Institute of Hydrology

Natural Environment Research Council

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National Rivers Authority
River Flow Forecasting System

RFFS Model Calibration Facilities

PDM Rainfall-Runoff Model

User Guide

Institute of Hydrology
Crowmarsh Gifford
Wallingford
Oxfordshire
OX10 8BB
UK

Tel: 0491 838800
Fax: 0491 832256
Telex: 849365 Hydrol G

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Introduction

This User Guide relates to a suite of programs which form the Model Calibration Facility of the River Flow Forecasting System (RFFS). A separate Transfer Function Noise (TFN) Model Package is available for linear modelling and exploratory data analysis. The suite of programs is essentially made up of four programs which perform specific hydrological modelling functions. These are:

Program PDM:	a general rainfall-runoff model based on probability-distributed moisture stores.
Program PSM:	a rainfall-runoff model incorporating Thames Conceptual Model (TCM) and Isolated Event Model (IEM) formulations.
Program KW:	a channel flow routing model based on the kinematic wave approximation.
Program PACK:	a snowmelt model.

Each model incorporates facilities for forecast updating and can be applied to single or multiple storm events. This user guide describes the PDM rainfall-runoff model.

The programs are built using a common control shell, called TSCAL (Time Series Calibration). This provides a framework within which any time series model may be optimised (ie. parameters of the model are estimated to minimise a prescribed objective function which makes the modelled time series approximate the observed). This shell is available to be used with other models to those described in this User Guide, thus allowing the Calibration Facility to be developed in an efficient manner.

Section 2 of the Guide describes the Shell. The PDM model program is described in Section 3, providing a brief description of the model, a summary of the contents and structure of the input tile, and examples of input and output files. A glossary of variables is given in Section 4.

This User Guide does not provide a technical description of the models used, but focusses on a description of the input parameters required to run each model. The report *Evaluation of FRONTIERS and Local Radar Rainfall Forecasts for use in Flood Forecasting Models* provides further details of the theoretical basis of the PDM, TCM and IEM models.

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2. TSCAL: Calibration Shell

2.1 INTRODUCTION

The calibration shell, which is common to all the model programs, provide the following facilities:

a) automatic parameter estimation using a modified Nelder & Mead simplex optimisation method;

b) interactive parameter adjustment;

c) analysis of mean and peak error statistics of simulated and forecast flows computed using specified or optimised parameters;

d) generation of time-series plots of observed, simulated and forecast flows, and related quantities;

e) generation of contour plots of response surface as a function of any two parameters.

Optimisation may be carried out using an objective function derived from one or more events. Events are analysed and plotted separately.

The operation of the shell is controlled by a single input file, described in Section 2.2. There are three principal modes of operation, selected according to the value of **maxfun** in the input file:

1. Interactive (**maxfun** = 9999)

   Provides interactive adjustment and automatic parameter optimisation, analysis and time-series plots. See Section 2.3.

2. Batch (**maxfun** ≥ 0)

   Provides automatic parameter optimisation, analysis and time-series plots.

3. Response surface generation (**maxfun** < 0)

   Generation of response surface plots only.

These modes are described in Sections 2.3 to 2.5.

2.2 INPUT FILE

The input file contains all the information and model data (with the exception of time-series data, which is retrieved from the modelling database) required to run one of the model programs. The number, sequence and content of the lines in the file are determined by the model and the options chosen, but the data fields on each line may be entered in a free format (i.e. text in single quotes (except for whole lines of text) and spaces between items).

The input file can be divided into six parts, some which are generic to all types of model, and some which contain information specific to different models. These parts are

1. Description, analysis and output.
2. Model parameter list and contour plot generation.
3. Data source selection.
4. Model control parameters.
5. Event selection.
6. Error and forecast settings.

The detailed structure and content of the input files are summarised in the form of tables in the sections describing each of the model programs. These tables contain references to the more comprehensive descriptions of the input data fields and their meanings which may be found in Section 4, the Glossary of Variables.

2.3 INTERACTIVE MODE

If **maxfun** = 9999 and there are parameters to be optimised, then after the initial evaluation of the objective function, control passes to a simple screen menu. Options are selected by entering a single character and the user is prompted for additional information if needed. The main options are

A - Attach to a remote process. Used for process control in a multiple process environment - not documented.

E - Evaluate the objective function using the current parameter settings.

L - List the current parameter settings and objective function value.

O - Optimise the current parameter set. The user is prompted for a maximum number of evaluations and a convergence tolerance for the objective function.

P - Set the step size and tolerance for a parameter. The user is prompted for the parameter number and two values.

R - Restore parameter settings previously saved to a file. The user is prompted for a file name.

S - Save parameter settings to a file. The user is prompted for a file name.

V - Set a new parameter value. The user is prompted for the parameter number and value.

W - As V, followed immediately by an evaluation of the objective function.

X - Exit to batch mode.

? - Display the menu options.

The progress of the optimisation can be monitored by inspecting the contents of the file MONITR.DAT, which is written after every evaluation of the objective function (options E and W) or whenever a smaller objective function value is found (option O). This file contains the following information

- value of the objective function
- number of parameters being optimised
- values of parameters being optimised
- number of datasets in the file
- number of events in a dataset
- pointers to start of dataset, and start of each event
- pointers to end of dataset, and end of each event
- datasets

The exact format of the file may be found in the MONITR subroutine. The first two datasets are always the observed and computed flows (or levels). Subsequent datasets are auxiliary variables which depend on the type of model.

If the contents of the file can be plotted automatically each time it is updated, then a truly interactive calibration session is possible.

2.4 BATCH MODE

If **maxfun**≥0 and not 9999, the program runs in batch mode. If **maxfun**>0 and there are parameters to be optimised, then the automatic optimisation procedure will operate until the convergence criteria have been met, or the objective function has been evaluated **maxfun** times.

Following any optimisation, or if maxfun=0, a final evaluation of the objective function is made, the time-series results are analysed, and plot files generated. If optimisation has taken place, the optimised parameters are used; otherwise, the given parameters are used.

2.5 RESPONSE SURFACE GENERATION MODE

If **maxfun**<0, two parameters are varied over prescribed ranges to generate contour plots of the response (objective) function. There is no time-series analysis or plotting.

3. Program PDM: A conceptual rainfall-runoff model based on Probability Distributed moisture stores and non-linear routing storages

3.1 INTRODUCTION

This program uses a fairly general conceptual rainfall-runoff model to transform rainfall and evaporation data to flow at a catchment outlet. A probability-distributed store model is used to partition water into direct runoff, groundwater recharge and soil moisture storage. Direct runoff is routed through a "fast response system", representing channel and other fast translation flow paths. Groundwater recharge from soil water drainage is routed through a "slow response system" representing groundwater and other slow flow paths. Both routing systems can be defined by a variety of nonlinear storage reservoirs or by a cascade of two linear reservoirs (expressed as an equivalent second order transfer function model constrained to preserve continuity). A variety of spatial distributions of store depth are available to define the probability-distributed store model. A 'groundwater demand' effect can be incorporated into the recharge process. A constant background flow can be defined to represent compensation releases from reservoirs, or constant abstractions if negative.

The model is specifically tailored for real-time application. The model may be updated using recent measurements of flow, either by state-correction or using an ARMA error model. A variety of empirical state-correction algorithms are provided: these partition the error to correct different state variables in the model in relation to their contribution to the total flow. The ARMA error model exploits the serial dependence in model errors to predict future errors which are used to construct an improved forecast.

Model calibration can be based on either single or multiple events. For the latter, daily rainfall and evaporation are used to maintain a water balance between events in order to ensure that the antecedent moisture conditions for each event, which influence storm response, are appropriate.

If daily flow data are available, the model will generate an extra output 'event' containing the daily data over the period from the start of the first event to the end of the last.

The parameter symbols used in the operational guidance notes on model calibration relate to the input field / program variable names used in Section 3.2 as shown in the following table.

Symbol	Field name	Description
f_c	**rainfac**	Rainfall factor
c_{min}	**cmin**	Minimum of soil store depth distribution
c_{max}	**cmax**	Maximum of soil store depth distribution
b	**b**	Exponent of distribution function
b_e	**be**	Exponent in actual evaporation function
k_g	**kg**	Groundwater recharge time constant
b_g	**bg**	Exponent of recharge function
s_t	**St**	Soil tension storage capacity
α	**kg**	Groundwater deficit ratio threshold
β	**St**	Exponent in groundwater demand function
q_{su}	**bg**	Maximum rate of recharge
α	**alpha**	Runoff splitting factor
k_s	**k1**	Time constant of surface flow storage
q_c	**qconst**	Constant background flow
k_b	**k2**	Time constant of baseflow storage
m	**indb**	Type (exponent) of baseflow storage
τ	**tdly**	Pure time delay

Table 3.1 PDM parameter symbols

3.2 INPUT FILE

The table below describes the structure and contents of a TSCAL input file for the PDM model. It is followed by a sample input file which illustrates most of the features in the table.

Each row of the table (which may extend over several printed lines) corresponds to a single physical line in the input file, and describes the information which is contained on that line. Optional lines, whose presence is conditional on other settings in the input file, are shown indented and introduced by the condition in italics. Each bold word is the name of a field on a line of the input file (and is also the name of the corresponding variable in the program). Full descriptions of these fields, and the meanings of the variables to which they relate, can be found in the Glossary of Variables, Section 4.

Input file part 1: Generic: Description, analysis and output

title	Description of input file
	Text describing following line
objtyp **maxfun** **konvge** **objtol**	Type of objective function Max no. of function evaluations / contour plot switch / interactive mode switch Convergence checking interval Tolerance for accepting convergence
	Text describing following line
analys **qmin** **qmax** **pkmin** **pkrge**	Units of measurement / summary output switch Min observed value for including point in objective function Max observed value for including point in objective function Minimum size of peaks to be analysed Range to scan when matching observed and computed peaks
	Text describing following line
prtfnf **prtopt** **pltfn**	Frequency of printing and parameters to be printed on function evaluation Values to be printed as optimisation proceeds Name for output plot file (in single quotes)

Input file part 2: PDM: Model parameter list and contour plot generation

	Text describing following lines, each of which has the form **indx** Switch to allow parameter value to vary (1) or not (0) **xp** Model parameter value - a different parameter on each line **xpstp** Initial step size for simplex optimisation **xptol** Convergence tolerance for simplex optimisation **xpnam** Name for parameter (in single quotes) Only the different meanings of **xp** are described on the following lines
rainfac	Factor multiplying rainfall to give effective rainfall $\{f_c\}$
c1	Minimum soil moisture store depth $\{c_{min}$ - mm$\}$
c2	Maximum soil moisture store depth $\{c_{max}$ - mm$\}$
b	Exponent in distribution function for soil moisture store depth $\{b\}$
be	Exponent in actual to potential evaporation rate formula $\{b_e\}$
k1	Time constant of surface water store $\{k_s$ - hour mm$^{m-1}\}$
k2	Time constant of second surface water store, if two linear reservoirs $\{k_{s2}$ - hour mm$^{m-1}\}$
kb	Baseflow time constant $\{k_b$ - hour mm$^{m-1}\}$

if ***indr*** *< 3 (standard recharge or runoff splitting options)*	
kg	Groundwater recharge time constant $\{k_g$ - hour $mm^{b_g-1}\}$
St	Soil tension control on groundwater recharge $\{S_t$ - mm$\}$
bg	Exponent of soil moisture content in recharge equation $\{b_g\}$
if ***indr*** *= 3 (demand-based recharge)*	
kg	Groundwater deficit ratio threshold $\{\alpha\}$
St	Maximum rate of recharge $\{q_{sM}$ - mm $hour^{-1}\}$
bg	Exponent in groundwater demand factor function $\{\beta\}$
qconst	Constant background flow $\{q_c$ - $m^3s^{-1}\}$
if ***indr*** *> 0 (runoff splitting option)*	
theta	Initial value of soil moisture storage as proportion of maximum.
alpha	Proportion of runoff entering surface-flow store.
if ***indr*** *= 2 (unrestricted runoff splitting option)*	
beta	Proportion of runoff entering baseflow store.
if ***i_sdp*** *> 0 (parameterised stage-discharge relationship)*	
xp(i_sdp)	Stage-discharge parameters, one per line starting at parameter no. **i_sdp**
if ***tdly*** *< 0 (parameterised time delay)*	
xp(-tdly)	Time delay is parameter number **-tdly**
if ***errpar(0)*** *= 1 (state-updating option)*	
gains	Gain factor for outflow from surface-flow store.
gainb	Gain factor for outflow from baseflow store.
gaing	Gain factor for contents of soil moisture store.
if ***gaintyp*** *is in range 11-15 or 31-35 (update surface store inflow)*	
gainu	Gain factor for inflow to surface-flow store.
if ***gaintyp*** *is in range 21-25 or 31-35 (update surface stores separately)*	
gains	Gain factor for outflow from first reservoir of surface-flow store.
if ***errpar(0)*** *= 2 (ARMA error predictor option)*	
xp(...)	**p + q** ARMA parameters, one per line
/	slash terminating list of model parameters

if ***maxfun*** *< 0 (contour plot to be generated)*		
		Text describing following line (x1 and x2 refer to the two parameters to be varied along the axes of the contour plot, selected by setting the appropriate two values of **indx** to 1)
	x1b	Start value of range of parameter x1
	x1e	End value of range of parameter x1
	n1	Number of values of x1 at which to evaluate response function.
	ind1	Scale of x1 parameter (0=linear, 1=ln, 2=log)
	x2b	Start value of range of parameter x2
	x2e	End value of range of parameter x2
	n2	Number of values of x2 at which to evaluate response function.
	ind2	Scale of x2 parameter (0=linear, 1=ln, 2=log)
	indz	Scaling for function values (0=none, 1=scale by **sf**, 2=square root)
	sf	Scaling factor to use if **indz**=1

Input file part 3: Generic: Data source selection

title	Text describing model, used to annotate output	
	Text describing following line	
flstn **rfstn** **pestn** **drfstn**	Flow station name (source of flow data) - Rainfall station name (source of 15-minute rainfall data) - may be 'MULTIPLE' Climate station name for potential evaporation Daily rainfall station number (in single quotes)	
if ***rfstn*** *= 'MULTIPLE' (multiple raingauge option)*		
		Text describing following line
	nrg	Number of raingauges
	rglist	List of raingauge station names
		Text describing following line
	nrz	Number of rainfall zones (must be 1 for PDM)
	rgzwts	Weights for each raingauge, for each zone, one line per zone

Input file part 4: PDM: Model control parameters

Text describing following line (if no stage-discharge model, **i_sdp** onward may be replaced by a slash)

indl	Type of distribution function for soil moisture store (1-6)
indr	Type of runoff model (0-3)
inds	Type of surface-flow storage model (0,1,2,3,4,22)
indb	Type of baseflow storage model (-1,0,1,2,3,4)
tdly	Time delay (time steps) / index into parameter list if negative
i_sdp	Index of first stage-discharge parameter in parameter list
nsdr	Number of stage-discharge relations in rating
sqmodel	Parameterisation for rating ('POINTS','LEVEL', or 'COEFF')
oap	Analyse using 'LEVEL' or 'FLOW'

Input file part 5: Generic: Event Selection

	Text describing following line
area	Catchment area (km^2)
	Text describing following lines, which comprise one line per event
btd	Begin time-date of event ('HH:MM DD-MMM-YYYY')
etd	End time-date of event ('HH:MM DD-MMM-YYYY')
noi	Number of observations to be used for initialisation at start of event
etd15	End time-date for 15-minute data following on from end of event
/	Slash terminating list of events

Input file part 6: PDM: Error and forecast settings

Text describing following line, which has the form

errpar List of error parameters

Depending on the first parameter, **errpar(0)**, the line may take one of several forms

if errpar(0) = 0 (simulation mode - no error prediction or updating)

0	**errpar(0)**
/	slash terminating list

if errpar(0) = 1 (state updating mode)

1	**errpar(0)**
updtyp	Type of updating (0-3)
miter	Number of update iterations to use if **updtyp**=3
gaintyp	Type of gain adjustment for PDM
/	slash terminating list

if ***errpar(0)*** *= 2 (ARMA error prediction mode)*	
2	**errpar(0)**
p	Number of autoregressive coefficients in ARMA model
q	Number of moving-average coefficients in ARMA model
indc	Use log errors if 1, linear errors if 0
/	slash terminating list
	Text describing following line
fcstmode	Forecast mode to be used for all events (0-3)
	Text describing following lines, one line for each event, which may take one of several forms depending on the value of **fcstmode**
if ***fcstmode*** *= 0 (no forecasts)*	
/	slash on an otherwise empty line
if ***fcstmode*** *= 1 (fixed origin forecasts)*	
fcstpar	list of up to 4 (origin,lead-time) pairs
/	slash terminator
if ***fcstmode*** *= 2 (fixed lead-time forecasts)*	
fcstpar	list of up to 4 lead-time values
/	slash terminator
	Text describing following line
prtflg	Flag controlling printing of intermediate values (0-2)

3.3 EXAMPLE INPUT FILE

```
R.Dove at KIRKBY MILLS
objtyp  maxfun  konvge  objtol
  11      100      4       8.
analys   qmin    qmax    pkmin   pkrge
  2         0.  1000.0    4.0     48
prtfnf prtopt  common file name of plot files (<= 64 chars)
  0      1         '[L_RCM.YW]PDM'
indx      xs    smpstp  smptol    xs name (<= 8 chars)
  0      0.718   -.1      .05     'rainfac'
  0      1.1       2      .02     'cmin'
  0     25.9     5.      1.       'cmax'
  0      1.0      .3      .05     'b'
  0      2.       .5      .1      'be'
  0      3.9     4.       .8      'sigs'
  0      0.        2      .01     'sigs2'
  0    109.8     8.      1.       'sigb'
  0     40.1     8.      1.       'sigg'
  0      0.      1        .5      'St'
  0     1.0      0.25     .05     'bg'
  0     -1.4202 -1.       .1      'AR1'
  0     -0.05682 -.0333   .1      'AR2'
  0        .48089  .333   .1      'AR3'
```

```
  0      .631   0.1     .5    'gains'
  0      .405   0.1     .5    'gainb'
  0      .900   0.1     .5    'gaing'
/
PROBABILITY DISTRIBUTED LOSS MODEL
Flow (7) Rainfall (16)   Climate-station (20)    Daily Rain (16)
'27042'  'Church Houses' 'High Mowthorpe'         '38178'  /
loss  runoff surface  base  tdly  ini_flow
  1      0      22      3    10         1
Catchment area (km**2)
  59.2
Event begin           Event end                 noi  End of 15' rainfall (<
  '9:00 28 Dec 1986' '24:00  7 Jan 1987'        96 '8 Jan 1987' /
/
error parameters:  0(SIM) /,  or  1(UPD) upd miter indg,  or  2(ARMA) p q
 1 1 0 1 /
forecast mode:  0 = no forecast,  1 = fixed origin,  2 = fixed lead-time
 2
forecast times (1 read-statement per event)
 50 /
prtFLG
 0
```

3.4 EXAMPLE OUTPUT FILE

```
Start up
 -10-DEC-90-        45.740 SECS SINCE LAST CALL

Invoke data-base
 -10-DEC-90-         0.080 SECS SINCE LAST CALL

retn finish datbase
 -10-DEC-90-         4.130 SECS SINCE LAST CALL

R.Dove at KIRKBY MILLS 17:07 10 DEC-90


Input file:  R7JBIA$DIA2:[L_RCM.YW]PDM.INP;22


OBJECTIVE FUNCTION:  mean-squared-error

qmin -  0.00000E+00        qmax =    1000.0           units - m**3/sec

pkmin =   4.0000           pkrge -    48

prtfnf =     0      prtopt = 1


Evaluate objective function at a single point.

R.Dove at KIRKBY MILLS 17:07 10-DEC-90


PROBABILITY DISTRIBUTED LOSS MODEL

T =  0.250 hours      catchment area =     59.2 km**2

observations        station
---------------     -----------------------------------------------------------
RIVER FLOW          U 27042   KIRKBY MILLS on the RIVER DOVE
15-MIN RAINFALL     Church Houses
POTENTIAL EVAP      High Mowthorpe

EVENT DATE    begin:  09:00 28/12/86      end:    7/01/87
   1021 observations;       96 are for initialisation
Time-of-day that event begins is time-interval 36

MODEL TYPES:  loss =  1   runoff =  0   surface flow = 22   base flow =  3

Time delay =  10 time steps
UPDATE MODE   model =  1   max iter =  0   gain type =  1

Fixed lead-time forecasts:       50
```

```
prtflg - 0

Parameter values for routing & loss models

BASE:      m = 3          k = 7.55428E-07     a = 2.73224E-02
SURFACE:  TF22           k1 = 2.56410E 01     k2 = k1
        15-min coeff a1 =-1.87582E+00 a2 = 8.79673E-01 b0 = 1.96884E-03 b1
= 1.88647E-03
PDLOSS:                 Smax = 1.35000E+01    St = 0.00000E+00    kg = 2.49377E-02
Constant flow parametqconst =-1.42020E+00 m**3/sease):


Initial values of loss & routing models

Soil moisture =    4.0283     Q_base =     0.1005     Q_surf =     0.0864
                                                           Q_surf_1 =     0.0860


Amounts of water (mm) during   1020 time-steps

         Rainfall :         42.79          Observed flow:       42.19
Potentl evaporation:         1.28
Actual evaporation :         0.76          Computed flow:       42.20
      Net rainfall :        42.03


R.Dove at KIRKBY MILLS 17:07 10-DEC-90
```

	OPT	NAME	VALUE
1	0	rainfac	0.7180000
2	0	cmin	1.100000
3	0	cmax	25.90000
4	0	b	1.000000
5	0	be	2.000000
6	0	sigs	3.900000
7	0	sigs2	0.0000000E+00
8	0	sigb	109.8000
9	0	sigg	40.10000
10	0	St	0.0000000E+00
11	0	bg	1.000000
12	0	AR1	-1.420200
13	0	AR2	-5.6820001E-02
14	0	AR3	0.4808900
15	0	gains	0.6310000
16	0	gainb	0.4050000
17	0	gaing	0.9000000

```
        objective function  2.3750044E-06          cpu time:  35.720 secs

R.Dove at KIRKBY MILLS 17:07 10-DEC-90


STATE-UPDATE MODE
```

OBS #	TIME day	OBSERVED m**3/sec	COMPUTED m**3/sec	ERROR % obs	ERROR # obs	PEAK #
233	2.7917	8.749	8.750	0.0	0	1
428	4.8229	7.487	7.489	0.0	0	2
Mean absolute				0.0	0.0	

```
    925 observations:      RMSE =     0.0015      R**2 = 1.0000

            mean    variance
observed    2.8338    2.1107
   error   -0.0002    0.0000

R.Dove at KIRKBY MILLS 17:07 10-DEC-90


STATE-UPDATED 12.5-HOUR FORECAST
```

OBS #	TIME day	OBSERVED m**3/sec	COMPUTED m**3/sec	ERROR % obs	ERROR # obs	PEAK #
233	2.7917	8.749	6.076	30.6	-1	1
428	4.8229	7.487	8.305	-10.9	-3	2
Mean absolute				20.7	2.0	

```
    925 observations:      RMSE =     0.6373      R**2 = 0.8076

            mean    variance
```

```
observed     2.8338     2.1107
   error     0.1925     0.3691

Plot File          Title
[L_RCM.YW]PDM     STATE-UPDATE MODE
[L_RCM.YW]PDM1    STATE-UPDATED 12.5-HOUR FORECAST

Unit  5    R7JBIA$DIA2:[L_RCM.YW]PDM.INP;22

R.Dove at KIRKBY MILLS
objtyp  maxfun  konvge  objtol
  11      100     4       8.
analys   qmin    qmax    pkmin   pkrge
  2        0.   1000.0    4.0     48
prtfnf prtopt  common file name of plot files (<= 64 chars)
  0      1          '[L_RCM.YW]PDM'
indx      xs     smpstp  smptol     xs name (<= 8 chars)
  0      0.718    -.1      .05      'rainfac'
  0      1.1       .2      .02      'cmin'
  0     25.9      5.      1.        'cmax'
  0      1.0       .3      .05      'b'
  0      2.        .5      .1       'be'
  0      3.9      4.       .8       'k1'
  0      0.        .2      .01      'k2'
  0    109.8      8.      1.        'kb'
  0     40.1      8.      1.        'kg'
  0      0.       1.       .5       'St'
  0     1.0       0.25     .05      'bg'
  0     -1.4202  -1.       .1       'AR1'
  0     -0.05682  .0333    .1       'AR2'
  0       .48089  .333     .1       'AR3'
  0       .631   0.1       .5       'gains'
  0       .405   0.1       .5       'gainb'
  0       .900   0.1       .5       'gaing'
/
PROBABILITY DISTRIBUTED LOSS MODEL
Flow (7) Rainfall (16)   Climate-station (20)   Daily Rain (16)
'27042'  'Church Houses' 'High Mowthorpe'        '38178'  /
loss  runoff surface  base  tdly  ini_flow
   1      0      22     3    10         1
Catchment area (km**2)
  59.2
Event begin             Event end                  noi  End of 15' rainfall (<
  '9:00 28 Dec 1986' '24:00  7 Jan 1987'      96 '8 Jan 1987' /
/
error parameters:  0(SIM) /,  or  1(UPD) upd miter indg.  or  2(ARMA) p q
 1 1 0 1 /
forecast mode:  0 = no forecast,  1 = fixed origin,  2 - fixed lead-time
 2
forecast times (1 read-statement per event)
 50 /
prtFLG
 0
```

4. Glossary of Variables

alpha Runoff factor that determines the amount of runoff that enters the surface-flow store when **indr** > 0.

analys Units of measurement for analysing the time-series and for generating plot files:

0 same units as used in subroutine TSMOD
1 mm/h
2 m^3/s
11 mm
12 m

The values of **qmin**, **qmax**, and **pkmin** are in these units.
When read in **analys** is reduced modulo 100 and the hundreds digit interpreted as follows

0 = full standard output file, no summary
1 = " " " " , summary file on unit oun2

area Catchment area in km^2

b Controls distribution of depths of stores over the basin. See **indl**

be Exponent in formula that specifies ratio of actual to potential evaporation rate in the probability-distributed stores model.

beta Runoff factor that determines the amount of runoff that enters the baseflow store when **indr** > 0: if **indr** = 1, then **beta** = 1 - alpha; if **indr** = 2, then **beta** = xp(14).

bg Groundwater recharge parameter, meaning depends on value of **indr** =

- 0 Exponent of soil moisture content when calculating depth of groundwater recharge.
- 1,2 Parameter not used.
- 3 Maximum rate of recharge (mm/hour)

btd Begin time and date for an event.

c1 Minimum store depth (cmin) or mean store depth ($\bar{c}$) in mm. See **indl** for more general specification.

c2 Maximum store depth in mm. See **indl.**

drfstn Daily rainfall station. The input is an integer in a left justified character format, and it is converted to a 50-character name. If only one event is used for calibration and therefore daily rainfall is not used to maintain a water balance between events then this can be replaced by a slash ie /. A value of 'NULL' indicates that a soil moisture balance is not to be maintained between events. Each event will be initialised as for the first event.

errpar Vector of error parameters. Component 0 specifies the error and forecast types, which pertain to all events. The number of other components that are read, depends on the value of component 0.

errpar(0)	error type	forecast type
0	simulation mode	no forecast
1	state update	simulation mode
2	ARMA 1-step-ahead	ARMA

0: Simulation mode

If **errpar(0)** = 0 no other components of errpar are used. The input line is:

0 /

1: State update

If **errpar(0)** = 1, local variables **updtyp**, **miter**, and **gaintyp** become errpar(1), errpar(2), and errpar(3). The input line is

1 updtyp, miter, gaintyp /

2: ARMA 1-step ahead

If **errpar(0)** = 2, **errpar(1)** and **errpar(2)** are the numbers of autoregressive and moving-average coefficients in the ARMA model; also **errpar(3)** = 1 invokes log-error ARMA model (= 0 otherwise). The input line is:

2 p, q, inde /

etd End time and date for an event. If etd is blank, then etd is set to btd.

etd15 End time and date for 15-minute rainfall and potential evaporation for an event. If etd15 is blank or a /, then etd15 is set to etd. This is not used for single event calibration and for the last event of a multiple event calibration.

fcstmode Forecast mode to be used for all events (see **fcstpar**).

0 No forecast
1 Fixed origin forecast
2 Fixed lead-time forecast

fcstpar Forecast times (each line pertains to a single event):

0: No forecast (fcstmode = 0)

Input line is a / (repeated **nev** times, one per line)

1: Fixed origin forecast (fcstmode = 1)

For fixed origin forecasts, the forecast times are specified in (origin, lead-time) pairs, where the origin is relative to the beginning of the event. The origins must form an increasing sequence. A maximum of 4 origins are allowed and if less than 4 a / terminator is required.

2: Fixed lead-time forecast (fcstmode = 2)

For fixed lead-time forecasts, the forecast times are lead-times, which must form an increasing sequence. A maximum of 4 lead-times are allowed and if less than 4 a / terminator is required.

flstn Flow station (7 characters, left-justified, in single quotes).

gainb Gain factor for baseflow when empirically updating. **gainb** = xp(i_gain+1). See variable **updtyp**.

gaing Gain factor for soil-moisture store contents when empirically updating. **gaing** = xp(i_gain+2). See variable **updtyp**.

gains Gain factor for outflow from surface-flow store when empirically updating. **gains** = xp(i_gain). See variable **updtyp**.

gains1 Gain factor for outflow from first reservoir of surface-flow store when empirically updating. **gains** = xp(i_gain). See variable **updtyp**.

gaintyp Type of gain adjustment when empirically updating S, qb, qs, and qs1:

0 no gain adjustment
1 error is non-proportional
2 error is split proportionally between base and surface flows
3 error is split proportionally between base and surface flows, except gain for surface-store is direct
4,5 as 2 and 3 but error super-proportionally weighted to surface flow
11,12,13,... as 1,2,3 but includes update to us
21,22,23,... as 1,2,3 but includes separate gain for qs1
31,32,33,... as 1,2,3 but includes separate gain for qs1 and us.

gainu Gain factor for inflow to surface-flow store when empirically updating. **gains** = xp(i_gain). See variable **updtyp**.

i_sdp Index, into the parameter list **xp**, of the first parameter defining the stage-discharge relationship, if one is to be used; otherwise **i_sdp** = 0. If not used, this and the remainder of the line may be replaced with a /. The stage-discharge relationship is $q = k(h+alpha)^p$, $h < ht$, where q is discharge in m^3/s, h is the river level in metres, and k, alpha, and p are the 3 parameters of the relation and ht is the upper limit of its range. There are **nsdr** sets of these making up one rating (see **sqmodel** below).

ind1, ind2 Indicate scale to use for parameters x1 and x2 on contour plot:
0 = linear, 1 = log, 2 = log10

indb Baseflow model:

-1	qb = ub
0	qb = constant
1	linear storage (subroutine ROUTNL)
2	quadratic storage (subroutine ROUTNL)
3	cubic storage (subroutine ROUTNL)
4	exponential storage (subroutine ROUTNL)

inde Invokes log-error ARMA model if **inde** = 1 (0 for linear errors).

indl Type of distribution function, F(c), used for distributed stores:

1 PARETO
$F(c) = 1 - ((c2-c)/(c2-c1))^b$, $c1 \leq c \leq c2$

2 RECTANGULAR:
$F(c) = (c-c1)/(c2-c1)$, $c1 \leq c \leq c2$

3 TRIANGULAR: $\bar{c} = (c1+c2)/2$
$F(c) = 2 * ((c-c1)/(c2-c1))^2$, $c1 \leq c \leq \bar{c}$
$= 1 - 2((c2-c)/(c2-c1))^2$, $\bar{c} \leq c \leq c2$

4 POWER:
$F(c) = ((c-c1)/(c2-c1))^b$, $c1 \leq c \leq c2$

5 LOGNORMAL: c1 = log(mean), b = standard deviation
$F(c) = .5 * \mathrm{erfc}(-(\log(c)-c1)/(b\sqrt{2}))$

6 EXPONENTIAL: c1 = mean store depth
$F(c) = 1 - \exp(-c/c1)$

indr Runoff model:

0 Normal PDM. The direct runoff forms the inflow into the surface-flow store; the groundwater recharge forms the inflow into the baseflow store.

1,2 No groundwater recharge. The direct runoff is separated into 2 components, forming the inflow into the surface-flow and baseflow stores. If **indr** = 1, the sum of the inflows must be the total rainfall runoff; if **indr** = 2, the sum of the inflows is unrestricted.

3 Demand-based recharge.

inds Surface-flow model:

0	qs = constant
1	linear storage (subroutine ROUTNL)
2	quadratic storage (subroutine ROUTNL)
3	cubic storage (subroutine ROUTNL)
4	exponential storage (subroutine ROUTNL)
22	cascade of 2 linear reservoirs.

indx Vector specifying whether (=1) or not (=0) the corresponding variable in xp will vary. If maxfun<0, exactly 2 components of **indx** should be 1, corresponding to the 2 components of xp that will be used to form a grid, when generating a surface for contour plots. If maxfun(0, each component of **indx** that is 1 corresponds to a component of xp that will be optimised.

indz Indicates scale for function values on contour plot

0 no rescale
1 rescale by factor **sf**
2 square root rescale

k1 Surface flow time-constant (h mm^{m-1}). It is the reciprocal of the surface water storage coefficient k, in the storage equation $q = k\ S^m$, where m is determined by **inds**.

k2 Time-constant (hours) of the second linear reservoir for routing surface flow when **inds** = 22; if set to zero then two identical reservoirs are assumed ie k2 = k1.

kb Baseflow time-constant (h mm^{m-1}). It is the reciprocal of the baseflow storage coefficient k, in the storage equation $q = k\ S^m$, where m is determined by **indb**.

kg Groundwater recharge parameter, meaning depends on value of **indr** =

0 Groundwater recharge time-constant (h mm^{kg-1}). It is the reciprocal of the groundwater recession constant.
1,2 Parameter not used.
3 Groundwater deficit ratio threshold.

konvge Check convergence every **konvge** iterations.

maxfun Depending on value, determines mode of operation:

<0 generate a surface for contour plots.
≥0 maximum number of function evaluations. This status is checked each time a check is made for convergence.
= 9999 invoke interactive control of optimisation.

miter Maximum number of update iterations when **updtyp** = 3

n1, n2 Number of values of parameter x1 or x2 to be evaluated along the axis of the contour plot.

noi Number of observations for initialisation at the start of an event. Errors in this part of the event are not used in forming the objective function.

nrg Number of raingauges

nrz Number of rainfall zones

nsdr Number of stage-discharge relations in rating, (the maximum is 5).

oap 'LEVEL ' or 'FLOW '. Specifies if the analysis is to be done in terms of level or flow. Do not use 'FLOW' if the stage-discharge relationship is to be optimised. See also **analys**.

objtol Tolerance, required for convergence, that specifies the maximum range of function values at simplex vertices. See variable **xptol**.

objtyp Type of objective function:

1 sum-of-squares
2 log sum-of-squares
3 log10 sum-of-squares
11 mean of sum-of-squares
12 mean of log sum-of-squares
13 mean of log10 sum-of-squares.

if 100 is added to one of the objtyp values, then errors in the daily flows (if computed) will be included in the objective function. If 200 is added, only the daily flow errors will be included (i.e. optimisation using daily flows)

p Number of autoregressive coefficients in ARMA error model

pestn Climate station for potential evaporation (20 characters, left justified, in single quotes). Potential evaporation may be obtained from

- i) a named climate station making daily observations,
- ii) a named region for which monthly values (time-stamped or long-term average) are interpolated to daily values,
- iii) a yearly sine curve, invoked as 'SIN CURVE float-value' where float-value is the amplitude in mm,
- iv) a constant value, invoked as 'CON FIXED float-value'.

pkmin Threshold value of the observed time series above which peak errors are calculated. See **analys** for units to use.

pkrge Peak scan-range:

- <0 do not compare peaks
- 0 compare at time of observed peak
- >0 scan range, on each side of an observed peak, in numbers of time-steps, and in which a predicted peak is sought.

pltfn Name field (up to 64 characters) of the file to which data and instructions for plotting are written. The file extension .PLT is appended to pltfn; if no name field is specified, then the file is not created.

prtflg Print flag for printing intermediate values:

- 0 no printing
- 1 values at each observation
- 2 values at each observation and each iteration of the empirical state updating.

prtfnf Controls the frequency of printing and which parameters are printed at each evaluation of the objective function. The number of function evaluations, the function value, and the values of either the parameters being calibrated or all parameters in the model, are printed at the first function evaluation, and at every abs(**prtfnf**) function evaluations thereafter.

- <0 print all parameters in the model
- 0 no printing
- >0 print the parameters being calibrated

prtopt Print progress of optimisation when checking for convergence and each time a new simplex is formed:

0 no printing
1 print number of function evaluations and best function value and vertex
2 print number of function evaluations, all function values, and entire simplex
3 same as **prtopt**=1, and each new point being considered
4 same as **prtopt**=2, and each new point being considered

q Number of moving average coefficients in ARMA error model

qconst Constant flow parameter (eg. reservoir release) in m^3/s (but transferred to mm/hr for working using catchment area)

qmax Maximum value of the observed time series that will be included in the objective function and used to analyse the time series. See **analys** for units to use.

qmin Minimum value of the observed time series that will be included in the objective function and used to analyse the time series. See **analys** for units to use.

rainfac Factor by which rainfall measurements are multiplied to obtain effective rainfall.

rfstn Rainfall station (16 characters, left-justified, in single quotes).
If the name of the rainfall station is 'MULTIPLE' then additional lines will be read which define the multiple raingauges and their relative weighting in each rain zone (the PDM has a single rain zone).

rglist List of raingauges (each up to 16 characters, left-justified, in single quotes)

rgzwts Weights for each raingauge within each rainfall zone

sf Scale factor for rescaling function values on contour plot (used only if **indz**=1)

sqmodel Stage-discharge model denoted by 'POINTS', 'LEVEL' or 'COEFF':

'POINTS': Points and slope parameterisation

If **sqmodel** is 'POINTS' then the rating is parameterised by the bottom point, (q_0, h_0), the level break-points h_i, i = 1, ..., **nsdr-1**, and the slopes $\{p_i\}$, i = 1, 2, ..., nsdr of the set of lines defining the relationship when plotted on a logarithmic scale. The parameter set is:

$$q_0, h_0, p_1, h_1, q_1, p_2, \ldots, h_{nsdr}, p_{nsdr}, q_{nsdr}$$

Note: the next two options constrain alpha to be the same across ranges

'LEVEL ': Threshold level (infer coefficient, k)

'COEFF ': Rating coefficient (infer threshold, ht)

If **sqmodel** is 'LEVEL' or 'COEFF' then the parameterisation is

k(.), alpha(.), p(.), ht(.)

in the stage-discharge relation, $q = k(h + alpha)^p$, $h < ht$, where h is the river level in metres and ht is the upper limit of the relations range. There are **nsdr** sets of relations making up a rating.

St Groundwater recharge parameter, meaning depends on value of **indr** =

- 0 Soil tension (mm) control on groundwater recharge.
- 1,2 Parameter mot used.
- 3 Exponent in groundwater demand factor function.

tdly Time delay (numbers of time steps) for observations of rainfall and potential evaporation. If **tdly** > 0, then no rainfall and potential evaporation is available for the first **tdly** time steps of an event, except for the first event when it is the first **tdly-1** time-steps. During this period rainfall is zero = 0 and evaporation equals the first observed value. If **tdly** < 0, the absolute value of **tdly** is taken as index into the parameter list, and **xp**(abs(**tdly**)) is taken as the time delay in hours.

theta Proportion of Smax that is the initial value of S when **indr** > 0.

title Title for page headings & plot titles

updtyp Update type:

- 0 No state-updating
- 1 Update at current time-step (state-corrected error)
- 2 Update at current time-step (1-step forecast error)
- 3 Iterative update at previous time-step to form prediction at new time step (1-step forecast error). The number of iterations is controlled by **miter**

x1b, x1e Begin and end values of parameter x1; these specify the range of x1 along the axis of the contour plot.

xp Vector of initial values of model parameters and ARMA coefficients.

xp(i_sdp...) Stage-discharge parameters (see **sqmodel**)

xpnam Vector of 16-character names of the variables in **xp**.

xpstp Vector of parameter-steps used to derive initial simplex. After the optimisation, each component is set to 0 or to the parameter-step from the optimum vertex to the old vertex, depending on whether the same component of indx is 0 or 1. See variables **smpstp** and **xptol**.

xptol Vector of parameter tolerances that determine convergence. Applies to the difference between the best and worst vertices of the current simplex, and between the best and old vertices. The old vertex is the best vertex in the most recent simplex for which the differences between the best and worst vertices and associated function values were found to meet the tolerances defined by **xptol** and **objtol**. After optimisation, each component is set to 0 or to the step from the optimum vertex to the worst vertex in the final simplex, depending on whether the corresponding **indx** is 0 or 1. See **smptol**.