INSTITUTE of HYDROLOGY

USER NOTES

MULTIPURPOSE RESERVOIR

SIMULATION PROGRAM

CONTENTS

INTRODUCTION

The original version of the reservoir simulation program was written in 1970 to solve a specific hydropower and irrigation problem in Ethiopia. Since then the program has been continually modified and expanded to deal with more complicated problems elsewhere.

By 1980 it was difficult to follow the program listing and, more seriously, there were doubts that some aspects of the program were sufficiently robust to provide correct solutions to problems only slightly different from those it had been set up to solve.

This major review of the program aimed to consolidate all previous improvements in a stronger framework and to provide the following specific improvements:

- a consistent nomenclature
- more and shorter subroutines to make further program development easier
- a general set of reservoir rule curves which can be adapted to all likely problems using option indices set in the data
- general solutions to minimum head criteria and secondary energy generation
- choice of output set by option indices in the data.

Inevitably further program development will be necessary but the new program structure should allow considerable development before another major review is required.

There are now many options governing the way in which the reservoir simulation can be carried out, and it is not feasible to test them all in combination with all likely inputs and demands.

Therefore in each new application, the program should be regarded as untested and it is the user's responsibility to check that the results are correct.

Errors in the program should be corrected in the master copy of the program listing and documented in the master copy of this user note.

PART 2

MAIN FEATURES OF THE PROGRAM

2.1 GENERAL DESCRIPTION

The program is a straightforward month by month simulation of the performance of a reservoir given a sequence of inflows and rainfall over the reservoir area. While it is not intended here to discuss the relative merits of simulation and other techniques offering more direct analytical solutions, it is found that simulation is usually the only satisfactory solution to problems involving hydropower particularly in a multi-purpose scheme.

For a given set of operating rules and constraints, the program computes releases to meet demands and flood control targets, spills, energy and power generated and keeps a running balance of the status of the reservoir. Necessarily the simulation is based on average conditions during each month usually derived from the start and end of month conditions. As end of month conditions are not known until the monthly balance is complete, the procedure is iterative with the average conditions for reservoir area, water level and so on being successively re-estimated until the monthly balance is consistent.

This procedure implies a uniform inflow and a uniform change in reservoir contents through the month, conditions which are not entirely realistic. If excess inflows are concentrated towards the end of the month in reality, spill will tend to be underestimated by the simple reservoir balance. Also the form of the reservoir area curve might mean that a simple average area derived from beginning and end of month values will always be an over-estimate and that evaporation will be over-estimated correspondingly. Similar effects could be noted for energy calculations from the way in which average head must be assessed.

The larger the reservoir and the more uniform the inflows, the less these approximations matter. Should they be significant the answer is probable that a 5 or 10 day simulation is necessary.

Many of the more complicated parts of the program are due to the calculation of energy and power. Therefore it is not recommended that the program be used for simple schemes involving only water supply or irrigation, unless these demands need to be considered in a multi-purpose scheme with flood control aspects in addition.

2.2 PROGRAM STRUCTURE

The relationship between the different subroutines is shown in Figure 2.1 and an outline of the function of each subroutine is given in section 5.

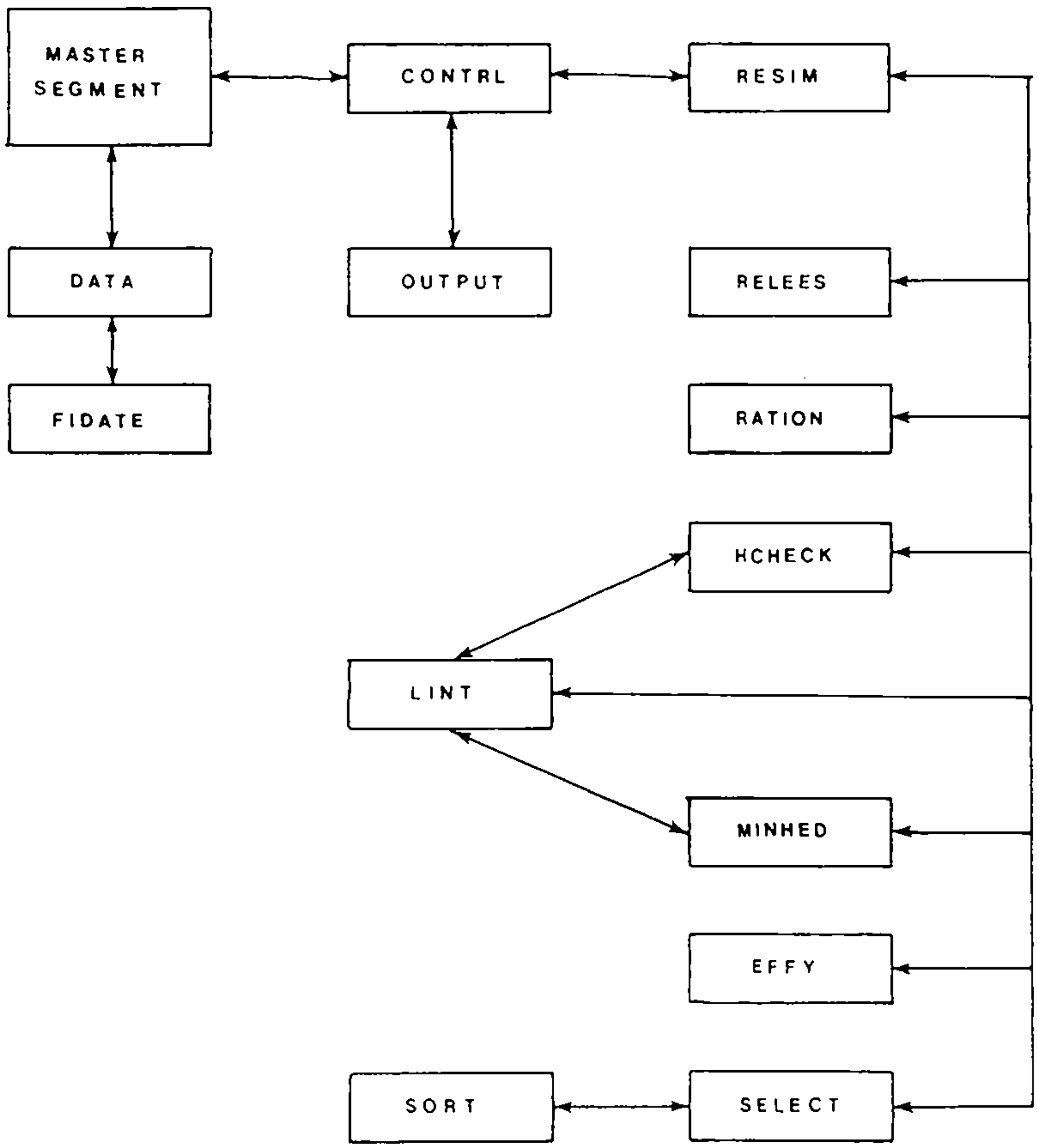
The two main routines are *CONTRL* and *RESIM*. The former, as its name implies, controls the whole framework of the simulation. The version defined in section 5.2 calls only for a single simulation through the inflow data. Other versions could be mapped in its place which would alter the operating rules or demands to achieve some preset benefit or level of reliability. Alternatively *CONTRL* could be set up to examine systematically the trade-off between two demands or between demands and flood control.

RESIM coordinates all the operational options, the operating rules and the constraints in a single framework. It should be capable of handling most possible schemes without adaptation. As much of the calculation as possible has been put into subroutines available to *RESIM* and it is these subroutines, *RATION* for example, which can readily be changed to provide for any special conditions or strategies.

As described in detail in section 3.2 the output side is very flexible and *OUTPUT* can be extended indefinitely to provide additional forms of output. *SELECT* would need to be modified accordingly if the new output required additional arrays of derived variables.

Figure 2.1

PROGRAM STRUCTURE



2.3 SOME DETAILS OF THE PROGRAM

Internal counting system

The simulation is based on a monthly time step and is continuous through the input record. Any annually accounted results such as those appearing in the annual summary refer to successive periods of 12 months counting from the beginning of the data set. Thus it is the sequence of the input data which governs the layout and the form of the output and the definition of 'hydrological' years for all output expressed in annual terms.

The input data comprising the inflows, rainfall, evaporation, demands and rule curves must all start from the same calendar month, usually the first month of a recognizable hydrological year. There must be an integral number of full years of record.

The indices ISY and ISM which define the start year and calendar month of the record are used only to set the titles for the output display. When a simulated inflow sequence is used which does not refer to a specific year, the years will be numbered sequentially from 1 if ISY is set to zero.

The number of years of record should not exceed 60 as this is the size of the arrays handling the input data and the derived annual results.

Option indices

Schemes being studied are rarely the same; the form of the input data, routing of the releases, the way in which turbine efficiency can be represented are among the variations from scheme to scheme which hitherto required a measure of reprogramming. To avoid this, all the common factors which could alter the way in which the simulation is carried out are represented by a series of options set in the data stream. They are defined in Table 2.1 Those associated with the choice of output require a fuller description which is given in section 3.2.

Values for all the indices must be set but few if any will change during a series of simulations of the same scheme.

Flags

The routing of the iterative calculation for each month is monitored and to

DEFINITION OF THE OPTION INDICES

INY	number of years of inflow record
ISY	starting year (1 if the record is wholly synthetic)
ISM	starting month of hydrological year
IDM	0 = standard month of 30.4 days 1 = variable number of days in the month
IRA	0 = no direct rainfall (or average is combined with evaporation) 1 = rainfall data to be input
IND	number of active demands
IPR(J)	priority associated with each demand. 1 = highest priority, 0 when demand not active
IFC	0 = no flood control 1 = flood control required
IMH	0 = no constraint on minimum head on turbines 1 = flood control releases constrained by minimum head criterion 2 = rationing if necessary to meet minimum head criterion
IWS	0 = water supply releases do not contribute to turbine or downstream flow 1 = contribute to both 2 = contribute to downstream flows only
IIR	0 = irrigation releases do not contribute to turbine or downstream flow 1 = contribute to both 2 = contribute to downstream flow only
IEF	0 = av. turbine efficiency is constant (EFC) 1 = " " " is a function of net head only 2 = is a function of net head and av. power.
IOP(12)	output variable list
IAS(12)	form of annual summary
IMT(2)	variables required as monthly tables
IRS(2)	variables required as ranked series
IMX	0 = include detailed monthly output 1 = omit detailed monthly output

some extent controlled by a series of flags K(1) to K(15) and three flags KE(1) to KE(3) which indicate possible errors in the calculation. These flags are defined in Table 2.2.

All flags are set to the passive value of 0 at the start of a monthly iteration. They take the value 1 when activated.

On the monthly output listing 18 columns are reserved for flags; K(1) to K(15) are shown in 3 groups of five followed by the three KE flags. An asterisk indicates an active flag.

Specification of demands

In making the program as general as possible it has been necessary to associate a number with each possible demand as follows:

demand 1	water supply
2	compensation flow
3	irrigation
4	energy
5	peak power.

These numbers in no way imply a priority, that is defined by the priority index IPR(J). So that if energy is to be accorded highest priority IPR(4) will be set to 1. J is the counter normally used to indicate demand number.

The only action required by the user is to ensure that the demands D(5,12) are entered in the correct order in the input data.

Demand 5 for peak power is used in the simulation in an 'advisory' capacity only in that it does not directly affect the simulation. Accordingly, it is not given a priority and there is no minimum draw off level Z associated with it.

Reservoir tables

The curves defining reservoir geometry, downstream channel conditions and turbine characteristics are represented by a series of points between which linear approximations to the true curves can be considered acceptable.

TABLE 2.2

DEFINITION OF K AND KE FLAGS

K(1)	failure to meet demand for water supply
K(2)	" " " " " compensation flow
K(3)	" " " " " irrigation
K(4)	" energy
K(5)	peak power
K(6)	minimum head criterion not met/no power generated
K(7)	flood control release constrained to meet the minimum head criterion
K(8)	rationing invoked to meet the minimum head criterion
K(9)	demands cannot be reduced further by rationing
K(10)	reservoir is empty
K(11)	maximum desirable downstream flow is exceeded by releases
K(12)	" " " " " " " releases and spill
K(13)	flood control release is constrained to meet maximum desirable downstream flow
K(14)	(vacant)
K(15)	failure to meet demands fully
KE(1)	extrapolation necessary in call to *LINT*. Source should be obvious from output variables for that month
KE(2)	no energy generated but there could be a release. Check the consistency of rule curves and the fact that IMH=2
KE(3)	impossible to achieve a proper reservoir balance as losses exceed inflows. Check input data especially evaporation, seepage, direct rainfall and/or storage area curves at very low storages

There are three sets of points:

i) reservoir storage, area and seepage are all related to the same list of water levels

ii) downstream flow is related to tailwater level

iii) peaking capability, turbine efficiency at peak power and turbine efficiency at average power are all related to the same list of net heads.

All tables contain up to 12 entries and values should be chosen to cover the full range of variation expected to avoid the need for extrapolation in *LINT* the subroutine which carries out the linear interpolation.

Also the points should be chosen such that the errors of interpolation are not all in the same direction. For example, if the curve is convex upwards the points chosen should be just above the curve so that the linear approximation intersects the curve twice between each pair of points.

PART 3

INPUT AND OUTPUT

3.1 INPUT

The order and format of the input data can only be defined precisely in Fortran and accordingly the relevant part of *DATA*, the subroutine where all the input is done, is reproduced as Table 3.1. The items in the input list have been annotated to show array sizes where these have been left out in the program on the assumption that the full array is read.

All the data on program options, reservoir characteristics and evaporation are read from channel 28 to allow data files to be created in advance of execution. The lengthy data sets comprising monthly historic rainfall (when IRA=1) and the monthly inflow data are read from channel 7.

At the start of each simulation the input data (except rainfall and inflows) are written out in an intelligible fashion to ensure that errors are spotted and to provide a permanent record of the conditions which led to the output. The name of the file containing the rainfall and inflow data is output as part of the job title on each page of output but a listing of this file must be obtained separately from the simulation.

An example of an input stream on channel 28 and the subsequent display of these input data are shown in Tables 3.2 and 3.3.

TABLE 3.1

SEQUENCE AND FORMAT OF THE INPUT DATA

```
      READ (28,100) NAME
      READ (28,101) NRUN,INY,ISY,ISM,IDM,IRA
      READ (28,101) IND,IPR                          4 values for IPR
      READ (28,101) IWS,IIR,IFC,IMH,IEF
      READ (28,101) IOP                             12 values for IOP
      READ (28,101) IAS                             12 values for IAS
      READ (28,101) IMX,IMT,IRS                      2 values each for IMT
                                                       and IRS

      READ (28,102) ((D(N,M),M=1,12),N=1,5)
      READ (28,102) Z                                4 values for Z
      READ (28,102) VDF,VOP,VDS                     12 values each

      READ (28,102) WL,CN,AR,SE,QD,TW,HN,PC,EP      12 values each
      READ (28,102) CONI,TWI,HLOS,HMIN

      GOTO (1,2,3),IEF+1
    1 READ (28,102) EFC
      GOTO 4
    2 READ (28,102) EA                              12 values for EA
      GOTO 4
    3 STOP '** IEF=1 CAUSED STOP IN SUB DATA **'

          OPTION IEF=2 NOT YET AVAILABLE

    4 READ (28,102) EV                              12 values for EV
      IF (IRA.EQ.0) GOTO 6
      READ (7,101) ((RA(M,L),M=1,12),L=1,INY)
    6 READ (7,101) ((Q(M,L),M=1,12),L=1,INY)

  100 FORMAT (10A4)
  101 FORMAT ()
  102 FORMAT (12F6.0)
```

TABLE 3.2

```
 1.      REVISED RESERVOIR PROGRAM TEST - CB DATA
 2.      1300 54 1924 10 1 0
 3.        2  4  3  0  0
 4.        0  0  1  2  1
 5.        1  5  7 10 13 14 15 19 20 21 27 34
 6.        1  4  4  2  1  1  1  1  1  1  1  1
 7.        0 19  21  19  8
 8.           0     0     0     0     0     0     0     0     0     0     0     0
 9.           0     0     0     0     0     0     0     0     0     0     0     0
10.         500   200     0     0     0     0     0     0     0   500  1000  1000
11.       1195. 1157. 1195. 1195. 1079. 1195. 1157. 1195. 1157. 1195. 1195. 1157.
12.       1960. 1960. 1960. 1960. 1960. 1960. 1960. 1960. 1960. 1960. 1960. 1960.
13.           0     0     0     0
14.      .51700.51700.37200.53100.60000.60000.60000.60000.51700.51700.51700.51700.
15.      16185.14568.13508.17911.19400.25556.24199.23020.21403.20305.18922.17247.
16.      18750.18140.18750.18750.16930.18750.18140.18750.18140.18750.18750.18140.
17.       265.5 260.0 295.0 300.0 305.0 310.0 313.0 317.0 320.0 326.0 327.0 331.0
18.           0     0     0 4745.10689.17963.23021.30631.37026.51700.54407.65991.
19.           0   7.6 838.01065.01317.01597.01777.02031.02233.02655.02741.03054.0
20.           0     0     0     0     0     0     0     0     0     0     0     0
21.        247. 1923. 5929.11709.19219.28440.39329.
22.        196.  200.  205.  210.  215.  220.  225.
23.        95.0 100.0 103.5 110.0 115.0 119.4 125.0 128.0 130.0 133.0
24.       1825. 1975. 2075. 2220. 2320. 2420. 2420. 2420. 2420. 2420.
25.        90.0  90.3  90.3  91.8  92.4  92.9  94.3  94.8  94.9  95.0
26.      25000.  205.    3.  99.5
27.        94.5  95.5  96.0  95.5  95.9  94.5  93.1  92.2  91.6  90.7
28.        256.  202.   78.   17.   19.   98.  157.  149.  123.  134.  179.  206.
```

TABLE 3.3

REVISED RESERVOIR PROGRAM TEST - CR DATA

RUN 1300 DATED 25 AUG 81 # 15147151
USING DATA FROM FILE RESOP*INFLOW3

INITIAL CONDITIONS — RESERVOIR CONTENTS 25000.0 MCM — TAILWATER LEVEL 205.0 M

		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
DEMANDS													
WATER SUPPLY	MCM	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
COMPENSATION FLOW	MCM	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
IRRIGATION	MCM	500.0	200.0	.0	.0	.0	.0	.0	.0	.0	500.0	1000.0	1000.0
FIRM ENERGY	GWH	1195.0	1157.0	1195.0	1195.0	1079.0	1195.0	1157.0	1195.0	1157.0	1195.0	1195.0	1157.0
PEAK POWER	MW	1960.0	1960.0	1960.0	1960.0	1960.0	1960.0	1960.0	1960.0	1960.0	1960.0	1960.0	1960.0
RULE CURVES													
DESIGN FLOOD CURVE	MCM	51700.0	51700.0	37200.0	53100.0	60000.0	60000.0	60000.0	60000.0	51700.0	51700.0	51700.0	51700.0
OPERATING CURVE	MCM	16185.0	14568.0	13508.0	17911.0	19400.0	25556.0	24199.0	23020.0	21403.0	20305.0	18922.0	17247.0
MAX RELEASE TARGET	MCM	18750.0	18140.0	18750.0	18750.0	16930.0	18750.0	18140.0	18750.0	18140.0	18750.0	18750.0	18140.0
EVAPORATION	MM	256.0	202.0	78.0	17.0	19.0	98.0	157.0	149.0	123.0	134.0	179.0	206.0

MINIMUM RELEASE LEVELS — WATER SUPPLY .0 M — COMPENSATION FLOW .0 M — IRRIGATION .0 M — ENERGY .0 M

RESERVOIR AND TURBINE CHARACTERISTICS

WATER LEVEL M	STORAGE MCM	AREA SQKM	SEEPAGE MCM/MTH	OUTFLOW MCM/MTH	TAILWATER LEVEL M	NET HEAD M	PEAK CAP MW	EFFICIENCY AT PK POWR %	EFFICIENCY AT AV POWR %
265.5	.0	.0	.0	247.0	196.0	95.0	1825.0	90.0	94.5
260.0	.0	7.6	.0	1923.0	200.0	100.0	1975.0	90.3	95.5
295.0	.0	838.0	.0	5929.0	205.0	103.5	2075.0	90.3	96.0
300.0	4745.0	1065.0	.0	11709.0	210.0	110.0	2220.0	91.8	95.5
305.0	10689.0	1317.0	.0	19219.0	215.0	115.0	2320.0	92.4	95.9
310.0	17963.0	1597.0	.0	28440.0	220.0	119.4	2420.0	92.9	94.5
313.0	23021.0	1777.0	.0	39329.0	225.0	125.0	2420.0	94.3	93.1
317.0	30631.0	2031.0	.0	.0	.0	128.0	2420.0	94.8	92.2
320.0	37026.0	2233.0	.0	.0	.0	130.0	2420.0	94.9	91.6
324.0	51700.0	2655.0	.0	.0	.0	133.0	2420.0	95.0	90.7
327.0	54407.0	2741.0	.0	.0	.0	.0	.0	.0	.0
331.0	65991.0	3054.0	.0	.0	.0	.0	.0	.0	.0

TURBINE HEAD LOSS 3.0 M — MINIMUM NET HEAD ON TURBINES 99.5 M

OPTIONS/OUTPUT

INY	ISY	ISM	IDM	IRA	INO	IPR(1)	IPR(2)	IPR(3)	IPR(4)	IWS	IIR	IFC	IMH	IEF
54	1924	10	1	0	2	4	3	0	0	0	0	1	2	1

IOP LIST	1	5	7	10	13	14	15	19	20	21	27	34
IAS LIST	1	4	4	2	1	1	1	1	1	1	1	1

IMX	IMT(1)	IMT(2)	IRS(1)	IRS(2)
0	19	21	19	8

3.2 OUTPUT

Reservoir simulation programs typically produce large amounts of output. This one is no exception; values of about 40 variables of potential interest are computed for each month in *RESIM*. But only a selection of these results are needed for a particular project and it would be convenient if the choice of output variables could be made with minimal effort by the user.

Thus the aim of this output scheme is:

> to provide a procedure for selecting those variables of interest without having to edit WRITE and FORMAT statements each time the selection is changed;
>
> to define the selection in the input data list;
>
> to provide a range of summary information for selected variables.

This has been achieved by separating the basic computation and the output functions into separate subroutines. Communication is through an array A which is filled in a predefined way each month in *RESIM*. Table 3.4 defines the contents of the A array. As variables always take the same poisition in the A array, a selection of variables for output can be made by simply specifying their locations in the array.

Selection of output variables

The selection is made in *SELECT* from indices set with the input data as follows:

- IOP is the array of up to 12 numbers from 1 to 40 which controls the selection of variables for monthly output. The same variables are automatically selected for output in the annual summary table.
- IAS is an array of up to 12 numbers from 1 to 4 which controls the form of annual summary for each variable, 1=total, 2=mean, 3=maximum, 4=minimum.

Thus if IOP(6)=19, QDS the downstream flow will appear in the monthly output. If IAS(6)=1 the annual summary will show the total downstream flow for each year; if IAS(6)=4, the lowest monthly downstream flow in each year will be listed.

- IMX is set to 0 for full output, and set to 1 if the detailed monthly output is to be suppressed.

OUTPUT VARIABLES IN THE A ARRAY

All values refer to the current month and are in million m^3 except where state

A(1)=QIN	inflow	
A(2)=RAIN	rainfall on reservoir area	
A(3)=EVAP	evaporation loss	
A(4)=SEEP	seepage loss	
A(5)=CON2	end of month reservoir contents	
A(6)=CON2-CON1	change in contents during month	
A(7)=WL2	end of month water level	(m)
A(8)=TW2	end of month tail-water level	(m)
A(9)=WL2-TW2-HLOS	end of month net head	(m)
A(10)=WLA-TWA-HLOS	average net head	(m)
A(11)=RWS	water supply release	
A(12)=RCF	compensation flow release	
A(13)=RIR	irrigation release	
A(14)=REN	energy release	
A(15)=RFC	flood control release	
A(16)=QSP	spill	
A(17)=REL+RFC+QSP	total outflow from reservoir	
A(18)=QTP	potential turbine flow	
A(19)=QDS	flow downstream	
A(20)=END	firm energy generated	(GWh)
A(21)=ENS	secondary energy generated.	(GWh)
A(22)=ENT	total energy generated	(GWh)
A(23)=QTD	turbine flow for firm energy	
A(24)=QTS	turbine flow for secondary energy	
A(25)=QTT	total turbine flow	
A(26)=PAV	average power generated	(MW)
A(27)=PPC	peaking capability	(MW)
A(28)=EFA	turbine efficiency at average power	(%)
A(29)=EFP	turbine efficiency at peaking power	(%)
A(30)=SFV(1)	shortfall on water supply	
A(31)=SFV(2)	shortfall on compensation flow	
A(32)=SFV(3)	shortfall on irrigation	
A(33)=SFV(4)	shortfall on energy (turbine flow)	
A(34)=SFT	total shortfall	
A(35)=SFV(1)*100.0/DI(1)	percentage shortfall on water supply	(%)
A(36)=SFV(2)*100.0/DI(2)	percentage shortfall on compensation flow	(%)
A(37)=SFV(3)*100.0/DI(3)	percentage shortfall on irrigation	(%)
A(38)=SFV(4)*100.0/DI(4)	percentage shortfall on energy (turbine flow)	(%)
A(39) A(40)	not currently used	

IMT is an array of up to 2 numbers from 1 to 40 defining the variables for which a separate monthly summary table is required. The variables selected need not be part of the IOP list. Each single variable summary table will automatically include the annual total for each year and the mean, maximum and minimum values for each calendar month.

IRS is an array of up to 2 numbers from 1 to 40 defining the variables for which ranked annual series are required. Again these variables need not be drawn from the IOP list. Plotting positions according to the Gringorten formula are listed automatically.

Indicator flags defined by the contents of the K and KE arrays are automatically included in the monthly output as described below.

A summary of shortfalls for each demand is also output automatically.

The arrays defined in *SELECT* to hold the output variables and their derivatives are defined in Table 3.5 and in section 5.11.

Format of the output

Titles for the output are set up in arrays held in *OUTPUT* from which a selection is made automatically in the same way as the variables are selcted using the IOP, IAS, IMT and IRS arrays. Details of these arrays are given in section 5.12.

The flexibility of output variable selection means that the precision of the output data has to be constant and the program has been written to give a general output variable format of F8.1. For very large or very small schemes this might not be satisfactory and some format statements in *OUTPUT* would need to be changed substituting F8.0 or F8.2 for F8.1. The field width must remain constant or the titles will not match.

Each line of the monthly output is defined by year and month according to the values of ISY and ISM, the start year and month of the data. If ISY=1 the hydrological years will be numbered sequentially from 1; if ISY is a real year, the years will change correctly according to the month.

The 25 columns on the right hand side of the monthly output pages are reserved for the indicator flags. The K flags are set out in 3 sets of 5 and the KE flags as 1 set of 3 each set being separated by a dot. When

ARRAYS USED TO HOLD OUTPUT VARIABLES

A(40)	current months value of all useful variables, set in *RESIM* used in *SELECT*.
AA(12)	dummy array carrying up to 12 values of A selected by IOP(12).
AB(12,60)	annual total/average/max/min (1 only) derived from AA using IAS(12).
AC(12)	period average/max/min (1 only) for same variables as AB.
AD(2,60,12)	monthly tables of up to 2 variables selected by IMT(2) derived from the A array.
AE(2,60)	ranked series of annual maxima of up to 2 variables selected by IRS(2) derived from the A array.
AF(60)	rankings associated with AE derived in *SORT*.
AG(2,12)	mean calendar month values of AD
AH(2,12)	max calendar month values of AD
AI(2,12)	min calendar month values of AD
AJ(2,60)	annual totals of AD output with the monthly tables.

Notes:

For the full monthly output (AB variables) the choice of one of total, average, max or min is governed by the relevant value of IAS(12). The AC variables follow the same choice and are therefore consistent with the AB variables.

The array dimensions shown are the maximum in each case.

The variables indicated by IMT and IRS need not be restricted to those included in the IOP list.

any K or KE value is 1 an asterisk appears in the appropriate location.

For example:

```
    *               *.*
```

would show that flags K(4), K(8), K(15) and KE(1) had non zero values in that month.

What these flags indicate is described in section 2.3.

Output control

All output, with the exception of a listing of the input data, is generated in *OUTPUT* which is divided into parts which can be activated independently by the argument in the subroutine call. These parts are described in section 5.12. All calls to *OUTPUT* are made in *CONTRL* so that it is easy to rearrange the output and to develop new types of output by adding a new part to *OUTPUT* and adding the appropriate call statement in *CONTRL*. If, as would probably be the case, the new output required arrays of variables derived from the basic A array, the computation of the new array should be an extension of *SELECT*.

Shortfalls

The amounts by which demands are not met are termed shortfalls and they are computed as volumes and as percentages of initial demands for each main demand in *RESIM*. These values appear in the A array and can be displayed in the detailed monthly output and the annual summary.

In addition the total shortfall for each demand over the period of record and the number of months and hydrological years in which shortfalls occurred are output in a separate summary table.

PART 4

DETAILS OF THE SIMULATION

4.1 POWER, ENERGY, EFFICIENCY AND TURBINE FLOW

The basic equations relating these variables are:

```
QTD=PAV*PEF*367.0/(HNET*EFA/100.0)
DEN=PAV*PEF
```

for average demand power and energy. For peaking power or maximum energy conditions, the appropriate variables can be substituted.

PEF defined as the power energy factor is a variable because of the option allowing a variable number of days in the month. It is defined in *CONTRL* as:

```
PEF=DM(M)*24.0/1000.0
```

and therefore it has the units: hours in the month/1000.0.

QTD the demand turbine flow has units: million m^3/month, for power in MW, head in m and efficiency expressed as a percentage. The factor 367 is 3600/9.81.

Energy variables have units: GWh/month.

Specification of power load curves

In practice a hydro station rarely operates as a base load station providing a constant output; it can react more quickly than thermal stations to changes in demand and therefore is used to meet some peak power demands. Generally the load curve for a hydro station is directly analogous to a flow duration curve.

As the power demand may vary in a regular diurnal pattern or in some irregular way dependent upon external factors such as temperature or industrial work loads, it is not usually possible to specify the load curve in other than general terms. In any event the approximations inherent in a monthly reservoir simulation make it unnecessary to go into much detail on the power demands.

Thus we have specified the load as a total energy demand for the month DEN, which is proportional to the area under the load curve, and the peak power demand DPO. These variables should ensure that the simulation is responsive to the volume demand on the reservoir and the need for sufficient head to generate the peak power.

In the simulation DEN is used to define the release required to generate the average demand energy (at the equivalent average power PAV) and this release forms part of the iterative reservoir balance calculation. The ability to generate the peak demand power DPO is checked after the reservoir balance has been completed and a flag K(5) is set to 1 if the average head during the month is too small. DPO is compared with PPC the peaking capability at the current net head HNET.

It is unlikely that rationing of other demands would be used merely to ensure peak power demands and so no procedure has been written into the program for rationing in this case. In a planning problem the way to avoid failures to meet peak power demands is to raise the operating curve VOP.

Turbine efficiency

The efficiency of a turbine is related to net head HNET and the actual power being generated. The relationship is complicated and is usually represented by a series of characteristic curves (Mussel diagram). These curves usually indicate any limits to the operation of the machines such as might arise from cavitation.

Again it is not necessary to specify these detailed relationships precisely given the context of a monthly reservoir balance. We should aim to specify the average efficiency EFA (under average power conditions PAV, equivalent to demand energy DEN) and its variation with net head HNET. This information is held in 2 arrays EA and HN read as data. In this case the efficiency option IEF is set to 1 (see *EFFY*)

In the event that the turbine characteristics are not known, a constant efficiency EFC is used and IEF is set to zero, and the arrays EA and HN are zero filled.

The efficiency at peaking capability EFP is specified as an array EP in the data corresponding to the array of net head values HN. This efficiency is used only in the estimation of secondary energy.

Note that the arrays PC, EA and EP all refer to the values of net head HN specified.

Secondary energy

Subject to the ability of the system to use extra energy, secondary energy ENS is generated from any additional releases available to the turbines. In planning studies it is usual to estimate the maximum secondary energy by passing the maximum flow available through the turbines to a limit imposed by the peaking capability of the machines.

A reasonably conservative estimate of secondary energy is obtained by assuming that all secondary energy is generated at peak power. Figure 4.1 shows the simplified load curve following this assumption, and outlines the equations which can be derived.

Generally y will be positive with an upper limiting value of 1. However should the turbine efficiency at peak power be substantially lower than at average demand power, it is possible that y will be negative. In these cases the error flag KE(2) will be set to 1, y will be set to zero and no secondary energy will be generated.

Installed capacity

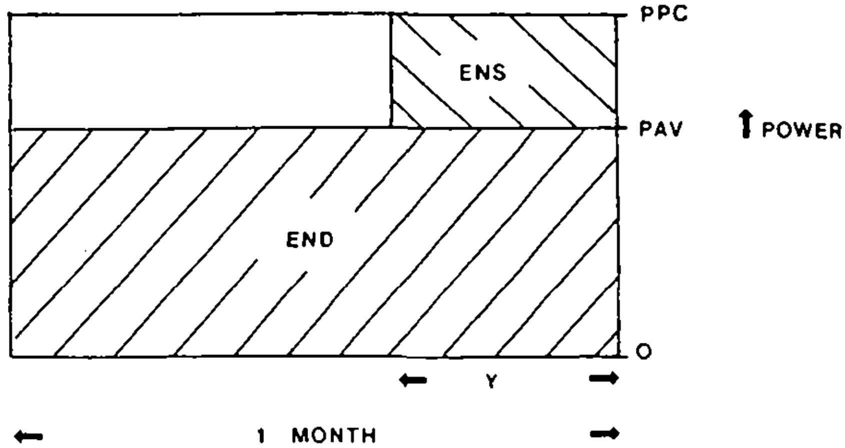
The installed capacity or projected capacity of the hydro station is not specified directly. However manipulation of the input data for DEN, DPO and PC allows any strategy or trade off to be examined.

Maximum firm energy defined in any reasonable way can be determined by successively increasing DEN until the appropriate failure level is reached. If the PC list is set to zero, no secondary energy will be generated.

Maximum secondary (or total) energy can be determined for successively larger installed capacities by increasing the values in the PC list,

ASSUMPTIONS CONCERNING THE GENERATION OF SECONDARY ENERGY

LOAD CURVE FOR SECONDARY ENERGY



Turbine flow for demand energy — QTD=k*PAV/EFA

where k=PEF*367.0/(HNET/100.0)

Maximum possible turbine flow — QTM=k*PPC/EFP

Turbine flow for intermediate case as illustrated — QTT=k*((1-y)*PAV/EFA+y*PPC/EFP)

QTT=(1-y)*QTD+y*QTM

and y=(QTT-QTD)/(QTM-QTD)

When QTT≥QTM, y=1 and secondary energy is the maximum possible

When QTT<QTM, QTT becomes QTP and y is given by

y=(QTP-QTD)/(QTM-QTD)

Total energy — ENT=y*PPC*PEF+(1-y)*PAV*PEF

Secondary energy — ENS=ENT-END

where END=DEN usually

until the marginal gain from further capacity ceases to be worthwhile. DEN controls the firm energy component of the total but in general the frequency of failure to meet firm energy targets could increase as secondary energy generation is allowed to increase.

The peaking capability of the system can also be examined by manipulating the PC list but only in the context of secondary energy generation. The demand power DPO plays no part in the control of reservoir operation but is a convenient way of highlighting deficiencies in peaking capability through flag K(5). As the reservoir simulation is essentially a monthly procedure it is difficult to examine precisely the performance of a station whose load curve contains short term elements.

Minimum head criterion

Turbines are designed to operate reasonably efficiently over a range of net head. Presumably the narrower the range, the greater the efficiency that can be achieved on average. Thus there could be some benefit in examining the scope for raising the minimum head to as high a level as possible. This would be a theoretical exercise in that for practical purposes there is not likely to be a specific minimum head at which the turbines would cease to function.

In this program three options are available:

- IMH=0 no minimum head constraints
- IMH=1 flood control releases can be constrained to meet the minimum head criterion
- IMH=2 rationing of demands can be used to meet the minimum head criterion if reduction of the flood control release to zero is insufficient.

Flag K(6) monitors the achievement of the minimum head criterion which is always tested in terms of end of month reservoir water level WL2 and tailwater level TW2.

HNET=WL2-TW2-HLOS

which is compared with HMIN

If the minimum head criterion cannot be met after flood control releases have been reduced in the case of IMH=1, no energy will be generated even though turbine flows have been computed. In this case KE(2) will be set to 1 to indicate an inconsistency in the simulation. This problem should not arise when rationing is used to maintain head.

4.2 RELEASES, RATIONING AND THE PRIORITY SCHEME

The four main demands, water suppiy, compensation flow, irrigation and energy, are ranked in order of priority by the index IPR(N) where N is the demand number. 1 is the highest priority, 4 is the lowest priority. The priority is exclusive in that two demands are not allowed to have the same priority. Also the priority is fixed for all months and all circumstances unless special provision is made in the subroutines governing releases and rationing.

Releases

A release is defined as a withdrawal (or outflow) of water from the reservoir sufficient to meet a stated type of demand which cannot be met by releases to meet other demands of high priority. Calculation of releases in this way is useful in the economic evaluation of reservoir performance as the cost of storage and water supplied can be assigned logically to the different demands in a multi-purpose scheme.

For example, suppose the reservoir has to meet an irrigation demand of 1000 million m^3 and an energy demand which requires 4000 million m^3 to pass through the turbines. If the irrigation water is taken off at a high level and cannot pass through the turbines, the releases will be the same as the demands, totalling 5000 million m^3. But if the irrigation water can pass through the turbines before being diverted, the total release will only be 4000 million m^3. Furthermore, if the energy demand has priority, the energy release will be 4000 million m^3 and the irrigation release zero; if irrigation has priority, the irrigation release will be 1000 million m^3 and the energy release only 3000 million m^3.

In any event the way that the releases are calculated ensures that no more than the minimum quantity of water is withdrawn from the reservoir but it does not affect the degree to which the demands are met.

Rationing

Under certain circumstances described in section 4.5, rationing is needed in order to meet the objectives of the operating strategy being tested. Many alternative procedures are possible and different versions of *RATION* can be developed to meet the requirements of the specific project.

In the simplest version defined in section 5.6, the demand of lowest priority is progressively reduced until further rationing is not necessary. In cases of severe rationing, the reduction can be continued until this demand is reduced to zero and the demand having second lowest priority is then progressively reduced and so on.

More complicated schemes, such as rationing all demands in stages possibly with some re-ordering of priorities for the more severe stages should all be possible within versions of *RATION* without impact on the structure of the program.

4.3 FLOOD CONTROL

In this program a distinction is drawn between a spill and a flood control release. Spill is regarded as uncontrolled either because it is physically uncontrollable as is the flow over a fixed spillway or it is a mandatory release to meet the requirements for safe operation of the dam. Thus releases necessary to reduce the reservoir level to the design flood rule curve are regarded as spills. Any further controlled release made only to reduce the severity or the likely severity of flooding downstream in future months is termed a flood control release. Thus by definition a flood control release is water which could be stored safely in the reservoir and which would otherwise have been used to meet the other demands on the reservoir.

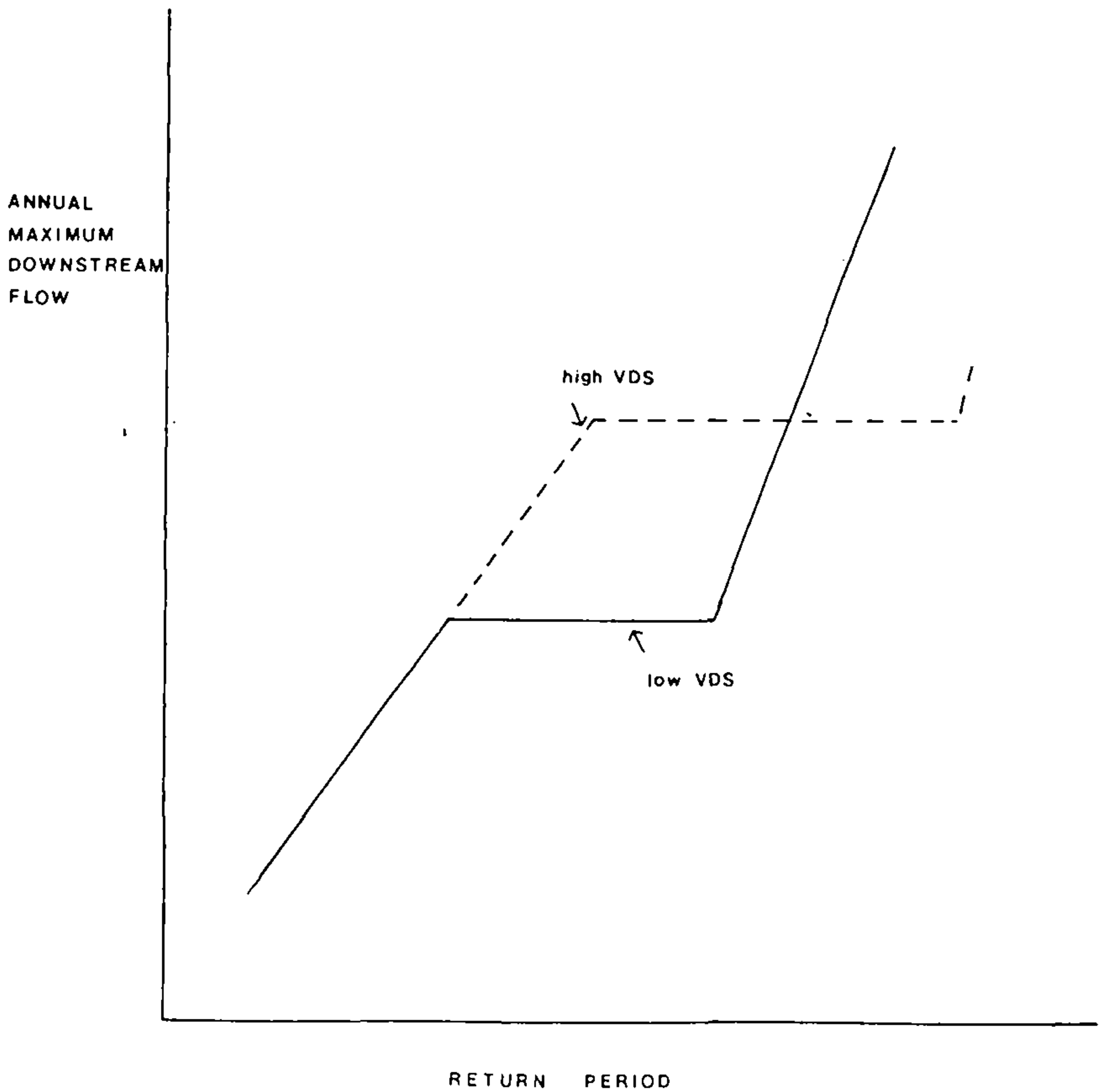
The way in which the flood control release is controlled by the operating rule curve is described in section 4.5. Otherwise only one further parameter is required namely VDS the maximum desirable downstream flow in each month.

In general the setting of the operating rule curve for a given set of demands governs the volume of the reservoir storage that is set aside in each month for flood control. The parameter VDS controls the way in which the downstream flow frequency curve is altered by the flood control measures. Figure 4.2 shows how the curve might be changed principally by altering VDS alone. Altering the operating rule curve would not necessarily change this pattern although it would alter the scale of the flood control benefits.

Flood control is omitted from the simulation by setting IFC=0, or included by setting IFC=1.

Figure 4.2

EFFECT OF VDS ON THE FLOOD FREQUENCY CURVE DOWNSTREAM



4.4 CONSTRAINING FLOOD CONTROL RELEASES TO MEET THE MINIMUM HEAD CRITERION

A reduction in the downstream flow through a reduction in the flood control release will affect the net head available in two ways. Firstly there will be a lower tailwater level and secondly the release foregone will increase the reservoir contents raising the reservoir water level. Knowledge of the tailwater rating curve and the reservoir storage curve is sufficient to calculate the total change in net head which would result from a given change in downstream flow.

The first part of the calculation determines X, the ratio of change in tailwater level to change in net head as follows:

- reduce TW2 by 0.1 m to TWX
- calculate the equivalent downstream flow QDX and hence the change in flow QX
- add QX to the end of month reservoir contents CON2 to give CONX
- calculate the new reservoir water level WLX, hence the change in reservoir water level WX.

X is given by $\frac{0.1}{0.1+WX}$ (the change in tailwater level) / (the change in net head).

If the tailwater rating curve and the reservoir storage curve are linear, the required reduction in the flood control release to give a known increase in net head could be derived using the ratio X. But in practice the curves are non-linear and represented in the reservoir tables by a sequence of linear approximations. Thus it is necessary to approach a solution iteratively. The tailwater level is successively adjusted by the difference remaining between the minimum head and the net head.

Three iterations are normally sufficient to give a precision of about 0.01 m or better in terms of net head. However the calculation is considered to be acceptable if the minimum head criterion is met to within 0.05 m.

4.5 RULE CURVES AND OPERATIONAL OPTIONS

Two rule curves and a number of operational options control the final reservoir balance for the given inputs and demands on the reservoir. By suitable manipulation of these variables (in the input data stream) many different operational strategies can be tested.

The design flood rule curve

This, the upper rule curve, controls only the amount of spill QSP required to ensure the safety of the dam by specifying the maximum acceptable reservoir level VDF in each month. For a simple overflow spillway VDF will be the level of the spillway crest. For a reservoir with a gated spillway which controls the 'flood storage', VDF will be defined in a separate design flood analysis.

VDF should not be used to specify a top operating level below the spillway level. This is better done by the operating rule curve VOP.

The operating rule curve

This lower rule curve VOP acts in different ways depending on the choice of operational options. Action is taken after the end of month reservoir contents CON2 have been estimated from the reservoir balance.

Table 4.1 shows the full range of options and the effect of the operational indices IFC and IMH.

Essentially the operating rule curve either controls the flood control release RFC (IFC=1) or it controls rationing of demands to use the reservoir contents over a longer period (IFC=0). It is not realistic to require both types of operation at the same time as the proper trade-off between flood control and demand rationing can be examined by raising or lowering the rule curve when it is acting as a threshold level for flood control releases (IFC=1)

The choice of IMH reflects the importance attached to power generation. In all applications the minimum head will be checked (K(6)) but the value of IMH controls the extent to which action will be taken to raise the

THE EFFECT OF RULE CURVES AND OPERATIONAL OPTIONS

Case 1. CON2 is above the design flood rule curve VDF

spill to reduce CON2 to VDF.

check minimum head (flag K(6)).

compute RFC (Case 2b below) only when K(12) and K(6)=0.

reiterate.

Case 2 CON2 is below design flood rule curve but above operating curve VOP

2a IFC=0

check minimum head (flag K(6)).

ration other demands to maintain minimum head if IMH=2.

reiterate or restart iteration after rationing.

2b IFC=1

compute RFC to reduce CON2 to VOP subject to RFC≤VDS.

compute new end of month contents CON2.

check minimum head (flag K(6)).

reduce RFC to maintain minimum head if IMH=1.

ration other demands to maintain minimum head if IMH=2 and reduction of RFC to zero is not sufficient.

reiterate or restart iteration after rationing.

Case 3 CON2 is below operating curve VOP

3a IFC=0

ration demands in inverse order of priority.

restart iteration if rationing is possible.

otherwise check minimum head (flag K(6)). No further action is taken to raise the head as it is assumed that the operating curve is set to guarantee the minimum head when IMH=1 or 2.

3b IFC=1

set RFC to 0.

check minimum head (flag K(6)). No further action.

reiterate.

net head when the minimum value is not achieved. When IMH=0, no action is taken but the K(6) flag still operates.

Note that after any successful call to ration demands, the reservoir balance iteration is restarted.

Table 4.2 illustrates the range of problems which can be tackled by appropriate use of the control variables VOP, IFC and IMH.

The concept of an energy rule curve has been found useful in some projects. It defines the minimum reservoir contents (or level) which must be preserved at the end of each month to ensure that a firm energy target can always be met. Any water above the energy rule curve can be used for any other purpose without detriment to the firm energy output. The operating rule curve VOP can obviously act in this way and various methods are available to estimate the shape of the rule curve in advance of full simulation.

TABLE 4.2

VALUES OF VOP(M), IFC AND IMH FOR TYPICAL RESERVOIR SIMULATION PROBLEMS

USE OF RESERVOIR		VOP(M)	IFC	IMH
Single purpose:	power	same as VDF(M) for maximum firm energy	0	0
	other	rationing threshold for the demand	0	0
Single purpose + flood control:	power	energy rule curve (see text)		0 or 1
	other	threshold for flood control or rationing threshold for the demand		0
Multipurpose:	including power as priority	energy rule curve	0	2
	including power as secondary	rationing threshold of secondary demand(s)	0	0
	excluding power		0	0
Multipurpose + flood control:	including power as priority	energy rule curve	1	1 or 2
	including power as secondary	rationing threshold of secondary demand(s) or threshold for flood control	1	0 or 1
	excluding power		1	0

PART 5

NOTES ON THE SUBROUTINES

5.1 THE MAIN SEGMENT

Defines *COMMON*

Calls *DATA* to read and display all the input data and option indices.

Calls *CONTRL* (version selected) which controls the form of simulation and the output.

5.2 SUBROUTINE *DATA*

This routine reads all the data available to the simulation as described in section 3.1.

From the option indices IOP, IMT and IRS it calculates the number of non-zero values requested.

It calls FIDATE to establish the date and time of the simulation run and the name of the file containing the rainfall and inflow data.

It reorders the arrays NM and DM, which initially contain the names and number of days in each calendar month starting in January, according to the start month ISM so that these arrays are consistent with the hydrological year chosen.

Finally it displays the input data for checking and as a record at the start of the output.

DATA is called only once during a simulation run.

5.3 SUBROUTINE *CONTRL* - Version 1

This routine controls the overall structure of the program run. Version 1 is the simplest form of the routine; it calls for a single run through the data and produces output as requested by the option indices.

Other versions could call for multiple runs through the data until pre-specified failure or shortfall targets are met by increasing or reducing demands. Or they could change specific thresholds such as the minimum release levels or minimum head for power generation to achieve the maximum or demand output.

Variables DRF, Z, HMIN, VDF, VOP and VDS are available in *CONTRL* to facilitate the development of other versions of this routine.

Any version of *CONTRL* must define the following variables

CON1 and TW1	the initial reservoir contents and tailwater level at the start of the first month.
L and M	the year and month number for each call of *RESIM* starting from 1 in each case irrespective of the calendar month and year of the data.
PEF	the power/energy factor which is dependent on the number of days in the month.
DI(N), N=1, 5	the demands used in *RESIM*.

It must call *RESIM* and it must make the appropriate calls to *OUTPUT* to produce the output display required. Initialisation of those output variable arrays which are cumulative or which store minima must be carried out in *CONTRL*.

5.4 SUBROUTINE *RESIM*

This routine is called once for each month of record by *CONTRL*. It carries out the reservoir balance and computes the reservoir output given the demands DI set in *CONTRL*. At the end of the routine values of all variables of potential interest are written to an array A and *SELECT* is called before control is returned to *CONTRL*.

The routine is in four main parts as follows:

setting the start of month demands and conditions and initialising the indicator flags.

> note that when rationing is invoked the main iteration is restarted and selected flags are re-initialised and the first approximations to average reservoir conditions are reset.

ii) the main iterative calculation of the reservoir balance.

> for the first iteration the monthly average reservoir level, and area, are assumed to be the start of month values. Rainfall, evaporation and seepage are calculated on this assumption as is the release required to meet demand energy generation. After the trial water balance determines the end of month water level, operating decisions are made (see section 4.5) and the balance is modified if necessary. At the end of the iteration, revised estimates of average reservoir level and area are made and the process is repeated. To avoid unnecessary computation the standard four iterations are reduced if the end of month contents estimate is less than 0.1% different from the estimate at the end of the previous iteration.
>
> Most of the detail of the calculations in this part of the program has been described elsewhere in the manual. Otherwise the comment statements indicate the order of computation.

iii) calculation of energy output given the final estimate of average reservoir conditions over the month.

> this part of the routine includes the calculation of secondary energy, peaking capability and the ability of the system to meet the demand power target.

iv) monitor the shortfalls, write the results in array A, call *SELECT*, reset the start of month conditions and return.

The correct functioning of this routine depends heavily on the correct setting of the K flags which are defined fully in section 2.3. They monitor the performance of the reservoir and they are used extensively in IF statements to determine the correct path through the routine. Any *modifications to the routine must fit in to this monitoring scheme.*

5.5 SUBROUTINE *RELEES*

This routine calculates the releases corresponding to each active demand so as to satisfy the criteria defined in section 4.2. Each active demand, N=1,IND is examined in order of decreasing priority defined by the indices IPR(N). In each case the current water level WLA is compared with the minimum draw off level Z(N) appropriate to the demand. If a release cannot be made because the reservoir level is too low, the appropriate flag K(N) is set to 1 as is K(5).

The total downstream flow QDS and the potential turbine flow QTP are also calculated in this routine, the indices IWS and IIR being used to define the routing of water supply and irrigation water. It is assumed that compensation flow is always available for energy generation and that turbine flows always contribute to total downstream flow.

5.6 SUBROUTINE *RATION* - Version 1

The circumstances in which rationing is invoked are defined in section 4.5.

Obviously rationing can be carried out in many different ways. Version 1 systematically reduces the lowest priority demand by 5% of the original value. When successive calls to *RATION* reduce this demand to zero, the demand of next lowest priority is reduced and so on.

The dummy array DD is equivalent to the four main demands DWS, DCF, DIR and QTD used in *RESIM*. The reduction is calculated on the basis of the array DI which are the initial demands set in *CONTRL*.

When rationing is made, the appropriate K flags are set to 1. If no further rationing is possible K(9) is set to 1.

A further check is made in *RATION* to ensure that minimum off-take levels have not been transgressed. (The initial check is in *RELEES*).

After *RATION* has been called the iterative calculation in *RESIM* is restarted unless the call to *RATION* has been unsuccessful K(9)=1.

5.7 SUBROUTINE *HCHECK*

Given the current downstream flow QDS and the projected end of month reservoir contents CON2, *HCHECK* calculates the end of month reservoir level WL2 and the tailwater level TW2 using *LINT*.

These values define the gross head HEAD and the net head HEAD-HLOS across the turbines.

If the net head is greater than the minimum for power generation HMIN, flag K(6)=0; otherwise K(6)=1.

HCHECK is usually called when IMH is set to 1 or 2 in the data. But the subroutine is always called at least once per call of *RESIM* so as to calculate WL2 and TW2. When IMH is zero, HMIN should also be zero to ensure that K(6) is not set spuriously to 1.

5.8 SUBROUTINE *MINHED*

This routine is called only when the minimum head criterion is invoked, IMH=1 or 2. Its objective is to calculate the reduction in flood control release RFC *consistent with the achievement of the* required minimum net head across the turbines.

The basis of the calculation is described more fully in section 4.4.

When the desired reduction in downstream flow is found the flood control release RFC, the total downstream flow QDS and the potential turbine flow QTP are reduced accordingly and the flag K(6) reset to zero. If the desired reduction exceeds RFC the reduction is constrained to a maximum equivalent to RFC and K(6) is left set to 1.

5.9 SUBROUTINE *EFFY* (incomplete)

This routine is used only to define average turbine efficiency EFA with energy or power at demand levels.

There are three options:

IEF=1	EFA is regarded as constant and set to EFC defined in the data.
IEF=2	EFA is a function of net head only and the value required is derived from tables (data) by *LINT*.
IEF=3	this option is not yet programmed but it is intended to provide a full description of the true relationship between efficiency, net head and power in a 3-dimensional look up table.

5.10 SUBROUTINE *LINT*

The subroutine call has four general arguments

```
(YVAL,XVAL,Y,X)
```

The arrays Y and X define a relationship by which YVAL is found by linear interpolation given XVAL.

For example, to find the peaking capability of the turbines PPC for a given net head HNET, the call would be:

```
CALL LINT(PPC,HNET,PC,HN)
```

If XVAL lies outside the range specified by X, YVAL will be found by linear extrapolation from the first two (or the last two) non-zero pairs of Y and X values. The flag KE(1) will be set to 1 to indicate extrapolation.

Up to 12 pairs of X and Y values are allowed.

5.11 SUBROUTINE *SELECT*

SELECT assembles the output data specified by the output option indices IOP, IAS, IMT and IRS from the array A calculated for each month in *RESIM*.

For monthly output (the most detailed), 12 variables can be selected by the IOP array from the 40 available and the selection is held in the AA array. The AA array is overwritten each month and must be output in *CONTRL* within the monthly loop. IMX set to 1 causes the monthly output to be omitted.

The AB array holds the annual summary table for the same set of variables defined by the IOP list and in each case the total, mean, maximum monthly value or minimum monthly value will be derived according to the IAS list.

The AC array is similar to the AB array but gives an overall mean, maximum or minimum for the period of the simulation given the IAS list. Total is automatically converted to mean in order to keep the size of the numbers in bounds.

The AD array holds the monthly output of up to 2 variables specified by the IMT list. The AE array holds the ranked series of up to 2 variables specified by the IRS list. The AD and AE arrays are derived directly from the A array so that the selection of variables required is not limited to those on the IOP list.

The AG, AH, AI, and AJ arrays are derived from the AD array and provide respectively the mean, maximum and minimum calendar month values and the annual total values to complete the monthly tables of selected variables.

The options and output format are described more fully in section 3.2.

5.12 SUBROUTINE *OUTPUT*

This routine is divided into a number of parts which are activated separately by the argument NNN.

OUTPUT(1) writes the project title, the run number, the date and time of the run and the source file for the inflow data. This information is written at the top of every page of output.

Some of this information is derived from *FIDATE* which is written for the Univac and needs to be adapted for use on other machines.

OUTPUT(2) sets up the arrays containing the 'active' titles and variable formats for the monthly and annual summary tables. The full set of titles are held in DATA arrays as are the variable format statements for the output where the number of variables can be changed.

OUTPUT(3) writes the titles for the monthly output.

OUTPUT(4) writes one month's results together with the indicator flags.

OUTPUT(5) writes the titles and the annual summary table.

OUTPUT(6) writes the monthly tables of selected variables. The number of tables requested is monitored automatically and only one call to *OUTPUT* is required.

OUTPUT(7) writes the ranked series of selected variables and only one call to *OUTPUT* is required irrespective of the number of ranked series.

OUTPUT(8) writes the shortfall summary tables.

The arrays holding the output information have been described in section 5.11.

The arrays holding the titles are as follows:

arrays NA, NB, NC and ND each hold one line of all the possible titles for the monthly output so that for example the title for variable 15 is

NA(15)	FLOOD
NB(15)	CONTROL
NC(15)	RELEASE
ND(15)	(MCM)

array NG holds the first line of the annual summary title which must be either TOTAL, AVERAGE, MAX or MIN according to the appropriate value of IAS. The remaining lines of all possible titles for the annual summary are held in arrays NE, NF and ND.

Thus, for example, the annual summary title for variable 15 given say IAS(15)=3 will be

NG(3)	MAX
NE(15)	FLOOD
NF(15)	RELEASE
ND(15)	(MCM)

Arrays NO, NP, NQ and NR hold the titles selected from NA, NB, NC and ND, according to the IOP list.

Arrays NS, NT, NU and NV hold the titles selected from NG, NE, NF and ND in the same way.

Some poetic licence has been necessary to fit the titles into the space available.

5.13 SUBROUTINE *SORT*

SORT is called only by *SELECT* at the end of the simulation. It ranks the selected variables assembled in the AE array specified by the IRS list, and derives an array AF which contains plotting positions according to the Gringorten formula.

5.14 SUBROUTINE *FIDATE*

This routine is called once during a program run by *DATA*. Its purpose is to call the Univac routines *ADATE* and *FACIL* which specify the date and time of the program execution and the file name from which the inflow (and rainfall data) have been read.

This information is rearranged in *FIDATE* to suit the form of title required in the output.

ANNEX A

GLOSSARY OF TERMS

Average power	the rate of generation of demand energy assumed uniform through the month
Demand (target)	the output or level of benefit sought under under normal operating conditions
Design flood rule curve	the maximum contents in each month consistent with the safety of the dam
Downstream flow	the flow which governs the tailwater level
Firm energy	the energy output which can be relied upon continuously or to a pre-specified high degree of reliability
Flood control release	the release which is made solely to reduce the likelihood of severe flooding downstream of the dam in subsequent months
Gross head (head)	the difference between reservoir water level and tailwater level
Head loss	the friction and other losses in the penstock and turbine system expressed in terms of head
Installed capacity	the rated output of all operational machines
Minimum head	the smallest net head at which the machines (turbines) will operate or be allowed to operate
Net head	the gross head reduced by the head loss, the effective head across the turbines
Operating rule curve	any set of rules defining an operating strategy which can be expressed or defined by a series of monthly reservoir levels

Peak power (peaking capability)	the maximum power which can be generated at the current net head
Rationing	any scheme which constrains demands so as to increase the likelihood of maintaining output in future months
Release	a withdrawal of water from the reservoir sufficient to meet a stated demand which cannot be met by releases to meet demands of higher priority
Secondary energy	energy generated over and above the demand using water which is being released for some other purpose (or spilled) and which can pass through the turbines
Spill	water passing over the spillway or released solely to ensure the safety of the dam
Tailwater level	the water level below the dam at the point where the flow from the turbines is discharged
Turbine characteristics	the relationships between turbine performance in terms of power and turbine flow and net head

ANNEX B

VARIABLE NAMES USED IN THIS PROGRAM

Ax — generally denotes an output variable array (see also Table 3.5)

A(40)	current months value all possible output variables
AA(12)	selected values from A array
AB(12,60)	annual total/average/max/min from AA
AC(12)	period average/max/min from AA
AD(2,60,12)	monthly tables of selected variables
AE(2,60)	ranked series of annual maxima of selected variables
AF(60)	rankings associated with AE
AG(2,12)	mean calendar month values of AD
AH(2,12)	max calendar month values of AD
AI(2,12)	min calendar month values of AD
AJ(2,60)	annual totals of AD
AX(60)	dummy array used in *SORT*
AY	dummy variable used in *SORT*

AR(12) — reservoir surface area list in the reservoir tables (relates to WL)

AREA — current value of reservoir area

Cxxx — always relates to reservoir contents

CON1	end of previous month contents
CON2	end of current month contents
CON3, COND	dummy variables used to test completion of iterative calculation
CONI	contents at start of simulation
CONX, CONY, CX	dummy values used in *MINHED*

CN(12) — reservoir contents list in the reservoir tables (relates to WL)

Dxx — generally denotes a demand

D(5,12)	demands specified in the input data stream	
DI(5)	initial demands for the month	
DRF(5)	demand reduction factor used in *CONTRL*	
DWS	water supply demand	≡ DI(1)
DCF	compensation flow demand	≡ DI(2)
DIR	irrigation demand	≡ DI(3)
DEN	energy demand	≡ DI(4)
DPO	peak power demand	≡ DI(5)
DD(4)	dummy demand array used in *RATION*	

DATE — date of program run defined in *FIDATE* (Univac only)

DM(12) — number of days in each month specified in the program

DM12 — dummy value used in re-ordering month names and numbers of days

EFx	always relates to turbine efficiency		
		EFA	current efficiency at average demand power
		EFC	optional constant efficiency (see IEF)
		EFP	current efficiency at peaking capability
ENx	always relates to energy		
		END	current firm energy generated
		ENS	current secondary energy generated
		ENT	current total energy generated
E	dummy variable used in *EFFY*		
EA(12)	efficiency at average power list in the reservoir tables (relates to HN)		
EP(12)	efficiency at peaking capability list in the reservoir tables (relates to HN)		
EV(12)	evaporation data input		
EVAP	current value of evaporation		
EQ	indicator used in *FIDATE* (Univac only)		
Hxxx	always relates to head		
		HEAD	current gross head
		HLOS	head loss across the turbines, input data
		HMIN	minimum head across the turbines, input data
		HNET	current net head
		HX	dummy variable used in *MINHED*
HN(12)	net head list in reservoir tables (relates to PC, EA, EP)		
Ixx	are always indices related to program options; all are input data		
		IAS(12)	form of annual summary
		IDM	controls number of days in the month
		IEF	form of turbine efficiency calculation
		IFC	flood control option
		IIR	routing of irrigation releases
		IMH	priority of minimum head criterion
		IMT(2)	selection of variables for monthly tables
		IMX	suppression of monthly output
		IND	number of active demands
		INY	number of years in simulation period
		IOP(12)	selection of variables for monthly output
		IPR(4)	priority of demands (excluding peak power)
		IRA	form of rainfall data input
		IRS(2)	selection of variables for ranked series output
		ISM	start month
		ISY	start year
		IWS	routing of water supply releases
	(for a full definition of these indices and their use see section 2.3)		
IK	dummy variable used in *FIDATE* (Univac only)		

J	counter only used to identify demands
K(15)	flags indicating current reservoir performance
KE(3)	flags indicating possible program errors/inconsistencies
KFM(5)	number of months when demands not met
KFY(5)	number of hydrological years when demands not met
L	counter used only to indicate year
LA, LB	dummy variables used in *OUTPUT* to indicate year
LL	dummy variable used in *CONTRL* to control output paging
LX(5)	dummy variable used in *RESIM* to calculate KFY
M	counter used only to indicate month
Nx	usually refers to a character array used in forming output titles

NA(40), NB(40), NC(40), ND(40)	titles for all possible variables which can appear in the monthly tables, set as DATA in *OUTPUT*
NE(40), NF(40), NG(4)	titles for all possible variables which can appear in the annual summary table, set as DATA in *OUTPUT*
NK(2)	blank or * characters used in flag output
NM(12)	month names, set as DATA in *DATA*
NO(12), NP(12), NQ(12), NR(12)	dummy arrays which hold the titles selected for the monthly tables
NS(12), NT(12), NU(12), NV(12)	dummy arrays which hold the titles selected for the annual summary table

NAME(10)	job title, up to 40 characters
NDAT	time and date of program run (Univac only)
NFIL	file name of flow data used (Univac only)
NCHAN	input channel containing inflow data (Univac only)
NONE	dummy indicator used in *FIDATE* (Univac only)
NRUN	current run number
NY	dummy variable in *SORT*
NZ(12)	month names in *FIDATE* only (Univac only)

NM12	dummy variable used in re-ordering month names
NMT	number of monthly tables requested, maximum 2
NOV	number of output variables requested, maximum 12
NRS	number of ranked series requested, maximum 2
PAV	average power derived from the current energy demand
PC(12)	peaking capability list in the reservoir tables (relates to HN)
PEF	'power-energy factor'; number of hours in month/1000
P	dummy variable used in *EFFY*
PPC	current value of peaking capability
Q(12,60)	inflow data
QD(12)	downstream flow list in reservoir tables (relates to TW)
Qxx	generally relates to flow

QDS	flow downstream
QIN	current month's inflow
QSP	spillway flow
QTD	turbine flow for demand energy
QTM	maximum turbine flow
QTP	total flow available to the turbines
QTS	turbine flow for secondary energy
QTT	turbine flow for total energy
QDX, QDY	dummy variables used in *MINHED*
QX	dummy variable used in *RELEES*

QUAL	identifier used in *FIDATE* (Univac only)
RA(12,60)	optional monthly rainfall input data
RAIN	current value of rainfall
Rxx	generally relates to a release from the reservoir

RCF	compensation flow release
REL	total release
REN	release for demand energy generation
RFC	flood control release
RFCM	maximum potential flood control release
RIR	irrigation release
RWS	water supply release

SE(12)	seepage list in the reservoir tables (relates to WL)
SEEP	current value of seepage
SFV(4)	shortfall on demands (volume)
SFX(4)	shortfall on demands (percentage)
SFT	total shortfall in month

TWx	always refers to tailwater levels	
	TWI	initial, start of run, tailwater level
	TW1	start of month tailwater level
	TW2	end of month tailwater level
	TWA	average tailwater level
TW(12)	tailwater level list in reservoir tables (relates to QD)	
TIME	time of run derived in *FIDATE* (Univac only)	
VDF(12)	upper or design flood rule curve	expressed as volumes, input data
VOP(12)	lower or operating rule curve	expressed as volumes, input data
VDS(12)	maximum desirable downstream flows	expressed as volumes, input data
VF1-VF8	variable formats governing output	
WLx	always refers to reservoir water level	
	WL1	start of month reservoir water level
	WL2	end of month reservoir water level
	WLA	average reservoir water level
	WLX, WLY, WX	dummy values used in *MINHED*
WL(12)	reservoir water level list in reservoir tables (relates to AR, CN, SE)	
X(12),Y(12), XVAL,YVAL	dummy values used in *LINT*	
Z(4)	minimum draw off levels for the demand related releases	

MULTIPURPOSE RESERVOIR SIMULATION PROGRAM

ADDENDUM TO USER NOTES

The program has been modified to run on the Honeywell computer. Modifications have mainly been the removal of the IF-THEN-ELSE structure and changes to the format statements.

However two toher changes involving the input data should be noted:

the data comprising program options, reservoir characteristics and evaporation are read from channel 5 which can be specified as a file or be the normal card input channel.

Subroutine FIDATE has been rewritten but the Honeywell cannot specify the data file name and this is input manually with the data on channel 5. The first read instruction is now

```
      READ (5,100) NAME,NFIL
  100 FORMAT(1X,A40,/1X,A20)
```

NFIL is output as before in the title box on each page.

The Honeywell version of the program is available in catalogue

OS/DTP/HYDRO

Each subroutine is in a file using the subroutine name. There is also a file /JCL containing a job control stream which expects data to be on files, such as

OS/DTP/H/1	channel 5 data
/2	channel 7 data

D T Plinston

8 June 1982

DTP/vw