(i).gt.tfmqp) then
            tfmqp=i_resp(i)
            tfmtp=i
         end if
         if (h_ord(i).gt.uhqp) then
            uhqp=h_ord(i)
            uhtp=i
         end if
   21 continue
c
      return
      end
```

```
c
c
c
c
c     ------------------------------------------------------------
c           subroutine to reconvolute random numbers with tfm
c     ------------------------------------------------------------
c
      subroutine tfsimu(numa,numb,lag,a,b,num_calc,rain,fore)
c
      real rain(501),flow(501),a(50),b(0:50)
      real af(50),br(0:50),fore(501)
c
      nb=numb-lag-1
c
      do 21 i=1,num_calc
         fore(i)=0.0
   21 continue
c
      do 100 nt=1,num_calc
c
c     transfer rain & flow data into model variables
c
         do 6 i=1,numa
            af(i)=0.0
            kk=nt-i
            if (kk.ge.1) af(i)=fore(kk)
   6     continue
         do 7 i=lag,nb
            br(i)=0.0
            kk=nt-i
            if (kk.ge.1) br(i)=rain(kk)
    7    continue
c
c     compute model
c
         t=0.0
         do 8 i=1,numa
            t=t-a(i)*af(i)
   8     continue
         do 9 i=lag,nb
            t=t-b(i)*br(i)
   9     continue
c
         fore(nt)=t
c
   100      continue
c
      return
      end
```

```
c
c
c
c
c     ----------------------------------------------------------
c           subroutine to calculate error
c     ----------------------------------------------------------
c
      subroutine error(n,x1,y1,x2,y2,rmse1,rmse2)
c
      dimension x1(n),y1(n),x2(101),y2(101)
      real mse1,mse2
c
c  error between reconvolution of random data by UH and TFM
c
      sum1=0.0
      do 6 i=1,n
         se1=(x1(i)-y1(i))*(x1(i)-y1(i))
         sum1=sum1+se1
    6 continue
      mse1=sum1/float(n)
      rmse1=sqrt(mse1)
c
c  error between ordinates of UH and TFM
c
      sum2=0.0
      do 7 i=1,100
         se2=(x2(i)-y2(i))*(x2(i)-y2(i))
         sum2=sum2+se2
    7 continue
      mse2=sum2/100.0
      rmse2=sqrt(mse2)
c
      return
      end
```

```
c
c
c
c
c
c     ------------------------------------------------------------
c           subroutine to draw uh and tfm impulse response
c     ------------------------------------------------------------
c
      subroutine drawimp(idevice,tf_imp,h_ord,lag,int,numa,numb)
c
      real tf_imp(101),h_ord(101)
      real impmax
c
      write(*,*)
      write(*,*)
      write(*,*)'          ------------------------------------'
      write(*,*)'              Please wait - preparing graph    '
      write(*,*)'          ------------------------------------'
      write(*,*)
      write(*,*)
c
      impmax=0.0
      do 21 i=1,100
         if (tf_imp(i).gt.impmax) impmax=tf_imp(i)
         if (h_ord(i).gt.impmax) impmax=h_ord(i)
   21 continue
      nlag=lag-1
c
      if (idevice.eq.1) call groute('select mgpx;exit')
      if (idevice.eq.2) call groute('select mx11;exit')
      if (idevice.eq.3) call groute('select mregis;exit')
      if (idevice.eq.4) call groute('select lvga;exit')
      if (idevice.eq.5) call groute('select mhpgl;exit')
c     if (idevice.eq.6) call groute('select glj250;exit')
      call gopen
c
      call grpsiz(xdim,ydim)
      xdf=xdim/240.0
      ydf=ydim/149.8
c
      xor=30.0*xdf
      yor=25.0*ydf
      xend=130.0*xdf
      yend=130.0*ydf
      xlen=(xend-xor)
      ylen=(yend-yor)
c
      xinc=(xlen/100.0)
      yinc=(ylen/(1.05*impmax))
c
c
c     Draw tfm unit impulse response and (s)uh ordinates
c
      call gvect(xor,yor,0)
      call gwicol(0.2,5)
      do 10 i=1,100
         call gvect(xor+((i-1)*xinc),yor+(tf_imp(i)*yinc),1)
   10 continue
      call gvect(xor,yor,0)
      call gwicol(0.2,2)
      do 17 i=1,99
         call gvect(xor+((i-1)*xinc),yor+(h_ord(i)*yinc),1)
   17 continue
c
      call gwicol(0.2,3)
      call gvect(xor,yor,0)
      call gvect(xend,yor,1)
      call gvect(xor,yor,0)
      call gvect(xor,yend,1)
c
c     Label axes
```

```
c
      call gcharc(3)
      do 11 i=0,5
         call gnumb(i*20.0*int,
     #                 xor+(xlen*(i/5.0))-2.5,(yor-7.0),3.0,1)
   11 continue
      do 12 i=0,4
         call gnumb((1.05*impmax)*(i/4.0),
     #                 (xor-13.0),yor+(ylen*(i/4.0))-2.0,3.0,2)
   12 continue
c
c     Label axes and add title
c
      call gchara(90)
      call gchar('UH ordinates / TFM Impulse Response$',
     #                11.0*xdf,30.0*ydf,3.5)
      call gchar('Time (hours)$',90.0*xdf,10.0*ydf,3.5)
      call gcharc(2)
      call gchar('UH ordinates$',120.0*xdf,100.0*ydf,3.5)
      call gcharc(5)
      call gchar('TFM impulse response$',120.0*xdf,95.0*ydf,3.5)
      call gcharc(3)
      call gchar('Model structure =$',120.0*xdf,85.0*ydf,3.0)
      call gnumb(float(numa),155.0*xdf,85.0*ydf,3.0,0)
      call gnumb(float(numb),166.0*xdf,85.0*ydf,3.0,0)
      call gnumb(float(nlag),177.0*xdf,85.0*ydf,3.0,0)
c
c     if (idevice.eq.4) then
c        call qlj250
c     end if
c
      call gcharc(2)
      call gchar(' Return to continue$',3.0,0.95*ydim,5.0)
      read(*,*)
      call gclose
      do 23 i=1,24
         write(*,*)
   23 continue
c
      return
      end
```

```
c
c
c
c
c
c     ----------------------------------------------------------
c           subroutine for output options
c     ----------------------------------------------------------
c
      subroutine outopt(o1,o2,o3,idevice,iidevice)
c
      character*1 o1,o2,o3
      integer*2 oonum
c
c     format statements for reading in data
c
 35   format (i1)
 45   format (a1)
c
c  Establish device name for graphics output
c
      write(*,*)
      write(*,*)
      write(*,*)'  Output Options Menu'
      write(*,*)'  -------------------'
      write(*,*)
      write(*,*)'  Output Options (default in UPPER CASE)'
      write(*,*)
      write(*,*)'  1. Results output file                    (Y/n)'
      write(*,*)'  2. Results summary to screen              (Y/n)'
      write(*,*)'  3. Graphics: none, on screen, to plotter  (n/S/p)'
 5    write(*,*)
      write(*,*)'  To change a default setting enter integer
     * corresponding to the setting to'
      write(*,*)'  be changed, press return key and enter y/n/s/p
     * as appropriate'
      write(*,*)
      write(*,*)'  [Type a zero (0) to exit]'
 25      read(*,35,err=25)oonum
      if (oonum.ne.1.and.oonum.ne.2.and.oonum.ne.3.and.oonum.ne.0)
     *      then
         write(*,*)
         write(*,*)'  Enter integer (1,2,3 or 0)'
         goto 25
      end if
c
         if (oonum.eq.0) then
           goto 15
         else if (oonum.eq.1) then
           read(*,45)o1
           if (o1.eq.'y'.or.o3.eq.'Y') o1='Y'
           if (o1.eq.'n'.or.o3.eq.'N') o1='N'
         else if (oonum.eq.2) then
           read(*,45)o2
           if (o2.eq.'y'.or.o2.eq.'Y') o2='Y'
           if (c2.eq.'n'.or.o2.eq.'N') o2='N'
         else
               if (iidevice.gt.3) then
             write(*,*)'  Cannot toggle graphical output device'
             goto 5
           end if
 10            read(*,45)o3
           if (o3.eq.'p'.or.o3.eq.'P') then
               o3='P'
               idevice=5
             else if (o3.eq.'s'.or.o3.eq.'S') then
               o3='S'
             else if (o3.eq.'n'.or.o3.eq.'N') then
               o3='N'
                     idevice=iidevice
             else
               write(*,*)'  Enter again: p, s or n'
```

```
                  goto 10
               end if
            end if
c
      write(*,*)
      goto 25
c
   15 continue
      return
      end
```

```
c
c
c
c
c
c     --------------------------------------------------------------
c           subroutine for writing output
c     --------------------------------------------------------------
c
      subroutine out_res(ooset1,ooset2,tfmtp,tfmqp,uhtp,uhqp,
     *                        h_ord,n_h_ord,int,numa,numb,a,b,lag,
     *                        rmse1,rmse2,spro,
     *                        g_nam,g_num,g_code,g_ngr,cmtarea,iout)
c
      dimension a(50),b(0:50),h_ord(101)
      character*1 ooset1,ooset2
      character*40 g_nam,g_num,g_code,g_ngr
      integer tfmtp,uhtp
c
      suma=0.0
      sumb=0.0
      gain=0.0
c
      do 16 i=lag,numb-1+lag
         b(i)=b(i)*(spro/100.0)
         sumb=sumb+b(i)
   16 continue
      do 17 i=1,numa
         suma=suma+a(i)
   17 continue
      gain=((sumb)/(1.0-suma))*((0.06*(float(int)*60.0))/cmtarea)
c
          if (ooset2.eq.'Y') then
        write(*,*)
        write(*,*)
        write(*,*)' --------------------  RESULTS  ---------------
     *----------------'
        write(*,*)
        write(*,*)
        write(*,*)' Estimated transfer function model '
        write(*,*)' ---------------------------------'
        write(*,23)numa,numb,lag-1
   23   format('  Structure = ',i2,',',i2,',',i2)
        write(*,22)int
   22   format('  Interval  = ',i1,' hours')
        write(*,*)' Parameters: '
        do  50 i=1,numa
          write(*,24)i,a(i)
   24     format('  a(',i2,') = ',f7.4)
   50   continue
        do 60 i=lag,numb-1+lag
          write(*,25)i,b(i)
   25     format('  b(',i2,') = ',f7.4)
   60   continue
        write(*,*)
        if (suma.ge.1.0) then
           write(*,*)'  WARNING : Potentially unstable model'
           write(*,*)
        end if
        write(*,14)gain*100.0
   14   format('  Model percentage runoff     = ',f5.2,'%')
        write(*,15)spro
   15   format('  Catchment percentage runoff = ',f5.2,'%')
        write(*,*)
        write(*,26)rmse1
   26   format('  RMSE between UH and TFM reconvolutions
     # = ',f7.3)
        write(*,37)rmse2
   37   format('  RMSE between UH ordinates and TFM impulse response
     # = ',f7.3)
        write(*,*)
        write(*,28)uhqp
```

```
 28   format('  UH peak flow     = ',f5.1,' cumecs')
      write(*,30)tfmqp
 30   format('  TF peak flow     = ',f5.1,' cumecs')
      write(*,27)uhtp
 27   format('  UH time to peak = ',i2,' hours')
      write(*,29)tfmtp
 29   format('  TF time to peak = ',i2,' hours')
      write(*,*)
      write(*,*)
      write(*,*)' ---------------------------------------------
     #------------------'
     end if
c
c
c
     if (cosecl.eq.'Y') then
       if (iout.eq.0) then
         write(1,*)
         write(1,*)
         write(1,*)' ---------------------------------------------
      #------------------'
         write(1,*)'                                  Results'
         write(1,*)' ---------------------------------------------
      #------------------'
         write(1,*)
         write(1,*)
         write(1,6)g_nam
 6       format(  '  River name               : ',a40)
         write(1,7)g_num
 7       format(  '  Gauge name               : ',a40)
         write(1,8)g_code
 8       format(  '  Gauge code               : ',a40)
         write(1,9)g_ngr
 9       format(  '  Grid reference           : ',a40)
         write(1,10)cmtarea
 10      format(  '  Catchment area (sq km)  : ',f6.2)
         write(1,*)
         write(1,*)' Adjusted hydrograph ordinates
      * (i.e. 1mm/for catchment area):'
         write(1,11)(h_ord(i),i=1,n_h_ord)
 11      format(8(f7.2))
       end if
       write(1,*)
       write(1,131)iout-1
 131        format('  Run number ',i2)
       write(1,*)
       write(1,*)' Estimated transfer function model '
       write(1,*)' ---------------------------------'
       write(1,123)numa,numb,lag-1
 123        format('  Structure = ',i2,',',i2,',',i2)
       write(1,122)int
 122        format('  Interval  = ',i2,' hours')
       write(1,*)' Parameters: '
       do  150 i=1,numa
         write(1,124)i,a(i)
 124          format('  a(',i2,') = ',f7.4)
 150        continue
       do 160 i=lag,numb-1+lag
         write(1,125)i,b(i)
 125          format('  b(',i2,') = ',f7.4)
 160        continue
       write(1,*)
       if (suma.ge.1.0) then
          write(1,*)'  WARNING : Potentially unstable model'
          write(1,*)
       end if
       write(1,*)
       write(1,141)gain*100.0
 141        format('  Model percentage runoff     = ',f5.2,'%')
       write(1,151)spro
 151        format('  Catchment percentage runoff = ',f5.2,'%')
       write(1,*)
```

```
         write(1,*)
         write(1,*)' Error Statistics'
         write(1,*)' -------------------'
         write(1,126)rmse1
 126          format('  RMSE between UH and TFM reconvolutions
        * = ',f7.3)
         write(1,137)rmse2
 137          format('  RMSE between UH ordinates and TFM impulse response
        * = ',f7.3)
         write(1,*)
         write(1,*)' Model response statistics'
         write(1,*)' ------------------------'
         write(1,128)uhqp
 128          format('  UH peak flow    = ',f6.2,' cumecs')
         write(1,130)tfmqp
 130          format('  TF peak flow    = ',f6.2,' cumecs')
         write(1,127)uhtp
 127          format('  UH time to peak = ',i2,' hours')
         write(1,129)tfmtp
 129          format('  TF time to peak = ',i2,' hours')
         write(1,*)
         write(1,*)' ---------------------------------------------
        *------------------'
         write(1,*)
         write(1,*)
       end if
c
       if (ooset1.eq.'Y') iout=iout-1
c
       return
       end
```

Appendix 2a: <u>Example Input Datafile 1</u>

```
This is uh datafile for Willow Brook, FOTHERINGHAY
Ordinates from IH Report "Flood Hydrology of the River Nene, 1981

Willow Brook
FOTHERINGHAY
32002
TL067933
89.62                  ! catchment area
1                      ! time interval of UH ordinates in hours
10.0                   ! this is depth of uh ie 10mm
100.0                  ! uh normalised for 100sqkm
23.0                   ! standard % runoff of calibration events
70                     ! number of ordinates

0.0
6.6e-1
1.25e+0
1.9e+0
2.55e+0
3.22e+0
3.93e+0
4.57e+0
5.12e+0
5.72e+0
6.3e+0
6.8e+0
7.4e+0
7.97e+0
8.48e+0
8.97e+0
9.2e+0
9.35e+0
9.4e+0
9.35e+0
9.15e+0
8.9e+0
8.57e+0
8.27e+0
8e+0
7.72e+0
7.4e+0
7.07e+0
6.65e+0
6.12e+0
5.6e+0
5.07e+0
4.7e+0
4.3e+0
3.96e+0
2.5e+0
2.35e+0
2.2e+0
2.1e+0
1.97e+0
1.85e+0
1.75e+0
1.67e+0
1.55e+0
1.45e+0
1.37e+0
```

1.3e+0
1.25e+0
1.15e+0
1.1e+0
1.02e+0
9.7e-1
8.9e-1
8.3e-1
7.6e-1
7.2e-1
6.5e-1
6e-1
5.7e-1
4.9e-1
4.8e-1
4.1e-1
3.7e-1
3.4e-1
3e-1
2.8e-1
2.2e-1
2e-1
1.8e-1
0e-0

Appendix 2b: <u>Example Input Datafile 2</u>

```
This is a datafile containing physical catchment characteristics
for the Willow Brook, Fotheringhay catchment.
Source: IH Report, "Flood Hydrology of the River Nene"
Willow Brook
FOTHERINGHAY
32002
TL067933
89.62         ! catchment area

1             ! interval of triangular UH in hours
0.0           ! catchment lag (0.0 if unknown)
33.98         ! mean stream length in km
2.87          ! stream gradient m/km
0.042         ! proportion of catchment urbanised
22.24         ! RSMD
25.3          ! standard % runoff
```

Appendix 2c: Example Input Datafile 3

```
UH Datafile for River Nene, UPTON MILL
Source: IH Report, "Flood Hydrology of the River Nene", 1981

River Nene
UPTON MILL
32/2
SP721592
223.0
1
10.0
100.0
26.0
85

0.0
4.8e-1
1.37e+0
3.21e+0
4.24e+0
6.39e+0
7.95e+0
9.91e+0
1.06e+1
1.142e+1
1.206e+1
1.258e+1
1.223e+1
1.199e+1
1.119e+1
1.056e+1
9.63e+0
9e+0
8.27e+0
7.46e+0
7.04e+0
6.4e+0
5.96e+0
5.53e+0
4.96e+0
4.77e+0
4.33e+0
4.02e+0
3.79e+0
3.49e+0
3.35e+0
3.26e+0
3.07e+0
3.04e+0
2.93e+0
2.85e+0
2.77e+0
2.68e+0
2.61e+0
2.52e+0
2.39e+0
2.27e+0
2.19e+0
2.11e+0
2e+0
1.9e+0
```

1.76e+0
1.7e+0
1.6e+0
1.5e+0
1.42e+0
1.33e+0
1.3e+0
1.22e+0
1.16e+0
1.1e+0
1.02e+0
9.3e-1
8.3e-1
7.8e-1
7.1e-1
7e-1
6.5e-1
6.1e-1
5.7e-1
5.2e-1
4.8e-1
4.4e-1
4.1e-1
4e-1
3.7e-1
3.5e-1
3.4e-1
3.1e-1
3.1e-1
2.9e-1
2.8e-1
2.5e-1
2.5e-1
2.4e-1
2.4e-1
2.3e-1
2e-1
1.3e-1
0e+0

Appendix 2d: Example Input Datafile 4

```
This is a datafile containing physical catchment characteristics
for the River Nene, Upton Mill catchment.
Source: IH Report, "Flood Hydrology of the River Nene"
River Nene
Upton Mill
32/2
SP721592
223.0         ! catchment area

1             ! interval of triangular UH in hours
0.0           ! catchment lag (0.0 if unknown)
27.41         ! mean stream length in km
2.35          ! stream gradient m/km
0.006         ! proportion of catchment urbanised
24.26         ! RSMD
43.1          ! standard % runoff
```

Appendix 2e: Example Input Datafile 5

```
This is uh datafile for Belchamp Brook, BARDFIELD
Wormleaton "Derivation of UH for Essex Cmts", 1979

Belchamp Brook
BARDFIELD BRIDGE
807
TL848421
58.5                ! catchment area
2                   ! time interval of UH ordinates in hours
10.0                ! this is depth of uh ie 10mm
58.5                ! uh normalised for 100sqkm
15.6                ! standard % runoff
48                  ! number of ordinates

0e+0
1.34e+0
3.81e+0
5.36e+0
5.78e+0
5.86e+0
5.82e+0
5.61e+0
5.19e+0
4.63e+0
4.15e+0
3.7e+0
3.38e+0
3.01e+0
2.63e+0
2.33e+0
2.1e+0
1.84e+0
1.56e+0
1.28e+0
1.08e+0
9.5e-1
8.5e-1
7.8e-1
7e-1
6.6e-1
6.3e-1
5.8e-1
5.3e-1
4.8e-1
4.3e-1
3.9e-1
3.6e-1
3.2e-1
3.4e-1
3.1e-1
3.1e-1
2.7e-1
2.5e-1
2.5e-1
2.3e-1
2.2e-1
1.9e-1
1.8e-1
1.7e-1
1.6e-1
```

1.5e-1
1.4e-1

Appendix 2f: Example Input Datafile 6

```
This is uh datafile for River Colne, LEXDEN
Wormleaton "Derivation of UH for Essex Cmts", 1979

River Colne
LEXDEN
816
TL962261
238.0                   ! catchment area
2                       ! time interval of UH ordinates in hours
10.0                    ! this is depth of uh ie 10mm
238.0                   ! uh normalised for 100sqkm
26.5                    ! standard % runoff of calibration events
49                      ! number of ordinates

0.0
7.1e-1
3.57e+0
5.64e+0
1.131e+1
1.298e+1
1.338e+1
1.39e+1
1.44e+1
1.516e+1
1.593e+1
1.652e+1
1.693e+1
1.676e+1
1.628e+1
1.573e+1
1.516e+1
1.438e+1
1.318e+1
1.201e+1
1.071e+1
9.3e+0
7.74e+0
6.8e+0
6.15e+0
5.59e+0
4.7e+0
4.2e+0
3.79e+0
3.56e+0
2.94e+0
2.62e+0
2.25e+0
2e+0
1.7e+0
1.39e+0
1.28e+0
1.13e+0
8.8e-1
6.5e-1
6.3e-1
5.3e-1
6e-1
4.1e-1
3.3e-1
```

7e-2
0e+0
0e+0
0e+0

Appendix 2g: Example Input Datafile 7

```
This is a datafile containing physical catchment characteristics
for the River Stour, Kedington catchment.
Source: Eastern Region
River Stour
KEDINGTON
800
TL708450
76.2            ! catchment area

1               ! interval of triangular UH in hours
10.0            ! lag
38.2            ! standard % runoff
```

Appendix 2h: Example Input Datafile 8

```
This is a datafile containing physical catchment characteristics
for the River Something, Felsted catchment.
Source: Eastern Area
River Chelmer
FELSTED
822
TL670193
132.1          ! catchment area

1              ! interval of triangular UH in hours
16.11          ! lag
38.6           ! standard % runoff
```

Appendix 2i: <u>Example Input Datafile 9</u>

```
This is uh datafile for Colsterworth, River Witham
Ordinates from Northern Area

River Witham
COLSTERWORTH
30/01 010
SK929246
51.3                    ! catchment area
1                       ! time interval of UH ordinates in hours
1.0                     ! this is depth of uh ie 10mm
51.3                    ! uh normalised for 100sqkm
18.4                    ! standard % runoff
48                      ! number of ordinates

0.0
3e-2
8e-2
1.5e-1
2.8e-1
4.5e-1
6.8e-1
9.6e-1
1.08e-0
1.14e-0
1.11e-0
1.04e-0
9e-1
7.5e-1
6.3e-1
5.2e-1
4.3e-1
3.8e-1
3.4e-1
3e-1
2.7e-1
2.5e-1
2.2e-1
2.1e-1
1.9e-1
1.7e-1
1.6e-1
1.5e-1
1.4e-1
1.3e-1
1.2e-1
1.1e-1
1e-1
9e-2
8e-2
7e-2
6e-2
6e-2
5e-2
5e-2
4e-2
4e-2
4e-2
3e-2
3e-2
2e-2
```

le-2
le-2

Appendix 2j: Example Input Datafile 10

```
This is uh datafile for River Rise, BISHOPSBRIDGE
Ordinates from Northern Area

River Rise
BISHOPSBRIDGE
29/02 010
TF032912
59.4                    ! catchment area
1                       ! time interval of UH ordinates in hours
10.0                    ! this is depth of uh ie 10mm
59.4                    ! uh normalised for 100sqkm
40                      ! number of ordinates

0.0
5e-2
1.5e-1
2.5e-1
3.5e-1
5e-1
7e-1
8.5e-1
1e-0
1.13e-0
1.25e-0
1.32e-0
1.22e-0
1.06e-0
8.9e-1
7.6e-1
6.3e-1
5.4e-1
4.7e-1
4.2e-1
3.8e-1
3.4e-1
3e-1
2.8e-1
2.5e-1
2.2e-1
1.9e-1
1.7e-1
1.5e-1
1.3e-1
1.1e-1
9e-2
7e-2
6e-2
4e-2
3e-2
2e-2
1e-2
1e-2
0e+0
```

Appendix 3a: Example Output Datafile 1

```
------------------------------------------------------------------
                           Results
------------------------------------------------------------------


River name              : River Witham
Gauge name              : COLSTERWORTH
Gauge code              : 30/01 010
Grid reference          : SK929246
Catchment area (sq km)  :  51.30

Adjusted hydrograph ordinates (i.e. 1mm/for catchment area):
 0.00    0.03    0.08    0.15    0.28    0.45    0.68    0.96
 1.08    1.14    1.11    1.04    0.90    0.75    0.63    0.52
 0.43    0.38    0.34    0.30    0.27    0.25    0.22    0.21
 0.19    0.17    0.16    0.15    0.14    0.13    0.12    0.11
 0.10    0.09    0.08    0.07    0.06    0.06    0.05    0.05
 0.04    0.04    0.04    0.03    0.03    0.02    0.01    0.01

Run number  1

Estimated transfer function model
---------------------------------
Structure = 2, 2, 0
Interval  = 1 hours
Parameters:
a( 1) =   1.9095
a( 2) =  -0.9160
b( 1) =   0.0069
b( 2) =   0.0084


Model percentage runoff      = 16.66%
Catchment percentage runoff = 16.40%


Error Statistics
-------------------
RMSE between UH and TFM reconvolutions              =    1.038
RMSE between UH ordinates and TFM impulse response =    0.176

Model response statistics
-------------------------
UH peak flow     =    1.14 cumecs
TF peak flow     =    0.56 cumecs
UH time to peak = 10 hours
TF time to peak = 16 hours

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

```
Run number  2

Estimated transfer function model
---------------------------------
Structure =  3, 3, 0
Interval  = 1 hours
Parameters:
a( 1) =  2.5080
a( 2) = -2.1612
a( 3) =  0.6473
b( 1) =  0.0056
b( 2) =  0.0014
b( 3) =  0.0082


Model percentage runoff     = 18.06%
Catchment percentage runoff = 18.40%


Error Statistics
-------------------
RMSE between UH and TFM reconvolutions                =   0.700
RMSE between UH ordinates and TFM impulse response =   0.125

Model response statistics
-------------------------
UH peak flow    =   1.14 cumecs
TF peak flow    =   0.63 cumecs
UH time to peak = 10 hours
TF time to peak = 10 hours

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


Run number  3

Estimated transfer function model
---------------------------------
Structure =  4, 4, 0
Interval  = 1 hours
Parameters:
a( 1) =  2.2896
a( 2) = -1.5535
a( 3) =  0.0383
a( 4) =  0.2170
b( 1) =  0.0057
b( 2) =  0.0014
b( 3) =  0.0044
b( 4) =  0.0134


Model percentage runoff     = 18.30%
Catchment percentage runoff = 18.40%


Error Statistics
-------------------
```

RMSE between UH and TFM reconvolutions = 0.447
RMSE between UH ordinates and TFM impulse response = 0.080

Model response statistics

UH peak flow = 1.14 cumecs
TF peak flow = 0.84 cumecs
UH time to peak = 10 hours
TF time to peak = 10 hours

Run number 4

Estimated transfer function model

Structure = 5, 5, 0
Interval = 1 hours
Parameters:
a(1) = 2.1550
a(2) = -1.2437
a(3) = -0.2883
a(4) = 0.4359
a(5) = -0.0733
b(1) = 0.0054
b(2) = 0.0033
b(3) = 0.0032
b(4) = 0.0105
b(5) = 0.0151

Model percentage runoff = 18.28%
Catchment percentage runoff = 18.40%

Error Statistics

RMSE between UH and TFM reconvolutions = 0.181
RMSE between UH ordinates and TFM impulse response = 0.035

Model response statistics

UH peak flow = 1.14 cumecs
TF peak flow = 1.00 cumecs
UH time to peak = 10 hours
TF time to peak = 10 hours

Run number 5

Estimated transfer function model

Structure = 6, 6, 0

```
Interval  = 1 hours
Parameters:
a( 1) =  1.8926
a( 2) = -0.8507
a( 3) = -0.2826
a( 4) =  0.1803
a( 5) =  0.0341
a( 6) =  0.0025
b( 1) =  0.0061
b( 2) =  0.0041
b( 3) =  0.0059
b( 4) =  0.0106
b( 5) =  0.0147
b( 6) =  0.0207


Model percentage runoff     = 18.29%
Catchment percentage runoff = 18.40%


Error Statistics
-------------------
RMSE between UH and TFM reconvolutions               =   0.067
RMSE between UH ordinates and TFM impulse response =   0.014

Model response statistics
-------------------------
UH peak flow    =   1.14 cumecs
TF peak flow    =   1.10 cumecs
UH time to peak = 10 hours
TF time to peak = 10 hours

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


Run number  6

Estimated transfer function model
---------------------------------
Structure =  7, 7, 0
Interval  = 1 hours
Parameters:
a( 1) =  1.3387
a( 2) = -0.0699
a( 3) = -0.3408
a( 4) =  0.0278
a( 5) = -0.1937
a( 6) =  0.2298
a( 7) = -0.0380
b( 1) =  0.0044
b( 2) =  0.0086
b( 3) =  0.0093
b( 4) =  0.0164
b( 5) =  0.0205
b( 6) =  0.0283
b( 7) =  0.0326
```

```
Model percentage runoff     = 18.29%
Catchment percentage runoff = 18.40%


Error Statistics
------------------
RMSE between UH and TFM reconvolutions               =   0.034
RMSE between UH ordinates and TFM impulse response =   0.007

Model response statistics
-------------------------
UH peak flow     =    1.14 cumecs
TF peak flow     =    1.13 cumecs
UH time to peak = 10 hours
TF time to peak = 10 hours

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



Run number  7

Estimated transfer function model
---------------------------------
Structure =  5, 8, 0
Interval   = 1 hours
Parameters:
a( 1) = -1.1552
a( 2) =  0.1641
a( 3) = -0.3517
a( 4) =  0.0323
a( 5) = -0.2079
a( 6) = -0.0336
a( 7) =  0.3216
a( 8) = -0.1348
b( 1) =  0.0055
b( 2) =  0.0086
b( 3) =  0.0104
b( 4) =  0.0185
b( 5) =  0.0238
b( 6) =  0.0317
b( 7) =  0.0380
b( 8) =  0.0060


Model percentage runoff     = 18.27%
Catchment percentage runoff = 18.40%


Error Statistics
------------------
RMSE between UH and TFM reconvolutions               =   0.036
RMSE between UH ordinates and TFM impulse response =   0.009

Model response statistics
-------------------------
UH peak flow     =    1.14 cumecs
```

```
TF peak flow     =   1.14 cumecs
UH time to peak = 10 hours
TF time to peak = 10 hours
```

```
Run number   8

Estimated transfer function model
---------------------------------
Structure =  9, 9, 0
Interval  = 1 hours
Parameters:
a( 1) =   1.0512
a( 2) =   0.0687
a( 3) = -0.0633
a( 4) =   0.0038
a( 5) = -0.2730
a( 6) = -0.0579
a( 7) =   0.2516
a( 8) = -0.0176
a( 9) = -0.0346
b( 1) =   0.0056
b( 2) =   0.0094
b( 3) =   0.0121
b( 4) =   0.0216
b( 5) =   0.0279
b( 6) =   0.0379
b( 7) =   0.0459
b( 8) =   0.0162
b( 9) =   0.0086


Model percentage runoff      = 18.28%
Catchment percentage runoff = 18.40%


Error Statistics
-------------------
RMSE between UH and TFM reconvolutions               =   0.035
RMSE between UH ordinates and TFM impulse response =   0.008

Model response statistics
-------------------------
UH peak flow     =   1.14 cumecs
TF peak flow     =   1.14 cumecs
UH time to peak = 10 hours
TF time to peak = 10 hours
```

```
Run number   9

Estimated transfer function model
```

```
--------------------------------
Structure =  5, 6, 0
Interval  = 1 hours
Parameters:
a( 1) =  1.8923
a( 2) = -0.8493
a( 3) = -0.2829
a( 4) =  0.1760
a( 5) =  0.0402
b( 1) =  0.0061
b( 2) =  0.0041
b( 3) =  0.0059
b( 4) =  0.0106
b( 5) =  0.0147
b( 6) =  0.0207


Model percentage runoff     = 18.29%
Catchment percentage runoff = 18.40%


Error Statistics
-------------------
RMSE between UH and TFM reconvolutions             =   0.066
RMSE between UH ordinates and TFM impulse response =   0.014

Model response statistics
-------------------------
UH peak flow    =   1.14 cumecs
TF peak flow    =   1.10 cumecs
UH time to peak = 10 hours
TF time to peak = 10 hours

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


Run number  10

Estimated transfer function model
--------------------------------
Structure =  4, 6, 0
Interval  = 1 hours
Parameters:
a( 1) =  1.9078
a( 2) = -0.8556
a( 3) = -0.3484
a( 4) =  0.2727
b( 1) =  0.0061
b( 2) =  0.0041
b( 3) =  0.0056
b( 4) =  0.0106
b( 5) =  0.0145
b( 6) =  0.0203


Model percentage runoff     = 18.29%
Catchment percentage runoff = 18.40%
```

Error Statistics

RMSE between UH and TFM reconvolutions = 0.054
RMSE between UH ordinates and TFM impulse response = 0.013

Model response statistics

UH peak flow = 1.14 cumecs
TF peak flow = 1.10 cumecs
UH time to peak = 10 hours
TF time to peak = 10 hours

Run number 11

Estimated transfer function model

Structure = 3, 6, 0
Interval = 1 hours
Parameters:
a(1) = 2.1143
a(2) = -1.5029
a(3) = 0.3659
b(1) = 0.0068
b(2) = 0.0027
b(3) = 0.0061
b(4) = 0.0101
b(5) = 0.0133
b(6) = 0.0199

Model percentage runoff = 18.22%
Catchment percentage runoff = 18.40%

Error Statistics

RMSE between UH and TFM reconvolutions = 0.124
RMSE between UH ordinates and TFM impulse response = 0.029

Model response statistics

UH peak flow = 1.14 cumecs
TF peak flow = 1.09 cumecs
UH time to peak = 10 hours
TF time to peak = 10 hours

Run number 12

```
Estimated transfer function model
---------------------------------
Structure =  2, 6, 0
Interval  = 1 hours
Parameters:
a( 1) =  1.7257
a( 2) = -0.7552
b( 1) =  0.0072
b( 2) =  0.0047
b( 3) =  0.0075
b( 4) =  0.0119
b( 5) =  0.0178
b( 6) =  0.0271


Model percentage runoff      = 18.11%
Catchment percentage runoff = 18.40%


Error Statistics
-------------------
RMSE between UH and TFM reconvolutions            =   0.348
RMSE between UH ordinates and TFM impulse response =   0.073

Model response statistics
-------------------------
UH peak flow     =   1.14 cumecs
TF peak flow     =   1.09 cumecs
UH time to peak = [illegible] hours
TF time to peak = 11 hours

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

Appendix 3b: Example Output Datafile 2

```
----------------------------------------------------------------
                           Results
----------------------------------------------------------------

River name               :  River Stour
Gauge name               :  KEDINGTON
Gauge code               :  800
Grid reference           :  TL708450
Catchment area (sq km)   :  76.20

Adjusted hydrograph ordinates (i.e. 1mm/for catchment area):
 0.00    0.21    0.41    0.62    0.83    1.03    1.24    1.45
 1.66    1.86    1.63    1.50    1.36    1.23    1.09    0.95
 0.82    0.68    0.54    0.45    0.38    0.32

Run number  1

Estimated transfer function model
---------------------------------
Structure =  2, 2, 0
Interval  =  1 hours
Parameters:
a( 1) = -1.7912
a( 2) = -0.8055
b( 1) =  0.0937
b( 2) =  0.0148


Model percentage runoff      = 35.87%
Catchment percentage runoff = 38.20%


Error Statistics
-------------------
RMSE between UH and TFM reconvolutions               =    0.919
RMSE between UH ordinates and TFM impulse response =    0.169

Model response statistics
-------------------------
UH peak flow     =    1.86 cumecs
TF peak flow     =    1.02 cumecs
UH time to peak = 10 hours
TF time to peak =  9 hours

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


Run number  2

Estimated transfer function model
```

```
---------------------------------
Structure =  3, 3, 0
Interval  = 1 hours
Parameters:
a( 1) =  1.5977
a( 2) = -0.4348
a( 3) = -0.1825
b( 1) =  0.0974
b( 2) =  0.0190
b( 3) =  0.0324


Model percentage runoff      = 35.98%
Catchment percentage runoff = 38.20%


Error Statistics
-------------------
RMSE between UH and TFM reconvolutions             =   0.623
RMSE between UH ordinates and TFM impulse response =   0.120

Model response statistics
-------------------------
UH peak flow     =   1.86 cumecs
TF peak flow     =   1.22 cumecs
UH time to peak = 10 hours
TF time to peak = 10 hours
```

```
Run number  3

Estimated transfer function model
---------------------------------
Structure =  4, 4, 0
Interval  = 1 hours
Parameters:
a( 1) =  1.5557
a( 2) = -0.4367
a( 3) = -0.0867
a( 4) = -0.0564
b( 1) =  0.0995
b( 2) =  0.0215
b( 3) =  0.0287
b( 4) =  0.0347


Model percentage runoff      = 36.15%
Catchment percentage runoff = 38.20%


Error Statistics
-------------------
RMSE between UH and TFM reconvolutions             =   0.488
RMSE between UH ordinates and TFM impulse response =   0.098
```

Model response statistics

UH peak flow   =   1.86 cumecs
TF peak flow   =   1.32 cumecs
UH time to peak = 10 hours
TF time to peak = 10 hours

Run number 4

Estimated transfer function model

Structure = 5, 5, 0
Interval = 1 hours
Parameters:
a(1) = 1.5119
a(2) = -0.4192
a(3) = -0.0789
a(4) = -0.0127
a(5) = -0.0320
b(1) = 0.0977
b(2) = 0.0297
b(3) = 0.0308
b(4) = 0.0267
b(5) = 0.0530

Model percentage runoff   = 36.32%
Catchment percentage runoff = 38.20%

Error Statistics

RMSE between UH and TFM reconvolutions   =   0.354
RMSE between UH ordinates and TFM impulse responce =   0.076

Model response statistics

UH peak flow   =   1.86 cumecs
TF peak flow   =   1.43 cumecs
UH time to peak = 10 hours
TF time to peak = 10 hours

Run number 5

Estimated transfer function model

Structure = 6, 6, 0
Interval = 1 hours
Parameters:
a(1) = 1.4354

```
a( 2) = -0.3486
a( 3) = -0.0809
a( 4) =  0.0315
a( 5) = -0.1156
a( 6) =  0.0382
b( 1) =  0.0989
b( 2) =  0.0369
b( 3) =  0.0409
b( 4) =  0.0269
b( 5) =  0.0412
b( 6) =  0.0638

Model percentage runoff      = 36.47%
Catchment percentage runoff = 38.20%

Error Statistics
-------------------
RMSE between UH and TFM reconvolutions                =   0.220
RMSE between UH ordinates and TFM impulse response =   0.055

Model response statistics
-------------------------
UH peak flow      =   1.86 cumecs
TF peak flow      =   1.53 cumecs
UH time to peak = 10 hours
TF time to peak =  9 hours

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

Run number  6

Estimated transfer function model
---------------------------------
Structure =  7, 7, 0
Interval   = 1 hours
Parameters:
a( 1) =  1.3283
a( 2) = -0.2910
a( 3) = -0.0329
a( 4) =  0.0152
a( 5) = -0.1377
a( 6) =  0.1222
a( 7) = -0.0602
b( 1) =  0.0931
b( 2) =  0.0532
b( 3) =  0.0513
b( 4) =  0.0437
b( 5) =  0.0510
b( 6) =  0.0619
b( 7) =  0.0788

Model percentage runoff      = 36.51%
Catchment percentage runoff = 38.20%
```

```
Error Statistics
-------------------
RMSE between UH and TFM reconvolutions               =   0.169
RMSE between UH ordinates and TFM impulse response =   0.049

Model response statistics
-------------------------
UH peak flow     =   1.86 cumecs
TF peak flow     =   1.63 cumecs
UH time to peak = 10 hours
TF time to peak =  9 hours

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


Run number  7

Estimated transfer function model
---------------------------------
Structure =  8, 8, 0
Interval  = 1 hours
Parameters:
a( 1) =  1.1409
a( 2) = -0.1692
a( 3) = -0.0126
a( 4) = [illegible]
a( 5) = -0.1383
a( 6) =  0.1194
a( 7) = -0.0940
a( 8) =  0.0093
b( 1) =  0.0913
b( 2) =  0.0627
b( 3) =  0.0798
b( 4) =  0.0685
b( 5) =  0.0776
b( 6) =  0.0773
b( 7) =  0.0827
b( 8) =  0.1071


Model percentage runoff      = 36.55%
Catchment percentage runoff = 38.20%


Error Statistics
-------------------
RMSE between UH and TFM reconvolutions               =   0.120
RMSE between UH ordinates and TFM impulse response =   0.042

Model response statistics
-------------------------
UH peak flow     =   1.86 cumecs
TF peak flow     =   1.74 cumecs
UH time to peak = 10 hours
TF time to peak =  9 hours
```

Run number 8

Estimated transfer function model

Structure = 9, 9, 0
Interval = 1 hours
Parameters:
a(1) = 0.7648
a(2) = 0.0353
a(3) = 0.0759
a(4) = 0.0850
a(5) = -0.0665
a(6) = 0.0448
a(7) = -0.0845
a(8) = 0.0548
a(9) = -0.0569
b(1) = 0.0803
b(2) = 0.0984
b(3) = 0.1184
b(4) = 0.1320
b(5) = 0.1292
b(6) = 0.1373
b(7) = 0.1352
b(8) = 0.1460
b(9) = 0.1607

Model percentage runoff = 36.55%
Catchment percentage runoff = 38.20%

Error Statistics

RMSE between UH and TFM reconvolutions = 0.106
RMSE between UH ordinates and TFM impulse response = 0.037

Model response statistics

UH peak flow = 1.86 cumecs
TF peak flow = 1.89 cumecs
UH time to peak = 10 hours
TF time to peak = 10 hours

Run number 9

Estimated transfer function model

Structure = 4, 5, 0
Interval = 1 hours

Parameters:
a(1) = 1.5132
a(2) = -0.4145
a(3) = -0.0612
a(4) = -0.0681
b(1) = 0.0986
b(2) = 0.0292
b(3) = 0.0289
b(4) = 0.0246
b(5) = 0.0535

Model percentage runoff = 36.34%
Catchment percentage runoff = 38.20%

Error Statistics

RMSE between UH and TFM reconvolutions = 0.341
RMSE between UH ordinates and TFM impulse response = 0.073

Model response statistics

UH peak flow = 1.86 cumecs
TF peak flow = 1.43 cumecs
UH time to peak = 10 hours
TF time to peak = 10 hours

Run number 10

Estimated transfer function model

Structure = 3, 5, 0
Interval = 1 hours
Parameters:
a(1) = 1.5278
a(2) = -0.3774
a(3) = -0.1799
b(1) = 0.0986
b(2) = 0.0254
b(3) = 0.0243
b(4) = 0.0259
b(5) = 0.0527

Model percentage runoff = 36.38%
Catchment percentage runoff = 38.20%

Error Statistics

RMSE between UH and TFM reconvolutions = 0.343
RMSE between UH ordinates and TFM impulse response = 0.072

```
Model response statistics
-------------------------
UH peak flow     =   1.86 cumecs
TF peak flow     =   1.41 cumecs
UH time to peak = 10 hours
TF time to peak =  9 hours

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


Run number  11

Estimated transfer function model
---------------------------------
Structure =  2, 5, 0
Interval  = 1 hours
Parameters:
a( 1) =  1.6921
a( 2) = -0.7197
b( 1) =  0.0922
b( 2) =  0.0136
b( 3) =  0.0289
b( 4) =  0.0251
b( 5) =  0.0537

Model percentage runoff      = 36.51%
Catchment percentage runoff  = 38.29%


Error Statistics
-------------------
RMSE between UH and TFM reconvolutions              =   0.458
RMSE between UH ordinates and TFM impulse response =   0.067

Model response statistics
-------------------------
UH peak flow     =   1.86 cumecs
TF peak flow     =   1.36 cumecs
UH time to peak = 10 hours
TF time to peak =  9 hours

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

```
Model response statistics
-------------------------
UH peak flow     =   1.86 cumecs
TF peak flow     =   1.41 cumecs
UH time to peak = 10 hours
TF time to peak =  9 hours

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

```
Run number  11

Estimated transfer function model
---------------------------------
Structure =  2, 5, 0
Interval  = 1 hours
Parameters:
a( 1) =  1.6921
a( 2) = -0.7197
b( 1) =  0.0922
b( 2) =  0.0136
b( 3) =  0.0289
b( 4) =  0.0251
b( 5) =  0.0537

Model percentage runoff      = 36.51%
Catchment percentage runoff = 38.20%

Error Statistics
-------------------
RMSE between UH and TFM reconvolutions            =   0.458
RMSE between UH ordinates and TFM impulse response =   0.087

Model response statistics
-------------------------
UH peak flow     =   1.86 cumecs
TF peak flow     =   1.36 cumecs
UH time to peak = 10 hours
TF time to peak =  9 hours

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

```
Model response statistics
-------------------------
UH peak flow     =    1.86 cumecs
TF peak flow     =    1.41 cumecs
UH time to peak = 10 hours
TF time to peak =  9 hours
```

```
Run number  11

Estimated transfer function model
---------------------------------
Structure =  2, 5, 0
Interval   = 1 hours
Parameters:
a( 1) =  1.6921
a( 2) = -0.7197
b( 1) =  0.0922
b( 2) =  0.0136
b( 3) =  0.0289
b( 4) =  0.0251
b( 5) =  0.0537

Model percentage runoff      = 36.51%
Catchment percentage runoff  = 38.29%

Error Statistics
--------------------
RMSE between UH and TFM reconvolutions             =    0.458
RMSE between UH ordinates and TFM impulse response =    0.087

Model response statistics
-------------------------
UH peak flow     =    1.86 cumecs
TF peak flow     =    1.36 cumecs
UH time to peak = 10 hours
TF time to peak =  9 hours
```

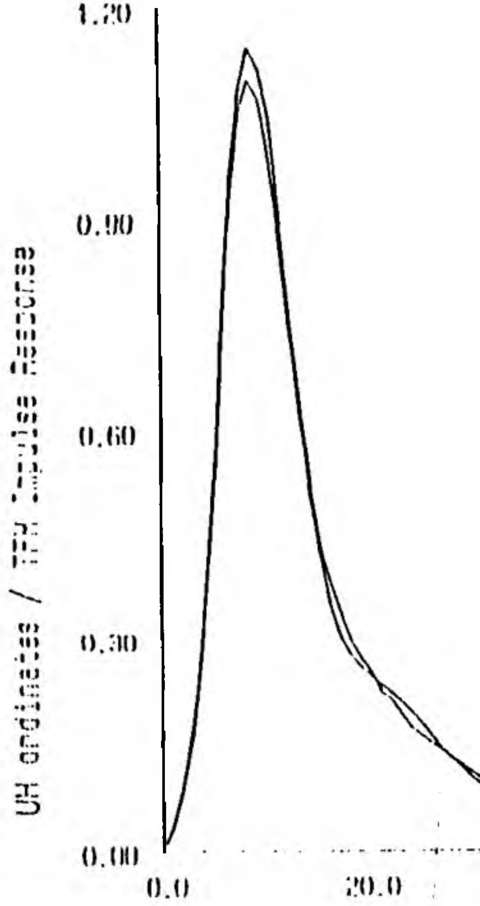
Appendix 4: Runtime Listing of TFUH

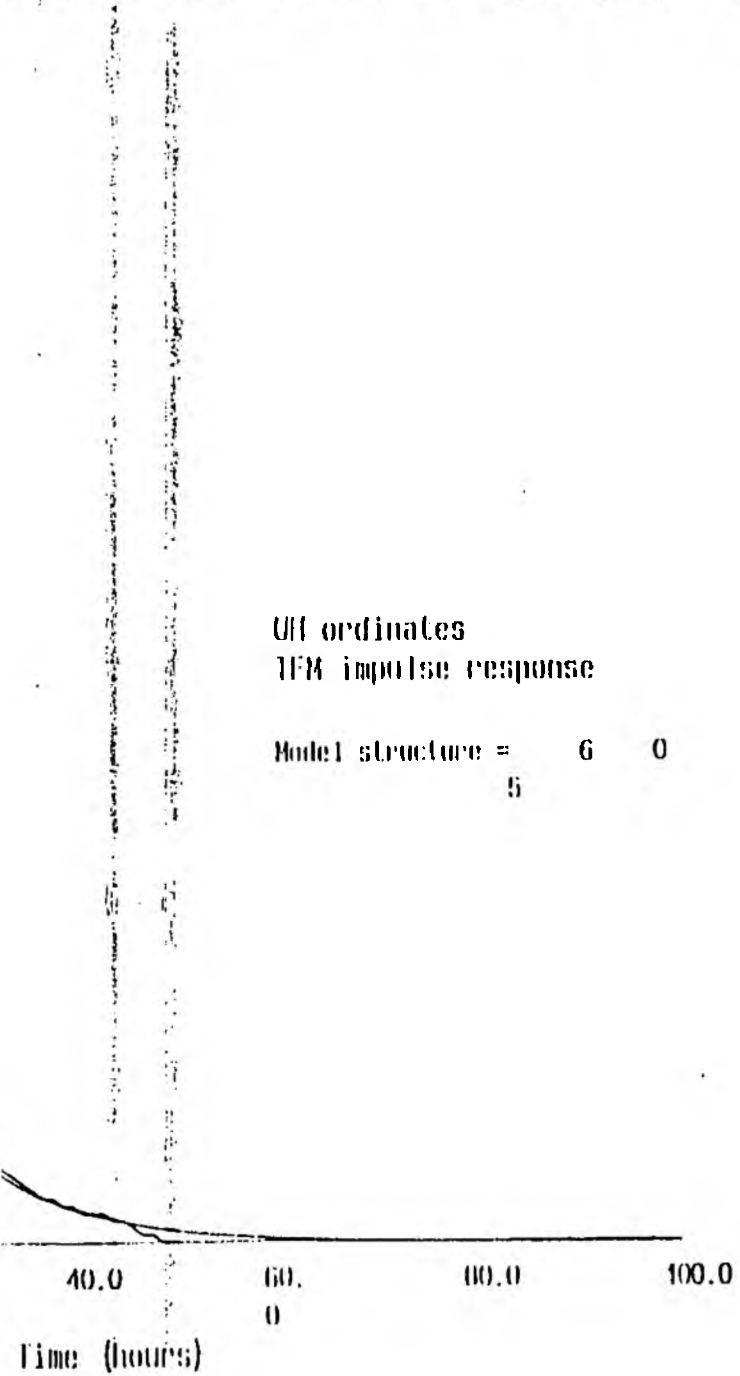
The following is a runtime listing of TFUH as described in section 7 of the main report. Bolded text indicates user input. Graphics are at the end of this Appendix.

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

     Transfer Function - Unit Hydrograph Program (TFUH)

A program to estimate the parameters of a transfer model from the
ordinates of a unit hydrograph or by application of the Flood Studies
Report procedure for ungauged catchments.

See TFUH Software Profile for further information.

Water Resources Research Group
Department of Civil Engineering
University of Salford
SALFORD
M5 4WT

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

$ Press RETURN (ENTER) to continue


-------------------------------------------------------------------
The UNIRAS graphic routine in this program is 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)

Output can be switched between screen and pen plotter output but only if
a screen option is selected at this stage: selecting a pen plotter
overides the screen/plotter toggle option.

Please type integer (1,2,3,4,5 or 6)
3


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


Output Options Menu
-------------------

Output Options (default in UPPER CASE)

1. Results output file              (Y/n)
2. Results summary to screen        (Y/n)
3. Graphics on screen or to plotter (S/p)
4. Graphic output required          (Y/n)

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

```
 [Type a zero (0) to exit]
3
P

0

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


 Which option is required ?
   (1) TF model from unit hydrograph ordinates
   (2) TF model from physical catchment characteristics
 Please type integer [1 or 2].
1

 Enter name of input file
colsterworth.dat

 Enter name of the results output file
results.out


 Model Structure Input
 ---------------------

 Enter number of a parameters (max. 30) [integer]
5
 Enter number of b parameters (max. 30) [integer]
6
 Enter model lag in multiples of model interval [integer]
0


       -------------------
       |   Please wait   |
       -------------------



 --------------------  RESULTS  ------------------------------

 Estimated transfer function model
 ----------------------------------
 Structure =  5, 6, 0
 Interval  = 1 hours
 Parameters:
 a( 1) =  1.3397
 a( 2) = -0.0068
 a( 3) = -0.3941
 a( 4) = -0.1849
 a( 5) =  0.2018
 b( 1) =  0.0103
 b( 2) =  0.0097
 b( 3) =  0.0154
 b( 4) =  0.0208
 b( 5) =  0.0272
 b( 6) =  0.0318

 Model percentage runoff     = 18.27%
 Catchment percentage runoff = 18.40%

 RMSE between UH and TFM reconvolutions            =   0.047
 RMSE between UH ordinates and TFM impulse response =   0.010
```

Return to continue





UH ordinates
TFM impulse response
Model structure = 6 0 5
40.0
60.0
80.0
100.0
Time (hours)

Appendix 5: Devices Supported

The following devices are explicitly supported by TFUH.

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)