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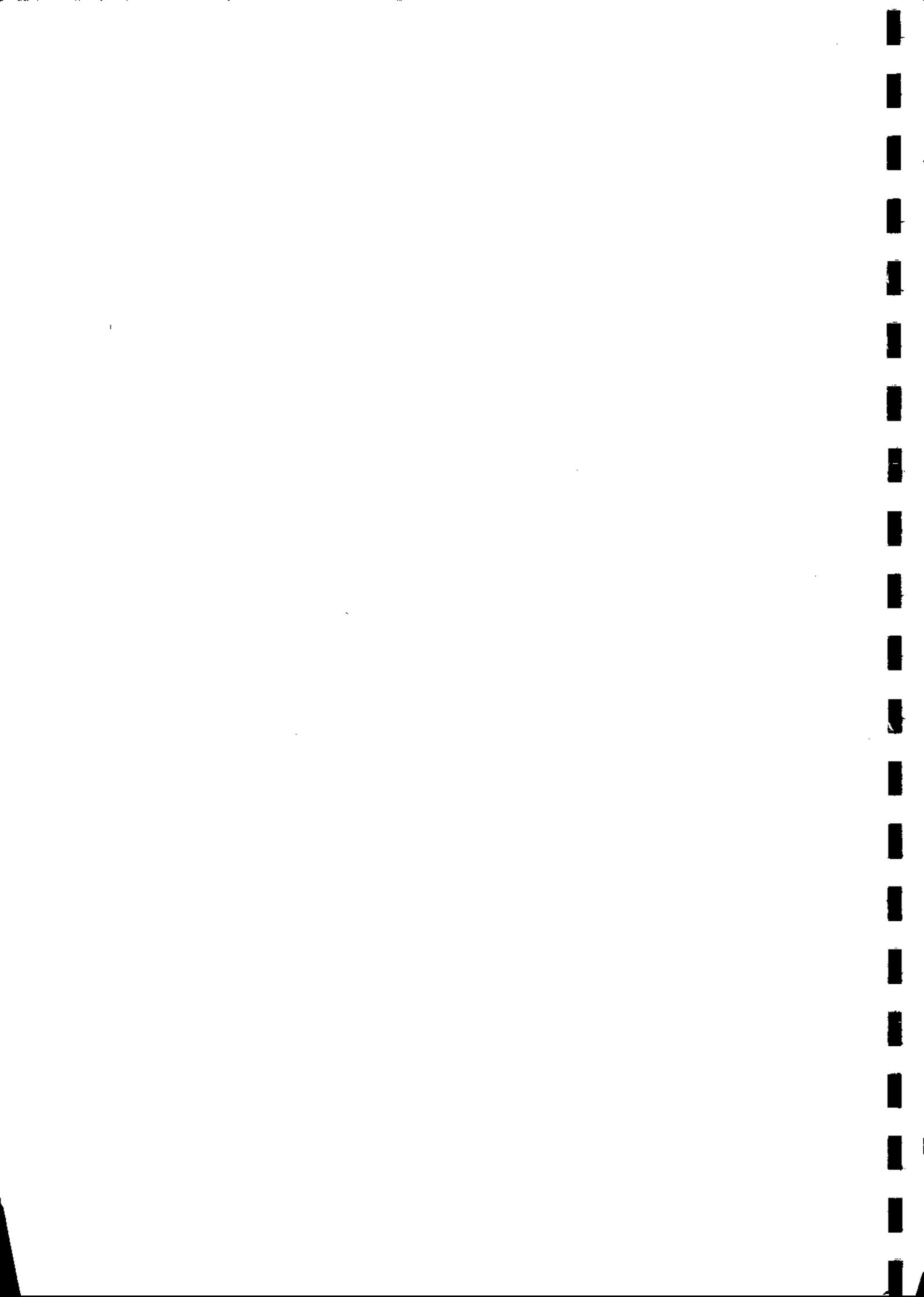
NATURAL ENVIRONMENT RESEARCH COUNCIL

INSTITUTE of HYDROLOGY

REPORT No 15 January 1974
A SYSTEM FOR THE QUALITY CONTROL
AND PROCESSING OF STREAMFLOW,
RAINFALL AND EVAPORATION DATA

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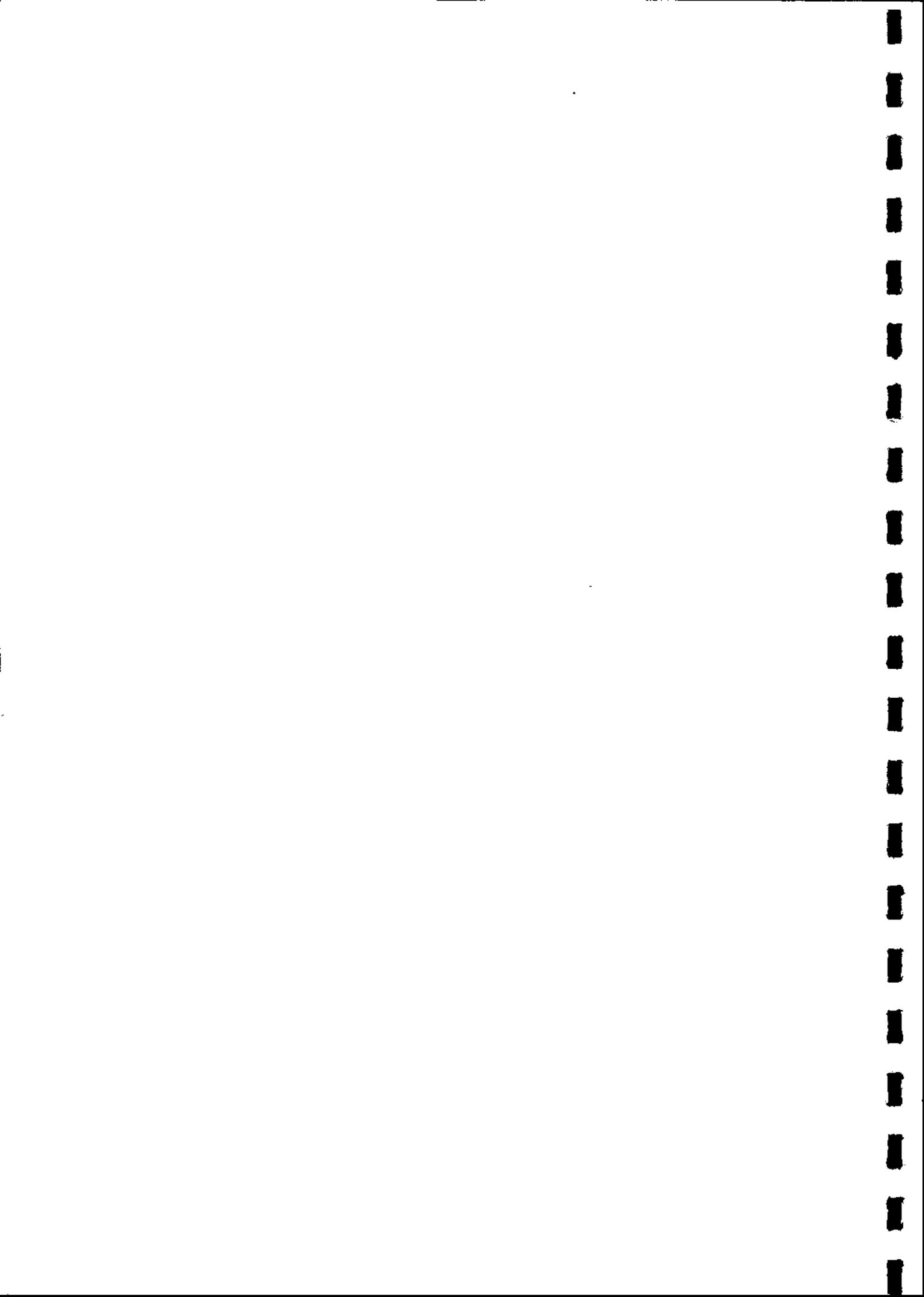
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SECTION 1

INTRODUCTION

1. INTRODUCTION

The success of much current hydrological research depends on the availability of continuous sequences of accurate runoff, rainfall and potential evaporation data for defined catchment areas. Using the advantages of high computation speed and compact storage of modern digital computers, it is possible to handle long sequences of such data. Thus there is a tendency for analysis to be based on short time intervals; hourly data might be used where previously daily values were adequate. This appetite for data in such analyses as conceptual modelling, makes considerable demands on the data collection and processing facilities. It is no longer efficient or even practicable to prepare the data by hand, nor is it possible by traditional methods to ensure that the improved accuracy of field measurement is carried through to the resulting processed data. The need for a computer-based data processing system is obvious and it is also clear that any system must contain an adequate method of quality control to maintain the accuracy of the data.

Anyone familiar with the collection of hydrological data will be aware of the diverse character both of the instrumentation and of the networks of measuring points used to sample the rainfall and meteorological variables. In addition, rainfall is often measured over different time intervals by different instruments in the same catchment area. Some variables are not measured directly; streamflow is usually inferred from a measurement of water level or stage while evaporation is usually estimated from various combinations of measurements of meteorological variables. No two situations are going to be identical although the analyst who will use the processed data requires that it should be in a consistent form which will enable him to apply the methods of analysis uniformly to different catchment areas.

Desirable as it might be, it is impossible to develop a processing system which will satisfy the demands of all users. From the beginning this system was developed principally for those studies which require as input the three major variables, streamflow, rainfall and potential evaporation, each with consistent units and with uniform time interval. These are the requirements for water balance and

mathematical model studies. Nevertheless it should be possible with the minimum of further processing to use the data for a wide range of studies on one or more of the variables. The requirements of the overall system can be stated simply:

- early transfer of data to punched cards or magnetic tape
- standard form of input data
- adequate labelling of input data
- facility for editing input data
- quality control scheme
- compact, permanent storage of input data
- adequate description of operational instrument networks, units and frequency of observation
- versatile main processing scheme for computing areal estimates
- compact, permanent storage of processed data
- facility for graphical display and summary listings
- standard data retrieval facilities

In addition to these particular requirements the system should be

- flexible to facilitate adaptation and improvement
- simple to operate
- internally consistent
- easily adapted to different computers and data storage systems

Although some of these requirements may seem to be in conflict, for example versatility is not always consistent with simplicity or flexibility, this list does suggest a broad framework within which the system can develop. This framework is shown as a flow diagram in Figure 1, and the main sequence of steps can be described as

- ANNOTATION
- PREPROCESSING
- QUALITY CONTROL
- MAIN PROCESSING
- DISPLAY

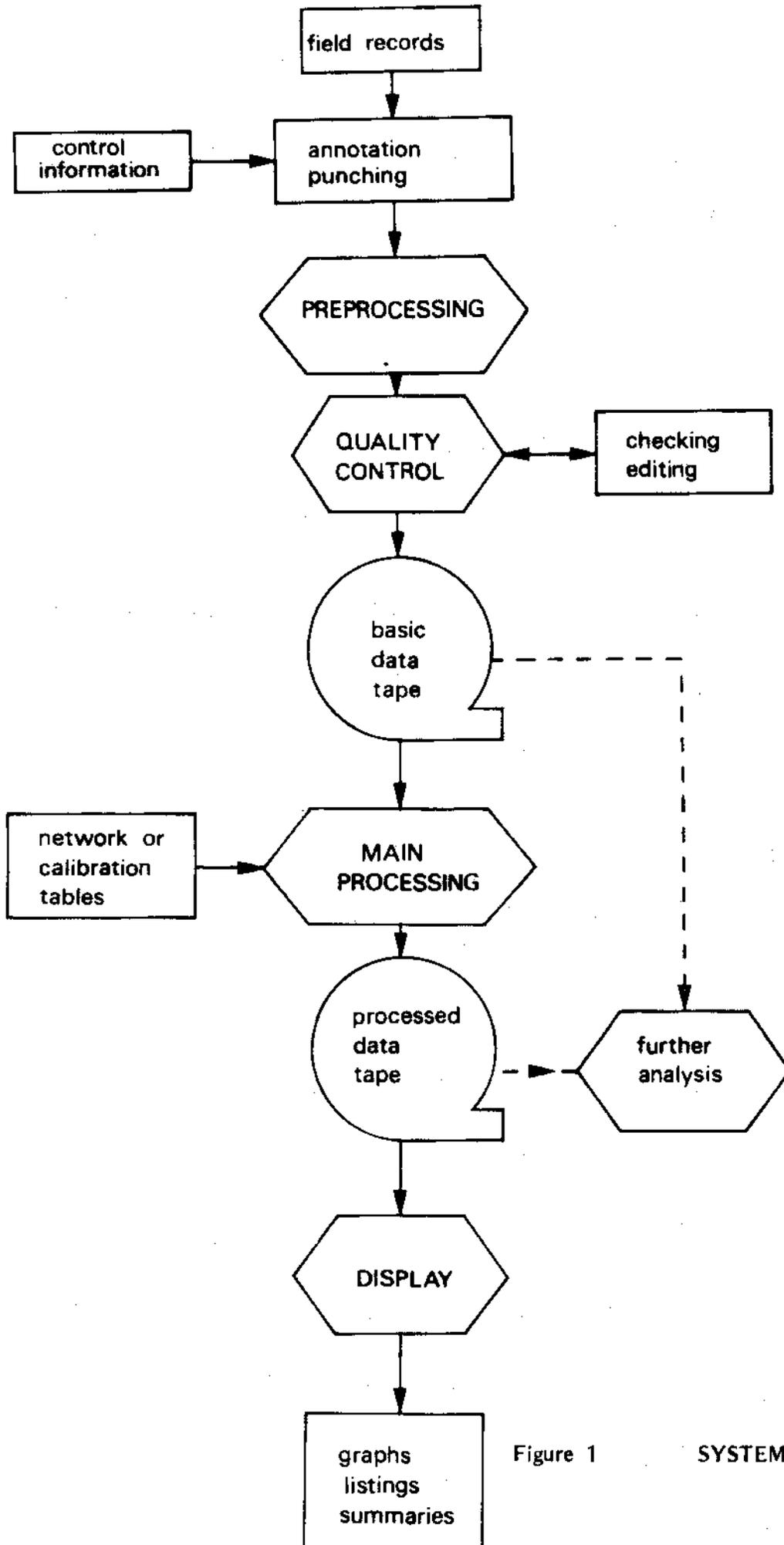


Figure 1 SYSTEM FLOW DIAGRAM

ANNOTATION covers all those office procedures involved in labelling and collating the data, providing the control information necessary to describe the instrument network and the frequency of observation, and the transfer of data to some computer storage medium such as punched cards or magnetic tape. Because of the variety of data collection and collation procedures in use, only that part of the ANNOTATION stage which is concerned with the form in which the data is input to the computer and the form of the control data is described in this report. Once the form of input is established it is desirable to adjust the office procedures so that the field records can be transferred to the computer with the minimum effort.

PREPROCESSING is that stage which is necessary when it is desirable to use the computer to translate the data into a form acceptable to the program system. No matter how comprehensive a system of programs might seem to be, there are always some circumstances where an extra step or process is required.

QUALITY CONTROL is self defining. It is also the stage in the processing of data which is most easily overlooked. This might be due to the difficulty in defining tests which draw a useful balance between not letting through discrepancies and yet minimising the time which must be spent in checking the error diagnosis. This stage can be continuously refined by experience. Also discussion of the results with field staff collecting the records may lead to improvement in field techniques.

THE MAIN PROCESSING stage is that in which the raw data are transformed to the desired output. For example, river levels are transformed to flows; point rainfalls are combined to give areal rainfall estimates. In general this process should be straightforward provided the ANNOTATION and QUALITY CONTROL have been carried out properly.

The final DISPLAY stage has been added to assist in the further analysis. It is expected that full numerical analysis will take the final output from the MAIN PROCESSING stage. Nevertheless there is always a need for graphical display and summary listings which help to define the approach to be taken in the full analysis.

Section 2 of this report describes more fully the approach that has been taken in each of the stages defined briefly here. The sections following describe these stages in detail for each variable for the benefit of a user of the system. Section 6 describes the operation of the system on an ICL 1900 series computer. In due course it will be possible to add to this when the system is adapted to run on other computers.

Similarly, it is expected that future experience will enable other sections of this report to be updated as more powerful techniques are introduced, both in terms of the hydrological and the computational methods employed. For example, the experience gained so far should enable some simple statistical tests to be introduced in the quality control stages especially in those areas where some variables are not adequately checked.

However the main purpose of this report is to set out some of the principles which should be followed in processing raw hydrological data. Many valuable sets of data exist in the U.K. but their use in advanced research is limited both by the unsuitable form in which they are stored and by uncertainty of their quality. Sooner or later a data bank must be developed; the authors believe that the system described here is a useful starting point for the processing of consistent sets of catchment data comprising the three major variables.

SECTION 2

OUTLINE OF THE SYSTEM

- 2.1 Introduction
- 2.2 Data and data storage
- 2.3 Preprocessing
- 2.4 Quality control
- 2.5 Calibration and network tables
- 2.6 Main processing
- 2.7 Display

All program listings will be found in Appendix A which is published separately.

2.1 INTRODUCTION

The previous section has served as an adequate introduction to the outline of the system. Nevertheless it is desirable at this point to describe some of the nomenclature which will be followed in this report.

The choice of programming language and technique is an important consideration when developing programs for continued use over a long period and when the programs are required to be easily adaptable to a range of computers. Fortran is the generally accepted high-level language for scientific programming. However there are several versions of the basic Fortran system and as far as possible the standard ASA Fortran has been used throughout the development of these programs.

Nevertheless there are certain computer-specific problems which arise, particularly those concerning the handling of data within the computer configuration being used. These are discussed in Section 6. All other routines should be acceptable unchanged to the appropriate compiler on many of the widely used computers.

Throughout the report all variables, parameters and other characteristics have been given the name used in the Fortran programs. In addition, tables giving the nomenclature used in the programs are given in each section so that the user can refer to the program listings in Appendix A and carry out any amendments that are necessary.

Also in the report reference will be made to punched cards even when it is obvious that the data are stored on disc file or magnetic tape. When these programs were first developed it was found to be easier to input all data on punched cards and to carry out the editing during the quality control stages also on cards. Although other methods are now used (described in section 6) it is convenient to retain the nomenclature and to describe formats in terms of the 80 column punched card.

Similarly, the principal media for data storage will be referred to as magnetic tapes even though alternative media such as discs are used when appropriate. The most suitable form of storage depends to a large extent on the computer configuration and software available particularly when carrying out editing procedures.

2.2 DATA AND DATA STORAGE

There are three major aspects of the data handling system which need to be defined before the processing system can be built up. These are:

- the time base of the data
- the control and labelling system
- the form in which the data are to be assembled

The time base of the data, that is the frequency of the stored records, must be governed both by the frequency of field observation and the requirement of the subsequent analysis. Although it was impossible to envisage all the possible analytical requirements, a maximum frequency of observation of once every 15 minutes was chosen. This figure is consistent with the frequency required to give an acceptable error level on the volume under a flood hydrograph for a small catchment area (Herbertson *et al.*, 1971) and is consistent with the level of time synchronisation which can be expected in a well instrumented experiment on a catchment scale. However, this high frequency of observation is uncommon and the system must allow for much lower frequencies of observation which, for rainfall and meteorological observations, could be once per day.

Thus the system is designed to accept a range of data input frequencies, the frequency being defined by a single index, IFREQ, which is defined by Table 2.2.1. The interpretation of this index as described in the Table is carried out in the various programs by SUBROUTINE MEFREQ.

It should be noted that the programs allow for modification of the data frequency within the processing program in those cases where a high

input frequency is necessary to give accuracy at a lower frequency. An example of this is streamflow where more accurate values of hourly flow are obtained from an integration of the 15 minute flows. Thus there is an independent output frequency index, JFREQ.

The control and labelling system is governed by the following requirements:

- all the information necessary to carry out the quality control and main processing stages must be stored with the data
- a full description of the instrument network should also be stored
- the labelling should allow for easy access and identification for checking purposes
- the labelling should enable the computer to know in advance what information it should expect

To satisfy these requirements a format based on calendar months and days was chosen. This tends to follow existing office procedures and thus minimises the time required to annotate and transfer the field observations to punched cards or tape. The data are then stored in separate, defined monthly batches with additional labelling by days.

The general form of a monthly batch of data cards is shown in Table 2.2.2. The LEAD CARD which precedes each monthly batch defines only the variable (streamflow, rainfall or evaporation) and the month and year of the batch. This card allows the computer to read the next card, the CONTROL CARD, in the format appropriate to the variable. The value 9 in column 61 of the LEAD CARD indicates that this card is the first card of a monthly batch and to avoid ambiguity and to speed up subsequent search procedures, this column is blank on all other cards. The format is given in Table 2.2.3.

The CONTROL CARD contains all the indices and information on catchment

characteristics which are required to ensure correct processing of the data. Table 2.2.2 defines the information which is common to all CONTROL CARDS; other information specific to each variable is given in the following sections of this report where complete format statements are given. In some cases additional CONTROL CARDS are required in order to specify completely the instrument network for those variables such as rainfall which require sampling in space. As will be seen in the detailed program descriptions there is adequate information on the main CONTROL CARD to allow the other cards to be read correctly.

The data are entered on daily DATA CARDS; where the frequency of observation makes it necessary there may be several cards per day. The first 60 columns of the cards are reserved for data, the remaining columns are used for labelling information and, in the case of rainfall data, for additional control information. The general labelling information common to all DATA CARDS is given in Table 2.2.2. Complete format statements for each variable are given in subsequent sections of the report.

A consequence of the choice of the calendar month as the batch size is that within a month's batch all the characteristics of the instrumentation and networks and the frequency of records must be constant. For example, it is not permissible to change the units of the observations during a month. If such a change is made in the field, a consistent data set must be prepared by hand if necessary, and the units index then changed at the beginning of the following month.

The standard formats used in coding and punching the data on cards or paper tape impose a pattern on the listed display of the data which is of considerable help to the office staff who must follow up the error checks resulting from the QUALITY CONTROL stage. Most punching errors can be detected readily.

The batching of the data by calendar months which are internally consistent allows flexibility in storing the data. Monthly batches may be stored in any order of dates or variable or catchment although obviously it is usually more convenient to arrange the batches in date order and to store the data from each catchment on a separate tape.

One of the aims of the system is to provide a permanent, safe and comprehensive stored record of all the basic input data. As described above the data are assembled in a systematic and comprehensive way. Following QUALITY CONTROL these data are stored permanently on magnetic tape which can be copied several times for additional safety. Following the MAIN PROCESSING stage the output to magnetic tape or disc is also stored permanently. Clearly the assembly of the basic data and the careful presentation of the background information in the CONTROL CARD scheme described here is fundamental to any further work. If it is carried out thoroughly and the QUALITY CONTROL scheme contains many tests which ensure that it is, then there is often little need subsequently to refer to the field books. Some streamflow data processing schemes advocate the transfer of observers' comments to punched cards along with the data. In our view this has two drawbacks. The more important is that subsequent analysis is generally numerical and thus there is little value in having taped comments which cannot be heeded by the computer. Secondly, the comments are often an excuse for not carrying out obvious corrections to the field data before they are presented for coding.

TABLE 2.2.1 DATA AND DATA STORAGE

Input and Output Frequency Indices

IFREQ = Input data frequency index

JFREQ = Output data frequency index

Index value	Frequency items/day
1	96
2	48
3	24
4	12
5	8
6	4
7	2
8	1

Any combination of IFREQ and JFREQ are admissible except;

1. Cases where $JFREQ < IFREQ$
2. The case where $IFREQ = 4$ and $JFREQ = 5$

TABLE 2.2.2 DATA AND DATA STORAGE

General form of a months data batch

LEAD CARD	LEAD CARD defines only data types, catchment number, month and year.
CONTROL CARD	CONTROL CARD defines catchment area, data type, input and output frequencies, units used, catchment number, number of days in the month, month and year together with information specific to the variable being processed.
ADDITIONAL CONTROL CARD(S)	ADDITIONAL CONTROL CARD(S) carry any further information specific to the variable which is required in the processing.
DATA CARD DAY 1 CARD 1	<p>The DATA CARDS are numbered 1 to n for each day, there being as many cards as are required to accommodate the data.</p> <p>On each DATA CARD the label contains the data type, card number, catchment number, day of month, month and year together with some control information when necessary to describe the data adequately (for example rainfall).</p> <p>Details of the format statements relevant to each variable are given in the appropriate Tables in sections 3 to 5.</p>
DATA CARD DAY 1 CARD 2	
etc	
DATA CARD DAY 2 CARD 1	
DATA CARD DAY 2 CARD 2	
etc	
DATA CARD Last Day CARD n-1	
DATA CARD Last Day CARD n	

TABLE 2.2.3 DATA AND DATA STORAGE
Lead Card Format

Item	Symbol	Format	Columns	Units of Remarks
Lead card symbol	NINE	I1	61	always 9
Data type	LTYPE	I1	62	1 = streamflow 2 = rainfall 3 = evaporation
Catchment number	LSITE	I3	72-74	
Month and year	LMONTH	I4	77-80	

2.3 PREPROCESSING

At present the main function of the preprocessing stage is the digitisation of information held on charts. Many of the instruments used to record water level or rainfall have a chart output and there is a considerable saving in office time by automating the data abstraction process. A comprehensive program has been written to take the output from a chart digitising machine (usually punched paper tape) and to produce an output on magnetic tape in a form suitable for further processing by the system described in this report. As this procedure is complicated it forms the subject of a separate report (Douglas, 1972).

From time to time it is necessary to write *ad hoc* translation programs so that data assembled by other organisations may be run through this data processing system for further analysis. All such programs come under the general heading of PREPROCESSING. Clearly it is not helpful to attempt to describe all such programs here. The output format is always the same and it is a simple matter to write a suitable program although incompatibility of some computer peripherals does sometimes add to the effort involved in making data transfers. Experience also suggests that data transfers are made more difficult than they should be by the poor quality of data sets, particularly in terms of missing data. There might often be some justification for carrying out some quality control at source following the principles described in this report.

2.4 QUALITY CONTROL

Within the system this is the only stage at which error control is exercised. The checking system should therefore be as comprehensive as possible. All possible errors can be classified under the headings

- errors in the field records
- punching errors
- errors in assembling the data cards

Of these, the last is by far the easiest to check because of the comprehensive labelling system. Each card that is read is tested by

SUBROUTINE TYPEST for consistency of catchment number, data type, month and year; the LEAD CARD being used as the master for comparison. Within the QUALITY CONTROL routines the day and, where there is more than 1 card per day, the card numbers are checked. Thus it is highly improbable that the final data batches contain an incorrect number of cards or that the cards are in the wrong order. Clearly punching errors in card labels are detected by inspection during these basic tests.

Errors in the field records and punching errors in the data require more sophisticated forms of checking. Possible forms of quality control could include

- statistical tests based on the expected variability of the data
- tests based on trends
- tests involving comparison of totals from the field books and those computed from the data input to the computer

At present only limited use is made of statistical and trend tests. In principle it is not difficult to include such tests but in practice some experience is required before suitable error levels can be defined. As this experience is built up, it is expected that improved tests will be incorporated. The structure of the programs enables additional subroutines to be incorporated without difficulty.

At present much reliance is placed on the comparison of totals from field books with those computed from the data input to the computer. Sometimes it is possible to compute sets of totals in two ways from the same batch of data. Taking rainfall data for example, it is possible to obtain the total of all observations for each day and also the total at each raingauge site for all days of the month. Thus any single discrepancy would appear in two totals which enables the office staff to locate the error quickly. Naturally this procedure does not detect errors in the original field observations or booking; however, it does ensure that almost all punching errors are detected. The actual tests performed are described in detail in the later sections.

The general procedure is the same for each variable. The data are run with the quality control program, a diagnostic list of possible errors is produced, these possible errors are checked and the data corrected where necessary. The quality control program is re-run and the procedure is repeated until the data are deemed to be consistent. They are then stored on magnetic tape, copies are made for safe keeping and the data are ready for the MAIN PROCESSING stage.

It is sometimes the case that with so many cross checks on the order and labelling of cards, a single error will give rise to a string of diagnostics. When cards are missing or there are too many, it is unlikely that the program will adjust to the situation, and a string of diagnostics will follow from the point of error. In these cases a built-in error count is exceeded and the quality control of that particular month's batch of data is curtailed. SUBROUTINE FAIL is called which initiates a search through the data file for the LEAD CARD of the following month's batch. The diagnostic QUALITY CONTROL FOR MONTH ABANDONED is written on the line printer output.

One serious kind of error which has been encountered occasionally is the non-synchronisation of rainfall and runoff events. Often the discrepancy is exactly 24 hours indicating an error in the date on the original charts or in the field books. Such errors are usually discovered during further analysis, that is, after the main processing and display stages have been completed. Although it is a simple matter to correct the basic data tapes and then to repeat the quality control, main processing and display stages for that month, there is much wasted time. Thus it is desirable to try to check such errors as part of the quality control stage. One method would be to display in graphical form, rainfall and flow data on the same time base. A visual check could then be made for non-synchronisation of storm events. The program for this additional display stage will be published as an appendix to this report.

Examples of the output from the QUALITY CONTROL routines are shown in the sections of this report which describe in detail the tests on each variable. In general the QUALITY CONTROL stage is not considered complete until the output contains the message DATA CONSISTENT. However

it is possible that certain apparently erroneous values are indicated when checking shows them to be accurate and realistic. Thus the QUALITY CONTROL stage may be considered completed when only these values are indicated on the output.

2.5 CALIBRATION AND NETWORK TABLES

Some aspects of the MAIN PROCESSING require information which is additional to that included on the CONTROL CARDS. This may be required for calibration of an instrument such as a gauging weir in a river, or a more complete description of a network such as might be required to determine which operational recording gauge is nearest to a given standard raingauge. It is most convenient to present this information numerically in the form of tables and as changes occur only occasionally, it is wasteful of storage space to include it with each month's data. Thus these tables are stored at the beginning of the magnetic tapes which hold the final processed data and they are identified by variable and catchment number only.

For the calibration of weirs and flumes, special programs have been written which compute the discharge for every millimetre increment of water level. The table is then used as a 'look up' table without any further interpolation. These programs are described in Section 3.5.

The tables which define instrument networks are at present necessary only in the case of rainfall. These tables are prepared manually and the procedure is described in Section 4.5.

When changes in either the calibration or network tables are necessary there is a procedure for storing the new tables on the processed data tape and this is described in Section 6.

2.6 MAIN PROCESSING

The aim of the processing system as a whole is to produce estimates of the variables integrated over the defined catchment area. Of the three major variables only streamflow is obtained from continuous water level measurement as an areally-integrated value. Measurements of other variables are necessarily point samples which must be combined in some fashion. The MAIN PROCESSING programs, one for each

variable, carry out this function. The hydrological problems involved in these procedures are diverse and are better left for a full description in the later sections of the report. However, it is pertinent at this point to discuss some of the general aspects of the programs.

Inevitably different catchments pose different problems for processing. For example, the network of raingauges may be different in the sense that one catchment may have daily-read gauges together with continuously recording gauges, whereas another catchment may have monthly-read gauges with a number of recording gauges. As another example, the instrumentation at different meteorological sites might necessitate the estimation of incoming solar radiation by any one of several different methods. Clearly having a different program for each eventuality would lead to needless duplication of the common aspects of each method and would certainly lead to confusion in operating the programs. The labelling and control information described in Section 2.3 and elsewhere has enabled the instrument and network systems to be completely defined. Thus a sensible approach is to make the MAIN PROCESSING programs sufficiently flexible to deal with all the expected variations. Although this may seem to make the programs complicated, the use of consistent symbols and nomenclature ensures that they are reasonably easy to follow.

Superimposed on this flexibility of method is the requirement that they should deal with different frequencies of input and output data and with data in a range of different units. However the units of the output data are standare, chosen to be millimetres depth of water over the catchment area.

The output from the MAIN PROCESSING programs is stored on the processed data tape. This is the data tape for further analysis and for input to the DISPLAY programs. The CONTROL information is carried through to this tape. The only variation in format on this tape is in the frequency of the data, that is the number of items per day. The output frequency index on the CONTROL CARD defines this frequency and thus allows the tape to be read using a standard reading routine.

As the processed data tape can be regenerated easily and efficiently, its safety is not as important as in the case of the basic data tape.

Nevertheless it is prudent to make copies of this tape. Users of the processed data may well find it an advantage to make further tapes to suit their particular needs for specialised analysis; for example, they may require only one variable as in certain time series analysis, or they may require all variables standardised to a common frequency but merged in some special way perhaps for modelling or catchment response to rainfall. It is not within the scope of this report to list such programs which are best developed on an *ad hoc* basis. However experience does suggest that the processed data tape should be regarded as the basic reference tape for most analyses. Some analyses which may require data not carried through to the final tape, such as water level or temperature, will need to refer to the basic data tape. Naturally this will be a more complicated procedure although it should be more efficient than repunching and validating the particular data set required.

2.7 DISPLAY

Although most analyses are now carried out numerically, there is always a need to refer to graphical display and summary tables both to obtain a general appreciation of the data and to identify events which require particular emphasis in a study.

To help satisfy these requirements, three forms of DISPLAY have been developed. The first is a graphical display, the three variables flow, rain and evaporation being plotted on a common time-scale. Since the graph is not intended to be used for measurement it is not necessary to use a very large format and the hard copy output from a microfilm plotter is ideal for this purpose, especially as a continuous time-scale can be obtained. The microfilm can be used directly if suitable microfilm readers are available.

The second form of display which has been found to be useful is a monthly summary sheet giving monthly and daily totals of the three variables together with the CONTROL CARD information. For long data sequences it is a simple matter to make a yearly summary by hand.

The final display form is a complete listing of selected parts of the processed data tape. Occasionally this form of listing is required for

detailed study of selected events such as storms. A similar facility for the basic data tape is not necessary as a complete listing is made for reference whenever new data are added to it.

Unfortunately the programming for graphical displays is usually specific to the computer system available. Consequently it is not possible to present a program for universal application. The program presented in this report has been developed specifically to be run on the Science Research Council's 1906A computer with the Stromberg-Carlson 4020 plotter. The Fortran program is listed in Appendix A and the operating instructions are given in section 6.7 of this report together with examples of the output.

The program has a limited amount of flexibility. Normally the processed data tape contains data with a 1 hour time interval (except evaporation data which is normally one value per day). If for any reason the time interval is longer, the data are adjusted before plotting to give the equivalent of hourly values.

Although this may give a stepped appearance to the hydrograph the result is acceptable for the purposes of appraisal.

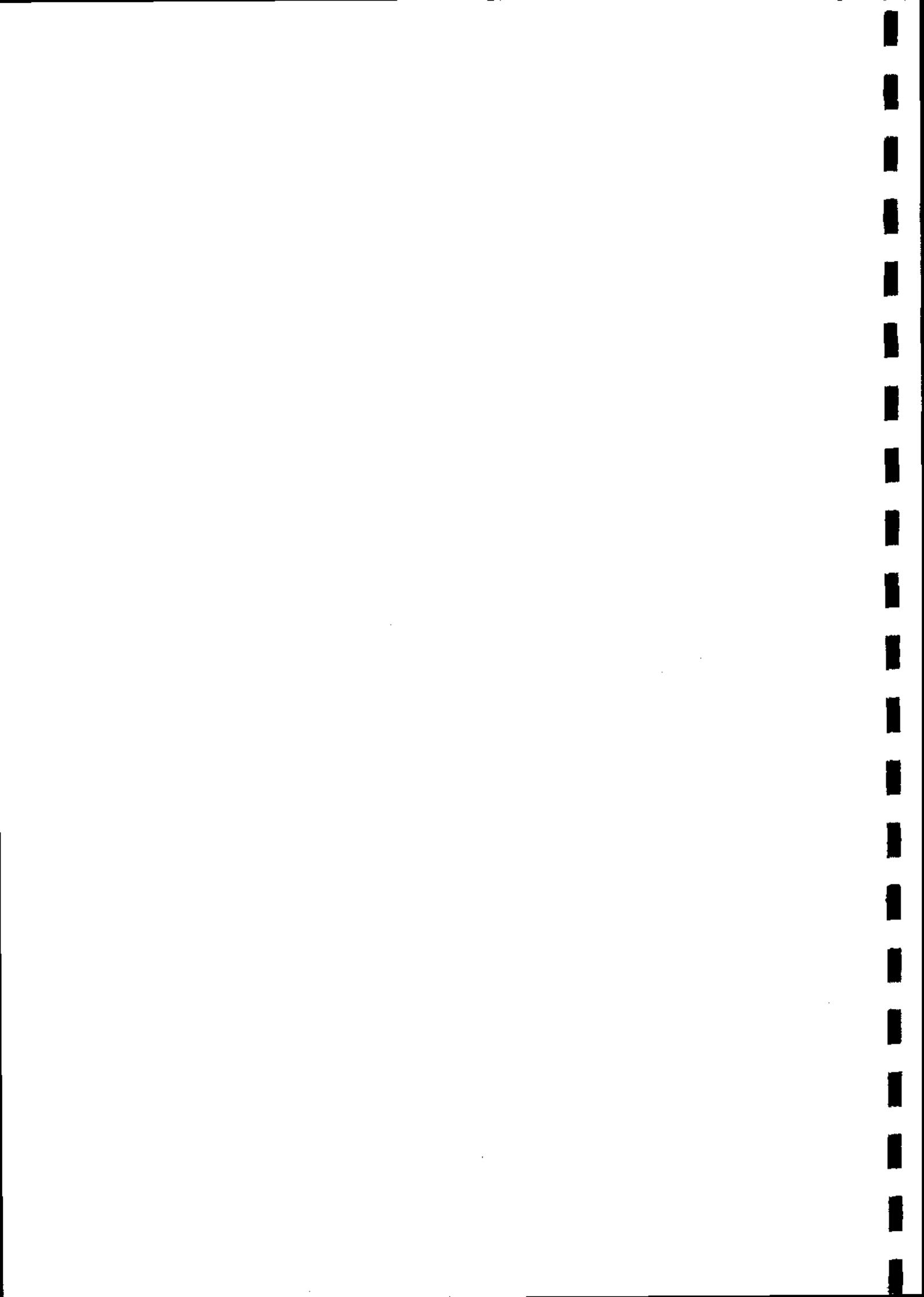
For further information concerning the SC4020 plotter and its uses, the reader is referred to the Atlas Computer Laboratory report "1900 FORTRAN SYSTEM FOR THE SC4020".

SECTION 3

STREAMFLOW

- 3.1 Introduction
- 3.2 Input data
- 3.3 Control information
- 3.4 Preprocessing
- 3.5 Calibration tables
- 3.6 Quality control
- 3.7 Main processing

All program listings will be found in Appendix A which is published separately.



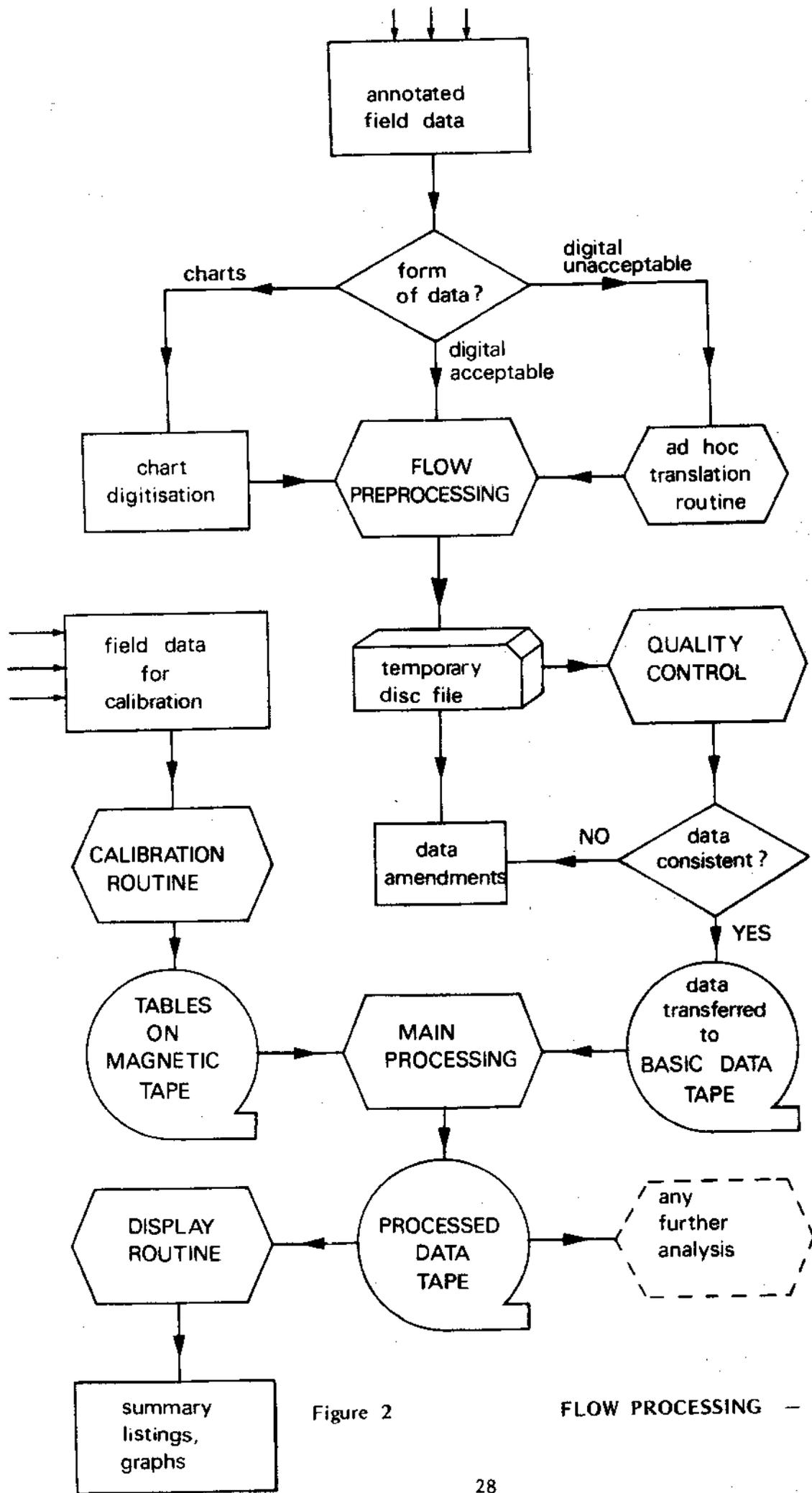


Figure 2

FLOW PROCESSING — Sequence diagram



3.1 INTRODUCTION

Only rarely is streamflow measured directly on a continuous basis. Usually the data are of river stage (water level) from which streamflow data are obtained using a calibration curve or table relating streamflow to stage. Such calibrations can be constructed from direct flow measurement (by current meter traverse or chemical dilution methods) or from theoretical considerations in situations where there is a gauging structure at the site.

Stage is recorded in a bewildering variety of ways which can be classified as manual records, chart records and punched paper tape records. Of these, only chart records are strictly continuous. In assembling data from these sources it was found desirable to separate the rather detailed and specialised procedure involved in bringing the data to a common format on magnetic tape and to form a PREPROCESSING package. This is described in full in a separate report, (Douglas, 1972), which covers the procedures for annotation of the basic data, for automatic chart reading and for transformation of the data to a standard format. It is in this annotation stage that all field checks are noted and when a complete visual check for gross anomalies is carried out. Timing errors in the recorder are the most serious kind of error which is corrected at this time.

The QUALITY CONTROL and MAIN PROCESSING of the stage data are described in this report together with the computation of calibration tables for gauging structures of the Crump weir and flume types. Figure 2 illustrates the overall sequence of the streamflow processing and it is self-explanatory.

3.2 INPUT DATA

Flow can vary rapidly on the smaller catchment areas commonly used in research projects and the main problems in achieving precise estimates of volume of flow over a specified time interval is in integrating this fluctuating flow. Either one can take measurements from a continuous record of flow (more commonly of water level) at short time intervals and use a simple linear method of integration or one can take less frequent measurements and adopt a more sophisticated form of integration involving a cubic or higher powered interpolation between observed points. The development of techniques for abstracting data from charts automatically has made it practicable to adopt the first alternative which in principle gives better precision. The programs will accept data with time intervals as short as 15 minutes and as long as 1 day. This frequency is defined by IFREQ on the CONTROL CARD as defined in Table 2.2.1.

For a given time interval and using simple linear integration it is most convenient if the data refer to the time at mid-interval. Thus the total flow in interval $t \rightarrow t + \Delta t$ will be $\Delta t * Q_{t + \Delta t/2}$ adjusted by an appropriate factor to account for units and calibration. If readings are taken on the time interval, that is at time t and $t + \Delta t$ then the volume will be the average of the 2 readings multiplied by Δt . The first method is slightly more efficient and it also avoids having to carry over the last reading of one month to the following month. However, although the automatic chart reading system is set up to give mid-interval readings, manually abstracted data are commonly abstracted on the time interval. In the processing system both are acceptable and they are distinguished by the interpolation index, INTERP, on the CONTROL CARD.

The stage or flow data are input, in card format, with 12 readings per card, there being up to 8 cards per day. The format is given in Table 3.2.1. The readings are punched without decimal points in a field width of 5; the units index, INDEX, indicates both the unit of measurement and the number of decimal places. Any unit is unacceptable provided that the field width is not exceeded. Units other than those listed in Table 3.3.1 will require a new value for INDEX and

the insertion of an appropriate factor in the MAIN PROCESSING program.

Table 3.2.2 shows a month's data assembled and ready for the quality control stage. There are 96 values per day, read at mid-interval, 8 cards per day and a total of nearly 250 cards per month.

TABLE 3.2.1 FLOW - INPUT DATA
Data card format

Item	Symbol	Format	Columns	Units and Remarks
12 Stages (discharges)	S	12F5.0	1-60	no decimal points and right-justified
Data type	ITYPE	I1	62	always 1
Card number	ICARD	I1	68	1 to n cards per day
Catchment number	ISITE	I3	72-74	
Day of month	IDAY	I2	75-76	
Month and year	IMONTH	I4	77-80	



3.3 CONTROL INFORMATION

The format of the CONTROL CARD is given by Table 3.3.1 which also defines the purpose of most of the items shown. However, the following require some further explanation.

The zero correction, ZERO, is a quantity which will be subtracted from the stage values before the stages are converted to discharge using the calibration tables. The tables are constructed in such a way that zero discharge is associated with zero stage, that is, the stage datum is the true hydraulic datum for the structure. Thus the ZERO correction has two main uses. Firstly it allows for the situation where stages have been recorded relative to Ordnance Datum which is invariably different from the hydraulic datum. Secondly, it allows a correction (always a mean correction for the month) to be made for any error in the datum of the stage recorder. These recorder datum errors are usually measured by levelling and a hydraulic levelling technique is recommended for accurate work.

The highest stage, SMAX, should be found by visual examination of the recorder charts or punched paper tapes. In some applications such as data on magnetic tape or punched paper tapes of the kind produced by the Ott recorder, it will be necessary to list the data. This may appear to be tedious but it is considered that every effort be made to ensure the precision of peak stages and hence of peak discharges.

The interpolation index, INTERP, allows for readings taken on the time interval or at mid-interval. This is related to the method of interpolation used to compute the runoff during the time interval. It is convenient in the MAIN PROCESSING routine to use mid-interval data; thus the PREPROCESSING routine produces data at mid-interval. However, most historic data will probably have been abstracted on the interval. In this case it is necessary, in a monthly batch, to have one more reading than there are time intervals. This

reading is taken as the 09.00 hrs reading for the first day of the month and is entered on the INITIAL DATA CARD whose format is given by Table 3.3.2. This card follows the CONTROL CARD.

The input frequency index, IFREQ, which is chosen depends on the discrimination of the recorder and on the method of data abstraction in the case of a chart record. Chart speed and thickness of trace must obviously be considered. The use of a chart digitiser such as the d-mac equipment described elsewhere (Douglas, 1972) allows any time interval to be used because there is an efficient interpolation scheme incorporated in the PREPROCESSING program. As a general rule it is desirable to abstract the maximum amount of information from the field data at this stage in the processing sequence as this will lead to a reduction in the errors of integration over longer time intervals in the MAIN PROCESSING program. The index IFREQ takes the values, 1 → 9 for data time intervals of 15 minutes → 24 hours as defined in Table 2.2.1.

The output frequency index, JFREQ, should be used to apply hydrological judgement concerning the time interval which is consistent with the accuracy of the recorder and the time base of the most detailed further analysis which is contemplated. Clearly the output frequency cannot exceed the input frequency; otherwise all combinations of IFREQ and JFREQ are admissible except the case, IFREQ = 4, JFREQ = 5.

Several alternative units can be used with the existing programs. It is a simple matter to insert further options when necessary in the MAIN PROCESSING program.

TABLE 3.3.1 FLOW - CONTROL INFORMATION

Control card format

Item	Symbol	Format	Columns	Units and remarks
Catchment area	AREA	F10.1	1-10	hectares
Zero correction	ZERO	F5.0	11-15	
Highest stage (discharge)	SMAX	F5.0	16-20	highest stage (discharge) for the month. Month extends from 0900 hours on first day to 0900 hours on first day of following month.
Data type	ITYPE	I1	62	always 1
Interpolation index	INTERP	I2	64-65	1 = readings on the interval 2 = readings mid-interval
Input frequency	IFREQ	I2	66-67) See Table 2.2.1.
Output frequency	JFREQ	I2	68-69	
Unit index	INDEX	I2	70-71	1 = stage x 10 ⁻³ ft 2 = stage mm 3 = flow ins/hour x 10 ⁻⁵ 4 = stage x 10 ⁻² ft
Catchment number	ISITE	I3	72-74	
Number of days in month	IDAYS	I2	75-76	
Month and year	IMONTH	I4	77-80	

TABLE 3.3.2 FLOW - CONTROL INFORMATION
Initial data card format

Item	Symbol	Format	Columns	Unit and Remarks
Initial stage (discharge)	S	F5.0	1-5	0900 hour reading on first day of month
Data type	ITYPE	I1	62	always 1
Catchment number	ISITE	I3	72-74	
Month and year	IMONTH	I4	77-80	

3.4 PREPROCESSING

The special suite of programs which cover the abstraction of data from chart records is described in full in a separate report, (Douglas, 1972).

The programs are written to take advantage of the facilities offered by the d-mac chart reader. This reader produces a punched paper tape output corresponding to the cartesian coordinates of the position of a target on the chart table. Thus when a chart is placed on the table and the trace followed by the target, a sequence of coordinates is produced on tape.

Procedures have been developed for annotation and calibration so that each paper tape is prefaced by all the information required for checking and for further processing up to the stage when the output is written on to the basic data tape. The program which analyses the punched paper tape includes some quality control which checks that correct procedures have been followed and that a sufficient length of chart has been covered.

The machine-based cartesian coordinates are translated into chart coordinates and if necessary, allowance is made for curvature of chart scales. It is convenient to abstract data at points chosen by considering only the rate of change of the trace, provided sufficient points are taken off in total. A cubic interpolation routine then reconstructs the trace and values are determined by interpolation at the time intervals required for further processing. The output to the basic data tape is then in a form consistent with the data format given in Table 3.2.1.

3.5 CALIBRATION TABLES

Streamflow is usually estimated from measurements of water level. As far as data processing is concerned, the form of the relationship between flow and water level or stage is not directly relevant. However, in the catchment areas used in research programmes it is desirable to achieve a relatively high accuracy in the estimation of flow. The catchment areas, and therefore the flows, tend to be relatively small and it is possible to achieve good accuracy by building a control structure such as a weir or flume at the gauging station. This ensures a consistent relationship between flow and stage; a relationship which can be derived from theoretical considerations.

This section describes a program which has been written to construct calibration tables for the more common types of control structure, particularly the Crump weir and the critical depth flume. It is not intended here to describe the derivation of the theoretical equations used in the program; they are fully described in the literature cited. For those structures or rated river sections for which this program is inapplicable, it will be necessary to write an *ad hoc* program to construct the calibration table.

The final form of the calibration table is a list of flows with the unit of cubic metres per second corresponding to a specified range of stages in increments of 1 mm. The datum of the stage range must correspond to the true hydraulic datum of the structure or river section, that is, a zero stage must imply zero flow. The way in which this table is written onto to processed data tape is described later in Section 6.

A short main routine, MASTER FLUME CALIBRATION, reads the input data comprising station or catchment number, range of stage, type of structure and details of its geometry. The appropriate subroutine performs the calibration computations. All input data concerning the geometry of the structure must be in metric units with length measurements in metres. Tables 3.5.1, 3.5.2 and 3.5.3 give the format of the input data cards. Of these, the first is obligatory together

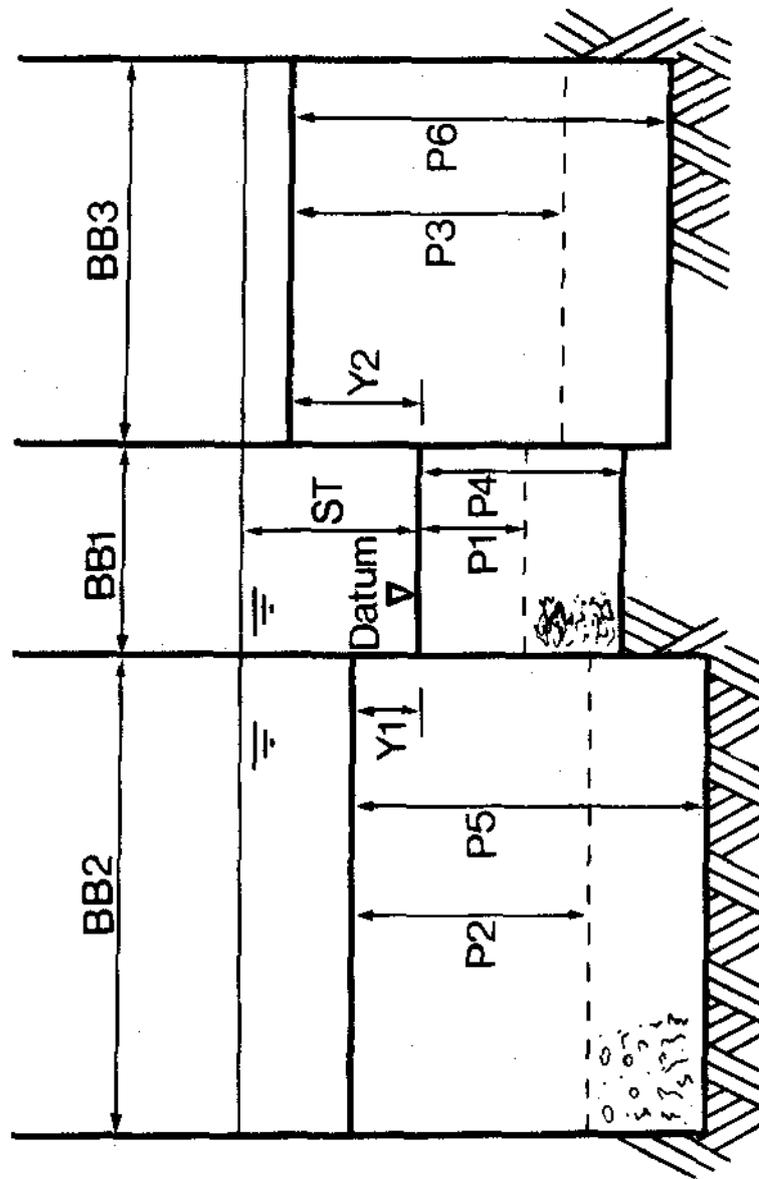


Figure 3

WEIR CROSS - SECTION

with one only of the others.

SUBROUTINE CALIBW applies a standard calibration technique (British Standard 3680) to weirs of triangular section (Crump weirs). It allows for compounding up to 3 crests at different levels. It also allows for variable upstream bed levels by allowing 3 conditions of flow as defined below;

- a. "low flow" below a stage HL1 when upstream bed levels are constant and weir heights P1, P2 and P3 are applicable.
- b. "medium flow" between stages HL1 and HL2 when the upstream bed level varies with discharge. It is assumed that the ratio HA/P is constant for each weir of the compound structure and, as ST is approximately equal to HA , it is assumed for ease of computation that ST/P is a constant given by CK .
- c. "high flow" above a stage HL2 when the bed level is again constant (due to aprons being swept clean, for example) when the weir heights P4, P5 and P6 are applicable.

The cross-section of a Crump weir is illustrated in Figure 3 and this defines the nomenclature used to describe its geometry. Table 3.5.4 gives the nomenclature used in the subroutine CALIBW which is not described on the cross-section or in the data card format.

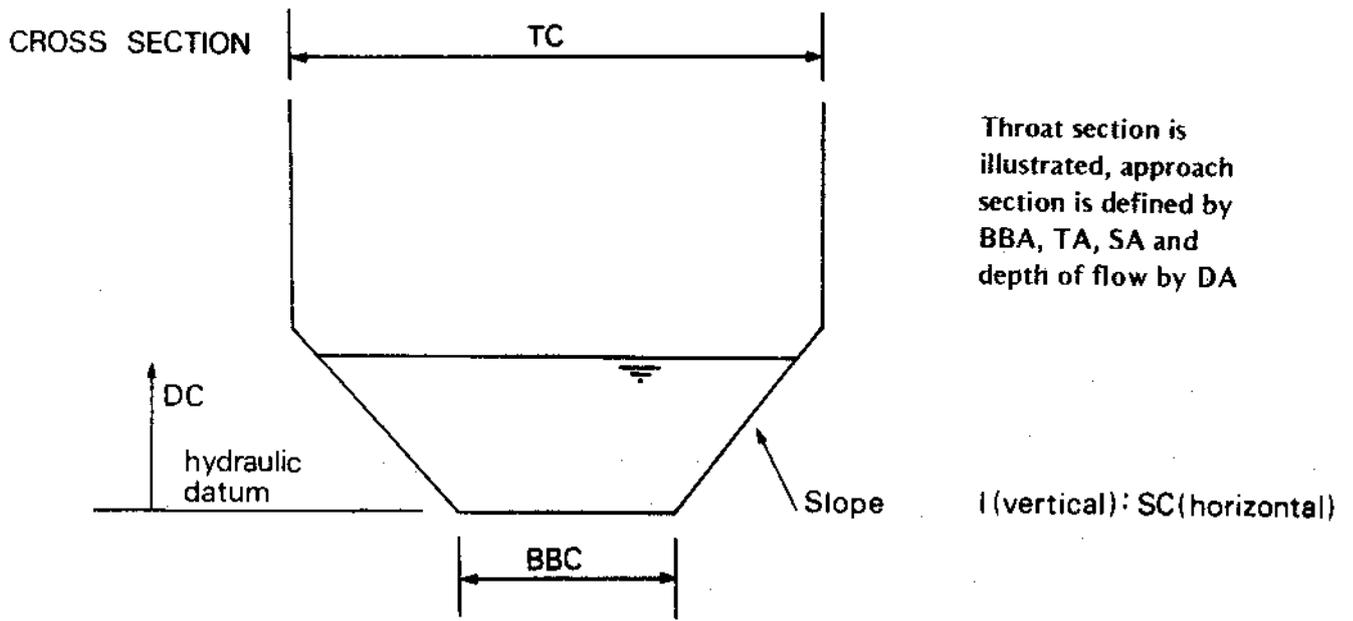
Table 3.5.5 describes the computation sequence which is followed for each increment of stage, ST . The current version of the routine does not allow for the non-modular or drowned flow condition.

SUBROUTINE CALIBF applies critical depth theory (Ackers and Harrison, 1963; Hydraulics Research Station, 1966) to a general flume cross-section illustrated in Figure 4. Clearly the choice of zero values for certain dimensions will allow rectangular, triangular or trapezoidal flumes to be calibrated with this routine.

The nomenclature used in the routine is defined in Table 3.5.6 excluding that already defined by the cross-section and longitudinal profile shown in Figure 4. The sequence of computation is described in Table 3.5.7.

Figure 4

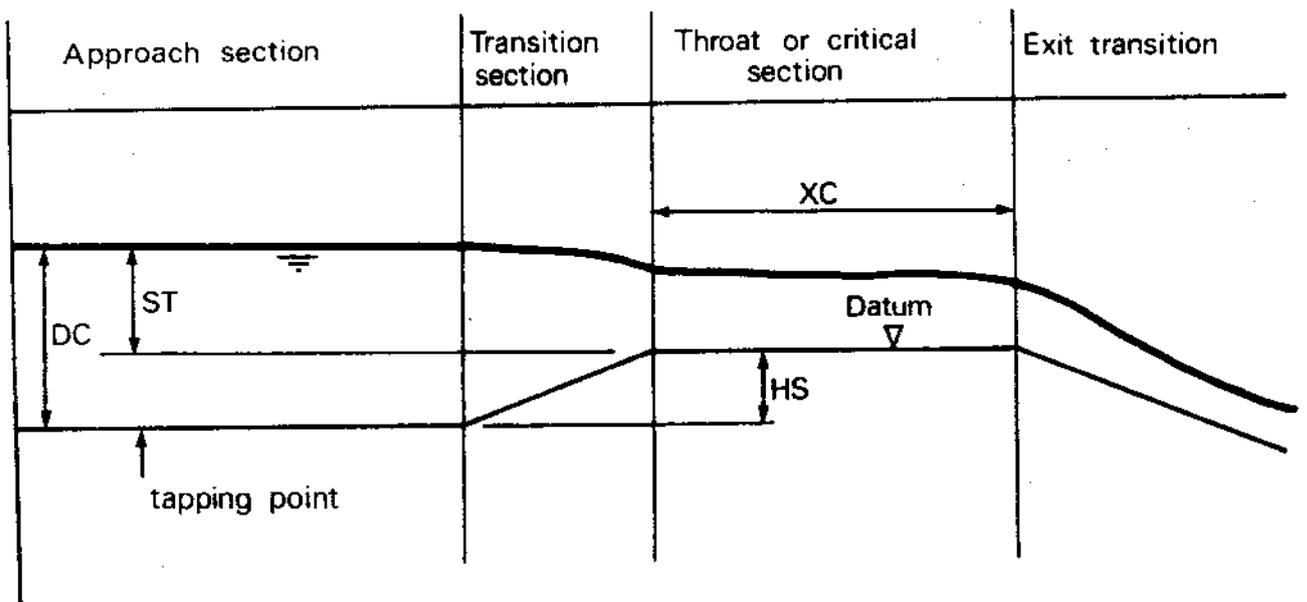
Flume cross-section and longitudinal profile



Notes:

1. If $TC = BBC + 2 \cdot SC \cdot DC$ (max), the calibration will refer to a trapezoidal flume.
2. If $SC = 0$, the calibration will refer to a rectangular flume.
3. If $BBC = 0$, the calibration will refer to a flume of triangular section at the base.

LONGITUDINAL PROFILE



The calculation of the friction head loss, HF, can take two forms; the choice is made by setting INDEX. When INDEX = 1, a value of CF must be included on the appropriate data card and the calculation follows the method described by Ackers and Harrison. When INDEX = 2, the subroutine uses the value DELTA which refers to the boundary layer thickness and the calculation follows the method described in the Hydraulics Research Station report cited above. Of the two methods the latter is preferred.

TABLE 3.5.1 FLOW - CALIBRATION TABLES
Main data card format

Item	Symbol	Format	Columns	Units and remarks
Station number	NUM	I3	1-3	usually the same as catchment number
Type of structure	ITYPE	I3	4-6	1 = Flume 2 = Crump weir
Minimum stage	IMIN	I6	7-12	mm, always 1
Maximum stage	IMAX	I6	13-18	mm

TABLE 3.5.2 FLOW - CALIBRATION TABLES
Weir data card format

Items	Symbol	Format	Columns
Crest width - crest 1 (lowest)	BB1	F5.3	1-5
- crest 2	BB2	F5.3	6-10
- crest 3 (highest)	BB3	F5.3	11-15
Height difference - between crests 1 and 2	Y2	F5.3	16-20
- between crests 1 and 3	Y3	F5.3	21-25
Weir heights above the approach invert at			
- crest 1	P1	F5.3	26-30
- crest 2	P2	F5.3	31-35
- crest 3	P3	F5.3	36-40
Weir heights above the approach invert at "high flows"			
- crest 1	P4	F5.3	41-45
- crest 2	P5	F5.3	46-50
- crest 3	P6	F5.3	51-55
Stage defining upper limit of "low flow" condition	HL1	F5.3	56-60
Stage defining lower limit of "high flow" condition	HL2	F5.3	61-65
Stage/weir height ratio for "medium flows"	CK	F5.3	66-70
Velocity head coefficient, approach section	ALPHA	F5.3	71-75
Index giving tapping point position	ITAP	I3	76-78

Notes. The tapping point index, ITAP, indicates the position of the effective point of measurement of water level relative to a weir crest.

TABLE 3.5.3 FLOW - CALIBRATION TABLES
Flume data card format

Item	Symbol	Format	Columns
Bed width - throat section	BBC	F6.3	1-6
- approach section	BBA	F6.3	7-12
Side slope - throat section	SC	F6.3	13-18
- approach section	SA	F6.3	19-24
Distance between vertical side walls			
- throat section	TC	F6.3	25-30
- approach section	TA	F6.3	31-36
Step height (positive when throat invert higher than approach invert)	HS	F6.3	37-42
Length of throat section	XC	F6.3	43-48
Method of computation of friction head loss (see text)	INDEX	I2	49-50
Friction coefficient (see text)	CF	F9.6	51-59
Boundary layer thickness (see text)	DELTA	F9.6	60-68
Velocity head coefficient, approach section	ALPHA	F5.3	69-73

Note: Side slope is entered in the form 1 (vertical): SC (horizontal)
 All units in metres.

TABLE 3.5.4 FLOW - CALIBRATION TABLES
Nomenclature used in subroutine CALIBW

ST	stage
AA	total area of flow in approach section
HVA	velocity head in approach section
HA	total head in approach section
QQ, Q	discharge
HANEW	revised value of HA in iterative calculation of discharge
RESID	residual error in iterative calculation
ACC	precision of final HA value
CW	weir constant

See also Tables 3.5.1 and 3.5.2

TABLE 3.5.5 FLOW - CALIBRATION TABLES
Sequence of subroutine CALIBW

For each increment of 1 mm stage ST;

1. compute the weir heights according to the flow condition defined in the text, say P1, P2 and P3 apply.

2. compute the area of flow in the approach section in which the tapping point is situated.

when ITAP = 1	AA = BB1 (ST + P1)
= 2	AA = BB2 (ST + P2 - Y2)
= 3	AA = BB3 (ST + P3 - Y3)

3. compute the discharge by successive approximation as follows,

a. choose HA = ST

b. $QQ = CW.BB1.HA^{3/2} + CW.BB2 (HA - Y2)^{3/2} + CW.BB3 (HA - Y3)^{3/2}$

where either of the last 2 terms are neglected when HA is less than Y2 or Y3 respectively.

c. the approach velocity and the velocity head are obtained from

$VA = QQ/AA$ and $HVA = ALPHA.VA^2/2G$

where G is the gravitational constant

d. The next estimate of HA is ST + HVA and the computation is repeated until the difference between successive estimates of total head is less than 1 part in 100,000.

TABLE 3.5.6 FLOW - CALIBRATION TABLES
Nomenclature used in subroutine CALIBF

DC, DA	depth of flow
BSC, BSA	surface width of flow
AC, AA	area of cross section of flow
PC	wetted perimeter of flow in throat section
VC, VA	velocity of flow
HC, HA	total head
HF	friction head loss
HVA	velocity head in approach section
DANEW	revised value of DA in iterative calculation of discharge
RESID	residual error in iterative calculation
ACC	precision of final DA value
QC, QA	flow in critical or approach section respectively

See also Tables 3.5.1 and 3.5.2.

Subscripts C and A indicate throat or approach section

DJC, DJA, AJC, AJA and PJC are the values of DC, DA, AC, AA and PC when the flow is such that the trapezoidal or triangular section of the flume is just full.

TABLE 3.5.7 FLOW - CALIBRATION TABLES
Sequence of subroutine CALIBF

For each increment of water depth in the throat section, DC:

1. compute the discharge, QC, and the total head, HC, in the critical section
2. compute the friction head loss, HF, between the approach section and the critical section, see text
3. compute the discharge, QA, and the total head, HA, in the approach section allowing for the step height, HS
4. compute the depth of flow in the approach section, DA, by successive approximation such that, $DA + HVA = HA$
5. interpolate for discharges, Q, corresponding to integer values of stage, ST.

3.6 QUALITY CONTROL

Of the three major variables, river stage or flow can be most easily checked for consistency because it is possible to take advantage of the continuous form of the stage hydrograph. Figure 5 shows a fairly typical set of discrete stage values taken from a continuous chart record with a short time interval between values. If for example points 9 and 20 are displaced significantly as shown in the Figure then the nearly smooth form of the sequence is disrupted.

These 'discontinuities' are obvious from visual inspection. However it is possible to search for them automatically by examining the trend of each sequence of four stage values. The use of four values rather than three allows peaks to be checked as real when the downward trend after the peak is confirmed by the following reading. Clearly the success of this trend test is better the closer the stage values are in time and this is one of the reasons why the PREPROCESSING stage of the system produces an output of 96 values per day.

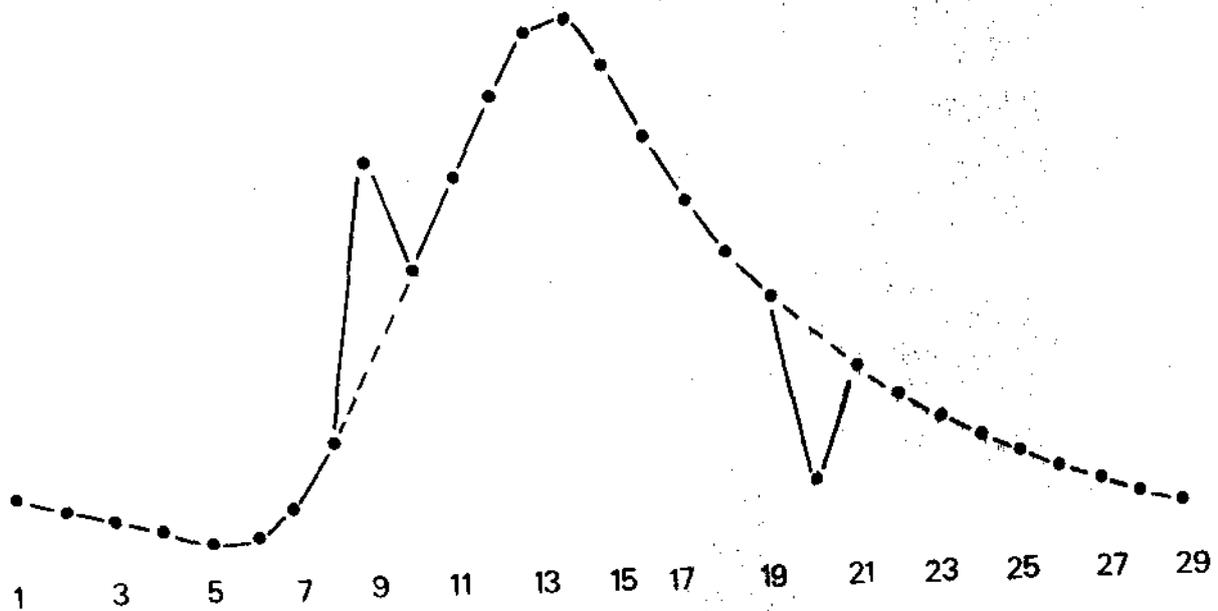
The trend test is applied successively to each sequence of four stage values, that is, points 1 to 4, 2 to 5, 3 to 6 etc. until the end of the month. When several batches of FLOW data are processed sequentially, the last three points of month n are carried over to month $n + 1$ to enable the trend test to continue without a break, otherwise it would be necessary to check manually the first three and last three stage values of a month.

All possible combinations of four successive stage values are shown in Figure 6 together with the action taken in each case. When the first three values indicate a continuous trend (cases 1 and 23) no further action is taken and the routine steps to the next set of values. When a stage value is 'queried' a diagnostic appears on the QUALITY CONTROL printout indicating that manual inspection is necessary.

Some water level records, usually of the punched tape kind, hunt when there are small variations in water level. This produces a step pattern in the record and it can be seen from Figure 6 that if the step is longer than one time interval many values would be queried by the routine. To avoid many diagnostics concerned with this trivial

Figure 5

A typical set of stage values indicating possible errors

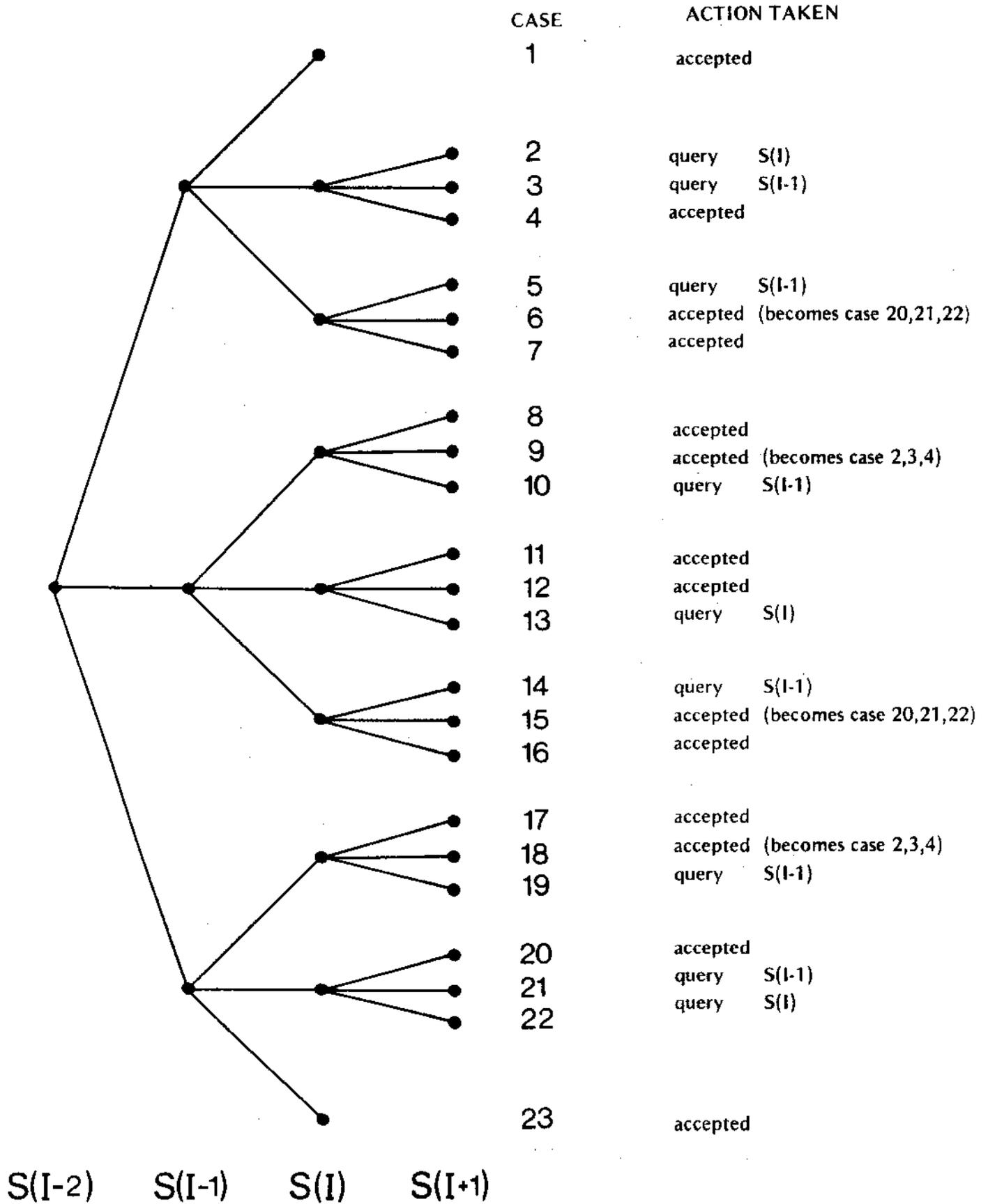


Points 9 and 20 show improbable departures from the trend which should be queried by the The Quality Control routine.

Figure 6

FLOW - QUALITY CONTROL

Action taken in the trend test



case, a maximum acceptable error has been introduced into the routine. When the step or other spurious departure from the trend is less than NDIFF, it is ignored.

The most important individual stage values are those defining peaks in the hydrograph. An error due to punching or misreading of the chart, which led to a gross overestimate of the peak stage, could not be detected by the trend test as the trend would not be altered by the error. Thus an additional test has been included. The maximum stage of the month is determined manually and entered on the CONTROL CARD. All stages for that month are checked to ensure that they lie between zero and this maximum value. The test is not foolproof although it does go a considerable way towards ensuring accuracy in the monthly peak stages.

The sequence of checks in the full QUALITY CONTROL routine is given by Table 3.6.1 and the nomenclature used in the routines is given by Table 3.6.2. Finally an example of an output listing is shown by Table 3.6.3. This shows most of the diagnostics which can be produced by the routine. In practice the output also contains a full listing of the input data to facilitate manual checking of the suspect points.

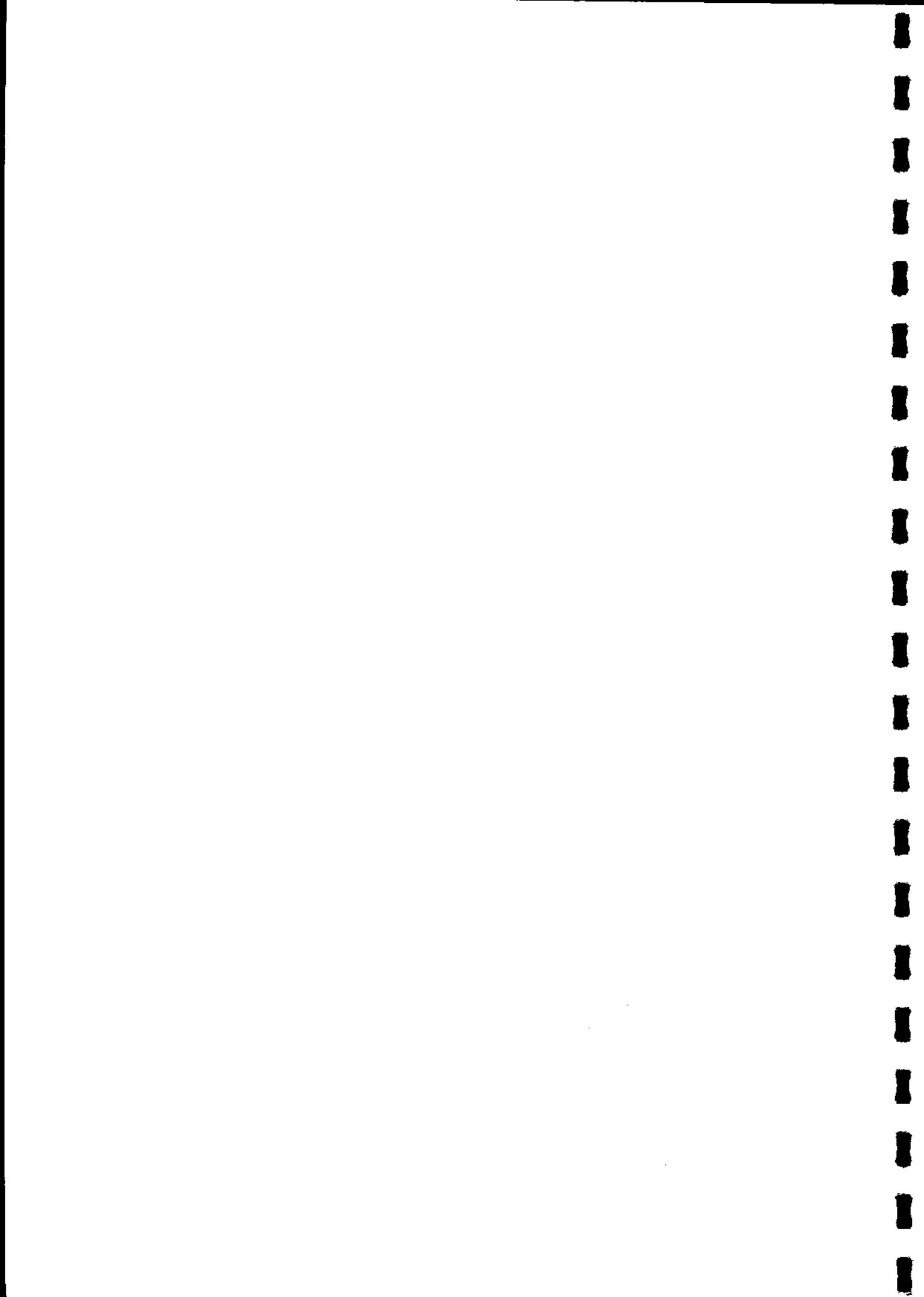
TABLE 3.6.1 FLOW QUALITY CONTROL
Sequence of the quality control checks

	Subroutine
1. Read number of months and error tolerance	MASTER
2. Read CONTROL CARD	FLQC1
3. Display control information and error tolerance	FLQC1
4. Test CONTROL CARD label	TYPEST
5. Test compatibility of input/output frequencies	FLQC1
6. Read INITIAL DATA CARD if appropriate	FLQC1
7. Test INITIAL DATA CARD label	TYPEST
8. For each day of the month	
a. Read the stage values, 12 per card	FLQC1
b. Test DATA CARD label(s) including card number	TYPEST
c. Test that all stages are less than the maximum for month, SMAX	MAXS
d. Test that all stages are greater than zero	MAXS
e. Test the continuity of stage values (trend test)	STAGE
9. Is the data consistent for the month?	FLQC1

TABLE 3.6.2 FLOW-QUALITY CONTROL
Nomenclature used in the quality control routine

NDIFF	error tolerance on stage values
ABB	absolute difference between successive stage values
S, SN or S1	stage

see also Table 3.3.1 for the list of FLOW CONTROL CARD symbols.



CATCHMENT NO. 2
AREA 1926.1
ZERO CORRECTION 0.
HIGHEST STAGE (DISCHARGE) 324.
INTERPOLATION INDEX 2
DATA TYPE 1
INPUT FREQUENCY INDEX 1
OUTPUT FREQUENCY INDEX 3
UNITS INDEX 1
NUMBER OF DAYS 31
MONTH AND YEAR 1963

STAGE ERROR TOLERANCE 2

21063 CHECK STAGE NO. 4 IS 191. NO. 5 IS 119.

21063 CHECK STAGE NO. 6 IS 191. NO. 7 IS 191.

31063 *** 2 - DATA TYPE SHOULD BE 1

41063 CHECK CARD NO.

51063 *** 3 - CATCHMENT NO. SHOULD BE 2

71063 *** 51063 - DATE SHOULD BE 71063

71063 MAXIMUM VALUE 325, GREATER THAN GIVEN MAX.

81063 *** 81163 - DATE SHOULD BE 81063

91063 *** 91073 - DATE SHOULD BE 91063

101063 CHECK CARD NO.

101063 ***111063 - DATE SHOULD BE 101063

111063 CHECK CARD NO.

101063 CHECK STAGE NO. 72 IS 225. NO. 73 IS 222.

111063 CHECK CARD NO.

151063 CHECK CARD NO.
151063 ***161063 - DATE SHOULD BE 151063
161063 CHECK CARD NO.
161063 ***171063 - DATE SHOULD BE 161063

QUALITY CONTROL FOR THE MONTH ABANDONED
EXECUTION ERROR 105 PROGRAM TERMINATED

3.7 MAIN PROCESSING

This program takes as input the quality-controlled data from the basic data tape. The purpose of the program is threefold:

- conversion of the data to metric units
- conversion of stage to discharge
- integration of discrete discharge data to total runoff expressed as a depth over the catchment area.

The output to the processed data tape is in a standard format where the only variation allowed is in the time interval of the runoff values. This is controlled by the index, JFREQ, on the CONTROL CARD.

The sequence of steps in the program is listed in Table 3.7.1 and the nomenclature used is defined in Table 3.7.2. The change of units is carried out by multiplying the data values by a factor, UNIT, which corresponds to the INDEX on the CONTROL CARD. These values are also listed in Table 3.7.2.

The appropriate calibration table is read from the beginning of the processed data tape (as described in section 6) before the program is initiated. Conversion from stage to discharge is then a simple matter of taking from store the n^{th} discharge value when n is the stage in mm.

Details of the output to processed data tape and the manner in which data are held in storage is largely a function of the computer hardware and these points are covered in section 6.

TABLE 3.7.1. FLOW - MAIN PROCESSING

Sequence of operations

	Subroutine
1. Read the number of months to be processed	MASTER
2. Read the CONTROL CARD(S)	FLOW
3. Write the CONTROL CARD(S) onto processed data tape	FLOW
4. For each day of the month:	
a. read ME stage values, 12 values per card	FLOW
b. apply the ZERO correction	FLOW
c. interpolate for mid-interval values if necessary	FLOW
d. convert data to metric units (mm)	FLOW
e. convert stages to discharges if necessary	FLOW
f. integrate the discharges over the time interval and divide by the catchment area to give runoff as a depth over the catchment	FLOW
g. combine runoff values as necessary to give correct output frequency (MF values/day)	FLOW
h. write runoff data to processed data tape	FLOW

TABLE 3.7.2 FLOW - MAIN PROCESSING

Nomenclature and values of UNIT used in subroutine FLOW

S	-	stage
Q	-	discharge (volume/unit time)
RUN	-	runoff (depth over catchment area)
UNIT	-	conversion constant for change of units (see below)
ME	-	number of values per day input
MF	-	number of values per day output
MRAT	-	the ratio ME/MF
ZERO	-	the zero correction to the stage data

See also Table 3.3.1 for the list of FLOW CONTROL CARD symbols.

INDEX	Units of original data	UNIT
1	feet x 10 ⁻³	0.3048
2	mm	1
3	in ³ /hour x 10 ⁻⁵	special case*
4	feet x 10 ⁻²	3.048

* in this case the original data have units of discharge

SECTION 4

RAINFALL

- 4.1 Introduction
- 4.2 Input data
- 4.3 Control information
- 4.4 Preprocessing
- 4.5 Network tables
- 4.6 Quality control
- 4.7 Main processing

All program listings will be found in Appendix A which is published separately.

4.1 INTRODUCTION

The purpose of this rainfall data processing scheme is to estimate average basin rainfall over the shortest time intervals consistent with the accuracy of the instrumentation and the requirements of the subsequent analysis. Of necessity, rainfall must be sampled at a network of points in the catchment and, since it is not usually practicable to locate automatic recording gauges at all sites, it is usual to collect data which refer to various time intervals.

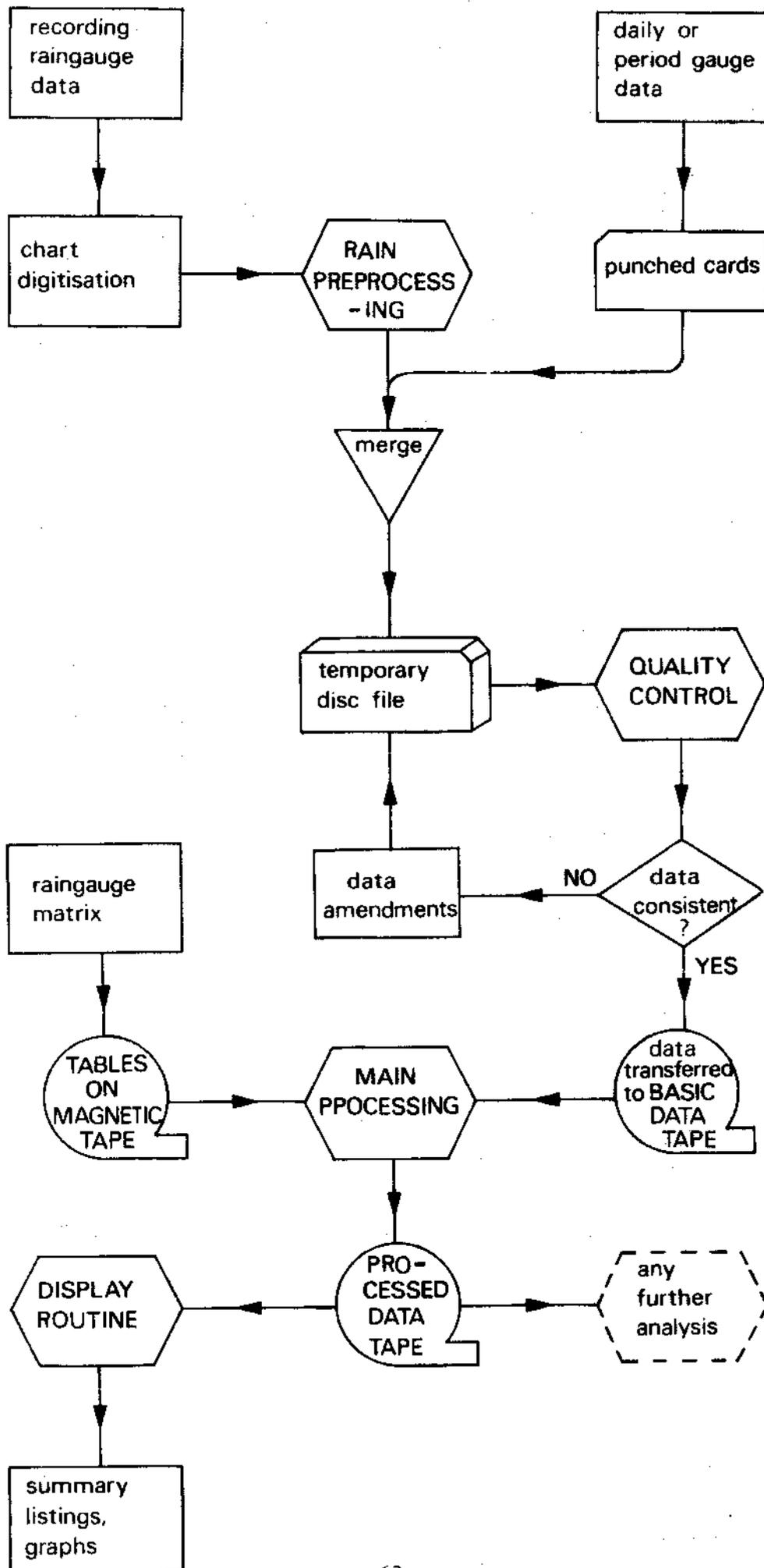
Thus the difficulties in defining the processing scheme are two-fold. There must be a flexible method of combining point measurements into a basin average which allows for missing data and changes in network. Also the method must be flexible enough to deal with records taken at time intervals from say one hour to a month or more.

In practice it is the latter criterion which has governed the form of the rainfall processing programs as it was considered desirable to have only one program which could deal with all situations rather than several programs, one for each situation. This should greatly simplify subsequent operation.

The first step is to classify the raingauges according to their data time interval. Three categories are sufficient:

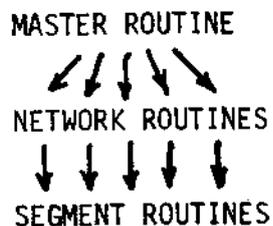
PERIOD gauges
DAILY gauges
RECORDING gauges

The DAILY gauges are read at 09.00 GMT (or the equivalent local time) each day and this has led to the definition of the start of a day as 09.00 GMT within the processing system as a whole. PERIOD gauges should also be read at 09.00 GMT but their data refer to a period of any length. In practice the time intervals tend to be 7 or 14 days or a calendar month. RECORDING gauges are defined as any



gauges which can indicate sub-daily rainfalls to a maximum frequency of 96 readings per day.

For all networks comprising one or more of these types of gauges many of the computations are common. Thus the overall scheme for both QUALITY CONTROL and PROCESSING can be built up as a composite program of the following form:



The MASTER ROUTINE will read the CONTROL information and select the appropriate NETWORK ROUTINE which will call those SEGMENT ROUTINES required for the particular network. This break-down is described in detail in the following sections.

One further problem should be mentioned at this stage. Instrument failure tends to be most common with RECORDING gauges. Clearly it is difficult to distribute in time a bulked record from a PERIOD gauge if the RECORDING gauge record is incomplete. Also there could well be a significant loss of information if all incomplete records were scrapped and only complete records from fewer RECORDING gauges were used to govern the time distribution. The logical approach would seem to be through a PREPROCESSING program designed to produce a synthetic RECORDING gauge record which was derived from all the information available, both incomplete and complete records. However, such a program is not yet included in the system.

An overall sequence diagram for the processing scheme is shown in Figure 7.

4.2 INPUT DATA

The main problem encountered in devising a system for the arrangement of rainfall data was that of continually describing the operational network. There are two reasons for this. Firstly a computer must be told in advance what it is to read so that predetermined DATA CARD formats can be used. Secondly it is inefficient to include DATA CARDS which do not contribute additional information to the system. This is particularly relevant when dealing with RECORDING gauge data when for long periods there may be no recorded rainfall. If a simple symbol or index can indicate zero rain for the day, the number of cards required can be considerably reduced.

The system is further complicated by the need to deal with a mixed set of data from the combination of PERIOD, DAILY and RECORDING gauges. In practice it is inefficient in computer storage to read a whole month's data into core before processing can begin. It is much more desirable to be able to process the data for one day before reading the data for the next. Thus all the required information should be presented sequentially, the data from each type of gauge being merged as appropriate.

In the resulting system each data card carries two symbols designated ISYM and KSYM on PERIOD or DAILY gauge data cards and JSYM and LSYM on RECORDING gauge data cards. The use of these symbols depends to some extent on the network and the specific rules attached to each symbol is described in detail below. However, before dealing with that it is necessary to describe the format of the data cards themselves.

In general the data are always entered in the order PERIOD data, DAILY data, RECORDING data, that is, from the longest to the shortest time interval of the data. The PERIOD or DAILY data cards have the format shown in Table 4.2.1. The data on each card, or set of up to three cards, depending on the number of gauges,

refer to a round of observations at all gauges at the same time. The data can be entered in any order in terms of the gauge numbers but this order must subsequently be strictly maintained through the month and it is defined on the AREA cards described in section 4.3. Each card carried the usual label and a card number when more than one card is necessary to complete the data set.

The RECORDING gauge cards have the format shown in Table 4.2.2 but in this case the data comprising a set refer to a single gauge, there being up to 96 observations per day depending on the input frequency. When there is more than one RECORDING gauge, the data sets are assembled in order following the PERIOD or DAILY gauge data cards. Again each card carries the usual label information together with a card number which refers only to the set of cards for that gauge, not for all gauges for a day.

The DAILY or PERIOD gauges are numbered in an arithmetic sequence; a limiting dimension of 30 has been written into the programs. It is unlikely that this will be exceeded in the usual scale of catchment experiments. If it is, however, some adjustment of the program is necessary. The RECORDING gauges are numbered in a geometric sequence 1, 2, 4, 8 etc. so that the sum of the gauge numbers completely described the network of operational RECORDING gauges. For example a sum of 10 would indicate that gauges 2 and 8 were operating as no other combination can sum to 10.

This leads directly to the use of the symbol system. JSYM on the RECORDING gauge data card is always the RECORDING gauge number. The sum of the JSYM values for the gauges operational on a given day is entered as ISYM on the DAILY gauge data card. Consequently when the DAILY gauge data card is read, it is possible to define exactly how many RECORDING gauge data cards follow. Where there are no DAILY gauge data cards the value ISYM on the PERIOD gauge data card is the sum of all the JSYM values for the whole period before the next PERIOD gauge is read. If in either case ISYM = 0, this indicates that

there is no rain in the day or period and all RECORDING gauge data cards are omitted. If ISYM = -1, this indicates that all recording gauges were out of service and that the rainfall must be distributed in time in some other way, such as an average over the day or period.

When there are no DAILY gauges a further symbol is required on the RECORDING gauge cards to determine the number of cards which need to be read in each day of the period. Thus the symbol LSYM fulfils the purpose of ISYM on the DAILY cards. It is the sum of RECORDING gauge symbols (JSYM) for the day and it is entered on the first card of the day only. This symbol can take the value 0 or -1 with the same meaning as for ISYM on the DAILY gauge data cards.

The final symbol KSYM is used on PERIOD gauge data cards only and indicates the number of days in the period, or the number of days in the period before the end of the month, whichever is the shorter. When a period extends into the following month, the PERIOD gauge data card is repeated verbatim as the first data card of the new month except the KSYM is adjusted to indicate the number of days remaining in the period. In the rare case when the period completely spans a month and includes parts of the month on either side then KSYM would be the number of days in the month on the data card for the middle month.

To make the interpretation of the rules governing the symbol system as clear as possible, Table 4.2.3 and 4.2.4 show examples for both the network situations for which the QUALITY CONTROL and MAIN PROCESSING programs have been written. Sample listings of a month's batch of data for networks comprising PERIOD and RECORDING gauges, and DAILY and RECORDING gauges are shown in Tables 4.2.5 and 4.2.6 respectively.

TABLE 4.2.1 RAIN - INPUT DATA

Data card format for PERIOD or DAILY gauges

Item	Symbol	Format	Columns	Units and remarks
Period or daily gauge data	PR or DR	F5.0	1-60	12 values per card
Data type	ITYPE	I1	62	always 2
Symbol 1	KSYM	I3	63-65	see notes on symbols in text
Card number	ICARD	I3	66-68	
Symbol 2	ISYM	I3	69-71	
Catchment number	ISITE	I3	72-74	
Day of month	IDAY	I2	75-76	
Month and year	IMONTH	I4	77-80	

Notes: when there are more than 12 gauges, further DATA cards are required. These should be in the same format. ICARD is used to ensure the correct sequence of DATA cards.

The units of the data are defined by INDEX on the CONTROL CARD, see section 4.3.

TABLE 4.2.2 RAIN - INPUT DATA

Data card format for RECORDING gauges

Item	Symbol	Format	Columns	Units and remarks
Recording gauge data	R	F5.0	1-60	12 values per card ME values per day
Data type	ITYPE	I1	62	always 2
Symbol 3	LSYM	I3	63-65	see notes on symbols in text
Card number	ICARD	I3	66-68	
Symbol 4	JSYM	I3	69-71	
Catchment number	ISITE	I3	72-74	
Day of month	IDAY	I2	75-76	
Month and year	IMONTH	I4	77-80	

Notes: When there are more than 12 readings per day, further DATA cards are required. These should be in the same format. ICARD is used to ensure the correct sequence of DATA cards.

The units of the data are defined by INDEX on the CONTROL CARD, see section 4.3.

TABLE 4.2.3 RAIN - INPUT DATA

Example of symbol system for a network comprising
DAILY and RECORDING gauges

For the 6 days shown in this example:

- a. there was rain on all days except day 3
- b. there are potentially 3 recording gauges numbered 1, 2 and 4
- c. no recording gauges operate on day 5.

DAY	OPERATIONAL RECORDING GAUGES	CARD SEQUENCE	ISYM	JSYM
1	1, 2 and 4	D R1 R2 R4	7	1 2 4
2	1 and 2	D R1 R2	3	1 2
3	1 and 4	D	0	
4	4	D R4	4	4
5	none	D	- 1	
6	2 and 4	D R2 R4	6	2 4

Note that D and R1 etc. represent a set of data cards where either the number of DAILY gauges or the number of time intervals per day require more than one card.

All cards carrying no useful information are omitted from the sequence. It would not be permissible, for example, to enter RECORDING gauge data cards on day 3.

Both KSYM and LSYM are not required and should be left blank.

TABLE 4.2.4 RAIN - INPUT DATA

Example of symbol system for a network comprising PERIOD and RECORDING gauges

For the 7 days shown in this example:

- a. a period starts on day 1, day 7 and 17
- b. there are potentially 3 recording gauges numbered 1, 2 and 4
- c. there is rain on all days except day 3

DAY	OPERATIONAL RECORDING GAUGES	CARD SEQUENCE	ISYM	KSYM	JSYM	LSYM
1	1, 2 and 4	P R1 R2 R4	22	6	1 2 4	7
2	1 and 2	R1 R2			1 2	3
3	1 and 4	R1			1	0
4	4	R4			4	4
5	none	R1			1	0
6	2 and 4	R2 R4			2 4	6
7	2 and 4	P R2 R4		10	2 4	6

Note that P and R1, etc., represent a set of data cards where either the number of period gauges or the number of time intervals per day require more than one card.

All cards carrying no useful information are omitted from the sequence. It would not be permissible to enter card R4 on day 3 for example.

In this case (in contrast to the previous example) it is not possible to say from the data presented whether it rained on day 5. Unless there is evidence to the contrary it must be assumed that no rain fell and day 5 takes the same form as day 3.

4.3 CONTROL INFORMATION

For rainfall data, the control system is complicated by the need to describe adequately the characteristics of the gauge network. The control data to be specified can be classified as follows:

1. Normal catchment information, data type and frequency and units indices, network index and data label.
2. Details of the numbers of possible and operational gauges.
3. Details of the CHECK gauges (defined below) when RECORDING gauges are present in the network.
4. Weighting factors for basin rainfall estimates.
5. Order in which the data are punched on the PERIOD or DAILY data cards.
6. Other day to day information on operational recording gauges.

The items 1 to 3 above appear on the main CONTROL CARD and its format is given in Table 4.3.1. Items 4 and 5 above appear on cards immediately following the main CONTROL card. These cards, termed AREA cards because the weighting factors are expressed in terms of the area which a gauge may be considered to represent, have a format given by Table 4.3.2. The information must be punched in the same order during processing. The information concerning day to day operation, item 6 above, must be on the DATA cards and this has been described fully in the previous section.

The network index, INET, follows from the classification of the instrument network discussed in the introduction to this section. With three types of gauge, there must be 7 alternative network routines. However, it is convenient to use this index to allow for the situation where gauges are not read at the proper time for some reason. Thus the final list defined in Table 4.3.3 has 8 possible networks. The case of PERIOD gauges only has been deleted as it is a trivial case in the research context. Table 4.3.3 also shows which NETWORK routines are used in processing data from the various networks.

Consistency in the order of the data on the DATA cards and the order of the weighting factors on the AREA cards are of critical importance.

The accuracy of the resulting processed data depends on the correct order being kept. No automatic checks are possible. DAILY and PERIOD gauges are identified by numbers in an arithmetic sequence normally starting at 1 and these numbers are entered on the AREA cards with the weighting factors in the same order as the data are entered on the DATA cards.

It is good field practice to site a storage type gauge, which may be a DAILY or a PERIOD gauge, next to each RECORDING gauge. This gauge is termed a CHECK gauge and allows a check on the overall total catch in the RECORDING gauge which might be over-exposed, inaccurate or unreliable in operation. To allow suitable automatic checking in the QUALITY CONTROL routine, the CHECK gauge numbers corresponding to the RECORDING gauge numbers are entered on the CONTROL card.

The frequency of input data, IFREQ, refers to the data time interval of the RECORDING gauges. The index is defined in Table 2.2.1. The output frequency, JFREQ, could be the same as the input frequency although if timing errors are significant, this can be allowed for by setting a more realistic level for the output frequency.

The ground level factor, GLF, allows adjustment to be made for the height of raingauges above ground level, if it is found that gauges mounted at a standard height of say 1 foot are consistently under-estimating the true ground level catch. Necessarily this index must be fixed by preliminary analysis.

TABLE 4.3.1 RAIN - CONTROL INFORMATION
Control card Format

ITEM	SYMBOL	FORMAT	COLUMN	UNITS AND REMARKS
Catchment area	AREA	F10.1	1-10	hectares
Possible number of recording gauges	NRG	I2	11-12	
Recording gauge symbol	IRG(I)	I3	} 13-48	up to 6 pairs of values can be entered
Check gauge number	NRGG(I)	I3		
Ground level factor	GLF	F4.2	49-52	
Possible number of period gauges	IPOSP	I2	53-54	IPOSP and IPOSD should be the maximum values for which the network table is prepared
Actual number of period gauges	IACTP	I2	55-56	
Possible number of daily gauges	IPOSD	I2	57-58	
Actual number of daily gauges	IACTD	I2	59-60	
Data type	ITYPE		62	always 2
Network Index	INET	I2	64-65	See table 4.3.3
Input frequency	IFREQ	I2	66-67	
Output frequency	JFREQ	I2	68-69	
Units Index	INDEX	I2	70-71	1=inches x 10 ⁻² 2=mm x 10 ⁻¹
Catchment number	ISITE	I3	72-74	
No. of days in month	IDAYS	I2	75-76	
Month and year	IMONTH	I4	77-80	

TABLE 4.3.2 RAIN - CONTROL INFORMATION
Area card format

	SYMBOL	FORMAT	COLUMNS	UNITS AND REMARKS
PERIOD or DAILY gauge number Areal weighting	IPG or IDG PAREA or DAREA	I3 F7.1		Up to 6 pairs of values per card. Areal weightings have the unit hectares. Gauges must be in the same order as on the data cards.
Data type	ITYPE	I1	62	always 2
Card number	ICARD	I3	66-68	
Catchment number	ISITE	I3	72-74	
Month and year	IMONTH	I4	77-80	

If there are more than 6 gauges, further AREA cards are required. These should be in the same format. ICARD is used to ensure the correct sequence of AREA cards.

TABLE 4.3.3 RAIN - CONTROL INFORMATION

Definition of the Network Index

INET	Types of gauge RECORDING	present in DAILY	the network PERIOD	Appropriate NETWORK routine
1	✓			
2	✓	✓		RAIN2
3	✓	✓ *		RAIN2
4	✓		✓	RAIN3
5	✓		✓ *	
6	✓	✓	✓	
7		✓		
8		✓	✓	

* indicates that correction must be made during PROCESSING for readings not taken at the standard time on some days of the month.

Where a NETWORK routine is not indicated above, an appropriate routine is not yet included in the system available.

4.4 PREPROCESSING

The output from RECORDING gauges is often in the form of a cumulative trace on a strip chart. The abstraction of data from such charts can be automated by using the equipment described in Sections 2.3 and 3.4. The program referred to in that section has been extended to produce as output the RECORDING gauge data in the format acceptable to this processing program. Reference should be made to the detailed report (Douglas, 1972) for full details of the procedure.

4.5 NETWORK TABLES

The processing program calculates average areal rainfall in a given time interval from data from a network of gauges comprising RECORDING and DAILY or PERIOD gauges. The procedure followed is described in section 4.7 where it is explained that it is necessary to know which RECORDING gauge is nearest to any DAILY or PERIOD gauge for any operational pattern of RECORDING gauges.

It will be remembered that the operational network of RECORDING gauges can be described by a single number, the sum of the gauge symbols (section 4.2). Thus a two-dimensional matrix can be defined which will give the symbol of the nearest RECORDING gauge given the sum of all RECORDING gauge symbols (ISYM on a DAILY gauge card, LSYM on a PERIOD gauge card) and the DAILY or PERIOD gauge number. Table 4.5.1 shows an example of the matrix. The matrix is devised by hand from a map of the catchment and it should allow for all possible combinations of RECORDING gauges operating. It is then stored at the beginning of the processed data tape.

The formats of the data cards which make up the matrix are given in Tables 4.5.2 and 4.5.3. The first card defines the dimensions of the matrix. Subsequent cards, one for each of the daily or period gauges in order starting from 1, give a list of the nearest operational recording gauge for all possible values of the sum of recording gauge symbols, again starting from 1. The Tables 4.5.2 and 4.5.3 show examples of the data cards that would be appropriate to the network shown in Table 4.5.1.

As the programs are written, the matrix, $M(I, ISYM)$, has maximum dimensions of (30, 63). That is, up to 30 DAILY or PERIOD gauges and up to 6 RECORDING gauges are allowed. The matrix is used in SEGEMENT routine SUMAR.

TABLE 4.5.1 RAIN - NETWORK TABLES

An example of the MATRIX table for the network illustrated on the catchment map shown below.

Sum of RECORDING gauge symbols	DAILY or PERIOD gauge number				
	1	2	3	4	5
1	1	1	1	1	1
2	2	2	2	2	2
3	1	2	2	2	2
4	4	4	4	4	4
5	1	1	4	1	4
6	2	2	2	2	4
7	1	2	2	2	4

Note: the number in the table is the symbol of the nearest recording gauge given the network defined by the sum of recording gauge symbols.

- RECORDING gauge
- DAILY or PERIOD gauge

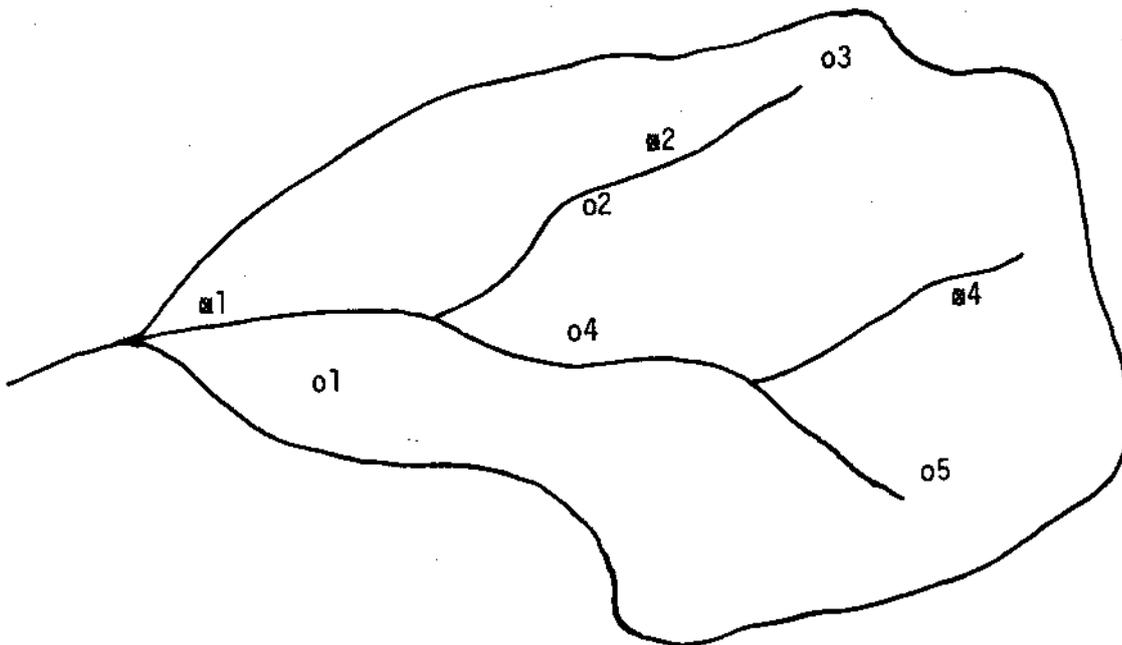


TABLE 4.5.2 RAIN - NETWORK TABLES

Main data card format

Item	Symbol	Format	Columns	Remarks
Catchment Number	ISITE	I0	-	Free format
Possible number of Daily or Period gauges	NY	I0	-	"
Sum of all recording gauge symbols	NX	I0	-	"

Note: For the network illustrated in Table 4.5.1, this data card would be:

ISITE 5 7

TABLE 4.5.3 RAIN - NETWORK TABLES

Network data card format

Item	Symbol	Format	Columns	Remarks
List of nearest operational RECORDING gauges	M	IO	-	Free format. New card for each daily or period gauge

NOTES: There must be as many cards (or sets of cards if the sum of RECORDING gauge symbols exceeds 8) as the number of the highest numbered DAILY or PERIOD gauge.

These cards (or sets of cards) must be entered in order starting from 1.

For the example illustrated in Table 4.5.1, the data cards would be:

1	2	1	4	1	2	1
1	2	2	4	1	2	2
1	2	2	4	4	2	2
1	2	2	4	1	2	2
1	2	2	4	4	4	4

4.6 QUALITY CONTROL

Rainfall can be highly variable in both time and space especially over short periods. This makes quality control in the sense of determining individual erroneous gauge readings extremely difficult. Recent studies in the field of surface fitting (Mandeville and Rodda, 1970) suggest that some progress will be made in the future towards identifying gauge errors. Meanwhile, the quality control program described here is used to test for data consistency and completeness and for errors of transcription from original records. There can be no automatic checks against mistakes such as the wrong identification of a gauge in the field or records entered under the wrong date in the field. Such mistakes often come to light following subsequent analysis and it is clear that further safeguards are necessary at an early stage in the quality control in order to avoid time consuming retrospective corrections.

The sequence of operations in the QUALITY CONTROL program is shown in Table 4.6.1 and the nomenclature used in the routines is defined in Table 4.6.2.

Most of the tests are self-evident and follow from the gauge numbering and symbol system described in the previous sections. In Table 4.6.1 and in the description of the MAIN PROCESSING program it is convenient to refer to DAILY and PERIOD gauges as STANDARD gauges, as the programming of the routines to read these data and apply the quality control tests is the same. The important difference lies in the frequency in which the STANDARD gaugesubroutine must be called and this is controlled by the network routines RFQCI, RFQC2 etc, acting on the index INET and the symbol indicating the number of days between PERIOD gauge readings.

The main checks for transcription errors use the displayed cumulative totals. For STANDARD gauges, the total in all gauges for each day and the total for each gauge for the month is displayed, enabling an easy check for error against the totals entered on the field sheets. Similarly the recording gauge totals for the month

should be checked against the original record. This is particularly easy for those gauges which exhibit a cumulative trace on a chart.

An example of the output from the QUALITY CONTROL program is shown in Table 4.6.3.

TABLE 4.6.1 RAIN - QUALITY CONTROL
Sequence of the quality control checks

	Subroutine
1. Read number of months to be controlled	MASTER
2. Read and check LEAD CARD	MASTER
3. Read CONTROL CARD	RAINQC
4. Display control information	RAINQC
5. Test CONTROL CARD label	RAINQC
6. Read AREA CARD(S)	RAINQC
7. Test AREA CARD label(s)	RAINQC
8. Test that all AREA CARDS have been read	RAINQC
9. Test that sum of areas is equal to catchment area	RAINQC
10. Transfer control to appropriate network routine which calls the segment routines for the following tests in the correct order.	
11. For each day of the month:	
a. Read the standard gauge amounts	SGRQC
b. Test the label on the standard gauge cards	SGRQC
c. Test for zero rainfall	SGRQC
d. Test standard gauge card symbol	SGRQC
e. Test order of standard gauge cards	SGRQC
f. Test that all standard gauge cards have been read	SGRQC
g. Compute cumulative totals of all gauges for the day	SGRQC
h. Compute cumulative total for each gauge	SGRQC
i. Test whether recording gauges operating	RFQC1, RFQC2
j. Read recording gauge amounts	RGRQC
k. Test the label on the recording gauge cards	RGRQC
l. Test the recording gauge symbol	RFRQC
m. Compute recording gauge daily total	RFRQC
n. Check this against the check gauge total	RFRQC
o. Test that correct number of recording gauge cards have been read	RGRQC
12. Test for the end of the month	RFQC1, RFQC2
13. Display cumulative totals for each standard gauge	RFQC1, RFQC2
14. Display totals of standard gauge amounts for each day	RFQC1, RFQC2
15. Display monthly total for each recording gauge	RFQC1, RFQC2

TABLE 4.6.2 RAIN - QUALITY CONTROL
Nomenclature used in the routines

RGM	Monthly cumulative total in recording gauge
SVR	Monthly cumulative total in daily or period gauge
SHR	Day's total in all daily or period gauges
IS	Running total of recording raingauge symbols
LS	Running total of number of recording raingauges read
ISS	Running total of ISYM values
DRE	Daily rainfall in extended array
PRE	Period rainfall in extended array
SRR	Cumulative total in recording gauge over period

See also Tables 4.2.1, 4.2.2, 4.3.1, 4.3.2

CATCHMENT NO. 2
AREA 1856.1
NO. OF RECORDING GAUGES 3
SYMBOL OF RECORDING GAUGE 1 NO. OF RECORDING CHECK GAUGE 23
SYMBOL OF RECORDING GAUGE 2 NO. OF RECORDING CHECK GAUGE 14
SYMBOL OF RECORDING GAUGE 4 NO. OF RECORDING CHECK GAUGE 2
GROUND LEVEL FACTOR 0.00
POSSIBLE NO. OF PERIOD GAUGES 0
ACTUAL NO. OF PERIOD GAUGES 0
POSSIBLE NO. OF DAILY GAUGES 25
ACTUAL NO. OF DAILY GAUGES 16
DATA TYPE 2
NETWORK INDEX 2
INPUT FREQUENCY 3
OUTPUT FREQUENCY 3
UNITS INDEX 1
DAYS IN MONTH 31
MONTH AND YEAR 1063

SUM OF AREAS NOT EQUAL TO TOTAL AREA AS PUNCHED ON THE CONTROL CARD

21063 CHECK SYMBOLS ON STANDARD GAUGE CARDS

51063 RECORDING GAUGE CARD NO. 2 READS 1 CHECK ORDER

81063 *** 1 = CATCHMENT NO. SHOULD BE 2

131063 ***141063 = DATE SHOULD BE 131063

151063 ***151103 = DATE SHOULD BE 151063

161063 ***161073 = DATE SHOULD BE 161063

191063 TOTAL RAIN 10. IN RECORDING GAUGE 1 NOT EQUAL TO TOTAL RAIN 1. IN STANDARD GAUGE 23

301063 *** 1 = DATA TYPE SHOULD BE 2

301063 CHECK SYMBOLS ON RECORDING GAUGE CARDS

301063 TOTAL RAIN 7. IN RECORDING GAUGE 2 NOT EQUAL TO TOTAL RAIN 17. IN STANDARD GAUGE 14

301063 TOTAL OF SYMBOLS ON RECORDING CARDS NOT EQUAL TO SYMBOL ON STANDARD CARD

QUALITY CONTROL FOR THE MONTH ABANDONED

4.7 MAIN PROCESSING

The processing program has two main functions; firstly it must compute an average basin rainfall from the point rainfall data and secondly, it must distribute this rainfall in time according to the distribution given by the recording gauges.

There is no perfect method for obtaining the mean basin rainfall. Techniques such as simple averaging or the Thiessen polygon method are widely used but are based on assumptions which are not always justifiable in practice. More sophisticated methods which involve the fitting of polynomial surfaces to the data points, are being developed though, as yet, their value is limited to the study of monthly or annual rainfalls. Clearly the choice of the best method in each catchment area must take account of the density of the gauge network and its distribution with respect to altitude or other significant characteristics of the catchment. In this program it has been assumed that each gauge can represent a characteristic area of the catchment and this area becomes the weighting factor for the gauge. Clearly these areas can be taken to be equal for each gauge (equivalent to simple averaging) or to be the Thiessen areas, or to be any other form of weighting which can be determined *a priori*.

Unfortunately the time distribution problem is even more arbitrary. It is not easy to demonstrate whether it is better to distribute the rainfall in time for each standard gauge (by reference to the nearest recording gauge) before computing the average basin rainfall or whether the distribution should be carried out on the average basin rainfall according to some average time distribution given by all recording gauges. This program follows the first of these alternative methods, time distribution being carried out before areal integration.

Although a single program, RAIN, has been written to accept any network situation through the arrangement of MASTER, NETWORK and SEGMENT routines (described in section 4.1), the program is best described separately for each NETWORK routine, through the use of sequence tables. The following tables describe the function of the routines currently in operation:

Table	4.7.1	MASTER	routine RAIN
	4.7.2	NETWORK	routine RAIN2
	4.7.3	NETWORK	routine RAIN3
	4.7.4	SEGMENT	routine SGRAIN
	4.7.5	SEGMENT	routine RGRAIN
	4.7.6	SEGMENT	routine SUMAR

These Tables should be read in conjunction with the program listings in Appendix A for a full explanation of the computational procedure.

NETWORK routine RAIN3 is a special case of RAIN2 in that it allows for the situation where through negligence or because of difficulty of access, the DAILY gauges are not read at 09.00 hours each day. The method of calculation is illustrated by an example shown in Table 4.7.7, which shows a 6-hourly record from the RECORDING gauge. However, in the period of three days the CHECK gauge and a remote STANDARD gauge (both nominally DAILY gauges) are read early by 6 hours on day two and late by the same amount on day three.

The RECORDING gauge record is transformed by division by the CHECK gauge reading in the usual way except that this CHECK gauge reading allows for the carry over of any rainfall not distributed in the previous day. Thus on day two the corrected CHECK gauge total is 110, i.e. 125 minus 15; in this case the 'carry over' is negative. In the same way the STANDARD gauge rainfall total to be distributed between 6-hour periods is corrected by any amount of carry over from the previous day. The procedure continues until the DAILY gauges are again read at 09.00 hours when the 'carry over' will be zero.

If there is 'carry over' at the end of the month, computation will continue correctly provided the next month's data are processed in the same run and provided there has not been any change in the DAILY gauge network. In the case where there is a change, the errors introduced will be small if the network change is relatively minor. In order to remove spurious 'carry over' amounts following network changes, the 'segment' routine TESTER will put all 'carry over' values, ER(I), to zero if all CHECK GAUGE carry over values, ER(NRGC(L)), are zero.

TABLE 4.7.1 RAIN - MAIN PROCESSING

Sequence of MASTER routine RAIN

1. Read the CONTROL CARD.
(Stop if INET is not in range for which routines are available).
2. Read the AREA CARD(S).
3. Write the CONTROL and AREA CARDS to the processed data tape.
4. Convert rainfall units to mm if necessary by applying a factor to the areas, DAREA or PAREA.
5. Interpret input frequency index, IFREQ, to give ME values per day.
6. Call the appropriate NETWORK routine, RAIN2 or RAIN3.

Note: In some cases a CHECK gauge will have an areal weighting of zero. Although this is permissible the value is changed to 0.0001, a negligible quantity, to avoid possible exponent overflow during computing.

TABLE 4.7.2 RAIN - MAIN PROCESSING
Sequence of Network routine RAIN2

1. For each day of the month:
 - a. Call SEGMENT routine SGRAIN to read DAILY rainfall at each gauge.
 - b. Set the areal rainfall store for each of ME time intervals to zero.
 - c. If there is no rain (ISYM = 0); go to h.
 - d. If there is rain in a daily gauge but not in a recording gauge (ISYM = - 1), distribute the rainfall between time intervals arbitrarily, using SEGMENT routine DIURNC
 - e. Set the cumulative count for RECORDING gauges to zero (JJSYM)
 - f. For each recording gauge;
 - i. call SEGMENT routine RGRAIN to read the rainfall in each time interval at the RECORDING gauge and calculate the proportion of the days total at that gauge which fell in each time interval.
 - ii. call SEGMENT routine SUMAR to identify which DAILY gauge totals should be distributed in time according to this RECORDING gauge record; calculate the increment to the areal total for each time interval and add to cumulative stores. The areal weighting is carried out at this time.
 - iii. Test that all RECORDING gauges have been read by comparing the sum of the JSYM values to the ISYM value.
 - g. Divide the results by the total catchment area (AREA).
 - h. Write result to the processed data tape.

Note: The use of SEGMENT routine TESTER at the end of this NETWORK routine is described in the text for the special case when INET = 3.

TABLE 4.7.3 RAIN - MAIN PROCESSING
Sequence of NETWORK routine RAIN3

1. Set the day count (ICOUNT) to 1.
2. Call SEGMENT routine SGRAIN to read the PERIOD rainfall at each gauge.
3. If there is no rain in the period (ISYM = 0), write the result to the processed data tape for each time interval of each day of the period.
4. For each day of the period (KSYM days):
 - a. Set the cumulative count for RECORDING gauges to zero.
 - b. Set the areal rainfall stores for each of ME time intervals to zero.
 - c. For each RECORDING gauge:
 - i. call SEGMENT routine RGRAIN to read the rainfall in each time interval at the RECORDING gauge, and calculate the proportion of the total for the period which falls in each time interval.
 - ii. if there is no rain in the RECORDING gauges for this day (indicated by LSYM = 0 on first and only RECORDING rainfall data card), set the areal rainfall to zero for each time interval of that day and return to 4 above.
 - iii. call SEGMENT routine SUMAR to identify which PERIOD gauge totals should be distributed in time according to this RECORDING gauge record; calculate the increment to the areal total for each time interval and add to the cumulative stores. The areal weighting is carried out at this time.
 - iv. test that all RECORDING gauges have been read by comparing the sum of the JSYM values with the LSYM value.
 - d. Divide the results by the total catchment area (AREA).
 - e. Write results to the processed data tape.

TABLE 4.7.4 RAINFALL - MAIN PROCESSING
Sequence of SEGMENT routine SGRAIN

1. Set the extended array stores to zero.
2. Read the STANDARD gauge data for one day, also ISYM and KSYM from the first DATA CARD.
3. If there is no rain indicated by $ISYM = 0$, return to the appropriate NETWORK routine.
4. Apply the areal weighting factors, that is, multiply each rainfall by the appropriate areal weighting factor for that gauge.
5. Put the weighted rainfall values in an extended array, that is, transfer the data from storage locations defined by their position on the DATA CARD to locations defined only by their gauge numbers, using SEGMENT routine PLACE2.
6. If $INET = 3$, add any weighted rainfall carried over from the previous day. (see text for notes on this special case when $INET = 3$)
7. Return to the appropriate NETWORK routine.

TABLE 4.7.5 RAIN - MAIN PROCESSING
Sequence of SEGMENT routine RGRAIN

1. Read the RECORDING gauge data for one gauge together with JSYM and, on the first DATA CARD only, LSYM.
2. If INET = 4 and there is no rain on that day in any RECORDING gauge indicated by LSYM = 0, return to the appropriate NETWORK routine.
3. If INET = 2 or 3 and there is no rain in that gauge indicated by JSYM = 0, return to the appropriate NETWORK routine. Normally such zero DATA CARDS should not be included in the sequence.
4. Determine the number of the DAILY or PERIOD gauge which is the CHECK gauge for this RECORDING gauge.
5. Transform the RECORDING gauge readings by dividing by the CHECK gauge rainfall. The data now indicates the proportion of the DAILY or PERIOD rainfall which occurred in each of the time intervals during the day.
6. Return to the appropriate NETWORK routine.

TABLE 4.7.6 RAINFALL - MAIN PROCESSING
Sequence of SEGMENT routine SUMAR

1. For a given RECORDING gauge, determine through the rainfall MATRIX table which STANDARD gauges have their totals distributed in time by this gauge.
2. For each time interval of the day calculate the increment to the areal total from each STANDARD gauge distributed by this RECORDING gauge.
3. If INET = 3 calculate the total rainfall to be carried over to the next day. See text for notes on this special case when INET = 3.
4. Return to the appropriate NETWORK routine.

TABLE 4.7.7 RAIN - MAIN PROCESSING
 Example of the distribution of rainfall when INET = 3

Time interval	DAY 1				DAY 2				DAY 3			
	1	2	3	4	1	2	3	4	1	2	3	4
RECORDING gauge catch	10	20	0	15	60	30	0	10	10	30	15	0
CHECK gauge catch	30				125						45	
STANDARD gauge catch	70				230						100	
Carry over CHECK STANDARD	0	0			- 15						10	
Corrected total CHECK STANDARD	0	0			- 35 (c)						17.5	
Transformed RECORDING gauge catch	0.33(a)	0.67	0	0.50	0.546	0.273	0	0.091	0.182	0.546	0.273	0
STANDARD gauge	23.3(b)	46.7	0	35.0	106.5	53.2	0	17.8	21.3	64.1	32.1	0
Total for day			105.0				177.5				117.5	

- Notes:
- (a) The RECORDING gauge catch is transformed by dividing by corrected total in CHECK gauge.
 - (b) The STANDARD gauge distributed value is obtained by multiplying the corrected catch in the STANDARD gauge by the appropriate transformed RECORDING gauge catch.
 - (c) This value, - 35, is obtained by difference of the corrected STANDARD GAUGE catch for the previous day and the total of the distributed STANDARD gauge values for the previous day.

SECTION 5

EVAPORATION

- 5.1 Introduction
- 5.2 Input data
- 5.3 Control information
- 5.4 Preprocessing
- 5.5 Network Tables
- 5.6 Quality Control
- 5.6 Main processing

All program listings will be found in Appendix A which is published separately.

5.1 INTRODUCTION

Although evaporation, or more precisely open water evaporation, can be measured directly using an evaporation pan, the small size of the pan and its inconsistency with its surroundings usually mean that the measurement is not strictly representative of the evaporation that would occur from a large water surface under the same meteorological conditions. Consequently analytical methods are usually employed to estimate evaporation from the meteorological data available. These methods can be firmly based on the physics of the evaporation process and, as evaporation from an open water surface is dependent principally on the meteorological factors alone, it is a more simple starting point than to consider also the biological and soil moisture constraints that apply to the transpiration from vegetation.

The Penman equation (Penman, 1948) is generally accepted as being well founded when applied to conditions where the supply of water is not limited and the aerodynamic conditions are equivalent to those over open water or a short grass cover. Thus it has been adopted as the basis for the processing program described here. More recent theoretical advances, for example Monteith (1965), are leading to equations which can take account of the aerodynamic effect of different crops through the aerodynamic resistance parameter and of the constraint imposed by the vegetation itself through its stomatal resistance. The latter is responsive to, among other things, shortage of water and the rate at which the vegetation can draw water from the soil. It is expected that in time such an equation will supercede the standard Penman equation currently in use.

It should be noted here that use of the Penman equation in areas where the supply of water for evaporation is limited or for areas where there is significant advected energy, will lead to exaggerated estimates of open water evaporation. This is because the method assumes that the meteorological variables, particularly temperature and humidity, are consistent with a freely evaporating surface. This is very nearly true in northern temperate latitudes and in those tropical areas where rainfall is adequate. However, in arid or seasonally arid areas care is necessary in interpreting the results.

5.2 INPUT DATA

Most meteorological data are from stations operated manually; usually a single round of readings at a standard time each morning. In temperate latitudes this has been found to be satisfactory though in the tropics it is usual to include a second set of readings of temperature in the afternoon. This practice leads to improved estimates of mean temperature through the day.

More recently the development of automatic weather stations which record directly onto magnetic tape has allowed measurements to be taken much more frequently. Time intervals of the order of a few minutes are easily achieved. Although one of the major advantages of these stations is that they can be sited in remote areas where continuous manual records would be difficult to obtain, the frequency of observation does allow improved methods of estimation of evaporation to be applied, particularly when short period estimates are required.

Programs for the PREPROCESSING, QUALITY CONTROL and MAIN PROCESSING of the data from the automatic stations are being developed in a manner consistent with this general processing system. Meanwhile, this section is restricted to the processing of data from manually-operated stations. There are a few minor items in the programs which are included at this stage to allow for further routines to be added in future. Thus all reference to the indices IMET, IAWS and JAWS should be ignored for the time being, except that their values should all be set to 1.

The format of the input data cards and of the control system must be sufficiently comprehensive to allow for considerable variety both in terms of instrumentation and in the units of measurement. Much of this variety occurs in the measurement of solar radiation, which is of prime importance in the estimation of evaporation.

The DATA CARD format is shown in Table 5.2.1. The MAIN PROCESSING program assumes that all the data on temperature and wind run are available except for afternoon readings of wet and dry bulb temperature. A minimum of one radiation measurement is required; there is provision for three alternative data sets and all three should be entered if

they are available. The preferential use of these data in the different parts of the program are described in the section on MAIN PROCESSING.

Whenever some of the data are in the form of cumulative totals which can happen in the case of wind run or radiation, it is necessary to enter the value for the last day of the previous month so that the true value for the first day of the month can be obtained by difference. In these cases an INITIAL DATA CARD is used having a format given by Table 5.2.2. This card which follows the CONTROL CARD, is omitted when none of the data are cumulative.

As usual in this processing system the data are punched right justified and without decimal points. The format indicates the number of decimal places required by the program. However for the evaporation data there is one exception. When either total or net radiation has the units of counts (IRAD or INET = 4) which are integer values, they should be entered as such; the programs take account of this.

An example of a monthly batch of data is shown in Table 5.2.3.

TABLE 5.2.1 EVAP - INPUT DATA

Data card format for a manually read station

Item	Symbol	Format	Columns	Units and Remarks
Temperature maximum	TMAX	F6.1	1-6	} could be negative values
Temperature minimum	TMIN	F6.1	7-12	
Temperature morning dry	TDM	F6.1	13-18	
Temperature morning wet	TWM	F6.1	19-24	
Wind run	U2	F6.0	25-30	
Sunshine	N	F6.1	31-36	
Total radiation	RC	F6.1	37-42	
Net radiation	NC	F6.1	43-48	
Temperature afternoon dry	TDA	F6.1	49-54	
Temperature afternoon wet	TWA	F6.1	55-60	
Data type	ITYPE	I1	62	always 3
Source index	IMET	I2	63-64) always 1) (see text)
Number of sources	JAWS	I2	65-66	
Catchment number	ISITE	I3	72-74	
Day of month	IDAY	I2	75-76	
Month and year	IMONTH	I4	77-80	

Note: When data are not available the relevant columns on the card are left blank.

TABLE 5.2.2 EVAP - INPUT DATA

Initial data card format

Item	Symbol	Format	Columns	Units and Remarks
Initial anemometer reading	UP	F6.0	1-6	always 3
Initial radiation reading	RCP	F6.1	7-12	
Initial net radiation reading	NCP	F6.1	13-18	
Data type	ITYPE	I1	62	
Catchment number	ISITE	I3	72-74	
Month and year	IMONTH	I4	77-80	

Notes: This card, placed directly after the CONTROL card(s) is used only when there is cumulative data for either wind run or total radiation or net radiation. Otherwise the card is omitted. Similarly any piece of data may be omitted when irrelevant.

In all cases these initial readings will generally be the readings taken at 0900 hours on the first day of the month.

5.3 CONTROL INFORMATION

The information required by the processing programs may be classified as follows:

1. Normal catchment information, data type and frequency, units indices, and label.
2. Latitude and altitude of the station to determine potential radiation and the values of various altitude-dependent physical constants.
3. Comprehensive information concerning the kinds of data available.
4. Calibration constants for certain instruments.

All these items appear on the CONTROL CARD whose format is given by Table 5.3.1. The usual catchment information, data type and label are described in the general section on control information, section 2.3. However IFREQ takes the value 1 when there is only 1 set of temperature data per day and the value of 2 when afternoon temperatures are available in addition. JFREQ, the output frequency takes the value 8 indicating one value per day.

The MAIN PROCESSING program demands that all values of the four temperatures shall be available although only one value of sunshine hours or total radiation is required. When the radiation data have units of counts it is assumed that the data are cumulative. However for wind run data this is not necessarily true and a double index is used, IW, to indicate both units and whether the data are cumulative. This index is defined in Table 5.3.1.

The requirement for calibration constants is defined by the indices for radiation in an order of preference defined by the MAIN PROCESSING program. In detail, the order is as follows:

1. If INET = 4 that is net radiation has the unit of counts then A and B take values appropriate to the calibration equation,
$$NC (cal) = A + B * NC (counts)$$
2. If IRAD = 4 that is the total radiation has the unit of counts then A and B take values appropriate to the calibration

equation,

$$RC (cal) = A + B * RC (counts)$$

3. If IRAD = 3 that is total radiation is measured by Gunn-Bellani radiometer with the unit mL, then A and B take values appropriate to the calibration equation,

$$RC (cal) = A + B * RC (mL)$$

4. If INET \neq 4 and IRAD \neq 4 but ISUN = 1 then A and B take values appropriate to the Angstrom equation,

$$RC/RA = A + B * N/NN$$

as described under MAIN PROCESSING.

5. If none of these requirements are met the constants A, B and C are not used.

In general these constants will be available from field calibration of the instrument although in case 4 above some general values have been quoted for various climatic zones by Glover and McCulloch (1958), and by Linacre (1967).

5.4 PREPROCESSING

5.5 NETWORK TABLES

At the present time the data from manually read meteorological stations do not require any PREPROCESSING or NETWORK TABLES.

The data from automatic weather stations will require PREPROCESSING in order to carry out the initial checks on completeness of the data and to estimate, for example, hourly mean values of the variables. Also there is some indication that in future there will be several stations in each catchment so that some areal integration will be necessary involving the use of some network information.

TABLE 5.3.1 EVAP - CONTROL INFORMATION
Control card format

	Symbol	Format	Columns	Units and Remarks
Catchment area	AREA	F10.1	1-10	hectares
Latitude	LAT	F6.1	11-16	degrees (+ = N - = S)
Altitude	ALT	F5.0	17-21	metres
Regression constants	A	F7.2	22-28) multipurpose) constants) see text
	B	F7.2	29-35	
	C	F5.2	36-40	
Albedo	ALB	F5.2	41-45	
Temperature index	IT	I2	46-47	1 = degs F 2 = degs C
Wind index	IW	I3	48-50	see below
Ht. of anemometer	ANEMON	F4.1	51-54	metres
Sun index	ISUN	I2	55-56	0 = no data 1 = hours
Total radiation index	IRAD	I2	57-58	0 = no data 1 = cal 2 = MWH 3 = mL 4 = counts
Net radiation index	INET	I2	59-60	0 = no data 1 = cal 2 = MWH 4 = counts
			61	
Data type	ITYPE	I1	62	always 3
Source index	IMET	I2	63-64) always 1, see text) see text
Number of sources	IAWS	I2	65-66	
Input frequency	IFREQ	I2	67-68	
Output frequency	JFREQ	I2	69-70	
			71	
Catchment number	ISITE	I3	72-74	
No. of days in month	IDAYS	I2	75-76	
Month and year	IMONTH	I4	77-80	

Notes:

- Wind index IW as follows

1 miles)	
2 km)	not cumulative
3 knots)	
11 miles)	
12 km)	cumulative
13 knots)	

5.6 QUALITY CONTROL

The full sequence of tests is listed in Table 5.6.1. As far as possible the program checks that the CONTROL CARD is internally consistent and that the regression constants and the INITIAL DATA CARD are included when required.

When daily values of wind run or any of the radiation inputs are determined by difference from cumulative values, the program tests for erroneous negative values. Otherwise the data are checked for punching errors by computing the monthly totals for each variable and the daily totals of all variables. These totals are then checked against the corresponding totals on the booking forms.

Some straightforward tests on the validity of the data can be made for temperature. There are clearly defined inequalities which must hold if the data are valid.

Unfortunately the most serious forms of error in meteorological measurement cannot be adequately checked without tests based on some knowledge of the expected value of each variable for each month. These errors are usually associated with calibration drift, deteriorating exposure, or poor maintenance of mechanical equipment such as anemometers. Field errors in individual readings are rare and it is unlikely that suitable tests could be developed which would pin-point such errors without calling for a great deal of inspection of data which are only marginally outside some predetermined range. On balance it would seem more desirable to carry out the checks in the field on a routine basis so that cases of calibration drift never become serious enough to cause significantly greater errors than are usual in the estimation of evaporation. In this context it is clearly important to determine the relative importance of each variable in the estimates produced.

An example of the output from the QUALITY CONTROL program is shown in Table 5.6.2.

TABLE 5.6.1. EVAP - QUALITY CONTROL

Sequence of the quality control checks

	Subroutine
1. Read number of months to be checked	MASTER
2. Read and check LEAD CARD	MASTER
3. Read CONTROL CARD	EVQC1
4. Display control information	EVQC1
5. Test CONTROL CARD label	EVQC1
6. Test IFREQ, JFREQ in acceptable range	EVQC1
7. Test INET, IRAD in acceptable range	EVQC1
8. If INET = 4 or INET \neq 4, IRAD = 3 or 4, test regression coefficients A and B \neq 0	REGTES
9. If any input variables are cumulative, read INITIAL DATA CARD	EVQC1
10. Test INITIAL DATA CARD label	
11. For each day of the month:	
a) Read a DATA CARD	EVQC1
b) Test the DATA CARD label	EVQC1
c) Compute daily totals from an cumulative data	CUMTES
d) Test for negative values from (c) above	CUMTES
e) Compute cumulative totals for each variable and of all variable for each day	EVQC1
f) Test the temperature: max > min wet bulb < dry bulb dry bulb < max dry bulb > min	EVQC1
g) Repeat (f) if afternoon temperatures included	EVQC1
h) Test morning dry bulb temperature < previous day's maximum	EVQC1
12. Display totals of all variables by days	EVQC1
13. Display totals and averages for each variable	EVQC1

CATCHMENT NO. 2
 AREA 1856.1
 LATITUDE 51.90
 ALTITUDE 67.
 REGRESSION A 0.00
 REGRESSION B 0.00
 REGRESSION C 0.00
 ALBEDO 0.25
 TEMPERATURE INDEX 1
 WIND INDEX 1
 HEIGHT OF ANEMOMETER 2.0
 SUN INDEX 1
 TOTAL RADIATION INDEX 1
 NET RADIATION INDEX 0
 DATA TYPE 3
 SOURCE INDEX 1
 NUMBER OF SOURCES 1
 INPUT FREQUENCY 1
 OUTPUT FREQUENCY 8
 NUMBER OF DAYS IN MONTH 31
 MONTH AND YEAR 1963

1. 1963 MAX. LESS THAN MIN

1. 1963 MORNING DRY GREATER THAN MAX

2. 1963 MORNING DRY GREATER THAN PREVIOUS MAX

15. 1963 MORNING WET GREATER THAN MORNING DRY

22. 1963 MORNING DRY GREATER THAN MAX

22. 1963 MORNING DRY GREATER THAN PREVIOUS MAX

31. 1963 MORNING DRY GREATER THAN MAX

DATE	TOTAL	DATE	TOTAL	DATE	TOTAL	DATE	TOTAL	DATE	TOTAL	DATE	TOTAL
1	306.50	2	368.50	3	458.00	4	641.40	5	348.80	6	375.00
7	361.10	8	451.30	9	546.10	10	443.40	11	301.00	12	572.00
13	497.80	14	414.50	15	410.60	16	362.50	17	420.50	18	513.60
19	574.10	20	380.10	21	515.30	22	510.30	23	411.90	24	285.00
25	351.70	26	458.30	27	395.70	28	317.60	29	372.10	30	429.70
31	306.00										
	STMAX	STMIN	STOM	STWM	SU2	SN	SNC	SNC	STDA	STWA	
TOTAL	1769.4	1343.8	1604.5	1538.8	2876.	78.9	4089.0	0.0	0.0	0.0	
MEAN	57.08	43.35	51.76	49.66	92.8	2.55	131.90	0.00	0.00	0.00	

5.7 MAIN PROCESSING

The Penman equation forms the basis of this processing program. Use of the equation is widespread and it is uncommon to find situations where there are insufficient meteorological data for its application.

Although the basic equation itself is straightforward, the choice of values of some of the constants and also the method of calculation of some of the variables, notably back radiation, is open to debate. However, this is not an appropriate place to discuss the physics of the problem. The method of application used here is described in some detail so that other workers in this field can modify the program to suit their judgement.

The basic Equation

In terms of the nomenclature used in the program as defined in Table 5.7.2, the basic equation may be written;

$$E_0 = \frac{\text{DELTA}}{\text{DELTA} + \text{GAMMA}} \left[\text{RC}(1-\text{ALB}) - \text{RB} \right] + \frac{\text{GAMMA}}{\text{DELTA} + \text{GAMMA}} (\text{EAT})$$

The first term represents the difference between net incoming shortwave and net outgoing longwave radiation; the second term is a bulk aerodynamic term. The factors involving DELTA and GAMMA, which are temperature and altitude dependent, are considered as weighting factors related to the efficiency by which the incoming heat may be used in the vapourisation of water. In practice the back radiation term and the aerodynamic term are of the same order numerically which means that the term involving net incoming radiation is predominant in determining potential evaporation. This emphasises the need for accurate measurement of solar radiation.

DELTA is the slope of the saturation vapour pressure curve at mean air temperature TD, and is given by Berry (1964) as;

$$\text{DELTA} = 1.59488 \cdot 10^{-6} \text{TD}^3 - 8.72748 \cdot 10^{-5} \text{TD}^2 + 7.92168 \cdot 10^{-3} \text{TD} - 3.4111 \cdot 10^{-2}$$

when TD > 32°F

$$\text{and DELTA} = 9.936 \cdot 10^{-5} \text{TD}^2 + 1.6256 \cdot 10^{-3} \text{TD} + 5.352 \cdot 10^{-2}$$

when TD < 32°F

Units: mm Hg, °F

GAMMA is the constant in the psychrometer equation and is given by:

$$\text{GAMMA} = 2.727 \cdot 10^{-4} (1013.0 - 0.1 \text{ ALT})$$

Units: mm Hg,m

This simplification is possible by ignoring the effect of temperature on the ratio of the specific heat of dry air at constant pressure to the latent heat of vapourisation. From the Smithsonian tables, the variation in GAMMA following this assumption can be shown to be less than 1% over a wide range of temperature.

Solar Radiation

RC is the incoming solar radiation which is obtained directly from the input data when IRAD \neq 0. The program is written with the unit of calories so a correction for other units is made depending on the value of INDEX. When a direct measurement of solar radiation is not available, IRAD = 0, the Angstrom equation is used to derive radiation from hours of sunshine.

$$\text{RC} = \text{RA} (\text{A} \cdot \text{COSPFI} + \text{B} \cdot \text{N}/\text{NN})$$

N is the observed value of hours of sunshine, NN is the potential value and RA is the radiation received at the upper limit of the earth's atmosphere. A and B are the regression constants referred to in Section 5.3 and suitable values can be found by experiment or from collected regional data (Glover and McCulloch, 1958; Linacre, 1967).

Both RA and NN are computed in SUBROUTINE RANN by the method described by Berry (1964). This routine requires the day number counting from 1 January and this is computed in SUBROUTINE DAYNUM.

COSPFI is the cosine of the station latitude which is required in McCulloch's modification of the Angstrom equation. When using regression constants proposed by Linacre it is necessary to adjust the value A to allow for multiplication by COSPFI in the program.

Albedo and Net Radiation

When calculating E01, the open water or potential evaporation, the program

assumes a value for albedo, ALB, of 0.05. The value input via the CONTROL CARD refers to the calculation of potential transpiration, ET3, from the local vegetation.

However if there are values of net radiation, INET \neq 0, then these data will be used preferentially and will replace the whole term, RC(1-ALB)-RB. This refers only to the calculation of ET3; net radiation is not used in the calculation of E01, since net radiation is not usually measured over a water surface.

Back Radiation

RB, the back radiation (the net loss of longwave radiation) is calculated by the following equation (Brunt 1934):

$$RB = \text{SIGMA} \cdot \text{TA4} (0.56 - 0.092 \sqrt{ED}) \cdot (0.10 + 0.90 \cdot N/NN)$$

SIGMA is Stefan's constant which is $1.9847 \cdot 10^{-9}$, from Smithsonian tables; TA4 is the fourth power of the absolute temperature in $^{\circ}\text{K}$; ED is the saturation vapour pressure at the dew point as described below; N and NN take the same values as described in the previous paragraphs.

When there is no measurement of hours of sunshine, a value is inferred from incoming solar radiation, RC, by using the Angstrom equation in reverse.

Aerodynamic Term

The bulk aerodynamic term, EAT in the basic equation is a function of wind speed, U2, at a height of 2m, and of the saturation vapour pressure at mean air temperature, EA, and the saturation vapour pressure at dew point, ED, which is the actual vapour pressure of the air.

$$EAT = 0.35 (1 + U2/100) (EA-ED) (1 + ALT/20000)$$

Units: mm/day, miles/day, mm Hg,m.

When vapour pressure is expressed in mb the constant takes the value 0.26.

The calculation of vapour pressure makes use of a polynomial fitted to the vapour pressure curve. The equations used here are taken from Berry (1964)

When $TW > 32^{\circ}\text{F}$

$$\begin{aligned} EA = & 3.98647 \times 10^{-7} TD^4 - 2.90916 \times 10^{-5} TD^3 + 3.96084 \times 10^{-3} TD^2 \\ & - 3.4111 \times 10^{-2} TD + 2.1565 \end{aligned}$$

$$\begin{aligned} ED = & 3.98647 \times 10^{-7} TW^4 - 2.90916 \times 10^{-5} TW^3 + 3.96084 \times 10^{-3} TW^2 \\ & - 3.4111 \times 10^{-2} TW + 2.1565 - 0.3 (TD - TW) \end{aligned}$$

and when $TW < 32^{\circ}\text{F}$, the ice-bulb condition:

$$\begin{aligned} EA = & 3.312 \times 10^{-5} TD^3 + 8.128 \times 10^{-4} TD^2 + 5.352 \times 10^{-2} TD + 9.479 \times 10^{-1} \\ ED = & 3.312 \times 10^{-5} TW^3 + 8.128 \times 10^{-4} TW^2 + 5.352 \times 10^{-2} TW + 9.479 \times 10^{-1} \\ & - 0.3 (TD - TW) \end{aligned}$$

In a later paper, (Penman, 1965), the wind term in the expression for EAT was changed to:

$$(0.5 + U2/100)$$

following evidence from the Lake Hefner studies. An alternative value for open water evaporation, E03, is calculated using this modification. The potential transpiration value, ET3, is however calculated using the original wind term.

The three estimates, two of open water evaporation and one of potential transpiration, are output to magnetic tape in the order E01, E03, ET3. They refer to a time period of one day and for any application requiring a shorter timer interval, it is necessary to assume an appropriate diurnal variation.

The following Tables 5.7.1 and 5.7.2 show respectively the sequence of operations in the main processing program and the nomenclature used in the program.

TABLE 5.7.1 EVAP - MAIN PROCESSING

Sequence of operations

	Subroutine
1. Read the number of months to be processed	MASTER
2. Read the CONTROL CARD(S)	EVAP
3. Write the CONTROL CARD(S) onto processed data tape	EVAP
4. Determine the values of altitude and latitude dependent constants	EVAP
5. Read the INITIAL DATA CARD if appropriate	EVAP
6. For each day of the month:	
a. read a day's data	EVAP
b. determine the average dry and wet bulb temperatures if appropriate	EVAP
c. determine the back radiation	EVAP
d. convert temperatures to °F if necessary	EVAP
e. test for ice-bulb conditions	EVAP
f. calculate the saturation vapour pressure and actual vapour pressure at mean air temperature	EVAP
g. determine the day number	DAYNUM
h. determine the Angstrom radiation and the potential hours of sunshine	RANN
i. convert all radiation values to calories/cm ² if necessary	EVAP
j. determine the radiation value to be used (see text for use of alternatives)	EVAP
k. convert the wind speed to miles/day at a height of 2 m if necessary	EVAP
l. calculate the bulk aerodynamic term(s)	EVAP
m. calculate the energy term(s)	EVAP
n. calculate the 2 values of evaporation and 1 value of transpiration	EVAP
o. write the results to the processed data tape	EVAP

TABLE 5.7.2 EVAP - MAIN PROCESSING

Nomenclature used in the routines

PI	3.14159
SIGMA	$1.9847 \cdot 10^{-9}$ Stefan's constant
GAMMA	constant in the psychrometer equation
DELTA	weighting factor (see text)
PHI	station latitude in radians
SIN50	correction for refraction and Sun's semi-diameter in hour angle calculation
JO	1.94 Joule's constant
L	latent heat of vapourisation ($60.74 - 0.0314 \cdot TW$)
D	day number from 1 January
RA	radiation at the upper edge of the atmosphere
NN	potential hours of sunshine
TD	mean daily air temperature
TW	mean daily wet bulb temperature
T	average of maximum and minimum temperature
TA4	absolute value of T raised to 4th power
EA	saturation vapour pressure at mean air temperature
EA1	saturation vapour pressure at wet bulb temperature
ED	actual vapour pressure at mean air temperature
EAT,EAD	bulk aerodynamic term
GEAT,GEAO	GAMMA * bulk aerodynamic term
SUM	DELTA + GAMMA
H02,HT3	energy term in basic equation

See also Tables 5.2.1, 5.2.2 and 5.3.1 for the nomenclature used on the data and control cards.

SECTION 6

RUNNING THE ROUTINE ON AN ICL 1900 SERIES COMPUTER UNDER THE GEORGE 3 OPERATING SYSTEM

- 6.1 Introduction
- 6.2 Methods of storing information in the
1904S
- 6.3 Quality control routines
- 6.4 Correcting the data files
- 6.5 Storing the data files
- 6.6 Processing routines
- 6.7 Display routines

All program listings will be found in Appendix A
which is published separately.

6.1 INTRODUCTION

To run the *quality Control*, *Main Processing* and *Lineprinter Display* routines, the following hardware and software must be available:

- 20K core
- a card reader
- a lineprinter
- 2 magnetic tape decks
- a Fortran compiler

The routines have been developed on an ICL 1904S configuration at the Hydraulics Research Station; it is a multi-programming system controlled by the GEORGE 3 operating system.

The Graph Plotting routines have been developed on the SC4020 graph plotter in conjunction with the ICL 1906A at the Atlas Laboratory of the Science Research Council. This machine is operated under the GEORGE 4 system.

The GEORGE operating system uses a filestore which resides in the direct access storage devices. Information in the filestore is held in files. These are device-independent and can be referred to by the name, so that the users do not have to be aware of the physical position of the files. The filestore enables users to store all the information necessary for running a job within the system. Also, the filestore enables a program to have more than one input/output stream of the same peripheral type, even when the configuration has only one of each of the relevant peripherals.

Directories

Before a user can create entrants or refer to them he must be introduced to the system and given a place in the filestore hierarchy. The user is given a directory which he refers to by his "USER NAME". Information about entrants created by the user is stored in files in his directory.

Filenames

The operating system, GEORGE 3, locates files in the area of the filestore allocated to the user by reference to a filename comprising of a maximum of 12 alpha-numeric characters of which the first must be an alphabetic character, and a generation number which refers to the version of the file being used. It is convenient to choose filenames which help the user to identify the contents of the file.

Macros

A macro is a series of GEORGE 3 commands designed to carry out a frequently required sequence of operations. The macro is stored in the filestore. System macros are stored in files under the directory name : MACROS and are available to all users in EXECUTE mode. They may be used simply by issuing the name of the macro as a command. User macros are stored in the user's directory and they are called in a similar manner. A complete description of the use and derivation of macros is given in the appropriate ICL manual.

6.2 METHOD OF STORING INFORMATION ON THE 1904S

Of the methods of storage available, two have been adopted; both require magnetic tapes.

Peripheral Type Files

Initially all source routines, object routines and basic data are in card format and are held in basic peripheral type files in the filestore.

For the data files, the following constraints are used:

One catchment per file

One data type per file

One to six months of data per file (if there is more than one month in a file they must be sequential and of the same half year).

The filename consists of ten alpha-numeric characters, and can be identified as follows:

where `ccctmmnnyy(g)`

- `ccc` = first three letters of the catchment name
- `t` = data type: streamflow = F
rainfall = R
evaporation = E
- `mm` = first month in the file
- `nn` = last month in the file (omitted if only one month)
- `yy` = year in the file
- `g` = generation number

e.g. Evaporation data from Grendon Underwood for the months of January - June 1966 would be found in the file named

GREE010666(1)

and streamflow data from the Cam for July - December 1968 would be found in the file named

CAMF071268(1)

Files which are correct are copied onto named magnetic tapes as subfiles of those tapes by the system macro HCOPYOUT. This and other system macros might be changed from time to time and the user should refer to the relevant user notices. Once a file is safely copied onto a magnetic tape it can be erased from the filestore thus releasing filestore space for other uses. If the subfile is required at a later date it is simply copied back into the filestore by the macro HCOPIIN, used and erased, the correct version still being held on the magnetic tape. The chances of losing a subfile is much reduced if a copy is made on another tape. The name and order of the subfiles on the magnetic tape can be listed by the macro LISTTAPE. Subfiles can be erased from the tape by the macro EDITTAPE.

Source and object routines are stored on the magnetic tapes labelled AHSOURCEM generations 0, 1 and 2. The basic data files are copied out to magnetic tape verbatim without alteration of the filename. Successive files are appended to the existing subfiles on the tape. The data files for each catchment are held on separate magnetic tapes of generation zero. Copies of these magnetic tapes are made on tapes of the same name but generation one. The tapes are identified by eight alpha-numeric characters as follows:

 cccDATA_n(g)
where ccc = first three letters of the catchment name
 n = sequence number of the data tapes, initially one.
 When the first tape is full a second tape is
 used hence n = 2
 g = generation number

e.g. The Grendon Underwood catchment data files are held as subfiles on magnetic tape

 GREDATA1(0)

A copy of this data is on GREDATA1(1).

On-line Magnetic Tape Files

The named magnetic tape contains input to or output from a Fortran program. The way the tape is used is controlled by the program. Information can be formatted or unformatted records, the processed data tapes are unformatted since this leads to economy of tape.

The identification of the processed data tapes is similar to the basic data tapes

 cccRESULT_n(g)
where ccc = first three letters of the catchment name
 n = sequence number of the result tape
 g = generation number

e.g. GRERESULT1(1) holds the processed results of data from Grendon Underwood.

There are three generations of each tape to facilitate up-dating as new data are available. The way in which these tapes are used

is described in section 6.6 below.

6.3 QUALITY CONTROL ROUTINES

A system diagram for running the quality control routines is shown in Figure 8.

The quality control routines QCF1 for streamflow, QCR1 for rainfall and QCE1 for evaporation are stored separately on the magnetic tapes and labelled AHSOURCEMT. A list of the source and object subfiles is given in Table 6.3.1.

Input

There are two input streams.

Stream 1 reads the data to be quality controlled from card reader zero (CRO). Explanation of the data formats is given in sections 3, 4 and 5.

Stream 3 reads the RUN CARD from card reader one (CR1). The RUN CARD indicates the number of months to be quality controlled NMONTH and, in the case of streamflow, gives the error tolerance, NDIFF. Its format is given in Table 6.3.2 and the use of NDIFF is described in section 3.6.

Output

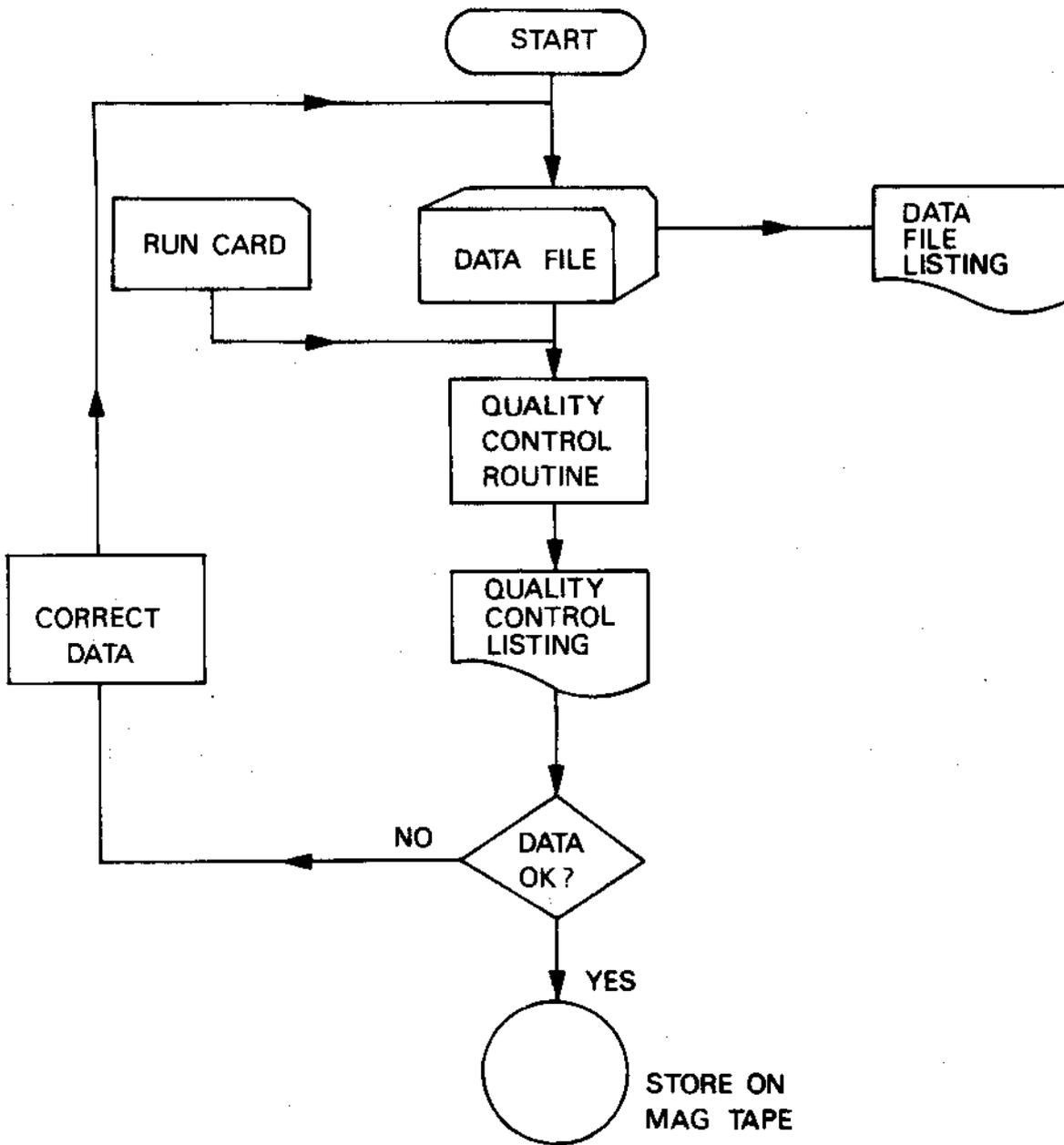
There is only one output stream, number 2, which lists the CONTROL CARD and possible errors in the data. Examples of the output are given in the previous sections.

Running the routines

To run the routines the following files are required in the filestore:

- Object file
- Data file
- Run control file

The output file is assigned during the run.



The data files can be input directly from a deck of cards of the given format or indirectly from another source via a program which outputs the data to a card punch file in the correct format. For example, most of the streamflow data is input indirectly through the program, FLOW PREPROC, which preprocesses data from autographic records.

Direct input is carried out by the following GEORGE instructions:

```
INPUT :CATCH,GRERO10671(1)
      data cards containing Grendon Underwood rainfall
      records for January to June inclusive of 1971
****
```

Note that this is generation 1 of the card file.

The data files must always end with **** and these must be included in the file.

A typical set of GEORGE instructions to quality control six months rainfall data from the Grendon Underwood catchment would be:

```
INPUT :CATCH,GRERO 10671(n)
      data
****
INPUT :CATCH,QCTEST
      6
****
JOB AHQC,:CATCH
HCOPYIN (x),T????
QCR1BIN
????
LOAD QCR1BIN
ASSIGN *CRO,GRERO 10671(n)
ASSIGN *CR1,QCTEST
CREATE !
ASSIGN *LPO,!
ENTER
LISTFILE !,*LP
ERASE !
LISTFILE GRERO10671(n),NU,*LP
ERASE QCR1BIN
ERASE QCTEST
ENDJOB
****
```

x is the number of the magnetic tape AHSOURCEMT used
n is the current generation of the data file.

TABLE 6.3.1 SUBFILES CONTAINING ROUTINES

Routine	Source	Object
Streamflow Quality Control	QCF1	QCF1BIN
Rainfall Quality Control	QCR1	QCR1BIN
Evaporation Quality Control	QCE1	QCE1BIN
Flume/Weir Calibration	FLUMWEIR	FLUMWEIRBIN
Rainuage Matrix	RMATRIX	RMATRIXBIN
Streamflow Processing	FLOW	FLOWBIN
Rainfall Processing	RAIN	RAINBIN
Evaporation Processing	EVAP	EVAPBIN
Processing	PROCESS	PROCESSBIN
Patching	PATCH	PATCHBIN
Inserting	INSERT	INSERTBIN
Table Listing	TABLST	TABLSTBIN
Matrix Listing	MATRIXLIST	MATLISTBIN
Display All	DISPLAY	DISPLAYBIN
Display Summary Only	DISPDAILY	DISPDAILYBIN
Print Flow Results	FLOWPRT	FLOWPRTBIN
Print Rain	RAINPRT	RAINPRTBIN
Print Flow and Rain Results	FRPRINT	FRPRINTBIN

TABLE 6.3.2 QUALITY CONTROL

Run card format

Item	Symbol	Format	Columns	Remarks
Number of months in the data file	NMONTH	I5	1-5	
Stage error tolerance	NDIFF	I5	6-10	Only used in streamflow quality control

6.4 CORRECTING THE DATA FILES

There are two methods used to correct data files, corresponding to the two methods used to input the file.

When the input is from a card deck, it is easier to correct the card deck and re-enter it incrementing the generation number. The GEORGE instruction to re-enter the data file would be:

```
INPUT :CATCH,GRERO10671(2)
      corrected data
****
```

Once the revised version of the data file is in the filestore the previous generation of it can be erased in any job run under the same Username by the instruction:

```
ERASE GRERO10671(1)
```

When the data are input indirectly from another source, there is not a card deck of the information in the data file and any errors in files created in this way have to be corrected in a job, using the editing facility, EDITOR. This can be made easier by obtaining a line number listing of the file to be corrected. The following instruction would do this:

```
LISTFILE GREF010671(1),NU,*LP
```

The GEORGE instructions for editing are:

```
EDIT GREF010671
```

instructions to change contents of current generation and transfer the corrected contents to generation plus one. See editing instructions in the GEORGE 3 operation system manual.

```
ERASE GREF010671(-1)
```

6.5 STORING DATA FILES

When a data file is correct, it is copied out of the filestore onto a magnetic tape, then erased from the filestore. A new listing is made of the subfile names on the magnetic tape. A typical set of instructions to store data files on a magnetic tape which already contains other subfiles would be:

```
RETRIEVE :CATCH,GRERO10671(n),:CATCH.GREF010671(n)
JOB AHCLEAR,:CATCH
HCOPIYOUT (x),T????
END
GREF010671(n),GREF010671
GRERO10671(n),GRERO10671
????
LISTTAPE (x),*LP
ENDJOB
****
```

It is safer to check that the data file has been copied out, by checking with the listing of the subfiles on the magnetic tape, before erasing the file from the filestore.

6.6 MAIN PROCESSING ROUTINES

The following routines are involved: FLUMWEIR, RMATRIX, FLOW, RAIN, EVAP, PROCESS, PATCH and INSERT.

Arrangement of Data on the Processed Tape

The information is written on to the magnetic tape in unformatted mode, with the stage/discharge table and/or the raingauge distribution matrix, if required, before the processed data. The data are in batches of half years, January to June, and July to December. The data types can be in any order within each batch but the dates of each type must be in sequential order along the tape. A diagram of the order of the information is shown in Table 6.6.1.

The results of one data type for one month are held as a set on the magnetic tape. Each set is identified by the initial record in the set, which is a RECORD KEY, consisting of three integer variables:

KTYPE, KSITE, KDATE

where

KTYPE = 1 indicates runoff results
 = 2 indicates rainfall results
 = 3 indicates evaporation results
KSITE = catchment number
KDATE = 0 if the following records are a table of KTYPE or the
 month and year if the following records are results of KTYPE.

The following are examples of the five different sets of records which can appear on the PROCESSED TAPE.

1. stage/discharge table

KTYPE = 1, KSITE = 2, KDATE = 0

1st record is the RECORD KEY as above

2nd record is $KNUM, (Q(I), I=1, KNUM)$ when KNUM is the maximum stage in millimeters and Q is the discharges corresponding to stage increments of 1 mm.

2. raingauge matrix

KTYPE = 2, KSITE = 2, KDATE = 0

1st record is the RECORD KEY as above

2nd record is $NY, NX, (M(I, J), J=1, NX), I=1, NY)$

where NY is the possible number of daily or period gauges in the catchment and NX is the sum of all the recording gauge symbols.

3. runoff data

KTYPE = 1, KSITE = 2, KDATE = 1063

1st record is the RECORD KEY as above

2nd record, variables of the CONTROL CARD

3rd record, runoff at intervals, defined by JFREQ, for the first day of the month, October 1963

33rd record, runoff at intervals, defines by JFREQ, for the last day of the month. ($n = IDAYS + 2$)

4. rainfall data
KTYPE = 2, KSITE = 2, KDATE = 0264
1st record is the RECORD KEY as above
2nd record, variables of the CONTROL CARD
3rd record, variables of the AREA CARD(S)
4th record, rainfall at intervals, defined by JFREQ, for the
first day of the month, February 1964
31st record, rainfall at intervals, defined by JFREQ, for
the last day of the month. (n = IDAYS + 3)

5. evaporation data
KTYPE = 3, KSITE = 2, KDATE = 0565
1st record is the RECORD KEY as above
2nd record, variables of the CONTROL CARD
3rd record, evaporation values for the first day
of the month, May 1965
33rd record, evaporation values of the last day of
the month. (n = IDAYS + 2)

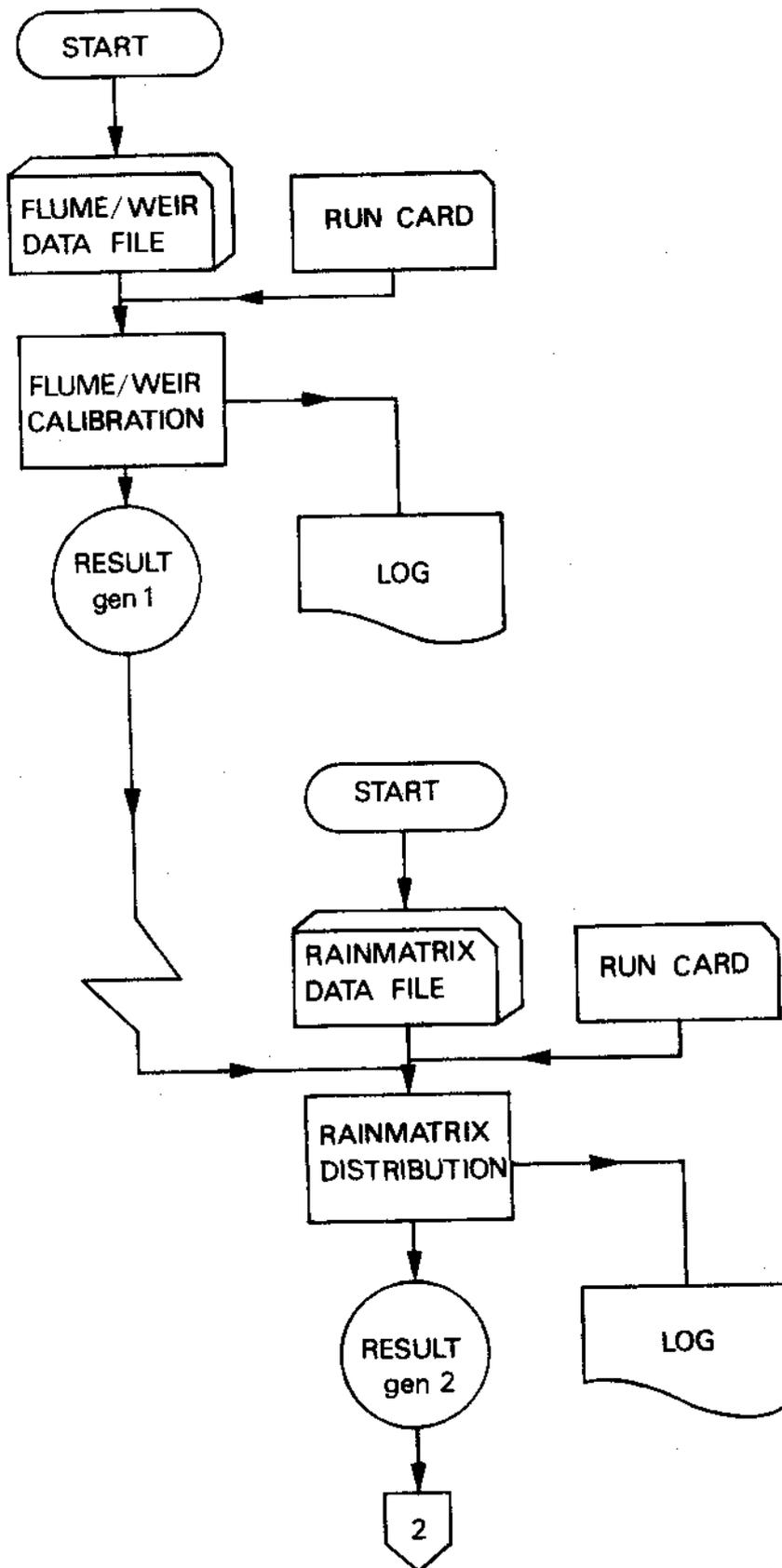
Running the Processing Routines

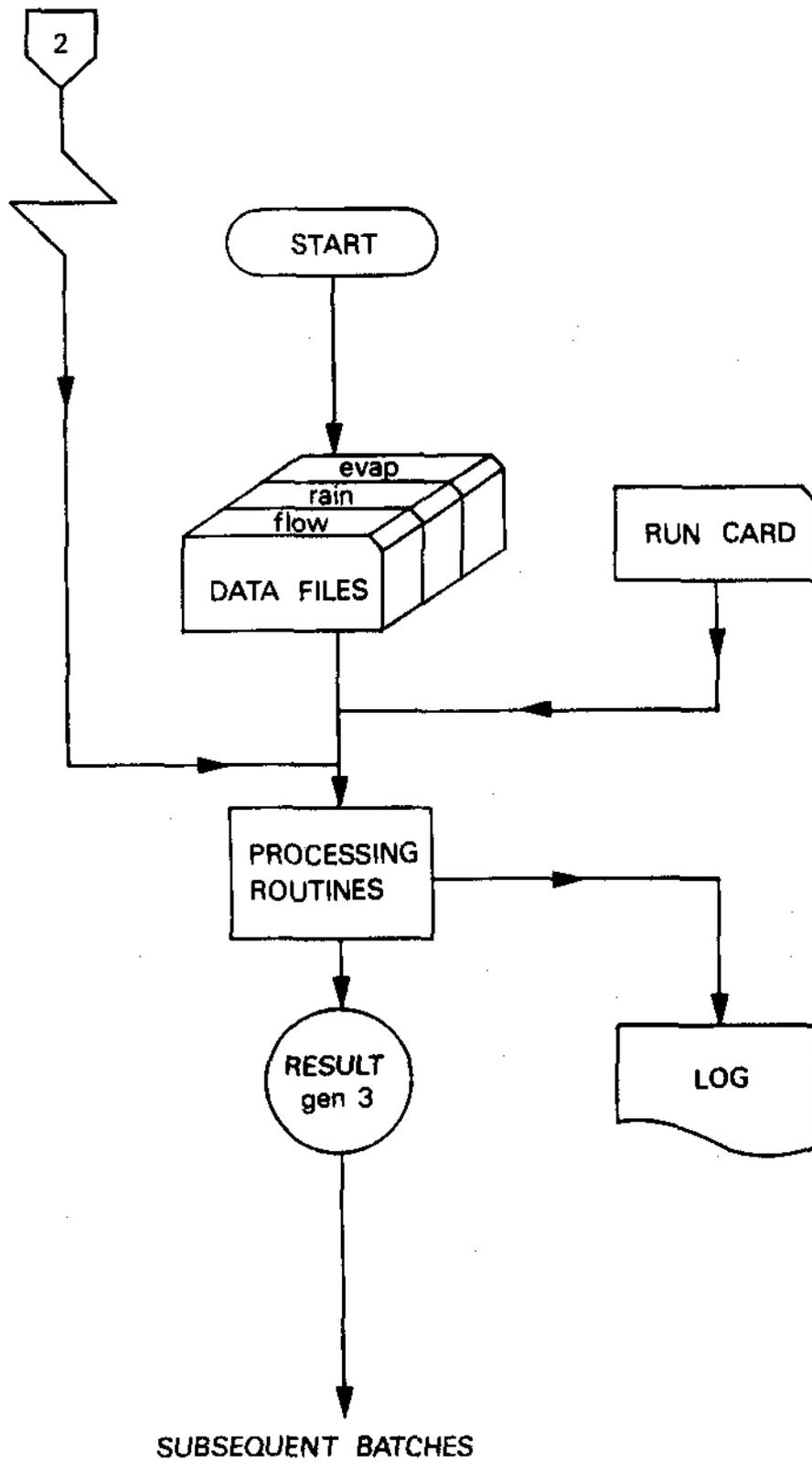
A system diagram for running the processing routines is shown in Figure 9. The routines are stored separately on the magnetic tapes labelled AHSOURCEMT, see Table 6.3.1.

Input

Stream 1 reads the data from the data file assigned to card reader zero (CRO), for the flume/weir calibration, the rainguage matrix or the catchment data to be processed, depending on the routine being run. Formats are given in sections 3, 4 and 5.

Stream 3 reads the RUN CARD from card reader 1 (CRI). The format for the RUN CARD is given in Table 6.6.2. The variable K is used in the subroutine TCHECK(K) to initiate the input tape on Stream 4 and/or output tape on Stream 5.





- K = 1 The magnetic tape whose name and generation are held in variables MFILE1 and MG1 respectively is opened for reading from input stream 4 by the ICL subroutine FILE.
- K = 2 The magnetic tape whose name and generation are held in variables MFILE2 and MG2 respectively is opened for writing to an output stream 5 by the ICL subroutine FILE.
- K = 3 Both the above actions are carried out.
- NSETS1 controls how many sets of information are transferred from the input tape to the output tape, by the subroutine TRANS, before the input tape is rewound and released.
- NSETS2 controls the number of sets of data to be processed and appended to the output tape.
- The numeric value assigned to NSETS1 can be obtained from the listing of the log of the tape used for input.

Output

Stream 2 is assigned to lineprinter zero (LPO), which lists the log of the output tape. An example of the log is shown in Table 6.6.3.

Running the routines

There are three generations of the processed data tapes for each catchment which are used in rotation for back up purposes. The tape containing the most recent records is used as input and the one containing the least recent records is used for output, leaving the third tape as back-up in case of any failure while using the other tapes.

The following files are required in the filestore to run any of the routines:

- Object file
- Data file
- Run Control File

The output file and the magnetic tapes are assigned during the run.

Before any processing of the data files can commence the stage/discharge table and/or the raingauge distribution matrix for the catchment have to be written onto the appropriate output magnetic tape. The derivation of these tables is described in section 3.3 and 4.3 respectively.

For the stage/discharge table the following files must be in the filestore, using Grendon Underwood as an example:

FLUMWEIRBIN Object routine to create the stage/discharge table

RUN CARD file if this is the first set of information to be stored on the magnetic tape, K = 2

MFILE2 = GRERESULT1

MG1 = 1

NSETS1 = 1

MFILE2 = GRERESULT1

MG = 2

NSETS2 = 1

Data file

If a raingauge matrix is required, the following files must be in the filestore, again using Grendon Underwood as an example:

RMATRIXBIN object routine to create the matrix

RUN CARD file if this is the second set of information to be stored on the magnetic tape, K = 3

MFILE1 = GRERESULT1

MG1 = 1

NSETS1 = 1

MFILE2 = GRERESULT1

MG2 = 2

NSETS2 = 1

Data file

Processing of the catchment data files can be run in two ways. If there is only one data file to be processed the appropriate object

routine FLOWBIN, RAINBIN, or EVAPBIN, can be used. If there is more than one data file, the routine PROCESSBIN must be used and all the data files to be processed must finish with ****, since the instruction which reads the LEAD CARD will initiate a pause if the end-of-file marker is read. This allows another data file to be assigned to the routine and the run continued.

Example of a job to run on a single data file.

```
INPUT :CATCH,RUNGREN
3GRERESULT11ΔΔΔΔΔΔΔΔΔΔ2ΔΔΔΔ2GRERESULT1ΔΔΔΔΔΔΔΔΔΔ3ΔΔΔΔ3
****
JOB AHGREN,:CATCH
HCOPYIN (x),T////
FLOWBIN
////
HCOPYIN (x),T////
GREF101263
////
LOAD FLOWBIN
ASSIGN *CRO,GREF101263
ASSIGN *CR1,RUNGREN
CREATE !
ASSIGN *LPO,!
ENTER
LISTFILE !, *LP
ERASE !
ERASE GREF101263
ERASE AHGREN
ERASE FLOWBIN
ENDJOB
****
```

This job would transfer two sets of information from magnetic tape GRERESULT1(2) to GRERESULT1(3) and then append three months of flow results to the second tape.

When more than one data file is to be processed the following GEORGE instructions are used, assuming the necessary files are

in the filestore:

```
INPUT :CATCH,AHGREN
3GRERESULT1ΔΔΔΔΔΔΔΔΔΔ3ΔΔΔΔ5GRERESULT1ΔΔΔΔΔΔΔΔΔΔ1ΔΔΔΔ6
****
JOB AHGREN RUN, :CATCH
LOAD PROCESSBIN
ASSIGN *CRO,GRER101263
ASSIGN *CR1,AHGREN
CREATE !
ASSIGN *LPO, !
ENTER
IF NOT HAL(1001),GO TEND
ERASE GRER101263
ASSIGN *CRO,GREE101263
RESUME
IF NOT DEL(00),GO TEND
ERASE GREE101263
ERASE PROCESSBIN
ERASE AHGREN
TEND
LISTFILE !,*LP
ERASE !
ENDJOB
****
```

Note the routine will pause 1001 when it reads **** at the end of the data file.

Additional routines

In practice it was found that delays can occur in processing one or other of the types of data. To avoid holding up the processing of the other data types, the routine PROCESS was modified to allow sets of results to be inserted. This modified routine is called INSERT. The subroutine TRANS has been replaced by PRANS, which does not rewind or release the input magnetic tape. The routine assumes there will be both input and output magnetic tapes, so TCHECK(K) has been extracted and the ICL subroutine FILE called in the main routine. The


```
ERASE PATCHBIN
ERASE RUNCARD
TEND
LISTFILE !,*LP
ERASE !
ENDJOB
****
```

In this case magnetic tape, MAGTAPE1 of generation 1, contains 10 sets of results and has errors in sets 3 and 8. The data files are corrected and the corrected data are held in DATA1 and DATA2 respectively. The object program PATCHBIN is in the filestore. The corrected results are written onto MAGTAPE1 of generation 2.

TABLE 6.6.1 ARRANGEMENT OF DATA ON THE PROCESSED DATA TAPE

KTYPE, KSITE, KDATE	Record Key KTYPE = 1, KSITE = 2, KDATE = 0
IMAX(Q(I), I=1, IMAX)	Grendon Underwood Discharge Table
KTYPE, KSITE, KDATE	Record Key KTYPE = 2, KSITE = 2, KDATE = 0
NY, NX, ((M(I, J), J=1, NX), I=1, NY)	Grendon Underwood Raingauge matrix
KTYPE, KSITE, KDATE	Record Key KTYPE = 1, KSITE = 2, KDATE = 1063
CONTROL CARD	Grendon Underwood Streamflow October 1963
RUN(K), K=1, MF	Runoff for 01 October 1963
.	
RUN(K), K=1, MF	Runoff for 31 October 1963
.	
.	
.	
KTYPE, KSITE, KDATE	Record Key KTYPE = 2, KSITE = 2, KDATE = 1063
CONTROL CARD	Grendon Underwood Rainfall October 1963
AREA CARD(S)	
AR(L), L=1, ME	Rainfall for 01 October 1963
.	
.	
AR(L), L=1, ME	Rainfall for 31 October 1963
.	
.	
.	
KTYPE, KSITE, KDATE	Record Key KTYPE = 3, KSITE = 2, KDATE = 1063
CONTROL CARD	Grendon Underwood Evaporation October 1963
E01, E03, ET3, ET4	Evaporation for 01 October 1963
.	Evaporation for 31 October 1963
.	
.	
.	
.	Evaporation for November and December 1963

TABLE 6.6.2 MAIN PROCESSING

Run card format

Item	Symbol	Format	Columns	Remarks
Tapes used	K	I1	1	
Filename of magnetic tape used for input	MFILE1	2A8	2-17	Max of 12 characters left justified
Generation number of input tape	MG1	I4	18-21	Range 1-3
Number of sets to be transferred from the input tape to the output tape	NSETS1	I5	22-26	
Filename of magnetic tape used for output	MFILE2	2A8	27-42	As for MFILE1
Generation number of output tape	MG2	I4	43-46	As for MG1
Number of Sets to be appended to the output tape	NSETS2	I5	47-51	

MAG TAPE : K14RESULT1
 GENERATION : 2
 DATE : 03/09/73

KTYPE	KSITE	KDATE	
2	14	0	TRANSFERRED
1	14	158	TRANSFERRED
1	14	258	TRANSFERRED
1	14	358	TRANSFERRED
1	14	458	TRANSFERRED
1	14	558	TRANSFERRED
1	14	658	TRANSFERRED
2	14	158	TRANSFERRED
2	14	258	TRANSFERRED
2	14	358	TRANSFERRED
2	14	458	TRANSFERRED
2	14	558	TRANSFERRED
2	14	658	TRANSFERRED
3	15	158	PATCHED
3	15	258	PATCHED
3	15	358	PATCHED
3	15	458	PATCHED
3	15	558	PATCHED
3	15	658	PATCHED
1	14	758	TRANSFERRED
1	14	858	TRANSFERRED
1	14	958	TRANSFERRED
1	14	1058	TRANSFERRED
1	14	1158	TRANSFERRED
1	14	1258	TRANSFERRED
2	14	758	TRANSFERRED
2	14	858	TRANSFERRED
2	14	958	TRANSFERRED
2	14	1058	TRANSFERRED
2	14	1158	TRANSFERRED
2	14	1258	TRANSFERRED
3	15	758	PATCHED
3	15	858	PATCHED
3	15	958	PATCHED
3	15	1058	PATCHED
3	15	1158	PATCHED
3	15	1258	PATCHED
1	14	159	TRANSFERRED
1	14	259	TRANSFERRED
1	14	359	TRANSFERRED
1	14	459	TRANSFERRED
1	14	559	TRANSFERRED
1	14	659	TRANSFERRED
2	14	159	TRANSFERRED
2	14	259	TRANSFERRED
	14	359	TRANSFERRED
		459	TRANSFERRED
			TRANSFERRED
			TRANSFERRED

TABLE 6.6.4 MAIN PROCESSING
Additional run card format

Item	Symbol	Format	Columns	Remarks
Number of sets to be transferred from input tape to output tape	NSETS1	I5	1-5	
Number of sets to be inserted or patched and skipped	NSETS2	I5	6-10	

6.7 DISPLAY ROUTINES

Line printer displays

The routines involved are named:

TABLST	lists any flow calibration table held on the processed data tape. An example is given in Table 6.7.1.
MATRIXLIST	lists any raingauge distribution matrix held on the processed data tape. An example is given in Table 6.7.2.
DISPLAY	lists the contents of the control cards and daily totals of flow rainfall and evaporation data for any month held on the Processed data tape. An example is given in Tables 6.7.3a, b, c, d.
DISPDAILY	lists the summary sheet only of the above Table 6.7.3d.
FLOWPRT	lists the actual flow values, at a frequency indicated by JFREQ on the control card, for every day of any month held on the processed data tape. An example is given in Table 6.7.4.
RAINPRT	lists the actual rainfall values, at a frequency indicated by JEFREQ on the control card, for every day of any month held on the processed data tape. An example is given in Table 6.7.5.

Input

Stream 3 reads the RUN CARDS from card reader zero (CR0). The initial RUN CARD assigns the appropriate magnetic tape to input stream 4 by the ICL subroutine FILE. The format of the run card is given in Table 6.7.6. Further RUN CARDS control the choice of tables or months of data to be listed. The formats are given in Tables 6.7.7 or 6.7.8 respectively.

Output

Stream 2 is assigned to lineprinter zero (LP0)
Stream 1 is assigned to lineprinter one (LP1) only in DISPLAY.

Running the routines

To run any of the display routine the following files are required in the filestore:

Object file
Run Control file

The output file(s) and magnetic tape are assigned during the run. Table 6.7.9 shows the instructions required to list the information used as examples in this section of the report.

Graphical Displays

Since the data are processed and stored on a 1904S computer and a soft-ware package for the plotter is available on the 1906A computer, it is necessary first to transfer the data between computer systems. This is achieved by using the following GEORGE instructions to transfer the data onto a pre-labelled magnetic tape.

```
JOB  job name, :CATCH, T????  
TRAPGO magnetic tape name, WRITE  
LOAD :LIB.PROGRAM XRMM  
ONLINE *MT0(READ), (processed data tape number, processed tape name(g))  
ONLINE *MT1(WRITE), (magnetic tape number, magnetic tape name)  
ONLINE *CR0  
CREATE !  
ASSIGN *LP0, !  
LISTFILE !, *LP  
ERASE !  
ENTER 1  
INP (processed data tape number: processed data tape name)  
OUT (magnetic tape number: magnetic tape name)  
****  
????
```

The second stage of the procedure is to run the routine GRAPHIC held in a file on the 1906A called :VEHY03.IHDISPLAY with the pre-labelled magnetic tape as input. In addition a pair of data cards whose format is given in Table 6.7.10, are necessary for each data batch (of up to 6 months) being plotted. These define the number of months in each batch together with the input and output frequencies.

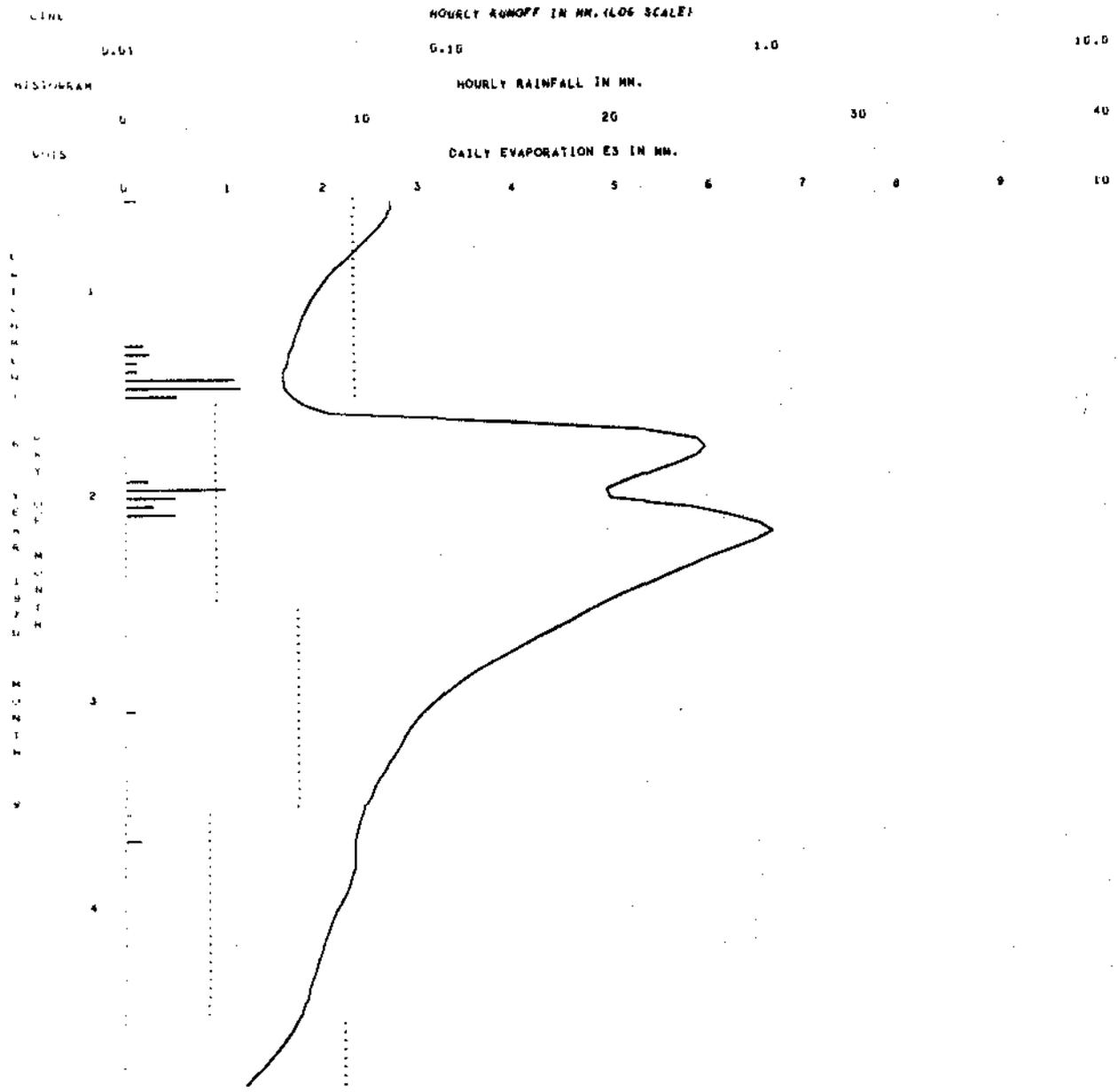
A typical job would require the following GEORGE instructions:

```
JOB jobname,:VEHY03
INPUT GRAPHS,T????
```

data cards (see table 6.7.10)

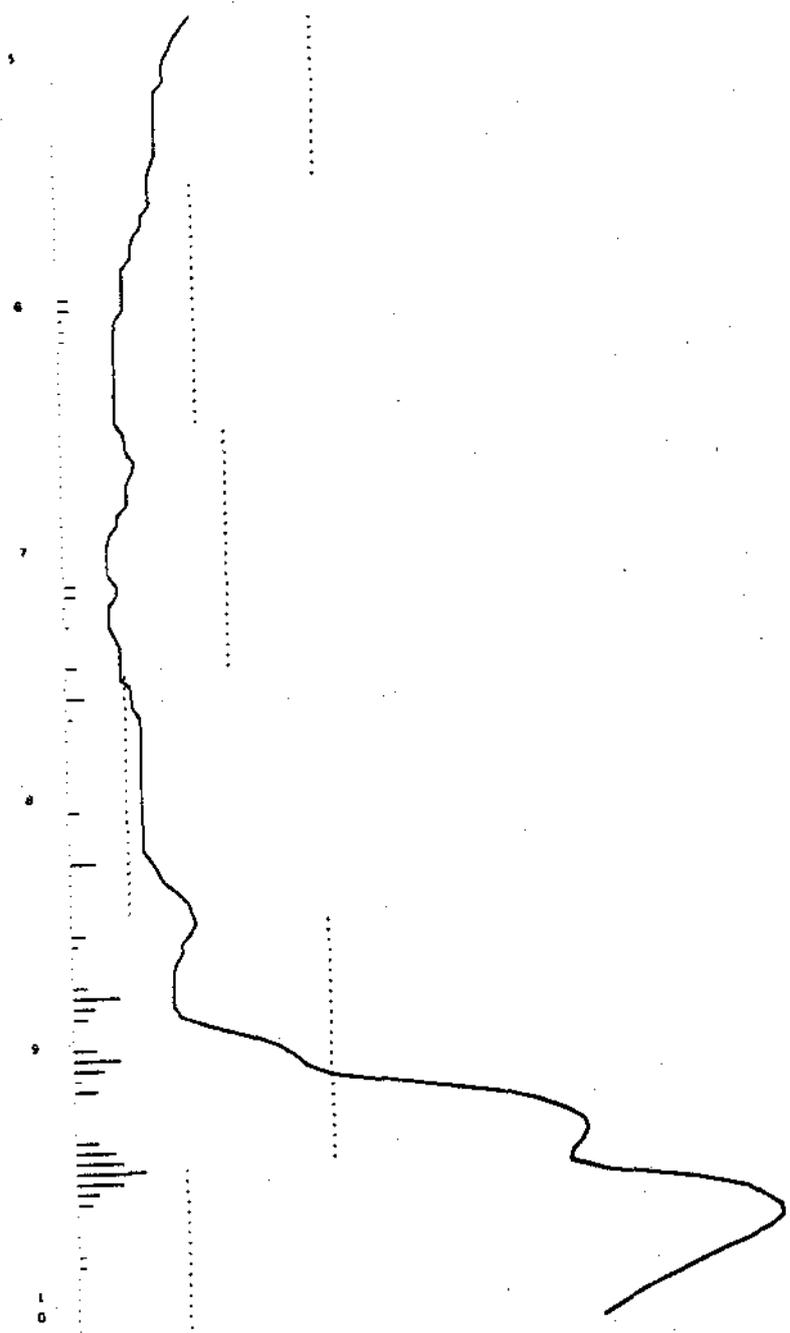
```
????
MEDIA TAPE7,2,(magnetic tape number)
JOBTIME 300 SECS          [ allow 5 secs per month ]
OBEY :SC4020.FORSC4020,PARAM(READGRAPHS,LOADDISPBIN,-
#??(DISPLAY 2,TAPE magnetic tape number IS IN POS. tape storage location),-
#??(ONLINE *MT0,(magnetic tape number)),-
TIME 300 SECS)
ENDJOB
****
```

An example of the graphical display is shown in Figure 10



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U. S. ARMY ENGINEERING CENTER
FORT BELLEVILLE, ILLINOIS



1170	3.0174	3.0267	3.0360	3.0453	3.0546	3.0639	3.0732	3.0825	3.0918
1171	3.0183	3.0276	3.0369	3.0462	3.0555	3.0648	3.0741	3.0834	3.0927
1172	3.0192	3.0285	3.0378	3.0471	3.0564	3.0657	3.0750	3.0843	3.0936
1173	3.0201	3.0294	3.0387	3.0480	3.0573	3.0666	3.0759	3.0852	3.0945
1174	3.0210	3.0303	3.0396	3.0489	3.0582	3.0675	3.0768	3.0861	3.0954
1175	3.0219	3.0312	3.0405	3.0498	3.0591	3.0684	3.0777	3.0870	3.0963
1176	3.0228	3.0321	3.0414	3.0507	3.0600	3.0693	3.0786	3.0879	3.0972
1177	3.0237	3.0330	3.0423	3.0516	3.0609	3.0702	3.0795	3.0888	3.0981
1178	3.0246	3.0339	3.0432	3.0525	3.0618	3.0711	3.0804	3.0897	3.0990
1179	3.0255	3.0348	3.0441	3.0534	3.0627	3.0720	3.0813	3.0906	3.0999
1180	3.0264	3.0357	3.0450	3.0543	3.0636	3.0729	3.0822	3.0915	3.1008
1181	3.0273	3.0366	3.0459	3.0552	3.0645	3.0738	3.0831	3.0924	3.1017
1182	3.0282	3.0375	3.0468	3.0561	3.0654	3.0747	3.0840	3.0933	3.1026
1183	3.0291	3.0384	3.0477	3.0570	3.0663	3.0756	3.0849	3.0942	3.1035
1184	3.0300	3.0393	3.0486	3.0579	3.0672	3.0765	3.0858	3.0951	3.1044
1185	3.0309	3.0402	3.0495	3.0588	3.0681	3.0774	3.0867	3.0960	3.1053
1186	3.0318	3.0411	3.0504	3.0597	3.0690	3.0783	3.0876	3.0969	3.1062
1187	3.0327	3.0420	3.0513	3.0606	3.0699	3.0792	3.0885	3.0978	3.1071
1188	3.0336	3.0429	3.0522	3.0615	3.0708	3.0801	3.0894	3.0987	3.1080
1189	3.0345	3.0438	3.0531	3.0624	3.0717	3.0810	3.0903	3.0996	3.1089
1190	3.0354	3.0447	3.0540	3.0633	3.0726	3.0819	3.0912	3.1005	3.1098
1191	3.0363	3.0456	3.0549	3.0642	3.0735	3.0828	3.0921	3.1014	3.1107
1192	3.0372	3.0465	3.0558	3.0651	3.0744	3.0837	3.0930	3.1023	3.1116
1193	3.0381	3.0474	3.0567	3.0660	3.0753	3.0846	3.0939	3.1032	3.1125
1194	3.0390	3.0483	3.0576	3.0669	3.0762	3.0855	3.0948	3.1041	3.1134
1195	3.0399	3.0492	3.0585	3.0678	3.0771	3.0864	3.0957	3.1050	3.1143
1196	3.0408	3.0501	3.0594	3.0687	3.0780	3.0873	3.0966	3.1059	3.1152
1197	3.0417	3.0510	3.0603	3.0696	3.0789	3.0882	3.0975	3.1068	3.1161
1198	3.0426	3.0519	3.0612	3.0705	3.0798	3.0891	3.0984	3.1077	3.1170
1199	3.0435	3.0528	3.0621	3.0714	3.0807	3.0900	3.0993	3.1086	3.1179
1200	3.0444	3.0537	3.0630	3.0723	3.0816	3.0909	3.1002	3.1095	3.1188
1201	3.0453	3.0546	3.0639	3.0732	3.0825	3.0918	3.1011	3.1104	3.1197
1202	3.0462	3.0555	3.0648	3.0741	3.0834	3.0927	3.1020	3.1113	3.1206
1203	3.0471	3.0564	3.0657	3.0750	3.0843	3.0936	3.1029	3.1122	3.1215
1204	3.0480	3.0573	3.0666	3.0759	3.0852	3.0945	3.1038	3.1131	3.1224
1205	3.0489	3.0582	3.0675	3.0768	3.0861	3.0954	3.1047	3.1140	3.1233
1206	3.0498	3.0591	3.0684	3.0777	3.0870	3.0963	3.1056	3.1149	3.1242
1207	3.0507	3.0600	3.0693	3.0786	3.0879	3.0972	3.1065	3.1158	3.1251
1208	3.0516	3.0609	3.0702	3.0795	3.0888	3.0981	3.1074	3.1167	3.1260
1209	3.0525	3.0618	3.0711	3.0804	3.0897	3.0990	3.1083	3.1176	3.1269
1210	3.0534	3.0627	3.0720	3.0813	3.0906	3.0999	3.1092	3.1185	3.1278
1211	3.0543	3.0636	3.0729	3.0822	3.0915	3.1008	3.1101	3.1194	3.1287
1212	3.0552	3.0645	3.0738	3.0831	3.0924	3.1017	3.1110	3.1203	3.1296
1213	3.0561	3.0654	3.0747	3.0840	3.0933	3.1026	3.1119	3.1212	3.1305
1214	3.0570	3.0663	3.0756	3.0849	3.0942	3.1035	3.1128	3.1221	3.1314
1215	3.0579	3.0672	3.0765	3.0858	3.0951	3.1044	3.1137	3.1230	3.1323
1216	3.0588	3.0681	3.0774	3.0867	3.0960	3.1053	3.1146	3.1239	3.1332
1217	3.0597	3.0690	3.0783	3.0876	3.0969	3.1062	3.1155	3.1248	3.1341
1218	3.0606	3.0699	3.0792	3.0885	3.0978	3.1071	3.1164	3.1257	3.1350
1219	3.0615	3.0708	3.0801	3.0894	3.0987	3.1080	3.1173	3.1266	3.1359
1220	3.0624	3.0717	3.0810	3.0903	3.0996	3.1089	3.1182	3.1275	3.1368
1221	3.0633	3.0726	3.0819	3.0912	3.1005	3.1098	3.1191	3.1284	3.1377
1222	3.0642	3.0735	3.0828	3.0921	3.1014	3.1107	3.1200	3.1293	3.1386
1223	3.0651	3.0744	3.0837	3.0930	3.1023	3.1116	3.1209	3.1302	3.1395
1224	3.0660	3.0753	3.0846	3.0939	3.1032	3.1125	3.1218	3.1311	3.1404
1225	3.0669	3.0762	3.0855	3.0948	3.1041	3.1134	3.1227	3.1320	3.1413
1226	3.0678	3.0771	3.0864	3.0957	3.1050	3.1143	3.1236	3.1329	3.1422
1227	3.0687	3.0780	3.0873	3.0966	3.1059	3.1152	3.1245	3.1338	3.1431
1228	3.0696	3.0789	3.0882	3.0975	3.1068	3.1161	3.1254	3.1347	3.1440
1229	3.0705	3.0798	3.0891	3.0984	3.1077	3.1170	3.1263	3.1356	3.1449
1230	3.0714	3.0807	3.0900	3.0993	3.1086	3.1179	3.1272	3.1365	3.1458
1231	3.0723	3.0816	3.0909	3.1002	3.1095	3.1188	3.1281	3.1374	3.1467
1232	3.0732	3.0825	3.0918	3.1011	3.1104	3.1197	3.1290	3.1383	3.1476
1233	3.0741	3.0834	3.0927	3.1020	3.1113	3.1206	3.1299	3.1392	3.1485
1234	3.0750	3.0843	3.0936	3.1029	3.1122	3.1215	3.1308	3.1401	3.1494
1235	3.0759	3.0852	3.0945	3.1038	3.1131	3.1224	3.1317	3.1410	3.1503
1236	3.0768	3.0861	3.0954	3.1047	3.1140	3.1233	3.1326	3.1419	3.1512
1237	3.0777	3.0870	3.0963	3.1056	3.1149	3.1242	3.1335	3.1428	3.1521
1238	3.0786	3.0879	3.0972	3.1065	3.1158	3.1251	3.1344	3.1437	3.1530
1239	3.0795	3.0888	3.0981	3.1074	3.1167	3.1260	3.1353	3.1446	3.1539
1240	3.0804	3.0897	3.0990	3.1083	3.1176	3.1269	3.1362	3.1455	3.1548
1241	3.0813	3.0906	3.0999	3.1092	3.1185	3.1278	3.1371	3.1464	3.1557
1242	3.0822	3.0915	3.1008	3.1101	3.1194	3.1287	3.1380	3.1473	3.1566
1243	3.0831	3.0924	3.1017	3.1110	3.1203	3.1296	3.1389	3.1482	3.1575
1244	3.0840	3.0933	3.1026	3.1119	3.1212	3.1305	3.1398	3.1491	3.1584
1245	3.0849	3.0942	3.1035	3.1128	3.1221	3.1314	3.1407	3.1500	3.1593
1246	3.0858	3.0951	3.1044	3.1137	3.1230	3.1323	3.1416	3.1509	3.1602
1247	3.0867	3.0960	3.1053	3.1146	3.1239	3.1332	3.1425	3.1518	3.1611
1248	3.0876	3.0969	3.1062	3.1155	3.1248	3.1341	3.1434	3.1527	3.1620
1249	3.0885	3.0978	3.1071	3.1164	3.1257	3.1350	3.1443	3.1536	3.1629
1250	3.0894	3.0987	3.1080	3.1173	3.1266	3.1359	3.1452	3.1545	3.1638
1251	3.0903	3.0996	3.1089	3.1182	3.1275	3.1368	3.1461	3.1554	3.1647
1252	3.0912	3.1005	3.1098	3.1191	3.1284	3.1377	3.1470	3.1563	3.1656
1253	3.0921	3.1014	3.1107	3.1200	3.1293	3.1386	3.1479	3.1572	3.1665
1254	3.0930	3.1023	3.1116	3.1209	3.1302	3.1395	3.1488	3.1581	3.1674
1255	3.0939	3.1032	3.1125	3.1218	3.1311	3.1404	3.1497	3.1590	3.1683
1256	3.0948	3.1041	3.1134	3.1227	3.1320	3.1413	3.1506	3.1599	3.1692
1257	3.0957	3.1050	3.1143	3.1236	3.1329	3.1422	3.1515	3.1608	3.1701
1258	3.0966	3.1059	3.1152	3.1245	3.1338	3.1431	3.1524	3.1617	3.1710
1259	3.0975	3.1068	3.1161	3.1254	3.1347	3.1440	3.1533	3.1626	3.1719
1260	3.0984	3.1077	3.1170	3.1263	3.1356	3.1449	3.1542	3.1635	3.1728
1261	3.0993	3.1086	3.1179	3.1272	3.1365	3.1458	3.1551	3.1644	3.1737
1262	3.1002	3.1095	3.1188	3.1281	3.1374	3.1467	3.1560	3.1653	3.1746
1263	3.1011	3.1104	3.1197	3.1290	3.1383	3.1476	3.1569	3.1662	3.1755
1264	3.1020	3.1113	3.1206	3.1299	3.1392	3.1485	3.1578	3.1671	3.1764
1265	3.1029	3.1122	3.1215	3.1308	3.1401	3.1494	3.1587	3.1680	3.1773
1266	3.1038	3.1131	3.1224	3.1317	3.1410	3.1503	3.1596	3.1689	3.1782
1267	3.1047	3.1140	3.1233	3.1326	3.1419	3.1512	3.1605	3.1698	3.1791
1268	3.1056	3.1149	3.1242	3.1335	3.1428	3.1521	3.1614	3.1707	3.1800
1269	3.1065	3.1158	3.1251	3.1344	3.1437	3.1530	3.1623	3.1716	3.1809
1270	3.1074	3.1167	3.1260	3.1353	3.1446	3.1539	3.1632	3.1725	3.1818
1271	3.1083	3.1176	3.1269	3.1362	3.1455	3.1548	3.1641	3.1734	3.1827
1272	3.1092	3.1185	3.1278	3.1371	3.1464	3.1557	3.1650	3.1743	3.1836
1273	3.1101	3.1194	3.1287	3.1380	3.1473	3.1566	3.1659	3.1752	3.1845
1274	3.1110	3.1203	3.1296	3.1389	3.1482	3.1575	3.1668	3.1761	3.1854
1275	3.1119	3.1212	3.1305	3.1398	3.1491	3.1584	3.1677	3.1770	3.1863
1276	3.1128	3.1221	3.1314	3.1407	3.1500	3.1593	3.1686	3.1779	3.1872
1277	3.1137	3.1230	3.1323	3.1416	3.1509	3.1602	3.1695	3.1788	3.1881
1278	3.1146	3.1239	3.1332	3.1425	3.1518	3.1611	3.1704	3.1797	3.1890
1279	3.1155	3.124							

WATER 1965

CATCHMENT NUMBER 2

DAY	WINDSPEED MPH	RAINFALL MM.	EO1 MM.	EO2 MM.	ETS MM.	ETA MM.
1	0.05	4.4	0.8	0.8	0.7	0.0
2	0.30	1.3	0.7	0.7	0.5	0.0
3	0.15	3.0	1.3	1.2	1.1	0.0
4	0.11	0.0	1.8	1.6	1.2	0.0
5	0.17	4.7	0.7	0.5	0.5	0.0
6	0.27	7.7	0.4	0.4	0.3	0.0
7	0.30	0.5	0.9	0.7	0.4	0.0
8	0.31	1.2	1.4	1.3	1.1	0.0
9	0.27	0.0	1.3	1.1	0.7	0.0
10	0.11	0.0	1.7	1.1	0.9	0.0
11	0.15	0.0	1.1	1.1	0.8	0.0
12	0.11	0.0	0.7	0.6	0.2	0.0
13	0.11	0.0	1.7	1.5	1.3	0.0
14	0.11	1.9	1.0	0.9	0.7	0.0
15	0.13	1.5	0.4	0.6	0.5	0.0
16	0.12	1.7	0.2	0.2	0.1	0.0
17	0.14	0.0	1.0	0.9	0.7	0.0
18	0.17	0.0	1.1	1.2	0.9	0.0
19	0.11	0.7	1.4	1.4	1.2	0.0
20	0.11	1.2	0.6	0.5	0.2	0.0
21	0.30	1.1	2.0	1.8	1.7	0.0
22	0.04	0.0	0.5	0.4	0.2	0.0
23	0.04	0.0	0.8	0.8	0.4	0.0
24	0.08	0.0	0.4	0.4	0.5	0.0
25	0.13	1.0	0.7	0.6	0.6	0.0
26	0.14	1.0	0.7	0.6	0.4	0.0
27	0.13	0.0	0.5	0.4	0.2	0.0
28	0.05	0.0	0.3	0.2	0.2	0.0
29	0.01	0.0	0.4	0.4	0.4	0.0
30	0.07	7.9	0.8	0.7	0.7	0.0
31	1.57	13.9	0.0	0.0	0.0	0.0
TOTAL	0.5	19.7	27.3	24.5	19.5	0.0

SUM OF POSITIVE DAILY EVAPORATION VALUES ONLY

 * 2 1965 *

.....
STREAMFLOW CONTROL INFORMATION
.....

CATCHMENT NO. 2
.....
MONTH AND YEAR 1063
.....
NO. OF DAYS 31
CATCHMENT AREA 1256.1 HECTARES
ZERO CORRECTION 0
HIGHEST VALUE 843
INTERPOLATION INDEX 2 ON THE INTERVAL ; MID-INTERVAL
INPUT FREQUENCY 1 15 MINS ; 30 MINS ; 1 HOUR ; 2 HOURS ; 3 HOURS ; 6 HOURS ; 12 HOURS ; 24 HOURS
OUTPUT FREQUENCY 3 - - - - - BITTO - - - - -
UNIT INDEX 1 1/1000 FT ; MM ; 1/100000 INK PER HOUR ; 1/100 FT

.....

.....
* 2 1063 *
.....

EVAPORATION CONTROL INFORMATION

CATCHMENT NO. 2

MONTH AND YEAR 1963

NO. OF DAYS 31

CATCHMENT AREA 1456 HECTARES

LATITUDE 51 DEGREES (N = N, S = S)

ALTITUDE 67 METRES

REGRESSION CONSTANTS

A 0.00
B 0.01
C 0.00

ALBEDO 0.25

TEMPERATURE INDEX 1 DEGS F - C

WIND INDEX 1 MILES ; KM ; KM/HR (450 CUMULATIVE)

HT. OF ANEMOMETER 2 METRES

SUN INDEX 1 0 = NO DATA ; HOURS

TOTAL RADIATION INDEX 1 1 = NO DATA ; CALS - MMH ; MI ; COUNTS

NET RADIATION INDEX 1 0 = NO DATA ; CALS - MMH ; MILLICALS ; COUNTS

WIND 1

WINDS 1

INPUT FREQUENCY 1 MORNING ; AND AFTERNOON DRY AND WET BULB READINGS

OUTPUT FREQUENCY A 15 MINS ; 30 MINS ; 1 HOUR ; 2 HOURS ; 3 HOURS ; 6 HOURS ; 12 HOURS ; 24 HOURS

2 1063

HMS OF RUINER OVER 60 MINS PERIODS

DAY

1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
28	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
31	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.005	0.006	0.006	0.009	0.012	0.014	0.014	0.015	0.015	0.015	0.014	0.013

TABLE 6.7.6 DISPLAY

Run Card Format

Item	Symbol	Format	Columns	Remarks
Filename of magnetic tape	MFILE1	2A8	1-16	Max. of 12 characters left justified
Generation Number	MG1	I2	17-18	Range 1-3

TABLE 6.7.7 TABLIST AND MATRIXLIST
Additional run card format

Item	Symbol	Format	Columns	Remarks
Version of table to be listed	NUM	I5	1-5	If more than one table is to be listed, the cards must be in order of the tables on the tape

TABLE 6.7.8 DISPLAY, DISPDAILY, FLOWPRT and RAINPRT
Additional run card formats

CARD 1

Item	Symbol	Format	Columns	Remarks
Number of months to be displayed	NUM	I2	1-2	Range 1-6 0 = end of run
Catchment Number	NSITE	I3	3-5	

CARD 2

Item	Symbol	Format	Columns	Remarks
Months to be displayed	MONTH	6I6	1-36	Max of 6 months in date order

TABLE 6.7.9 EXAMPLE OF GEORGE INSTRUCTIONS FOR DISPLAY ROUTINES

```

JOB DISPLAYS,:CATCH
INPUT GRETAPE(1),T////
GRERESULT1ΔΔΔΔΔΔΔ1
ΔΔΔΔ1
ΔΔΔΔ0
////
INPUT GRETAPE(2),T////
GRERESULT1ΔΔΔΔΔΔΔ1
Δ1ΔΔ2
ΔΔ1063
Δ0ΔΔ0
////
LOAD TABLISTBIN
ASSIGN *CRO,GRETAPE(1)
ASSIGN *LPO,TABLISTOUT
ENTER
LISTFILE TABLISTOUT,*LP
ERASE TABLISTOUT
ERASE TABLISTBIN

LOAD MATLISTBIN
ASSIGN *CRO,GRETAPE(1)
ASSIGN *LPO,MATLISTOUT
ENTER
LISTFILE MATLISTOUT,*LP
ERASE MATLISTOUT
ERASE MATLISTBIN
ERASE GRETAPE(1)

LOAD DISPLAYBIN
ASSIGN *CRO,GRETAPE(2)
ASSIGN *LPO,DISPLAYOUTO
ASSIGN *LP1,DISPLAYOUT1
ENTER
LISTFILE DISPLAYOUTO,*LP
ERASE DISPLAYOUTO
LISTFILE DISPLAYOUT1,*LP
ERASE DISPLAYOUT1
ERASE DISPLAYBIN

LOAD FLOWPRTBIN
ASSIGN *CRO,GRETAPE(2)
ASSIGN *LPO,FLOWPRTOUT
ENTER
LISTFILE FLOWPRTOUT,*LP
ERASE FLOWPRTOUT
ERASE FLOWPRTBIN

LOAD RAINPRTBIN
ASSIGN *CRO,GRETAPE(2)
ASSIGN *LPO,RAINPRTOUT
ENTER
LISTFILE RAINPRTOUT,*LP
ERASE RAINPRTOUT
ERASE RAINPRTBIN
ERASE GRETAPE(2)
ENDJOB
****

```

TABLE 6.7.10 GRAPH PLOTTING

Run Card Formats

	Item	Symbol	Format	Columns
CARD A	No. of months in batch	NUM	I5	1-5
	Flow frequency	MEV	I5	6-10
	RAIN frequency	MER	I5	11-15
CARD B	Month numbers in batch on CARD A eg. 000167 = Jan 1967	MONTHS (I)	12I6	1-6 7-12 etc

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These programs have been developed at the Institute of Hydrology over a period of several years. In fact the need for a comprehensive system which included quality control became apparent when the programme of research into the techniques of mathematical modelling on a catchment scale was started in 1967. Consequently, many of the authors' colleagues have contributed in some way to ensure the successful development of the system and its application to the data from a wide variety of catchment studies both in the UK and overseas.

In particular the contribution of A N Mandeville in helping to define the structure of the system and in writing many of the early programs has had a considerable influence on the present form of the system. Also the continued help of the catchment office staff and particularly S W Smith has enabled improved office procedures to be defined which are consistent with the quality of the data. More recently J R Douglas has developed a system for translating chart records through a chart digitiser and although this forms the subject of a separate report, it is an integral contribution to the overall processing system.

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