INSTITUTE
OF
HYDROLOGY

THE PROCESSING OF HYDROLOGICAL DATA

by

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Abstract

A description of the processes involved in converting and combining data from a range of field records to give estimates of hydrological variables. These processes include quality control, editing and data storage. Special emphasis is given to data recorded on cassettes by a Microdata logger.

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1. INTRODUCTION

The advent of more detailed and varied hydrological investigations has led to the demand for frequent records of a wide range of variables. These include rainfall, runoff, and evaporation estimates for hydrological modelling and water resources studies, soil moisture for detailed sub-surface water movement studies, and the meteorological variables such as solar radiation, temperature, humidity, and wind run for the estimation of evaporation rates.

Measurements are collected from several types of instruments in a variety of ways ranging from manual readings for soil moisture, the meteorological variables, and period rainfall; to recording on cassette tape in the case of automatic weather stations, water level recorders, and rainfall recorders. In some instances, measurements from a point source are sufficient but quite often areal estimates of variables are needed; these require networks of instruments and much data manipulation. Often the measured variable has to be converted into a more commonly used form before it can be used in hydrological investigations.

Because of the increasing amount of data being collected and the number of manipulations required, it was recognised several years ago that there was a real requirement for an efficient and speedy computer-based data processing system at the Institute of Hydrology. Several systems were set up, some as yet unpublished, each dealing with specific types of data. Most of these systems include some form of quality control to minimise error due to instrument failure or observer error.

Plinston and Hill (1974) describe a system for processing streamflow, rainfall and evaporation data which has been used successfully at the Institute for several years for both British and overseas catchments. The system includes a comprehensive quality control of the "raw" data (stage values, rainfall, and the meteorological variables) and routines for calculating areal estimates of runoff, rainfall and evaporation for pre-determined frequencies. These areal estimates are held on a "processed" data tape whilst the "raw" data are held in temporary disc files for subsequent transfer to a "raw" data tape. Routines are available to produce summary listings of the "processed" data and to produce a disc or tape file suitable for modelling purposes. Some pre-processing is required to ensure that the data are in a form suitable for quality control and subsequent processing. Evaporation estimates are calculated using data from manually-read meteorological stations only and there is no facility to handle data recorded by the new logger and cassette tape facilities.

Roberts (1972) describes a system for the quality control and processing of soil moisture data collected using a manually-read neutron probe. The "raw" data are quality-controlled and expressed as water contents through the soil profile. Routines have been written to provide summary listings and graphic displays of the derived values. When the data have been deemed to be "correct" they are written to temporary files for subsequent transfer to permanent storage on magnetic tape.

Smith and Wikramaratna (1978) describe a system for processing data collected in groundwater studies (water levels, water chemistry, pumping tests). In this system, the data are held on direct access files, the location of data values being determined by means of a station index file. Several application programs to analyse, model and output the data in tabular form have been written.

Although the systems described briefly above are excellent in dealing with the data for which they were designed, it was felt that a new system was necessary:

(i) To process all the data being collected at the Institute using one system thus ensuring a common level of quality control and user access.

(ii) To make use of the data being recorded by the new logging devices (Strangeways, 1972; Strangeways and Templeman, 1974).

(iii) To introduce more refined techniques of quality control and editing and to provide more flexibility to the user when accessing the final data values.

Much of this report deals specifically with processing data from the new logging devices although the conventional recording systems (Plinston and Hill, 1974) play an important part in providing back-up facilities in the case of instrument malfunction. Also, much of the software, especially that dealing with quality control, used in the old systems was transferred with little or no modification to this new system, the main changes being in the input and output parts.

Some important refinements have been introduced into this data processing system. One such refinement is that of data labelling whereby each data value has an associated quality index, the value of this index being set as a result of tests carried out in the quality control routines. But labelling is used only for those data which are recorded at sufficient frequency and for which the quality control routines are sufficiently sophisticated for such a scheme to be effective. If data conversions or the summation or averaging of data values are necessary, the quality indices of the original data values are passed on to the new calculated values.

Another concept used in this data processing system is that of automatic data correction. This is useful when correcting spurious values in an otherwise steady trend and it minimises the amount of manual data editing that has to be carried out.

The use of the new logging devices means that frequent observations of the various recorded values are available. In particular, the automatic weather stations provide records of the meteorological variables at a frequency of five minutes thus making it possible to calculate improved estimates of open water evaporation and evapotranspiration than was possible using data collected only from manually-read stations.

In order to make the data freely available to the various users, it was decided to design a disc-based data processing system where the "processed" data are stored in direct access files. This means that any records may be accessed directly without the need to read through consecutive records until the required data are found. Where necessary, areal estimates are calculated and these are stored together with the data from individual sites/instruments. All the file manipulations are done within the software to simplify the accessing of data files, and all that is required of the user is to specify the data records required.

The system has been written in standard ASCII FORTRAN for a UNIVAC 1108. For transfer to a different computer system, it is likely that some modification, particularly to the input and output routines, will be necessary.

2. SYSTEM DESCRIPTION

2.1 Introduction

One major problem in designing a data processing system for hydrological purposes is the variety of instrumentation used. Some, such as rain gauges, record one single variable; others such as weather stations record several different variables. Some record on a set time basis while others are read manually at variable time intervals. Some instruments, such as neutron probes, record several values of the same variable at the same location. In some cases, instruments that measure the same variable record on different media, and different pre-processing routines are required to bring the data to a common format. It is clear, therefore, that there must be some means of specifying not only the type of instrument, but also the recorder type, its recording frequency, and the type of variable it measures.

Another problem is that of storage and accessing of data. The volume of data is such that there has to be some means of indicating where on the computer the data from the various instruments are stored.

Most of the quality control and conversion routines require standard values, derived for each individual instrument. These values must be readily accessible on the computer in order that those routines may be carried out.

All of these problems are solved by setting up a site directory which is a computer file containing all of the relevant information for all of the instruments currently being used. Before the data from any instrument can be processed using this system, an entry for that particular instrument must exist in the site directory. The information stored for each instrument in the site directory is described in the next section.

The rest of the data processing system consists of a number of well defined procedures, most of which require access to the site directory. Some of the procedures also require access to various calibration and network tables; this is done automatically using pointers from the site directory. A generalised flowchart of the new data processing system is given in Figure 2.1.

Much of the data currently being used at the Institute are collected from instruments connected to a Microdata logger and recorded automatically on cassette tape. These instruments include weather stations, well level recorders, and rainfall gauges.

The processing of those data recorded on cassette tape are carried out in a similar manner for all instrument types. A flow chart showing the various stages of this processing is given in Figure 2.2.

A suite of computer programs has been written to process the data once they have been transferred to the UNIVAC. In the main routine, a number of options are available, these options being determined by the value of INPUT, an integer specified by the user. INPUT can take the values 1, 2, 3, or 4.

INPUT = 1. This signifies the quality control of data in logger steps transferred to a file on the UNIVAC via a seven-track tape. Normally several cassette lengths are processed at the same time. Accompanying each cassette length is an information record on punched cards; this contains data identifiers and quality control aids abstracted from the field data form (Section 2.3). Prior to quality control, the data are translated into real units using factors in the site directory (Section 2.2) and on the information record. The data are quality controlled and, depending on the results, two options are available.

(i) If the data are 'error free' and no manual intervention is necessary, the data are stored on magnetic tape, converted into their required units and stored on direct access files.

(ii) If errors are found which cannot be corrected automatically, the data are written to a named temporary file for manual editing.

INPUT ≠ 1. This signifies the editing of data written to a named temporary file following a quality control run. Editing of the information record or of the individual data values may be carried out. Following this the data may be re-submitted to the quality control routines or may be assumed to be correct, and converted into the required units and stored. This is controlled by the value of INPUT.

The various stages in the processing will be described more fully in the relevant sections.

2.2 Site directory

The site directory is contained in a direct access file on the computer system. It consists of a number of records, each of which contains information for one individual instrument/site. The information held in each record may be split into two parts: control information and standard/conversion values.

Control information

IGRDEW - the east west grid reference of the site
IGRDNS - the north south grid reference of the site
IALT - the altitude of the site
BSITE - the local site name
ICYC - not used at present
INST - the instrument type

KREC - the recorder type
IFREQ - the recording frequency
JFREQ - the required output frequency
ICHANN - the number of variables recorded by the instrument, except in the case of the neutron probe
ISTART - the starting date of data from the site
JSTART - the finish date of data from the site.

Standard/Conversion values

Each variable recorded by the instrument has the following:

ITYPE - the variable/data type
CHAN(12) - up to 12 standard/conversion values, except in the case of the neutron probe.

When referencing data from any particular site, whether it be for quality control, data storage or retrieval purposes, it is necessary to specify the local site name. This local site name will be tested consecutively against those appearing in the site directory. If no such site name is found, an error message will be output and processing discontinued. However, on finding the correct site name, the required control information and standard/conversion values may be accessed.

The number of the record containing the correct site name is used to identify the names of data files associated with the site. If, for instance, record number 52 in the site directory contains the required local site name, then 0052 is known as the internal site number of the site and the 1977 processed data for this site will be held in a file whose filename is 005277000000. This is also useful in accessing temporary data files during the quality control stage; for example, data from the site with internal site number 0004, beginning on 4.1.79 will be held in a temporary file called 000404017901. This data will be held in this temporary file until it has been quality controlled, converted into useable units, and stored in 000479000000, at which point file 000404017901 will be deleted. All file assignments and deletions are carried out within the FORTRAN programs. This is particularly useful when dealing with data from a number of different sites/instruments because file names need not be specified.

2.3 Data collection

One of the major facets of data collection, that of site/instrument identification has already been discussed. The other major requirement of data identification is that of time and date at which the variables were measured.

In the case of a single measurement, a single time and date is required: for automatic recorders, the start and finish time and date are required so that the time and date of individual records may be calculated using the recording frequency found in the site directory. The finish time and date is used to verify the quantity of data measured by the recorder.

When visiting sites having automatic recorders, it is sometimes possible to carry out manual measurements of the variables being recorded. This is extremely useful for quality control purposes and is most often carried out at the beginning and end of a period during which the automatic instrument was recording. In the case of rainfall measurement, the catch in the check gauge is the only certain quality control check of the total rainfall recorded by an automatic raingauge. Field data forms have been designed so that the data identification and any quality control aids may be noted. For those various data recorded using the microdata loggers, a single form is used, as shown in Figure 2.3.

For those data recorded manually, forms have been designed in such a way that no further re-coding is necessary before the data are transferred into a computer compatible medium. These various forms will be described in the relevant sections. The field data forms, together with any recorded data, are sent to Wallingford for further processing.

2.4 Office procedures, pre-processing

It is very unusual if the hydrological data recorded in the field can be fed directly into a computer system without the need for pre-processing. But there are so many different means of recording data in use that it is necessary to have many pre-processing procedures, their complexity depending on the recording medium and on the input peripherals of the computer system.

Data recorded on cassette tape are converted via a Microdata cassette tape reader and a suite of computer programs into computer compatible form. They are then input, together with any data identification and quality control aids punched on computer cards, into the computer system. At the same time a Microdata "logger and tape faults" form is initiated for each cassette tape (Figure 2.4). On this form are noted any errors detected in the data during the various stages of processing. Data recorded manually are usually transferred to punched computer cards prior to input to the computer system.

2.5 Input to the computer system

The UNIVAC 1108 at Rutherford is equipped with a card reader and seven- and nine-track magnetic tape decks. Because of the large amounts of data generated from automatic recorders, these data are generally handled by magnetic tape. This is done by using the Institute's PDP8 computer which has a Microdata cassette tape reader and a seven-track tape deck. The sequence of events is: input to the PDP8 via the cassette tape reader, output to seven-track tape, transfer of tape to the UNIVAC as input to the quality control and processing system (see Figure 2.2).

2.6 Quality control

Many of the quality control routines used in this new system are updated versions of those used previously (Plinston and Hill, 1974; Roberts, 1972).

However, for those data recorded by new instrumentation such as automatic weather stations, it has been necessary to write new quality control routines which will be described later.

Two new concepts have been introduced in this new system, those of data labelling and automatic correction. Data labelling is used to denote the quality of data values. Each data value has a quality index associated with it; this index has the value 3 (good), 2 (suspect) or 1 (bad). These quality indices are set as a result of the quality control tests applied to the data. Once the quality indices have been set, they are stored together with the data values in the processed data files. Any values that are calculated from a number of individual data values will also have quality indices associated with them, these being set according to the quality indices of the individual data values. This applies both to totals and average values and to different variables calculated from the original measured variables, for example, specific humidities from wet bulb depressions. This data labelling is used only on those data which are measured at sufficient frequency so that such a quality control scheme is feasible.

Automatic correction can be carried out during periods of "bad" data for those variables such as river stage, which show a marked trend. It is only used when a smooth, slowly-changing trend is expected. Any data values synthesised in this way will automatically be given a quality index of 2 (suspect).

Although great efforts have been made to reduce the amount of manual editing to a minimum by the use of automatic correction procedures and the careful selection of acceptable limits in the quality control stage, it is inevitable that some manual intervention will be necessary. In these cases, comprehensive error messages are output.

When the data have been deemed "correct", they are converted into their final processed form, written to the relevant file, and any temporary files that have been created to hold the data during the quality control stage automatically deleted.

2.7 Editing

The means of editing will depend on the type of data; for those data input into the computer on cards, the simplest way is to edit the card(s) and re-submit the data for quality control. In the case of those data from automatic recorders which were input into the computer on magnetic tape, the data will be output to an automatically created temporary file which may be edited using a number of alternative routines. There are several options available for editing the data: fixed amounts may be added or subtracted from data values, the quality indices associated with data points may be changed, the "timing" of the data may be changed by changing the time and date of the start of the data. The data records required to carry out this editing are normally punched on to computer cards.

2.8 Data conversion, summary printouts and data retained

Many of the hydrological variables recorded are not those used for modelling purposes. Streamflow is generally measured as a river level but it is the river flow which is of interest to the hydrologist. The meteorological variables are recorded primarily so that estimates of evaporation rates may be made. Routines are therefore needed to convert the measured variables into the normally used variables. Conversion factors and tables are necessary to carry out these procedures; the factors are generally accessed via the site directory whilst the tables are stored in named files which are automatically accessed in the FORTRAN programs. During these data conversions any data quality indices are transmitted to the calculated variables. Quite often the recorded data frequency is greater than the required storage frequency. In this case averages or sums, depending on the variable, over the required frequency must be calculated. Again quality indices are calculated for the sums/averages where necessary. On completion of the data conversions, summary printouts are produced; these will be described in the relevant chapters.

The amount and nature of data stored on the direct access "processed" files depends on the type of instrument. Because of the finite nature and cost of permanent storage on computer discs, it is highly desirable to limit the amount of data stored to a minimum. This is generally achieved by storing only those values that cannot be generated by other stored variables and by limiting the storage frequency. In theory, to minimize the space used on the disc, only the measured variables need be stored. However, in some cases, such as the calculation of evaporation rates, it is found that calculating derived values from the measured variables is so time consuming and therefore expensive that it is not economic to store only the measured variables.

Consideration must also be given to the user's requirements and, where possible, it is the variables normally used for hydrological studies which are stored. In some studies, the requirement is for data from a point source, in others areal estimates are required; these must be calculated and stored in the computer system.

2.9 Areal estimates

For those variables such as rainfall which exhibit appreciable variation over relatively small distances and for which areal estimates are required, records from individual sites within the area are combined in such a way so as to produce mean areal estimates. These are produced as routine for all catchments under consideration using all the available instruments within the catchment and suitable weighting factors for each instrument. These catchment estimates are stored together with the data from the individual instruments in the computer system.

There is also provision for individual users to calculated alternative areal estimates using any combination of instruments with appropriate weighting factors however calculated.

2.10 Data storage on disc and tape, retrieval and display

The final data values and, where relevant, quality indices are stored in direct access files, each file containing the data from one site/instrument for one year. The means of identifying these files in the FORTRAN programs via the site directory has already been described in Section 2.2. For those data which are recorded at sub-daily intervals, the direct access files consist of 366 records, each record representing one day (midnight to midnight) of the year. The size of each record depends on the type of site/instrument and on how much data per day needs to be stored. This is controlled by factors in the site directory.

For those data which are recorded manually at variable time intervals, the situation is rather more complicated because the number of data occurrences per year and the time and date of recording is so variable. In these cases, a variable length direct access file is used, records being created when they are required. An array, occupying the first five records in the direct access file, specifies which records in the direct access file contain the data measured at any particular day (if no data were measured for one day, then no record exists for that day). Again, the size of the records depends on the instrument type and is specified in the site directory.

As the name implies, one of the benefits of using direct access files for data storage is the ability to access the data from individual records, and hence for particular days, without the necessity of reading through the data from preceding days.

For those data recorded on cassette tape, a facility exists for storing the raw or measured data on 9-track magnetic tape. This is used as a back-up facility in case of data loss and as a starting point for data re-processing if, for example, data conversion factors or tables are updated.

Routines have been written to access and display data from the various sites/instruments (Figure 2.5). For instruments which record several variables, the order in which the variables are recorded and subsequently stored is specified as ITYPE in the site directory (Section 2.2). Although programs have been written to display the data in a wide variety of ways, it is hoped that individual users will write their own routines for their own particular needs.

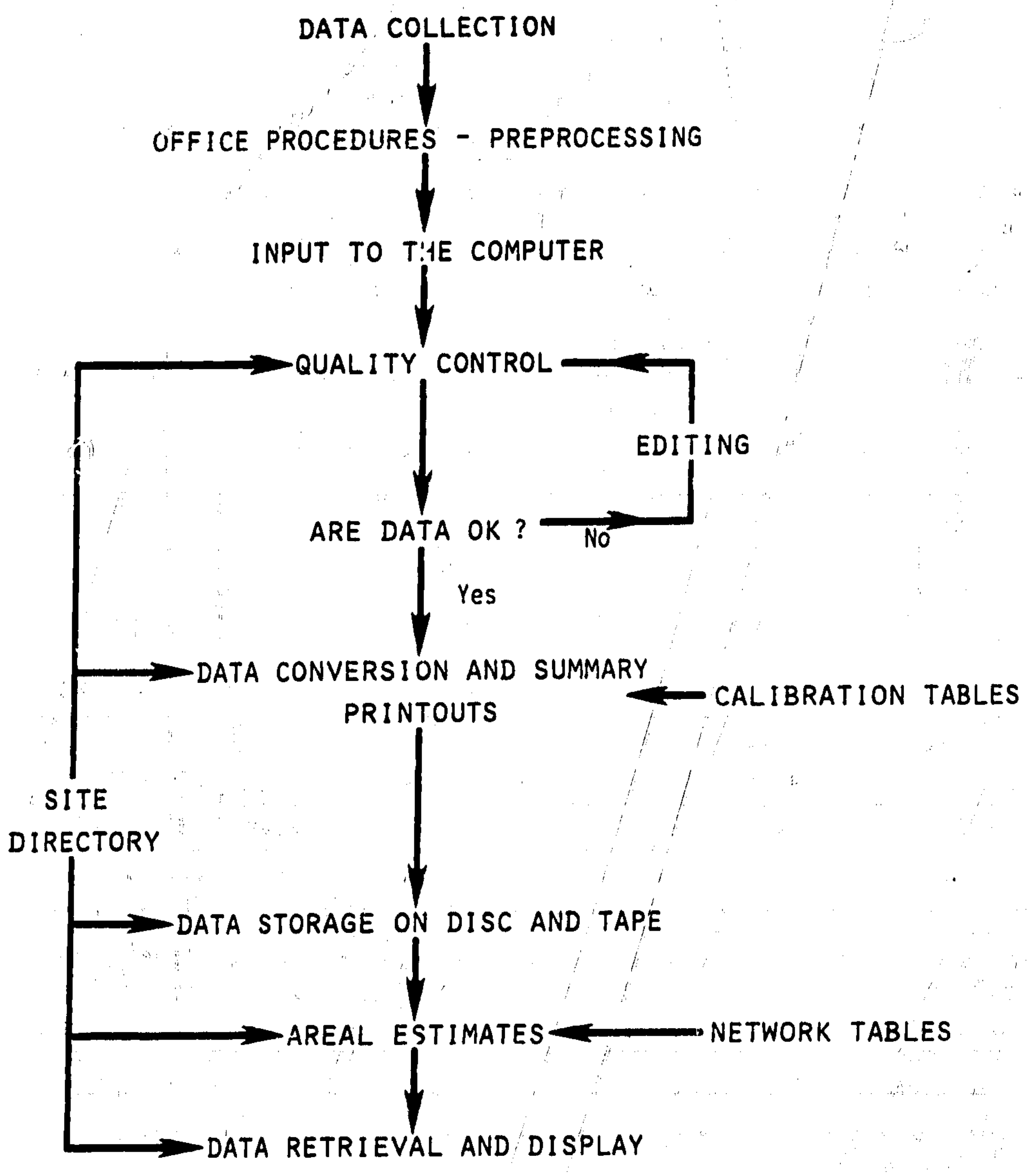

FIGURE 2.1 Flowchart showing the general data processing framework

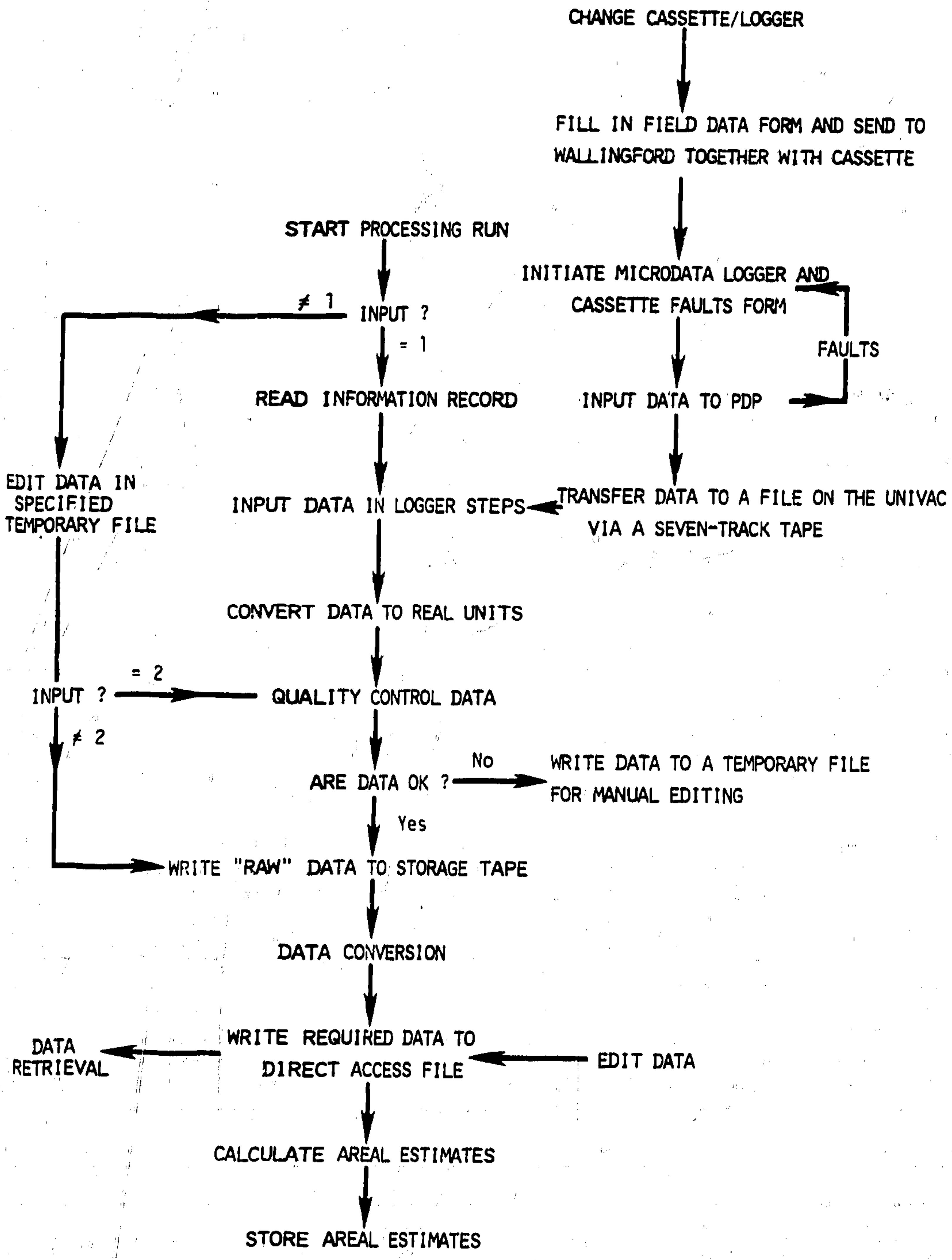

FIGURE 2.2 Processing of the data recorded by Microdata logger

EQUIPMENT TYPE: sensor / net / solar: no. date fitted if new

CATCHMENT:

SITE:

Station no: Interface no:
Logger no: Battery no: Battery volts:
Cassette no: Cassette side: Water level:

CONNECTED AT: GMT ON:
DISCONNECTED AT: GMT ON:

Tape used: Battery volts: Water level:

Change wick? Top up wet bulb? Net domes dry?
Change net gel? Solar domes dry? Change solar gel?
Adjust net level? Check rain level? Vane free? Cups free?

NOTES:

FIGURE 2.3 Field data form for Microdata loggers

STATION:

INSTRUMENT TYPE:

PERIOD:

FAULT:

DATE RECEIVED:

DATE INSTRUMENT SECTION NOTIFIED:

NOTIFIED BY: ....

ACTION TAKEN BY INSTRUMENT SECTION:

ACTION TAKEN BY: ....

FIGURE 2.4 Microdata logger and tape faults form

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                                CYFF CATCHMENT AREAL DAILY ESTIMATES                    FCH   178
                                                              EVAPORATION ESTIMATES (MM)
              RUNOFF (MM)          RAINFALL (MM)          EVAP1                  EVAP2

      1          6.72                  .00                 .70                    .67
      2          5.39                 6.69                 .27                    .20
      3          5.39                12.33                 .86                    .83
      4          4.70                 4.57                 .00                    .00
      5          6.90                18.90                 .30                    .27
      6          4.67                  .65                 .30                    .28
      7          3.70                 1.22                 .30                    .26
      8          3.22                 2.85                 .06                    .04
      9          6.27                20.92                 .23                    .20
     10          9.28                40.69                 .31                    .30
     11         11.56                 2.35                 .23                    .19
     12          5.27                  .24                 .00                    .00
     13          5.32                 6.11                 .00                    .00
     14          5.03                  .00                 .12                    .10
     15          4.00                  .32                 .00                    .00
     16          3.33                  .08                 .00                    .00
     17          2.73                  .00                 .00                    .00
     18          2.54                  .00                 .00                    .00
     19          2.53                  .33                 .29                    .22
     20          6.04                10.50                 .34                    .32
     21          8.38                 8.64                 .14                    .12
     22         17.51                25.88                 .33                    .25
     23         16.28                33.59                 .14                    .13
     24         12.53                 8.24                 .63                    .58
     25          6.27                  .40                 .49                    .42
     26          5.41                 8.18                 .57                    .50
     27          7.24                28.11                 .37                    .34
     28          7.83                 9.63                 .23                    .20
     29          5.96                  .89                 .48                    .41
     30          4.33                 1.66                 .02                    .00
     31          7.03                 6.90                 .08                    .02

  TOTAL        203.37               260.89                7.78                   6.85


         EVAP1 - PENMAN OPEN WATER EVAPORATION
         EVAP2 - PENMAN ET

  ALL DAILY VALUES ARE MIDNIGHT TO MIDNIGHT TOTALS
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FIGURE 2.5 Monthly catchment data summary listing

3. WEATHER STATIONS

3.1 Introduction

Much of the meteorological data collected to date at the Institute has been from manually-read stations. These are visited once, or sometimes twice a day at standard times. As well as providing information of interest to meteorologists, these data can also be used to estimate evaporation using the Penman equation (Penman, 1948). The procedures used for processing these data have been described (Plinston and Hill, 1974) and it is sufficient to say here that these data are used occasionally as infill for those periods when no data from the automatic stations are available. The advantages of using an automatic system (Strangeways, 1972) for measuring the meteorological variables are obvious; (i) for those sites where a daily visit would be expensive, time consuming and, in some cases, impossible and (ii) to provide frequent, normally 5 min, observations, thus enabling more accurate estimates of evaporation rates to be made. The variables normally measured by automatic weather stations are solar radiation, net radiation, wet bulb depression, dry bulb temperature, wind run, wind direction, and rainfall. These are recorded on cassette tape in logger step units. In addition a scan mark is recorded; this is a measurement of a reference voltage within the logger. If the value of this scan mark is different from that expected, then all the recorded values are adjusted accordingly.

The processing of those data recorded by automatic weather stations consists of translation, quality control, editing, data conversion, and storage procedures (Fig 2.2). The quality control introduces a new concept into data processing; that of data indexing which is used to differentiate between "good", "suspect", or "bad" data. In common with all the data being processed on this system, an entry must exist in the site directory for the particular instrument before data processing can be carried out.

3.2 Site directory

The format of the entries in the site directory has already been described in Section 2.2. For automatic weather stations the number of variables normally recorded is seven, each variable having up to twelve standard/conversion values. These are tabulated in Table 3.1.

The control information used for automatic weather stations is similar to that used for other instrumentation. The values unique to automatic weather stations are:

BSITE - is of the form AWS XXXXX..... where XXXXX..... is the local site name of the weather station.
INST - 1.
KREC - 1.
ICHANN - 7.

An example of an automatic weather station entry in the site directory is given in Figure 3.1.

3.3 Data collection

Automatic weather stations recording seven variables and a scan mark at five minute intervals [illegible] in theory, be visited and serviced at monthly intervals [illegible] is the maximum possible period in terms of cassette tape capacity and battery charge. However, in order to reduce data loss through logger, battery, or sensor failure, it is now Institute policy to visit these stations every two weeks. During these visits, the logger, battery, and cassette are changed and checks made on the various sensors. To simplify the procedure and to ensure that the correct information accompanies the data to Wallingford, a field data form is used; this is shown in Figure 2.3. This form contains the name of the site, the period during which the data are collected, and has space for noting logger number, cassette number, battery number, etc. There are also reminders to carry out such procedures as checking the water reservoir for the wet bulb thermometer, checking the cups on the anemometer, etc. Although very little of what is noted on these field forms is actually required for processing the data recorded on the cassette tape, nevertheless the information noted down is invaluable for (i) pinpointing faulty loggers, batteries, etc, and (ii) in ensuring that the correct sensor checks are carried out.

3.4 Office procedures; pre-processing

When the tapes arrive at the Institute they are passed to the catchment office where a record is kept on site record cards of the date of arrival and period of data contained on the cassettes. At the same time a Microdata "logger and tape faults" form is initiated (Figure 2.4). On this form are noted any data errors caused by logger, tape, battery, etc. malfunctions which are detected during the various stages of the processing (Sections 3.5-3.8). When instrument malfunctions are suspected the information is passed to the Instrument Section for fault rectification. In this way, it is hoped to minimize data loss. The cassettes are then passed on for processing on the computer system.

3.5 Input to the computer system

Because of the unique way in which data are recorded on Microdata cassette tapes, the input of these data into the computer system presents problems and necessitates the use of indirect time-consuming procedures. The sequence of events used at the Institute is:

(1) (2) (3)
Cassette tape → PDP8 → DEC tape → 7-track tape
↓ (4)
UNIVAC

Stages (1) and (2) have been fully documented and carry out a translation and a coarse quality control function. The types of malfunctions likely to be picked up at this stage have been described (Templeman, 1978) and, should they occur, are noted on the "faults" form described previously. The DEC tapes produced are purely for data storage purposes, cassette data to be processed are written on to 7-track tape for subsequent transfer on to fixed disc on the UNIVAC. Normally the data from several cassette tapes are written to one 7-track tape.

3.6 Quality control

The quality control routines are applied to the data contained in the file produced as described above. Each cassette length must have an associated information record on a punched card, the values on this record being abstracted from the field data form (Section 3.3). In addition to the local site name and time and date of start and end of data, the information record associated with an automatic weather station contains:

ISEN, INET which are pre-determined (Templeman, 1978) solar and net radiation conversion factors.

IRAIN, JRAIN, KRAIN which are the amounts of rain in the two check gauges plus the check total.

Before quality control can be carried out, the data are translated into real units using conversion factors found in the information record and the site directory. At the same time, each data record is given a "flag", its value being determined by the results of the data translation (Templeman, 1978). If the record is acceptable, the flag is given the value of 0; if not, flag = 1, and all the values in the record will be assumed to be incorrect at the quality control stage.

Time checks are applied to the data by calculating the apparent noon each day as the mid-point between apparent sunrise and sunset. The time of apparent noon is tested to be within ± 1½ hours of true noon. The apparent day length (given as the difference between apparent sunset and sunrise) is tested to be within ± 2 hours of true day length. For each cassette a timing summary printout (Figure 3.2) is produced showing times and deviations from noon, sunset, sunrise, and day length. From this it is possible to ascertain whether the loggers are maintaining a good time synchronisation.

Individual data values are quality controlled using the routines described in detail later in this section. As a result of this quality control each data value is allocated a quality index which will be retained during subsequent processing. Comprehensive error messages are output where necessary and, in general, any "incorrect" data are listed to aid editing.

Many of the errors detected in the data from individual sensors are as a result of comparisons with data from other sensors. The variables recorded by automatic weather stations are particularly suitable for inter-comparisons, for example, solar and net radiation, wet bulb depression and dry bulb temperature, wind run and wind direction. For this reason, the variables except for rainfall are considered in pairs for quality control purposes. The quality control is applied to five minute data one day at a time. The data values are assumed to be correct prior to quality control and the quality indices set to 3.

Should the data from a particular cassette be deemed "correct", they are written to a 9-track tape for storage purposes, the values required for further processing calculated, and these values stored in the appropriate direct access file. Listings of the stored values are produced. If, however, 'errors' which have to be manually inspected have been detected in the data, the complete cassette file is written out to a temporary file (the name being determined as indicated in Section 2.2) for manual editing.

A detailed description of the quality control routines follows.

3.6.1 Solar and net radiation

As an aid to quality control, the maximum expected radiation, R, expected under clear skies is calculated for each hour of the day. It is expressed as a quadratic function of the solar altitude, a, as shown below:-

$$R = -\ 128.5227 + 23.\text{[illegible]}05a - 0.118755a^2$$

where

$$\text{Sin}(a) = \sin(\varnothing)\ \sin(\delta) + \cos(\varnothing)\ \cos(\delta)\ \cos(h)$$

and

$\varnothing$ = latitude of station

δ = declination

h = hour angle

The declination, δ, is a function of the day number, D,

$$\delta = 23.4\ \sin\left(\frac{(D - 80)}{370}\ .\ 2\pi\right)$$

and the hour angle, h, varies through the day as

$$h = \text{ABS}\ (11.5 - H)\ .\ 180.0/12.0$$

where

H is the hour (12.0 = 12 noon)

For values of solar altitude of less than 5°, $R = 42\ \text{Wm}^{-2}$ for the first hour, $R = 20\ \text{Wm}^{-2}$ for the hour with the next lower solar altitude, and $R = 5\ \text{Wm}^{-2}$ for night time hours.

Before being quality controlled the solar radiation data are corrected for voltage offset by subtracting the maximum value that occurs during the periods 0000-0200 hours and 2200-2400 hours from all the values for that day. This procedure is carried out for every complete day of data for correction factors ≤ 40 Wm^{-2}; the factor that has been applied is listed out on the timing summary sheet (Figure 3.2). If the factor exceeds 40 Wm^{-2}, the data are printed out for manual inspection; often this happens when the timing is completely wrong. If, by carrying out this correction, any solar radiation value becomes negative, then it is re-set to zero.

The average solar radiation value for the day, neglecting those individual values below 0.1 Wm^{-2} and those having scan flags not equal to 0, is calculated. This is also printed on the timing summary sheet (Figure 3.2).

Two types of quality control checks are applied; those concerning the data for the day as a whole (including the time checks), and those concerning individual values (including solar/net checks). The checks involving the data for the day as a whole are outlined in Table 3.2.

Time checks are now carried out provided:

(i) a whole day's data is being dealt with, that is, it is not the first or last day of the cassette, and

(ii) the checks already carried out on the solar radiation data (Table 3.2) were successful.

These timing checks involve the comparison of true (as derived from the Smithsonian Meteorological tables) and apparent (as indicated by the solar radiation data) noon and day length. The true (actual) values are calculated as indicated in Table 3.3 whilst the apparent values are derived as shown in Table 3.4.

The absolute difference between true and apparent noon is calculated. If this is greater than 1½ hours an error message together with the solar radiation for the day is output, and the timing checks are deemed to be unsuccessful. Similarly the absolute difference between the true and apparent day length is calculated. If this is greater than 2 hours an error message together with the solar radiation data for the day is output, and the timing checks are deemed to be unsuccessful.

For those days when it was possible to apply the timing checks the calculated true and apparent values and the differences between them are output on the timing summary sheet (Figure 3.2).

Following the timing checks, further quality control tests are carried out on individual data values. These include comparisons between solar and net radiation values and are outlined in Table 3.5.

Should individual values of solar or net radiation fail any of the quality control tests, the outcome is generally a revaluation of the quality index associated with the data value to either 2 (doubtful) or 1 (bad). However, should any of the tests involving the whole day's data, including the timing checks, fail then the solar radiation and net radiation data are printed together with an error message. This also means that all of the data from the cassette will be written to a temporary file for editing purposes.

3.6.2 Dry bulb temperature and wet bulb depression

Before any quality control can be carried out, two further values, wet bulb temperature and specific humidity deficit, are calculated using the recorded values of wet bulb depression and dry bulb temperature as shown below:

Wet bulb temperature, T_W = Dry bulb temperature, T_D - Wet bulb depression

Specific humidity deficit $= q_{WD} - q_{WT} + K(T_D - T_W)$

where q_{WD} = saturated specific humidity at dry bulb temperature, T_D
$= 0.62197/(P/(1.0045 \times SVP_{TD}) + 0.62197 - 1.0)$.

q_{WT} = saturated specific humidity at wet bulb temperature, T_W
$= 0.62197/(P/(1.0045 \times SVP_{TW}) + 0.62197 - 1.0)$.

SVP_{T_D} = saturated vapour pressure at dry bulb temperature, T_D
$= 17.044 + X_D \times (5.487 + X_D \times (0.766 + X_D \times (0.063 + X_D \times 0.003)))$

SVP_{T_W} = saturated vapour pressure at wet bulb temperature, T_W
$= 17.044 + X_W \times (5.487 + X_W \times (0.766 + X_W \times (0.063 + X_W \times 0.003)))$

$X_D = T_D/5 - 3$

$X_W = T_W/5 - 3$

K = the psychrometric constant = 5×10^{-4} kg.kg^{-1} $^{\circ}$C^{-1}

P = atmospheric pressure = $1012 \times (1 - (0.0065 \times IALT/288))^{5.2553}$

IALT = altitude of station.

The quality control tests are applied to values of dry and wet bulb temperature, wet bulb depression or specific humidity deficit. These involve checks on individual data values and comparisons between data values. These tests and their outcome are tabulated in Table 3.6. Errors found in individual data values usually result in a revaluation of the quality indices of the particular values. For temperatures and depression these revaluations will also affect the quality indices of the generated humidities. The failure of any of the tests involving the data for the whole day means that the data from the whole cassette are written out to a temporary file for future editing.

3.6.3 Wind speed and direction

The quality control tests applied to wind speed and direction are tabulated in Table 3.7. The outcome of these tests is to adjust the values of individual quality indices; no manual editing of wind speed or wind direction is carried out.

3.6.4 Rainfall

Very little quality control of rainfall data from individual gauges is possible. It consists of:

(i) A comparison of the total as recorded by the gauge and the total collected in the check gauge and entered in the information record. If the totals do not agree to within ± 10%, an error message will be output and all the data from the cassette written out to a temporary file for manual inspection.

(ii) If any 5-minute recorded rainfall total is greater than 10 mm, the quality index is set to 1.

(iii) If the current or previous scan flag ≠ 0, the quality index = 1. (The rainfall in any time period is calculated from the present and previous recorded values.)

Further quality control tests involving comparisons of rainfall totals at different sites are applied when computing areal estimates of rainfall (section 5.9).

3.6.5 Quality control summary sheet

After the completion of the quality control a line printer listing is produced (Figure 3.3) giving the total number of each type of quality index attributed to each variable. This is to aid the monitoring of station and sensor performance.

3.7 Editing

As indicated in Section 2.1 the editing of 'incorrect' data is carried out by the same suite of programs used for the initial quality control. Different types of editing facilities are available, the options used being determined by the value of INPUT; this value also determines whether the data need be quality controlled following the editing.

Two types of edits may be carried out, those affecting the information record and those affecting individual data and quality indices.

(i) The information record

All the values stored in the information record may be edited. In some instances, such as changing solar and net radiation calibration factors, it is advisable to re-submit the data for quality control following the edit. This also applies to editing the starting time as this will affect the timing controls.

(ii) Data values and quality indices

An individual or a consecutive series of data values may be edited by:

(a) replacing with a fixed value,

(b) replacing with variable values, or

(c) adding or subtracting a fixed amount. For those data types which cannot be negative, any generated negative values are re-set to zero.

The quality indices of edited data values are automatically re-set to 2 thus indicating that the values are not as recorded.

Similarly, the quality indices associated with an individual or a consecutive series of data values may be changed.

The timing of the data values for any particular day may be adjusted by up to six hours. This is particularly useful to overcome such problems as missing data etc.

Examples of the printouts which are produced to aid editing are given in Figures 3.4 and 3.6; check listing of other variables for comparison with the suspect data are automatically produced, Figure 3.5.

3.8 Data conversion, summary printouts and data retained

Once the data have been deemed 'error free', they are converted into those values that are to be stored on the appropriate direct access file. These consist of hourly and daily sums or averages of all the recorded data types plus hourly and daily estimates of humidities and various evaporation rates. A list of all the stored values and the appropriate units is given in Table 3.8.

All the calculated values are given quality indices, their values depending on those of the data used in their calculation. These quality indices are stored together with the calculated and recorded values.

A daily summary printout of all the recorded and calculated variables is output on the line printer (Figure 3.7). The data to be retained are stored in a direct access file, the name of which is obtained as outlined in Section 2.2. Each record in the direct access file holds one day's data.

There now follows a detailed description of the calculation of the various evaporation estimates.

3.8.1 The basic Penman equation

The basic Penman equation is written in the form:

$$\text{Evaporation, } \lambda E = \frac{\Delta' \text{ (Radiation)} + M\rho c_p \text{ (EA)}}{\Delta' + N\gamma} \qquad (1)$$

where the various terms are defined in Table 3.9. The basic and modified forms of this equation are fully described in Thom and Oliver (1977).

A dimensional analysis of the Penman equation is given below to help clarify the use of SI units as applied to this equation.

$$\lambda E \text{ in } J\ s^{-1}m^{-2} = \frac{{}^{o}C^{-1}(J\ s^{-1}m^{-2}) + M\ \underline{kg\ m^{-3}}\ \underline{J\ kg^{-1}{}^{o}C^{-1}}(ms^{-1})}{{}^{o}C^{-1} + \dfrac{N\ J\ kg^{-1}\ {}^{o}C^{-1}}{J.kg^{-1}}}$$

$$= \frac{(J\ s^{-1}m^{-2}) + M(J\ s^{-1}m^{-2})}{1 + N} \qquad (2)$$

As indicated in Table 3.8, evaporation estimates are made using the basic Penman equation (above) plus the modified forms, Penman-Monteith and Thom-Penman, of this equation. These calculations will be described in detail in Sections 3.8.2 to 3.8.4.

Evaporation estimates are made for three surfaces; grass, forest and water. This means that net radiation values measured over one surface must be converted into equivalent values over alternative surfaces before any estimates can be made. Also, if necessary, net radiation may be calculated using solar radiation and albedo. The equations used to carry out these transformations are shown in Table 3.10.

3.8.2 Calculations using the basic Penman equation

Estimates of daily and daylight open water and evapotranspiration are made. If net radiation is not available, solar radiation is used instead and only a daily value of evapotranspiration calculated.

The steps involved in carrying out these calculations are as follows:

- (i) In calculating open water evaporation use equations (3) and (4) in Table 3.10 to obtain net radiation over water (surface y) for each hour.
  In calculating evapotranspiration when net radiation is not available use equation (5) in Table 3.10 to obtain net radiation for each hour.

(ii) Sum the hourly net radiations to obtain daily or daylight, where appropriate, totals in MJm^{-2}.

(iii) Calculate the mean net radiation in $Jm^{-2}s^{-1}$.

(iv) Use the daily or daylight mean wind speed and humidity deficit x 10^{3} (ie in units of kg kg^{-1}) to calculate the daily or daylight, where appropriate, aerodynamic factor.

(v) Use equation (1) to obtain the mean evaporation in $Js^{-1}m^{-2}$.

(vi) Multiply by the appropriate number of hours to obtain either daily or daylight total evaporation in MJm^{-2}.

(vii) Multiply by .405 to obtain results in mm of water.

3.8.3 Calculations using the Thom modification to the Penman equation

Estimates of daily and daylight evaporation totals are made if net radiation is available. If not available, solar radiation is used and a daily value only of evaporation calculated. The steps involved in these calculations are:

(i) If net radiation is not available, calculate net radiation values using equation (5) in Table 3.10 and carry out the following steps for a daily total only.

(ii) For each hour, use the hourly value of deficit x 10^{3} and windspeed to obtain an aerodynamic factor.

(iii) Use the hourly value of net radiation with the aerodynamic factor for the hour to obtain hourly mean rate of evaporation in $J\ s^{-1}\ m^{-2}$. Continue for each hour.

(iv) Sum the hourly mean evaporation values to obtain daily and daylight totals in $M\ J\ m^{-2}$.

(v) Multiply by 0.405 to obtain totals in mm water.

The Thom-Penman equation is also used to calculate daily totals using 24 hour average meteorological data following similar procedures to those used for the basic Penman equation.

Information on the M and N values used for a particular site are stored in the site directory. The values used at present are provisional annual averages and may be changed as knowledge about more appropriate values increases.

For weather stations mounted above a forest, in a forest clearing or at a forest edge, the M and N values appropriate to the forest are used.

3.8.4 Calculations using the Monteith-Penman evaporation equation

This rigorous evaporation equation takes into account hour by hour variations in aerodynamic and surface resistances (Monteith, 1965; Thom and Oliver, 1977). The equation is written in the form:

$$\text{Evaporation flux } E = \frac{\Delta' A + \rho c_p (q_{W,TD} - q)/r_a}{\Delta' + (c_p/\lambda)(1 + r_s/r_a)} \ \text{J s}^{-1} \text{ m}^{-2}$$

where the constants and variables are as defined in Table 3.9, with the exception of the aerodynamic resistance, r_a, and the surface resistance, r_s, which are defined below:

The current system uses the following simplified relationship for aerodynamic resistance:

$$r_a = \frac{\left[\log_e \left(\frac{Z-d}{Z_o}\right)\right]^2}{k^2 u} \quad \text{where } \frac{Z-d}{Z_o} = 500 \text{ for water}$$

$$100 \text{ for grass}$$

$$5 \text{ for forest}$$

$$k = 0.41$$

$$u = \text{mean hourly wind speed in ms}^{-1}$$

The $\left(\frac{Z-d}{Z_o}\right)$ values are stored in the site directory so that they can be changed if required.

For surface resistance, the following approximations are used:

r_s = 0 for water

0 for all surfaces when wet (SHD < 1 g kg^{-1} continuously since last rain)

= 40, 50, 70 sm^{-1} at 0800, 1200, 1600 for grass (fitted curve)

= 80, 100, 140 sm^{-1} at 0800, 1200, 1600 for forest (fitted curve)

The values of the noon surface resistance for the particular crops in the site directory can be varied from 50 and 100 if required but at present a diurnal curve of the same shape is always fitted.

3.9 Areal estimates

Areal estimates can be made of all the retained variables using different stations within a given catchment or area. Each station is given a weighting factor, these factors adding up to 100% for all the stations.

A direct access file will be created to accommodate the areal estimates in exactly the same fashion as those for individual stations. Quality control indices will be given to the estimated areal values, their values depending on the quality indices of the data from the individual stations.

3.10 Data storage on disc and tape, retrieval and display

3.10.1 Introduction

Two forms of storage of data from automatic weather stations are carried out; the storage of 'processed' or finalised data on direct access files has already been described, the other is the storage of the recorded values, in real units, on nine-track magnetic tape. This is carried out immediately the data is deemed 'error free', the data from each cassette occupying one file on the magnetic tape. At the end of a quality control or editing 'run' a listing is produced on the line printer showing the names, dates and the space taken by each file on the current tape being used for storage purposes. Also output is the total number of files and space taken; it is policy to use an alternative tape once the current one is more than 60% full.

If it is decided that processed data on a direct access file are incorrect, there are two ways in which they or the quality indices may be changed.

(i) Editing the data/quality indices on the file using subroutines written for that specific purpose. These subroutines are similar in nature to those used for editing the recorded values as described in Section 3.7.

(ii) Extracting stored data from a nine-track magnetic storage tape, editing the data or conversion factors, and running the data through the conversion routines. The new processed values will overwrite those already on the file.

There is also a facility of substituting values from manually-read weather stations during those periods when data from automatic weather stations were unavailable. A general computer program has been written to display the stored data in a number of ways depending on what options are used.

3.10.2 Printout options

1. Calculated net radiation for water, grass and forest using solar and net, solar only, or back radiation (hourly, 24 hour and daylight values, 1 day/page).

2. (a) EO and ET Penman.

   (b) Thom-Penman from hourly and daily data.

   (c) ET Penman and Thom-Penman at 0900 using 0900 deficit and average max/min 5 minute temperature for Δ.

(d) ET Penman and Thom-Penman at 0900 using 0900 specific humidity and average max/min 5 min temperature for Δ and saturated specific humidity.

(e) True mean daily temperature.

(f) Average max/min 5 min temperature.

(g) True mean deficit, 0900 deficit and deficit using saturated specific humidity calculations from max/min temperature and 0900 specific humidity. (24 hour and daylight values, 1 day/page.)

3. Penman-Monteith evaporation for water, grass and forest (hourly and daylight values, 1 day/page).

4. General listing:

AWS values and humidities (24 hour values).

Penman-Monteith evaporation for water, grass and forest (daylight values).

Penman EO and ET and Thom-Penman evaporation (24 hour values).

Several days/page.

Options 5 onward allow selection of any combination of data types and evaporations.

5. Selected AWS values, humidities and Penman-Monteith evaporations, listing hourly, 24 hour, daylight and max/min 5 minute values. 1 day/page.

6. As option 5 plus 24 hour Penman EO and ET, and Thom-Penman evaporations. 1 day/page.

7. Selected 24 hour data types (several days/page).

8. Selected daylight data types (several days/page).

The data types are given in Table 3.8 plus the Penman-Monteith values for water, grass and forest.

3.10.3 Site comparison package

This compares the data from two given sites using only data of a pre-specified quality. The differences, the standard deviations and the number of days used for the sites are listed (Figure 3.8).

TABLE 3.1 STANDARD/CONVERSION VALUES USED FOR THE VARIABLES RECORDED BY AUTOMATIC WEATHER STATIONS

DATA TYPE 2. SOLAR RADIATION

1. Lower limit of radiation at dawn/sunset.
2. Upper limit of solar radiation.
3. Constant A used when calculating true day length.
4. Constant B used when calculating true day length.
5. Constant C used when calculating true day length.
6. Longitude of station.
7. Latitude of station.
8. 'Dummy' 1-Albedo value (1.0).
9. Cover index (1 = grass, 2 = forest, 3 = clearing).
12. Automatic weather station type code (1 = old type, 2 = Didcot type).

DATA TYPE 3. NET RADIATION

1. Lower limit at dawn/sunset.
2. Upper limit of net radiation.
3. Upper limit 1 of net/solar ratio.
4. Upper limit 2 of net/solar ratio.
5. Lower limit 1 of net/solar ratio.
6. Lower limit 2 of net/solar ratio.
8. 1-Albedo value.

DATA TYPE 4. WET BULB DEPRESSION

1. Lower limit of wet bulb temperature.
2. Upper limit of wet bulb temperature.
3. Lower limit of wet bulb temperature variability.
5. Lower limit of wet bulb temperature jump.
6. Wet bulb temperature 'jump' factor.
7. Upper limit of specific humidity at dawn.
11. Number of logger steps equivalent to 0°C.
12. Temperature sensitivity (°C/logger step).

TABLE 3.1 Continued

DATA TYPE 5. DRY BULB TEMPERATURE

1. Lower limit of dry bulb temperature.
2. Upper limit of dry bulb temperature.
3. Lower limit of dry bulb temperature variability.
5. Limit of dry bulb temperature jump.
6. Dry bulb temperature 'jump' factor.
12. Wet bulb depression factor.

DATA TYPE 6. WIND RUN

1. Upper limit of wind run in recording time period.
2. Lower limit of wind run in recording time period.
12. Maximum number of logger steps allowed.

DATA TYPE 7. WIND DIRECTION AND EVAPORATION CONSTANTS

1. Upper limit of wind direction.
3. Annual precipitation in metres.
4.)
5.) Constants used in the Thom-Penman estimates.
6.)
7. Water)
8. Grass) Roughness factors used in Penman-Monteith estimates.
9. Forest)
10. Grass) 1200 GMT surface resistances for Penman-Monteith estimates.
11. Forest)

DATA TYPE 8. RAINFALL

1. Upper limit of rainfall total in recording time period.
12. Tipping bucket capacity.

TABLE 3.2 SOLAR AND NET RADIATION QUALITY CONTROL CHECKS FOR WHOLE DAY'S DATA

QUALITY CONTROL CHECK		OUTCOME
(i)	More than 11 solar radiation values greater than 1400 Wm^{-2}	Print error message and solar radiation values. No time checks carried out.
(ii)	All solar radiation values less than a lower limit of 10 Wm^{-2}	Set the quality indices of all the solar radiation values equal to 1. Print error message and solar radiation values. No time checks carried out. Abandon the quality control for solar radiation for the day.
(iii)	All net radiation values less than a lower limit. The outcome depends on the lower limit.	
	LIMIT = -50 Wm^{-2}	Set the quality indices of all the net radiation values equal to 1. Print error message and net radiation values.
	LIMIT = 9 Wm^{-2}	Set the quality indices of all the net radiation values equal to 2. Print error message and net radiation values.

TABLE 3.3 CALCULATION OF THE TRUE (ACTUAL) VALUES REQUIRED FOR THE TIMING CHECKS

(i) True day length or possible number of sunshine hours, JDUR, is given by

JDUR = 24 x H/Π

where H = ACOS (SIN50 - SIN(PHI) x SIND/(COS(PHI) x COSD))

ACOS = trigonometric cosine

SIN50 = SIN (-5.0 x Π /(6.0 x 180.0)

PHI = Latitude x Π /180.0

SIND = 0.00678 + 0.39762 x COS (THETA) - 0.00513 x SIN (THETA) - 0.00661 x COS (THETA x 2) - 0.00159 x SIN (THETA x 2)

COSD = SQRT (1 - SIND x SIND)

THETA = 2.0 x Π x (D-172)/365

D = day number

(ii) True noon, JNOON, is given by 1200 hours corrected for the equation of time by a factor, CORR, and the longitude of the station, LONG.

JNOON = 1200 + CORR + (LONG x 4)

where CORR = 7.0 x SIN(D x 0.0172) + (10.0 x SIN((D + 10) x 0. 344))

(iii) True dawn, JDAWN = JNOON - JDUR/2

(iv) True sunset, JSUN = JNOON + JDUR/2

TABLE 3.4 CALCULATION OF THE APPARENT VALUES REQUIRED FOR THE TIMING CHECKS

(i) Apparent dawn, IDAWN, is found as that point in time between midnight and mid-day when the solar radiation value is greater than 10 Wm^{-2} and when 10 out of the following 12 data points are also greater than 10 Wm^{-2}. If no such point is found, an error message together with the solar radiation data for the day is printed, and the timing checks are deemed to be unsuccessful and are abandoned.

(ii) Apparent sunset, ISUN, is found as that point in time between mid-day and midnight at which the solar radiation value is less than 10 Wm^{-2} and when 10 out of the following 12 data points are also less than 10 Wm^{-2}. If no such point is found, an error message together with the solar radiation for the day is printed, and the timing checks are deemed to be unsuccessful and are abandoned.

(iii) Apparent noon, INOON = (ISUN + IDAWN)/2.

(iv) Apparent day length, IDUR = ISUN - IDAWN.

TABLE 3.5 QUALITY CONTROL CHECKS FOR INDIVIDUAL SOLAR AND NET RADIATION VALUES

	QUALITY CONTROL CHECK	OUTCOME
(i)	For both solar and net radiation, scan flag $\neq 0$	Set quality index = 1
(ii)	If data value greater than an upper limit SOLAR UPPER LIMIT = 1400 Wm^{-2} NET UPPER LIMIT = 1260 Wm^{-2}	Set quality index = 1
(iii)	For both solar and net, if data value is less than -120 Wm^{-2}	Set quality index = 1
(iv)	Compare the radiation values with the maximum expected radiation, R, in the same hour. Only carried out if timing checks were successful and only for data values in period DAWN + 2 hours to SUNSET - 2 hours.	
	SOLAR RADIATION > 1.4 x R	Set quality index = 2
	SOLAR RADIATION > 1.7 x R	Set quality index = 1
	NET RADIATION > 1.2 x R	Set quality index = 2
	NET RADIATION > 1.36 x R	Set quality index = 1
(v)	Any net radiation values between 0000 and 0300 hours > 0.	Set the quality indices of all the net radiation values during the day equal to 2.

Net/Solar radiation ratio checks

These are applied only to 'correct' hourly solar and net radiation values and only when temperatures are above freezing. The net/solar ratio is calculated and tested against standard values found in the site directory. The standard values most commonly used and the outcome of the tests are shown below.

(vi)	Used only when the hourly solar radiation value is $\geq$ 30 Wm^{-2}	
	Net $\geq$ 85% solar for grass	Set net quality index = 1
	Net $\geq$ 100% solar for forest	Set net quality index = 1
	Net $\geq$ 80% solar for grass	Set net quality index = 2
	Net $\geq$ 95% solar for forest	Set net quality index = 2

TABLE 3.5 Continued

	QUALITY CONTROL CHECK	OUTCOME
(vii)	Used only when the hourly solar radiation value is $\geq$ 30 Wm^{-2} and for data recorded within two hours of noon.	
	Net < 15% solar for grass	Set net quality index = 1.
	Net < 25% solar for forest	Set net quality index = 1.
	Net < 45% solar for grass	Set net quality index = 2.
	Net < 55% solar for forest	Set net quality index = 2.
(viii)	Used only when the hourly solar radiation value is < 30 Wm^{-2}.	
	If solar < 0 and net > 1.2 x solar	Set net quality index = 1.
	If solar < 0 and net > solar	Set net quality index = 2.
	If solar = 0 and net > 20 Wm^{-2}	Set net quality index = 1.
	If solar = 0 and net > 0	Set net quality index = 2.

TABLE 3.6 QUALITY CONTROL TESTS FOR DRY BULB TEMPERATURE, WET BULB TEMPERATURE AND SPECIFIC HUMIDITY DEFICIT

	QUALITY CONTROL CHECK	OUTCOME
(i)	Scan flag ≠ 0 for both dry and wet bulb temperature	Set quality index = 1.
(ii)	For dry and wet bulb temperature, deviation from the mean daily temperature is less than 0.3°C	Set the quality indices of all the data values for the day equal to 1. Print error message and data values. No dry/wet bulb temperature comparison carried out.
(iii)	For dry and wet bulb temperature, values less than -9.9°C	Set the quality index = 2.
(iv)	For dry and wet bulb temperature, values greater than 29.9°C	Set the quality index = 2.
(v)	A comparison of the trends in the dry and wet bulb temperature values is carried out. If a 'step' of greater than 2°C occurs in the dry bulb temperature, an associated 'step' of greater than 1°C in the same direction is sought in the wet bulb temperature. Similarly, an associated 'step' of over 2°C in dry bulb temperature is sought for every 'step' of over 1°C in wet bulb temperature. If no such associated 'step' is found, the quality index of the data point is modified according to the size of the 'step'.	
(vi)	Only carried out if (a) time checks for the day were 'correct', and (b) dry and wet bulb temperature at dawn are 'correct'. Specific humidity deficit at dawn is greater than 3 g kg^{-1}.	Print error message and dry and wet bulb temperatures for the day.
(vii)	Only carried out if (a) dry bulb temperature at dawn > 2°C, (b) the difference between the maximum dry bulb temperature for the day and that at dawn is greater than 3°C, (c) the time checks for the day were correct, and (d) no rain during the day up to one hour past the time of maximum temperature. If $\frac{\text{Depression}_{\text{max. temp.}} - \text{Depression}_{\text{dawn}}}{\text{max. temp.} - \text{dawn temp.}} < 0.$[illegible]	Print error message and dry and wet bulb temperatures for the day.

	QUALITY CONTROL CHECK	OUTCOME
(viii)	If the wet bulb depression is less than 0.2 for the whole day.	Code the quality indices of dry and wet bulb temperature for the whole day = 1.

TABLE 3.7 QUALITY CONTROL TESTS FOR WIND SPEED AND DIRECTION

	QUALITY CONTROL CHECK	OUTCOME
(i)	For both wind speed and direction scan flag ≠ 0	Set quality index = 1.
(ii)	Wind speed greater than 20 ms^{-1}	Set quality index = 1.
(iii)	Direction greater than 360°	Set quality index = 1.
(iv)	Direction equal to 0°	Set quality index = 1.
(v)	Wind speed less than 0.25 ms^{-1}	Set quality index = 2.
(vi)	Wind speed is less than 0.03 ms^{-1}. Not carried out when the wind run is zero all day	Set quality index of wind direction = 2.
(vii)	Wind speed is zero all day, but the wind direction varies by more than 5°	Set quality indices of wind speed all day = 1.
(viii)	If the direction is constant to within ± 5° all day, but the wind speed is not zero all day	Set quality indices of direction all day = 1.

TABLE 3.8 STORED AUTOMATIC WEATHER STATION RECORDED AND CALCULATED VALUES

Recorded values

Hourly, daylight and 24 hour sums/averages plus the maximum and minimum five minute values of all the recorded variables are stored. The units in which these variables are expressed are shown below.

Solar radiation	Hourly	Joules sec^{-1} metres^{-2} (Js^{-1}m^{-2}), 1Js^{-1} = 1 watt
	Daily	Sum of $\left(\frac{\text{hourly values x 3600}}{10^6}\right)$ in megajoules metre^{-2}.
Net radiation	Hourly	Joules sec^{-1} metres^{-2} (Js^{-1}m^{-2})
	Daily	Sum of $\left(\frac{\text{hourly values x 3600}}{10^6}\right)$ in megajoules metre^{-2}.
Wet bulb depression	Hourly	degrees centigrade (°C)
	Daily	average in degrees centigrade
Dry bulb temperature	Hourly	degrees centigrade (°C)
	Daily	average in degrees centigrade
Wind speed	Hourly	metres per second (ms^{-1})
	Daily	average in metres per second
Wind direction	Hourly	degrees of angle (°)
	Daily	mean calculated by vector addition of hourly values (as is done to get hourly values from 5 min values)
Rainfall	Hourly	mm (m x 10^3)
	Daily	total in mm (also 0900-0900 total in mm).

The hourly recorded values are used to calculate hourly and thence daily values of humidities and evaporation.

TABLE 3.8 Continued

Calculated values

Hourly, daylight and 24 hour averages plus the maximum and minimum five minute values of:

Specific humidity	Hourly	grams kg^{-1} (kg kg^{-1} x 10^3) (calculated as shown in section 3.6.2).
	Daily	average of hourly values in g kg^{-1}
Specific humidity deficit	Hourly	grams kg^{-1} (kg kg^{-1} x 10^3) (calculated as shown in section 3.6.2)
	Daily	average of hourly values in g kg^{-1}

Hourly and daylight totals of Penman-Monteith evaporation estimates for water, grass and forest. Hourly values in joules sec^{-1} metre^{-2}, daily values in megajoules metre^{-2} and in mm.

Daily and daylight totals of Penman EO, Penman ET, and Thom-Penman evaporation estimates in megajoules metre^{-2} and in mm.

Data type key

Key	Data type
2	Solar radiation
3	Net radiation
4	Temperature depression
5	Dry bulb temperature
6	Wind speed
7	Wind direction
8	Rainfall
9	Specific humidity
10	Specific humidity deficit
11	Penman-Monteith evaporation for water
12	Penman-Monteith evaporation for grass
13	Penman-Monteith evaporation for forest

TABLE 3.9 DEFINITIONS OF CONSTANTS USED IN PENMAN TYPE CALCULATIONS

Radiation = net radiation in $Js^{-1}m^{-2}$ ($1\ Js^{-1} = 1$ watt)

(EA) = the aerodynamic factor which is a function of deficit (no units) and wind speed (ms^{-1})
$= 0.004(q_w - q)(1+0.54u)$

q_w = specific humidity at saturation

q = specific humidity at dry bulb temperature

u = wind speed

Δ' = slope of saturated specific humidity against temperature
$= (dq_w/dT)$ at dry bulb temperature in $kg\ kg^{-1}\ {}^{o}C^{-1}$

ρ = density of air ($\sim 1.20\ kg\ m^{-3}$) (Table 3.11)

c_p = specific heat of air at constant pressure ($= 1.01 \times 10^3\ Jkg^{-1}\ {}^{o}C^{-1}$) (Table 3.11)

λ = the latent heat ($\sim 2.47 \times 10^6\ Jkg^{-1}$) (Table 3.11)

γ $= c_p/\lambda$

For standard Penman: $M = 1$, $N = 1$

For Thom-Penman. $M = \left[\log_e(Z/Z_{op})/\log_e(Z/Z_o)\right]^2$

where: Z_o = actual roughness of surface

Z_{op} = 1.4 mm

Z = the measurement height (2 m)

$N = 1 + n$

n = the mean ratio of the surface resistance to the aerodynamic resistance (Thom and Oliver, 1977).

TABLE 3.10 RADIATION VALUES FOR ESTIMATING EVAPORATION

(i) If net radiation values are available.

The hourly net radiation, R_{Ny}, over a surface y with albedo α_y can be calculated from the net radiation, R_{Nx}, over the measured surface x with albedo α_x and the solar value S_{Tx} by:

$$R_{Ny} = S_{Tx}\ (1 - \alpha_y) - S_{Tx}\ (1 - \alpha_x) + R_{Nx} \qquad (3)$$

(ii) If net radiation values are not available for any surface and maximum possible solar value for the hour, S_{TMAX}, $\geq 50\ Wm^{-2}$:

$$R_{Ny} = S_{Tx}\ (1 - \alpha_y) - 10\ \frac{S_{Tx}}{S_{TMAX}} \qquad (4)$$

$$R_{Nx} = S_{Tx}\ (1 - \alpha_x) - 100\ \frac{S_{Tx}}{S_{TMAX}} \qquad (5)$$

where $\alpha_{water} = 0.05$, $\alpha_{forest} = 0.1$, $\alpha_{grass} = 0.2$.

(iii) If net radiation values are not available and $S_{TMAX} < 50\ Wm^{-2}$

$$R_{Ny} = R_{Nx} = -40\ Wm^{-2} \text{ (average night value)}$$

TABLE 3.11 EXACT VALUES OF THE 'CONSTANTS' USED IN AWS PROCESSING

(i) Density

The density of air varies with temperature and pressure (and therefore altitude). Its variation with water vapour content is only ½% and can be ignored in this application. A mean value is 1.20 kg m^{-3}.

The relationship used is: $\rho \simeq \left(\frac{1.293}{1 + .00367T}\right) \cdot \left(\frac{P}{1013}\right)$ kg m^{-3}

where T is the temperature in degrees C and P is the pressure in mb.

(Pressure, P, in mb at z metres = $1012 \times \left(1 - \frac{.0065z}{288}\right)^{5.256}$

(ii) Specific heat

This can be considered as a constant of value 1.01×10^{3} J kg^{-1} $^{o}C^{-1}$.

(iii) Latent heat

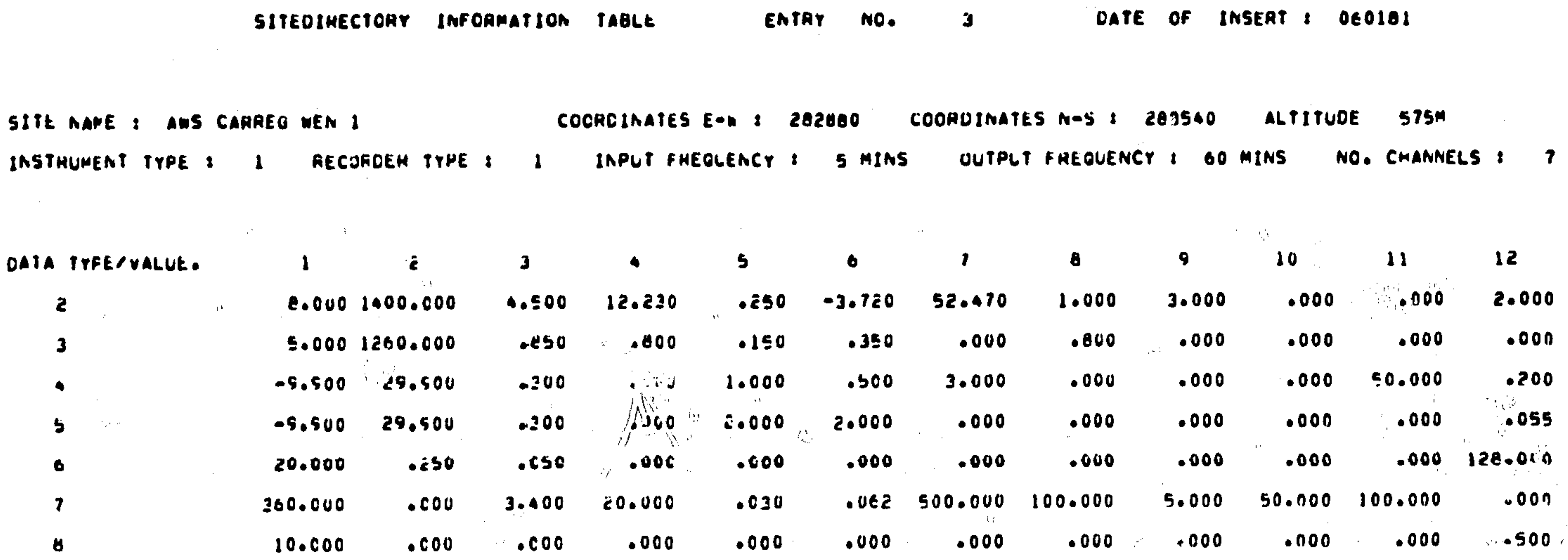
This varies by a few per cent over the full meteorological temperature range. A suitable mean value is 2.47×10^{6} J kg^{-1}.

The relationship used is: $\underline{\lambda = (2.5 - 2.38 \times 10^{-3}T) \times 10^{6} \text{ J kg}^{-1}}$

where T is the temperature in degrees C.

(iv) Psychrometric constant

The 'psychrometric constant' is known to vary with aspiration and only becomes constant at high aspiration rates. The value employed is appropriate to a Stevenson screen (0.5 for units of ^{o}C and g kg^{-1}). The assumptions, that the two types of AWS screen in use offer the same aspiration to the wet bulb as that in a Stevenson screen, and that the aspiration in any of the screens is constant, are somewhat dubious; but until better information becomes available, .5 will continue to be used.



```
                    SITEDIRECTORY  INFORMATION  TABLE        ENTRY   NO.     3          DATE  OF  INSERT : 060181


SITE NAME :  AWS CARREG WEN 1                COORDINATES E-W :  282880   COORDINATES N-S :  283540    ALTITUDE    575M
INSTRUMENT TYPE :   1   RECORDER TYPE :   1   INPUT FREQUENCY :   5 MINS    OUTPUT FREQUENCY :  60 MINS    NO. CHANNELS :   7


DATA TYPE/VALUE.        1        2         3         4         5         6         7         8         9        10        11        12
     2              8.000 1400.000     4.500    12.230      .250    -3.720    52.470     1.000     3.000      .000      .000     2.000
     3              5.000 1260.000      .250      .800      .150      .350      .000      .800      .000      .000      .000      .000
     4             -9.500   29.500      .200 [illegible]   1.000      .500     3.000      .000      .000      .000    50.000      .200
     5             -9.500   29.500      .200      .300     2.000     2.000      .000      .000      .000      .000      .000      .055
     6             20.000     .250      .050      .000      .000      .000      .000      .000      .000      .000      .000   128.000
     7            360.000     .000     3.400    20.000      .030      .062   500.000   100.000     5.000    50.000   100.000      .000
     8             10.000     .000      .000      .000      .000      .000      .000      .000      .000      .000      .000      .500
```

FIGURE 3.1 Automatic weather station entry in the site directory

```
                                        TIMING SUMMARY SHEET
                                        ********************

         STATION : AWS CEFN BRWYN 2                START : 1105 ON  31180     FINISH : 1100 ON 181180


                      DAWN                         SUNSET                      DAY LENGTH                    NOON                 AVERAGE
  DAY                 ****                         ******                      **********                    ****                  SOLAR
 NUMBER     TRUE    APPARENT  DIFF.      TRUE    APPARENT   DIFF.     TRUE    APPARENT  DIFF.     TRUE    APPARENT  DIFF.          VALUE
 ******    (HOURS)  (HOURS)  (MINS)     (HOURS)  (HOURS)   (MINS)    (HOURS)  (HOURS)  (MINS)    (HOURS)  (HOURS)  (MINS)         *******

  309        745      740        5        1705     1635        30       920      855       25      1225     1205       20        66.4    24
  310        745      755      -10        1705     1635        30       920      840       40      1225     1215       10        38.3    24
  311        750      745        5        1700     1635        25       915      850       25      1225     1210       15        23.8    24
  312        750      750        0        1700     1645        15       910      855       15      1225     1215       10        35.3    24
  313        755      835      -40        1655     1615        40       905      740       85      1225     1225        0        21.6    24
  314        755      740       15        1655     1635        20       905      855       10      1225     1205       20        92.6    24
  315        755      735       20        1655     1610        45       900      835       25      1225     1150       35       175.7    32
  316        800      810      -10        1650     1620        30       855      810       45      1225     1215       10        38.5    40
  318        800      805       -5        1650     1615        35       850      810       40      1225     1210       15        66.9    24
  319        805      855      -50        1645     1445       120       845      550      175      1225     1150       35        14.9    24
  320        805      900      -55        1645     1545        60       845      645      120      1225     1220        5        29.5    16
  321        805      825      -20        1645     1555        50       840      730       70      1225     1210       15        44.2    16
  322        805      850      -45        1645     1620        25       840      730       70      1225     1235      -10        29.5    16
```

FIGURE 3.2 Automatic weather station timing summary listing

FIGURE 3.3

Sensor and station performance indices

```
                    STATION  AWS CEFN BRWYN 2            PERIOD OF OPERATION 18.11.80  TO  02.12.80

        SENSOR 2 = SOLAR RADIATION
        SENSOR 3 = NET RADIATION
        SENSOR 4 = TEMPARATURE DEPRESSION
        SENSOR 5 = DRY BULB TEMPERATURE
        SENSOR 6 = WIND RUN
        SENSOR 7 = WIND DIRECTION
        SENSOR 8 = RAINFALL
        SENSOR 9 = STAGE RECORDER


                 SENSOR                2      3      4      5      6      7      8

                 QUALITY OF DATA

                 TYPE 3             4027   2596   4036   4037   3932   3510   4036

                 TYPE 2                8   1440      1      0    103    476      0

                 TYPE 1                9      8      7      7      9     58      8

      NUMBER OF RECORDS:   ACTUAL=  4044     EXPECTED=  4044
```

FIGURE 3.4 Automatic weather station data translation summary listing

```
AWS CEFN BRWYN 2

THIS IS A DIDCOT MICRODATA STATION

THE SOLAR CALIBRATION FACTOR IS 116 AND THE NET FACTOR IS  89

 60. LOGGER STEPS CORRESPOND TO    DEG C
 THE DEPRESSION CHANNEL SENSITIVITY IS .055 DEG C/LOGGER STEP
THE TEMPERATURE CHANNEL SENSITIVITY IS .25 DEG C /LOGGER STEP
AND THE RAINGAUGE BUCKET SIZE IS  .5MM

THE HOUR AFTER THE LAST COMPLETE HOUR OF DATA STARTS AT  1400HRS ON  2.12.1980                    IO COMPLETION STATUS IS: -1
SCAN MARK FREQUENCY DISTRIBUTION:
SM: 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227
      7   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
SM: 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255
      0   0   0   0   0   0   0   0   0 27620081751   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0

QUALITY CONTROL OF CASSETTE DATA FROM  AWS CEFN BRWYN 2                         STARTING TIME  1105   DATE  181180
●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●●
```

```
DIFFERENCE IN TRUE AND APPARENT DAY LENGTHS GREATER THAN TWO HOURS ON DAY   319
SOLAR RADIATION DATA                DAY NUMBER   319           DATE  14.11.80
            DATA IS IN COLUMN  1 ON RECORDS  3037 TO  3324 OF DATA FILE 000603118002.

0000      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
0100      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
0200      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
0300      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
0400      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
0500      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
0600      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
0700      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
0800      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)    8.1(3)    8.1(3)
0900     8.1(3)    8.1(3)    8.1(3)    8.1(3)    8.1(3)    8.1(3)    8.1(3)   16.1(3)   24.2(3)   24.2(3)   24.2(3)   24.2(3)
1000    16.1(3)   24.2(3)   24.2(3)   32.3(3)   32.3(3)   24.2(3)   16.1(3)   16.1(3)   16.1(3)   16.1(3)   16.1(3)   16.1(3)
1100    16.1(3)   16.1(3)   16.1(3)   16.1(3)   24.2(3)   16.1(3)   24.2(3)   16.1(3)   24.2(3)   16.1(3)   24.2(3)   24.2(3)
1200    16.1(3)   16.1(3)   16.1(3)   16.1(3)   16.1(3)   16.1(3)    8.1(3)    8.1(3)   16.1(3)   16.1(3)    8.1(3)   16.1(3)
1300    16.1(3)    8.1(3)    8.1(3)    8.1(3)    8.1(3)    8.1(3)   16.1(3)   16.1(3)    8.1(3)   16.1(3)    8.1(3)    8.1(3)
1400    16.1(3)   16.1(3)    8.1(3)    8.1(3)    8.1(3)     .0(3)    8.1(3)    8.1(3)     .0(3)     .0(3)    8.1(3)    8.1(3)
1500      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
1600      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
1700      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
1800      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
1900      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
2000      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
2100      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
2200      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
2300      .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)     .0(3)
```

FIGURE 3.5 Listing of solar radiation data for manual inspection

```
CHECK START AND FINISH TIMES
LAST RECORD EXPECTED AT  1000 ON  21280
LAST RECORD ACTUALLY AT  2300 ON  81280
UNSUCCESSFUL QUALITY CONTROL FOR SITE AWS TANLLWYTH 1                    STARTING DATE 241180
```

FIGURE 3.6

Checking the quantity of data on a cassette tape

```
          DAILY  SUMMARY  SHEET   FOR  AWS CEFN BRWYN 2                    DATE   1.12.80(336)     FREQUENCY  OF  VALUES  =  60  MIN.

   2 SOLAR RADIATION(WATTS/SQ METER)  TOTAL  IN MEGAJOULES/SQ METER              9 SPECIFIC HUMIDITY(GRAMS/KG)  AVERAGE IN GRAMS/KG
   3 NET RADIATION(WATTS/SQ METER)    TOTAL  IN MEGAJOULES/SQ METER             10 SPEC HUM DEFICIT(GRAMS/KG)   AVERAGE IN GRAMS/KG
   4 TEMP DEPRESSION(DEGREES C)       AVERAGE  IN DEGREES C                        PENMAN-MONTEITH EVAPORATION
   5 DRY BULB TEMPERATURE(DEGREES C)  AVERAGE  IN DEGREES C                     11 WATER(WATTS/SQ METER)        TOTAL IN MEGAJOULES/SQ METER
   6 WIND SPEED(METRES/SEC)           AVERAGE  IN METRES/SEC                    12 GRASS(WATTS/SQ METER)        TOTAL IN MEGAJOULES/SQ METER
   7 WIND DIRECTION(DEGREES)          AVERAGE  IN DEGREES                       13 FOREST(WATTS/SQ METER)       TOTAL IN MEGAJOULES/SQ METER
   8 RAINFALL(MM)                     TOTAL  IN MM

   TIME(HRS)            2       3        4        5        6        7       8       9      10           11        12        13

   0000-0100            0       .       .1     -6.0       .6      350 ?    .0     2.5      .1            0         0         0
   0100-0200            0     -10       .0     -6.3       .8      356 ?    .0     2.4      .0            0         0         0
   0200-0300            0     -10       .0     -7.2       .7      348 ?    .0     2.3      .0            0         0         0
   0300-0400            0     -12       .0     -7.3       .6      358 ?    .0     2.3      .0            0         0         0
   0400-0500            0     -10       .0     -7.4       .7      347      .0     2.3      .0            0         0         0
   0500-0600            0     -10       .1     -7.0       .5      338      .0     2.3      .1            0         0         0
   0600-0700            0      -9       .1     -5.3       .4      355 ?    .0     2.6      .1            0         0         0
   0700-0800            1      -8       .3     -3.4      1.0      307      .0     2.8      .3            0         0         0
   0800-0900           12      -6       .4     -2.3      1.3      259      .0     3.0      .3            2         4        46
   0900-1000           34      -4       .5     -1.7      1.7      271      .0     3.1      .3            5         7        71
   1000-1100           45       2       .5     -1.2      2.4      277      .0     3.3      .3           10        13       100
   1100-1200           64      10       .4      -.7      3.3      293      .0     3.4      .3           16        18       123
   1200-1300           58      12       .3      -.5      3.7      290      .0     3.5      .3           16        18       114
   1300-1400           63      18       .3      -.1      5.1      294      .0     3.6      .3           22        26       165
   1400-1500           26       8       .3      -.1      3.1      279      .0     3.7      .2           11        14        88
   1500-1600            5       2       .4       .1      1.5      284      .0     3.7      .3            0         0         0
   1600-1700            0      -3       .3       .4      3.5      269      .0     3.8      .2            0         0         0
   1700-1800            0       2 ?     .2       .9      4.6      290      .0     4.0      .2            0 ?       0 ?       0 ?
   1800-1900            0       2 ?     .2      1.4      5.7      277      .0     4.2      .1            0 ?       0 ?       0 ?
   1900-2000            0       2 ?     .1      1.6      6.2      282     1.5     4.3      .1            0 ?       0 ?       0 ?
   2000-2100            0       2 ?     .1      2.4      8.3      287     1.5     4.6      .1            0 ?       0 ?       0 ?
   2100-2200            0       2 ?     .1      2.8      7.2      292     2.0     4.7      .1            0 ?       0 ?       0 ?
   2200-2300            0       2 ?     .1      3.9      7.3      283     3.0     5.1      .1            0 ?       0 ?       0 ?
   2300-2400            0       2 ?     .2      4.8      6.6      280     2.5     5.3      .2            0 ?       0 ?       0 ?

   MAX 5 MIN VALUE     73      21       .5      5.2      9.3      349      .5     5.5      .4
   MIN 5 MIN VALUE      0     -16       .0     -7.9       .0 ?      0 ?    .0     2.2      .0

   DAYLIGHT TOT/AV    1.1      .1       .4      -.9      3.0      28[illegible]      .0     2.4      .3           .3        .4       2.5
                                                                                                    MM    .1        .1       1.0

   24 HOUR TOT/AV     1.1     -.1 ?     .2     -1.6      3.2      302    10.5     3.5      .0
                                                              09-9 RAIN   .0

   TOTAL EVAPORATION                    DAILY MJ/SQM     DAILY MM                DAYLIGHT MJ/SQM   DAYLIGHT MM

   EO PENMAN                                .1 ?           .0 ?                        .3               .1

   ET PENMAN                                .0 ?           .0 ?                        .2               .1

   THOM-PENMAN                              .4 ?           .2 ?                        .2               .1
```

FIGURE 3.7 Automatic weather station daily summary listing

```
MEAN DIFFERENCES FOR SITES  AWS CARREG WEN 1          1979     6  AWS CARREG WEN 2          1979

FOR DAY NUMBERS  305 TO  324   LOWEST CODE USED  2


HOURLY          SOL    NET      [illegible]  DRY   SPEED   DIRECT   RAIN   SP HUM     DEF    PM W     PM G      PM F

0000-0100        0.     -3. ?    -.1    -.2    .7 ?   -13. ?    .0     .0       -.1    0. ?     0. ?      0. ?
0100-0200        0.     -4. ?    -.1    -.2    .7 ?    -6. ?    .0     .0       -.1    0. ?     0. ?      0. ?
0200-0300       -0.     -4. ?    -.1    -.2    .7      -6.      .1     .0       -.1    0. ?     0. ?      0. ?
0300-0400       -0.     -4. ?    -.1    -.2    .8      -8.             .0       -.1    0. ?     0. ?      0. ?
0400-0500       -1.     -4. ?    -.1    -.2    .8                      .0       -.1    0. ?     0. ?      0. ?
0500-0600       -1.    -15. ?    -.1    -.2    .8 ?                     0       -.1    0. ?     0. ?      0. ?
0600-0700       -1.     -4. ?    -.1    -.2    .8                               -.1   -1. ?    -3. ?    -38. ?
0700-0800       -1.     -5. ?    -.1    -.2    .8                               -.1    0. ?    -3. ?    -61. ?
0800-0900       -1.    -23. ?    -.1    -.2    .8                               -.1    8. ?     9. ?     43. ?
0900-1000       -1.    -25. ?    -.1    -.2    .8 ?                             -.1   -1. ?    -2. ?     -4. ?
1000-1100              -20. ?    -.1    -.2    .8                               -.1   -1. ?    -3. ?    -13. ?
1100-1200              -14.      -.1    -.1    .9                               -.1    2. ?    -1. ?     -9. ?
1200-1300      -11.    -14. ?    -.1    -.1    .9                                     -0. ?    -5. ?     -6. ?
1300-1400              -24. ?    -.1    -.1    .9                                      4. ?     2. ?     -0. ?
1400-1500      -15.    -10. ?    -.1    -.1    .9                                      7. ?     5. ?     16. ?
1500-1600      -11.    -28. ?    -.0    -.1    .9                               -.0    8. ?     7. ?     29. ?
1600-1700      -13.    -32. ?    -.0    -.1    .8                               -.0    0. ?     0. ?      0. ?
1700-1800      -14.    -33. ?           -.1    .8                      .0       -.0    0. ?     0. ?      0. ?
1800-1900      -14.    -33. ?    -.0    -.1    .8                      .0       -.0    0. ?     0. ?      0. ?
1900-2000              -34. ?    -.0    -.1    .7 ?                   -.0       -.0    0. ?     0. ?      0. ?
2000-2100      -14.    -31. ?    -.1    -.1    .7      -5.     -.1     .0       -.0    0. ?     0. ?      0. ?
2100-2200      -14.    -25. ?    -.1    -.2    .8      -6.      .0     .0       -.1    0. ?     0. ?      0. ?
2200-2300      -14.    -26. ?    -.1    -.2    .8 ?    -5. ?   -.1     .0       -.1    0. ?     0. ?      0. ?
2300-2400      -16.    -33. ?    -.1    -.2    .7 ?    -6. ?    .0     .0       -.1    0. ?     0. ?      0. ?

MEAN DAYLIGHT    .1     -.2 ?    -.1     .1   1.1      -3.      .8     .1       -.1     .1 ?     .0 ?     -.3 ?

MEAN 24 HOUR     .1     -.4 ?    -.1    -.1    .8 ?    -5.  [illegible]  .0       -.1

24 HOUR PENMAN EO       .5 ?        DAYLIGHT PENMAN EO        .1 ?

24 HOUR PENMAN ET       .5 ?        DAYLIGHT PENMAN ET        .1 ?

24 HOUR THOM-PENMAN    -.2 ?        DAYLIGHT THOM-PENMAN      .2 ?
```

FIGURE 3.8 Listing of the comparisons between the data from two automatic weather stations

4. RUNOFF RECORDERS

4.1 Introduction

A system for the quality control and processing of records from chart and punched tape recorders has been fully documented (Plinston and Hill, 1974), and has been in use at IH for the past decade. However, these recorders, while still used as back-up, have been superseded on all the Institute's catchment experiments by automatic river level sensors whose output is logges on cassette tape.

The logger records river level every 5 minutes giving 288 data points per day, three times the amount of data normally abstracted from the best chart recorders. Furthermore the data are not open to visual inspection until the cassette tapes are translated. Thus greater emphasis must be placed on the numerical quality control and there is a good case for automatic correction procedures, where these can be used reliably, to minimise the amount of manual editing during the quality control stage. This section of the report describes the new routines developed to process data from the new instruments.

The river level sensor, described by Strangeways and Templeman (1974), is float operated but instead of actuating a pen the float pulley is directly linked to two fine potentiometers. A change of river level of 30 cm causes one rotation of the pulley and of the potentiometers whose outputs are divided into 200 logger steps. Thus the discrimination is 1.5 mm over an effectively unlimited range of river level. Each potentiometer has a small 'blind spot' where the windings terminate but as the potentiometers are set 180° out of phase, one is at mid-range when the other reaches its 'blind spot'. Most of the time there are two valid readings and comparison of these during tape translation provides a useful initial stage of quality control. A third potentiometer geared to rotate once over the full range of river level provides a check on the number of complete rotations of the fine potentiometers. In addition a scan mark, a reference level of the voltage of the logger, is recorded.

The cassettes are changed every two weeks at which time the operator makes a manual measurement of river level above the station datum. Each cassette with the start and end times, dates and the check measurements can be processed independently. After the quality control stage, the data from cassettes taken sequentially from the same station can be run together using routines developed to ensure correct time synchronisation and continuity of river levels.

4.2 Site directory

The format of the entries in the site directory has already been described in Section 2.2. For water level recorders the number of variables normally processed is one; that being river level or stage above the datum point. There is provision in the site directory for up to twelve standard/conversion values associated with river level, the values currently being used are shown below:

Data type 9, River Level.

1. Zero adjustment
2. Tolerance between suspect differences.
3. Tolerance between manually-read and recorded values.
4. Tolerance between overlapping values.
5. Area of catchment.
10. Phase correction tolerance for the two potentiometers.
11. Scan mark value.
12. Phase difference between coarse and fine potentiometers.

The control information used for water level recorders is similar to that used for other instrumentation. Those values unique to water level recorders are:

BSITE - is of the form WLR XXXXXX.... where XXXXXX ... is the local site name associated with the water level recorder.

INST - 2.

KREC - 2.

ICHANN- 1.

An example of a water level recorder entry in the site directory is given in Fig. 4.1.

4.3. Data collection

Although there is sufficient capacity for storing several months' data on the currently used logging system, it is policy at the Institute to visit the various water level recorder sites every two weeks. This is to minimize data loss due to battery failure, logger malfunction etc. During these fortnightly visits the battery and cassette tape are changed and a manual reading of the water level taken. This level, together with the start and end times and dates of data and the site name, are noted on the field data form (Fig. 2.3). This form, together with the cassette, is then sent to Wallingford for processing.

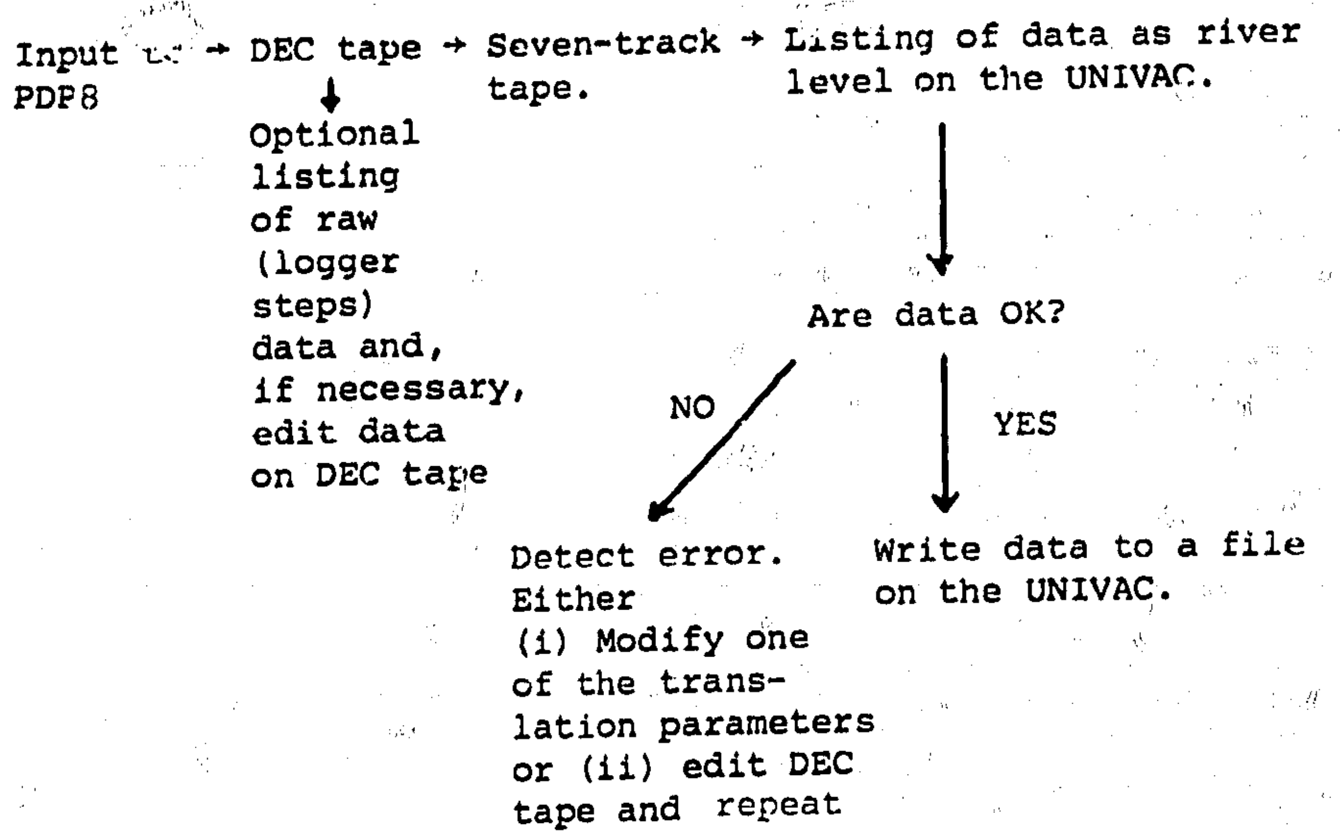
4.4. Office procedures, pre-processing

When the tape and field data form arrive at Wallingford, an entry is made on a site record card indicating the start and end times of the data. A Microdata logger and faults form (Fig. 2.4) is initiated on which is noted any errors caused by instrument, tape, battery, or logger malfunction detected during the various stages of processing.

These forms are usually completed within 7 days of receipt of the cassette to facilitate rapid correction of faults.

4.5. Input to the computer system

Because of the unique nature in which the data are recorded on the cassette tape, the input to the computer system is necessarily time consuming. The sequence of events is shown below:



The data in logger steps contained on the cassette tape are first input to the PDP8 computer at Wallingford via the Microdata cassette reader. They are then written on to DEC tape which acts as a permanent storage and editing medium. The data are written to a seven-track tape which is transferred to the UNIVAC at Rutherford. A line printer listing of the data as river level (the translation from logger steps to river level is described in Section 4.6) is produced and inspected manually. If the data are satisfactory, they are written, in logger steps, into a file on the UNIVAC for quality control and processing. If the data are not satisfactory then, depending on the cause of the error, one of two courses of action may be taken; (i) one or more of the translation parameters may be modified (see section 4.6) or (ii) the data on the DEC tape may be edited and the process repeated.

Normally this procedure is carried out on data from several cassettes at the same time, the end result being a file on the UNIVAC containing several cassette lengths of data for quality control and processing.

4.6. Quality control

The quality control routines are applied to the data contained in the file produced as described above. Each cassette length must have an associated information record punched [illegible] computer card. This information record contains the values [illegible] field data form (Section 4.3) plus some factors needed [illegible] conversion of logger steps into river level. These values [illegible]

KSCAN - minimum permitted value [illegible]

KDIFF - the maximum tolerance of phase difference between the two fine potentiometers,

KCOAR - the maximum change permitted in coarse potentiometer reading between two scans,

OLD - an integer determining the method used for converting potentiometer reading to river level (depends on how the fine potentiometers have been set),

JSCAN - the maximum permitted change in scan mark value.

The values of these factors are normally pre-set but can be changed as a result of errors found in the coarse quality control on input to the computer system (Section 4.5).
Before the data are subjected to the quality control routines they are converted from logger steps into stage values. This is done by means of the initial manually-read river level which acts as a reference, and the average change in the two fine potentiometer readings. The reading of the coarse potentiometer indicates which revolution the fine potentiometers are on. A coarse quality control is applied during this translation, involving the values of KSCAN, KDIFF, KCOAR, and JSCAN. Each generated river level is given a flag, the value of which indicates the acceptability of the value. If the value of the flag = 0, then the river level is acceptable; if flag = 1, then the value is unacceptable and will be given a quality index of 1 during the quality control stage. The criteria for rejecting a river level value are as follows:

(i) The expected scan mark is missing ie. no value greater than the minimum scan mark value, KSCAN, is found,

(ii) The scan has too few recorded values, ie. a value greater than KSCAN is found before the end of the scan,

(iii) Both fine potentiometer values are outside the expected range of $10 \leq x \leq 190$,

(iv) Both fine potentiometer values are within the expected range but their difference exceeds KDIFF (currently set at 12 logger steps).

During the course of the quality control, each data value is given a quality index (3 = good, 2 = acceptable, 1 = bad). The values are assumed to be correct prior to the quality control except for those with flag = 1.

There are three quality control aspects:

(i) checking for errors relative to the station datum

(ii) checking that there are no unusual fluctuations in the trend of river levels

(iii) checking that the maximum river level is in the expected range.

The results of the second of these checks triggers automatic correction routines which, under certain circumstances described in detail below, allow the data to be corrected without further manual intervention. Data so corrected are given an index value of 2 indicating that they can be used in most further analysis although they are not genuine recorded values.

The aim has been to produce a quality control package which is not over-complicated and which does not produce an excessive workload for the manual editing phase. For this reason, statistical tests on rates of rise of river levels, their monthly means or maxima, have been avoided. They might well not lead to useful improvements to the quality of the data and would certainly lead to much staff time being spent deriving and refining index values for the many different gauging stations in various parts of the country.

The automatic correction procedures have removed a number of persistent yet often trival problems in editing from the need for manual intervention. With more experience of their reliability, it might be possible to extend the limits constraining their application.

(i) Errors relative to station datum

Comparison of the recorded and observer-measured river levels at the nominal end of the cassette period will indicate potential errors due to a river level sensor going out of adjustment.
There are two possible results of this check:

(a) the recorded and observer-measured levels agree to within the acceptable tolerance (standard value 3 in the site directory),

(b) the recorded and observer-measured levels are inconsistent. Appropriate diagnostics are printed for subsequent manual checking (Fig 4.2).

(ii) Errors in the trend of river levels.

River levels recorded at 5 minute intervals should form a smooth hydrograph except at flood peaks. In general, any single data point which is significantly in error should stand out from the otherwise smooth hydrograph. Similarly, any sudden shift in the setting of the recorder should appear as an easily identifiable step in the sequence of data points.

A simple trend test applied successively to each possible sequence of 4 river levels is sufficiently powerful to identify potential errors of these two kinds. All the relevant combinations of 4 successive river levels are shown in Figure 4.3 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 sequence of 4 levels.

When a river level is found to be suspect, its quality index is set to 1 but no diagnostics are printed until the automatic correction procedure indicates that manual editing is necessary.

(iii) Checking the maximum river level

Because of the importance of peak flood flows in many river training, flood warning and reservoir design problems, it is desirable to try to ensure that peak river levels are recorded accurately. However, there is no simple computer based procedure which is sufficiently sensitive to detect all possible forms of error. For example, the temporary blockage of a flume by driftwood can give an apparently smooth hydrograph acceptable to the trend test, but readily identified as false by an experienced observer scanning a conventional recorder chart.

Where a standby chart recorder is in use a visual check of the record is possible; otherwise a hydrograph could be produced by the computer graph plotter from the cassette data. The maximum river level recorded in the cassette period is printed to aid whatever manual checking is considered appropriate.

(iv) Automatic correction procedures.

Following the quality control checks, all possible bad data will carry a quality index of 1.

The automatic correction procedure identifies these data and subject to the following constraints replaces them by alternative values derived by linear interpolation between the good data on either side of the bad patch:

(a) there must be at least 6 good data points preceding and following the bad data

(b) the data must refer to a period of falling river levels

(c) the period of bad data must not exceed 3 hours.

Short periods of good data (less than 6 points) following bad data are regarded as a continuation of the bad patch. Also the first constraint means that bad data too near the start or end of the cassette will not be corrected automatically.

In the test to ensure that river levels are falling, very small rises, less than the tolerance between suspect differences, are ignored. No attempt is made to carry out automatic correction during a period of rising river level when linear or even more powerful techniques of interpolation could lead to unacceptable errors.

When data are corrected automatically, their quality indices are set to 2. Otherwise, the bad data are listed with the appropriate diagnostic for manual editing (Fig 4.4). If errors are found which cannot be automatically corrected, the data from the cassette are written out to a temporary file for manual editing (Section 4.7). However, should the data be found to be "error free" then any temporary files created during the quality control stage will be automatically deleted and the data further processed as indicated in section 4.8.

4.7. Editing

Cassette lengths of data which contain "incorrect" values which cannot be automatically corrected are written to temporary files for subsequent manual editing. This can be carried out on the information record or on individual data values. The type of editing is governed by the value of INPUT (Section 2.6); this also determines whether the data require quality control following the edit.

(i) All the values contained in the information record may be edited. For changes in the values involved in the conversion of logger steps to river level, it is advisable to re-run the data through the translation and quality control routines.

(ii) An individual or successive series of data values may be changed by.

(a) replacement by a single value,

(b) adding or subtracting a fixed [illegible] (if , after such action, the water level becomes negative, it is re-set to zero),

(c) replacement by variable values.

The quality indices of all data points edited are automatically re-set to 2 indicating that the values are not as recorded.

(iii) The quality indices of an individual or successive series of data values may be edited.

4.8 Data conversion, summary printouts and data retained

River levels are generally converted into flow using a stage/discharge relationship obtained theoretically using the flume or weir dimensions and sometimes modified using techniques such as dilution gauging and current metering. The stage/discharge relationship is stored in tabular form in a file the name of which is determined from the internal site number (Section 2.2), eg if the internal site number is 101, the name of the file containing the stage/discharge table in TABLES 101. This table contains flow values (in cumecs) corresponding to each stage value from zero to the maximum height of the flume/weir in increments of 1 mm. For most catchment studies, the required unit of flow is mm over the catchment: this requires access to the catchment area, stored in the site directory. The steps involved in converting river level to flow in mm over the catchment for the required frequency are:

(i) Calculate the flow (in mm over the catchment) for the time periods between successive river level values by using the stage/discharge table and the catchment area,

(ii) Sum the flow values over the required frequency.

The quality indices of the river levels are transferred to the final flow values, and are stored together with the flow values in direct access files as indicated in Section 2.10, the name of the file being determined as outlined in Section 2.2. A line printer listing (Figure 4.5) of the final flow and average river level values is produced.

4.9 Areal estimates

The final stored values are flows in depth over the catchment and no further conversion is required.

4.10 Data storage on disc and tape, retrieval and display

In addition to storing the final flow values in direct access files, the river levels in mm are stored on 9-track magnetic tape, each cassette length occupying one file on the magnetic tape. At the end of each quality control/editing run, the contents of the current 9-track storage tape are listed, together with the number of files on the tape and the percentage of tape used.

Data retrieval may be carried out via a computer program. A further programe has been written to display the data in graphical time series form. This is particularly useful as a final quality control check. If errors are detected in the stored data, they may be rectified in one of two ways:

(i) Subroutines have been written to edit the final data using similar techniques to those described in Section 4.7.

(ii) The river levels stored on 9-track magnetic tape may be retrieved on to disc, the values and information records edited as before and the flow values re-calculated.

Gaps in the data are filled using data from other recorders, eg Leupold and Stevens, Fischer-Porter, at the same time. These data are processed by modified versions of the system described by Plinston and Hill (1974).

```
SITEDIRECTORY  INFORMATION  TABLE          ENTRY  NO.  101          DATE  OF  INSERT :  060181

SITE NAME :  WLR CEFN BRWYN                    COORDINATES E-W :  282900    COORDINATES N-S :  283800    ALTITUDE   360M
INSTRUMENT TYPE :   2    RECORDER TYPE :   2    INPUT FREQUENCY :   5 MINS    OUTPUT FREQUENCY :  15 MINS    NO. CHANNELS :   1

DATA TYPE/VALUE.        1        2        3        4        5        6        7        8        9       10       11
    9                 .000    3.000    3.000    1.000 1055.000    .000     .000     .000     .000    7.000  220.000
```

FIGURE 4.1 Water level recorder entry in the site directory

```
WLR TANLLWYTH

INITIAL RIVER LEVEL TAKEN AS  148 MM

DATA STARTS AT 1010.0N  1/10/1980

LAST DATA WAS RECORDED AT 1035 HRS ON  3/11/1980 :  THE FINAL LEVEL WAS    100 MM

SCAN MARK FREQUENCY DISTRIBUTION:
SNT 210  211  212  213  214  215  216   217  218  219  220  221  222  223  224  225  226  227  228  229  230  231  232  233  234
           0    0    0    0    0    0     0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
SNT 235  236  237  238  239  240  241   242  243  244  245  246  247  248  249  250  251  252  253  254  255
      0    0    0    0    0 3422 6088     0    0    0    0    0    0    0    0    0    0    0    0    0    0

DISTRIBUTION OF DIFFERENCE FINE POT 2 - FINE POT 1
     88   89   90   91   92   93   94   95   96   97   98   99  100  101  102  103  104  105  106  107  108  109  110  111  112
      0    0    0    0    0    0    0    0    0    0   61  638  579   59    0    0    0    0    0    0    0    0    0    0    0
[illegible] 3    2    5    5   12    9    5   30  650 2683 2913 1052   31    0    0    0    0    0    0    0    0    0    0    0
DISTRIBUTION OF COARSE POT NON-LINEARITY
RANGE:  26-30   31-35   36-40   41-45   46-50   51-55   56-60   61-65   66-70   71-75   76-80   81-85   86-90   91-95   96-100+
COUNT:    0       0       0       0       0       0       0       0       0       0       0       0       0       0       0

MAIN CONSTANTS:    KSCAN   KDIFF   KCOAR   OLD   JSCAN
DEFAULT VALUES:     220     12      10      0      2
VALUES FOR RUN:     220     12      10      0      2

OTHER CONSTANTS WERE:   KSLIP= 80   DELTA1= -10   DELTA2=  85   DEPC=-212

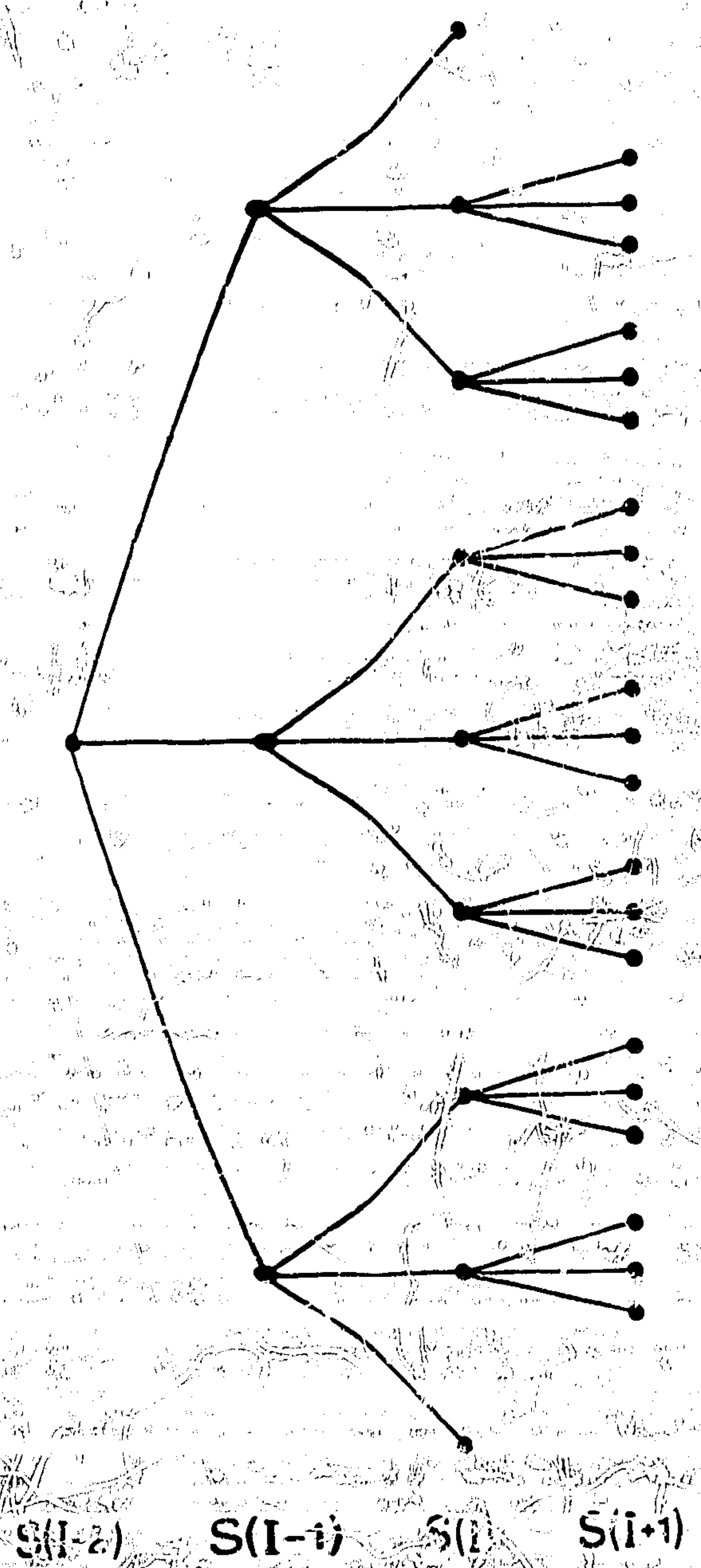
QUALITY CONTROL OF CASSETTE DATA FROM  WLR TANLLWYTH                       STARTING TIME  1010    DATE  011080
***************************************************************       *******************************************   ******


   CHECKS ON FIRST AND LAST VALUES                      FIRST VALUE   148.0 (3)   AT 1010 ON DAY  275      CHECK VALUE  148.0
                                                        LAST VALUE    100.0 (3)   AT 1035 ON DAY  308      CHECK VALUE  100.0

                                               ***** FIRST AND LAST VALUES CONSISTENT WITH CHECK VALUES *****
```

FIGURE 4.2 Water level recorder data translation summary testing

Action taken in the trend test



CASE	ACTION TAKEN	
1	accepted	
2	query	S(I)
3	query	S(I-1)
4	accepted	
5	query	S(I-1)
6	accepted	(becomes case 20,21,22)
7	accepted	
8	accepted	
9	accepted	(becomes case 2,3,4)
10	query	S(I-1)
11	accepted	
12	accepted	
13	query	S(I)
14	query	S(I-1)
15	accepted	(becomes case 20,21,22)
16	accepted	
17	accepted	
18	accepted	(becomes case 2,3,4)
19	query	S(I-1)
20	accepted	
21	query	S(I-1)
22	query	S(I)
23	accepted	

FIGURE 4.3 Trend test for water levels

```
***** FROM 1350 ON DAY 280 TO 1350 ON DAY 280     BAD DATA   AUTO CORRECTION IMPOSSIBLE   DATA NOT DURING RECESSION     *****

WATER LEVEL DATA                          DAY NUMBER   280           DATE    6.10.80

           DATA IS IN COLUMN  1 ON RECORDS  1608 TO  1655 OF DATA FILE 011101108002.


0000      243.0(3)  242.0(3)  240.0(3)  239.0(3)  238.0(3)  236.0(3)  234.0(3)  233.0(3)  231.0(3)  231.0(3)  231.0(3)  229.0(3)
0100      228.0(3)  227.0(3)  226.0(3)  225.0(3)  223.0(3)  223.0(3)  221.0(3)  220.0(3)  218.0(3)  217.0(3)  216.0(3)  215.0(3)
0200      214.0(3)  213.0(3)  212.0(3)  211.0(3)  209.0(3)  208.0(3)  208.0(3)  206.0(3)  205.0(3)  205.0(3)  203.0(3)  203.0(3)
0300      202.0(3)  201.0(3)  198.0(3)  197.0(3)  195.0(3)  194.0(3)  195.0(3)  194.0(3)  191.0(3)  191.0(3)  190.0(3)  188.0(3)
0400      189.0(3)  187.0(3)  188.0(3)  186.0(3)  185.0(3)  184.0(3)  185.0(3)  184.0(3)  183.0(3)  179.0(3)  180.0(3)  179.0(3)
0500      179.0(3)  179.0(3)  178.0(3)  178.0(3)  176.0(3)  176.0(3)  176.0(3)  175.0(3)  174.0(3)  174.0(3)  174.0(3)  173.0(3)
0600      172.0(3)  173.0(3)  172.0(3)  171.0(3)  172.0(3)  170.0(3)  169.0(3)  165.0(3)  169.0(3)  169.0(3)  170.0(3)  169.0(3)
0700      168.0(3)  167.0(3)  168.0(3)  167.0(3)  167.0(3)  [illegible]  167.0(3)  166.0(3)  167.0(3)  164.0(3)  166.0(3)  166.0(3)
0800      166.0(3)  164.0(3)  165.0(3)  164.0(3)  165.0(3)  163.0(3)  163.0(3)  162.0(3)  164.0(3)  163.0(3)  162.0(3)  162.0(3)
0900      162.0(3)  162.0(3)  161.0(3)  162.0(3)  161.0(3)  161.0(3)  161.0(3)  161.0(3)  161.0(3)  159.0(3)  159.0(3)  161.0(3)
1000      161.0(3)  160.0(3)  160.0(3)  159.0(3)  161.0(3)  159.0(3)  161.0(3)  161.0(3)  161.0(3)  161.0(3)  163.0(3)  163.0(3)
1100      163.0(3)  164.0(3)  164.0(3)  165.0(3)  165.0(3)  165.0(3)  165.0(3)  165.0(3)  167.0(3)  167.0(3)  168.0(3)  171.0(3)
1200      173.0(3)  175.0(3)  176.0(3)  178.0(3)  179.0(3)  183.0(3)  185.0(3)  187.0(3)  191.0(3)  195.0(3)  201.0(3)  206.0(3)
1300      215.0(3)  224.0(3)  230.0(3)  245.0(3)  266.0(3)  287.0(3)  306.0(3)  327.0(3)  357.0(3)  386.0(1)  386.0(3)  437.0(3)
1400      479.0(3)  502.0(3)  524.0(3)  548.0(3)  575.0(3)  619.0(3)  662.0(3)  707.0(3)  755.0(3)  808.0(3)  852.0(3)  900.0(3)
1500      943.0(3)  984.0(3) 1024.0(3) 1058.0(3) 1086.0(3) 1102.0(3) 1108.0(3) 1124.0(3) 1136.0(3) 1161.0(3) 1179.0(3) 1193.0(3)
1600     1211.0(3) 1222.0(3) 1231.0(3) 1232.0(3) 1237.0(3) 1239.0(3) 1243.0(3) 1253.0(3) 1261.0(3) 1275.0(3) 1295.0(3) 1316.0(3)
1700     1337.0(3) 1356.0(3) 1358.0(3) 1361.0(3) 1361.0(3) 1368.0(3) 1380.0(3) 1396.0(3) 1401.0(3) 1387.0(3) 1365.0(3) 1324.0(3)
1800     1273.0(3) 1229.0(3) 1174.0(3) 1132.0(3) 1091.0(3) 1061.0(3) 1032.0(3)  997.0(3)  965.0(3)  928.0(3)  906.0(3)  883.0(3)
1900      861.0(3)  841.0(3)  821.0(3)  803.0(3)  780.0(3)  761.0(3)  747.0(3)  732.0(3)  719.0(3)  705.0(3)  690.0(3)  675.0(3)
2000      663.0(3)  650.0(3)  639.0(3)  630.0(3)  619.0(3)  609.0(3)  597.0(3)  587.0(3)  577.0(3)  568.0(3)  561.0(3)  556.0(3)
2100      558.0(3)  557.0(3)  549.0(3)  543.0(3)  538.0(3)  533.0(3)  527.0(3)  520.0(3)  517.0(3)  514.0(3)  510.0(3)  504.0(3)
2200      501.0(3)  497.0(3)  492.0(3)  489.0(3)  483.0(3)  481.0(3)  476.0(3)  475.0(3)  470.0(3)  467.0(3)  463.0(3)  460.0(3)
2300      457.0(3)  454.0(3)  451.0(3)  448.0(3)  445.0(3)  443.0(3)  439.0(3)  437.0(3)  432.0(3)  430.0(3)  428.0(3)  425.0(3)
```

FIGURE 4.4 Listing of water level data for manual inspection

```
WLR NAKI TAGO                        DATE : 27. 6.78

            0      15      30      45     100     115     130     145     200     215     230     245    TOTAL/AV
   0      .026    .026    .026    .026    .025    .025    .025    .025    .025    .025    .025    .025     .304
         126.0   126.0   126.0   125.5   125.0   125.0   125.0   125.0   124.5   124.0   124.0   124.0    125.0
 300      .025    .025    .024    .024    .024    .024    .024    .024    .024    .024    .024    .023     .289
         124.0   123.8   123.0   123.0   122.0   122.8   122.3   122.0   122.0   122.0   121.5   121.0    122.5
 600      .023    .023    .023    .021    .023    .023    .023    .022    .022    .022    .022    .022     .272
         121.0   121.0   120.5   120.1   120.0   120.0   119.5   119.0   119.0   119.0   118.8   118.3    119.7
 900      .022    .022    .022    .022    .021    .021    .021    .021    .021    .021    .021    .021     .257
         118.0   118.0   118.0   117.8   117.0   117.0   117.0   117.0   117.0   116.5   116.3   116.0    117.1
1200      .021    .021    .021    .021    .020    .020    .020    .020    .020    .020    .020    .020     .243
         115.8   115.5   115.8   115.7   115.0   115.0   114.5   114.0   114.0   114.0   114.0   114.3    114.8
1500      .020    .020    .019    .019    .019    .019    .019    .019    .019    .019    .019    .019     .232
         113.8   113.7   113.0   113.0   113.0   112.0   113.0   112.5   112.0   112.0   112.0   112.0    112.8
1800      .019    .019    .019    .019    .019    .019    .019    .019    .019    .019    .019    .019     .232
         112.0   112.0   112.5   113.0   113.0   112.0   113.0   113.0   113.0   112.0   113.0   113.0    112.8
2100      .019    .020    .020    .020    .020    .020    .020    .020    .021    .021    .021    .022     .244
         113.0   113.5   114.0   114.0   114.0   114.0   114.8   115.0   115.5   116.2   117.0   117.5    114.9

WLR NAKI TAGO                        DATE : 28. 6.78

            0      15      30      45     100     115     130     145     200     215     230     245    TOTAL/AV
   0      .022    .022    .022    .022    .022    .022    .022    .022    .022    .022    .024    .024     .271
         118.0   118.0   118.0   118.0   118.2   119.0   119.0   119.0   118.5   119.1   121.5   125.0    119.3
 300      .027    .030    .031    .032    .033    .035    .037    .039    .040    .040    .039    .036     .421
         128.7   132.5   135.3   138.8   138.5   142.0   146.0   149.7   150.5   150.8   150.0   149.2    142.4
 600      .038    .037    .036    .036    .035    .034    .033    .033    .032    .032    .031    .031     .407
         148.0   146.5   145.0   143.5   142.0   141.5   139.5   138.5   137.5   136.5   135.5   134.8    140.7
 900      .030    .030    .029    .029    .029    .028    .028    .028    .027    .027    .027    .026     .337
         133.8   133.0   132.2   132.0   131.2   129.5   129.5   129.2   128.5   128.0   127.2   127.0    130.2
1200      .026    .026    .026    .025    .025    .025    .024    .024    .024    .024    .024    .024     .298
         126.2   125.0   125.7   125.0   124.0   124.0   123.2   123.0   123.0   123.0   122.5   122.0    124.0
1500      .024    .024    .023    .023    .023    .023    .023    .023    .022    .022    .022    .022     .275
         122.0   121.5   121.0   121.0   121.0   120.5   120.0   120.0   119.2   119.0   119.0   119.0    120.1
1800      .022    .022    .022    .022    .022    .022    .022    .021    .021    .021    .021    .021     .260
         119.0   118.2   118.0   118.0   118.0   118.0   117.8   117.0   117.0   117.0   117.0   116.5    117.6
2100      .021    .021    .021    .021    .021    .021    .020    .020    .020    .020    .020    .020     .247
         116.0   116.0   116.0   116.0   116.0   115.8   115.0   115.0   115.0   115.0   115.0   115.0    115.5

WLR NAKI TAGO                        DATE : 29. 6.78

            0      15      30      45     100     115     130     145     200     215     230     245    TOTAL/AV
   0      .020    .020    .020    .020    .020    .020    .020    .020    .019    .019    .019    .019     .237
         115.0   114.2   114.0   114.0   114.1   114.0   114.0   113.5   113.0   113.0   113.0   113.0    113.7
 300      .019    .019    .019    .019    .019    .019    .019    .019    .019    .019    .019    .019     .230
         113.8   113.0   113.0   112.7   112.7   113.0   113.0   113.0   112.5   112.3   112.0   112.2    112.7
 600      .019    .019    .019    .019    .019    .020    .020    .020    .020    .020    .020    .020     .236
         113.0   113.0   113.0   113.0   113.0   113.3   113.5   114.0   114.0   114.0   114.0   114.0    113.5
 900      .020    .020    .020    .020    .019    .019    .019    .019    .019    .019    .019    .019     .233
         114.0   114.0   113.2   113.3   113.0   113.6   113.0   113.0   112.2   112.3   112.0   112.0    112.9
1200      .019    .019    .019    .019    .018    .018    .018    .018    .018    .018    .018    .018     .224
         112.0   112.0   111.8   111.7   111.0   111.0   111.0   111.0   111.0   111.0   111.0   110.8    111.3
1500      .018    .018    .018    .018    .018    .018    .018    .018    .018    .018    .017    .018     .213
         110.0   110.0   110.0   110.0   109.8   109.7   109.0   109.0   109.0   109.0   108.5   109.0    109.6
1800      .019    .021    .022    .022    .024    .025    .026    .025    .025    .026    .028    .031     .254
         112.3   115.2   117.7   119.3   122.5   124.2   125.0   125.0   125.0   125.5   130.5   134.5    123.1
```

FIGURE 4.5 Listing of finalized water level and discharge data

FAINT ORIGINAL

5. RAINFALL ESTIMATIONS

5.1 Introduction

The diverse nature of hydrological investigations require different types of rainfall records. Some investigations need point rainfall whilst catchment studies use areal estimates. In order to satisfy all demands, it is necessary to design a system which will process data from individual gauges and also combine the records from these individual gauges to produce areal estimates.

Because of the spatial variability of rainfall, it is necessary to have a network of raingauges in order to produce reliable areal estimates. The density of the network depends on the topography and meteorological conditions occurring within the area.

The types of raingauges within the area may vary; some are manually-read, others record rainfall at fixed time intervals. Plinston and Hill, 1974, describe a system for processing data from gauges read manually at fixed time intervals and from chart recorders. The system described here is similar but allows more flexibility in defining the gauges to be used in calculating areal estimates. Also, emphasis is placed on processing the data recorded on cassette tape via the Micro-data logger (event recorders). These have superseded the chart recorders at all of the Institute's experimental sites. However, there is provision for using data abstracted from chart recorders as back-up in case of instrument failure.

The rainfall event recorder is connected to a "Rimco" tipping bucket and records time and the number of tips of the bucket in a fixed time interval (usually five minutes). The size of bucket [illegible]ed is chosen so that each tip is equivalent to 0.5 mm of rainfall. [illegible] the data have been translated as described in Section 5.6, they are treated in exactly the same manner as those rainfall data recorded by the automatic weather station. No discrimination is made between rainfall recorded by automatic weather stations, event recorders, or, if necessary, chart recorders, when calculating areal estimates.

5.2 Site directory

The number of variables recorded by the rainfall event recorder is one only - the number of tips of the bucket in a five minute period. The standard/conversion values required for processing the data are the same as those needed for the rainfall channel of the automatic weather station. These are:

DATA TYPE 8	RAINFALL
1	Upper limit of rainfall total in recording time period.
12	Tipping bucket capacity.

The control information used for rainfall event recorders is similar to that used for other instrumentation. Those values unique to rainfall event recorders are:

BSITE is of the form RER xxxxx..... where xxxxx..... is the local site name associated with the rainfall event recorder.
INST - 3
KREC - 1
ICHANN - 1

An example of a rainfall event recorder entry in the site directory is given in Fig 5.1.

5.3 Data collection

Rainfall event recorders are serviced every two weeks at which time the logger and tape are changed and the site name, time and date of start and end of data, and check gauge total noted on the field data form (Fig 2.3). This form, together with the cassette tape, is then sent to Wallingford for processing.

5.4 Office procedures, pre-processing

When the tape and field data form arrive at Wallingford, a note is made of the start and end times and dates of the data on a site record card and a Microdata logger and tape faults form (Fig 2.4) initiated. On this form are noted all the errors due to instrument, tape or battery malfunction found during the various stages of processing. Should any malfunction be apparent, the form is passed to the Instrument Section for fault rectification.

5.5 Input to the computer system

The unique way in which the data are recorded on the cassette tapes necessitates an indirect and time consuming set of procedures to input the data to the computer system. The sequence of events is shown below.

Input to PDP8 ⟶ Dec tape ⟶ Seven track tape ⟶ File on the UNIVAC

The data are first input to the PDP8 computer at Wallingford by means of a Microdata cassette reader. They are then written out to a DEC tape which acts as a permanent storage and editing medium. The data are transferred to the UNIVAC using a seven-track tape. Normally several cassette lengths of data are transferred at the same time. The data in the file produced are in a form suitable for translation and quality control.

5.6 Quality control

The quality control routines are applied to the data contained in the file produced as described above. Each cassette length of data must have an associated information record on punched cards containing the values noted on the field data form (Section 5.2).

Before the data are quality controlled, they are converted into real units (mm) by multiplying the number of tips in each scan (given as the difference between the number of tips in successive scans) by the capacity of the tipping bucket, found in the site directory. Each data value is given a flag, the value of which depends on the results of a coarse quality control carried out during the translation stage. If flag = 0, the scan is acceptable; if flag = 1, the scan is unacceptable, and the quality index associated with the rainfall total during that time period will be set to 1 during quality control.

The quality control tests applied to the data are as follows:

(i) A comparison of the total as recorded by the gauge and the total collected in the check gauge and entered on the information record. If the totals do not agree to within ± 10%, an error message will be output and all the data from the cassette written out to a temporary file for manual inspection.

(ii) If any five-minute recorded rainfall total is greater than 10 mm, the quality index is set to 1.

(iii) If the current or previous scan flag = 1, the quality index = 1. (The rainfall in any time period is calculated from the present and previous recorded values.)

Should manual inspection be necessary, the data are written out to a temporary file. If the data are "correct" they are further processed as described in Section 5.8.

5.7 Editing

The editing to be carried out is determined by the value of INPUT, an integer specified by the user (Section 2.1). Two types of edits may be undertaken, those affecting the information record and those affecting individual data and quality indices.

(i) The information record

All the values stored on the information record may be edited.

(ii) Data values and quality indices

An individual or a consecutive series of data values may be edited by:

(a) replacing with a fixed value,
(b) replacing with variable values, or
(c) adding or subtracting a fixed amount

The quality indices of edited data values are automatically re-set to 2 thus indicating that the values are not as recorded. Similarly, the quality indices associated with an individual or a consecutive series of data values may be changed.

Following the editing, the data may be re-submitted for quality control or further processing as required (Section 2.1).

5.8 Data conversion, summary printouts and data retained

The recording frequency of the rainfall event recorder (normally 5 min) is greater than that required for most hydrological investigations. This means that rainfall totals at the required frequency must be calculated. Each calculated value has an associated quality index, its value depending on the quality indices of the original 5-min totals. The calculated values together with the quality indices are stored in direct access files. A summary of the stored values is output on the line printer (Fig 5.2).

5.9 Areal estimates

As indicated in Section 5.1, many hydrological investigations require areal estimates of rainfall. This is achieved using networks of raingauges, both manually-read (period) and recording gauges. Normally, each period gauge is assumed to represent a certain percentage of the area and is thus given a weighting. The total in each period gauge is distributed in time according to the data in the nearest recording gauge. In this way, areal rainfall estimates at the required frequency are produced by:

(a) distributing each period gauge total in time to the required frequency using the data from the nearest recording gauge, and

(b) expressing the areal estimate as the sum of the period gauge values multiplied by the relevant weighting factor.

This is done as routine for all the catchments currently being studied at the Institute using all the available gauges and adopting the Theissen area technique for calculating weighting factors. However, there is provision for users to calculate alternative areal estimates using different combinations of gauges with alternative weighting factors. The areal estimates so produced are stored in direct access files in a similar manner to the data from individual gauges (Section 5.10).

The way in which areal estimates are calculated follows that described by Plinston and Hill, 1974, with the following differences:

(i) Period gauges must refer to the same period, ie there is no facility to deal with, say, weekly and daily gauges in the same network. If this occurs, then the totals in the various period gauges must be converted into a common time period. However, the common period may be of any length and there is no need for the gauges to be read at 0900 hours GMT.

(ii) There is no need for a check count total for each recording gauge, this information has already been incorporated at the quality control stage. However, comparisons are made of period gauge totals and of daily totals from the recording gauges. These will be described later in this section.

(iii) There is no need to merge punched computer cards containing recording gauge data. Data from direct access files are automatically accessed.

(iv) Recording gauge data from a variety of instruments can be used providing that these data are in standard direct access form. This includes data from rainfall event recorders, automatic weather stations, and those from chart and paper tape recorders.

(v) There is no need to ensure that the data from one particular recording gauge is complete. Should any gaps arise, they are simply infilled by data from the next nearest recording gauge.

A flow chart showing the steps involved and data required to calculate areal estimates is shown in Fig 5.3, and an explanation given below.

(a) Input information record no 1. This contains the name of the site, eg, WYERAIN, associated with the areal rainfall, the time/date of start of period, and number of period gauges used to calculate the areal rainfall.

(b) Using the site name, assign and input the network table. This indicates the recording gauges to be used to time distribute the rainfall in each period gauge.
Find the areal entry in the state directory and assign the direct access file used to hold the areal rainfall data (Section 2.2).

(c) Input the period gauge numbers and weightings.

(d) Ensure that the sum of the weightings is one; if not, output an error message on the line printer.

(e) Input information record number (2). This contains the time/date of end of period and the period gauge totals in the order indicated in (c) above.

(f) Apply a coarse quality control to the period gauge totals by testing the difference between each period gauge total and the mean total against the standard error multiplied by 4. If an "error" occurs, a warning is printed on the line printer and the period gauge total checked.

(g) For each day in the period, apply a coarse quality control to the daily totals of each recording gauge. This is done in a similar manner as for the period gauge totals. If an "error" is found, a warning is printed and the day's data from that particular recording gauge not used in calculating the areal estimates.

(h) Loop (h) to (j) for each period gauge. Find the nearest recording gauge. As noted previously, the source of the recording data is irrelevant; pointers found in the site directory will ensure that the correct data are accessed.

(i) Loop for the number of days in the period. If there is a full day's data in the nearest recording gauge then this is stored. If not, the next nearest recording gauge is found and the data from this gauge tested. This is continued until a full day's data is found.

(j) Calculate RATIO: the ratio of the period gauge total to the total in the recording gauge record for the period. Multiply the recording gauge record by RATIO and by the relevant weighting factor, accumulate the subsequent recording gauge record for each period gauge in the areal direct access file.

5.10 Data storage on disc and tape, retrieval and display

In addition to storing the final values in direct access files, the rainfall values for each 5-min period from individual event recorders are stored on 9-track magnetic tape, each cassette length occupying one file on the magnetic tape. At the end of each quality control/editing run, the contents of the current 9-track storage tape are listed, together with the number of files on the tape and the percentage of tape used.

Data retrieval from direct access files may be carried out using a computer program. If errors are detected in the final data, they may be rectified in one of two ways:

(i) Subroutines have been written to edit the final data using similar techniques to those described in Section 5.7.

(ii) The 5-min values stored on 9-track tape may be retrieved, the values and/or information record edited and the data re-processed.

This may mean the recalculation of areal estimates.

```
                 SITEDIRECTORY  INFORMATION  TABLE         ENTRY   NO.   161          DATE  OF  INSERT :  060181

SITE NAME :  RER PLYNLIMON AUN 1            COORDINATES E-W :  282655    COORDINATES N-S :  265270    ALTITUDE   377M
INSTRUMENT TYPE :    3    RECORDER TYPE :   1    INPUT FREQUENCY :   5 MINS    OUTPUT FREQUENCY :  60 MINS    NO. CHANNELS :   1


DATA TYPE/VALUE.        1        2        3        4        5        6        7        8        9       10       11       12
    8                10.000    .000     .000     .000     .000     .000     .000     .000     .000     .000     .000     .500
```

FIGURE 5.1 Rainfall event recorder entry in the site directory

```
NEW ESGAIR-Y-MAEN 2                          DATE : 20.11.79

                 0      100      200      300      400      500      600      700      800      900     1000     1100     TOTAL/AV
      0       .000     .000     .000     .000     .000     .000     .000     .000     .000     .500     .000     .000      .500

   1200       .000     .000     .000     .000     .000     .000     .000     .000     .000     .000     .000     .000      .000

NEW ESGAIR-Y-MAEN 2                          DATE : 21.11.79

                 0      100      200      300      400      500      600      700      800      900     1000     1100     TOTAL/AV
      0       .000     .000     .000     .000     .000     .000     .000     .000     .000     .000     .000     .000      .000

   1200       .000     .000     .000     .500     .000     .000     .500     .000     .500     .000     .500     .000     2.000

NEW ESGAIR-Y-MAEN 2                          DATE : 22.11.79

                 0      100      200      300      400      500      600      700      800      900     1000     1100     TOTAL/AV
      0       .000     .500     .500     .500     .000     .000     .000     .000     .000     .500    1.000     .000     3.000

   1200       .500     .000     .000     .000     .000     .000     .000     .000     .000     .000     .000     .500     1.000

NEW ESGAIR-Y-MAEN 2                          DATE : 23.11.79

                 0      100      200      300      400      500      600      700      800      900     1000     1100     TOTAL/AV
      0       .500     .000     .500     .500    1.000     .000     .000    1.500    2.000    3.000    1.500    1.500    12.500

   1200       .000     .000     .500     .500     .000     .000     .000     .000     .000     .000     .000     .000     1.000

NEW ESGAIR-Y-MAEN 2                          DATE : 24.11.79

                 0      100      200      300      400      500      600      700      800      900     1000     1100     TOTAL/AV
      0       .000     .000     .000     .000     .000     .000     .000     .000     .000     .000     .000     .500      .500

   1200       .000    1.500     .000     .000     .500     .500     .500     .500     .500     .000     .000     .000     4.000

NEW ESGAIR-Y-MAEN 2                          DATE : 25.11.79

                 0      100      200      300      400      500      600      700      800      900     1000     1100     TOTAL/AV
      0       .500     .000     .000     .000     .000    1.000     .500    1.500    3.000    2.000    2.500    1.000    12.000

   1200       .000     .000     .000   .00077     .000     .000     .000     .000     .000     .500     .000     .000      .000

NEW ESGAIR-Y-MAEN 2                          DATE : 26.11.79

                 0      100      200      300      400      500      600      700      800      900     1000     1100     TOTAL/AV
      0       .000     .000     .000     .000     .500    6.500   14.500    4.000     .500    3.000    4.000    7.500    42.500

   1200      1.000     .000     .500     .000     .000     .000     .500    2.000    1.000     .500    3.000    2.500    11.000
```

FIGURE 5.2 Listing of finalized rainfall data

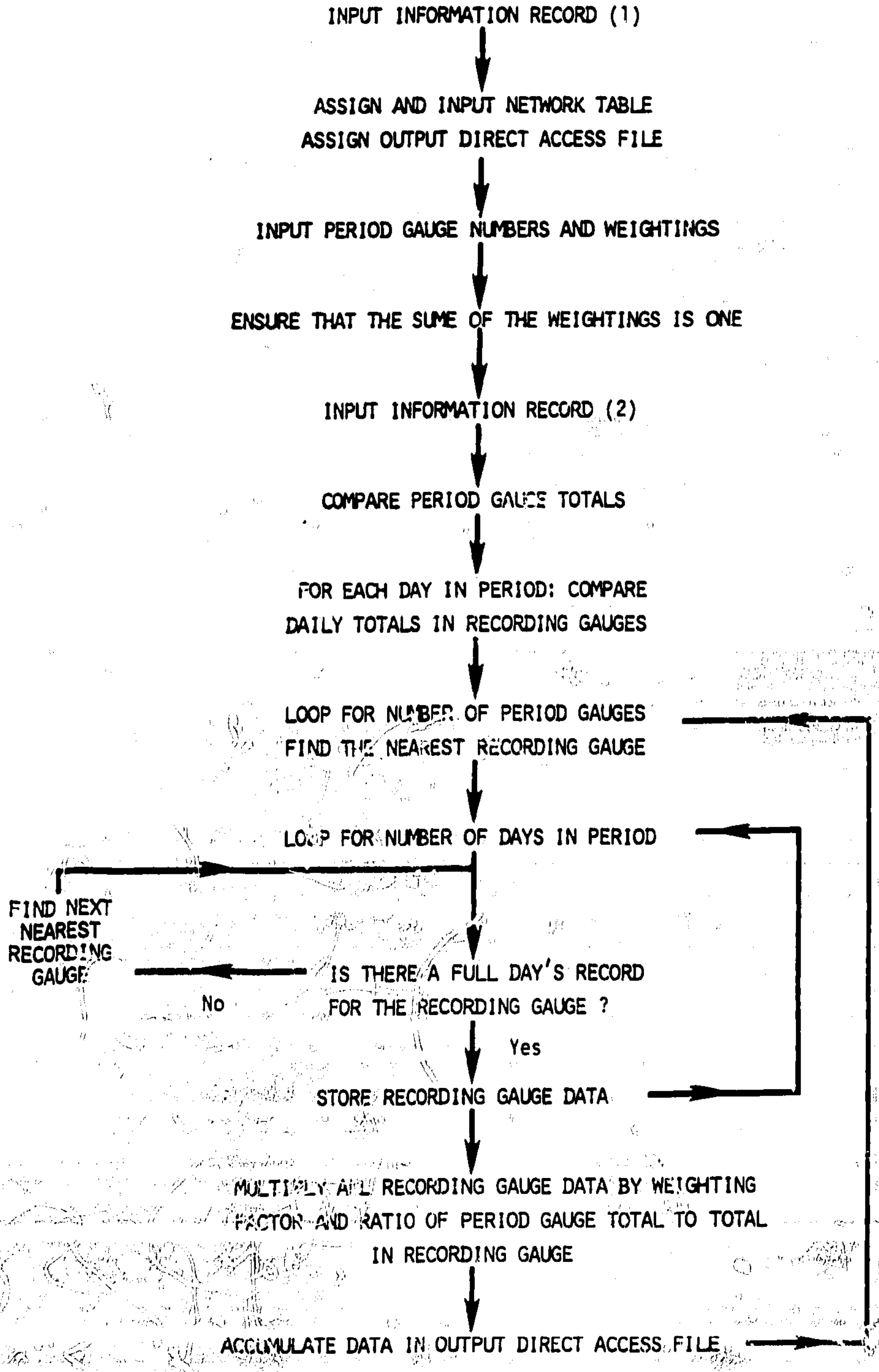


FIGURE 5.3 Flowchart showing the steps in calculating areal estimates

6. SOIL MOISTURE

6.1 Introduction

Almost all of the data at the Institute pertaining to the measurements of soil moisture are collected using the Wallingford neutron probe. The exceptions are when soil cores are collected for calibration purposes. In these cases, the data processing is trivial and need not be enlarged upon; this section will therefore concentrate on the procedures required to quality control and process data collected by the neutron probe.

A detailed description of the neutron probe and its working principles has already been published (Bell, 1976) and it is sufficient here to provide a brief description of the use of the probe and to reiterate those practices affecting the quality control and processing of the data.

Basically the instrument consists of a probe, incorporating a fast neutron source and a slow neutron detector, connected by means of a cable to a pulse counter. It is enclosed in a transport shield which provides user protection from the neutron source and facilitates simple transportation in the field. In use the probe is lowered into an access tube by means of the cable to a pre-determined depth indicated on a cable counter in the transport shield. The access tube is a hollow aluminium tube of 41.25 mm internal diameter installed vertically into the ground to a predetermined depth leaving some of the tube, usually about 20 cm, above ground. The end of the tube embedded in the soil is sealed by means of an aluminium plug. The fast neutrons emitted by the source collide with the various nucleii, mostly those of hydrogen in the soil water, occurring within the soil. They are scattered, producing a cloud of slow neutrons the density of which may be measured by the slow neutron detector in the probe. The measurement is conveyed by means of the cable to the pulse counter where it is displayed on activating the instrument. The units of the displayed variable varies with the type of pulse counter/meter. These will be described later. The measurements are usually carried out at a number of depths thus producing a 'soil moisture profile' of the site. To minimise the effect of any day-to-day drift in the measurements due to for example, temperature, battery charge, etc it is usual to carry out a "water count" each time the probe is used. This is done by taking a measurement in an access tube installed in a bin filled with water. The values obtained in the soil, together with that taken in the water bin, are used to calculate moisture volume fractions in the soil profile.

When initially installing the access tube in the soil, core samples are taken at various points in the profile. These are used to identify the type of soil and, sometimes, to carry out a soil calibration. This is done by measuring the amount of water in the soil by gravimetric

means, i.e. as the difference between the weight of wet and dry soil, and plotting it against the value obtained at the same depth using the probe. A series of straight line graphs exists for different soils showing gravimetric moisture volume fraction, i.e. weight of water per unit volume of soil, against the neutron probe measurement in soil divided by the water count. Use is made of the slopes and intercepts of these various graphs on converting data values collected in the field to moisture volume fractions.

A natural extension to the manually-read neutrons probe is the "autoprobe" or automatic neutron probe. This will take measurements at predetermined depths and at pre-determined time intervals in a fixed access tube. The data can be stored on cassette-type magnetic tape or on solid-state type loggers. The advantages of the autoprobe are obvious for those seldom visited sites and for those soil profiles where water changes occur rapidly. This instrument is currently being tested at the Institute. The rest of the section will be concerned with data collected using the manually-read probe.

6.2 Site directory

As indicated in Section 2.2 the format of those data held in records of the site directory pertaining to "soil moisture sites" is different from that described for other types of instrumentation. The reason for this is that, unlike other instruments, the neutron probe measures the same variable at different depths in the soil profile. The number of readings taken in the soil profile will sometimes be large and it would be unnecessarily wasteful in terms of space on the computer to regard each "reading depth" as a separate data type. This is especially so since only three standard/conversion values are stored per reading depth.

The way in which these standard/conversion values are stored in the site directory and subsequently accessed is as follows. The twelve data allocations per record (Section 2.2) are split into four sets of three, each set referring to a reading depth. In each set, the standard/conversion values are:

JDEPTH - the reading depth.

ISOIL - the soil type/index determining the slope and intercept of the graph used in the conversion to moisture volume fraction.

STDMVF - the standard moisture volume fraction for that particular depth. This is used for quality control and graphical purposes.

Additional records are used if required, and in each case ITYPE, the variable/data type, will be 10. The sets of standard/conversion values are terminated by putting ISOIL = 0. In this case, JDEPTH will be equal to the depth of moisture change (the depth to which the total water content of the soil profile is computed) and STDMVF will be the "field capacity" value (in mm of water) of the profile.

The control information used for soil moisture sites is similar to that used for other instrumentation. Those values unique to soil moisture sites are:

BSITE - is of the form NEUTRON ACCESS TUBE NO XXYY, where XX is the site number of the tube and YY the catchment number.

INST - 4.

KREC - 2.

IFREQ)
) - - 1. (Indicating infrequent manual observations).
JFREQ)

ICHANN - the number of records (see above) required to store the necessary standard/conversion values.

An example of a neutron access tube entry in the site directory is given in Fig 6.1.

6.3 Data collection

The data collected using the manually-read neutron probe are noted on a field data form (Fig 6.2). This form has been especially designed so that the data contained on it may be translated into computer compatible form without further annotation. The form consists of two parts; that appearing within the thick-lined boundary and which contains the data required for further processing, and that containing the data which is for information only. The values to be retained for further processing are of two types; the information record, containing details of probe used, site and date, etc., and the measured values together with the depths below ground level at which the values were measured.

Some of the data are entered on the form in the field; these will be described in this section. The form is completed in the office; this will be described in the next section under office procedures.

The information values to be entered on the field sheet when measuring soil moisture are as follows:

(i) DATE - the date, in full, is entered at the head of the field sheet.

(ii) SITE - the site name, in full, is entered at the head of the field sheet.

(iii) PROBE - each probe used in measuring soil moisture has an associated three digit probe code, the first two digits of which are used to identify the type of probe used as follows:

PROBE CODE	TYPE OF PROBE
103	Danbridge
19X	E.A.L.
1XX	Wallingford

The probe code determines which calibration equation is used in the quality control and processing programs. The code is normally indicated on the probe.

(iv) METER - each meter has an associated three digit code, the first digit of which is used to identify the type of meter used.

METER CODE	TYPE OF METER	UNIT DISPLAYED
1XX	Scaler	Time for preset count
2XX	Ratemeter	Counts per second
3XX	Ratescaler	Counts per second

The units of measurement displayed on the meter depends on the type of meter as does the calculation of moisture volume fraction. The code to be used is normally indicated on the meter.

(v) TUBE HEIGHT - this is the height of the access tube protruding above ground level. It is used, in conjunction with the depth as indicated on the depth counter, to calculate the depth below ground level at which measurements are taken.

(vi) C - when taking measurements, it is possible to vary the time over which each individual reading is taken. The way in which this is carried out depends on the type of probe and meter used but, in the most common combination presently used, i.e. the Wallingford probe and ratescaler, the C value is the time constant in seconds over which the measurement, displayed as counts/second on the meter, is averaged and can be set at 16 or 64 seconds.

(vii) TIME - this is the time, in GMT on a twenty-four hour basis, at which the measurements at a particular site were taken.

(viii) GROUND CONDITION - this is a description of the state of the ground around the access tube.

(IX) CROP - this is the type of crop growing in the vicinity of the access tube.

(x) D and E - when taking soil moisture measurements, it is advisable to take a reading whilst the probe is in its transport shield. The reading thus obtained can be compared with the value indicated on the shield and can be used to ensure that the probe, meter and battery pack are working correctly. The D and E values are, respectively, the preset constant (equivalent to the C value for measurements in the soil) and the meter reading for measurements taken whilst the probe is in its transport shield.

For each reading taken whilst the probe is in the access tube, the following values are entered on the field sheet:

(xi) DEPTH BELOW ACCESS TUBE RIM - this is the depth (cm) as indicated on the cable counter. These are always entered in increasing depth.

(xii) READING - this is the observation as indicated on the meter.

The field sheet has been designed to accommodate up to 27 readings from each site. If more readings are required, then further field sheets may be used but, in this case, it is necessary only to enter the depths and the readings.

6.4 Office Procedures, pre-processing

The office procedures to be carried out involve infilling those values on the field sheet that are not normally entered in the field. These values are:

(i) OBS - each person collecting soil moisture data has a two-digit identifying code. This code is subsequently stored along with the data but is not required for processing purposes.

(ii) CROP - this is a two-digit code identifying the type of crop in the vicinity of the access tube. The code is subsequently stored along with the data but is not required for processing purposes. However, it is useful in identifying any changes in crop which may change the soil moisture status of the site.

(iii) GROUND COND. - this is a two-digit code indicating the ground condition at the time the measurements were taken. The code is subsequently stored along with the data but is not required for processing purposes. It is, however, a useful aid during data analysis.

(iv) SUM OF DEPTHS - this is the manually calculated sum of the depths below ground level. It is used for quality control purposes to ensure that the depths have been correctly translated into computer compatible form.

(v) SUM OF READINGS - this is the manually calculated sum of the readings. It is used for quality control purposes to ensure that the readings have been correctly translated into computer compatible form.

(vi) A and B - these are, respectively, the preset constant (equivalent to the C value for measurements in the soil) and the meter reading for measurements taken in the water standard described previously. These readings should be taken frequently at long time intervals for greater accuracy. The values are noted for each probe for subsequent transfer to the field sheets.

(vii) GRAV M.V.F. - this is the calculated gravimetric moisture volume fraction of the top 15 cms of soil as given by a core sample, if one is taken. If no sample is taken at a particular site, then the gravimetric moisture volume fraction is entered as 0.000

(viii) DEAD TIME - this is the dead time associated with the ratemeter (Bell, 1976). This is measured in the laboratory and is entered in microseconds. If a meter other than a ratemeter is used, then the dead time is entered as zero.

(ix) NO. OF READINGS - this is the number of observations taken with the probe (excluding the gravimetric M.V.F.).

(x) SITE - this is the site number of the access tube at which the readings were taken.

(xi) AREA - this integer identifies the catchment or area in which the readings were taken.

(xii) DAY, MTH, YEAR - this is the date on which the measurements were taken.

For each reading taken with the probe, the DEPTH BELOW GROUND LEVEL is calculated as the DEPTH BELOW ACCESS TUBE RIM-TUBE HEIGHT.

There is also room on the sheet for the observer's signature and any remarks that may be pertinent to the measurements made.

The required values on the field sheet may now be translated into computer compatible form with no further annotation. This is described in the next section.

6.5 Input to the computer system

As noted previously, two types of records are retained from the values entered on the field sheet. These records are:

(i) The information record

This contains those values pertaining to details of instruments used, conditions, site, date, etc., and are transferred from the field sheet in FORMAT (6I3, 2F6.0, F7.0, 2F6.0, F6.3, F4.0, I3,2X, I4,1X, 2I2,1X, 3I2).

(ii) The data record(s)

These contain pairs of depth below ground level and reading, together with site and date identifiers. Each record can accommodate a maximum of seven pairs of depth and reading; for additional observations further data records may be used.

Each record contains the following information:

(DEPTH(K), READING(K), K = 1,7), ICARD, SITE, AREA, DAY, MTH, YEAR in FORMAT (7(I5, F4,0), 3X, I2, 1X, 2I2, 1X, 3I2). ICARD is a record sequence number used to ensure that the data records are in the correct sequence.

Each completed field sheet is hence translated into an information record and a number of data records which may be fed into the computer system for quality control. The most convenient form of these records is punched computer cards and it is this form which is used at the Institute.

6.6 Quality control

Most of the initial quality control tests applied to soil moisture data are designed to minimize errors due to translation from the field sheets into computer compatible form. Because soil moisture is often measured infrequently and depends on such factors as rainfall and evaporation losses, quality control of the actual data values are best carried out on long records and by comparison with measurements from other sites. However, crude quality control limits have been worked out and are applied to some of the variables.

In reality, the quality control, data conversion, storage, and summary printouts, are carried out in the same computer program, the last three operations being operative only in those cases when the data satisfies the quality control requirements. If this is not the case, comprehensive error diagnostics are printed and the data is edited before re-submission to the quality control routines.

The data from several neutron access sites may be submitted in one quality control "run", the only restricting factors are those concerned with the time taken and amount of output generated during the computer run.

The quality control tests carried out on the data are:

(i) the area/catchment number is tested to ensure that it is known to the system,

(ii) the observer number is tested to ensure that it is known to the system,

(iii) the crop type code is tested to ensure that it is known to the system,

(iv) the ground condition code is tested to ensure that it is known to the system,

(v) the first digit of the meter code is tested to ensure that it is 1, 2, or 3, i.e. a scaler, ratemeter, or a ratescaler,

(vi) the time at which the readings were taken is checked to ensure that it is between 0 and 2400 hours,

(vii) the B value or "water count" of the probe is checked to ensure that it is within standard limits for that probe,

(viii) the day on which the measurements were taken is checked to ensure that it is within the month,

(ix) for meter code 2, i.e. a ratemeter, the dead time is tested to be between 50 and 15 microseconds,

(x) the ordering of each data record is checked by testing the record sequence number,

(xi) the date appearing on each data record is tested to be the same as that appearing on the information record,

(xii) the site and area numbers on each data record are tested to be the same as those appearing on the information record,

(xiii) the sum of the observations is calculated and tested against that appearing on the information record,

(xiv) the sum of the depths is calculated and tested against that appearing on the information record,

(xv) the depths are checked to be in increasing order.

For each quality control error a diagnostic is output on the line printer and the information or data records may be edited before re-submission to the quality control routines. In the event of the data being "error free" data conversion and storage is carried out in the same program.

6.7 Editing

Editing is carried out by simply changing a punched card. Alternatively data files may be edited using standard software facilities available on most computer systems.

6.8 Data conversion, summary printouts, and data retained

The most generally used unit of soil moisture is moisture volume fraction, the amount of water in unit volume of soil. This may be converted into quantities of water by multiplying by the length of the layer of soil which the measurement represents. Another much used unit of soil moisture is total water content of the soil profile. This is simply the sum of the water quantities in the various layers down to the depth of moisture change, the depth below which no significant seasonal variation in soil moisture occurs. The various formulae used in soil moisture data conversion are shown in Figure 6.3 and the abbreviations used are as follows:

OBSV(I) = the measurement taken using the probe.
RMVF(I) = the calculated moisture volume fraction.
EM(I) = the calculated standard deviation in moisture volume fraction.
RATIO(I) = the ratio of the measurement in soil to the measurement in the water standard.
IDEPTH(I) = the reading depth.
WF(I) = the layer factor (the layer represented by IDEPTH(I)).
WW(I) = the calculated quantity of water (mm) in WF(I).
EWW(I) = the standard deviation.
SLOPE = the slope of the appropriate calibration curve.
INTERCEPT = the intercept of the appropriate calibration curve.
T = the dead time associated with a ratemeter.
SWW = the water content (mm) of the soil profile above the depth of moisture change.
SEWW = the standard error in SWW.

All the other symbols used in Figure 6.3 are as appearing on the field sheet.

The steps taken in the processing routine are as follows:

1. If a core sample is taken at the surface, it is assumed to represent the top 15 cm of soil in which case the moisture volume fraction will equal the gravimetric moisture volume fraction. No reading in the depth range 0-15 cm need be taken with the probe.

2, 3, 4, 5. The calculation of moisture volume fraction and standard deviation from measurements taken with the probe depends on the type of meter used. The slope and intercept of the relevant calibration curve for each reading depth are determined by first finding from the site directory the soil type occurring at that particular depth and then accessing the slope and intercept from a calibration table.

6, 7, 8. The layer factor is calculated as the distance from the mid-point of the previous and current depth to the mid-point of the current and the following depth. In the case of the first reading depth, the layer factor is the distance from the surface to the mid-point of the first and second reading depths. In the case of the last reading depth the layer factor is given as twice that distance between the mid-point of the previous and current depth and the current depth.

9. The water in layer and standard deviation associated with it is given, respectively, by the product of the layer factor and moisture volume fraction and the product of the layer factor and standard deviation of moisture volume fraction.

10. The total water content in the profile and the error associated with it are calculated as the sum of the water in layers and the sum of the squares of the standard deviations in the water in layers respectively.

A listing of the observations and the calculated values is output on the line printer. An exemple of such a listing is given in Figure 6.4. In addition accumulated water totals to specific depths and for specific layers are calculated and output. Quality control profiles are displayed. These show moisture volume fraction deviations (shown by *) from standard values (shown by I) for each reading depth. The standard values are accessed from the site directory. These quality control profiles are a useful aid in determining the validity of the data points and giving a visual indication of the soil moisture status of the profile.

The values stored on the computer are the information record and the data record(s) transferred from the field sheet. It was felt that this was sufficient because: (i) all other possible required values may be calculated from these, and (ii) in the event of changing calibration factors, there is no need to restore the data onto the computer. However, it is necessary to calculate moisture volume fractions or any other variable when required. This is relatively inexpensive in terms of computer time and routines have been written to carry this out.

The data are stored in direct access files, each file containing the data from one site for one year. The name of each file is determined by the record number of the site in the site directory and the year in which the measurements were taken (Section 2.2). The format of the data in the direct access files is described in Section 10 of this chapter.

6.9 Areal estimates

Because of its spatial variability, any estimate of areal soil moisture status must be treated with care. However, in some instances, it is highly desirable to be able to calculate these areal estimates and routines have been written to carry this out. The data from any number of sites may be used, each site having an associated weighting factor.

6.10 Data storage on disc and tape, retrieval and display

The direct access files used to store the data are indexed. This means that there are pointers at the beginning of each file indicating the record number in which the data from each occurrence are stored. This is a convenient way of structuring these files because it means that for data such as soil moisture which are collected relatively infrequently, only as much space in the file as required is used. This is important because the number of neutron scatter sites currently being read means that massive savings in storage space on the computer system is achieved by using such a structuring system.

In common with all data files on the system, those direct access soil moisture files are stored on exchangeable discs. The contents of these discs are backed up on magnetic tape frequently. No additional storage on magnetic tape is carried out. This means that, should any data be found to be incorrect, then editing can be carried out in two ways; (i) edit the original punched cards and re-run the quality control routines, or (ii) by editing the direct access file.

Because of their structure, no access can be made directly to those files via systems software such as the EDITOR processor. This means that any access to the data must be via a computer program. Routines have been written to do this, and also to convert the measured variables into those more commonly used variables. Because of the different requirements of different users many programs have and will continue to be written to retrieve and display data in many different forms. In all of these programs, it is sufficient to specify only the site(s) required, all the file manipulations will be carried out automatically by the software.

Three general programs have been written to display soil moisture data; one summary printout and two graphical outputs.

(i) Single site summary listings

This lists calculated moisture volume fractions for each specified reading depth and total water content of the profile for each data occurrence (Figure 6.5) for one site year. Also output are annual means and standard deviations for the variables at each reading depth, and for the total water content. This output gives a quick check on the soil moisture status of the site at any time of the year and also indicates the amount of soil moisture change at any of the reading depths. Obviously the program may be modified to output any other variable such as water in layer, accumulated water totals, very simply.

(ii) Single site plots

This program plots soil moisture data from one site year together with other relevant hydrological data. A number of different types of plots can be obtained, the combination of plots required being specified by the user. Figure 6.6 gives an example of some of the different options available, these being:

(a) Moisture volume fraction time series graphs

These are time series plots of the deviation in moisture volume fraction from a standard value (that found in the site directory) for each specified depth.

(b) Soil moisture profiles

These are plots of moisture volume fraction against depth.

(c) Total water content time series

These are time series plots of the deviation in total water content from a standard "field capacity" value (found in the site directory).

In addition the program will plot, if required, daily totals of rainfall, runoff, and evaporation estimates on the same time scale as the soil moisture time series plots.

The physical size of the plots may be adjusted by a parameter as can the scale of each individual plot. The data for the soil moisture plots are accessed automatically on specifying the required site whilst the data for the other plots are fed in on punched cards. The time scale may be changed by specifying the months required.

The program may be adapted quite simply to individual users' needs, e.g. values other than moisture volume fractions may be required or other hydrological variables, e.g. soil temperature, can be plotted.

(iii) Multiple site plots

This program is an adaptation from the one giving single site plots ((ii) above). The two outputs are very similar (Figure 6.7) the differences being:

(a) This program plots superimposed soil moisture data from any number of specified sites. The different data sets will be identified by symbols.

(b) No soil moisture profiles will be plotted.

The other facilities are as described for the single site plots.

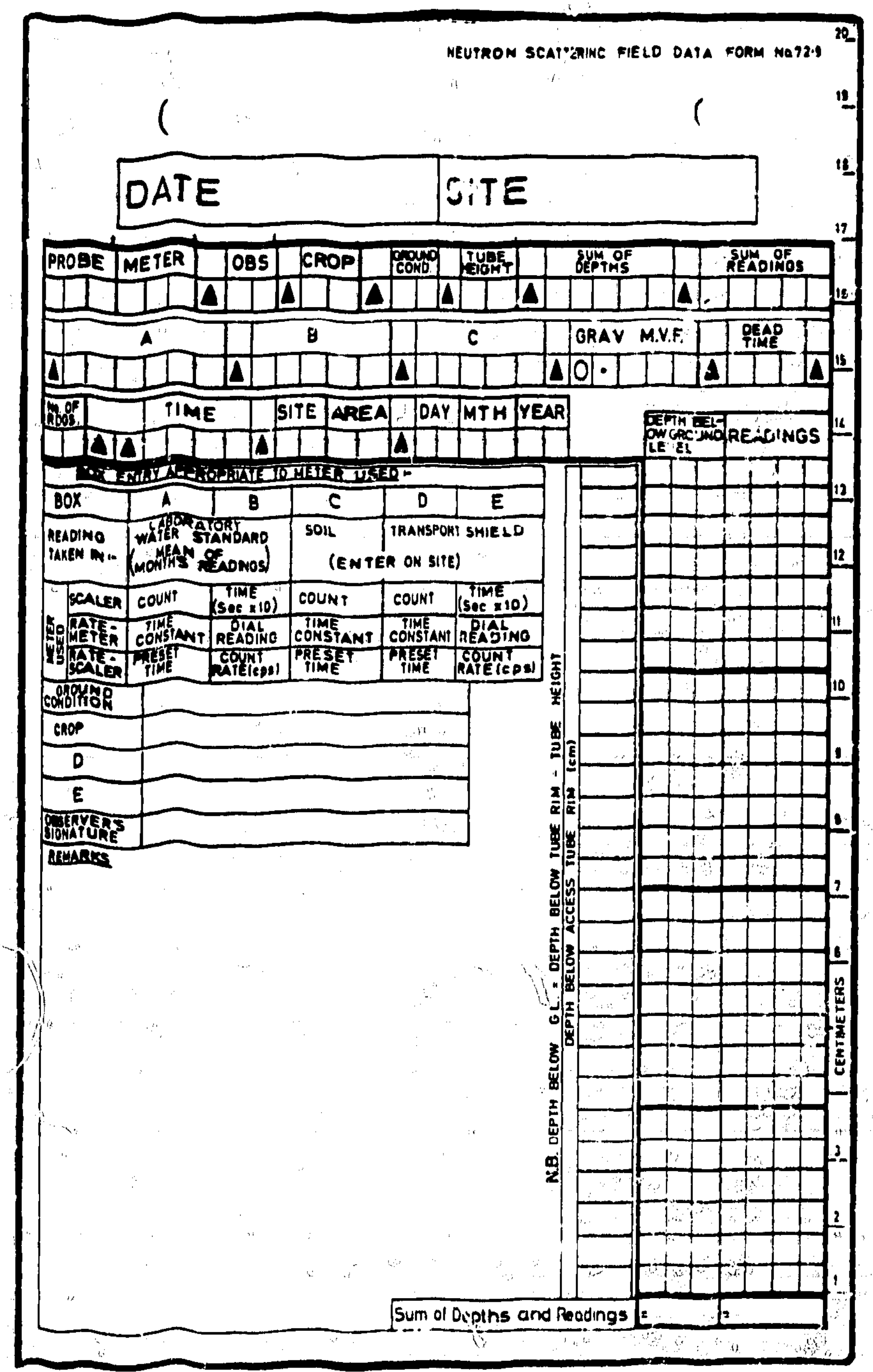
As more use is made of the system and of the data sets already processed, it is hoped that users will write their own routines or modify existing routines to their own needs. In this way, the number of programs available for the display and manipulation of soil moisture data will increase and will be incorporated in this list.

```
                SITEDIRECTORY  INFORMATION  TABLE          ENTRY   NO.   452            DATE  OF  INSERT :  190679

SITE NAME :  NEUTRON ACCESS TUBE NO.    222  COORDINATES E-W :        0    COORDINATES N-S :        0    ALTITUDE      0M
INSTRUMENT TYPE :    4     RECORDER TYPE :   2    INPUT FREQUENCY :  -1 MINS    OUTPUT FREQUENCY :  -1 MINS    NO. CHANNELS :   5

DATA TYPE/VALUE.        1          2         3         4         5         6         7         8         9        10         11        12
   10               10.000     3.000      .720    20.000     3.000      .850    30.000     3.000      .690    40.000     3.000      .560
   10               50.000     3.000      .440    60.000     2.000      .340    70.000     2.000      .340    80.000     2.000      .310
   10               90.000     2.000      .300   100.000     2.000      .280   110.000     2.000      .270   120.000     2.000      .270
   10              130.000     2.000      .250   140.000     2.000      .260   150.000     2.000      .260   160.000     2.000      .270
   10              170.000     2.000      .310   180.000     2.000      .330   185.000      .000   741.000      .000      .000      .000
```

FIGURE 6.1 Neutron access entry in the site directory



NEUTRON SCATTERING FIELD DATA FORM No.72·9

DATE

SITE

PROBE | METER | OBS | CROP | GROUND COND. | TUBE HEIGHT | SUM OF DEPTHS | SUM OF READINGS

A | B | C | GRAV M.V.F. 0 · | DEAD TIME

No. OF RDGS. | TIME | SITE | AREA | DAY | MTH | YEAR

BOX ENTRY APPROPRIATE TO METER USED -

BOX		A	B	C	D	E
READING TAKEN IN -		LABORATORY WATER STANDARD (MEAN OF MONTH'S READINGS)		SOIL	TRANSPORT SHIELD	
				(ENTER ON SITE)		
METER USED	SCALER	COUNT	TIME (Sec x10)	COUNT	COUNT	TIME (Sec x10)
	RATE-METER	TIME CONSTANT	DIAL READING	TIME CONSTANT	TIME CONSTANT	DIAL READING
	RATE-SCALER	PRESET TIME	COUNT RATE (cps)	PRESET TIME	PRESET TIME	COUNT RATE (cps)

GROUND CONDITION

CROP

D

E

OBSERVER'S SIGNATURE

REMARKS

N.B. DEPTH BELOW G.L. = DEPTH BELOW TUBE RIM - TUBE HEIGHT

DEPTH BELOW ACCESS TUBE RIM (cm)

DEPTH BELOW GROUND LEVEL | READINGS

Sum of Depths and Readings Σ Σ

FIGURE 6.2 Neutron scatter field data form

FIGURE 6.3 FORMULAE USED IN PROCESSING PROGRAM

1. IF FIRST OBSERVATION IS GRAVIMETRIC

$$OBSV(1) = 0$$

$$RMVF(1) = GMVF$$

$$EM(1) = 0.05 \times GMVF + 0.05$$

$$RATIO(1) = 0$$

2. FOR METER CODE 1

$$RATIO(I) = \frac{C \times B}{A \times OBSV(I)}$$

$$EM(I) = SLOPE \times RATIO(I) \times \sqrt{\frac{1}{C} + \frac{1}{A}}$$

3. FOR METER CODE 2

$$B = B + B^2 \times \frac{\tau}{10^5} + B^3 \times \frac{\tau^2}{10^{12}}$$

$$OBSV(I) = OBSV(I) + OBSV(I)^2 \times \frac{\tau}{10^5} + OBSV(I)^3 \times \frac{\tau^2}{10^{12}}$$

$$RATIO = \frac{OBSV(I)}{B}$$

$$EM(I) = SLOPE \times RATIO(I) \times \sqrt{\frac{1}{OBSV(I) \times C} + \frac{1}{B \times A}} \times \frac{1}{\sqrt{2}}$$

4. FOR METER CODE 3

$$RATIO(I) = \frac{OBSV(I)}{B}$$

$$EM(I) = SLOPE \times RATIO(I) \times \sqrt{\frac{1}{OBSV(I) \times C} + \frac{1}{B \times A}}$$

5. FOR METER CODE 1, 2 and 3

$$RMVF(I) = SLOPE \times RATIO(I) + INTERCEPT$$

6. IF FIRST READING

$$WF(I) = IDEPTH(I) + \tfrac{1}{2}(IDEPTH(2) - IDEPTH(1))$$

FIGURE 6.3 (continued)

7. IF LAST READING

$$WF(I) = (IDEPTH(I) - IDEPTH(I-1))$$

8. READING BETWEEN 6 and 7

$$WF(I) = \tfrac{1}{2}(IDEPTH(I) - IDEPTH(I-1)) + \tfrac{1}{2}(IDEPTH(I+1) - IDEPTH(I))$$

9. FOR ALL READINGS

$$WW(I) = RMVF(I) \times WF(I)$$

$$EWW(I) = EM(I) \times WF(I)$$

10. SUMMARIES

$$SEWW = \sum_{I} EWW(I)^2 \qquad SWW = \sum_{I} WW(I)$$

WATER CONTENT OVER DMC = SWW, PROBABLE ERROR = SEWW

```
                    QUALITY CONTROL OF SOIL MOISTURE DATA USING PROGRAM PROG36*PROGS.NSQUAL ON DATE 190679

                     DATE  18 178        TIME  1300  GMT              CATCHMENT  PLANT IAGO(22)              TUBE   4
                           ------

PROBE  119   METER  318   OBSERVER   COKE/ROBERTS(38)         CROP  GRASSLAND(01)        GROUND CONDITION  ALL SNOW/ICE(70)
METER TYPE - RATESCALER
 COUNT TIME FOR STANDARD  1800 SECS.      COUNT RATE IN WATER STANDARD   1050.           COUNT TIME FOR SOIL    16 SECS.

                                      DOWN ACC.                                                         WATER IN LAYER  DOWN ACC.
DEPTH                                WATER TO ROG                                              LAYER      +/-ERROR      WATER IN
(CM)      READING     MVF+/-ERROR     DEPTH(MM)        QUALITY CONTROL PROFILES                (CM)         (MM)          (MM)
-----     -------     -----------    ------------     --------------------------               -----    --------------  ---------
  10        855.     .8026+/- .0069      80.3                                       I  *       0- 15     120.4+/-1.0      120.4
  20        998.     .9378+/- .0075     167.3                                       I  *      15- 25      93.8+/- .8      214.2
  30       1015.     .9539+/- .0076     261.9                                       I *       25- 35      95.4+/- .8      309.6
  40       1024.     .9624+/- .0076     357.7                                       *         35- 45      96.2+/- .8      405.8
  50        894.     .8395+/- .0071     447.8                                       *         45- 55      83.9+/- .7      489.7
  60        667.     .5966+/- .0059     519.6                                      *I         55- 65      59.7+/- .6      549.4
  70        465.     .4123+/- .0049     570.0                                       *         65- 75      41.2+/- .5      590.6
  80        414.     .3657+/- .0046     608.9                                       *         75- 85      36.6+/- .5      627.2
  90        395.     .3484+/- .0045     644.6                                       *         85- 95      34.8+/- .5      662.0
 100        343.     .3009+/- .0042     677.1                                       *         95-105      30.1+/- .4      692.1
 110        311.     .2718+/- .0040     705.7                                       *        105-115      27.2+/- .4      719.3
 120        295.     .2572+/- .0039     732.2                                       *        115-130      38.0+/- .6      757.9
 140        317.     .2772+/- .0041     785.6                                       *        130-150      55.4+/- .8      813.3
 160        304.     .2654+/- .0040     839.9                                       *        150-170      53.1+/- .8      866.4
 180        317.     .2772+/- .0041     894.1                                       *        170-190      55.4+/- .8      921.8
WATER CONTENT OF UPPER   185  CM.  =  908.0+/-2.6  MM.

(STANDARD ERRORS QUOTED IN ALL CASES)
```

FIGURE 6.4 Listing of neutron scatter data

```
                    INSTITUTE  OF  HYDROLOGY  SOIL  MOISTURE  SUMMARY  SHEET

              MOISTURE  VOLUME  FRACTIONS  AND  TOTAL  PROFILE  WATER  CONTENTS

          NEUTRON ACCESS TUBE NO.    122  FOR YEAR 1978    DEPTH OF INTEGRATION =  125(CM)


DEPTH(CM)    10     20     30     40     50     60     70     80     90    100    110    120       WATER
DAY                                                                                              CONTENT
                                                                                                  (MM)
   6       .703   .662   .615   .563   .474   .400   .309   .313   .306   .276   .264   .287      552.6
  17       .676   .660   .585   .615   .477   .387   .304   .310   .298   .279   .267   .291      549.3
  18       .622   .666   .592   .520   .480   .399   .311   .307   .306   .281   .266   .275      533.6
  34       .686   .699   .683   .573   .485   .403   .310   .311   .304   .278   .268   .294      563.6
  40       .728   .641   .580   .509   .483   .364   .306   .303   .293   .276   .264   .305      541.5
  55       .622   .676   .588   .509   .464   .340   .308   .304   .300   .280   .257   .286      529.5
  66       .624   .659   .579   .511   .455   .376   .306   .303   .302   .277   .268   .296      526.8
  81       .720   .737   .670   .556   .467   .396   .310   .312   .307   .279   .271   .288      567.2
  93       .617   .663   .587   .525   .466   .391   .310   .309   .309   .282   .273   .293      533.5
 136       .664   .644   .568   .500   .450   .383   .321   .310   .314   .275   .269   .298      532.9
 142       .550   .646   .559   .481   .431   .372   .299   .296   .303   .273   .266   .303      505.3
 153       .379   .600   .547   .467   .416   .366   .299   .296   .293   .270   .253   .279      465.5
 171       .239   .571   .549   .479   .429   .380   .304   .303   .298   .278   .262   .285      449.0
 179       .450   .644   .565   .510   .482   .397   .314   .301   .311   .275   .270   .293      504.5
 185       .418   .675   .554   .568   .474   .399   .314   .308   .302   .274   .276   .303      517.5
 186       .597   .679   .665   .566   .482   .387   .316   .312   .310   .280   .271   .297      546.0
 194       .554   .645   .563   .508   .464   .382   .291   .297   .301   .276   .266   .296      512.1
 201       .418   .627   .548   .461   .433   .372   .291   .303   .305   .285   .261   .277      479.1
 209       .547   .620   .566   .494   .452   .377   .316   .306   .306   .277   .269   .299      517.6
 215       .531   .548   .483   .426   .393   .318   .254   .251   .248   .221   .221   .239      440.0
 229       .618   .660   .576   .511   .455   .384   .322   .309   .308   .276   .282   .303      531.7
 244       .517   .636   .543   .475   .419   .375   .299   .303   .300   .272   .258   .280      493.3
 255       .511   .680   .558   .483   .417   .377   .310   .296   .299   .274   .256   .276      499.1
 265       .408   .647   .571   .483   .439   .381   .309   .303   .304   .273   .279   .299      490.0
 284       .472   .685   .599   .525   .477   .411   .319   .310   .310   .281   .272   .296      519.3
 296       .525   .692   .593   .510   .470   .399   .328   .313   .302   .281   .278   .298      525.2
 312       .549   .672   .513   .504   .470   .400   .325   .314   .305   .276   .274   .308      518.4
 331       .603   .709   .635   .565   .481   .404   .330   .308   .299   .282   .273   .302      549.6

MEAN       .557   .655   .583   .514   .457   .385   .309   .304   .301   .275   .266   .291      517.6

STD. DEV.  .114   .038   .045   .040   .025   .018   .014   .011   .012   .011   .011   .014       31.3
```

FIGURE 6.5 Soil moisture summary listing

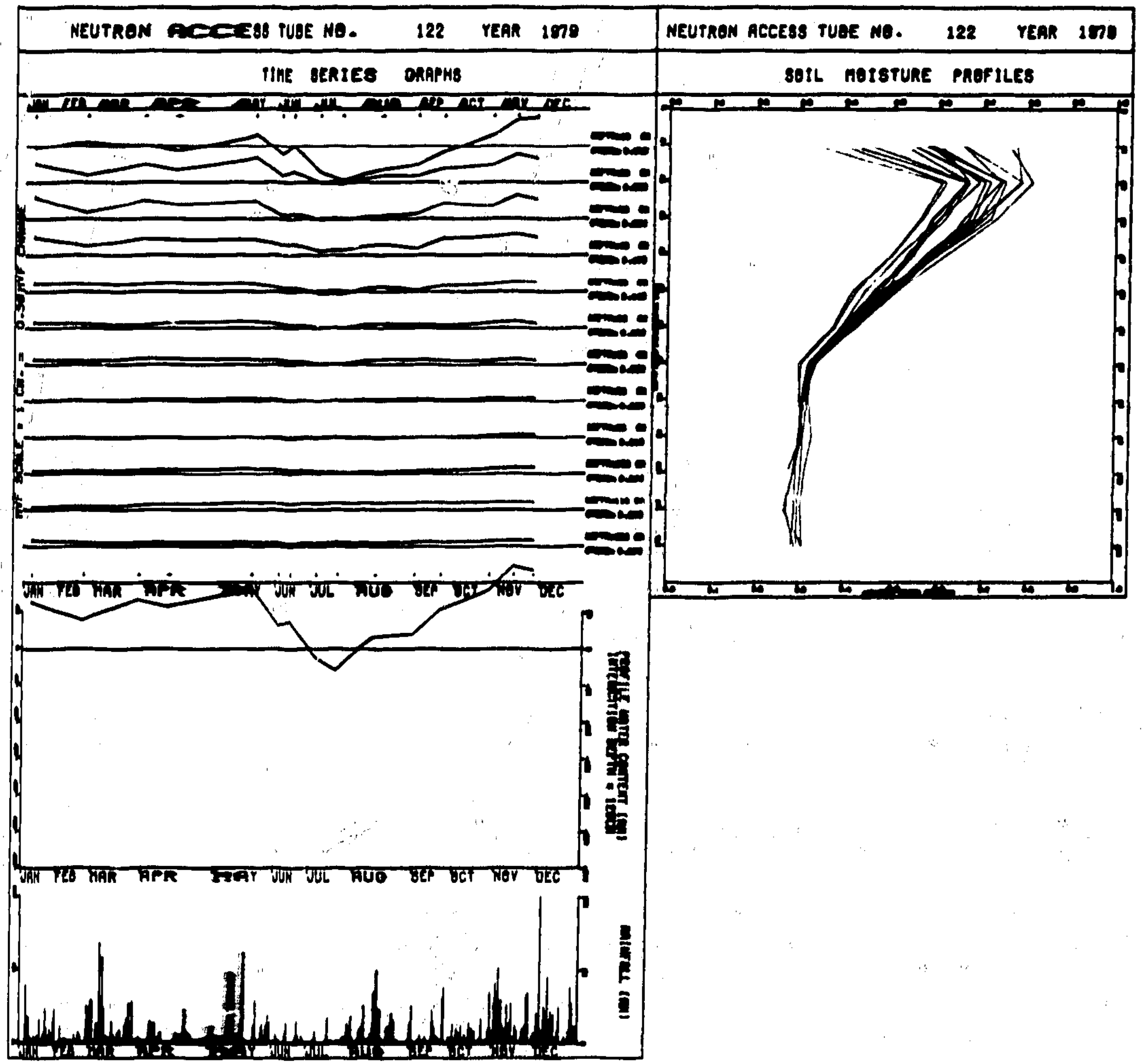


FIGURE 6.6 Plot of soil moisture from a single site

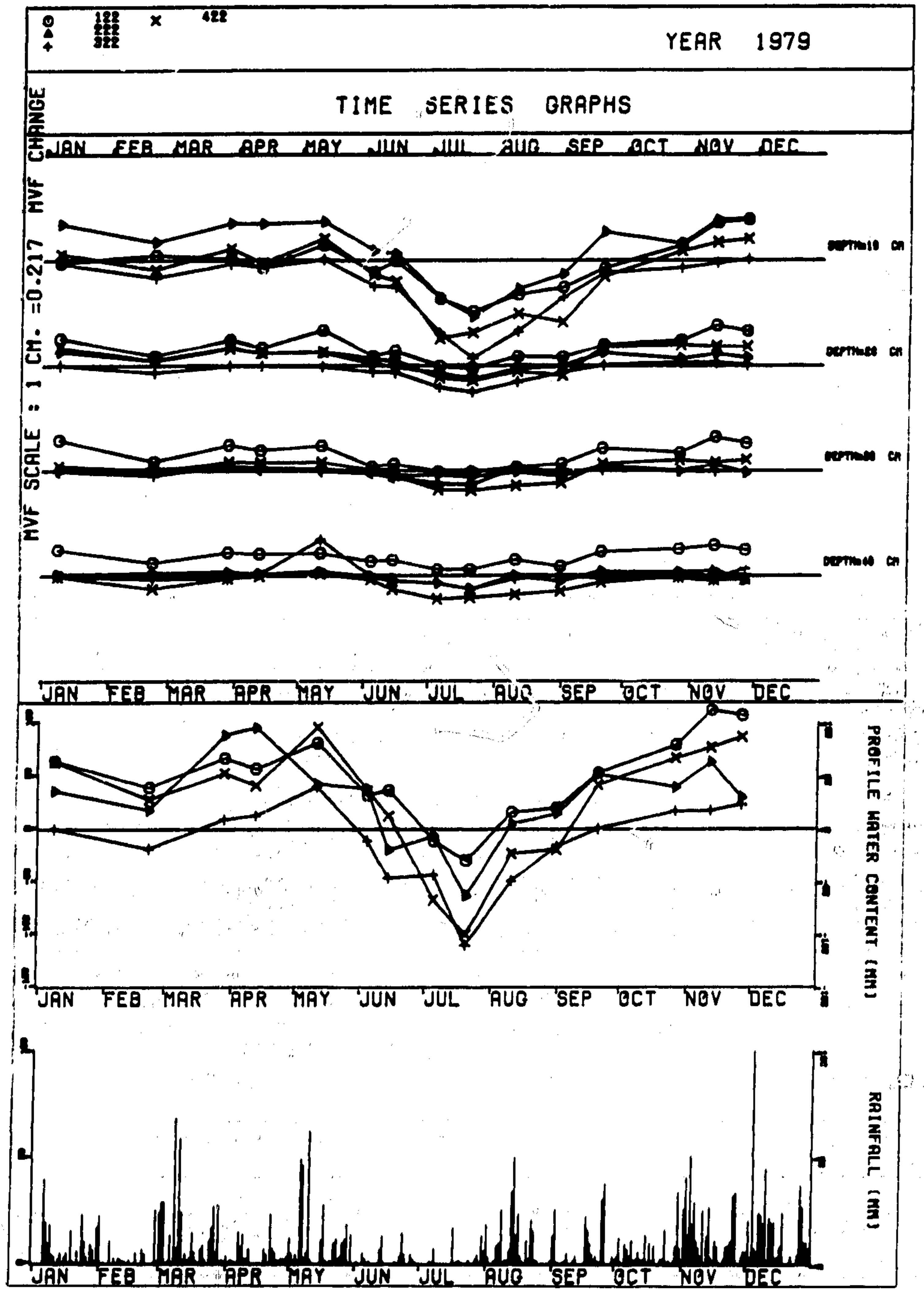


FIGURE 6.7 Plot of soil moisture from several sites

7. WATER QUALITY

7.1 Introduction

Although many water quality studies have been carried out at the Institute, very little work has been done on the quality control and handling of the data collected. This is because the majority of these studies are of a short term nature and the amount of data collected does not warrant the use of a data processing system. However, two aspects of water quality currently being studied at IH do require large amounts of data, these being groundwater resources and nitrogen pollution. The data collected in the groundwater resources studies are used to predict groundwater availability and to indicate its suitability for human consumption, agriculture, etc. As part of a project funded by the Overseas Development Ministry, a system was developed (Smith and Wikramaratna, 1978) for handling these data. Several Institute of Hydrology reports describing the quality control, analysis, handling and displaying the data have been written.

The study of nitrogen pollution has assumed greater importance recently because of the high levels of nitrate-nitrogen in sources of drinking water in some parts of the country and the cost of reducing these levels to acceptable limits. A number of studies have been initiated at IH in conjunction with the Ministry of Agriculture, including studies of surface water pollution and nitrogen movements down to groundwaters. The quantity of data collected in the course of these studies is such that some measure of automated data handling is necessary. It was decided therefore to write a system for dealing with these data and to incorporate it into the framework of the data processing system described in this report. The reasons for writing a new system and not using the one written for the groundwater resources studies were:

(i) A great deal of use is made of data from other instrumentation e.g. rainfall and runoff to calculate input and output loads of nitrogen, soil moisture to calculate nitrogen movements in soil profiles, and it is desirable that all the data be stored and accessed in a similar way.

(ii) Much of the software written for the groundwater data processing system is specific for the type of data analysis required for geochemical studies. It would have been necessary to extend this software to provide appropriate quality control and data analysis for surface water studies.

However, it is a relatively simple task to abstract data from one system and add it to the other.

The type and quantity of water quality data collected is so variable that it is extremely difficult to generalize when designing a data processing system. Some studies require continuous records from selected points, whilst others require infrequent values from a large number of locations. For soil nitrogen movements, water samples are extracted from a number of depths down a soil profile. It is clear, therefore, that it is important to define the nature of the study and the type of data collected before processing can commence. This is done in the site directory.

7.2 Site directory

The format of water quality entries in the site directory depends to a great extent on the type of study being undertaken, which also determines what is measured and subsequently stored. A study requiring a series of concentrations of a fixed number of ions from one particular location is simple; all that needs to be stored are times/dates and the concentrations. The number and type of chemical analyses carried out on the water samples are specified in the site directory, each data type (chemical analysis) having up to 12 standard/conversion values. An example of such an entry in the site directory is given in Fig. 7.1. The standard value associated with each data type is for quality control purposes.

For those studies requiring infrequent concentration values of different ions from different locations, it is necessary to store the times/dates, data types (chemical analyses), and grid references as data together with the concentration values. Very little information may be stored in the site directory.

Before processing any water quality data therefore, it is necessary to determine what information is non-changing and may be stored in the site directory and what has to be stored together with the data values in their final form. It is necessary to have an entry in the site directory containing a study or location identifier before processing can commence. This study/location identifier is specified whenever access to the data is made.

7.3 Data collection

Water samples can be extracted either manually or by an automatic liquid sampler. For those samplers which are clock driven ie. where water samples are taken at specified increments of time, it is necessary only to specify the time and date at which the first sample was taken. The times and dates at which subsequent samples are taken can be calculated. For those samplers which work on a flow proportional basis i.e. the greater the flow, the greater the sampling frequency, it is necessary to analyse the flow record in order to determine the sampling times. For these samples and for those taken manually, it is necessary to specify the time and date at which each sample was extracted.

Water sampling forms are used to note the results of the chemical analyses. Such a form is shown in Fig 7.2. These forms are designed in such a way that the data contained on them may be transferred on to a computer compatible medium without further annotation.

7.4 Office procedures, pre-processing

The amount of pre-processing required depends on how and where the samples were collected. For those samples collected using a clock driven automatic sampler, it is necessary only to specify the start time as the times at which each sample was extracted can be calculated using the sampling frequency. However, for those samples extracted on a flow proportional basis, it is necessary to study listings of the associated flow data in order to determine sampling times.

Similarly, for those studies requiring samples from different locations, it is necessary to determine grid references for the locations at which the samples were collected.

7.5 Input to the computer system

The data are normally punched on to cards and input to the computer system via the card reader.

7.6 Quality control

The quality control of the results of the chemical analyses carried out on water samples is difficult because (i) there is no way of checking the results obtained unless duplicate analyses are done, and (ii) the interrelationships between the concentrations of the various ions with such variables as flow, soil temperature, etc, depend so much on soil types, vegetation, agricultural practices, etc. Quite often the quality control has to be done retrospectively, ie. large quantities of the data are first analysed to identify any trends and relationships which are then applied as quality control to the data using appropriate limiting factors in order to pinpoint any "rogue" values.

The types of quality control tests are:

(i) Check that the values are within defined limits.
(ii) Compare the trends of different ions from the same location.
(iii) Compare the trends of similar ions from different locations.
(iv) Compare the trends in ion concentrations with such variables as flow, soil temperature, etc.

The tolerances for such quality control tests are obtained from experience of the data and are stored in the site directory. As more work is done on water quality, it is possible that more sophisticated quality control routines may be developed. However, those tests outlined above using sensible tolerance limits do identify any errors due to coding and transfer onto a computer compatible medium. The data are written into the appropriate direct access file as described in Sections 7.8 and 7.10, listings and any error messages are output on the line printer for manual inspection (Fig. 7.3).

7.7 Editing

The listings produced above are inspected manually and, if necessary, reference is made to the coding forms and to the chemical analyst. If errors are detected, these are simply rectified by editing the computer cards and re-submitting the data for quality control. This data will overwrite the previously stored data in the direct access file.

7.8 Data conversion, summary printouts, and data retained

The most commonly used unit of ion concentration in natural streams is mg/l (parts per million) and it is this unit which is adopted in this data processing system. If other units are quoted for particular chemical analyses, then the results may be converted into mg/l before storage on the relevant direct access file. As indicated previously, the amount of information required to describe the data (time/date, location, analysis) and therefore to be stored together with the data depends on the type of study. In general, the minimum amount of data stored are the results of the various chemical analyses and the time/date at which the water sample was extracted.

7.9 Areal estimates

A water quality datum is a measure from one single location and cannot be taken as an average for an area. However, this datum is a reflection of the processes occurring at all upstream contributing points and an estimate of areal ion loss may be determined by multiplying the ion concentration by flow. Many studies require this estimate and routines have been written to calculate these values from specified water quality and runoff data sets. These values are not generally stored within the data processing framework.

7.10 Data storage on disc and tape, retrieval and display

In common with all the other data processed using this system, water quality data are stored in direct access files, each one containing one years' data from one location/study. The appropriate direct access file is accessed using the location/study name and the site directory as indicated in Section 2.2.

The format of the data file depends on the frequency of sampling. For those data sets which are "continuous", each record in the direct access file is filled with one days' data. Those direct access files containing intermittent data are indexed, ie. there are pointers at the beginning of each file indicating the record number in which the data from each occurrence are stored. This is the most efficient way to store these data because it minimizes the file space used.

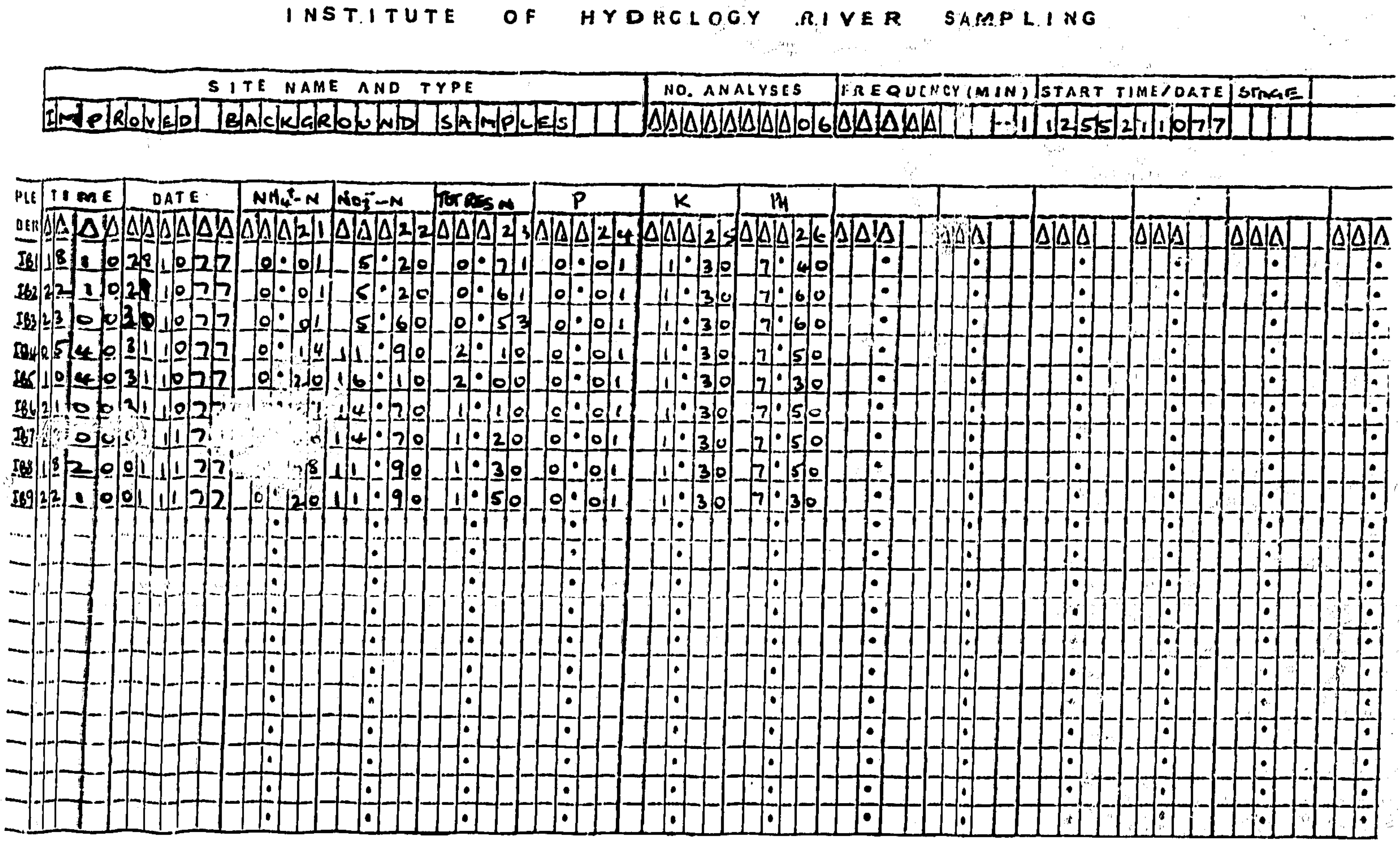
The data are written in unformatted mode on the files and access must be by computer program. Several programs have been written to display water quality data, often together with other data such as flow or rainfall. The outputs from these programs especially the graphical ones are useful as a final visual quality control check. An example of such a display is given in Fig. 7.4.

```
                    SITEDIRECTORY  INFORMATION  TABLE        ENTRY  NO.  341          DATE  OF  INSERT : 060181

SITE NAME :  CEFN BRWYN BACKGROUND SAMPLES   COORDINATES E-W :       0    COORDINATES N-S :       0    ALTITUDE     0M
INSTRUMENT TYPE :   5    RECORDER TYPE :   1    INPUT FREQUENCY :  -1 MINS    OUTPUT FREQUENCY :  -1 MINS    NO. CHANNELS :  5

DATA TYPE/VALUE.         1       2       3       4       5       6       7       8       9       10      11      12
  21                   .060    .000    .000    .000    .000    .000    .000    .000    .000    .000    .000    .000
  22                   .060    .000    .000    .000    .000    .000    .000    .000    .000    .000    .000    .000
  23                   .110    .000    .000    .000    .000    .000    .000    .000    .000    .000    .000    .000
  24                   .030    .000    .000    .000    .000    .000    .000    .000    .000    .000    .000    .000
  25                   .110    .000    .000    .000    .000    .000    .000    .000    .000    .000    .000    .000
```

FIGURE 7.1 Water quality entry in the site directory



INSTITUTE OF HYDROLOGY RIVER SAMPLING

SITE NAME AND TYPE	NO. ANALYSES	FREQUENCY (MIN)	START TIME/DATE	STAGE
IMPROVED BACKGROUND SAMPLES	06	1	1255 211077	

PLE DER	TIME	DATE	NH4+-N (21)	NO3-N (22)	TOT RES N (23)	P (24)	K (25)	PH (26)
161	1810	281077	0.01	5.20	0.71	0.01	1.30	7.40
162	2210	2[illegible]1077	0.01	5.20	0.61	0.01	1.30	7.60
163	2300	301077	0.01	5.60	0.53	0.01	1.30	7.60
164	0540	311077	0.14	11.90	2.10	0.01	1.30	7.50
165	1040	311077	0.20	16.10	2.00	0.01	1.30	7.30
166	2100	31102[illegible]	[illegible]	14.70	1.10	0.01	1.30	7.50
167	[illegible]000	[illegible]117[illegible]	[illegible]	14.70	1.20	0.01	1.30	7.50
168	1820	011177	[illegible]8	11.90	1.30	0.01	1.30	7.50
169	2210	011172	0.20	11.90	1.50	0.01	1.30	7.30

FIGURE 7.2 Water sampling form

```
                         INSTITUTE OF HYDROLOGY RIVER SAMPLING

                         SITE 1   SEVERN  TRAP BACKGROUND SAMPLES


  .08     .01   DIFFERENCE BETWEEN VALUES GREATER THAN     .06  FOR  NH4+   AT TIME  1705  ON DATE  080776
  .24     .17   DIFFERENCE BETWEEN VALUES GREATER THAN     .06  FOR  NO3-   AT TIME  1705  ON DATE  080776
  .37     .24   DIFFERENCE BETWEEN VALUES GREATER THAN     .06  FOR  NO3-   AT TIME  0105  ON DATE  090776
  .28     .37   DIFFERENCE BETWEEN VALUES GREATER THAN     .06  FOR  NO3-   AT TIME  0905  ON DATE  090776
  .18     .26   DIFFERENCE BETWEEN VALUES GREATER THAN     .06  FOR  NO3-   AT TIME  0905  ON DATE  100776
  .10     .01   DIFFERENCE BETWEEN VALUES GREATER THAN     .06  FOR  NH4+   AT TIME  1705  ON DATE  120776
  .07     .01   DIFFERENCE BETWEEN VALUES GREATER THAN     .03  FOR    P    AT TIME  1705  ON DATE  120776
  .01     .10   DIFFERENCE BETWEEN VALUES GREATER THAN     .06  FOR  NH4+   AT TIME  0105  ON DATE  130776
  .04     .07   DIFFERENCE BETWEEN VALUES GREATER THAN     .03  FOR    P    AT TIME  0105  ON DATE  130776


                        NH4+    NO3-     N      P       K
 80776                   .04     .21    .11    .02     .29
 90776                   .03     .28    .18    .01     .26
100776                   .04     .21    .13    .01     .20
110776                   .01     .14    .09    .02     .25
120776                   .04     .14    .11    .03     .24
130776                   .01     .12    .09    .03     .22
140776                   .01     .14    .08    .01     .18
  .21     .28   DIFFERENCE BETWEEN VALUES GREATER THAN     .06  FOR  NO3-   AT TIME  0905  ON DATE  080776
  .28     .21   DIFFERENCE BETWEEN VALUES GREATER THAN     .06  FOR  NO3-   AT TIME  0905  ON DATE  090776
  .28     .21   DIFFERENCE BETWEEN VALUES GREATER THAN     .06  FOR  NO3-   AT TIME  0905  ON DATE  090776
  .21     .28   DIFFERENCE BETWEEN VALUES GREATER THAN     .06  FOR  NO3-   AT TIME  0905  ON DATE  100776
  .21     .14   DIFFERENCE BETWEEN VALUES GREATER THAN     .06  FOR  NO3-   AT TIME  0905  ON DATE  100776
  .14     .21   DIFFERENCE BETWEEN VALUES GREATER THAN     .06  FOR  NO3-   AT TIME  0905  ON DATE  110776
```

FIGURE 7.3   Water quality error diagnostics

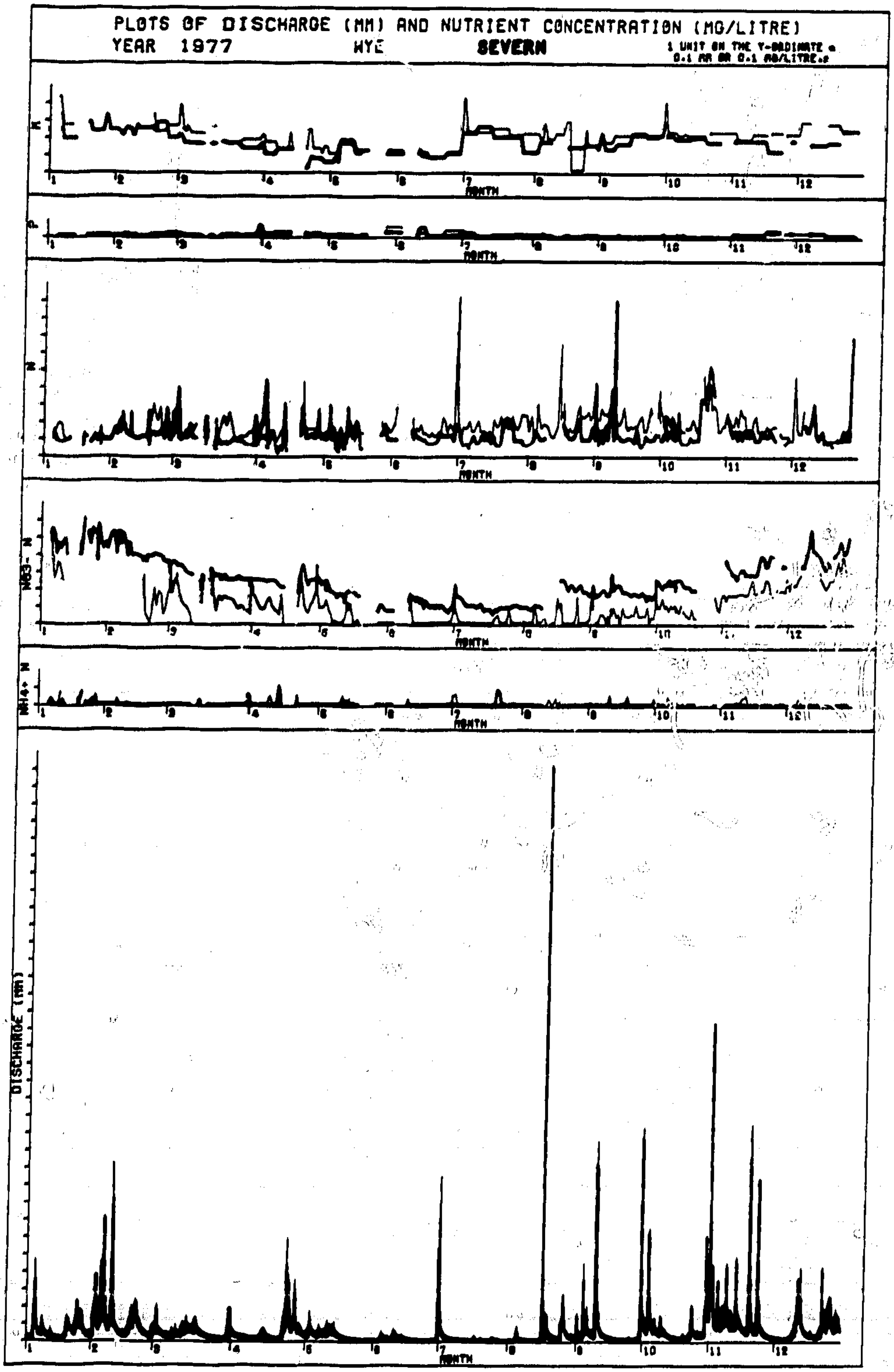


FIGURE 7.4 Water quality time series plots

8. MISCELLANEOUS RECORDERS

8.1 Introduction

The advent of the Microdata logger and cassette tape recording system has enabled users to collect the large quantities of data required to carry out the various studies being undertaken at the Institute. Each logger is capable of recording twelve separate variables and any combination of sensors may be used provided that the interfacing and the software for translating the data from logger steps into real units exists. For quality control and processing purposes, the variables recorded on the logger are specified in the site directory and appropriate subroutines utilized. However, in some instances, improved quality control may be achieved by comparisons between the data recorded by the various instruments. It is then up to the individual user to write appropriate software to fit into the general framework of the data processing system.

As indicated above, the number of combinations of instruments recording on one logger is so large that a description of all of them would be rather tedious and probably not very informative. Therefore, a detailed description of one combination of instruments currently being used in the field is given to show how the data are processed and to indicate what possible further software would be required to process data from a logger recording a different combination of instruments. The recording system chosen is that used to measure rainfall and both surface and sub-surface discharge from two small (100 m^2) lysimeters (Blackie, Roberts, and Hudson, 1979). The instrumentation consists of four tipping bucket flow recorders (Edwards *et al.*, 1974) and one "Rimco" tipping bucket rainfall recorder. In each case, the variable recorded is the number of bucket tips in a set time interval. Because each recording channel can only accommodate integers up to a value of 128 and to ensure against any discrepancy during high flows, the data from each tipping bucket flow recorder is recorded on two channels, one being the "unit" channel and the other the "times 128" channel. The data from the raingauge is recorded on one channel. As a measure of the voltage of the battery a 'scan mark' is also recorded. This is used to identify the start of a data scan and to assess its quality (Section 8.6).

The various stages in processing these data are as shown in Figure 2.2. A detailed description of each stage is given in subsequent sections.

8.2 Site directory

The general format of entries in the site directory has already been described in Section 2.2. In this particular case the number of recorded variables is five, each being the number of tips of a bucket in a set time period. However, the conversion of number of tips to flow is different from that to rainfall and requires different conversion factors. The standard/conversion values to be used for both flow and rain recorders are shown below.

DATA TYPE 9. FLOW RECORDER

1. Maximum number of tips in recording period.
2. Tolerance of manual to recorded total number of tips.
3. Total area contributing to flow.
4. Variable A in conversion of number of tips to flow (Section 8.8).
5. Variable B in conversion of number of tips to flow (Section 8.8).

DATA TYPE 8. RAINFALL

1. Maximum number of tips in recording period.
2. Tolerance of manual to recorded total number of tips.
3. Tipping bucket capacity (in mm).

The control information used is similar to that used for other instrumentation. The values unique to this recording system are:

BSITE - is NANT IAGO LYSIMETERS
INST - 6
KREC - 1
ICHANN - 5

Figure 8.1 gives a listing of the entry in the site directory.

8.3 Data collection

There is sufficient capacity on each cassette to hold several months' data but, in order to minimize data loss through battery failure, logger malfunction, etc., the instrument is serviced every two weeks. This involves changing the cassette tape and battery and noting any information required for data identification, quality control, and data conversion purposes. To do this, use is made of the field data form (Section 2.3 and Figure 2.3) and a manual observations form (Figure 8.2) used specifically for this study. On this form are noted the start and end readings on the mechanical counters attached to each of the tipping bucket flow recorders, as well as the total rainfall caught in a check gauge. All of these values are used as a check on the total number of tips in the quality control routines.

The rest of the form is concerned with associated instruments and as a means of noting any observations regarding the instrumentation and the study in general.

The two forms and the cassette tape are sent to Wallingford for processing.

8.4 Office procedures, pre-processing

Very little pre-processing is necessary except to act on any comments noted on the manual observations form.

8.5 Input to the computer system

Because of the unique way in which the data are recorded on the cassette tapes, input to the computer system is both tedious and time consuming. The sequence of events is shown below:

Input to the PDP8 via a Microdata cassette reader → Write to seven-track tape. → Output to a disc file on the UNIVAC.
↓
"Raw" data listing

Initial input is via the Microdata cassette tape reader on the PDP8 at Wallingford. The PDP8 produces a line printer listing of the "raw" data and a copy of the data on a seven-track magnetic tape. This tape is transferred to the UNIVAC at Rutherford where the data are written to a disc file.

8.6 Quality control

The quality control, editing, conversion, and data storage are all carried out using the same programs and follow the same general flow chart shown in Figure 2.2. The quality control/editing option is controlled by the value of INPUT, specified by the user. The quality control is applied to the data contained in the file produced as described above in Section 8.5. Any number of cassette lengths of data may be processed at the same time subject to limitations of disc space and elapsed computer time.

Each cassette length has two associated information records, held on computer cards containing information from the field data form (Figure 2.3) and manual observation form (Figure 8.2). This information consists of data identifiers and quality control aids.

The first information card contains:

ASITE - the local site name, as found in the site directory;
ITIME, IDAY, IMONTH, IYEAR - the time and date of start of data record;
JTIME, JDAY, JMONTH, JYEAR - the time and date of end of data record,
in FORMAT (A6 ,I4,3I2,I4,3I2).

The second information card contains:

ITIP1L, ITIP1R, ITIP2L, ITIP2R, ITIP3L, ITIP3R, ITIP4L, ITIP4R - the number of tips registered on the left and right hand mechanical counters of tipping buckets 1, 2, 3 and 4, respectively.

IRAIN - the total rainfall, expressed as the number of tips of a 0.5 mm bucket, in the check gauge, in FORMAT (9I5).

Before applying the quality control tests, the data are converted into normal units, ie. number of tips of the buckets in the recording time frequency. This is done by subtracting the previous recorded values

from the current ones (in the case of the flow recorders, this involves two channels; for the rainfall recorder, one channel). At the same time, a coarse quality control is applied to the data by ensuring that each record is of the correct length, ie. twelve integers. The start of a record is identified by the scan mark, normally having a value of 240. Each record is given a scan flag, having a value of 0 if the record is "correct", and 1 if the record is "incorrect". The data in any record which is deemed "incorrect" is also regarded as being incorrect at the quality control stage. A line printer listing (Figure 8.3) is given at this conversion stage. This contains a list of "incorrect" records and a scan mark frequency distribution.

The quality control tests are applied to the five minute data and consist of:

(i) If the scan flag is 1, then all the recorded values in the scan are regarded as being incorrect.

(ii) If the number of tips recorded in five minutes is greater than the maximum expected (standard value no. 1 in the site directory, Section 8.2) then the value is deemed to be incorrect.

(iii) The total recorded number of tips is compared with that noted on the manual observations form. If the difference between the two is greater than a certain tolerance (standard value no. 2 in the site directory) then an error message is output on the line printer.

(iv) A comparison of the recorded values from the two surface and the two sub-surface discharges is carried out. Although neither the capacities of the tipping buckets (and hence the conversion of number of tips to flow) or the areas of the lysimeters are identical, nevertheless a constructive comparison can be carried out by ensuring that the differences between the recorded values is less than the maximum of the two recorded values. Should such a discrepancy be found, the day's data from the two tipping buckets is output on the line printer for manual inspection. Figures 8.4 and 8.5 show such an output for the sub-surface and surface discharges, respectively.

The total number of scans recorded is compared with that expected from the start and end times of the data. If the amount of data agree to within ± 12 scans (1 hour), an automatic adjustment of the start and end times is carried out. If the difference is more than 12 scans, an error message is output on the line printer.

If the data are deemed "correct" and no manual editing is required, data conversion and storage are carried out as indicated in Sections 8.8 and 8.10. However, if "errors" are found, the data are written out to a temporary file for manual inspection and editing.

8.7 Editing

Two types of edits may be carried out, those involving the information record and those involving data values and scan flags.

(i) All the values contained in the information record may be replaced. This is particularly useful in changing the timing of the data set should the quality control indicate an incorrect number of scans.

(ii) A consecutive series of data values may be replaced by a fixed value. (Any "incorrect" data are given a value of -1.0).

(iii) A consecutive series of values may be modified by adding or subtracting a fixed amount.

(iv) A consecutive series of values may be modified by multiplying by a fixed amount.

(v) A consecutive series of values may be replaced with variable values.

(vi) The scan flags of a consecutive series of scans may be replaced.

The editing is generally carried out using computer cards. Following the editing the data may either be re-submitted for quality control or submitted to data conversion (Section 8.8) depending on the value of INPUT (Section 2.1).

8.8 Data conversion, summary printouts, and data retained

Each of the tipping bucket flow recorders in use has been calibrated separately over the whole range of flows expected. A relationship between flow F (litres/sec) and number of tips, n, in a given period, t (secs) has been derived (Calder and Kidd, 1978).

$$F = \frac{A}{(\frac{t}{n} - B)}$$

where A is the "static" capacity (litres) of the bucket (standard value no. 4 in the site directory).
B is the time taken (secs) for the bucket to tip (standard value no. 5 in the site directory).

For the particular study in question, flow, Q, is required in mm over the area. This is done using the following conversion.

$$Q = \frac{F \times t}{AREA}$$

where AREA = area (m^2) of lysimeter (standard value no. 3 in the site directory).

The size of the tipping buckets used in the rainfall recorders is such that each tip of the bucket represents a number of mm of rainfall. In this case, each tip represents 0.5 mm of rain and to convert from number of tips to mm rainfall in the recording time period, it is simply necessary to multiply by 0.5.

Summary printouts of daily flow (mm) from each recorder and daily rainfall (mm) are produced. An example is given in Figure 8.6.

The data to be retained are five minute values of flow from each of the recorders and rainfall. They are stored in direct access files as indicated in Section 8.10.

Once the data have been stored, any temporary files created during the editing stage are deleted.

8.9 Areal estimates

The values produced in Section 8.8 are rainfall and runoff in mm over the area and no further conversions are required.

8.10 Data storage on disc and tape, retrieval and display

The data retained are stored in direct access files, each one of which contains one year's data. The names of the direct access files are obtained as indicated in Section 2.2. Each file consists of 366 records, each one containing one day's data. As the name implies, each record may be accessed directly without the need for reading through preceding records. The data are written to the file in unformatted mode. In addition to storing the data on direct access files, the "raw" data are stored on nine-track magnetic tape. The data from each cassette are stored in one file on the tape. At the end of each quality control/editing "run" a line printer listing of the files on the current tape, and the percentage of tape used is output.

Because of the internal structure of direct access files, the data cannot be read using a system routine such as EDITOR. This means that any data access must be via computer programs. Many such programs have been written to edit and display the data, some of which will be described briefly below.

As a final quality control check, the flow data from each of the flow recorders and the rainfall data are plotted on a time series basis (Figure 8.7). Normally, the flow from the two surface flow recorders are superimposed, as are the flow from the two sub-surface recorders. This is an excellent way of pin-pointing errors in the data.

Editing the final data values may be carried out in one of two ways:

(i) Routines, similar to those used for the "raw" data (Section 8.7) have been written.

(ii) The "raw" data stored on the nine-track magnetic tapes may be loaded into disc files, edited, quality-controlled, and processed as before. The new generated values will overwrite the original data on the direct access files.

The instrumentation described here has been used in conjunction with flow proportional liquid samplers in a water quality study (Blackie, Roberts, Hudson, 1979). Programs to calculate and display flow and nutrient losses as well as inputs in rainfall have been written. An example of such a display is given in Figure 8.8. The water quality data used in this study are processed as described in Section 7.

ACKNOWLEDGEMENTS

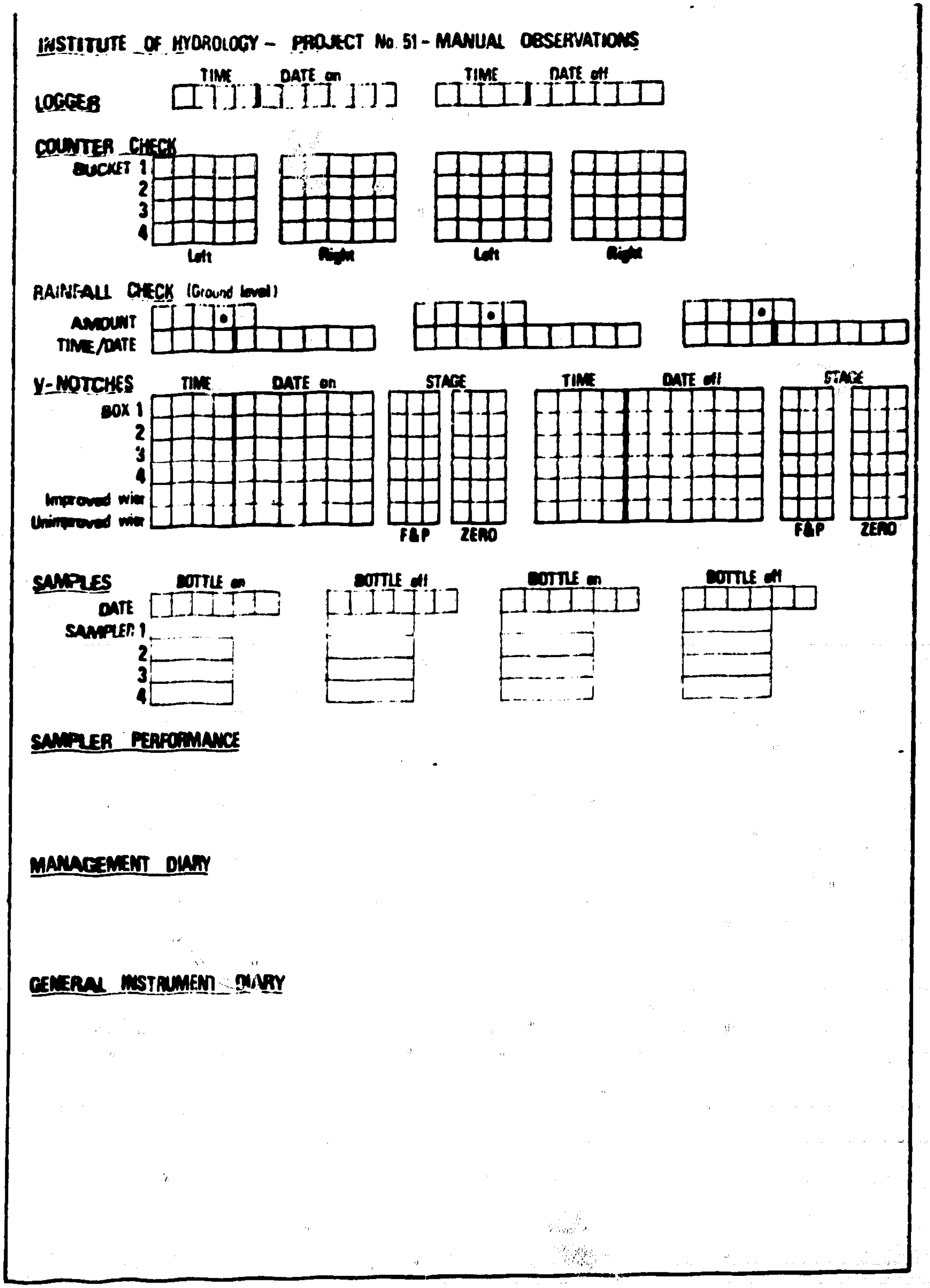
The author gratefully acknowledges the work done by Dr H. R. Oliver on the quality control of the meteorological data and the calculation of the evaporation estimates, and by Dr D. T. Plinston on the quality control of the water level data. He would also like to thank Mrs G. N. Bell for writing the software for calculating the evaporation estimates.

```
                    SITEDIRECTORY  INFORMATION  TABLE        ENTRY   NO.   348         DATE  OF  INSERT :  060181


SITE NAME :  NANT IAGO LYSIMETERS              COORDINATES E-W :        0    COORDINATES N-S :        0     ALTITUDE     0M
INSTRUMENT TYPE :   6    RECORDER TYPE :   1    INPUT FREQUENCY :   5 MINS    OUTPUT FREQUENCY :   5 MINS    NO. CHANNELS :   5


DATA TYPE/VALUE.        1         2        3         4         5         6         7         8         9        10        11        12
    9              150.000     5.000  117.723     1.717      .483      .000      .000      .000      .000      .000      .000      .000
    9              150.000     5.000  117.723     1.860      .427      .000      .000      .000      .000      .000      .000      .000
    9              150.000     5.000  109.766     1.152      .539      .000      .000      .000      .000      .000      .000      .000
    9              150.000     5.000  109.766     1.634      .450      .000      .000      .000      .000      .000      .000      .000
    8               20.000     5.000     .500      .000      .000      .000      .000      .000      .000      .000      .000      .000
```

FIGURE 8.1 Rainfall and runoff logger entry in the site directory



INSTITUTE OF HYDROLOGY - PROJECT No. 51 - MANUAL OBSERVATIONS

LOGGER
TIME DATE on
TIME DATE off

COUNTER CHECK
BUCKET 1
2
3
4
Left Right Left Right

RAINFALL CHECK (Ground level)
AMOUNT
TIME/DATE

V-NOTCHES
TIME DATE on STAGE
TIME DATE off STAGE
BOX 1
2
3
4
Improved wier
Unimproved wier
F&P ZERO
F&P ZERO

SAMPLES
BOTTLE on BOTTLE off BOTTLE on BOTTLE off
DATE
SAMPLER 1
2
3
4

SAMPLER PERFORMANCE

MANAGEMENT DIARY

GENERAL INSTRUMENT DIARY

FIGURE 8.2 Manual observations form

```
NANT IAGO LYSIMETERS

NUTRIENT PROJECT RAINFALL AND RUNOFF RECORDER

DATA STARTS AT 1110 ON 26/11/1980
SCAN MARK TOO SOON                                                                                   (BLOCK  241 WORD  88)
  9:55   5/12/1980     240      47       9       0     108      42       0       0      92       0      17    240
SCAN MARK TOO SOON                                                                                   (BLOCK  275 WORD  67)
 16:00   6/12/1980     244     110      50       9       0     125      47       0       0     102      26    244
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  275 WORD 127)
 16:30   6/12/1980       6••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  276 WORD  11)
 16:35   6/12/1980      22••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  276 WORD  23)
 16:40   6/12/1980      45••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  276 WORD  35)
 16:45   6/12/1980     112••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  276 WORD  71)
 17:00   6/12/1980       5••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  276 WORD  83)
 17:05   6/12/1980      51••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  276 WORD  95)
 17:10   6/12/1980       9••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  276 WORD 107)
 17:15   6/12/1980       0••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  276 WORD 119)
 17:20   6/12/1980      25••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  277 WORD   3)
 17:25   6/12/1980      48••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  277 WORD  15)
 17:30   6/12/1980       0••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  277 WORD  27)
 17:35   6/12/1980       0••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  277 WORD  39)
 17:40   6/12/1980     103••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  277 WORD  51)
 17:[illegible]   6/12/1980       1••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  277 WORD  63)
 17:50   6/12/1980      51••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  277 WORD  75)
 17:55   6/12/1980       9••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  277 WORD  87)
 18:00   6/12/1980       0••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  277 WORD  99)
 18:05   6/12/1980      42••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  277 WORD 111)
 18:10   6/12/1980      48••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  277 WORD 123)
 18:15   6/12/1980       0••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  278 WORD   7)
 18:20   6/12/1980     103••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  278 WORD  19)
 18:25   6/12/1980       0••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  278 WORD  31)
 18:30   6/12/1980       0••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
EXPECTED SCAN MARK MISSING                                                                           (BLOCK  278 WORD  43)
 18:35   6/12/1980       0••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••••
```

FIGURE 8.3   Rainfall and runoff logger data translation summary listing

```
DAY NUMBER   328        CHANNELS  1 AND  3
INCORRECT SCANS ARE :-
 263 264 268 277 279

  3.   2.   3.   3.   3.   2.   3.   3.   3.   3.   2.   2.   3.   3.   2.   3.   3.   3.   2.   3.   3.   3.   2.   3.
  4.   2.   3.   3.   3.   3.   3.   4.   3.   3.   3.   3.   3.   3.   3.   3.   3.   3.   4.   3.   3.   3.   3.   3.

  3.   2.   3.   3.   3.   2.   3.   3.   2.   3.   3.   2.   3.   3.   2.   3.   3.   2.   3.   3.   2.   3.   3.   2.
  3.   2.   3.   3.   3.   2.   3.   3.   3.   3.   3.   2.   3.   3.   3.   3.   3.   3.   3.   2.   3.   3.   3.   3.

  3.   2.   3.   3.   2.   3.   3.   2.   3.   2.   3.   3.   2.   3.   2.   3.   3.   2.   3.   2.   3.   2.   3.   3.
  3.   3.   3.   2.   3.   3.   3.   3.   3.   3.   2.   3.   3.   3.   3.   2.   3.   3.   3.   2.   3.   3.   3.   3.

  2.   3.   2.   3.   2.   3.   3.   2.   3.   2.   3.   2.   3.   2.   3.   2.   3.   3.   2.   3.   2.   3.   2.   3.
  2.   3.   3.   3.   3.   2.   3.   3.   3.   2.   3.   3.   3.   3.   2.   3.   3.   2.   3.   3.   3.   2.   3.   3.

  2.   2.   2.   3.   2.   3.   2.   3.   2.   3.   2.   2.   2.   3.   2.   3.   2.   3.   2.   3.   2.   3.   2.   3.
  3.   2.   3.   3.   2.   3.   3.   2.   3.   3.   3.   2.   3.   3.   2.   3.   2.   3.   3.   2.   3.   3.   2.   3.

  2.   3.   2.   3.   2.   3.   2.   3.   2.   3.   2.   2.   3.   2.   3.   2.   3.   2.   3.   2.   3.   2.   3.   2.
  3.   2.   3.   2.   3.   3.   2.   3.   2.   3.   3.   2.   3.   2.   3.   2.   3.   2.   2.   3.   2.   3.   2.   3.

  2.   3.   2.   3.   2.   3.   2.   2.   3.   2.   3.   2.   2.   3.   2.   3.   2.   3.   2.   2.   3.   2.   3.   2.
  2.   2.   3.   2.   3.   2.   3.   2.   3.   2.   3.   2.   3.   2.   3.   2.   3.   2.   3.   2.   3.   2.   3.   2.

  2.   3.   2.   3.   2.   2.   3.   2.   2.   3.   2.   2.   2.   2.   3.   2.   2.   3.   2.   3.   2.   2.   3.   2.
  3.   2.   2.   3.   2.   3.   2.   3.   2.   2.   3.   2.   3.   2.   3.   2.   2.   3.   2.   3.   2.   2.   3.   2.

  2.   3.   2.   2.   3.   2.   2.   3.   2.   2.   3.   2.   3.   2.   2.   3.   2.   2.   2.   3.   2.   2.   3.   2.
  3.   2.   2.   3.   2.   2.   3.   2.   3.   2.   2.   3.   2.   2.   3.   2.   2.   3.   2.   2.   3.   2.   2.   3.

  2.   3.   2.   2.   3.   2.   2.   3.   2.   2.   3.   3.   2.   3.   2.   3.   2.   2.   3.   2.   2.   3.   2.   2.
  2.   2.   3.   2.   2.   3.   2.   2.   3.   2.   3.   2.   2.   3.   2.   3.   3.   2.   3.   2.   3.   2.   3.   2.

  3.   2.   2.   3.   2.   2.   3.   2.   2.   3.   2.   3.   2.   2.   3.   2.   2.   3.   2.   2.   3.   4.   7.   7.
  3.   2.   3.   2.   3.   3.   2.   3.   2.   3.   2.   3.   2.   3.   3.   2.   3.   2.   3.   3.   2.   3.   3.   2.

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

FIGURE 8.4 Sub-surface runoff data for manual inspection

```
DAY NUMBER   322      CHANNELS  2 AND  4
INCORRECT SCANS ARE :-
  75  76  77  78  79  80  88  89  90  92 106 121 122 123 185 186 187 188 189 270 271 272 273 274 275 276 277

   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.

   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.

   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   1.   0.
   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.

   0.   0.   2.   3.   2.   2.   2.   2.   1.   1.   1.   1.   1.   1.   1.   2.   2.   2.   1.   2.   0.   1.   1.   0.
   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.

   1.   1.   1.   1.   1.   1.   1.   1.   1.   2.   1.   1.   0.   0.   1.   0.   0.   0.   0.   0.   0.   0.   1.   1.
   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.

   4.   2.   2.   1.   1.   0.   0.   1.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
   0.   0.   0.   1.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.

   0.   0.   0.   0.   0.   1.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.

   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   3.   6.   5.   3.   2.   1.   1.   0.
   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.

   0.   0.   1.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.

   0.   0.   0.   0.   0.   0.   0.   0.   1.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.

   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.

   0.   0.   0.   0.   0.   9.  14.  22.  20.  12.   8.   4.   2.   1.   1.   0.   1.   0.   0.   0.   0.   0.   0.   0.
   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
```

FIGURE 8.5   Surface runoff data for manual inspection

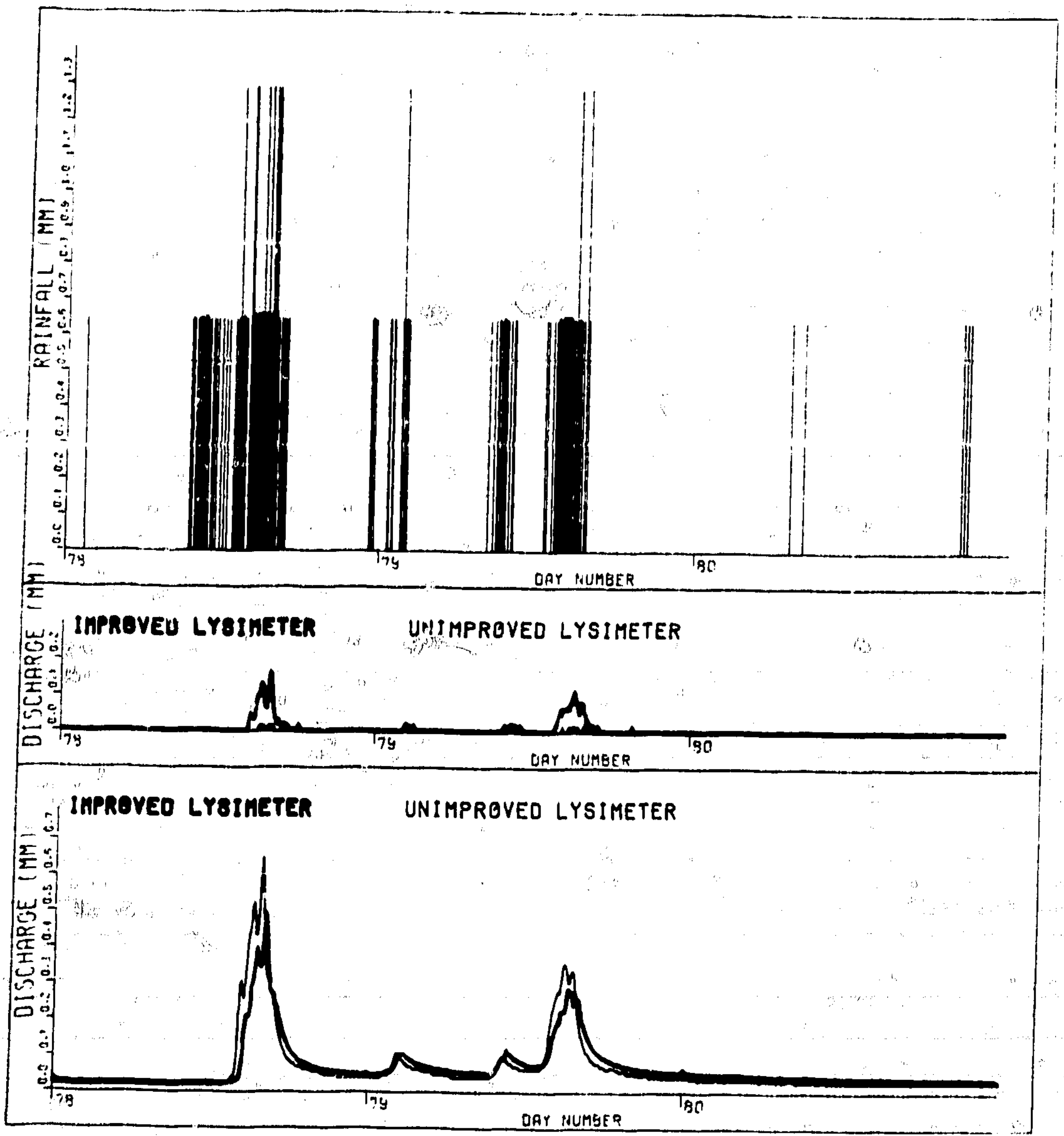


FIGURE 8.7 Time series graphs of rainfall and runoff

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                    INSTITUTE OF HYDROLOGY/MINISTRY OF AGRICULTURE,FISHERIES AND FOOD

     SUMMARY LISTINGS OF RAINFALL AND DISCHARGE FROM THE NATURAL LYSIMETERS IN THE NANT  IAGO SUB-CATCHMENT

          RAINFALL/DISCHARGE IN MM/DAY         NUTRIENT GAIN/LOSS IN KG/HA/DAY          MONTH  1177
                                                                                                ----

                            RAINFALL                               TOTAL DISCHARGE FROM LYSIMETERS
                                                    IMPROVED                                     UNIMPROVED
 DAY  TOTAL   NH4+  NO3-   N     P     K     TOTAL  NH4+   NO3-    N      P     K     TOTAL  NH4+  NO3-    N     P     K

   1   42.5   .038  .034  .017  .013  .072   31.9  .054  3.964  .451   .003  .415   30.9  .057  3.936  .257  .007  .436
   2   32.0   .029  .026  .013  .010  .054   37.0  .091  5.468  .482   .004  .462   36.0  .127  3.651  .266  .006  .477
   3   10.0   .009  .008  .004  .003  .017   22.3  .025  2.767  .274   .002  .267   19.1  .039  1.451  .110  .004  .267
   4    4.0   .004  .003  .002  .001  .007   11.7  .006  1.311  .120   .001  .141    8.8  .012   .642  .053  .002  .123
   5   14.5   .013  .012  .006  .004  .025   12.5  .001  1.085  .095   .001  .150   10.6  .015   .774  .064  .002  .147
   6    1.0   .001  .001  .000  .000  .002   12.2  .001  1.142  .097   .001  .135    9.5  .013   .692  .057  .002  .133
   7   15.5   .014  .012  .006  .005  .026   11.6  .001  1.028  .089   .001  .119    9.7  .012   .685  .050  .002  .133
   8    8.5   .008  .007  .003  .003  .014   14.8  .001  1.316  .121   .001  .148   13.0  .011   .792  .110  .001  .163
   9   27.5   .025  .022  .011  .008  .047   28.9  .023  3.078  .274   .009  .266   26.3  .037  1.479  .190  .003  .275
  10    4.1   .004  .003  .002  .001  .007   14.3  .015  1.617  .132   .003  .119   12.3  .011   .813  .091  .001  .136
  11    8.3   .007  .007  .003  .002  .014   11.8  .001  1.026  .084   .002  .111   10.5  .008   .736  .075  .001  .126
  12    5.5   .005  .004  .002  .002  .009   [illegible]  .001  1.161  .096   .003  .126   13.1  .007   .830  .075  .001  .145
  13   18.0   .016  .014  .007  .005  .031   [illegible]  .002  1.360  .120   .002  .148   15.2  .011   .830  .097  .002  .167
  14    7.0   .006  .006  .003  .002  .012   23.0  .008  1.562  .197   .002  .200   20.1  .021  1.109  .133  .002  .206
  15   12.2   .011  .010  .005  .004  .021   14.8  .004  1.311  .115   .001  .124   12.9  .014   .720  .085  .001  .129
  16    8.0   .007  .006  .003  .002  .014   14.3  .001  1.243  .109   .001  .120   12.1  .013   .678  .080  .001  .121
  17    8.1   .007  .006  .003  .002  .014   13.6  .001  1.183  .102   .001  .113   10.5  .011   .600  .064  .001  .112
  18     .5   .000  .000  .000  .000  .001   11.2  .001   .919  .066   .002  .099    9.6  .009   .554  .049  .003  .111
  19   33.7   .030  .027  .013  .010  .057   25.9  .029  1.878  .195   .011  .203   28.1  .028  1.234  .130  .010  .275
  20   21.1   .019  .017  .008  .006  .036   43.4  .059  3.957  .345   .011  .359   37.1  .053  1.082  .150  .011  .302
  21    2.0   .002  .002  .001  .001  .003   13.2  .003   .929  .075   .005  .106    9.7  [illegible]   .561  .066  .002  .088
  22    6.4   .006  .005  .003  .002  .011   11.3  .001   .618  .077   .002  .094    8.3  .003   .463  .039  .002  .077
  23   33.6   .030  .027  .013  .010  .057   29.5  .027  1.968  .224   .010  .225   23.6  .016  1.549  .150  .006  .308
  24   10.8   .010  .009  .004  .003  .018   20.0  .010  1.699  .164   .007  .161   18.4  .022   .664  .088  .006  .153
  25    3.6   .003  .003  .001  .001  .006   12.3  .002   .730  .079   .004  .091    5.0  .012   .501  .041  .003  .091
  26     .5   .001  .001  .000  .000  .002   10.0  .001   .535  .066   .003  .075    6.2  .000   .325  .029  .002  .063
  27     .0   .000  .000  .000  .000  .000    8.4  .002   .356  .034   .003  .066    4.8  .003   .250  .030  .002  .053
  28     .0   .000  .000  .000  .000  .000    7.5  .001   .321  .032   .003  .058    4.0  .001   .185  .025  .002  .052
  29     .0   .000  .000  .000  .000  .000    6.7  .001   .284  .022   .003  .041    3.5  .000   .158  .022  .001  .046
  30     .0   .000  .000  .000  .000  .000    6.0  .002   .296  .030   .002  .043    3.0  .000   .155  .017  .001  .042

 SUM  338.9   .303  .272  .130  .102  .576  510.2  .374 46.092 4.374   .102 4.795  442.1  .593 28.077 2.693  .091 4.961
```

FIGURE 8.8 Listing of daily inputs to and outputs from two lysimeters

```
CHANNEL                 1           2          3            4           5
                  11.0 MM       .0 MM     8.0 MM        .0 MM      7.5 MM

NANT IAGO LYSIMETERS                    DAY NUMBER    348
CHANNEL                 1           2          3            4           5
                  15.9 MM       .1 MM    13.1 MM        .0 MM      7.5 MM

NANT IAGO LYSIMETERS                    DAY NUMBER    349
CHANNEL                 1           2          3            4           5
                  13.4 MM       .1 MM    11.2 MM        .0 MM      9.5 MM

NANT IAGO LYSIMETERS                    DAY NUMBER    350
CHANNEL                 1           2          3            4           5
                  13.2 MM       .0 MM    11.3 MM        .0 MM     13.0 MM

NANT IAGO LYSIMETERS                    DAY NUMBER    351
CHANNEL                 1           2          3            4           5
                  11.2 MM       .0 MM     8.3 MM        .0 MM     10.5 MM

NANT IAGO LYSIMETERS                    DAY NUMBER    352
CHANNEL                 1           2          3            4           5
                  47.1 MM     19.0 MM    54.9 MM        .5 MM     46.5 MM

NANT IAGO LYSIMETERS                    DAY NUMBER    353
CHANNEL                 1           2          3            4           5
                  14.4 MM       .0 MM    11.4 MM        .0 MM      6.0 MM

NANT IAGO LYSIMETERS                    DAY NUMBER    354
CHANNEL                 1           2          3            4           5
                  12.3 MM       .0 MM     9.7 MM        .0 MM     10.5 MM

NANT IAGO LYSIMETERS                    DAY NUMBER    355
CHANNEL                 1           2          3            4           5
                  31.5 MM     23.0 MM    36.9 MM        .4 MM     40.0 MM

NANT IAGO LYSIMETERS                    DAY NUMBER    356
CHANNEL                 1           2          3            4           5
                  16.9 MM       .4 MM    14.7 MM        .0 MM      8.0 MM

NANT IAGO LYSIMETERS                    DAY NUMBER    357
CHANNEL                 1           2          3            4           5
                   5.3 MM       .0 MM     4.6 MM        .0 MM       .5 MM
```

FIGURE 8.6 Daily runoff and rainfall summary listing

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