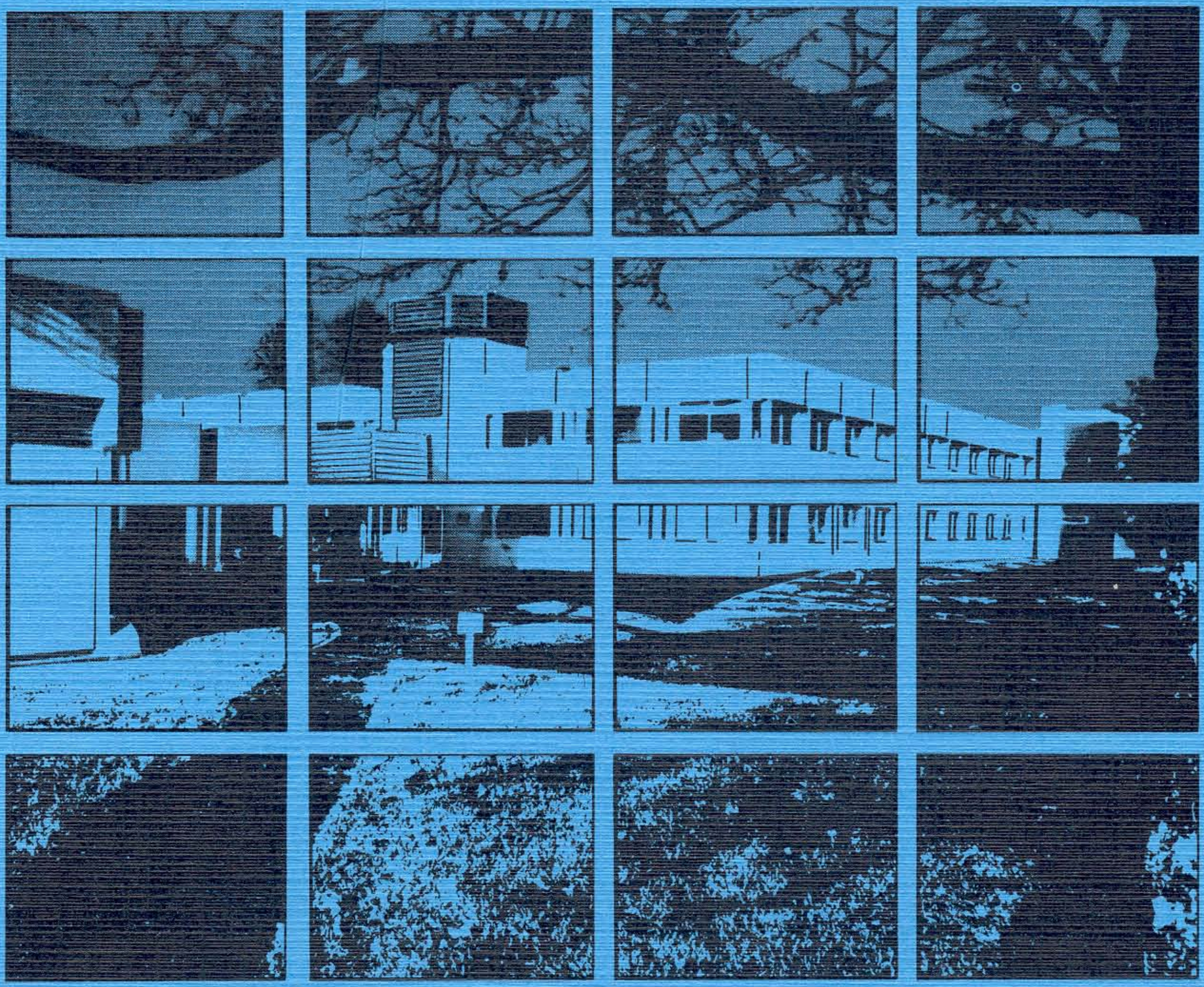
INSTITUTE of HYDROLOGY

The Catchment Research Data Base at the Institute of Hydrology



Report No 106

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The Catchment Research Data Base at the Institute of Hydrology

Anne M Roberts

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Institute of Hydrology
Wallingford
Oxon
OX10 8BB, UK

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Abstract

This report summarises the collation and archiving of data on hydrological variables collected from the IH experimental catchments. Details are given of the quality control procedures carried out and the calculated data values stored. The final section describes the current computer storage and retrieval options; summary listings are appended.

Contents

Introduction

It has long been recognised that an efficient data base is required to handle the ever increasing volume of data collected during the course of various Institute of Hydrology (IH) Experimental Catchment Studies. Plinston and Hill (1974) described a system for processing streamflow, rainfall and evaporation data and this formed a basis of a data processing system written in the late 1970s. This system was in use until 1978. After 1978 a data processing system was written and described by Roberts (1981) which would:

(i) Process all the data being collected mainly from IH catchment studies plus other data sets from other IH projects.

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

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

Since the Roberts report was written, there have been two important changes. First, the introduction of solid state logging and second, the evaluation and purchase by the NERC Computing Service (NCS) of a "state of the art" commercial database management system. This followed from the reorganization of the NERC computing facilities in which NCS took delivery of two main frame computers, a VAX 8600 and an IBM 4381. These are for NERC-wide use and both computers are on a distributed network. As part of this reorganization it was decided that a commercially available Relational Database Management System (RDMS) supplied by the ORACLE Corporation should be made available on both types of computer architecture.

The original concept of the Data Processing System described by Plinston and Hill (1974), Roberts (1972) and Roberts (1981) was of data from logging systems being quality controlled and then either stored in files on magnetic computer tapes or on Random Access computer files. This system worked reasonably well for some time but as the amount of data has increased over the years, the amount of data that have been available "on-line" has steadily declined. Also, the old data processing system did not allow for any "user friendly" system description or documentation of the data. Most users were generally unaware of how much and what types of data are available on the system.

All the IH Catchment section data are now stored on the ORACLE database on the IBM 4381 at Wallingford. The data can be accessed by both inside and outside users provided that they have the capability of linking to the IBM.

A most important difference in this new RDMS is the fact that <u>all</u> catchment section data from UK catchments will be stored on-line. This fact will greatly enhance the reliability of the retrieval of long data sets.

The quality control software is written in FORTRAN 77 and can be used by any computer with a FORTRAN 77 compiler. The manipulation of data uses SQL which is a simple retrieval language.

The Institute of Hydrology is also responsible for the maintenance of the UK national archive of surface water data. This contains daily mean flows for over 1200 stations and includes a number of the study catchments described in this report.

Data for a subset of the national network are published annually in the Hydrological data: UK series. Copies of these reports and retrievals from the main surface water archive may be obtained from the Surface Water Archive Office at the Institute of Hydrology.

1. Research Studies operated by IH Catchment Section

1.1 INTRODUCTION

The Institute of Hydrology, the fore-runner of The Hydrological Research Unit, became part of the newly-formed Natural Environment Research Council in 1965. This was also the start of the International Hydrological Decade when many of the catchment studies described below were initiated.

Originally, the main emphasis of the Institute's research programme was on water quantity, and studies were initiated to estimate streamflow losses from catchments under differing land use or to model streamflow responses to rainfall inputs. In order to do this, four basic variables are required. These are:

(i) Rainfall inputs to the catchment, P

(ii) Streamflow losses from the catchment, Q

(iii) Evaporative losses from the catchment, E

(iv) Change of water storage within the catchment, ΔS

Using these four variables, the water balance of a catchment may be assessed, this being the relationship between water inputs to, outputs from and changes within the catchment. This is normally estimated on an annual basis and is given by:-

$$P = Q + E + \Delta S$$

This led to the concept of the 'water use' of the catchment, this being the variable E, the evaporative losses. This cannot be measured directly but is either estimated as the difference between water inputs to and outputs from the catchment with due regard to changes of storage (ΔS), or calculated using theoretically derived equations using variables such as radiation, wind speed and humidity.

Many studies adopt a twin-catchment approach, with water use estimates being made for areas under different vegetation or following land use changes, such as the conversion of upland pastures to forestry. More recently, there has been a growing emphasis on water quality and sediment losses, and a number of further variables are being measured in addition to the four basic hydrological parameters described above. These water quality variables are not processed and stored as described in this report and will not be considered further.

A map of all the UK catchment studies presently being undertaken by the Catchment Section of the Institute of Hydrology can be seen in Figure 1. It does not include catchments being operated by other sections of IH.

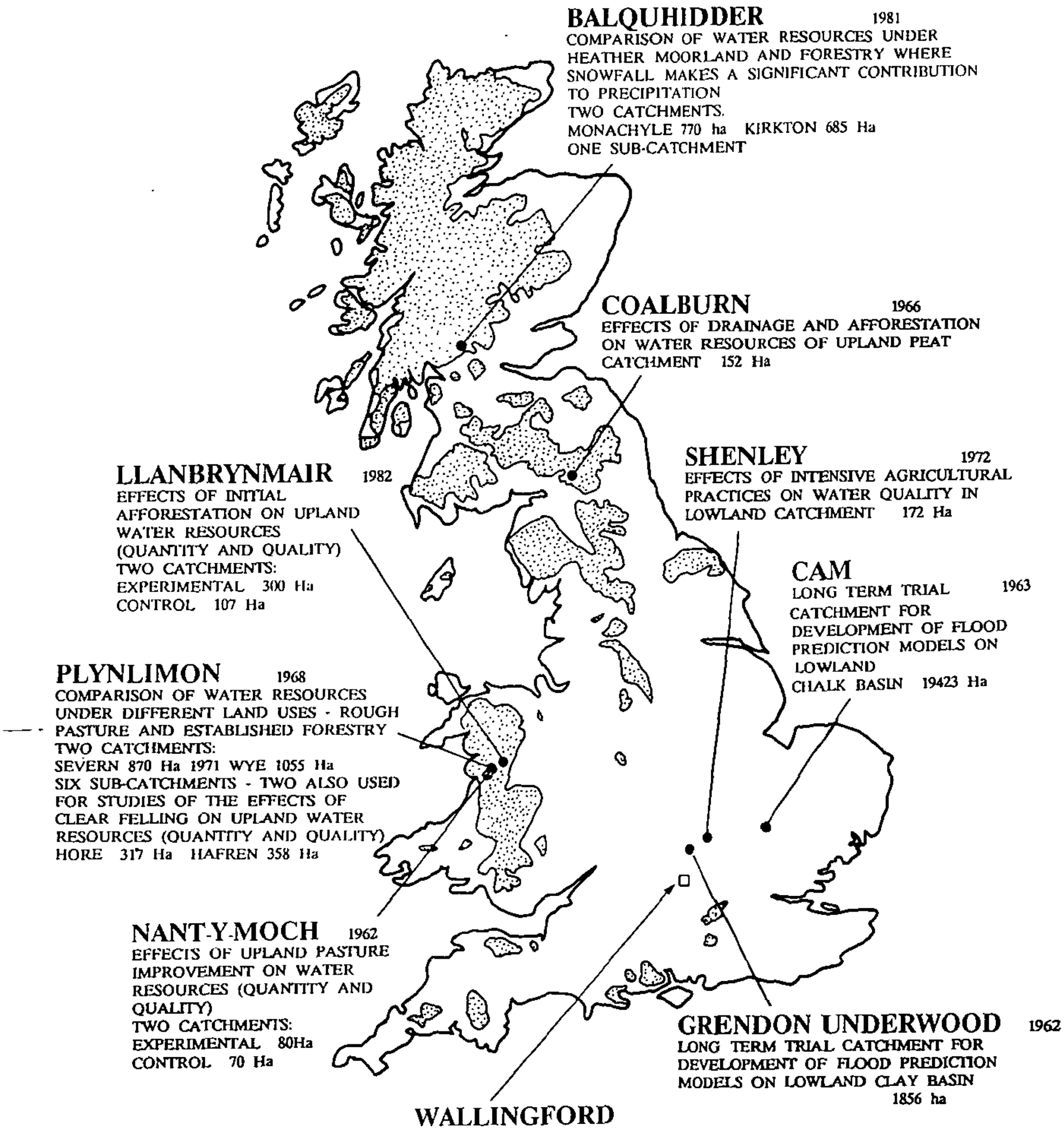


Fig. 1 Experimental studies operated by catchments section.

1.2 PLYNLIMON EXPERIMENTAL CATCHMENT STUDY

This experiment was originally set up to answer the question "Do trees use more water than grass?" As more of the uplands of Great Britain are being planted with conifer trees the question is of direct relevance to the water authorities, who supply water to our industrial conurbations from these uplands, and also to the CEGB who also use upland reserovirs for the generation of hydro-eletricity. The two catchments chosen to monitor this experimental catchment study were the Upper Wye and the Upper Severn on the Plynlimon range of hills in Mid-Wales. (Figure 2).

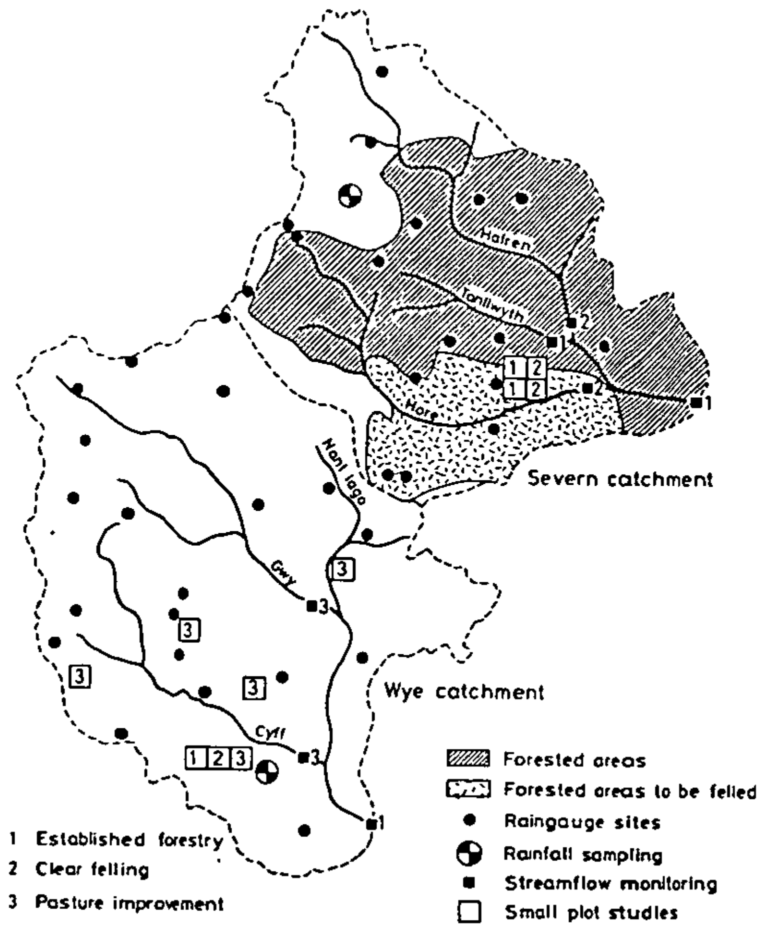


Fig. 2 Plynlimon Catchment Areas

The Upper Wye is 1055 ha in area, and is composed of 82% acid grassland, 10% heath and 8% mire vegetation. The grassland has been subjected to various forms of improvement including open drainage, ploughing, liming, slagging and reseeding, mainly in the 1920s and 1930s. Fertilizer, in the form of basic slag, is still spread every two or three years. The soils are peats, peaty podsols, acid brown earths and peaty gleys.

The Upper Severn is 870 ha in area, the vegetation and soils being similar to the Wye prior to the afforestation which took place over 25 years ago, beginning in 1937. Until 1985 the forest covered 70% of the total area; the remaining 30% is composed of peat bog and rocky outcrops. Two of the sub-catchments, the Hore and the Hafren, are being used to monitor the effects of clear-felling of the coniferous plantations. Approximately 47% of the afforested area of the Hore was felled between 1985 and 1988. The Hafren is unaffected and acts as a control catchment for the Hore.

Both catchments have an altitude range of about 320-780 m. Geologically the catchments are part of the Plynlimon Inlier; the rocks are of Silurian, Valentian and Ordovician eras which consists mainly of mudstones, shales and grits with some siltstone and impure limestone bands.

Rainfall is measured by a network of period and recording gauges in both catchments. In the Wye the network consisted of 21 ground level monthly read storage gauges and three recording gauges (two attached to Automatic Weather Stations (AWS) and one Rimco tipping bucket). The Severn network consists of 18 monthly read period gauges; 11 gauges are at canopy level while the remainder are at ground level in the unforested part of the upper Severn and at Moel Cynnedd (a clearing in the forest at which a meteorological station is situated). There are also three recording gauges, two AWS and one Rimco tipping bucket. The mean annual rainfall for the catchments over the period of data collection, is approximately 2500 mm.

Flow from the Wye is estimated using a modified Crump Weir and that from the Severn by a trapezoidal flume. Specially designed steep stream structures were built to monitor three subcatchments in each of the main catchments. The results from the experiment have shown that of the 2500 mm of annual rainfall, 85% runs off the Wye (grassland) and 75% runs off the Severn (forest). Process studies have shown that the difference in runoff from the two catchments is mainly a result of rainfall interception and subsequent loss due to evaporation within the forest canopy.

Evaporation on a daily basis is estimated using Penman E_O and Penman E_T equations from hourly meteorological variables recorded using two Automatic Weather Stations in each of the main catchments.

The Plynlimon experiment was set up in the late 1960s and a complete set of data for the two main catchments and the six subcatchments exists from 1971 to the present. The project is ongoing and future data will be added to the database. Table 1 in Appendix 1 gives a summary of the monthly totals of rainfall, flow and evaporation on the Wye and the Severn.

1.3 BALQUHIDDER EXPERIMENTAL CATCHMENT STUDY

As a sequel to the Plynlimon experiment, a similar study is being conducted in Balquhidder, central Scotland (Figure 3). This area receives a greater proportion of its precipitation in the form of snow than is the case at Plynlimon. Also the effects of heather rather than grass on the hydrology is being studied. The two catchments chosen to monitor these effects were the Kirkton and the Monachyle.

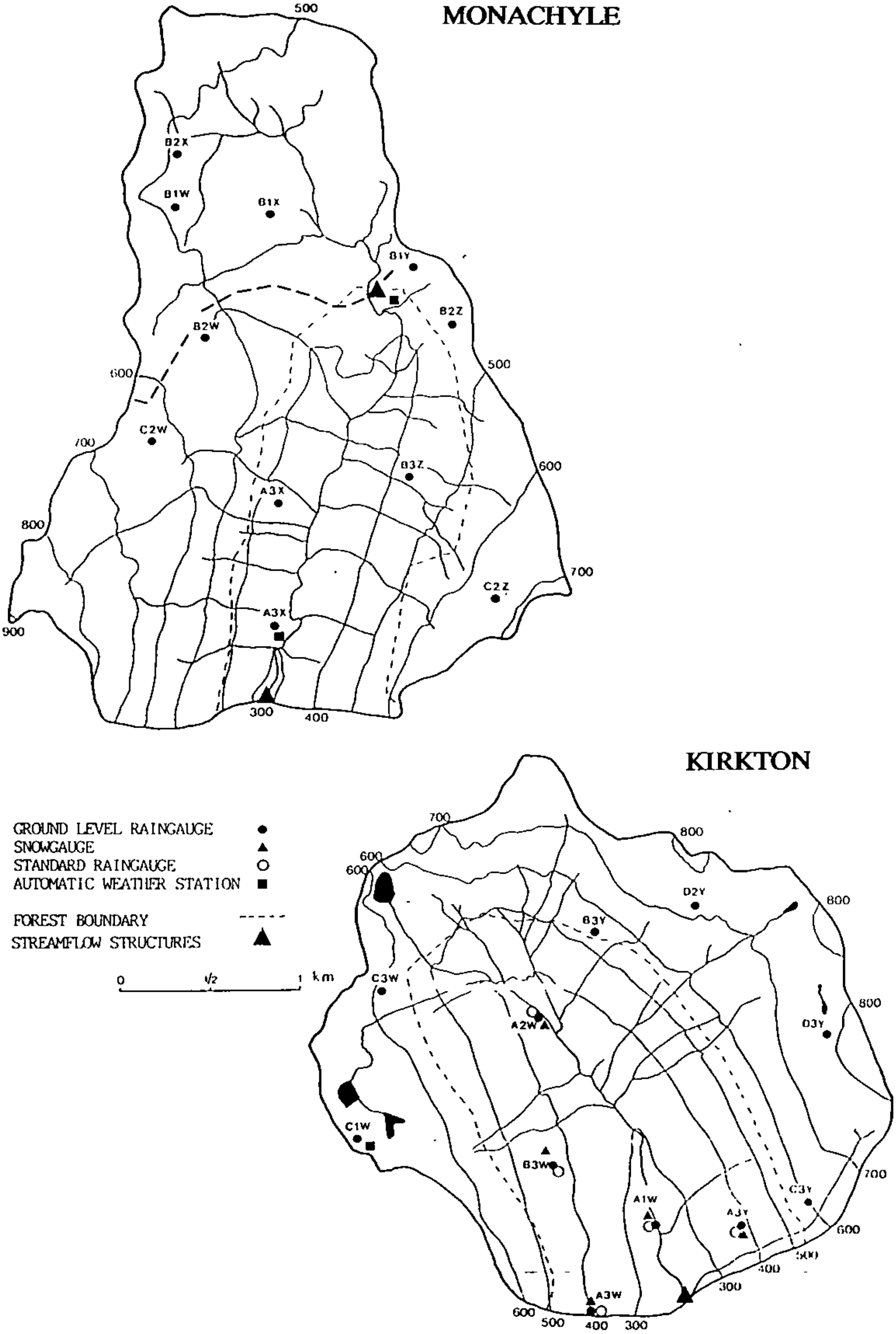


Fig. 3 Balquhidder catchments

The Kirkton catchment is 680 ha in area, has an altitude range of 250-850 m, and is comprised of 44% forest, the rest being under a mixed heather/grass cover with grasses dominant on the valley slopes and heather dominant on the flat ridge tops. Clear felling has started on the lower western side of the Kirkton and by the end of 1987 40% of the forest was felled. The Monachyle catchment is 770 ha in area, and has an altitude range of 300-900 m. The vegetation is mainly a heather/grass mix. The heather dominates the ridges in the upper basin. There is a considerable area of exposed rock on the west side of the catchment. In 1987/88 31% of the area was planted with conifer trees, which represents 43% of the lower part of the catchment.

Both catchments are steep-sided glaciated valleys aligned approximately N-S with soils that are peats, peaty gleys and upland brown earths overlying mica-schists and variable depths of glacial debris in the valley bottoms. The underlying geology is mainly Ben Lur Schists but a survey of the Kirkton commissioned in 1987 has revealed an outcropping of the Loch Tay Series of metamorphosed limestone which is not present in the Monachyle. While the survey shows no significant cross-catchment flow in the limestone, its presence means that the Kirkton stream is much less acid than that from the Monachyle.

The basic raingauge network of 11 sites in each catchment was completed in 1982 with further additions of snow gauges and standard gauges in the Kirkton clearing sites in 1983 and 1984. These gauges are read approximately once per month but in snow months the time and frequency varies according to accessibility. Recording raingauges attached to Automatic Weather Stations (AWS) have been installed at the Lower Monachyle, Upper Monachyle, Kirkton High and above the forest canopy. The mean annual rainfall for the Kirkton and the Monachyle is 2236 mm and 2636 mm respectively, the majority falling as snow from December to March.

The design chosen for the main gauging structure on each catchment was the Crump weir. This design provides the ability to give accurate estimates of flow over a very wide range. The disadvantage of this type of weir is poor sensitivity at low flows. To enable accurate measurement of flows below 0.3 m, separate low flow structures have been built in series with the main weirs. One of the main problems of streamflow measurement in Balquhidder is icing and the subsequent "melt" period. During very cold periods flow tends to be very low so this error has a minimal effect on flow totals but the subsequent "melt" event has a much greater effect with possible errors of ± 15%.

To complete the water balance picture, evaporation, expressed as Penman E_T on a daily basis is estimated using the four AWS in the catchments plus a further AWS at Tulloch Farm which is outside the catchments and at a lower altitude (140 m).

The network of instrumentation was complete by 1982, with the data set running from 1983 until the present. The project, which is funded jointly by the Scottish Office and the Institute of Hydrology, is ongoing with further phases of clear felling in the Kirkton and the planting in the Monachyle. Future years data will be added to the data base. Table 2 in Appendix 1, gives a summary of the monthly water balance totals.

1.4 LLANBRYNMAIR MOOR AFFORESTATION STUDY

The Llanbrynmair Moor study in mid-Wales is an investigation of the effects of initial afforestation and its associated practices of draining planting and fertilizing on streamflow, nutrient and sediment losses (Figure 4). The study uses a twin catchment approach, with one catchment undisturbed and acting as a control while the other, the experimental catchment, is being afforested after a period of initial catchment comparison. Llanbrynmair Moor is situated 15 miles north of the Plynlimon Catchment Study, with an area of approximately 8000 ha and composed of poor draining peaty ground. It is of low fertility and has been used in the past 100 years as a grouse moor and as sheep grazing. As the grouse shooting declines so sheep grazing is increasing with subsequent attempts at grassland improvement. The two catchments chosen to monitor the effects of afforestation were the Cwm and the Delyn.

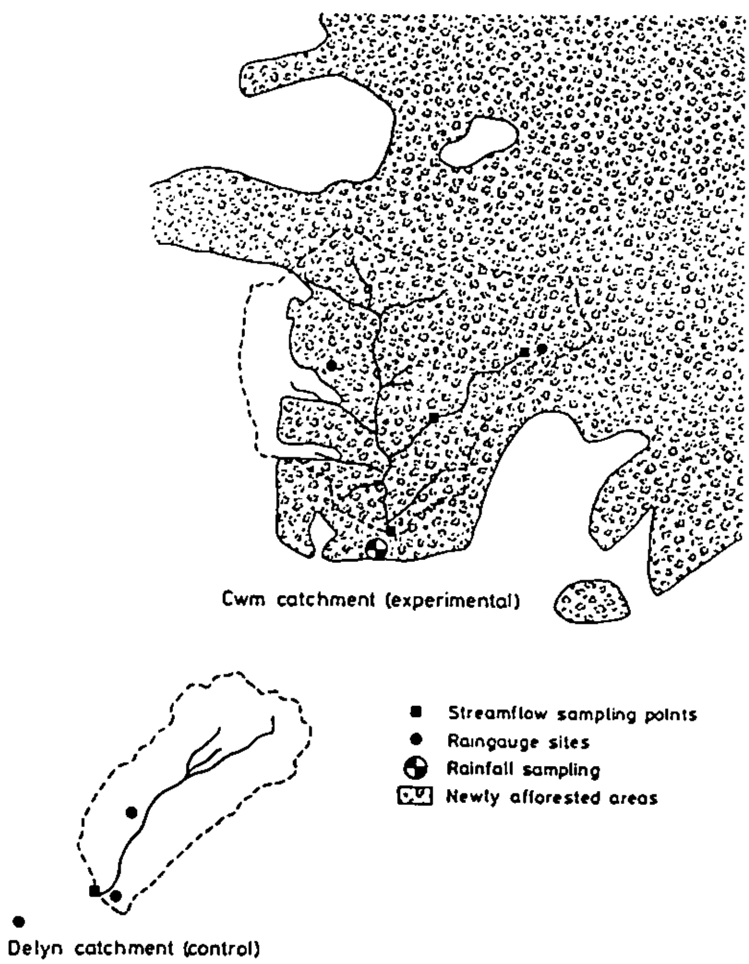


Fig. 4 Llanbrynmair catchments

The Cwm catchment is 300 ha in area, at an altitude range of 285-503 m. Between 1983 and 1986 about 90% of the catchment was contour ploughed, a small area was fertilized and the catchment was planted with coniferous trees. The Delyn catchment is approximately 100 ha in area and has an altitude range of about 215-459 m; it is steeper sided than the Cwm and acts as a control for the experimental Cwm catchment.

The soils of both catchments are brown podzolic soils, peats and peaty gleys and geologically are part of the Silurian era with rocks of mudstones, shales and grits. The dominant vegetation communities prior to forest planting in Llanbrynmair are Blanket Bog (heathland vegetation); dwarf shrub communities (drier Blanket Bog); Molinia grassland and acidic grassland.

To estimate rainfall and nutrient inputs into the two catchments three period gauges were installed:

Gauge 1 - Installed at the outfall of the Delyn catchment in December 1982.

Gauge 2 - Installed at the outfall of the Cwm catchment in April 1983.

Gauge 3 - Installed towards the top of the Cwm catchment in October 1982.

These were supplemented by two further gauges belong to the Welsh Water Authority, a daily read gauge at Pentre Celyn (No. 4) and a telemetry gauge at Rhyd-y-Meirch (No. 5). To enable time distributions to be made for the two catchments, automatic recording gauges were installed at sites 2 and 3 in July 1982.

The type of flow measuring structure employed at Llanbrynmair was dictated by catchment size and stream bed topography. In the Cwm catchment, a Crump weir was constructed, this being adequate to measure the range of flows expected from a catchment of approximately 300 ha. Also, the stream bed at its outfall is relatively flat, enabling such a structure to be employed. In the Delyn, on the other hand, the stream bed at the outfall is very steep and this, together with its smaller size (approximately 100 ha), dictated that the most suitable structure was a sharp-crested weir having a v-notch for greater sensitivity at low flows.

Data collection and processing began in 1982 after completion of the network of instrumentation. The project is continuing to monitor the effects on the hydrology and water quality of the Cwm catchment as the trees planted begin to mature. Future data will be processed and added to the database; Table 3 in Appendix 1 gives a summary of the Llanbrynmair data.

1.5 NANT-Y-MOCH PASTURE IMPROVEMENT STUDY

The main objective of Nant-y-Moch study was to quantify the effects of upland pasture improvements on quality and sediment loadings of upland streamflow. The study area is part of the Upper Rheidol Valley, about 21 miles north east of Aberystwyth, mid-Wales. Much of the area is owned by the Crown Estate Commissioners who proposed an upland management scheme in 1981 to commemorate the marriage of the Price and Princess of Wales. The scheme involved improving grazing land and constructing a car park and footpaths. As the site is part of a "Site of Special Scientific Interest"

(S.S.S.I) the scheme went to public enquiry. In 1983 permission was granted for part of the scheme and implementation began almost immediately. The two catchments chosen to monitor the grassland improvement were the Maesnant Fach, part of which was to be improved and the Maesnant which was outside the improvement area. (Figure 5).

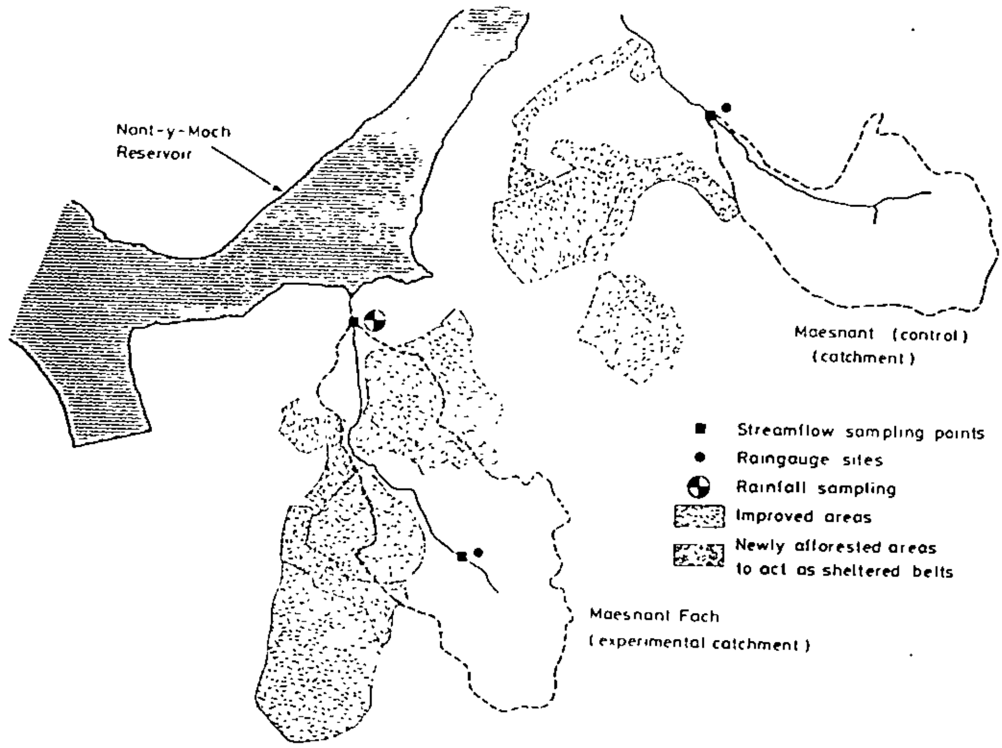


Fig. 5 The Nant-y-Moch grassland improvement study

The Maesnant Fach is 80 ha in area, and has an altitude range of 350-645 m. Three improvement schemes were employed in the catchment:

Ditching for shelter belts and subsequent planting of a mixture of hardwood and softwood trees;

Grassland improvement on the northern boundary which involved cutting and burning the existing vegetation, application of lime, spike seeding followed by an application of general fertilizer.

Thirdly, pasture improvement using the same techniques as the first pasture improvement on the southern side of the catchment.

The Maesnant, 56 ha in area, with an altitude range of 472 m to 752 m, is outside the improvement area and acts as control catchment to the experimental Maesnant Fach.

The vegetation in both catchments is influenced by the hydrology of the area.

There tends to be a succession of Nardus → Molinia → Eriophorum mire with increasing wetness and stagnation. Soils are of the Hiraethog Series in the Maesnant and of the Hiraethog and Ynys series in the Maesnant Fach. Those soils are mainly peat, peaty gleys with dark brown subsoil. Both soils are poor but due to lower altitude and its structure the Ynys series areas are more suitable for drainage and subsequent improvement. Geologically the area is part of the Plynlimon Inlier which has been created from the sedimentary rocks of the Ordovician era. The rocks are mainly mudstone, siltstone and sandstone intervals and are mainly pelargic in origin.

Rainfall was originally measured by one ground level period gauge in each catchment and the total rainfall was time distributed by a recording gauge situated at the outfall of the Maesnant Fach. Subsequently, in 1987, one more recording gauge was added at the outfall of the Maesnant and two more recording gauges sited at the head and at the middle of each catchment. Rainfall in the Maesnant Fach is approximately 2490 mm per year and in the Maesnant approximately 2600 mm per year.

Runoff from both catchments is measured by compound sharp-crested weirs. These weirs are rectangular in shape and have a 90°v-notch to give precision at low flows. The mean annual runoff for the Maesnant Fach and the Maesnant is 1595 mm and 1990 mm giving an approximate yearly water use of 895 mm in the Maesnant Fach and 620 mm in the Maesnant. The water use of both catchments, particularly the Maesnant Fach is higher than for grassland at Plynlimon (IH, 1976) and for the Llanbrynmair Catchments (Roberts et al., 1986). These discrepancies are currently being investigated with a view to determining the effectiveness of the sparse rainfall network in estimating inputs to the catchments particularly during snow periods.

Monitoring of the effects of the land improvement began at the end of 1984. Data exists for these catchments from 1985 to the end of 1987, and although the original experiment has now finished some data collection is likely to continue. Appendix 1, Table 4 summarises the Nant-y-Moch data.

1.6 THE COALBURN EXPERIMENTAL CATCHMENT

This study was set up to study the effects of open drainage, afforestation and the application of ground rock phosphate on

(i) the response of the catchment to rainfall inputs,

(ii) sediment losses in the streamflow,

(iii) phosphorus concentrations and losses in the stream.

In 1966 the Forestry Commission planned to incorporate the area into the Wark Forest and the catchment was subsequently instrumented by the Institute of Hydrology together with the North West Water Authority. After a control period of approximately five years the Forestry Commission ploughed the catchment and planted Sitka Spruce.

The Coalburn Catchment is an area of 152 ha at an altitude of about 300 m. It is situated in the headwaters of the River Irthing some 40 km northeast of Carlisle (Figure 6). The natural vegetation is comprised of rough Molinia grass and peat bog. Most of the catchment is covered by a thick deposit of boulder clay under a thin covering of peat, although the underlaying carboniferous rocks are exposed in places.

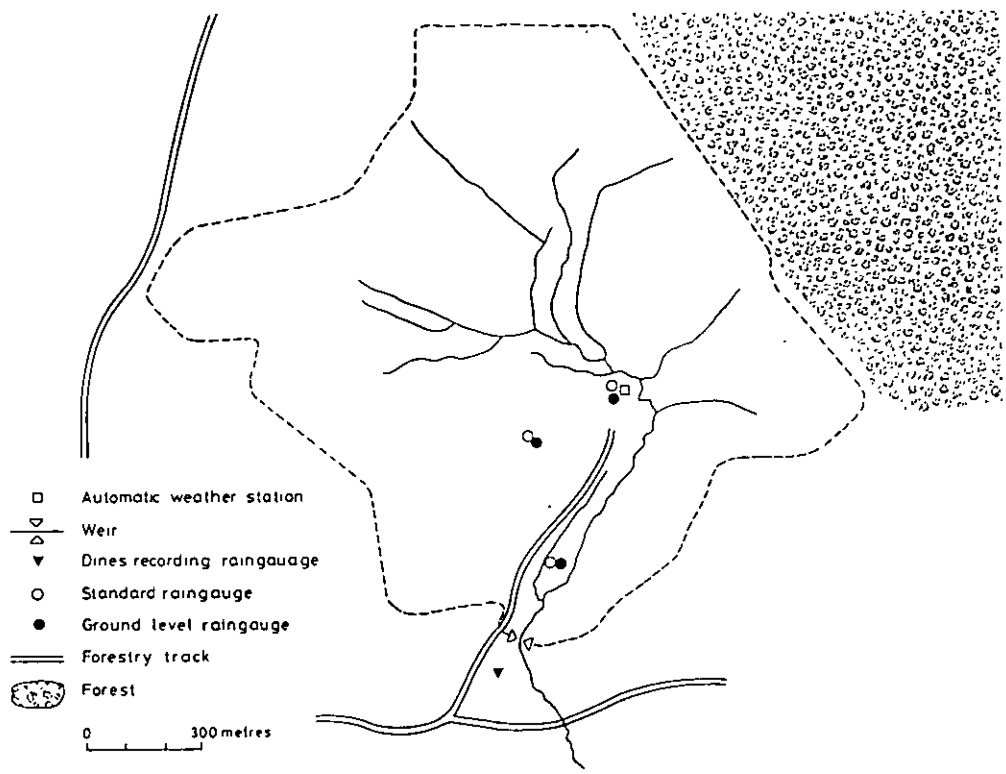


Fig. 6 Coalburn catchment topography and instrumentation

To determine the average catchment rainfall, 14 raingauges were installed initially and read at two week intervals. The number of raingauges had to be reduced just prior to planting in 1973 as they would have interfered with forestry operations. As an analysis of the results from the network showed only small differences between the gauges, it was concluded that a restricted number of raingauges would be enough to estimate a catchment average. A further analysis of four years data confirmed the overall homogeneity of the rainfall and the number of gauges was reduced to four. The period gauge totals are time-distributed using an Automatic Weather Station recording gauge.

Runoff from the catchment is estimated using a compound Crump weir design. This design was chosen for ease of construction in an upland area and to contain all flow up to 5.75 cumecs. A large apron was constructed upstream to reduce turbulence at high flows and to encourage sediment deposition away from the weir.

This is a long term study as it is intended to study the hydrological effects from planting to clear felling. Data collection started in 1967 and continues to be processed a summary of the available data is given in Table 5 in Appendix 1.

1.7 THE RIVER RAY CATCHMENT AT GRENDON UNDERWOOD

The Grendon experiment was set up for the development of flood prediction models for lowland clay catchments. It is the longest running of the catchment studies at the Institute of Hydrology with 24 years continuous data.

The Ray catchment is 1856 ha in area at an average altitude of between 50 m to 187m at Quainton Hill and is situated near the village of Grendon Underwood in Buckinghamshire (see Figure 7). The River Ray itself is a tributary of the River Thames and the entire catchment is underlain by Jurassic clays, predominantly Ampthill and Oxford Clays. The presence of these clays producing the apparent water tightness of the catchment was the main reason for this experiment being set up here. Vegetation in the catchment is 70% short grass with some areas of woodland and arable farmland. The hills that form the northern watershed have a clay capping with underlying thin covering of glacial drift. There is some glacial head towards the centre of the catchment, but the southern boundary is free from such deposits. Quainton Hill is a limestone outcrop.

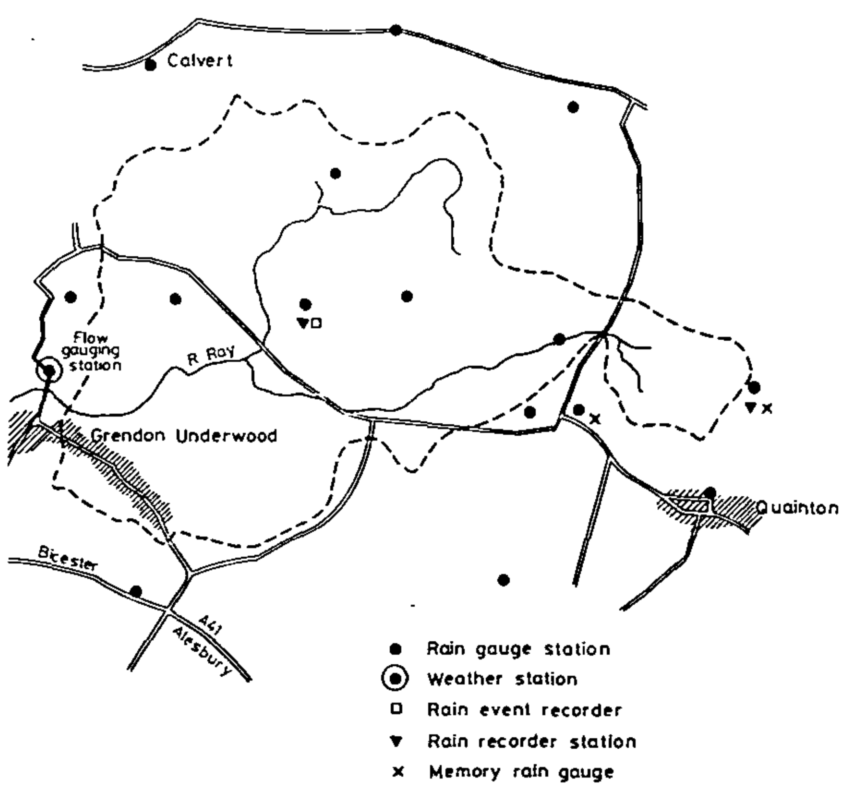


Fig. 7 The River Ray experimental catchment

The availability of volunteer observers determined the distribution of the raingauge network, rather than the requirements of any calculating technique, but in the event a fairly uniform cover has been achieved. There are 20 sites with standard meteorological raingauges, one with its rim at ground level inside a non splash surface and three equipped with Dines recording gauges. In addition there were two recording gauges, one situated on the meteorological site attached to an Automatic Weather Station and the other a Rimco tipping bucket at Hill Farm. Average rainfall for the area is about 666 mm with little or no snow.

Streamflow from the catchment is estimated using a critical-depth trapezoidal flume constructed in 1962. Originally this had a capacity of 5.5 cumecs but, following a flood which submerged it, the walls of the flume were raised to increase its capacity to 8.5 cumecs. This was though to correspond to a flood of about a 10 year return period.

Although the Grendon experiment was finished at the end of 1986 the routine collection of streamflow data is being undertaken by the Thames Water Authority and the Met. readings by the Meteorology Office. The data stored for Grendon at IH runs from 1962 to 1986. Table 6 in Appendix 1 gives a summary of the data available at present.

1.8 THE RIVER CAM EXPERIMENTAL CATCHMENT

The purpose of this study was to develop a runoff simulation model for a semi-permeable basin. The objectives were: (i) to hypothesize a conceptual runoff model for the Cam Catchments and (ii) to test the suitability of the model with given periods of data.

The area selected for study was the catchment area of the River Cam above Dernford Mill (Figure 8). It is 19,423 ha in area, has an altitude range of 30-120 m and is predominantly agricultural. The catchment is situated on the margin of the Fens; the central branch of the river rises in the Chalk uplands south of Saffron Walden. The vegetation is mainly arable crops and the soils are mainly Calcareous gleys, Chalky Boulder Clay and Chalk Marl with Sandy drift over chalk. The chalk formation rests on Cambridge Greensand. The greensand and the underlying gault clay exhibit a low regional dip to the southeast, causing outcrops in the chalk tending northeast to soutwest. There is a hard, relatively impermeable band of greensand which out crops in the vicinity of Dernford Mill. The presence of this band is likely to prevent the occurrence of much subsurface seepage northwards past the gauging station.

Rainfall was measured by a network of nine daily read raingauges plus one at the climate station. The daily totals were time distributed using a Dines recording gauge at the climate station. The rainfall pattern over the area is fairly uniform with an average rainfall of about 635 mm per year and potential evaporation 530 mm per year.

Runoff from the catchment was estimated using a Crump weir with a stage/discharge relationship developed by the Anglian Water Authority. The stage was recorded on a Leopold & Stevens chart recorder.

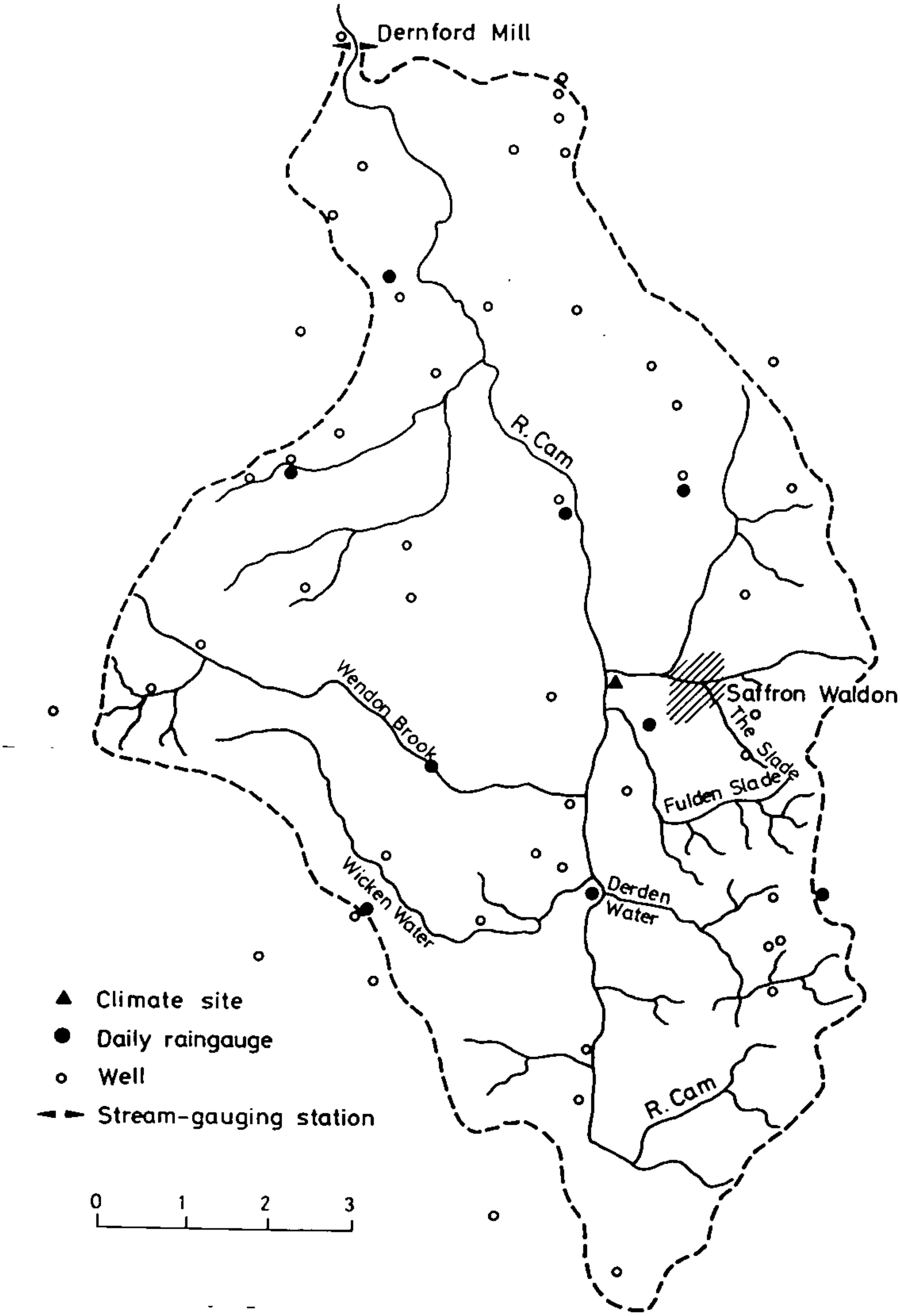


Fig. 8 The River Cam experimental catchment

This catchment study began in 1967 and data was collected, processed and stored until 1985, after which the Anglian Water Authority carried on the responsibility of running the gauging station at Dernford Mill. Table 7 in Appendix 1, gives a summary of the Cam data.

1.9 SHENLEY BROOK END CATCHMENT STUDY

This catchment was chosen to assess the effects of intensive agriculture on streamflow nitrate concentrations (Roberts, 1987). It was originally the control catchment of the Milton Keynes urbanization study. The catchment is situated near the village of Shenley Brook End on the outskirts of Milton Keynes, Buckinghamshire (see Figure 9).

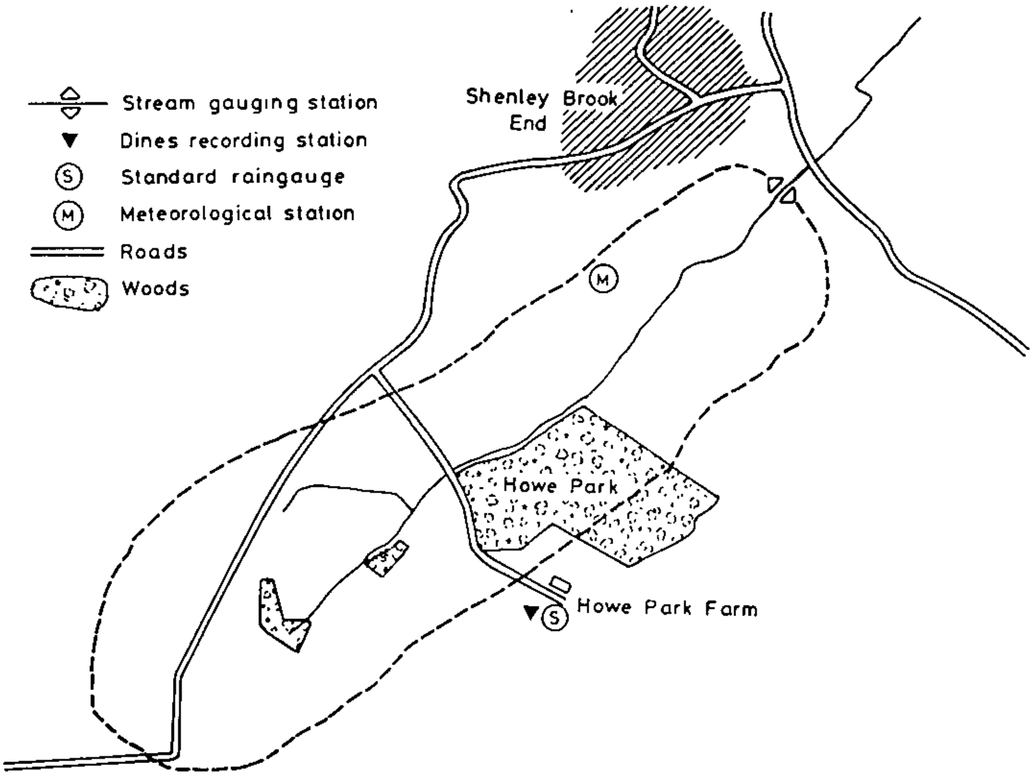


Fig. 9 Shenley Brook End Catchment

The area chosen for the study is a small (170 ha) clay catchment with an altitude range of between 50-150 m. The catchment consists mainly of gently undulating agricultural land with 11% deciduous woodland, 23% arable land and 66% grassland. Part of the grassland was used for dairying; the rest was used for sheep rearing and the production of hay and silage. The soils of the catchment range from Chalky Boulder Clay, Valley Bottom Head to Fluvioglacial drift.

Rainfall over the catchment was measured by means of a daily read period gauge at the meteorological station and a weekly read period gauge at Lower

Park Farm. The rainfall totals were time distributed using a Dines recording gauge at Lower Park Farm. The annual precipitation is about 759 mm with about 548 mm potential evaporation; this was estimated using data from the Shenley meteorological station.

Runoff from the catchment was estimated using a trapezoidal flume. Two recorders were used, a Leopold and Stevens chart with a Fischer-Porter punch tape recorder as a back up. Runoff is about 220 mm (33% of precipitation) and on average streamflow ceases for 5 months in the summer.

Data collection in the catchment started in January 1970 and ceased in 1983. Table 8 in Appendix 1, gives a monthly summary of the Shenley data.

2. Instrumentation and logging systems

2.1 RAINFALL ESTIMATES

Rainfall onto a catchment is normally estimated using the results from a network of period gauges, their totals being distributed in time by the results from a number of recording gauges. The period gauges can be read at any time interval but, for convenience, the intervals are usually restricted to daily, weekly or monthly. An exception to this is Balquhidder, where the climatic conditions during the winter months are such that the period gauges can only be visited infrequently.

Each period gauge is assumed to represent a certain proportion of the catchment and is allocated a weighting. In some instances, period gauges are sited according to specific geographical variables, such as the aspect, slope and altitude domain classification used at Plynlimon and at Balquhidder. In other cases, such as Grendon, raingauges are sited for convenience of access. The various raingauges are given a weighting according to a mapping technique such as the Thiessen polygon area method, by altitude as at Llanbrynmair or simply according to the number of gauges, such as at Shenley.

Three basic means of recording rainfall have been used:-

(i) The Dines siphoning bucket recorder, where 'events' in the form of the movement of a pen attached to the siphoning arm are recorded on a chart recorder. The data are abstracted manually as hourly intervals and input to the computer, together with period gauge data, as sequential files as described by Plinston and Hall (1974). These recorders have now been mainly superceded by the following types of gauges.

(ii) A Microdata cassette logger attached to a tipping bucket raingauge.

(iii) A Mussel solid state logger attached to a tipping bucket raingauge.

(iv) A Campbell "intelligent" solid state logger attached to a tipping bucket raingauge.

The latter two record the number of tips of the bucket at, normally, five minute intervals. They are quite often employed as part of the normal automatic weather station range of instruments. The data are input to the computer system using software written for the purpose (Templeman, 1978). Period gauge data are input manually to be combined with the recording data as described in Section 2.5.

2.2 STREAMFLOW

Stream discharge is measured as the head of water or stage in a stilling well connected to a weir or flume. This is normally measured by means of a float connected to a counterweight by a metal band over a pulley system. A number of recorder types have been employed. They include:-

(i) Chart recorders, where the water level is traced in ink on a rotating chart. In these cases, the trace is analysed by a D-mac follower and water levels, normally at fifteen minute intervals, abstracted using a suite of computer programs.

(ii) Punch recorders, where the water levels are recorded as a series of holes at set time intervals on a paper tape. These tapes are translated automatically and input to sequential files on the computer systems.

These two types of recorders are now only normally used as back-up, having been superceded by:-

(iii) A Microdata cassette logger attached to a potentiometric water level sensor.

(iv) A Mussel solid state logger attached to a potentiometric water level sensor.

The latter two normally record stage at five minute intervals and are input to the computer system using software written for this purpose (Templeman, 1978).

2.3 WEATHER STATIONS

Two types of weather stations have been used:-

(i) **Manually-read stations.** These are read at 0900 hours GMT. The variables recorded are maximum temperature, minimum temperature, dry bulb temperature, wet bulb temperature, run of wind and rainfall. The data are manually input to the computer system and the climatological variables used to give estimates of open water evaporation and two estimates of evapotranspiration using two different equations. Full details are given in Plinston and Hill (1974).

(ii) **Automatic weather stations.** These record solar radiation, net radiation, dry bulb temperature, wet bulb depression, wind rain, wind direction and rainfall, normally at five minute intervals, onto cassette tapes or solid state loggers. The data are input to the computer system using existing software (Templeman, 1978). They are then used to calculate various evapotranspiration estimates as indicated in Section 3.2.

3. Quality Control of Data and Calculated Data Values

3.1. AUTOMATIC WEATHER STATIONS

Before quality control can be carried out, the data from Automatic Weather Stations (AWS) are translated into real units using standard conversion factors. At the same time, each data record is given a "flag", its value being determined by the results of the data translation. 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 days as the mid-point between apparent sunrise and sunset. The time of apparent noon is tested to be within plus or minus half an hour of noon. For each period a timing summary printout 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. Comprehensive error messages are output where necessary and, in general, any "incorrect" data are listed as an aid to 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, except for rainfall, the variables are considered in pairs for quality control purposes. The quality control is applied to five minute data one day at a time.

3.1.1 Solar and net radiation quality control

As an aid to quality control, the maximum expected radiation, R, 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:-

$$R = -128.5 + 23.7a - 0.119a^2$$

where

$$\mathrm{Sin}(a) = \sin(\emptyset)\sin(\delta) + \cos(\emptyset)\cos(\delta)\cos(h)$$

and

$\emptyset$ = latitude of station
δ = declination
h = hour angle

TABLE 1 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 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.
LIMIT = 9 Wm^{-2}	Set the quality indices of all the net radiation values equal to 2. Print error message and net radiation values. (Quality index 2 = possibly incorrect)

TABLE 2 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 (-50 x Π /(6.0 x 180.0)
	phi	=	Latitude x Π /180.0
	SIND	=	0.00678 + 0.39762 x COS (THETA) - 0.00613 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

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

$$h = ABS\ (11.5 - H) * 180.0/12.0$$

where

H is the hour (12.0 = 12 noon)

For values of solar altitude of less than 5°, R = 42 Wm^{-2} for the first hour, R = 20 Wm^{-2} for the hour with the next lower solar altitude, and R = 5 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 $\leq$ 40 Wm^{-2}; the factor that has been applied is listed out on the timing summary sheet. 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, it is then 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. 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 1.

Time checks are now carried out, provided that:

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

(ii) the checks already carried out on the solar radiation data (Table 1) 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 2 whilst the apparent values are derived as shown in Table 3.

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

TABLE 3 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 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.

---

for the day is output and the timing checks are deemed to be unsuccessful. The absolute difference between the true and apparent day length is calculated similarly; 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.

Further quality control tests are then carried out on individual data values. These include comparisons between solar and net radiation values as outlined in Table 4.

If the quality indices are set to 1 the data are deemed "incorrect" and subsequently not stored. If the quality indices are set to 2 or 3 (i.e. "possibly incorrect" or "correct") the data values are passed to ORACLE and stored.

TABLE 4 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	Set quality index = 1
	SOLAR UPPER LIMIT = 1400 Wm^{-2} NET UPPER LIMIT = 1260 Wm^{-2}	
(iii)	For both solar and net, if data value is less than -120 Wm^{-2} for net or less 0 for solar	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 period DAWN + 2 hours to SUNSET - 2hours.	
	SOLAR RADIATION > 1.4 x R	Set quality index = 1
	SOLAR RADIATION > 1.7 x R	Set quality index = 1
	NET RADIATION > 1.2 x R	Set quality index = 1
	NET RADIATION >1.36 x R	Set quality index = 1
(v)	Any net radiation values between 0000 and 0300 hour > 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 $\geqslant$ 30 Wm^{-2}	
	Net $\geqslant$ 85% solar over grass	Set net quality index = 1
	Net $\geqslant$ 100% solar over forest	Set net quality index = 1
	Net $\geqslant$ 80% solar over grass	Set net quality index = 2
	Net $\geqslant$ 95% solar over forest	Set net quality index = 2

cont'd...............

TABLE 4 continued..

	QUALITY CONTROL CHECK	OUTCOME
(vii)	Used only when the hourly solar radiation value is $\geqslant 30\ Wm^{-2}$ and for data recorded within two hours of noon.	
	Net for grass < 15% solar	Set net quality index = 1
	Net for forest < 25% solar	Set net quality index = 1
	Net for grass < 45% solar	Set net quality index = 2
	Net for forest < 55% solar	Set net quality index = 2
(viii)	Used only when the hourly solar radiation value < $30\ Wm^{-2}$	
	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 > $2.0\ Wm^{-2}$	Set net quality index = 1
	If solar = 0 and net > 0	Set net quality index = 2

3.1.2. Dry bulb temperature, wet bulb depression and calculated specific humidity deficit quality control

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 (gr kg^{-1})

$= (0.62197/(P/(1.0045 * SVP_{TD}) + 0.62197 - 1.0)) *1000$

q_{WT} = saturated specific humidity at wet bulb temperature, T_W, (gr kg^{-1})

$= (0.62197/(P/(1.0045 * SVP_{TW}) + 0.62197 - 1.0)) *1000$

SVP_{T_D} = saturated vapour pressure at dry bulb temperature, T_D, (mb)

$= 17.044 + X_D * (5.487 + X_D * (0.776 + X_D * (0.063 + X_D * 0.003)))$

SVP_{T_W} = saturated vapour pressure at wet bulb temperature, T_W, (mb)

$= 17.044 + X_W * (5.487 + X_W \times (0.776 + X_W * (0.063 + X_W * 0.003)))$

X_D = $T_D/5 - 3$ (°c)

X_W = $T_W/5 - 3$ (°c)

K = the psychrometric constant = $5 * 10^{-4}$ kg.kg^{-1} °C^{-1}

P = atmospheric pressure = $1012 *(1 - 0.0065 * IALT/288))^{5.2559}$ (mb)

IALT = altitude of station (metres)

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 5. 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 for the whole cassette are written out to a temporary file for future editing.

TABLE 5 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 the minimum of temperature range of the AWS.	Set quality index = 2
(iv)	For dry and wet bulb temperature, values greater than the maximum of temperature range of the AWS	Set 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 great 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 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 $\frac{\text{Depression}_{\text{max. temp.}} - \text{Depression}_{\text{dawn}}}{\text{max. temp. - dawn temp.}} < 0.1$	Print error message and dry and wet bulb temperatures for the day.
(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.

3.1.3 Windspeed and Direction Quality Control

The quality control tests applied to wind speed and direction are tabulated in Table 6. The outcome of these tests is to adjust the values of individual indices; no manual editing of wind speed and wind direction are carried out.

TABLE 6 Quality Control Tests for Wind Speed and Direction

	QUALITY CONTROL CHECK	OUTCOME
(i)	For both wind speed and direction scan flag $\neq 0$	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 run is zero all day, see (vii)	Set quality indices 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 with ± 5° all day, but the wind speed is not zero all day	Set quality indices of direction all day = 1.

3.1.4 Rainfall Quality Control

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 $\neq 0$, the quality index is set to 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.

3.2 CALCULATED PENMAN VALUES USING STORED AWS VALUES

3.2.1 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 7.

TABLE 7 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} $°C^{-1}$
ρ	=	density of air (~ 1.20 kg m^{-3})
C_p	=	specific heat of air at constant pressure (= 1.01×10^3 Jkg^{-1} $°C^{-1}$
λ	=	the latent heat (~ 2.47×10^6 Jkg^{-1})
γ	=	C_p/λ

For standard Penman: M = 1, N = 1

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

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)

(i) Density

The density of air varies with temperature and pressure (and therefore altitude). Its variation with water vapour content is ± ½% and can be ignored in this application. A mean value is 1.2 kg m^{-3}.

The relationship used is: $\rho = \left(\frac{1.292}{1 + .00367T}\right) * \left(\frac{P}{1013}\right)$ 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 = $1012 * \left(1 - \frac{.0065z}{288}\right)^{5.256}$

(ii) Specific heat

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

(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: $\lambda = (2.5 - 2.38 * 10^{-3}T) \times 10^6$ J kg^{-1}

where T is the temperature in degrees C.

(iv) Psychrometric constant

The 'pyschrometric 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 °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 somehwat dubious; but until better information becomes available, 0.5 will continue to be used.

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

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

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

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 8.

TABLE 8 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 values 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 the maximum possible solar value for the hour, S_{TMAX}, $\geqslant$ 50 Wm^{-2}:

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

$$R_{Nx} = S_{Tx}\ (1 - \alpha_x) - 10\ \frac{S_{Tx}}{S_{TMAX}} \qquad (5)$$

where α_{water} = 0.05, α_{forest} = 0.1, α_{grass} = 0.2.

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

$$R_{Ny} = R_{Nx} = -40\ Wm^{-2}$$

3.2.2 Calculations using the basic Penman equation

Estimates of daily and daylight open water evaporation 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) or (4) in Table 8 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 8 to obtain net radiation for each hour.

(ii) Sum the hourly net radiations to obtain daily or daylight totals, where appropriate, 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 aerodynamic factor, where appropriate.

(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 0.405 to obtain results in mm of water.

3.2.3 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 8 and carry out the following steps for a daily total only.

(ii) For each hour, use the hourly values 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 (Table 7) values used for a particular site are stored in the site directory.

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.

3.2.4 Calculations using the Penman-Monteith 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:

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

where the constants and variables are as defined in Table 7, 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:

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

$$\begin{aligned} & \quad 100 \text{ for grass} \\ & \quad 5 \text{ for forest} \\ k &= 0.41 \\ u &= \text{mean hourly wind speed in } ms^{-1} \end{aligned}$$

The mean $(\frac{Z-d}{Z_o})$ 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 (Sspecific Humidity Deficit (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.

3.3 FLOW DATA

3.3.1 Quality Control

Before the Water Level Recorder (WLR) type 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. 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:

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

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

c) both fine potentiometer values are outside the expected range of $10 \leq x \leq 190$,

d) both fine potentiometer values are within the expected range but their difference exceeds 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. Any data indexed as 1 is flagged in ORACLE as null data. Data indexed as 2 or 3 is passed to ORACLE and stored.

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.

(i) Errors relative to station datum

Comparison of the recorded and observer-measured river levels at the nominal end of the 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.
(b) the recorded and observer-measured levels are inconsistent. Appropriate diagnostics are printed for subsequent manual checking.

(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.

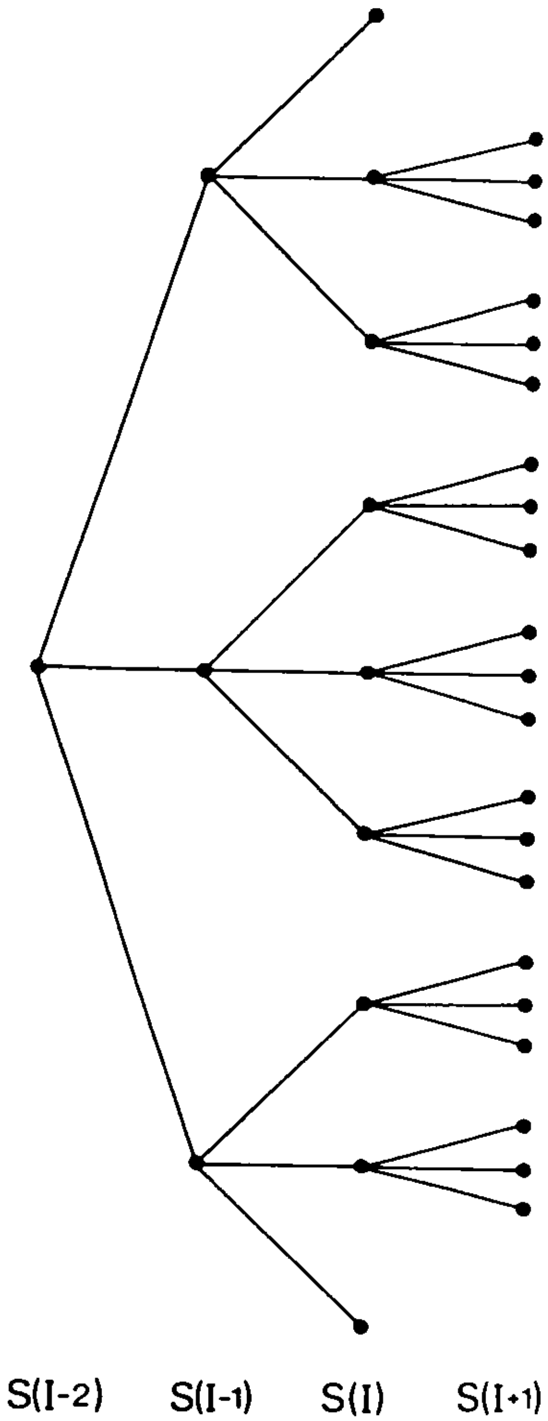
A simple trend test applied successively to each possible sequence of four river levels is sufficiently powerful to identify potential errors of these two kinds. All the relevant combinations of four successive river levels are shown in Figure 10 together with the action taken in each case. When the 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 four 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 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.

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

Fig. 10 Trend test for water levels

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 raw 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 with alternative values derived by linear interpolation between the good data on either side of the bad patch:

(a) there must be at least six 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 six 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 time period 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. If errors are found which cannot be automatically corrected, the original data are written out to a temporary file for manual editing. However, should the data be found to be "error free" then any temporary files created during the quality control stage will be automatically deleted.

3.3.2 Data Conversion

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. 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. The steps involved in converting river level to flow in mm over the catchment for the required frequency are:

a) 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.

b) Sum the flow values over the required frequency.

The accuracy of 'true' catchment areas was obtained by using the largest scale map available at the time. In the case of the Plynlimon catchments a special 1:10000 map was commissioned whereas colour areal photography on a 1:10000 scale was obtained for the other mid-Wales catchments and the accuracy of the original catchment boundary tested using stereoscopic pairs of photographs.

3.4 RAINFALL EVENT RECORDER DATA

3.4.1 Quality Control

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. 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 logger 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 and defined in ORACLE as a NULL value.

(iii) If the current or previous scan flag = 1, the quality index set to 1 and defined in ORACLE as a NULL value.

3.4.2 Data Conversion

The recording frequency of the rainfall event recorder (normally 5 min) is greater than that required for most hydrological investigations. This means that hour rainfall totals are calculated and stored. Each hourly value has an associated quality index, its value depending on the original 5 min total. If the index is 1, i.e. 'bad' data, it is defined in ORACLE as a NULL value. If the index is 2 or 3, i.e. 'acceptable' or 'good', the value is passed to ORACLE and stored.

3.5 AREAL CATCHMENT RAINFALL ESTIMATES

Many 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,

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

1. 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 total 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.

2. There is no need for a check gauge total for each recording gauge as 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.

3. Data from ORACLE are automatically accessed.

4. Recording gauge data from a variety of instruments can be used provided that these data are in stored in ORACLE. This includes data from rainfall event recorders and automatic weather stations.

5. 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.

4. Computer Storage and Retrieval

The previous sections have described WHERE the data were collected and WHAT the data are. This section will describe HOW much is stored for each type of data and also HOW the data can be retreived. Table 9 describes the extent of the data stored up to the present (1987).

4.1 ORACLE RELATIONAL DATABASE MANAGEMENT SYSTEM

SQL*PLUS is software that lets a user access the ORACLE Relational Database Management System (RDMS) efficiently and effectively. The ORACLE RDMS stores vast amounts of information in tables, keeping all kinds of data available for instant use or update.

SQL*PLUS provides a user with the commands to use this storage capability to its fullest extent. It combines the simple command language SQL (Structured Query Language) with SQL*PLUS commands to let you, for example:-

- Create new ORACLE tables.
- Store information on these tables
- Select any information you need from these tables
- Make changes, updating or deleting the tables as required
- Combine and calculate data from more than one table.

The data in ORACLE tables are stored in columns and rows, with data values in their own slots called fields.

4.2 DESCRIPTION OF CATCHMENT SECTION TABLES

All the data shown in Table 9 are stored in the following tables:-

- AUTOMATIC-WEATHER-STATION	(Synonym	AWS)
- AWS-EVAPORATION		
- AREAL-CATCHMENT-RAINFALL	(Synonym	ACR)
- FLOWDB		
- RAINFALL-EVENT-RECORDER	(Synonym	RER)
- CATCHMENT-EVAPORATION	(Synonym	C-E)
- SITE		

TABLE 9 Experimental Catchment Section Tables, showing extent of data held

TABLE: AUTOMATIC-WEATHER-STATION
and TABLE: AWS-EVAPORATION

SITENAME	SITE NUMBER	START YEAR	FINISH YEAR
AWS CARREG WEN 1	3	1976	1981
AWS CARREG WEN	4	1976	continuing
AWS CEFN BRWYN 1	5	1975	1982
AWS CEFN BRWYN	6	1975	continuing
AWS EISTEDFFA GURIG	7	1976	continuing
AWS EISTEDFFA GURIG 2	8	1976	1982
AWS KIRKTON FOREST	10	1987	continuing
AWS KIRKTON HIGH	11	1981	continuing
AWS MONACHYLE GLEN	12	1981	continuing
AWS UPPER MONACHYLE	13	1983	continuing
AWS THETFORD FOREST 1	14	1976	1977
AWS THETFORD FOREST 2	15	1976	1977
AWS THETFORD CLEARING	16	1976	1977
AWS THETFORD FARM	17	1976	1976
AWS COALBURN	18	1977	1983
AWS TULLOCH FARM	19	1982	continuing
AWS GRENDON	20	1976	1984
AWS SYRIA 1	28	1983	1984
AWS SYRIA 2	29	1983	1984
AWS BOTSWANA	31	1981	1983
AWS INDIA	32	1981	1983
AWS GLENMORE LODGE	40	1978	continuing
AWS ROSEISLE	41	1977	1977
AWS TANLLWYTH	50	1976	continuing
AWS TANLLWYTH 2	51	1976	1982
AWS NANT IAGO	55	1978	1983
AWS MARSHLAND FEN	60	1979	1979
AWS COIRE CAS	86	1978	continuing
AWS SNEATON MOOR 1	797	1979	1983
AWS SNEATON MOOR 2	798	1977	1983

TABLE: RAINFALL-EVENT-RECORDER

SITENAME	SITE NUMBER	START YEAR	FINISH YEAR
RER KIRKTON HIGH	193	1982	1983
RER NANT-Y-MOCH C	194	1985	continuing
RER NANT-Y-MOCH E	195	1982	continuing
RER LLANBRYNMAIR C	196	1982	continuing
RER LLANBRYNMAIR E	197	1982	continuing
RER GRENDON	213	1978	1985
RER WATERSHED	254	1978	continuing
RER ESGAIR-Y-MAEN	255	1978	continuing
RER ESGAIR-Y-MAEN 2	263	1979	1980

Table 9 continued

TABLE: CATCHMENT-EVAPORATION

SITENAME		SITE NUMBER	START YEAR	FINISH YEAR
EVAPWYE		170	1978	continuing
EVAPSEV		171	1978	continuing
MWS WYE	23	684	1968	1978
MWS SEVERN	27	685	1968	1977
MWS GRENDON	2	686	1967	1984
MWS COALBURN	6	687	1967	1978
MWS CAM	5	688	1966	1983
MWS SHENLEY	9	689	1972	1984
MWS WALLINGFORD	1	725	1982	continuing

TABLE: FLOWDB

SITENAME	SITE NUMBER	START YEAR	FINISH YEAR
WLR THORSGILL	97	1978	1984
WLR EGGLESHOPE	98	1978	1984
WLR CARLBECK	99	1978	1984
WLR HUNDERBECK	100	1978	1984
WLR CEFN BRWYN	101	1968	continuing
WLR SEVERN TRAPEZOIDAL	103	1971	continuing
WLR GWY	105	1973	continuing
WLR CYFF	107	1973	continuing
WLR NANT IAGO	109	1973	continuing
WLR TANLLWYTH	111	1973	continuing
WLR HAFREN	113	1975	continuing
WLR HORE	115	1973	continuing
WLR GRENDON	116	1963	1986
WLR COALBURN	118	1967	continuing
WLR SHENLEY	719	1972	1983
WLR CAM	720	1966	1984
WLR LLANBRYNMAIR E	721	1981	continuing
WLR LLANBRYNMAIR C	722	1982	continuing
WLR KIRKTON	723	1982	continuing
WLR KIRKTON LOW FLOW	724	1982	continuing
WLR MONACHYLE	726	1982	continuing
WLR UPPER MONACHYLE	755	1983	continuing
WLR MONACHYLE LOW FLOW	756	1983	continuing
WLR NANT-Y-MOCH E	762	1984	continuing
WLR NANT-Y-MOCH C	763	1984	continuing

TABLE: AREAL-CATCHMENT-RAINFALL

SITENAME	SITE NUMBER	START YEAR	FINISH YEAR
GRERAIN	160	1964	1984
WYERAIN	250	1968	continuing
SEVRAIN	256	1969	continuing
GWYRAIN	257	1973	continuing
CYFFRAIN	258	1973	continuing
IAGORAIN	259	1973	continuing
HORERAIN	260	1973	continuing
HAFRAIN	261	1976	continuing
TANRAIN	262	1973	continuing
COARAIN	616	1967	1977
SHERAIN	717	1972	1984
CAMRAIN	718	1966	1983

TABLE: AUTOMATIC-WEATHER-STATION

Contains hourly values from Automatic Weather Stations and the columns in this table are as follows:-

Column Name	Column Type	Comment
SITENO	Number	Site number as defined in Table SITE
STIME	Date	Date/time for the averaged 1 hour period
SN	Number	Solar Radiation (w m^{-2})
RN	Number	Net Radiation (w m^{-2})
TD	Number	Temperature Depression (Degrees C)
T	Number	Temperature (Degrees C)
WS	Number	Wind speed (metres/sec)
WD	Number	Wind Direction (Degrees)
RF	Number	Rainfall (mm)
SH	Number	Specific Humidity (g/kg)
SHD	Number	Specific Humidity Deficit (g/kg)
PM-W	Number	Penman-Monteith evaporation for water (wm^{-2})
PM-G	Number	Penman-Monteith evaporation for grass (wm^{-2})
PM-F	Number	Penman-Monteith evaporation for forest (wm^{-2})

TABLE: AWS-EVAPORATION

Contains daily calculated potential evaporation, evapotranspiration and Thom-Penman evaporation using Automatic Weather Station meteorological data.

The columns in this table are as follows:-

Column Name	Column Type	Comment
SITENO	Number	Site number as defined in Table SITE
DAY	Date	Date of calculated values
EO	Number	Potential Penman evaporation from water (MJm^{-2})
ET	Number	Evapotranspiration from grass (MJm^{-2})
TH- P	Number	Thom-Penman evaporation (MJm^{-2})
DL-EO	Number	Daylight hours EO value (MJm^{-2})
DL-ET	Number	Daylight hours ET value (MJm^{-2})
DL-TH-P	Number	Daylight hours Thom-Penman (MJm^{-2})

TABLE: AREAL-CATCHMENT-RAINFALL

Contains the hourly Thiesson polygon method of distributed rainfall over a catchment area. The columns in this table are as follows:-

Column Name	Column Type	Comment
SITENO	Number	Site number as defined in Table SITE
STIME	Date	Date/time for calculated 1 hour period
ACR	Number	Averaged hourly rainfall over catchment (mm)

TABLE : FLOWDB

Contains the averaged 15 minute streamflow for a catchment area. The columns in this table are as follows:-

Column Name	Column Type	Comment
SITENO	Number	Site number as defined in Table SITE
SDAY	Date	Date of streamflow records
SQNUM	Number	The quarter hour number of SDAY (00:00 = 0 and 23.45 = 95)
FLOW	Number	The averaged 15 min flow over a catchment

TABLE: RAINFALL-EVENT-RECORDER

Contains averaged hourly rainfall from a rainfall event recorder. The columns in this table are as follows:-

Column Name	Column Type	Comment
SITENO	Number	Site number as defined in Table SITE
STIME	Date	Date/time of hourly value
RER	Number	Total hourly rainfall (mm)

TABLE: CATCHMENT EVAPORATION

Contains the daily averaged evaporation for a catchment area. Evaporation is calculated using weighted AWS evaporation values in a given catchment. Some sites in this table contain the daily evaporations calculated from meterological readings taken from a Manual Weather Station (MWS)

Column Name	Column Type	Comment
SITENO	Number	Site number as defined in Table SITE
DAY	Date	Date of daily evaporation values
EO	Number	Potential Penman evaporation (mm)
ET	Number	Penman evapotranspiration (mm)
TH-P	Number	Thom-Penman evaporation (mm)

TABLE: SITE

Contains the site number and the site details of all current and past Catchment Section sites. The columns for this table are:

SITENO	Number	Unique Catchment Section site number
GRDNS	Number	North/South grid reference
GDEW	Number	East/West grid reference
ALT	Number	Altitude of site
SITENAME	Number	Name of site
INST	Number	Instrument type
KREC	Number	Recorder type
IFREQ	Number	Input frequency
JFREQ	Number	Output frequency
CHAN	Number	Number of recording channels

4.3 ACCESSING CATCHMENT SECTION DATA

For users who may not wish to use the ORACLE RDMS directly, a program has been written to read any Catchment Section data from ORACLE. i.e.:

1. Hourly Automatic Weather Station data.
2. Hourly Rainfall Event Recorder data.
3. Hourly estimated areal catchment rainfall.
4. Quarter hour flow data.
5. Daily evaporation data calculated from hourly AWS data.
6. Daily estimated areal catchment evaporation data.

The program has four options:-

Option 1 lists the required hourly (or quarter-hourly) values, daily, monthly and yearly totals.

Option 2 lists the daily values, daily, monthly and yearly totals.

Option 3 lists monthly and yearly totals.

Option 4 lists just yearly totals.

The program and subroutine libraries are contained in a file called DATARD MODULE D and can be accessed by linking to userid AMR 192 disk on the IBM e.g.

```
LINK AMR 192 992 RR
ACCE 992 Z
```

This program also has the option of writing the retrieved data to a sequential file. This file is FORTRAN readable and can be transferred to any computer connected to the JANET network.

Further information on the use of these programs can be obtained by MAILing userid AMR on the IBM at Wallingford (ie NWL.IA)

Catchment section data can also be accessed from ORACLE by means of subroutines. The following subroutines are needed for reading data direct using a FORTRAN PROGRAM:-

a) SUBROUTINE OPNSQL. This routine logs on to ORACLE and will give a user access to any table belonging to the Catchment Section.

b) SUBROUTINE INSITE. This routine reads from table SITE all the information for a given site or instrument.

c) SUBROUTINE SQLRD. This routine reads any catchment section data and returns the data through common blocks.

d) SUBROUTINE LOGOFF. This routine logs off from ORACLE.

4.4 TRANSFER OF DATA TO REMOTE SITES

Because IH Experimental Catchments Section data are stored on the IBM 4381 at Wallingford, access is possible by logging onto ORACLE through a personal ID via the JANET network and using program DATARD (See Section 3.3. for description of this program). Alternatively it is possible to read these data direct from ORACLE and write on to a 9 track tape for transfer to another site.

The cost of such transfers of data to users other than internal IH members will be negotiated with IH management.

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APPENDIX 1

Table 1 PLYNLIMON DATA - Wye and Severn Catchments

****
Wye Catchment

Year: 1971

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	207.1	268.0	4.3
February	172.1	191.0	11.4
March	116.8	157.7	30.6
April	45.3	70.5	49.8
May	22.8	75.4	99.9
June	143.1	197.2	90.0
July	27.1	75.5	133.9
August	136.7	208.5	74.1
September	61.7	102.3	54.0
October	182.8	208.7	24.5
November	264.0	312.4	6.8
December	129.3	126.2	3.4
Total	1508.8	1993.4	582.8

Year: 1972

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	209.8	224.8	3.8
February	128.0	149.3	5.0
March	137.6	214.8	30.0
April	276.5	287.8	61.0
May	91.2	136.8	78.8
June	166.4	192.0	82.5
July	113.0	114.8	96.0
August	90.0	145.1	102.2
September	26.1	58.7	47.5
October	22.8	74.3	18.0
November	235.4	285.4	5.8
December	261.7	247.4	3.3
Total	1758.3	2131.2	533.9

Year: 1973

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	169.0	201.8	3.3
February	243.5	316.9	10.2
March	156.9	140.5	37.5
April	145.6	187.5	60.9
May	156.7	211.4	86.1
June	39.9	51.8	101.4
July	107.9	193.9	93.8
August	180.2	222.2	81.3
September	183.6	255.4	48.3
October	211.9	216.4	18.0
November	237.2	279.8	7.5
December	267.4	328.2	3.0
Total	2099.9	2606.0	551.4

Year: 1974

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	261.4	332.3	5.6
February	212.3	224.2	6.9
March	106.9	146.3	28.9
April	15.8	12.4	54.8
May	31.6	114.5	82.7
June	86.4	151.0	99.8
July	233.6	328.0	87.6
August	110.2	130.4	77.8
September	299.0	349.9	41.9
October	199.3	224.2	17.4
November	268.7	310.2	5.7
December	396.7	469.6	3.9
Total	2221.9	2793.0	513.1

Year: 1975

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	302.0	415.2	4.9
February	95.1	78.0	6.9
March	34.8	141.7	20.0
April	139.1	225.9	43.8
May	0.0 *	80.2	88.1
June	11.7	41.7	120.3
July	67.4	159.1	102.1
August	31.0	87.3	94.5
September	177.0	259.2	47.0
October	108.4	113.8	16.3
November	222.6	254.1	4.0
December	227.1	244.4	2.3
Total	1416.2	2100.6	550.1

Year: 1976

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	294.5	274.4	4.2
February	167.1	193.4	5.2
March	113.4	151.8	23.6
April	67.3	55.4	51.3
May	87.5	155.6	77.4
June	22.9	44.9	121.7
July	30.9	101.6	113.5
August	9.4	12.3	100.2
September	69.4	184.2	38.5
October	212.7	231.7	14.4
November	136.5	168.7	3.0
December	132.7	148.5	2.0
Total	1344.2	1722.4	555.0

Year: 1977

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	187.6	199.4	1.8
February	307.9	340.6	6.5
March	146.6	159.6	26.8
April	171.5	191.0	43.3
May	102.6	105.7	99.8
June	46.1	136.0	95.9
July	93.6	133.3	103.0
August	74.8	152.6	66.9
September	183.9	246.3	37.6
October	198.5	216.7	15.8
November	392.8	395.7	6.5
December	211.9	244.5	2.3
Total	2117.9	2521.5	506.3

Year: 1978

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	215.0	261.4	7.9
February	177.7	172.1	4.7
March	228.0	249.2	23.0
April	130.3	135.7	39.1
May	55.5	56.1	75.9
June	49.9	141.9	81.7
July	199.4	252.9	72.2
August	131.8	159.6	57.4
September	156.7	229.4	37.4
October	89.1	76.5	13.0
November	315.5	339.7	10.1
December	268.0	279.8	2.8
Total	2016.8	2354.2	425.1

Year: 1979

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	159.3	221.0	2.1
February	104.4	83.4	5.0
March	405.2	397.2	15.5
April	110.9	111.9	53.7
May	289.5	360.1	63.9
June	57.3	74.9	79.8
July	24.1	68.9	93.7
August	219.1	271.6	67.6
September	146.1	198.7	47.5
October	126.4	162.9	21.4
November	367.2	381.0	13.2
December	369.0	416.1	9.1
Total	2378.5	2747.7	472.5

Year: 1980

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	197.1	203.7	6.5
February	248.5	241.8	12.9
March	204.7	273.1	18.6
April	49.0	18.7	61.0
May	13.2	63.7	103.5
June	143.4	240.3	71.7
July	89.3	110.1	72.8
August	167.9	227.1	51.0
September	139.4	160.6	43.6
October	327.6	345.2	22.1
November	305.5	320.2	14.2
December	373.8	413.2	10.5
Total	2259.4	2617.7	488.5

Year: 1981

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	275.7	280.8	10.6
February	145.6	191.7	12.1
March	440.2	491.0	35.9
April	43.7	103.8	62.2
May	126.4	168.9	65.3
June	92.8	98.7	71.0
July	83.0	142.2	76.8
August	50.8	93.8	75.6
September	199.5	285.1	46.6
October	449.8	497.9	25.5
November	264.8	279.4	12.1
December	141.2	188.4	3.7
Total	2313.8	2821.7	497.5

Year: 1982

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	298.9	231.3	37.0
February	142.0	151.7	16.6
March	254.8	272.1	40.9
April	41.9	50.6	61.1
May	20.4	70.8	87.6
June	71.0	159.9	75.4
July	33.9	47.1	91.1
August	159.6	258.6	66.4
September	129.9	163.0	47.0
October	170.7	190.6	23.9
November	332.8	353.3	11.1
December	305.1	352.0	5.3
Total	1961.1	2300.8	563.5

Year: 1983

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	472.6	508.7	15.3
February	142.0	170.6	10.2
March	211.2	254.2	26.2
April	126.3	163.8	47.8
May	116.5	148.1	62.0
June	68.8	116.0	77.9
July	31.2	37.4	118.0
August	25.5	94.2	82.3
September	249.7	318.7	41.5
October	335.3	381.4	26.4
November	183.9	186.7	8.8
December	309.7	313.2	13.0
Total	2272.6	2693.0	529.6

Year: 1984

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	384.8	381.2	7.0
February	223.8	187.9	15.0
March	52.4	62.5	23.1
April	23.2	18.2	74.2
May	14.4	52.9	84.0
June	26.6	90.1	88.8
July	13.6	49.9	111.3
August	28.4	142.2	80.1
September	200.4	258.9	45.9
October	285.5	308.0	20.2
November	261.6	278.3	12.3
December	253.4	257.1	6.0
Total	1767.9	2087.1	567.8

Year: 1985

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	122.9	119.3	2.5
February	83.0	79.7	10.5
March	129.8	179.5	28.7
April	220.1	205.4	48.0
May	57.9	88.0	74.0
June	232.6	305.5	81.9
July	161.4	213.3	85.0
August	294.1	329.3	58.0
September	146.8	157.3	50.6
October	109.6	117.3	27.5
November	118.5	159.8	13.4
December	361.7	340.2	11.5
Total	2038.2	2294.7	491.6

Year: 1986

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	346.3	402.2	15.1
February	33.8	11.2	9.1
March	251.4	283.5	33.9
April	159.2	172.2	41.3
May	103.9	144.7	79.1
June	68.0	68.4	89.2
July	90.7	195.6	74.3
August	162.1	175.5	55.1
September	62.6	53.4	50.7
October	202.3	273.0	29.6
November	448.8	415.2	19.8
December	442.3	460.4	15.3
Total	2371.2	2655.3	512.4

Year: 1987

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	172.1	140.3	8.8
February	149.5	185.2	11.5
March	240.4	247.5	20.7
April	153.6	147.6	56.9
May	81.4	136.3	71.5
June	146.6	200.8	62.4
July	144.8	155.5	77.6
August	123.5	115.2	70.7
September	129.4	175.4	44.8
October	329.2	355.0	22.8
November	239.0	241.7	12.6
December	252.8	257.2	4.3
Total	2162.2	2357.8	464.5

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Severn Catchment

Year: 1971

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	0.0 *	256.3	4.3
February	0.0 *	191.0	11.4
March	0.0 *	139.0	30.6
April	0.0 *	70.7	49.8
May	0.0 *	74.5	99.9
June	0.0 *	190.7	90.0
July	0.0 *	70.1	133.9
August	0.0 *	213.2	74.1
September	0.0 *	90.7	54.0
October	149.3 *	213.1	24.5
November	207.4	306.9	6.8
December	103.8	132.0	3.4
Total	460.5	1948.2	582.8

Year: 1972

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	186.0	231.5	3.8
February	106.5	141.3	5.0
March	115.8	198.7	30.0
April	258.2	317.3	61.0
May	75.9	150.3	78.8
June	135.7	195.0	82.5
July	90.9	110.2	96.0
August	80.9	150.3	102.2
September	21.8	62.6	47.5
October	17.8	81.1	18.0
November	217.8	307.7	5.8
December	260.1	255.5	3.3
Total	1567.3	2201.5	533.9

Year: 1973

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	136.6	172.8	3.3
February	212.6	265.2	10.2
March	137.6	140.9	37.5
April	127.4	188.9	60.9
May	120.8	197.0	86.1
June	31.3	58.2	101.4
July	90.4	190.9	93.8
August	160.8	226.4	81.3
September	152.2	253.2	48.3
October	187.6	214.0	18.0
November	194.1	257.9	7.5
December	271.0	338.2	3.0
Total	1822.3	2503.8	551.4

Year: 1974

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	307.2	360.5	5.6
February	200.6	230.2	6.9
March	87.4	121.0	28.9
April	14.0	16.2	54.8
May	18.9	109.1	82.7
June	64.6	154.5	99.8
July	192.9	337.4	87.6
August	95.4	127.7	77.8
September	284.0	388.9	41.9
October	167.0	222.2	17.4
November	241.1	300.4	5.7
December	401.9	478.8	3.9
Total	2075.0	2847.0	513.1

Year: 1975

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	347.9	445.5	4.9
February	97.2	84.4	6.9
March	63.8	121.5	20.0
April	133.9	195.5	43.8
May	50.1	90.4	88.1
June	13.4	47.6	120.3
July	52.0	162.5	102.1
August	24.8	87.2	94.5
September	149.4	263.4	47.0
October	98.9	116.2	16.3
November	190.8	248.5	4.0
December	207.5	259.3	2.3
Total	1429.9	2121.9	550.1

Year: 1976

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	266.5	287.2	4.2
February	144.5	170.8	5.1
March	100.7	140.3	23.0
April	50.7	55.9	51.2
May	69.4	160.8	77.4
June	18.2	44.8	122.0
July	26.8	123.4	113.5
August	10.0	13.0	100.2
September	49.2	189.2	38.5
October	185.6	240.9	14.4
November	122.1	177.2	3.0
December	114.5	127.6	2.0
Total	1158.1	1731.1	554.7

Year: 1977

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	166.2	197.2	1.8
February	290.8	340.6	6.5
March	132.4	178.3	26.8
April	147.2	210.0	43.3
May	87.3	108.4	99.8
June	31.4	133.9	95.9
July	64.7	126.6	103.0
August	116.5	223.9	66.9
September	167.0	264.9	37.6
October	186.8	246.8	15.8
November	379.1	430.8	6.5
December	186.1	258.3	2.3
Total	1955.5	2719.7	506.2

Year: 1978

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	208.8	264.5	6.3
February	188.3	189.2	5.5
March	240.0	282.3	19.5
April	119.9	141.7	30.6
May	63.2	68.1	75.9
June	39.5	148.5	80.0
July	169.0	262.4	77.0
August	113.7	149.5	61.9
September	121.4	236.8	40.9
October	73.1	78.0	20.3
November	330.3	379.1	10.5
December	264.5	279.1	3.0
Total	1931.7	2479.2	431.6

Year: 1979

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	143.7	219.4	1.8
February	82.7	83.3	4.9
March	421.3	395.7	16.2
April	108.0	120.2	52.5
May	250.8	342.9	73.2
June	44.3	67.5	81.3
July	18.6	68.3	97.3
August	173.1	277.2	72.5
September	119.3	197.1	49.2
October	115.2	171.1	20.7
November	358.7	410.1	12.5
December	384.2	444.2	9.2
Total	2219.9	2797.1	491.2

Year: 1980

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	185.6	203.7	6.1
February	262.5	263.5	13.0
March	175.7	215.1	22.0
April	55.1	21.4	56.0
May	14.6	63.5	107.1
June	106.7	240.6	76.7
July	71.5	104.6	81.4
August	148.3	236.4	57.9
September	118.7	162.5	47.3
October	276.0	346.0	23.4
November	314.9	347.0	12.4
December	351.0	431.4	8.0
Total	2080.6	2635.9	511.1

Year: 1981

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	250.4	260.3	10.2
February	146.6	165.2	12.0
March	481.6	520.0	30.0
April	40.6	63.3	53.8
May	114.7	166.4	64.2
June	80.4	97.5	77.3
July	60.9	145.3	83.1
August	36.7	91.1	80.5
September	167.8	278.8	46.5
October	454.9	498.9	22.9
November	254.6	287.7	9.9
December	126.2	188.7	2.1
Total	2215.4	2763.1	492.6

Year: 1982

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	289.0	231.3	46.6
February	135.0	151.9	14.4
March	274.2	288.2	43.3
April	41.8	55.5	71.3
May	26.3	75.1	89.3
June	71.1	172.1	76.6
July	33.6	47.1	91.1
August	142.1	272.0	70.5
September	123.3	169.5	45.4
October	148.1	174.8	20.7
November	334.4	386.3	9.1
December	295.5	314.2	4.0
Total	1914.5	2338.2	582.3

Year: 1983

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	478.8	531.1	9.9
February	130.6	133.7	7.7
March	187.6	228.6	24.5
April	106.5	138.9	47.2
May	103.7	142.1	57.7
June	59.3	105.1	74.2
July	29.2	44.1	119.1
August	17.6	79.9	84.8
September	234.2	343.8	37.6
October	312.0	381.4	23.7
November	166.8	205.6	6.6
December	275.1	315.4	7.4
Total	2101.4	2649.6	500.4

Year: 1984

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	329.5	378.4	3.1
February	215.9	187.9	11.9
March	52.7	62.5	23.1
April	24.3	18.4	68.6
May	14.3	57.2	81.4
June	19.6	92.0	91.7
July	13.4	43.4	118.5
August	22.9	144.9	85.0
September	153.6	269.7	42.7
October	264.7	315.6	22.2
November	272.6	292.9	11.2
December	218.6	272.2	3.7
Total	1601.9	2135.3	563.1

Year: 1985

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	109.7	119.3	2.9
February	96.5	79.7	10.9
March	123.1	179.5	22.3
April	209.6	212.7	44.5
May	48.3	92.4	70.1
June	188.7	292.0	83.1
July	141.7	214.4	89.4
August	287.8	359.0	52.1
September	132.8	163.5	49.5
October	107.4	120.6	24.6
November	122.3	177.7	7.1
December	329.1	343.8	4.2
Total	1896.9	2354.7	460.9

Year: 1986

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	342.1	403.7	3.7
February	52.9	11.2	1.5
March	231.9	283.5	26.5
April	148.2	171.3	36.1
May	97.9	161.0	78.5
June	60.6	60.0	90.8
July	61.6	188.4	78.1
August	151.7	181.0	56.9
September	53.2	46.9	50.1
October	166.8	277.4	27.7
November	429.9	456.9	13.8
December	397.5	479.1	6.1
Total	2194.3	2720.5	469.7

Year: 1987

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	162.9	140.0	4.4
February	148.4	185.2	11.0
March	221.4	247.5	18.5
April	142.5	145.9	55.7
May	58.9	125.2	81.2
June	125.9	206.6	69.3
July	87.7	147.0	75.1
August	81.7	110.3	74.3
September	108.4	174.6	42.9
October	325.7	373.5	19.8
November	200.7	221.0	6.7
December	245.4	277.8	2.1
Total	1909.7	2354.6	461.2

NB Missing data is denoted by a *

Table 2 BALQUHIDDER DATA - Monachyle and Kirkton Catchments

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Monachyle Catchment

Year: 1984

	Flow(mm)
January	204.7
February	215.9
March	126.5
April	156.9
May	16.2
June	17.2
July	12.7
August	7.3
September	149.0
October	328.0
November	404.0
December	290.8
Total	1929.2

Year: 1985

	Flow(mm)
January	74.1
February	110.4
March	82.5
April	135.5
May	82.5
June	27.0
July	181.1
August	343.9
September	231.8
October	230.9
November	135.7
December	420.5
Total	2055.8

Year: 1986

	Flow(mm)
January	279.0
February	18.6
March	374.4
April	86.1
May	389.2
June	49.6
July	37.8
August	137.6
September	25.7
October	243.1
November	450.8
December	430.6
Total	2522.7

Year: 1987

	Flow(mm)
January	138.4
February	124.8
March	178.2
April	87.0
May	27.2
June	87.3
July	62.5
August	90.4
September	263.6
October	256.4
November	172.6
December	236.4
Total	1724.6

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Kirkton Catchment

Year: 1983

	Flow(mm)
January	337.7
February	63.5
March	191.3
April	71.8
May	96.5
June	60.1
July	19.5
August	12.0
September	143.7
October	354.1
November	83.7
December	291.5
Total	1725.4

Year: 1984

	Flow(mm)
January	191.2
February	161.5
March	149.4
April	171.6
May	34.6
June	24.6
July	18.5
August	15.4
September	100.2
October	271.2
November	378.5
December	264.2
Total	1780.8

Year: 1985

	Flow(mm)
January	69.8
February	118.3
March	83.8
April	154.4
May	84.9
June	48.8
July	175.8
August	300.0
September	211.2
October	249.9
November	105.5
December	357.5
Total	1959.8

Year: 1986

	Flow(mm)
January	216.9
February	37.0
March	300.4
April	100.1
May	331.3
June	76.2
July	50.5
August	139.1
September	26.4
October	163.9
November	389.1
December	411.4
Total	2242.2

Year: 1987

	Flow(mm)
January	143.9
February	116.6
March	160.8
April	105.7
May	42.3
June	98.8
July	61.1
August	95.2
September	215.4
October	220.2
November	143.6
December	188.3
Total	1591.9

NB Missing data is denoted by a *

Table 3 LLANBRYNMAIR DATA - Delyn (Control) Catchment and Cwm (Experimental) Catchment

****

Delyn Control Catchment

Year: 1982

	Flow(mm)
January	0.0 *
February	0.0 *
March	0.0 *
April	0.0 *
May	0.0 *
June	0.0 *
July	0.0 *
August	0.0 *
September	0.0 *
October	58.2 *
November	252.2
December	284.7
Total	595.0

Year: 1983

	Flow(mm)
January	380.8
February	0.0 *
March	0.0 *
April	43.3 *
May	102.7
June	50.7
July	11.2
August	6.5
September	189.3
October	276.4
November	97.5
December	268.2
Total	1426.5

Year: 1984

	Flow(mm)
January	277.0
February	168.3
March	14.8 *
April	19.5
May	6.8
June	9.3
July	4.0
August	8.1
September	108.9
October	228.0
November	231.2
December	166.8 *
Total	1242.7

Year: 1985

	Flow(mm)	
January	85.9	
February	87.4	
March	78.9	
April	162.9	
May	26.1	
June	114.1	
July	48.1	*
August	180.8	*
September	16.2	*
October	105.3	
November	99.0	
December	290.3	
Total	1294.9	

Year: 1986

	Flow(mm)
January	248.0
February	32.7
March	154.6
April	113.4
May	72.5
June	35.1
July	24.5
August	100.0
September	29.9
October	121.2
November	313.5
December	305.0
Total	1550.4

Year: 1987

	Flow(mm)	
January	137.9	
February	127.7	
March	162.6	
April	96.9	
May	22.9	
June	95.5	
July	83.2	
August	51.0	
September	110.1	
October	258.7	
November	188.3	
December	93.5	*
Total	1428.3	

****

Cwm Experimental Catchment

Year: 1982

	Flow(mm)
January	0.0 *
February	0.0 *
March	0.0 *
April	0.0 *
May	0.0 *
June	0.0 *
July	14.7 *
August	192.9
September	128.7
October	113.7
November	265.5
December	282.7
Total	998.2

Year: 1983

	Flow(mm)
January	375.8
February	94.5
March	150.5
April	93.8
May	96.2
June	22.7 *
July	14.1
August	6.0 *
September	104.2 *
October	267.9 *
November	99.6 *
December	264.8
Total	1590.0

Year: 1984

	Flow(mm)
January	269.2
February	147.0
March	45.7
April	12.8
May	6.5
June	13.7
July	3.1
August	37.9
September	155.7
October	227.1
November	194.1
December	150.7
Total	1263.5

Year: 1985

	Flow(mm)
January	88.3
February	65.7
March	104.6
April	102.9
May	31.4
June	107.0
July	122.8
August	219.7
September	126.4
October	99.2
November	86.5
December	173.4 *
Total	1327.8

Year: 1986

	Flow(mm)
January	217.9
February	32.9
March	177.8
April	99.5
May	113.4
June	31.9
July	46.7
August	123.4
September	25.3
October	11.5 *
November	269.7 *
December	272.3
Total	1422.4

Year: 1987

	Flow(mm)
January	119.9
February	156.2
March	164.3
April	100.3
May	30.7
June	110.2
July	81.3 *
August	28.8 *
September	124.6
October	239.1
November	169.5
December	111.8 *
Total	1436.8

NB Missing data is denoted by a *

Table 4. NANT-Y-MOCH DATA - Maesnant (Control) and Maesnant Fach (Experimental) catchments

****

Maesnant Control Catchment

Year: 1984

	Flow(mm)
January	0.0 *
February	0.0 *
March	0.0 *
April	0.0 *
May	0.0 *
June	0.0 *
July	0.0 *
August	0.0 *
September	45.8 *
October	26.6 *
November	13.8 *
December	210.9
Total	297.1

Year: 1985

	Flow(mm)
January	110.3
February	83.5
March	105.1
April	192.1
May	57.4
June	217.4
July	169.0
August	289.2
September	151.8
October	107.4
November	113.0
December	169.9 *
Total	1766.0

Year: 1986

	Flow(mm)
January	285.9
February	30.5
March	198.8
April	136.8
May	93.7
June	62.0
July	109.6
August	163.0
September	66.5 *
October	150.7 *
November	296.5 *
December	188.4 *
Total	1782.4

Year: 1987

	Flow(mm)
January	153.3
February	130.6
March	213.6
April	150.0
May	79.5
June	142.4
July	125.2
August	117.7
September	118.3
October	289.4
November	201.5
December	238.7
Total	1960.2

****

Maesnant Fach Experimental Catchment

Year: 1984

	Flow(mm)	
January	0.0	*
February	0.0	*
March	0.0	*
April	0.0	*
May	3.3	*
June	15.0	
July	9.4	
August	25.0	
September	153.5	
October	239.1	
November	242.3	
December	189.8	
Total	877.4	

Year: 1985

	Flow(mm)	
January	90.9	
February	67.6	
March	81.8	
April	158.9	
May	44.2	
June	182.0	
July	82.2	*
August	74.8	*
September	117.1	
October	84.2	
November	~~86.4~~	
December	237.6	
Total	1307.6	

Year: 1986

	Flow(mm)
January	240.4
February	21.8
March	165.4
April	106.7
May	60.9
June	39.2
July	92.1
August	119.0
September	57.6
October	130.4
November	315.7
December	161.3 *
Total	1510.6

Year: 1987

	Flow(mm)
January	50.9 *
February	103.4
March	184.1
April	124.0
May	59.5
June	73.0 *
July	99.5 *
August	86.2
September	91.1
October	219.1
November	66.1
December	72.6
Total	1229.5

NB Missing data is denoted by a *

Table 5 COALBURN CATCHMENT DATA

****

Year: 1967

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	61.6 *	70.0 *	2.7
February	108.2	137.6	8.7
March	65.9	81.9	25.9
April	25.6	46.9	56.2
May	76.3	139.2	71.4
June	18.8	84.4	109.8
July	55.4	123.6	88.5
August	109.9	171.2	73.4
September	54.9	104.0	45.7
October	269.5	324.8	20.1
November	78.4	105.7	3.4
December	73.7	90.3	2.4
Total	998.2	1479.6	508.3

Year: 1968

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	106.4	128.2	3.6
February	21.0	36.2	9.6
March	176.0	226.2	30.8
April	51.8	81.7	52.0
May	42.7	84.0	78.7
June	19.6	90.0	110.9
July	42.8	84.5	81.2
August	46.6	115.8	81.0
September	112.1	182.5	42.1
October	92.5	128.0	15.9
November	52.7	63.1	7.0
December	57.8	83.5	2.3
Total	821.9	1303.9	514.9

Year: 1969

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	125.8	117.2	2.5
February	54.4	56.3	9.6
March	71.0	53.7	20.1
April	53.1	84.8	48.3
May	65.8	111.6	64.2
June	31.5	73.1	112.1
July	9.7	72.8	78.6
August	54.3	130.8	79.6
September	46.1	106.1	42.3
October	19.4	53.6	22.0
November	123.5	154.5	5.6
December	68.9	69.9	1.8
Total	723.5	1084.2	486.9

Year: 1970

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	90.7	101.5	2.7
February	88.4	123.5	5.8
March	53.9	73.4	24.4
April	96.0	113.1	44.3
May	15.1	49.4	78.7
June	1.8	46.7	111.0
July	54.6	133.5	69.8
August	42.8	93.0	77.4
September	94.5	138.7	39.4
October	153.3	190.4	20.2
November	152.4	152.5	5.0
December	70.6	81.6	1.2
Total	914.0	1297.2	479.9

Year: 1971

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	80.6	67.4	5.8
February	72.5	81.7	8.3
March	69.0	79.3	24.4
April	13.1	39.2	49.4
May	8.7	52.4	73.1
June	17.3	59.4	80.0
July	19.7	83.5	92.0
August	123.0	182.1	51.8
September	14.3	40.5	36.5
October	71.9	108.6	13.7
November	109.8	128.8	3.7
December	54.9	67.3	5.1
Total	654.8	990.2	443.9

Year: 1972

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	96.0	93.5	2.5
February	74.4	67.8	7.0
March	57.6	72.6	22.6
April	91.3	118.1	45.8
May	57.8	106.7	73.0
June	82.8	117.4	72.1
July	30.2	57.2	85.2
August	41.7	61.0	65.9
September	12.3	32.0	39.0
October	4.7 *	22.5	16.1
November	0.0 *	139.4	2.3
December	0.0 *	96.4	4.2
Total	548.8	984.4	435.8

Year: 1973

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	0.0 *	85.0	9.7
February	0.0 *	41.3	8.7
March	0.0 *	71.7	23.2
April	0.0 *	92.6	49.6
May	0.0 *	97.5	73.5
June	0.0 *	46.1	83.2
July	18.2 *	85.9	82.2
August	52.0	119.7	83.5
September	16.0	44.4	40.3
October	52.3	71.7	17.9
November	46.0	65.3	4.2
December	123.0	120.2	3.8
Total	307.5	941.4	479.9

Year: 1974

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	105.9	116.0	6.0
February	87.5	85.6	4.0
March	73.0	82.9	23.6
April	8.8	22.0	54.3
May	6.2	34.0	88.8
June	16.8	68.5	114.8
July	51.8	137.0	94.7
August	35.4	83.7	72.6
September	115.6	151.6	38.5
October	59.7	73.5	14.9
November	168.2	184.9	7.0
December	127.7	248.6	9.4
Total	856.7	1288.2	528.7

Year: 1975

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	174.5	183.6	10.5
February	66.1	49.4	2.2
March	40.4	53.9	29.7
April	54.1	75.5	47.9
May	49.4	69.5	84.8
June	7.6	31.1	127.7
July	49.3	125.3	91.0
August	98.1	171.9	89.3
September	109.6	161.1	51.9
October	64.0	67.7	21.3
November	45.4	65.8	4.7
December	35.3	48.6	6.1
Total	793.6	1103.3	567.1

Year: 1976

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	148.4	0.0 *	8.6
February	74.8	0.0 *	8.2
March	110.8	0.0 *	29.1
April	48.4	0.0 *	56.2
May	76.3	0.0 *	76.9
June	34.1	0.0 *	113.9
July	6.4	0.0 *	117.9
August	1.9	0.0 *	80.1
September	31.6	0.0 *	34.2
October	152.2	0.0 *	15.0
November	67.2	0.0 *	3.0
December	65.7	0.0 *	1.4
Total	817.9	0.0	544.4

Year: 1977

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	126.0	102.4	2.2
February	127.6	97.7	4.4
March	52.6	83.4	27.5
April	103.0	138.9	44.5
May	67.2	71.3	87.3
June	44.9	108.2	108.7
July	6.9	54.2	93.3
August	19.6	90.2	74.9
September	71.6	119.4	37.5
October	72.7	105.7	12.9
November	140.7	151.7	2.9
December	131.6	140.4	2.1
Total	964.5	1263.5	498.1

Year: 1978

	Flow(mm)
January	118.0
February	113.7
March	129.1
April	33.4
May	37.1
June	16.9
July	18.3
August	75.3
September	141.0
October	39.5
November	169.3
December	141.1
Total	1032.7

Year: 1979

	Flow(mm)
January	89.8
February	91.5
March	212.3
April	46.4
May	60.0
June	22.7
July	9.3
August	83.4
September	102.5
October	88.4
November	212.2
December	209.9
Total	1228.3

Year: 1980

	Flow(mm)
January	81.9
February	108.3
March	101.5
April	15.4
May	6.8
June	120.1
July	46.9
August	92.4
September	109.5
October	137.7
November	187.1
December	186.6
Total	1194.1

Year: 1981

	Flow(mm)
January	143.2
February	70.2
March	209.4
April	53.3
May	55.3
June	141.0
July	47.7
August	12.4 *
September	107.2
October	24.1
November	184.7
December	40.9
Total	1089.4

Year: 1982

	Flow(mm)
January	265.7 *
February	99.2
March	117.5
April	22.1
May	34.5
June	53.6
July	29.0
August	78.9
September	44.7
October	131.0
November	182.6
December	216.6
Total	1275.3

Year: 1983

	Flow(mm)
January	203.1
February	94.7
March	138.7
April	104.1
May	80.5
June	48.8
July	24.8
August	4.2
September	53.5
October	202.8
November	75.3
December	210.2
Total	1240.6

Year: 1984

	Flow(mm)
January	138.0
February	150.0
March	75.8
April	21.2
May	1.8
June	49.7
July	2.6
August	11.7
September	58.6
October	137.4
November	95.4
December	0.1
Total	742.4

Year: 1985

	Flow(mm)	
January	82.3	
February	55.0	
March	110.4	
April	94.7	*
May	45.3	
June	52.1	
July	163.0	
August	187.8	
September	87.1	
October	31.0	*
November	107.0	
December	101.6	
Total	1117.2	

Year: 1986

	Flow(mm)	
January	95.3	*
February	43.2	
March	52.6	
April	156.8	
May	188.8	
June	91.0	
July	4.3	*
August	0.0	*
September	0.0	*
October	0.0	*
November	0.0	*
December	0.0	*
Total	632.1	

NB Missing data is denoted by a *

Table 6 THE RIVER RAY AT GRENDON UNDERWOOD CATCHMENT DATA .

****

Year: 1964

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	9.7	15.9	3.9
February	8.9	20.3	9.9
March	62.4	86.3	21.3
April	18.8	58.4	61.0
May	2.2	42.2	110.9
June	3.4	74.4	104.3
July	10.9	91.6	120.2
August	0.0	18.3	94.4
September	0.0	18.5	63.0
October	0.0	20.7	19.8
November	0.0	21.8	7.2
December	0.1	42.0	5.6
Total	116.6	510.4	621.5

Year: 1965

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	6.1	56.2	5.9
February	1.0	11.2	13.2
March	16.1	48.3	35.1
April	3.9	50.5	55.3
May	4.7	55.7	95.0
June	0.7	63.9	116.7
July	9.0	105.4	100.0
August	1.5	54.5	91.3
September	11.7	82.9	50.9
October	3.5	10.4	24.7
November	14.5	55.2	7.0
December	73.5	99.6	3.4
Total	146.0	693.9	598.6

Year: 1966

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	28.7	33.1	5.1
February	59.8	77.9	16.2
March	4.6	15.2	35.6
April	45.6	84.4	51.6
May	22.1	66.2	107.1
June	0.9	65.7	123.2
July	0.2	64.6	107.6
August	6.9	102.0	91.3
September	1.0	44.2	55.4
October	64.1	119.6	20.2
November	14.9	41.4	8.1
December	53.3	76.2	3.8
Total	301.9	790.5	625.2

Year: 1967

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	25.1	31.5	4.2
February	33.8	60.6	13.6
March	19.1	30.0	43.4
April	5.6	43.7	56.9
May	22.4	104.7	90.5
June	1.2	32.5	116.1
July	1.8	88.0	125.2
August	0.2	33.2	89.9
September	0.1	55.2	44.4
October	17.3	116.1	25.0
November	20.8	33.5	3.9
December	33.1	58.0	3.3
Total	180.4	686.9	616.4

Year: 1968

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	49.2	56.4	5.3
February	9.4	16.8	7.5
March	1.9	25.7	42.0
April	3.2	50.8	63.7
May	14.6	64.1	82.3
June	1.1	65.4	104.7
July	44.6	121.7	94.6
August	3.0	72.1	65.3
September	31.8	114.8	50.7
October	22.9	54.0	23.9
November	35.3	57.5	7.0
December	44.8	64.1	2.3
Total	261.8	763.3	549.4

Year: 1969

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	64.1	70.8	4.4
February	32.0	36.8	7.1
March	33.1	48.6	22.2
April	4.3	33.3	64.3
May	25.0	104.6	91.6
June	4.1	24.8	144.3
July	0.2	43.8	129.4
August	2.2	69.7	81.4
September	0.0	12.0	47.2
October	0.0	3.5	25.3
November	0.3	52.2	10.5
December	7.8	60.7	3.4
Total	173.1	560.6	631.2

Year: 1970

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	28.0	61.1	4.2
February	34.9	51.7	9.2
March	28.1	42.7	31.4
April	40.3	81.5	52.4
May	1.7	19.3	106.0
June	0.0	32.7	135.7
July	0.0	50.9	108.3
August	0.3	66.8	84.9
September	0.0	31.8	54.0
October	0.0	19.6	25.8
November	16.3	142.7	8.9
December	19.6	37.4	5.7
Total	169.3	638.1	626.7

Year: 1971

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	61.4	95.9	4.1
February	22.9	16.9	9.8
March	21.0	42.9	30.9
April	8.6	41.1	54.4
May	0.4	28.7	102.3
June	9.0	97.8	91.1
July	0.3	43.4	127.7
August	3.3	98.1	79.9
September	0.0	16.9	52.9
October	8.4	75.5	21.5
November	30.5	76.2	6.5
December	10.9	22.8	5.6
Total	176.8	656.2	586.6

Year: 1972

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	26.7	62.8	6.2
February	34.8	46.5	6.7
March	24.3	51.5	36.4
April	8.5	45.8	60.1
May	4.5	53.0	92.5
June	0.3	36.4	99.1
July	0.2	62.9	100.9
August	1.3	33.8	78.5
September	0.1	31.4	45.1
October	0.0	19.3	22.8
November	2.2	63.6	6.5
December	27.5	69.4	6.3
Total	130.5	576.5	561.1

Year: 1973

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	8.2	23.3	4.4
February	6.0	18.4	11.1
March	2.3	14.0	35.3
April	1.3	43.6	61.8
May	3.5	51.8	97.2
June	1.5	70.7	122.7
July	3.9	73.1	100.3
August	0.2	35.0	108.3
September	0.0	33.2	51.3
October	0.0	24.7	20.5
November	0.0	36.5	9.6
December	2.7	40.5	6.1
Total	29.5	464.7	628.5

Year: 1974

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	29.4	64.3	6.5
February	41.6	72.7	13.2
March	22.1	44.0	26.6
April	0.4	7.0	57.4
May	0.2	31.5	104.1
June	1.2	89.8	112.3
July	0.4	42.9	100.1
August	0.6	92.0	76.7
September	17.8	118.8	45.1
October	39.2	76.3	17.8
November	79.7	114.7	13.1
December	13.5	30.6	9.4
Total	246.1	784.5	582.6

Year: 1975

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	43.7	68.1	9.3
February	23.7	30.2	10.8
March	57.9	87.5	24.7
April	21.2	46.0	56.8
May	4.0	40.1	88.5
June	0.0	10.2	138.5
July	0.5	58.2	131.0
August	0.0	25.7	108.7
September	0.2	78.5	53.9
October	0.0	10.8	21.5
November	0.1	39.3	6.2
December	0.4	23.3	3.4
Total	151.8	517.9	653.4

Year: 1976

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	0.7	18.3	7.4
February	0.8	20.2	10.9
March	0.2	16.2	36.3
April	0.0	9.0	65.9
May	0.0	28.1	105.4
June	0.0	16.0	141.7
July	0.0	17.8	134.9
August	0.0	16.3	96.9
September	0.3	100.7	45.5
October	2.6	92.3	25.1
November	5.7	55.5	5.0
December	48.4	87.2	3.2
Total	58.6	477.7	678.2

Year: 1977

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	71.3	74.5	3.8
February	87.5	108.0	13.0
March	26.2	59.4	35.8
April	4.1	37.4	59.8
May	9.0	35.6	107.7
June	8.3	99.6	81.0
July	0.1	4.9	109.4
August	3.9	130.2	62.0
September	1.8	20.0	49.8
October	0.1	32.7	23.2
November	2.9	42.7	9.8
December	30.7	63.8	3.1
Total	246.1	708.9	558.5

Year: 1978

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	40.2	63.3	6.0
February	29.4	42.2	10.6
March	28.2	60.4	34.7
April	8.8	42.9	46.4
May	34.8	49.7	75.0
June	0.0	38.9	94.7
July	0.1	64.9	88.5
August	0.6	32.0	78.9
September	0.0	30.3	53.0
October	0.0	2.0	24.7
November	0.0	23.9	15.1
December	9.1	93.1	5.9
Total	151.1	543.5	533.4

Year: 1979

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	24.5	51.7	4.7
February	42.8	41.5	8.9
March	67.0	110.9	27.8
April	18.6	45.2	52.8
May	29.0	104.3	73.6
June	8.7	48.2	83.4
July	0.0	22.7	96.0
August	0.3	70.3	68.7
September	0.0	17.3	50.2
October	0.3	55.0	20.0
November	1.6	36.9	7.8
December	56.5	142.3	9.0
Total	249.2	746.2	502.8

Year: 1980

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	13.6	27.5	6.1
February	20.4	39.6	14.6
March	26.6	63.3	31.2
April	11.3	14.8	60.9
May	0.6	55.3	97.9
June	2.9	87.8	99.5
July	3.3	72.2	91.0
August	13.9 *	78.6	74.6
September	2.2	47.7	48.4
October	12.9	71.1	23.3
November	21.5	46.2	14.9
December	18.3	32.3	12.9
Total	147.4	636.3	575.3

Year: 1981

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	23.0 *	37.1	8.7
February	3.5 *	21.6	15.2
March	45.3 *	100.8	35.4
April	21.0 *	57.6	52.4
May	25.1 *	88.8	71.2
June	4.3 *	28.4	99.1
July	0.0 *	31.1	97.8
August	0.4 *	38.5	73.7
September	1.4 *	87.8	49.4
October	12.2 *	79.4	23.2
November	8.2 *	31.3	11.8
December	38.3 *	50.6 *	3.8
Total	182.7	653.1	541.8

Year: 1982

	Flow(mm)	Penman ET(mm)
January	28.8*	8.3
February	14.5*	13.8
March	67.2	42.1
April	2.2*	58.7
May	0.0*	95.8
June	0.7*	91.1
July	0.2*	98.2
August	0.0*	81.4
September	0.2*	46.2
October	8.3	22.9
November	31.1*	15.4
December	38.0	8.2
Total	191.3	582.2

Year: 1983

	Flow(mm)	Penman ET(mm)
January	19.1	14.9
February	15.1	14.8
March	12.6	34.3
April	40.1	50.2
May	32.3	73.5
June	9.6	97.0
July	0.4	119.4
August	0.3	83.4
September	0.4	50.8
October	0.9	27.9
November	1.8	12.1
December	9.2	7.9
Total	141.7	586.2

Year: 1984

	Flow(mm)	Penman ET(mm)
January	31.5	9.5
February	20.6	13.9
March	16.7	36.0
April	2.4	71.8
May	1.3	83.6
June	1.9	113.7
July	0.1	123.8
August	0.1	98.4
September	0.4	56.4
October	1.9	30.0
November	24.4	14.7
December	20.6	3.4
Total	121.9	655.0

Year: 1985

	Flow(mm)
January	34.2
February	21.2
March	11.3
April	4.1
May	13.7
June	18.8
July	0.6
August	1.8
September	0.1 *
October	0.0 *
November	0.0 *
December	0.0 *
Total	105.7

NB Missing data is denoted by a *

Table 7 THE RIVER CAM CATCHMENT DATA

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Year: 1966

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	17.7 *	26.0 *	7.8
February	25.8	67.0	13.2
March	16.1	8.6	39.8
April	19.9	55.2	59.2
May	13.5	47.0	96.4
June	9.8	63.8	121.0
July	8.7	76.3	92.5
August	8.3	71.9	89.9
September	7.6	22.8	61.5
October	9.8	81.7	24.1
November	10.5	37.5	6.3
December	20.6	76.7	3.7
Total	168.3	634.5	615.5

Year: 1967

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	18.3	27.1	1.4
February	17.2	43.8	7.9
March	16.5	19.8	40.7
April	15.3	58.2	59.4
May	16.8	92.1	86.5
June	10.9	32.4	112.5
July	8.7	52.6	131.0
August	6.8	44.2	96.1
September	6.7	47.3	43.8
October	8.2	95.6	24.2
November	15.4	48.6	4.4
December	18.1	54.2	2.1
Total	158.9	616.1	610.0

Year: 1968

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	22.9	40.5	4.2
February	17.5	22.5	7.5
March	13.8	24.3	39.3
April	11.7	42.6	65.0
May	11.3	33.1	87.6
June	9.3	88.7	110.4
July	10.9	107.7	99.2
August	19.6	102.0	63.1
September	26.0	119.7	47.7
October	21.1	38.7	23.0
November	17.1	28.7	6.1
December	23.5	49.0	1.3
Total	204.8	697.6	554.6

Year: 1969

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	30.9	63.5	3.3
February	23.6	40.6	4.8
March	31.7	42.7	17.9
April	19.8	30.8	59.1
May	19.9	75.4	76.7
June	13.8	41.5	117.5
July	11.2	62.1	110.0
August	12.2	76.3	77.0
September	9.0	4.9	46.4
October	8.3	5.4	21.9
November	8.8	67.9	5.7
December	16.0	60.8	2.5
Total	205.4	571.9	542.7

Year: 1970

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	183.1	64.6	1.3
February	200.7	56.3	7.4
March	222.3	43.6	29.7
April	209.7	78.8	52.3
May	143.0	10.4	108.0
June	94.6	25.4	128.7
July	77.8	39.8	97.0
August	74.2	52.1	87.2
September	66.9	55.3	60.5
October	65.9	17.6	24.6
November	132.1	142.5	9.3
December	168.9	45.0	2.0
Total	1639.3	631.6	608.1

Year: 1971

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	32.3	75.6	2.2
February	22.4	13.0	7.5
March	23.4	40.4	32.8
April	17.3	29.5	56.4
May	15.8	48.6	101.7
June	16.3	78.1	92.3
July	10.8	48.4	119.6
August	10.3	68.1	74.2
September	7.7	20.4	52.4
October	10.6	72.5	17.9
November	13.2	65.5	4.5
December	9.8	17.9	5.4
Total	190.0	578.0	567.0

Year: 1972

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	20.7	56.7	7.7
February	21.3	47.3	8.7
March	20.2	39.6	33.5
April	15.2	47.3	66.2
May	11.9	33.1	102.1
June	8.9	23.3	106.4
July	6.7	42.9	96.2
August	6.2	34.0	78.0
September	5.2	29.2	44.1
October	4.9	3.0	24.4
November	5.4	50.1	10.1
December	9.1	62.4	7.5
Total	135.7	468.9	585.1

Year: 1973

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	6.1	13.7	5.8
February	4.8	14.2	16.1
March	8.3	9.2	38.9
April	6.0	44.7	61.9
May	6.4	61.0	97.1
June	4.9	63.3	113.2
July	6.0	69.2	94.5
August	4.4	25.9	80.9
September	4.4	71.7	51.2
October	4.9	20.9	16.2
November	5.0	26.5	6.4
December	4.8	30.0	2.5
Total	66.1	450.4	584.8

Year: 1974

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	9.6	57.4	4.4
February	13.1	45.3	8.9
March	10.8	28.1	27.5
April	8.7	11.8	55.9
May	7.6	24.4	91.2
June	6.2	60.1	95.2
July	5.0	29.7	92.7
August	4.9	87.7	77.4
September	8.2	100.1	44.8
October	22.8	105.5	19.3
November	37.3	99.5	6.2
December	21.1	22.4	9.8
Total	155.2	671.9	533.4

Year: 1975

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	28.7	72.2	8.8
February	19.6	20.5	10.4
March	34.1	82.2	18.7
April	30.5	66.6	58.5
May	25.8	60.0	88.8
June	14.8	26.0	130.5
July	10.3	30.9	111.6
August	7.4	9.1	101.4
September	7.9	95.1	50.1
October	8.1	11.5	15.9
November	8.2	46.6	4.7
December	8.6	28.5	4.8
Total	204.1	549.1	604.1

Year: 1976

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	8.8	23.0	8.5
February	8.2	18.0	11.3
March	7.7	14.2	35.0
April	5.9	20.8	59.2
May	5.8	21.3	94.7
June	3.6	9.6	129.9
July	3.5	24.1	122.3
August	3.1	24.7	85.0
September	3.3	76.4	40.1
October	4.9	95.2	19.1
November	7.9	79.9	5.2
December	20.3	60.5	3.1
Total	83.0	467.6	613.5

Year: 1977

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	28.6	62.1	6.1
February	28.2	65.8	11.8
March	22.8	51.1	31.5
April	15.9	29.8	57.8
May	13.9	31.3	96.7
June	10.7	53.6	83.0
July	7.0	5.4	104.0
August	6.7	90.6	62.0
September	8.7	17.1	47.8
October	6.0	28.2	20.8
November	6.3	56.6	10.6
December	8.7	53.8	4.8
Total	163.5	545.4	537.1

Year: 1978

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	21.0	81.3	8.0
February	22.8	48.3	14.7
March	23.1	56.7	35.4
April	17.5	42.5	52.4
May	29.1	67.9	87.1
June	13.9	47.2	99.5
July	10.7	51.0	83.9
August	9.9	68.9	73.1
September	8.4	27.8	49.5
October	11.0	5.5	20.4
November	8.8	17.3	8.1
December	17.3	112.1	5.2
Total	193.5	626.5	537.2

Year: 1979

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	18.1	65.1	7.5
February	33.3	50.6	14.2
March	34.2	93.7	33.0
April	31.2	63.3	55.3
May	26.0	89.6	89.5
June	18.1	16.0	95.5
July	12.8	15.7	104.4
August	9.4	57.6	72.5
September	10.8	14.2	51.2
October	11.7	60.5	21.6
November	13.5	50.0	7.8
December	20.7	99.2	7.0
Total	239.7	675.3	559.5

Year: 1980

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	19.1	54.6	7.2
February	22.7	36.4	15.2
March	24.7	66.8	34.3
April	18.0	23.4	61.9
May	12.6	14.0	108.6
June	8.7	61.8	98.0
July	9.3	72.8	81.0
August	7.0	37.0	76.6
September	5.8	16.0	49.1
October	6.6	74.8	19.7
November	7.2	42.8	11.4
December	10.8	33.1	7.6
Total	152.6	533.5	570.7

Year: 1981

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	11.4	36.9	8.6
February	8.6	17.0	15.9
March	24.5	90.9	33.4
April	16.0	50.5	62.0
May	16.6	70.6	80.1
June	11.7	21.7	89.7
July	8.2	54.5	86.2
August	8.7	53.9	75.4
September	7.4	81.0	46.9
October	10.9	64.7	20.2
November	9.6	32.0	11.0
December	16.9	50.7	6.7
Total	150.7	624.5	536.1

Year: 1982

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	24.7	38.7	5.4
February	15.1	18.3	15.9
March	17.5	46.3	39.7
April	12.4	12.3	56.8
May	11.3	60.2	101.6
June	9.3	76.5	99.4
July	8.1	35.9	0.0
August	7.3	38.3	0.0
September	6.0	44.1	0.0
October	16.6	122.2	0.0
November	21.4	77.4	0.0
December	27.9	52.3	0.0
Total	177.7	622.4	318.9

Year: 1983

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	0.0 *	0.2	9.8
February	0.0 *	0.5	15.7
March	0.0 *	4.4	38.5
April	0.0 *	87.5	57.2
May	0.0 *	71.1	77.6
June	0.0 *	40.3	107.6
July	0.0 *	0.0 *	0.0
August	0.0 *	0.0 *	0.0
September	0.0 *	0.0 *	0.0
October	0.0 *	0.0 *	0.0
November	0.0 *	0.0 *	0.0
December	0.0 *	0.0 *	0.0
Total	0.0	204.1	306.5

NB Missing data is denoted by a *

Table 8 SHENLEY BROOK END CATCHMENT DATA

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Year: 1972

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	41.5 *	0.0 *	0.0
February	32.6	0.0 *	0.0
March	17.3	42.4 *	43.0
April	10.1	58.3	65.6
May	2.6	50.3	95.1
June	0.0	33.7	101.3
July	0.0	56.5	99.1
August	1.1	50.2	81.3
September	0.0	31.5	44.8
October	0.0	17.9	20.6
November	3.6	56.3	7.9
December	35.5	69.8	6.4
Total	144.3	466.8	565.1

Year: 1973

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	10.7	25.2	5.9
February	8.0	22.6	13.3
March	3.7	15.8	42.2
April	3.5	53.1	71.1
May	3.7	66.0	104.1
June	2.0	78.3	128.0
July	0.0	35.2	110.0
August	0.0	34.6	119.8
September	0.0	29.5	60.3
October	0.0	27.5	19.6
November	0.0	39.4	14.1
December	2.5	41.1	10.4
Total	34.2	468.3	698.8

Year: 1974

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	42.4	72.6	11.3
February	54.2	73.3	16.1
March	30.9	43.7	31.0
April	1.9	13.0	60.6
May	0.0	23.9	113.2
June	0.1	95.7	117.9
July	0.0	41.9	100.4
August	0.0	96.1	89.2
September	6.0	95.5	52.3
October	39.4	85.0	22.0
November	77.9	127.2	10.8
December	17.5	34.8	12.5
Total	270.4	802.9	637.4

Year: 1975

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	42.0	68.6	9.8
February	31.3	37.6	14.5
March	66.9	99.6	30.9
April	31.7	58.2	65.1
May	27.2	53.2	95.7
June	0.0	13.9	154.1
July	0.0	31.0	144.9
August	0.0	20.1	122.6
September	0.0	79.8	65.2
October	0.0	14.2	29.7
November	0.0	36.1	10.8
December	0.0	28.1	5.1
Total	199.1	540.5	748.5

Year: 1976

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	0.6	30.5	11.6
February	0.5	20.1	13.1
March	0.2	19.5	44.0
April	0.0	17.7	76.2
May	0.0	34.1	119.7
June	0.0	13.9	153.6
July	0.0	17.5	149.1
August	0.0	18.1	121.1
September	0.0	88.2	55.9
October	0.2	98.8	27.0
November	5.3	50.2	6.1
December	45.7	87.9	3.8
Total	52.4	496.5	781.2

Year: 1977

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	71.9	75.9	5.4
February	86.1	111.2	17.0
March	28.3	63.8	42.0
April	3.6	33.9	75.6
May	11.2	50.8	116.3
June	3.3	73.8	81.8
July	0.0	6.3	116.8
August	6.8	135.8	67.1
September	0.4	12.6	52.4
October	0.0	30.3	26.7
November	1.7	44.0	11.4
December	28.2	63.3	4.4
Total	241.4	701.8	617.0

Year: 1978

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	48.0	72.6	4.5
February	34.4	44.8	10.4
March	28.7	61.6	39.4
April	11.1	46.1	49.3
May	41.5	59.0	89.6
June	0.1	46.6	107.1
July	0.0	72.9	100.9
August	0.3	35.6	95.0
September	0.0	28.3	63.8
October	0.0	2.8	26.6
November	0.0	26.6	11.4
December	16.3	111.9	2.6
Total	180.4	608.8	600.5

Year: 1979

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	24.2	55.8	3.5
February	51.7	45.2	11.1
March	90.8	123.1	31.8
April	36.2	67.1	63.0
May	35.1	105.7	88.9
June	8.5	40.0	102.3
July	0.0	21.9	118.1
August	0.0	71.2	84.9
September	0.0	21.1	57.2
October	0.8	68.9	23.0
November	3.6	39.2	7.9
December	77.8	129.6	8.0
Total	328.8	788.7	599.7

Year: 1980

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	29.0	36.8	3.8
February	39.0	44.0	14.7
March	35.2	73.3	33.8
April	14.1	23.2	74.9
May	0.2	29.1	121.9
June	0.8	91.5	114.8
July	22.2	114.9	102.0
August	32.2	76.0	83.4
September	1.9	19.7	58.2
October	28.2	84.7	21.5
November	43.8	59.0	7.6
December	49.3	41.3	7.1
Total	295.9	693.4	643.8

Year: 1981

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	45.0	38.3	6.4
February	15.9	23.5	16.3
March	80.3	106.9	36.7
April	41.5	75.2	63.5
May	25.0	79.0	82.8
June	10.9	31.6	113.6
July	1.8	72.4	109.4
August	2.5	43.4	93.8
September	4.0	90.6	62.6
October	42.3	91.3	21.2
November	32.3	52.1	11.4
December	45.4	50.4	3.3
Total	346.9	754.7	621.1

Year: 1982

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	29.6	45.2	7.7
February	4.1	29.8	13.1
March	66.1	95.4	46.3
April	0.4	19.3	71.8
May	0.2	56.0	115.0
June	10.4	119.4	108.6
July	0.2	34.7	117.7
August	0.0	37.9	95.6
September	0.0	49.0	57.2
October	34.2	102.1	24.7
November	63.4	83.4	11.1
December	54.0	49.5	6.1
Total	262.6	721.8	674.8

Year: 1983

	Flow(mm)	Rainfall(mm)	Penman ET(mm)
January	28.9	48.5	11.4
February	19.9	30.3	16.9
March	23.3	54.9	39.4
April	51.3	84.9	64.7
May	43.1	92.1	87.2
June	11.2	49.0	120.5
July	0.2	47.8	150.8
August	0.0	16.4	109.5
September	0.2	79.2	54.0
October	1.8	47.5	27.1
November	4.5	39.7	12.5
December	21.5	47.3	5.6
Total	206.0	637.6	699.6

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