Fld Stud. (1977), **4**, 555–573

THE HYDROLOGY OF A SMALL CATCHMENT

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ABSTRACT

Gregory and Walling (1971) described how simple equipment could be used to monitor processes operating in a small drainage basin. Similar experiments were then started in the small basin closest to the Leonard Wills Field Centre (Grid Square Reference ST 0537), involving the daily measurement of rainfall at two sites and of stream discharge at one. During the succeeding four years monitoring was expanded to include autographic rain recording at two sites, continuous recording of stream level at two sites and daily recording at a third, estimation of potential evapotranspiration and the monitoring of the height of the groundwater zone using a series of bore holes. The results enable a monthly water balance to be calculated for the catchment and provide information concerning the stream response to rainfall.

INTRODUCTION

THE circulation and relationship of water in its various forms between the atmosphere, the land and the sea, is encompassed by the study of hydrology. Water is held in the atmosphere as water vapour, condenses and falls to the ground as precipitation and eventually returns to the atmosphere by evaporation, thereby completing the hydrological cycle. If the precipitation falls directly into the sea it immediately becomes part of a water body from which it will be evaporated back to the atmosphere. If, however, it falls on the land, only a small proportion will enter surface water bodies directly, the remainder reaching streams, rivers and lakes via the soils and rocks of the surrounding area: processes which may take a long time and during which large volumes of water may return to the atmosphere through evaporation and transpiration. The amount of water therefore entering streams and rivers may only be a small proportion of that which fell as precipitation.

The processes by which precipitation reaches paths of surface drainage within a single drainage basin are shown diagrammatically in Fig. 1 (after Weyman). A small proportion of the precipitation will enter the stream directly and is known as channel precipitation, the rest falls onto the surrounding area. Of this, some will be intercepted by the vegetation cover, the degree of interception depending on the type of vegetation, the time of year and the intensity of the rain, sleet or snow. Some of the intercepted water will evaporate, but the remainder will fall to the ground and pass into the soil by infiltration. The rate of infiltration varies with the texture of the soil, the root system of the vegetation, the gradient of the site and the existing state of moisture within the soil. If the rate of precipitation exceeds that of infiltration the excess water collects on the surface, initially in existing depressions as depression storage. When these depressions overflow, water flows over the land surface and enters the stream as direct surface runoff.

Water passing into the soil by infiltration is held as soil moisture for a period of time which may vary from a few hours to several months. Some of this water is used by plants in transpiration and eventually evaporates from their leaf surfaces. The rest moves gradually downslope through the soil, a process caused by gravity

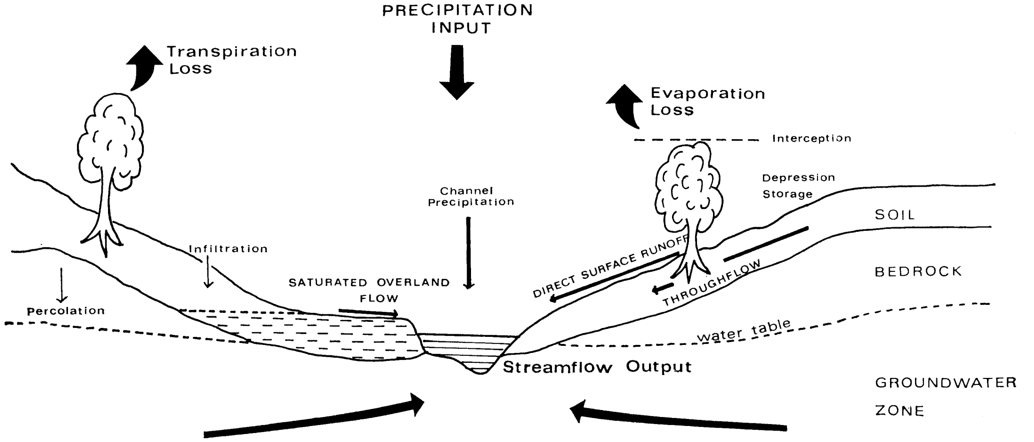


FIG. 1.
Diagrammatic Form of the Basin Hydrological Cycle.

and known as throughflow. Soil moisture conditions are therefore higher at the base of the slope than at the top, and under high moisture conditions this may result in the lower part of the slope becoming saturated. If this occurs water will start to move over the surface as saturated overland flow.

Finally, water will percolate from the base of the soil, into and through the underlying bedrock, the rate of percolation being controlled by the permeability of the rock. The water moves slowly downwards towards the groundwater zone or the zone of permanent saturation. The top of this zone is usually referred to as the water table although in practice it is not a smooth surface but reflects the surface topography, the similarity increasing as the permeability of the rock decreases. This is explained by the fact that in a relatively impermeable rock, resistance to water movement is high and the slope of the water table therefore steep and similar to the ground surface. The discharge of groundwater into the stream takes place over a long period of time and supplies the steady year-round flow.

Considering a single drainage basin, precipitation may be regarded as input into the system, stream discharge as output and evaporation and transpiration as losses. Over the long term these balance; over the short term any imbalance reflects changes in the amount of water stored within the basin. The experiments at the Leonard Wills Field Centre were designed to study this balance and have since been developed to look in detail at the relationship between rainfall and runoff, that is, between precipitation input and stream discharge output.

EXPERIMENTAL DESIGN

The drainage basin studied (shown in Fig. 2) has a total area of 1·098 sq kms and is easily accessible. Using the Strahler scheme of stream ordering, it is a first order tributary of the River Doniford which flows into the Bristol Channel 2 kms east of Watchet. The geology of the catchment is a sequence of Devonian sandstones and slates with the valley bottom containing an infill of periglacial head. Cores of rock taken from boreholes have shown the thickness of head to vary from a few centimetres in the valley bottom adjacent to the middle weir, to several metres

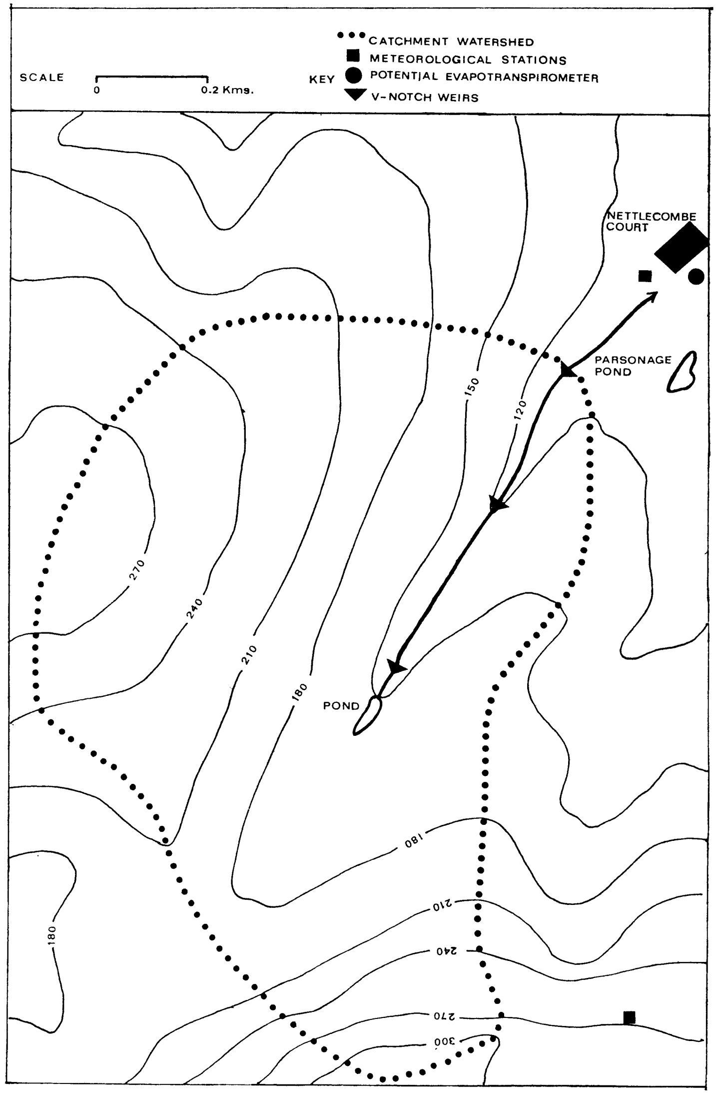


FIG. 2.
Map of the catchment, showing the position of the equipment.

adjacent to the most downstream weir. Whereas the head is an unconsolidated material composed of angular stone fragments in a fine matrix and as such is relatively permeable, the underlying rocks are metamorphosed and are permeable only through structural weaknesses.

The source of the present stream is a spring immediately above the pond shown on the map. The position of the spring is not fixed but varies by several metres with different moisture conditions. During very wet periods, such as February 1977, direct surface runoff occurs in the normally dry part of the valley upstream of the spring. The surface form of the valley changes considerably at the maximum height of the spring. Above this the valley is open with the angle of the sides less than 15°; below the valley becomes steeply incised and the angle of the sides increases at the base to between 20 and 25°. Downstream of the middle weir the valley widens out considerably and by the level of the downstream weir it has lost its incised nature.

During the past there has been considerable interference with the stream and some channelling of water from it. The pond shown at the source of the stream is man-made and at least 200 years old. Water from it now feeds four cattle troughs within the catchment with the level of water in each controlled by a ball valve. Downstream of the highest weir water is occasionally pumped off for the water supply of a local cottage although the frequency with which this occurs is very low. Just upstream of the lowest weir the stream was channelled underground during a landscaping programme in the eighteenth century but a large proportion of this has now been excavated.

The present vegetation is dominated by rough grassland and bracken with a small amount of woodland concentrated in the upper part of the catchment and around the pond.

The equipment has been installed to measure three main variables: precipitation input, streamflow output and combined losses by evaporation and transpiration.

Precipitation input

The aim in the measurement of precipitation is to collect a volume of water from a known area and to express it as units of depth, usually millimetres. The area over which precipitation is collected is defined by the raingauge rim and it is assumed that the depth of water collected by the gauge is the same as that falling on the surrounding area. There are a number of problems with this assumption; a tall rain gauge acts as an obstacle to the flow of wind which may result in falling rain being carried past the gauge, whereas if the rim is placed very close to the ground, insplashing may occur giving an excess catch. The Meteorological Office has tried to compromise by issuing a standard rain gauge of 5 inches diameter with the rim 1 foot above the ground.

The location of rain gauges is also important, the adequacy of the results depending partly on the extent to which the sites chosen are representative of the surrounding area. Two meteorological stations including rain gauges were established at the Centre in 1968 and 1971, the first just outside the catchment at 100 metres and the second on the watershed to the River Doniford at 270 m (Ratsey 1973). Both contain standard meteorological office rain gauges sited on grassland, from which the total amount of rain for the previous twenty-four hours is measured at 0900 GMT each day. To obtain records of intensity and duration of rainfall, self-syphoning autographic recorders have been installed at both sites, each fitted with daily charts on which 1 mm of rain is represented by a rise of 1 cm on the chart (Fig. 9).

The final results used in the water balance are the average of the two standard meteorological rain gauges. In practice calculating the average is inaccurate unless there is an even distribution of rain gauges situated in a flat area. The data collected could be improved considerably by introducing a much denser network of rain gauges in a greater variety of sites, and by applying techniques such as Thiessen polygons or Height-balanced polygons to calculate average precipitation (Ward 1975, pp 38–40).

Streamflow output

Stream discharge can be measured in a number of ways. The method most suitable for long term recording on a small stream involves the construction of a V-notch weir, shown in Fig. 3. The weir is formed by cutting a sharp edged

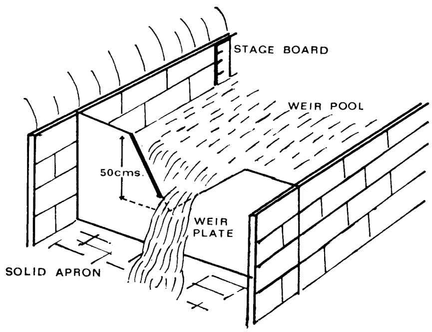


FIG. 3.
Diagram of a sharp crested V-notch weir.

triangular notch into a metal plate and installing it in a watertight manner across the stream. The angle of the notch is chosen to suit the size of the stream and is conventionally $22\frac{1}{2}°$, 45°, 90°, or 120°. The stream is channelled to flow through the notch, and the height of water over the V, measurable anywhere in the weir pool, is proportional to the discharge.

For a 90° notch the relationship can be written mathematically as:

$Q = 0{\cdot}015\ H^{2.48}$ (Gregory and Walling 1971)

where

Q is stream discharge in litres per second (l/s)

H is the head of water over the notch in cms.

The equation can be represented as a regression line on logarithmic graph paper from which the head of water in cms can be converted directly to discharge in litres per second.

Three 90° weirs were installed on the stream draining the basin, the first having a drainage area of 0·505 sq km, the middle an area of 0·721 sq km, and the downstream one an area of 1·098 sq km. For the first eighteen months all three weirs were read daily between 0900 and 1000 GMT. The downstream one is still monitored in this way but the other two are now equipped with automatic water level recorders fitted with weekly charts and recording changes in level of up to 50 cms.

Instead of the expected increase in discharge downstream, the results collected during the first year showed a decrease during the summer months when flows were less than 5 l/s. To investigate this discrepancy, a series of seven bore holes of 3 cms diameter were drilled to varying depths across the valley adjacent to the lower weir (shown in Fig. 12). Each bore hole is lined with perforated plastic piping and the position of the water table is obtained using a conductivity probe, consisting of two electrodes between which a current flows only on contact with a water surface. Measurements are taken monthly.

Evapotranspiration losses

Evaporation and transpiration are notably difficult to measure and are often considered together as evapotranspiration. Actual rates of evapotranspiration are equally difficult to assess and as yet no satisfactory technique of measuring or estimating them has been devised, although attempts to measure and estimate potential rates are reasonably successful. Potential evapotranspiration assumes a constant supply of moisture sufficient to meet the requirements of the transpiring vegetation cover, and therefore tends to be an overestimate of actual rates, especially during dry conditions.

One method of measuring potential evapotranspiration is to measure directly water losses from moist vegetated surfaces. To do this an evapotranspirometer was constructed based on the design in Fig. 4. This instrument consists of three watertight

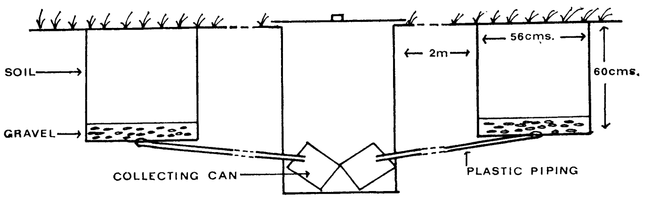


FIG. 4.
Diagram of an evapotranspirometer showing two of the three soil tanks.

oil drums, each connected by plastic piping to polythene bottles housed in a fourth, central, drum. Each of the peripheral drums is filled with soil and supports vegetation, in this case grass, similar to that of the surrounding area. The soil moisture content of the drums is maintained at near field capacity, which, allowing for rainfall, involves adding the equivalent of 3 mms of rain each day during the winter and 6 mms during the summer. The only exception to this was during the summer of 1976 when water equivalent to 12 mms of rain had to be added. The only exit for the added water, other than by evapotranspiration, is via the bottom outlets as percolation, and into the polythene bottles acting as collecting vessels. The percolate is recycled whenever possible to reduce the effects of leaching. Assuming that the amount of water held in each drum remains constant near field capacity, it is straightforward to calculate a water balance for each tank; the difference between the amounts of water entering and leaving the tanks representing the quantity lost by evapotranspiration. Readings are taken daily and an average obtained for the three tanks which is then used to calculate a monthly total.

The accuracy of this method depends on the success with which the drums are kept at field capacity and the extent to which they are representative of the catchment area. Although changes in the soil moisture storage are important on a daily basis, their importance is negligible in the long term, a fact illustrated by the daily variation between the three drums cancelling out in the monthly totals. The three drums are sited on a flat piece of ground where there is no obstruction to falling precipitation. They are all vegetated by grass which is similar to about one third of the catchment area; experiments involving bracken have been unsuccessful. When using results obtained in this way in a water balance equation the greatest drawback is the departure of potential rates from actual rates, especially during the summer months.

Results

The water balance for any drainage basin may be summarized by

$$P = Q + ET \pm \triangle S$$

where

P is precipitation in mms.

Q is stream discharge converted to mms.

ET is losses by evapotranspiration, in mms.

$\triangle S$ is changes in storage.

Precipitation is calculated as the average of both meteorological stations for each month.

Stream discharge is taken from the middle weir as the level recorded on the chart for 0900 GMT each day. The records from the middle weir were used in preference to those from the lower weir because of the observed loss of water from the lower reaches of the stream, at low discharges. Discharge is converted to mms by dividing the discharge (cu cms per sec*) by the catchment area (sq cms) and multiplying by ten and then by the number of seconds in a day (86,400). Daily results are then totalled for each month.

If the volumes of precipitation, discharge and evapotranspiration are known the storage component can be calculated. For the summer months potential evapotranspiration will be an overestimate of actual rates and so the resulting storage component will be an underestimate. Monthly, seasonal and annual results are given in Tables 1 and 2 and are shown in Fig. 5.

The daily results of stream discharge were plotted to give the annual hydrographs (Fig. 7) and compared with the equivalent rainfall data (Fig. 6). A second method for summarizing flow patterns is shown in the flow duration curve in Fig. 8. This is constructed by calculating the cumulative percentage time with which certain flows are equalled or exceeded (Table 3). The mean monthly flows were also calculated from this data (Table 4). Individual storm hydrographs are shown in Fig. 10 a and b.

Discussion

The Water Balance

Taking each element of the water balance equation in turn: From Fig. 5 and Table 1 it can be seen that, as expected, precipitation is greatest during the winter months. Two points are worth special note; the exceptionally dry summer of 1976 and the consistently wet Septembers. There has been a decrease in the total annual rainfall over the three years in question, from 1137·9 mms in 1973/1974 to 685·7 mms in 1975/1976. Potential evapotranspiration rates increase during the summer months with increasing temperatures and the growth of vegetation. It is during this period that the potential rates will differ most, that is be greater, than the actual rates. Stream discharge shows high winter and low summer levels for the first two years and consistently low levels for 1975–1976, ceasing to flow completely for November and August of that (water) year.

* 1 ls = 1000 cu cms per sec.

Table 1. *The Water Balance*

	1973–1974				1974–1975				1975–1976			
	P mms	ET mms	Q mms	ΔS mms	P mms	ET mms	Q mms	ΔS mms	P mms	ET mms	Q mms	ΔS mms
October	54·0	24·5	3·4	+ 26·1	72·7	22·0	51·7	− 1·0	36·0	25·0	0·2	+ 10·8
November	52·7	13·9	3·4	+ 35·4	122·4	0·9	65·5	+56·0	73·8	26·9	0·0	+ 46·9
December	75·4	19·4	22·4	+ 33·6	105·7	25·6	62·0	+18·1	54·3	32·5	12·7	+ 9·1
January	188·5	32·1	108·0	+ 48·4	159·6	15·1	97·7	+46·8	50·2	24·4	8·9	+ 16·9
February	186·8	33·3	163·7	− 10·2	29·9	8·0	68·6	−46·7	51·5	16·8	17·8	+ 16·9
March	62·0	12·9	47·9	+ 1·2	82·4	17·3	42·1	+23·0	82·9	18·7	21·6	+ 42·6
April	19·1	28·0	21·2	− 30·1	51·5	33·9	27·5	− 9·9	6·8	35·8	21·7	− 50·7
May	94·3	65·2	18·0	+ 11·1	20·3	63·7	16·9	−60·3	45·0	77·5	7·6	− 40·1
June	66·4	88·0	11·6	− 33·2	8·3	101·2	6·8	−99·7	13·8	108·8	3·2	− 98·2
July	43·1	93·9	5·4	− 56·2	54·6	87·0	3·9	−36·3	8·7	186·5	0·9	−178·2
August	90·5	76·1	3·1	+ 11·3	38·4	64·9	1·9	−28·4	53·7	210·4	0·1	−156·2
September	205·1	42·3	14·9	+147·8	151·9	79·9	1·1	+70·9	209·0	134·5	1·2	+ 75·3
Annual	1137·9	529·6	423·0	+185·3	897·7	519·5	445·7	−67·5	685·7	897·8	95·9	−308·0

where P is precipitation input
ET are potential evapotranspiration losses
Q is stream discharge output
ΔS is changes in storage

Table 2. *Seasonal and Annual Water Balance*

	P mms	ET mms	Q mms	△S mms	Q mms % P
3 years 1973–1976	2721·3	1946·9	964·6	−190·2	35·5
Annual 1973–1974	1137·9	529·6	423·0	+185·3	37·2
1974–1975	897·7	519·5	445·7	− 67·5	49·7
1975–1976	685·7	897·8	95·9	−308·0	14·0
Seasonal					
Winter 1973–1974	619·4	136·1	348·8	+134·5	56·3
Summer 1973–1974	518·5	393·5	74·2	+ 50·8	14·3
Winter 1974–1975	572·9	88·9	387·6	+ 96·4	67·7
Summer 1974–1975	324·8	430·6	58·1	−163·9	17·9
Winter 1975–1976	348·7	144·3	61·2	+143·2	41·0
Summer 1975–1976	337·0	753·5	34·7	−451·2	10·3

where P is precipitation input
ET is potential evapotranspiration losses
Q is stream discharge output
△S is changes in storage
Winter is defined as 1 October–31 March.
Summer is defined as 1 April–30 September.

Table 3. *Construction of the Flow Duration Curve 1973–1976*

	Number of Days					
Discharge l/s	1973–1974	1974–1975	1975–1976	Total 1973–1976	Cumulative Total	%
120–129·9	1			1	1	0·1
110–119·9	0			0	0	0·1
100–109·9	1			1	2	0·2
90– 99·9	0			0	0	0·2
80– 89·9	0			0	0	0·2
70– 79·9	5			5	7	0·6
60– 69·9	1	2		3	10	0·9
50– 59·9	3	7		10	20	1·8
40– 49·9	14	5		19	39	3·6
30– 39·9	7	13		20	59	5·4
20– 29·9	11	23		34	93	8·5
10– 19·9	42	88	2	132	225	20·5
0– 9·9	280	227	364	871	1096	100·0
	365	365	366	1096		

When the storage component is calculated for each month, it shows either a surplus, when water is being added to the soil and ground reserves, or a deficit when water is being withdrawn from them. As a general rule there is an overall surplus in each of the six months from October to March and a deficit in the six months April to September. On an annual basis this cancels out, meaning that at the end of September soil and ground moisture reserves should be at a minimum. Most hydrological data is given for a "water year", 1 October to 30 September, starting and ending in the period of minimum storage.

The calculated monthly balance shows the expected pattern with one or two anomalies. May and August 1974 both showed exceptionally high rates of precipitation resulting in a surplus instead of the expected deficit, whilst February 1975 was very dry resulting in an unexpected deficit. The most notable exceptions are the three Septembers, all of which had a total of 150 mms of rain and in two

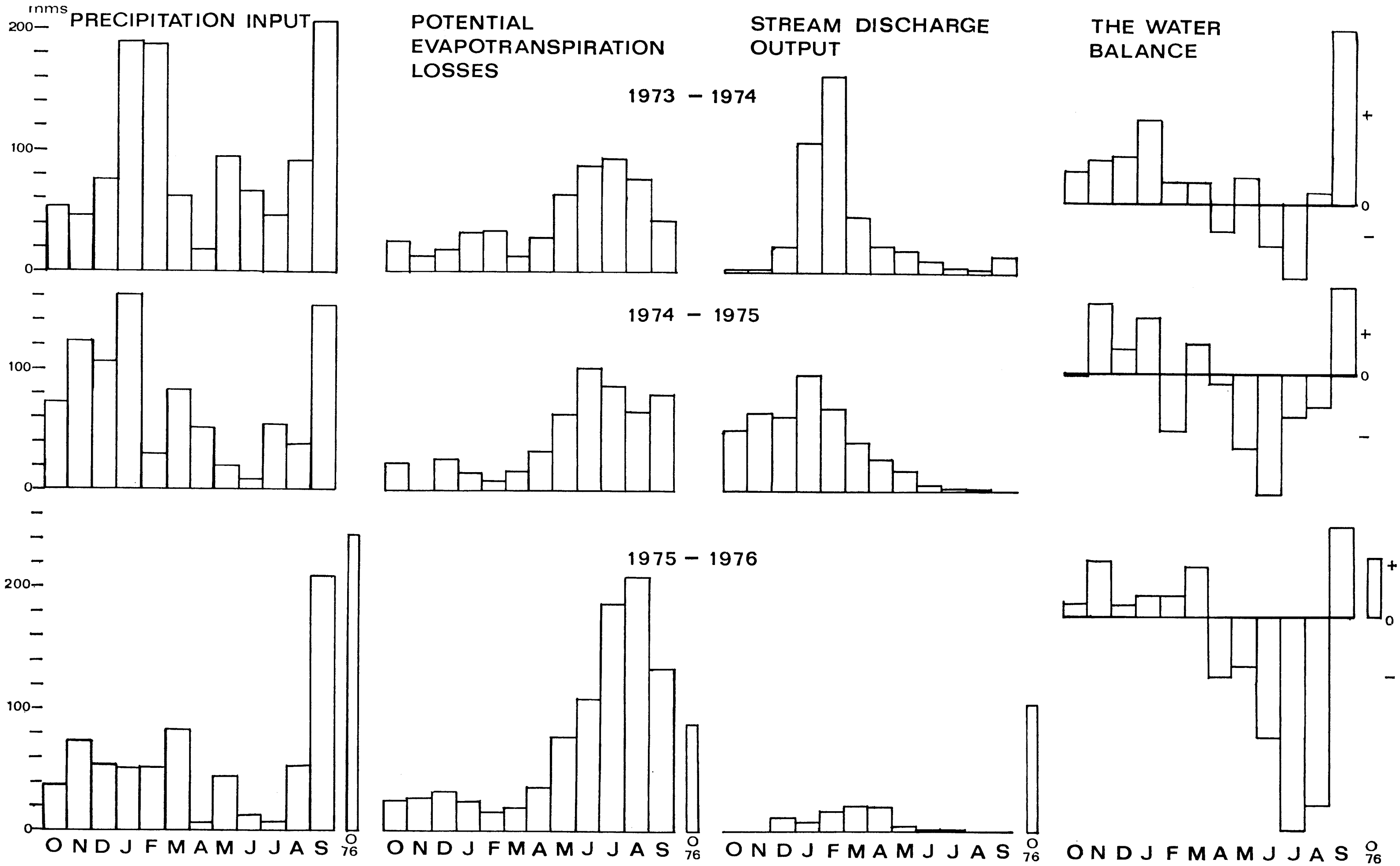


Fig. 5.

Monthly estimates of the four major components of the water balance, for the years 1973–1974, 1974–1975 and 1975–1976. Precipitation values were an average of the amounts recorded at the two meteorological stations and stream discharge is the flow recorded at the middle weir at 0900 G.M.T. each day.

Table 4. *Mean Monthly Flows l/s*

	1973–1974	1974–1975	1975–1976
October	0·0	13·9	0·04
November	0·9	18·2	0·0
December	4·6	16·8	3·4
January	28·8	26·3	2·4
February	48·9	20·4	5·0
March	13·3	11·4	5·8
April	5·9	7·7	6·0
May	4·8	4·6	2·1
June	3·2	1·9	0·9
July	1·5	1·1	0·3
August	0·7	0·5	0·03
September	4·2	0·04	0·3

Table 5. *Monthly Flows as % of Annual*

	1973–1974	1974–1975	1975–1976
October	0·8	11·6	0·2
November	0·8	14·7	0·0
December	5·3	13·9	13·2
January	25·5	21·9	9·3
February	38·7	15·4	18·6
March	11·3	9·5	22·5
April	5·0	6·2	22·6
May	4·3	3·8	7·9
June	2·7	1·5	3·3
July	1·3	0·9	0·9
August	0·7	0·4	0·1
September	3·5	0·2	1·3

instances proved to be the wettest month of the year. For September 1975 the calculated surplus may be greater than the actual surplus. On the night of 13 September, 67 mms of rain fell in six hours, producing a rapid increase in stream discharge large enough to wash away the newly built construction housing the water level recorder. By 0900 GMT the next morning the stream was back to its level of the previous day at 0·9 l/s although it is estimated to have reached 100 l/s during the night. It would therefore appear that a large proportion of the rain which fell that night may in fact have passed down the stream unrecorded, as channel precipitation and possibly direct surface runoff.

However, bearing this inaccuracy in mind the seasonal and annual balances show some interesting trends. All the seasonal results show the expected surplus or deficit, apart from the summer of 1974 when almost 300 mms of rain fell during August and September. When looking at these figures it is important to remember that during the summer the calculated surplus will be an underestimate because of the use of potential rather than actual rates of evapotranspiration in the equation. The percentage of precipitation leaving the basin via the stream fell noticeably for both seasons of 1975–1976, a year which started off with very low moisture reserves. The large deficit shown at the end of this year was reflected in local reservoir levels and the introduction of stand-pipes for domestic consumers in the area. However, exceptionally high rainfall in October (243·4 mms) balanced this remarkably quickly, regaining a near normal situation by early November.

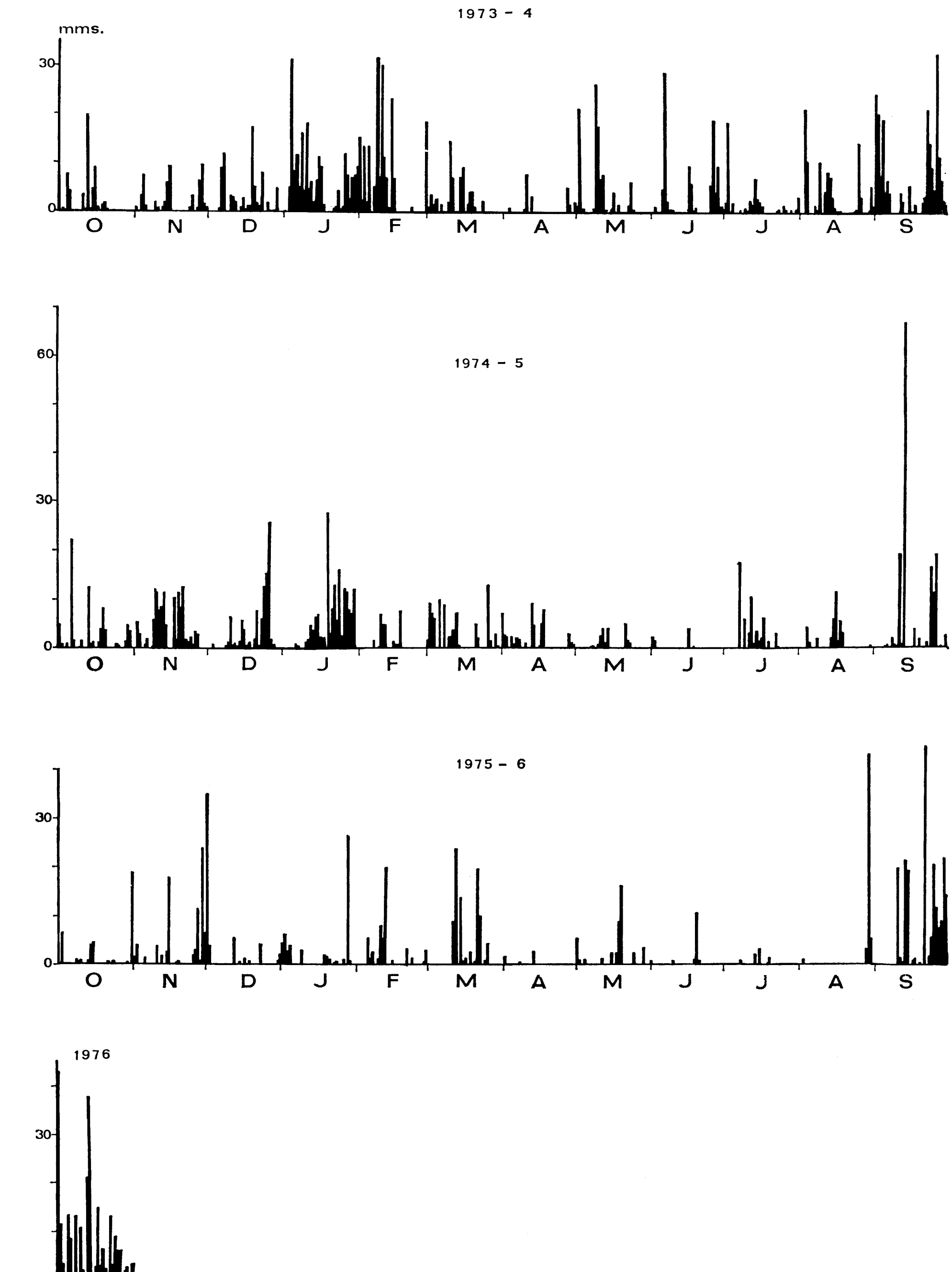


FIG. 6.

Graph of daily rainfall totals, averaged from the two meteorological stations.

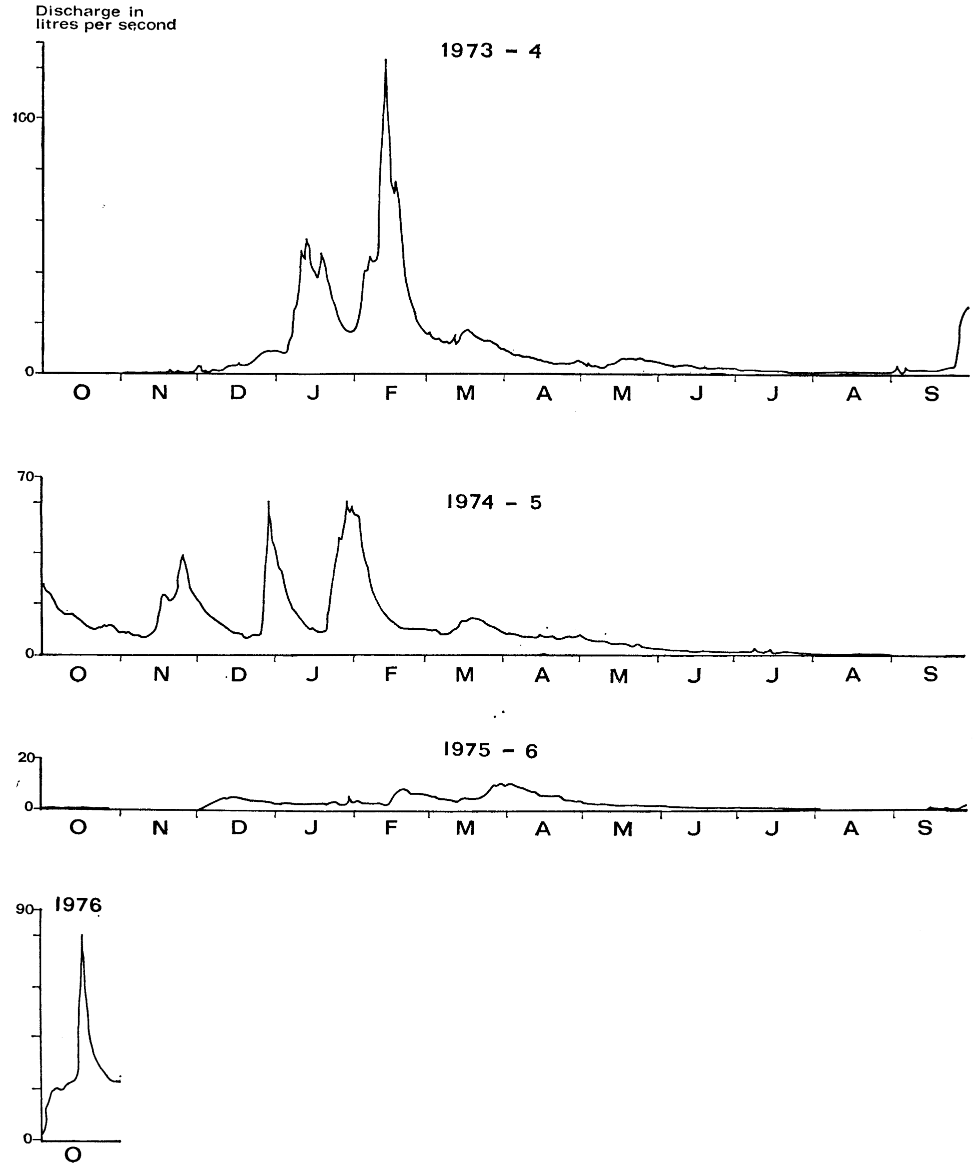


FIG. 7.

The annual hydrographs for the years 1973–1974, 1974–1975, 1975–1976, and the monthly hydrograph for October 1976. These are based on stream discharge recorded at the middle weir at 0900 G.M.T. each day.

The Rainfall-Runoff Relationship

The response of stream discharge to precipitation is known as the rainfall-runoff relationship. In drainage basins with poor storage facilities and low infiltration rates, most of the rain will enter the stream directly as surface runoff, resulting in an immediate rise in stream discharge following each storm. Basins with good storage facilities will only show this response when infiltration rates are reduced by high moisture levels within the soil.

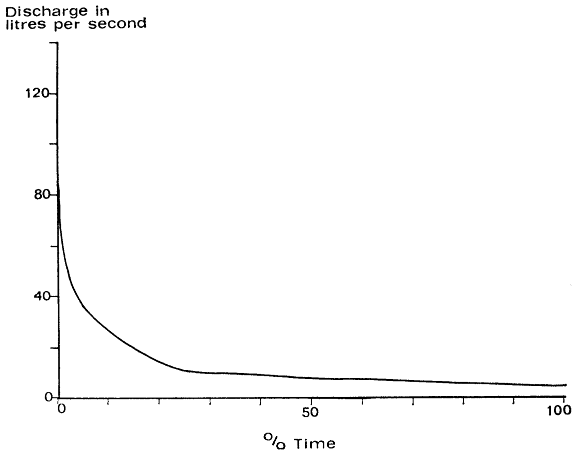


FIG. 8.

The flow duration curve for the middle weir, October 1973 to September 1976.

The characteristics of a drainage basin can be illustrated by the flow duration curve. The method of construction is shown in Table 3. For the three years concerned the cumulative number of days on which each flow is equalled or exceeded was calculated and worked out as a percentage. This was then plotted as shown in Fig. 8. The steep slope on the graph represents flows where water reaches the stream quickly, known as storm runoff, and the flat part indicates the slower feed from groundwater, known as baseflow. The rapid rise of a stream, may be the result of channel precipitation, direct surface runoff or saturated overland flow. A stream supplied mainly by baseflow indicates a basin with good storage facilities.

The flow duration curve shown in Fig. 8 is compiled from the daily discharges at the middle weir. The stream is fed by baseflow at all flows of less than 10 l/s which occur for 79·5 per cent of the time (Table 3). When this curve is used in conjunction with the annual hydrographs (Fig. 7), it can be seen that flows greater than 10 l/s only occur during the winter months when soil moisture reserves are high. Thus, in September 1974 after two months of exceptionally heavy rain (Fig. 6), the stream started to rise immediately the rain fell (Fig. 7) and subsequently showed a rapid response to rainfall throughout November, December and January, dropping only as soil moisture reserves were depleted during the following, drier months. April to September 1975 seems to have been a period when the stream was largely supplied by baseflow, this being lowered to such an extent that the stream dried out for November. The fact that the stream dries out at times suggests that baseflow in this catchment is supplied by subsoil storage rather than by groundwater.

The mean annual flows show that in all three years more than 45 per cent of the annual discharge occurred in the three months December, January and February with the figure as high as 75 per cent in 1973–1974. In contrast, the total for July, August and September was always less than 6 per cent. When looking at these results it must be remembered that the pond at the source of the stream will act as a reservoir, delaying the streams response to precipitation especially during the summer months, although the surface area of pond decreases considerably under dry conditions. So far, it has not been possible to calculate the effect of the pond in terms of volumes nor the amount which is fed out to the cattle troughs in the catchment, although this is not thought to be large.

The discharges used to construct the annual hydrographs were simply those recorded at 0900 GMT each day, making no allowance for changes which may have taken place during the intervening 24 hours. These short-term changes, marking immediate response to storms, can be seen on the weekly charts. The first recorder was obtained on loan from the Somerset River Authority in October 1974 and installed at the lower weir. The hydrograph shown in Fig. 10a was recorded during a five day period from the 26–30 December of that year, showing the stream response to rainfall totalling 45 mms as recorded by the autographic gauge (39·4 mms by the standard 5 inch gauge). The rain started on the 25th when a total of 18·3 (15·2) mm fell in 19 hours. This was followed on the 26th by 27·6 (24·2) mm, most of which was concentrated into two intense storms, 21 mm falling in three hours. At the start of the rain the stream was flowing at 12 l/s and rose steadily throughout the 25th to reach 24 l/s at the beginning of the first storm on the following day. One hour after the end of the first storm stream discharge reached a peak of 75 l/s and then dropped within three hours to 35 l/s. Following the second storm discharge rose to a smaller peak of 50 l/s and then fell to 32 l/s, to gradually rise again to a crest of 60 l/s 27 hours later; 36 hours after the start of the first storm. It then dropped gradually to a more constant level of 50 l/s.

The storm hydrograph can be separated into its major components using a scheme proposed by Hewlett and Hibbert (1967). A line is projected upwards from the start of the hydrograph rise, at a gradient of 0·545 l/s per sq km per hour (Fig. 11). All flow above this line is classed as quickflow or storm runoff, while flow below the line is delayed flow which includes throughflow and baseflow. For the two storms shown, quickflow accounts for only 0·5 per cent of the total rainfall, which is similar to that described by Troake and Walling (1973), for a

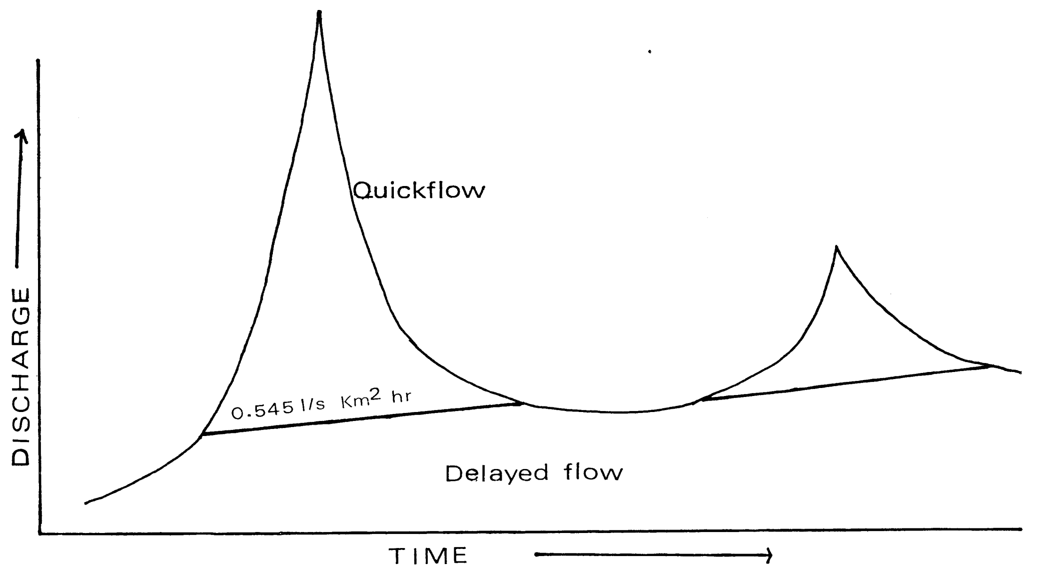


Fig. 11.
Hydrograph separation into Quickflow and Delayed flow.

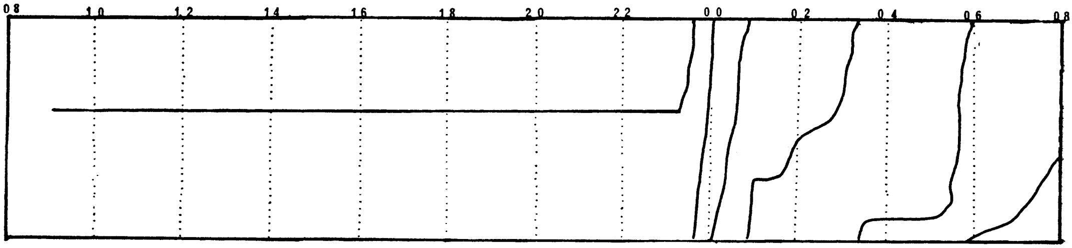
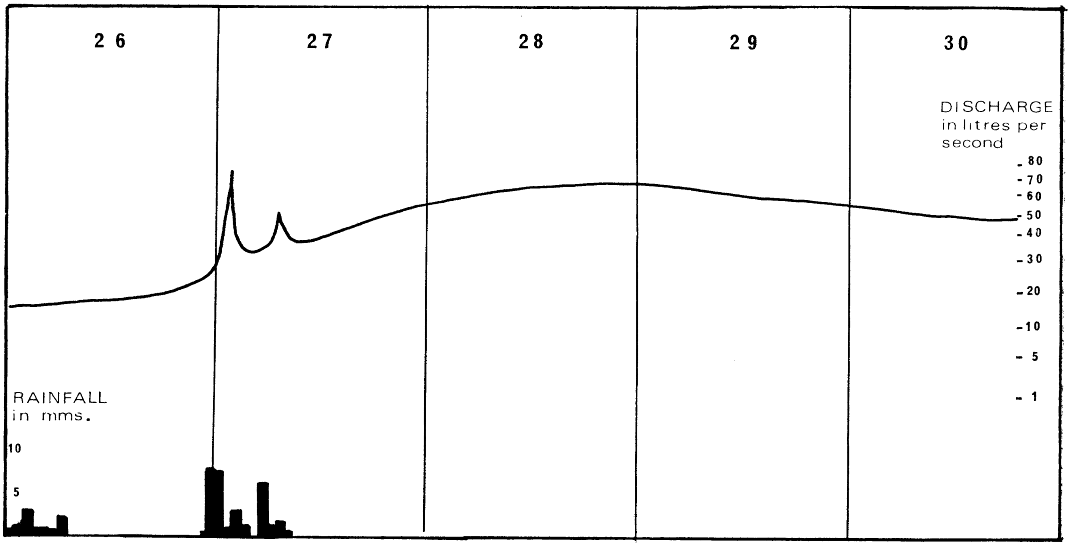
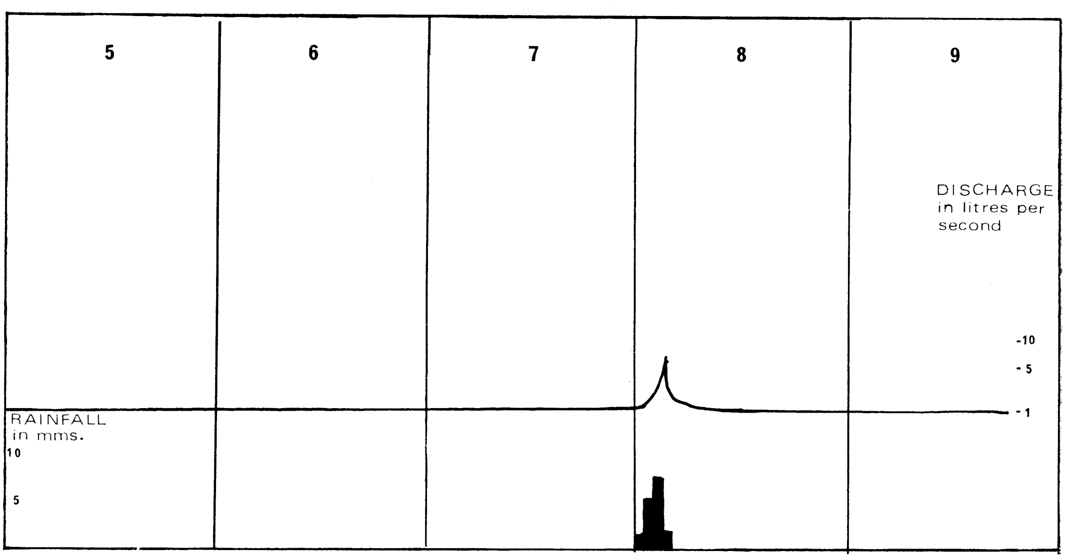


FIG. 9.
Autographic rain recorder chart for 26–27 December 1974.



a



b

FIG. 10.

Weekly Hydrographs:
a. Hydrograph recorded on the lower weir, 26–30 December 1974.
b. Hydrograph recorded on the middle weir, 5–9 July 1975.

catchment in South Devon. It seems probable that quickflow is accountable for by channel precipitation and by saturated overland flow from a very small proportion of the catchment area. A strip of land 5·5 metres wide down the whole length of the stream gives 0·5 per cent of the catchment area, suggesting that in this case, the "Partial Area" concept where only a small part of the catchment contributes to storm runoff, applies. The gradual rise of the stream after the initial peaking almost certainly represents water entering the stream as throughflow from lower down in the soil profile. The time lag of 36 hours is again very similar to that described by Troake and Walling (1973). The level at which the stream settles, shows a rise from 12 l/s to 50 l/s, the increase representing a rise in baseflow.

In February 1975 a second recorder was purchased and placed on the middle weir, whilst the first recorder was transferred to the upper weir, in the hope of tracing individual storm events downstream. Since that time conditions have been exceptionally dry and all the hydrographs recorded are similar to the one shown in Fig. 10b, the only difference between the two weirs being a greater peaking downstream. On this occasion quickflow only represents 0·1 per cent of the precipitation, and there is no secondary throughflow response and no overall increase in baseflow. Soil moisture reserves were extremely low at the time, so that the rain falling on the surrounding area will have infiltrated into, and been held by, the soil.

The Groundwater Table

The position of the bore holes drilled across the valley is shown in Fig. 12a, and the results of measurements taken using the bore holes in Fig. 12b. The results show a line marking the top of the zone of saturation which is inversely related to relief. One explanation for this could be that the widening of the valley at this point, accompanied by the dramatic increase in the volume of head, would have a "sponge" effect. In other words, as the stream flows from the restricted valley at the middle weir, to the open valley at the lower weir, the water spreads out from the channel and into the thick, permeable head deposit. This would create a "ground water mound" above the regional water table and with a hydraulic gradient away from the stream. This in turn would produce a decrease in discharge between the two weirs especially under low moisture conditions.

There are other explanations for the loss of water downstream at low discharges. One possibility is "leaking" along a structural weakness or through some old drainage scheme connected with the estate. It is known that the stream in this area was channelled underground during the eighteenth century, but as yet the full extent of this scheme has not been discovered.

Conclusion

Some of the methods used in these experiments are open to criticism and the calculated results suspect. This is especially true in the calculation of the water balance; using only the average of two rain gauges, and potential rather than actual rates of evapotranspiration. However, the experiments were designed to illustrate techniques rather than to prove scientific facts, and in this context they have been invaluable in both geographical and ecological freshwater field courses. It is hoped that in the future, with increased records, it will be possible to take

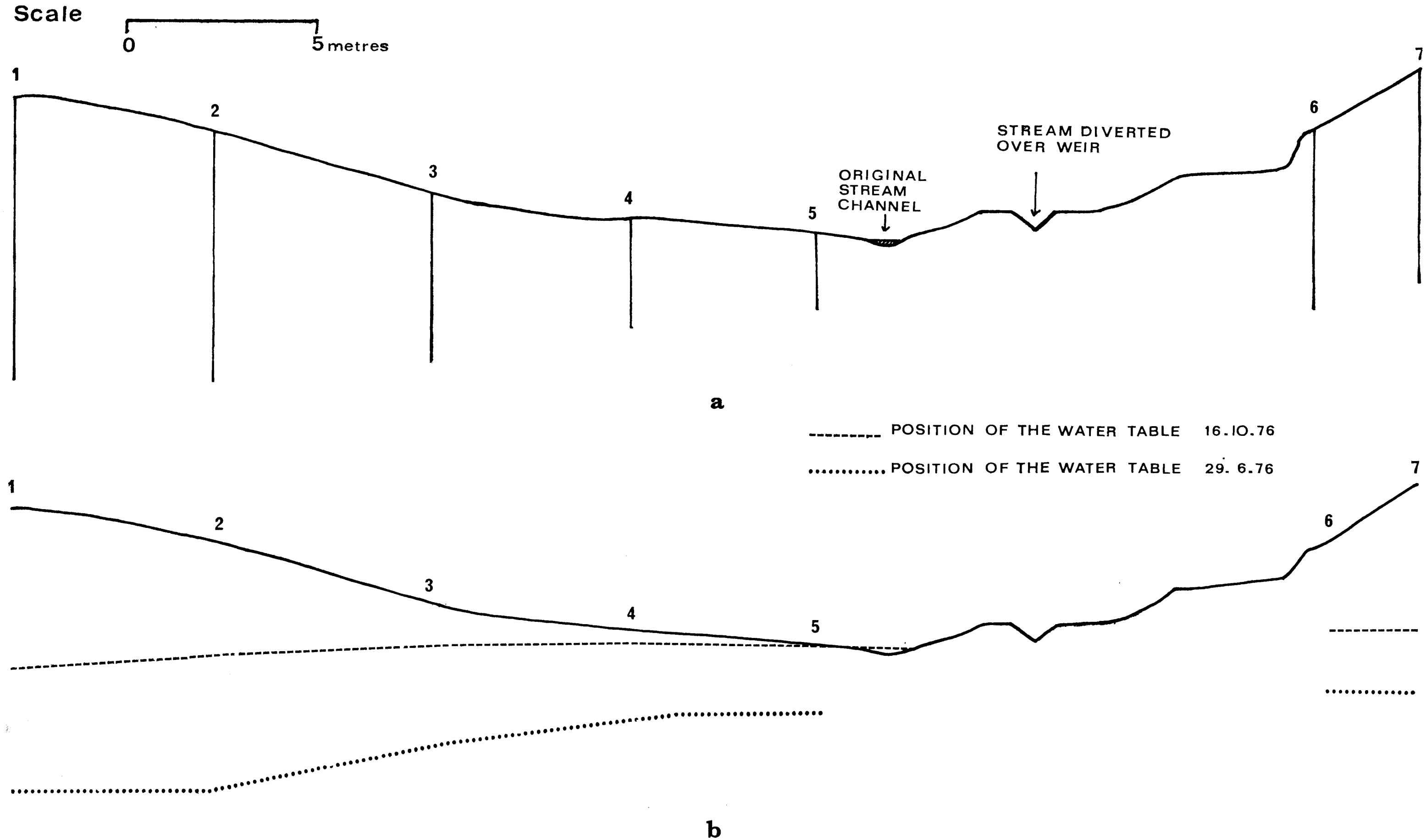


FIG. 12.

The transect line of bore holes adjacent to the lower weir.
a. Position and depth of bore holes.
b. The assumed height and shape of the water table as recorded from the bore holes in the summer and autumn of 1976.

the analysis from the present general level to a more detailed study of specific storm events and also to investigate more thoroughly other factors which may be affecting the hydrology of the catchment, especially drainage schemes in the area and the effect of the pond at the source.

Acknowledgements

I would like to thank Mr J. H. Crothers, Warden of the Centre for his encouragement in writing this paper, also Mr R. P. Troake, then Warden of Slapton Ley Field Centre for his help in the setting up of the experiment. Invaluable help has been given by Wessex Water Authority in advice and the loan of equipment and also by the staff of the Department of Civil Engineering and Construction, Hatfield Polytechnic. Many staff employed by the Field Studies Council at the Centre, have assisted in the recording and without them the experiment would not have been possible. Finally, I would like to thank Mr A. D. Thomas and Professor K. M. Clayton for their advice in writing this paper.

References

Gregory, K. J., and Walling, D. E. (1971). Field Measurements in the Drainage Basin. *Geography*, **56**, 277–292.

Gregory, K. J., and Walling, D. E. (1973). *Drainage Basin Form and Process;* a geomorphological approach (1st edition). Edward Arnold Ltd. London.

Imeson, A. C., and Ward, R. C. (1972). The Output of a Lowland Catchment. *Journal of Hydrology*, **17**, 145–159.

Ratsey, S. (1973). The Climate at and around Nettlecombe Court, Somerset. *Field Studies*, **3**, 741–762.

Troake, R. P., and Walling, D. E. (1973). The Natural History of Slapton Ley Nature Reserve: VII. The Hydrology of Slapton Wood Stream. *Field Studies*, **3**, 719–740.

Ward, R. C. (1967). *Principles of Hydrology* (1st edition). McGraw Hill, Maidenhead.

Ward, R. C. (1975). *Principles of Hydrology* (2nd edition). McGraw Hill, Maidenhead.

Weyman, D. R. (1974). Runoff Process, contributing area and streamflow in a small upland catchment. In *Fluvial Processes In Instrumented Watersheds*. Eds. Gregory, K. J., and Walling, D. E.; Institute of British Geographers Special Publication, No. 6.

Weyman, D. R. (1975). *Runoff Processes and Streamflow Modelling*. O.U.P. London.

Other papers published in *Field Studies* relating to the area around The Leonard Wills Field Centre at Nettlecombe Court.

BUSH, R. J. E. (1970). Nettlecombe Court: I. The Trevelyans and other residents of the Court. Volume 3 part 2, 275–287.

CORBETT, G. U. S. (1970). Nettlecombe Court: II. The Buildings. Volume 3 part 2, 289–296.

RATSEY, S. (1973). The climate at and around Nettlecombe Court, Somerset. Volume 3 part 5, 741–762.

GILBERTSON, D. D., and MOTTERSHEAD, D. N. (1975). The Quaternary deposits at Doniford, West Somerset. Volume 4 part 2, 117–129.

CROTHERS, J. H. (1976). On the distribution of some common animals and plants along the rocky shores of West Somerset. Volume 4 part 3, 369–389.

BISHOP, M. J. (1976). Woodland mollusca around Nettlecombe, Somerset. Volume 4 part 3, 457–464.

BOYDEN, C. R., CROTHERS, J. H., LITTLE, C., and METTAM, C. (1977). The Intertidal Invertebrate Fauna of the Severn Estuary. Volume 4 part 4, 477–554.