INSTITUTE of HYDROLOGY

HYDROLOGICAL ANALYSIS OF THE TRURO FLOODS OF JANUARY AND OCTOBER 1988

M C Acreman

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HYDROLOGICAL ANALYSIS
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M. C. Acreman

1. Introduction

On 27th January 1988 serious flooding occurred in the city of Truro from the River Kenwyn. Fifteen residential and 50 city centre commercial properties were flooded, resulting in damage which may exceed £1M. A return period of 350 years was attributed to the flood; thus most residents considered that it would be unlikely to occur again in their lifetime. On 11th October 1988 an even greater flood occurred flooding similar properties and causing traffic disruption. Given the small probability of experiencing two floods within 10 months, both with return periods greater than 300 years, the Institute of Hydrology was asked to re-analyse the available information and assess the future flood risk.

2. Description of catchment

2.1 HYDROMETRIC CHARACTERISTICS

The River Kenwyn has been gauged by South West Water since 1968. The gauging station is situated just inside the city limits. Flows are measured by a three bay compound Crump weir. Upstream shoals affect the precision of low flow measurements but high flows, up to a stage of 1.98 m (the height of the piers and wing walls), are measured accurately. Some 30 m downstream of the station a twin arch bridge carries the main road over the river. It is thought that throttling of flows by these culverts may cause drowning of the gauging structure during extreme floods.

There is a daily read rain gauge in Truro, but the nearest autographic gauge is at Rosewarne (Figure 2.1). Until the summer of 1988 a weather radar was operating at Camborne. It was then moved to Predannack. Absolute rainfall depths are not as accurate as conventional rain gauges but radar data gives an indication of the relative depths in different hours through the storm from which daily totals can be distributed.

2.2 PHYSICAL CHARACTERISTICS

The city of Truro is built on the banks of the rivers Kenwyn and Allen in mid-Cornwall. The reference catchment used for this study is that above the gauging station, which has a drainage area of 19.1 km^2 (Figure 2.2.1). At present, just over 6% of the catchment is urbanised, as depicted on the 1984 1:50,000 O.S. map. Previous map editions show that there has been some urban development over the last 30 years, particularly at Threemilestone, Shortlanesend and the Highertown area of the city. Nevertheless, these developments account for only 0.5% of the catchment area; just less than 6%

Figure 2.1 Location of instrumentation

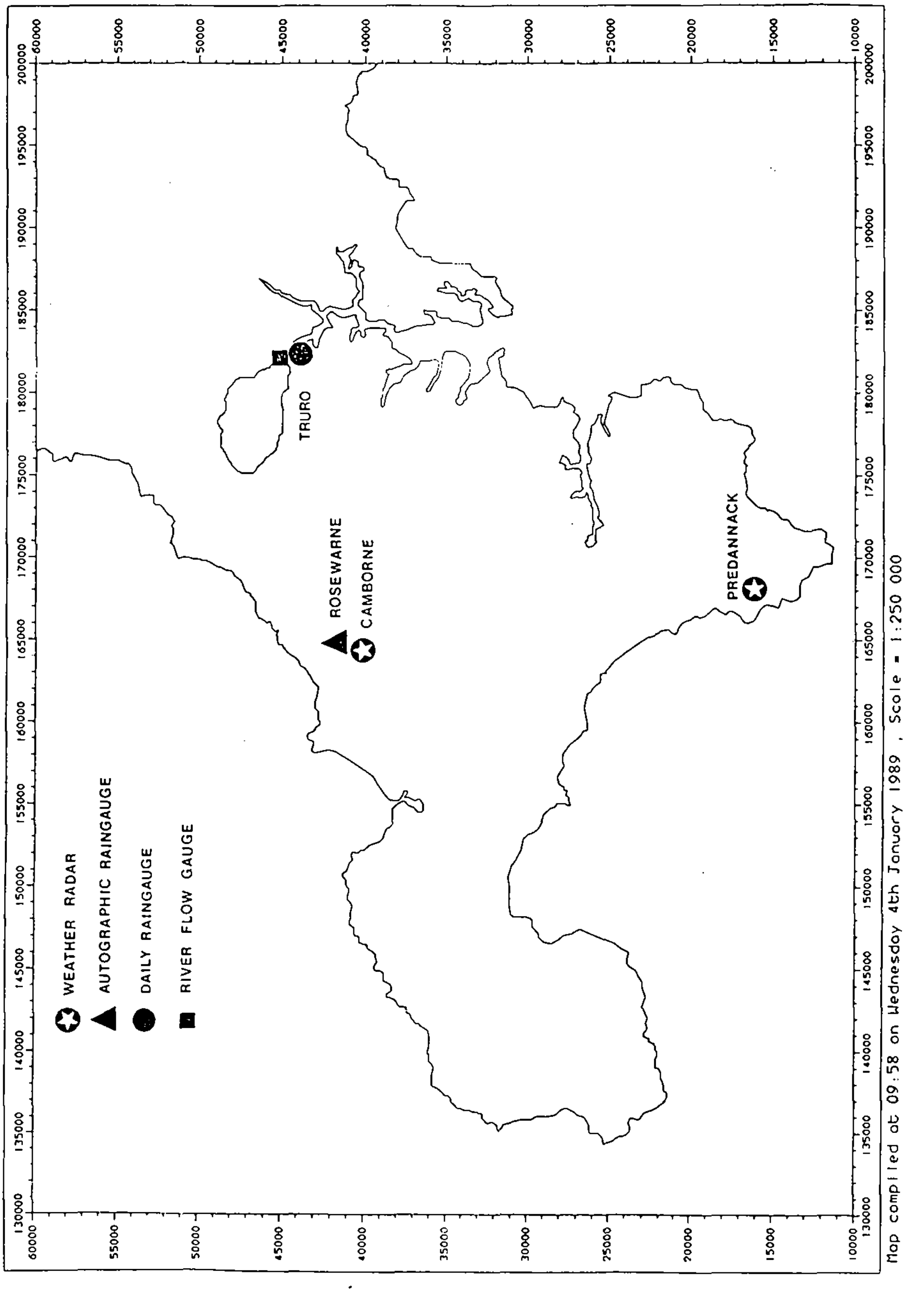


Figure 2.2.1 Classification of soils underlying Kenwyn and Allen Catchments

of the catchment area shown on the 1:25,000 O.S. map published in 1960 (revised 1933-58) is urbanised. The drainage area near to the centre of the city (at the entrance to the culvert, see Section 2.3) is 19.4 km^2. The extra 0.3 km^2 is entirely developed; thus, to this point, 7.4% of the catchment is urbanised.

There is an abrupt change in land use at the city limits. Outside the city the catchment is almost entirely rural with only a few small villages (including Threemilestone and Shortlanesend) and farms. Land use is predominantly pasture though there are small areas of copse and woodland. The terrain is broadly rolling, with rounded hills, though locally steep; the mainstream has a slope (S1085) of 13.1 m km^{-1}. The length of the main channel above the gauging station (MSL) is 7.18 km. Other catchment characteristics are given at the beginning of Appendix 2.

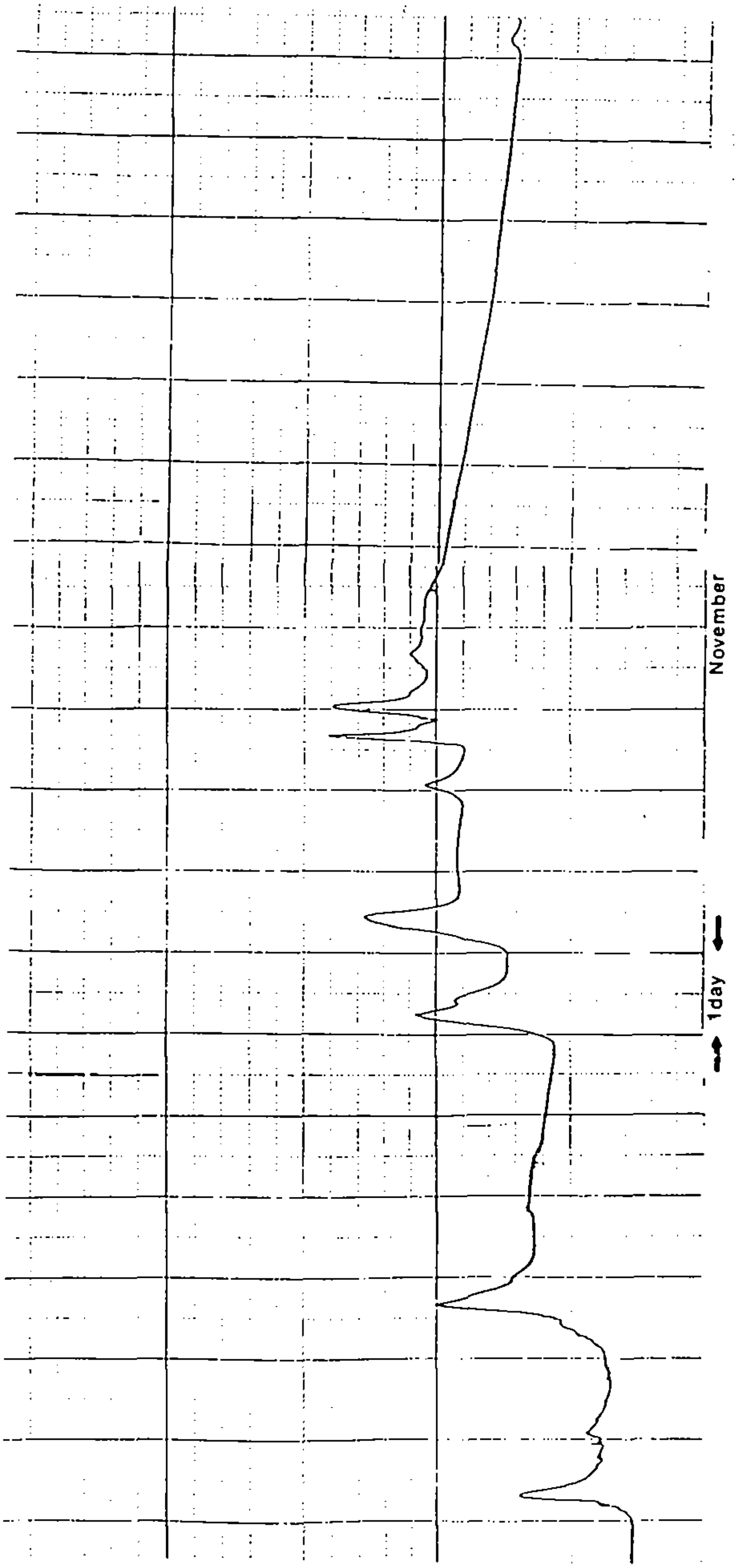
The Kenwyn and Allen catchments are underlain by rocks of Devonian age, predominantly slates and greywackes. The deposits were laid in an east-west geosynclinal trough and are known as the Gramscatho beds. Figure 2.2 shows that soils are predominantly typical brown earths of the Denbigh association (mostly Denbigh 1) consisting of brown, slightly stony clay loam (Findlay *et al*, 1984). These soils are permeable and naturally well drained and accept most winter rain. But temporary water storage capacity is limited by rock or, locally, compact drift at less than 80 cm depth which causes some runoff. Small amounts of cambic stagnogley soils of the Sportsmans association occur along parts of the watershed. These soils are moderately stony, gleyed and seasonally waterlogged.

2.3 HYDROLOGICAL CHARACTERISTICS

The hydrograph for part of November 1972 (Figure 2.3.1) illustrates many of the hydrological characteristics of the Kenwyn catchment. It can be seen that rainfall has two effects. Firstly, the hydrograph is dominated by a slow rise in base flow which lasts for many days before recessing slowly to a residual level. Secondly, there are short-lived, fairly steep rises, followed, within a few hours, by a recession to a slightly higher base flow level. The 1:25,000 O.S. map of the area shows a number of wells and springs along the water course. However, the hydrogeology of the catchment is not well understood. Geological survey records indicate that several exploratory boreholes sunk in the area have yielded little commercially exploitable water; thus there is no evidence for a large deep aquifer. Nevertheless sub-surface storage is clearly sufficient to delay runoff for several days on many occasions. Groundwater level data would have been very useful for this study.

Analysis has shown (Boorman, 1985) that the majority of the flood hydrographs contain only a small percentage (less than 10%) of the rainfall volume, due mainly to the permeable soils. There is no evidence of the import or export of water between catchments along mine-shafts or day-levels. The major proportion of rainfall supplies the slowly responding base flow component. The flow at the peak of the flood is therefore controlled by a combination of the quick response from immediately preceding rainfall and the slower response from rainfall several days earlier. Thus antecedent conditions are very important in the flood hydrology of this catchment. Large floods are

Figure 2.3.1 Hydrograph of River Kenwyn, November 1972



therefore less likely to occur in the summer when the antecedent conditions are usually dry. Historical records (Section 3) show that even when more than 50 mm of rainfall was recorded in one day in August 1959, no river flooding occurred.

The average annual rainfall for the Kenwyn catchment is around 1120 mm, for the standard period 1941-70. Just over 40% of the rain falls during the months November to February, with a further 20% falling in September and October (Bleasdale, 1971). These are therfore the critical months for flooding.

2.4 HYDRAULIC CHARACTERISTICS

Above the flow measurement station the catchment is predominantly rural and water levels are controlled by the natural variations in channel geometry and roughness. Within the city limits the river is confined within artificial banks (Figure 2.4.1).

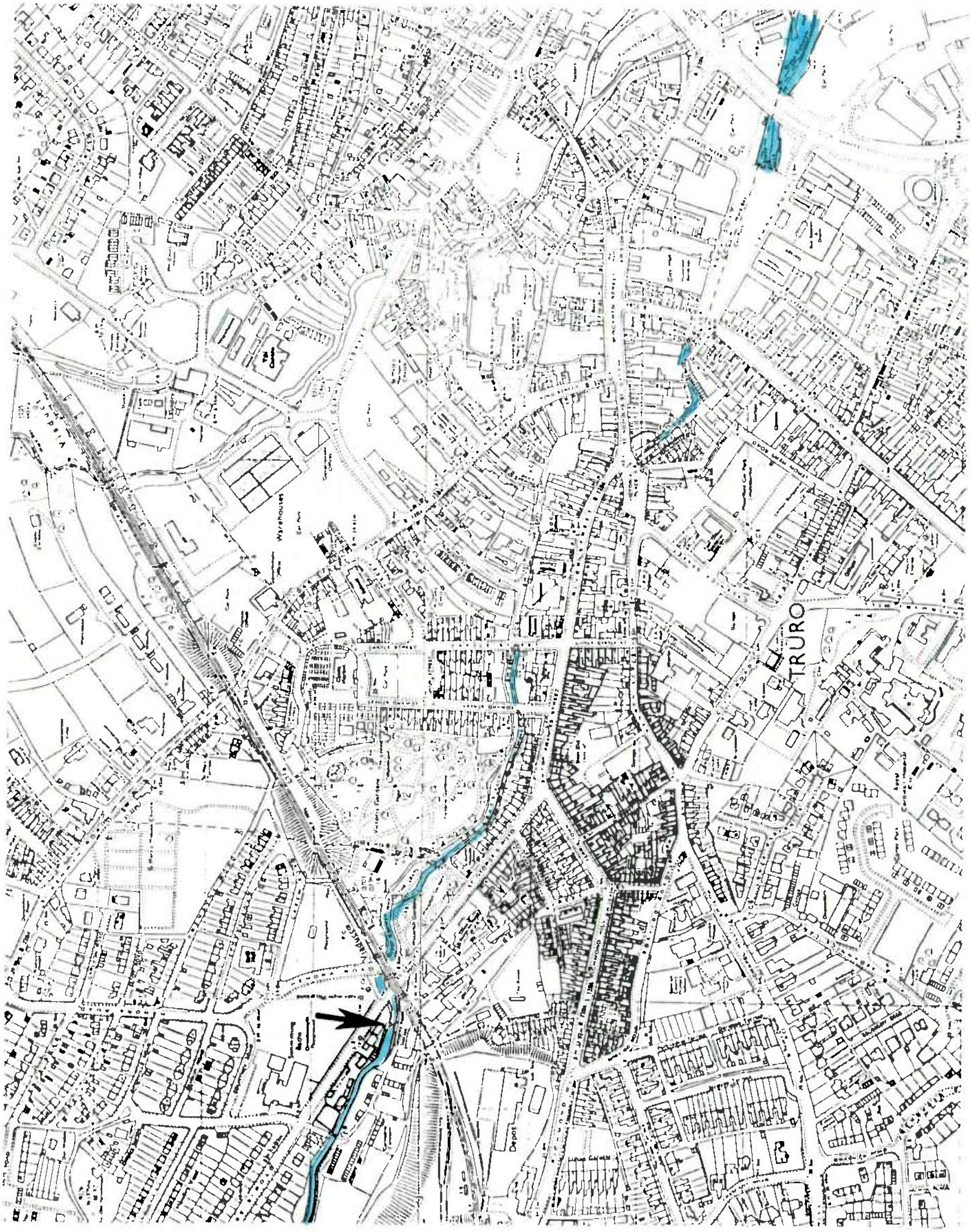
Some 200 m downstream of the gauging station, in Waterfall Gardens, a pair of sluice gates, which are normally closed, are used to provide sufficient head to supply water to the Truro leat system. These can be opened (raised) in times of flood. Below the sluices the river flows between a high right bank retaining walls and a vertical left bank which carries a footpath. The wall protects basement properties in St Georges Road which, given their very low level relative to the river bed, are at risk from surcharging drains and, more seriously, from failure of the wall.

Further downstream the river is culverted under the city centre for about 800 ft (325 m). The culvert was constructed in Victorian times, a period of major change in Truro with the development of River Street and the construction of St Georges Road. The original capacity of the culvert was around 15 m^3s^{-1}. Inevitably, silting occurred over the years and a major clearance operation was undertaken in February 1956 removing silt and debris from the culvert. Major structural improvements and maintenance were also carried out around 1971. In particular the tunnel was lined to improve its hydraulic efficiency and thus its capacity was increased to around 18 m^3s^{-1}. A debris screen in the Waterfall Gardens prevents material from entering the culvert and is regularly cleaned. The screen was, however, poorly designed and its blockage may have contributed to flooding upstream in the gardens on a few occasions.

Immediately below the city centre the river enters the tidal dock area. On a few occasions the coincidence of large flows and a high tide have caused flooding of properties adjacent to the docks. However, the gradient of the culvert is quite steep, thus confining the tidal influence to the reach immediately above the dock area. An analysis of the maximum water levels in this reach would require additional water level data and/or hydraulic modelling.

Some past flooding incidents reported in the press (see Section 3 below) appear to be a result of poor surface drainage within the city centre. Direct runoff from roofs and paved areas appears to be too great for the gutters and drains during heavy rainfall. While concurrent high water levels in the Kenwyn can aggravate surface drainage problems, the primary requirement for

Figure 2.4.1 Plan of Truro showing River Kenwyn and gauging station (arrowed).



their resolution would be hydraulic rather than a hydrological modelling analysis.

3. History of flooding in Truro

Severe floods which cause damage to property and disruption of traffic are almost invariably recorded in newspapers and journals. Furthermore these accounts often draw attention to previous floods. For example, a headline in the *West Briton Argus* (WBA), Monday, February 1st 1988 (following the January flood) read *Flashback to 1956* and showed a photograph depicting a scene in the city centre during a flood 32 years previously.

A search of the newspaper and journal archives in Truro and Redruth was undertaken by Richard Horrocks from South West Water. To concentrate the search effort a preliminary list of potential dates of flooding was compiled by analysing heavy rainfalls, from daily records available from 1890. As intimated in Section 2, there is no simple relationship between rainfall and flooding for the Kenwyn, therefore this list was used only as a rough guide. However, the threshold of rainfall was set sufficiently low to catch most floods.

The period from about 1830 to 1870 witnessed major changes in Truro with the development of River Street and the construction of St Georges Road and the culvert from Castle Street to downstream of Victoria Place. It would therefore be very difficult to compare the magnitude of floods before about 1870 with those later.

On 13th November 1875 'there was very heavy rain ... and the river rose ... so high that some houses in the lower part of the town were inundated' (Royal Cornwall Gazette, RCG, 20/11/1875). There is no mention of any tidal influence. Further flooding occurred on the following day but this was associated with a high tide.

Eight inches (203 mm) of rain fell during the 4th and 5th of October 1880; this was 'the greatest rainfall within human recollection'. 'Many houses in the city were flooded' (RCG 8/10/1880). The report does not say that flooding was a result of high river levels but this amount of rainfall would almost certainly have produced very high flows, unless the catchment was very dry, which is unlikely in October. Nevertheless, much of the flooding may have been due to surface drainage problems. A later edition of this newspaper (15/11/1894) says that 3.0 (76 mm) inches fell in 24 hours.

On 28th September 1882 'the tide rose very high and covered Green Street and rose into the cellars in Old Bridge Street' (West Briton 2/10/1882).

'The spring tide reached an unprecedented height' on 2nd February 1885 'flooding a number of businesses and causing great damage to property. About 7:30 there was water enough in Victoria Square to float a boat' (RCG 6/2/1885).

'During the week ending' 13th November 1894 'no less than 6.73 inches (171 mm) fell'. Between 9.00 am on 11th and 9.00 am on the 12th 'the fall amounted to 2.36 inches' (60 mm). Stressing the importance of wet antecedent conditions in causing floods on this catchment the article states that; the October 1880 storm 'had not such disastrous effects as the present, as it was not preceded by so much rain'. By the 12th 'the streams had risen to such an extent that the houses at the east side of St Georges Road were inundated, the shops in River Street ... were almost knee deep through the stream having become choked and forced its way through the floors of the houses' (RCG 15/11/1894). It is not clear whether choked means with debris or just too much water.

'In the early hours of ...' 6th February 1899 ' ... a heavy rain storm burst over Truro and district doing damage to property ... the street grates quickly became choked and water spread into the road and many houses in the lower part of the city were flooded'. This event was clearly dominated by poor surface drainage since 'the water rushed through the pottery yard *to* the river' (RCG 9/2/1899).

'There was a torrential downpour of rain in Truro during' the night of 7/8th October 1924. 'Water flowed down the River Allen with such force that ... it rose over the banks and ocaused the flooding of premises' (WB, 9/10/1924). There is no mention of flooding from the River Kenwyn.

In January 1956 an estimate of' '£5000 for the Truro anti-flood work' was suggested by the City Council. (WB & RCG, now a combined newspaper, 16/1/1956). By 6th February of that year, after 'clearing and removal of silt and debris from the 800-ft length of culvert beneath River Street ... 2,000 tons of soil had been taken away' (WB & RCG 6/2/1956).

On Christmas Day 1956 'Truro, the scene of four disastrous floodings in the last two years, was once again one of the places where the storm brought the most damaging floods ... The River Kenwyn rose rapidly and overflowed its channel ... in several houses in St Georges-villas water covered floors up past the skirting boards ... It was estimated that the river's rate of flow was 200,000 gallons a minute' (15 $m^3 sec^{-1}$). Antecendent conditions were again important 'Mr O'Farrell (City Surveyor) said that flooding ... was due entirely to the heavy rainfall on saturated land'. Residents voiced the same sentiments then as today about the irregular nature of the flooding; 'This is the fifth time in two years we have had the floods yet for 15 years before we never had the water in'. (WB & RCG, 27/12/1956). As yet reports on the previous floods mentioned have not been found.

'Truro had its wettest night on Monday (10th August 1959) since 1927 ... In all 3.1 inches (79 mm) fell with the result that water at various depths entered some business premises and private dwellings in different parts of the city' Again reference is made to floods in 1954: 'the flooding this time had a different cause from that of five years ago. Then the country was water-logged ... this time the deluge was too much for the drains' (WB & RCG, 13/8/1959) implying that the cause of flooding was surface drainage. Despite heavy rainfall, dry antecedent August conditions presumably helped to avoid river flooding.

The next accounts of flooding occurred after the building of the gauging *station on the Kenwyn. '1 1/2 inches (38 mm) of rain fell on the Truro area* on Monday (29th November 1971)' and the Water Boards 'welcomed the rain because underground supplies were starting to dry up'. These dry antecedent conditions suggest that 'flooding ... in the Truro area' (WB & RCG, 2/12/1971) was due to surface drainage problems, thus explaining why high flows were not recorded at the flow gauging station.

Flooding as a result of surface water also occurred in August 1975, August 1977 and October 1977. On 28th December 1979 'Torrential rain ... 3 3/4 inches (95 mm) in 48 hours ... turned Truro's normally placid River Allen into a raging torrent which overflowed its banks in the city centre' (WB & RCG, 3/1/1980). However, the Kenwyn appears not to have flooded despite recording the highest flow previous to 1988.

These accounts demonstrate that flooding is certainly a problem in Truro and has been for many years. However, many of the floods are due to poor surface drainage, sometimes aggravated by high tides, rather than river flooding *per se*.

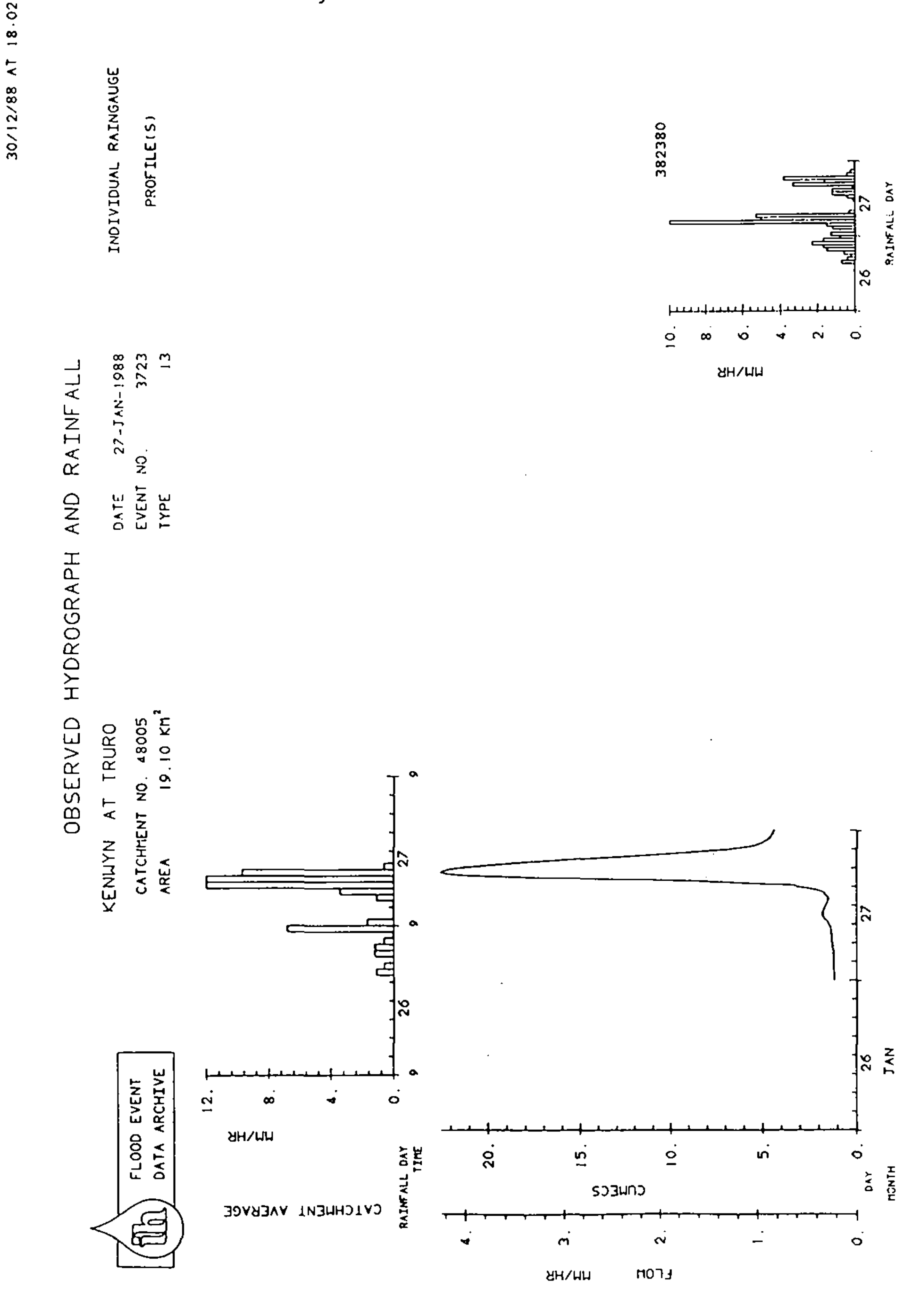
4. Accounts of the 1988 floods

27th January 1988

On the afternoon of 27th January 1988 heavy rain fell over much of central Cornwall. The highest daily fall recorded was 91 mm at Trevince, 10km WSW of Truro, whilst 58.1 mm was measured in Truro itself. A catchment average rainfall of 67 mm was calculated for the two day period starting at 9.00 hr 26th, using the Institute of Hydrology triangle method described by Jones (1982). This total was apportioned between the 24 hours using data from the Camborne weather radar. The catchment average rainfall hyetograph for the event is shown in Figure 4.1. The estimated rainfall for the five hours between 13.00 and 18.00 was 38.2 mm. Also shown in Figure 4.1 are the hyetograph recorded by the autographic gauge at Rosewarne, and the runoff hydrograph for the Kenwyn at the Truro gauging station, which peaked at 2.12 metres at 17.30 hrs. Extrapolation of the stage-discharge rating relationship to this level gives a flow of over 30 m^3s^{-1}. However, the peak flow was revised to 22.5 m^3s^{-1}, following evidence that the water level had been elevated by debris which had collected across the weir (Horrocks, 1988) . A post-flood survey of the city centre culvert found no evidence of obstructions or debris.

Further downstream the flood led to failure of the river retaining wall behind St Georges Road. The resultant rapid flooding of basement flats to a depth of 1.5 m, almost drowned one of its residents. At around 16.45 hrs the culvert beneath River Street reached capacity and approximately 50 commercial properties were flooded, some to a depth of over 0.5 m. The total cost of damage may exceed £1M. A preliminary assessment by South West Water put the return period of the flood at 350 years.

Figure 4.1 Observed hydrograph and catchment rainfalls 27 January 1988



11th October 1988

Heavy rainfall returned to Cornwall on the 10th and 11th October, following a week of widespread rain which had saturated the catchment. In Truro, 31.9 mm was recorded for the 24 hours up to 9.00 hr on the 12th. A catchment average rainfall for the two day period commencing 9.00 hr on the 10th was 45.1 mm. This total was apportioned amongst the 48 hours using data from the weather radar at Predannack. This profile apportions 32.5 mm to the five hours between 9.00 and 14.00 on the 11th October. The resulting event hyetograph is shown in Figure 4.2, together with that from the autographic gauge at Rosewarne. The level of the River Kenwyn reached 2.11 m at the gauging station at 15.15 hrs on the 11th, corresponding to a peak flow of almost 31 m^3s^{-1}. The flood hydrograph is shown in Figure 4.2.

A photograph of the gauging station was taken just after the peak of the flood (Plate 4.1), showing that water levels are very high both upstream and downstream of the measuring structure. If the road culvert was producing a back-water effect and causing drowning of the weir, the estimated peak flow should be decreased. Herschy *et al*, (1977) provides a diagram from which the drowned flow characteristics of Crump weirs can be calculated given the ratio of the upstream and downstream heads. Very approximate estimates of the heads were evaluated separately for each of the three weirs by comparing the photograph with the engineering drawings of the structure. The highest ratio estimated was for the central weir at just less than 0.8. The diagram shows that even at this ratio, the reduction factor is only around 0.97. For the two side weirs the ratio is smaller. Thus there is little evidence that the peak flow should be significantly reduced. The photograph also shows that some water is by-passing the structure since the level is slightly above the wing walls. It is likely that this unmeasured quantity may compensate for any over-estimate in flow due to drowning. Consequently, given the uncertainties in the calculation, unless a full hydraulic study of the flow conditions at the peak of the flood is undertaken, the estimate should not be altered.

The leat sluices had been raised on the evening of the 10th after a flood warning was issued. The high river flows led to a further failure of the retaining wall behind St Georges Road, immediately downstream of section recently re-built after the January flood, and one basement property was flooded. However, other flooding in the St Georges Road area appears to be have been primarily the result of surcharging drains. As in the January event, flooding in the city centre occurred once the capacity of the culvert had been exceeded. Plate 4.2 shows the culvert surcharging through access manholes. High tide was not until 18.00 hrs by which time the river levels had dropped.

Figure 4.2 Observed hydrograph and catchment rainfall 10 October 1988

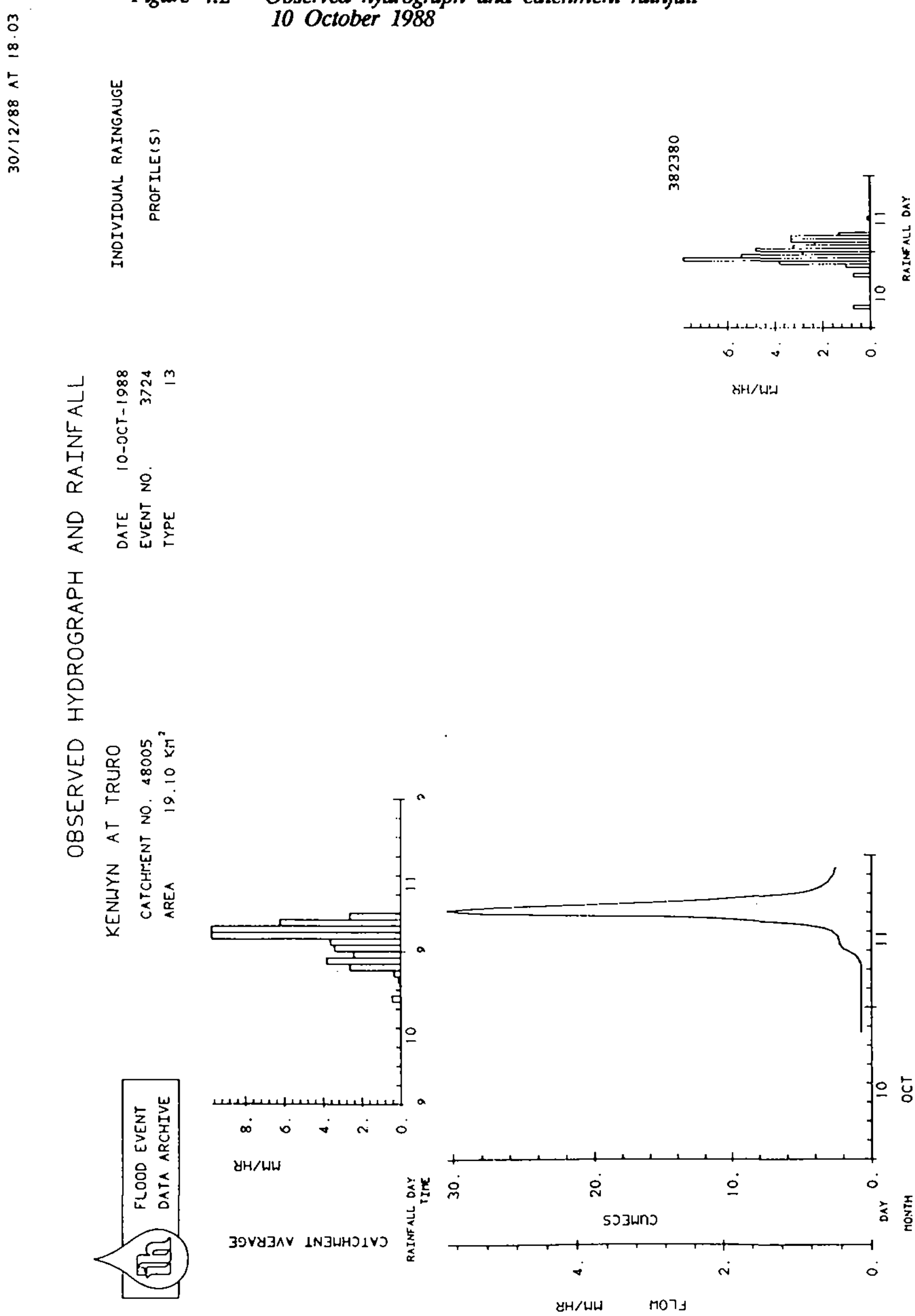


Plate 4.1 *River Kenwyn gauging station taken at just after the peak of the flood on 11th October 1988*

Plate 4.2 *Flooding in Truro city centre due to river culvert surcharging through access manholes*

5. Statistical analysis of flood peak data

The return periods of floods of various magnitudes can be estimated by performing a statistical analysis of the recorded flood data. Two types of flood data are available for statistical analysis of the River Kenwyn at Truro: firstly, the flood peaks which have been recorded at the Truro gauging station since it was built in 1968, and secondly details of historical floods recorded in newspaper and journals.

Annual maximum peak flows recorded at Truro gauging station

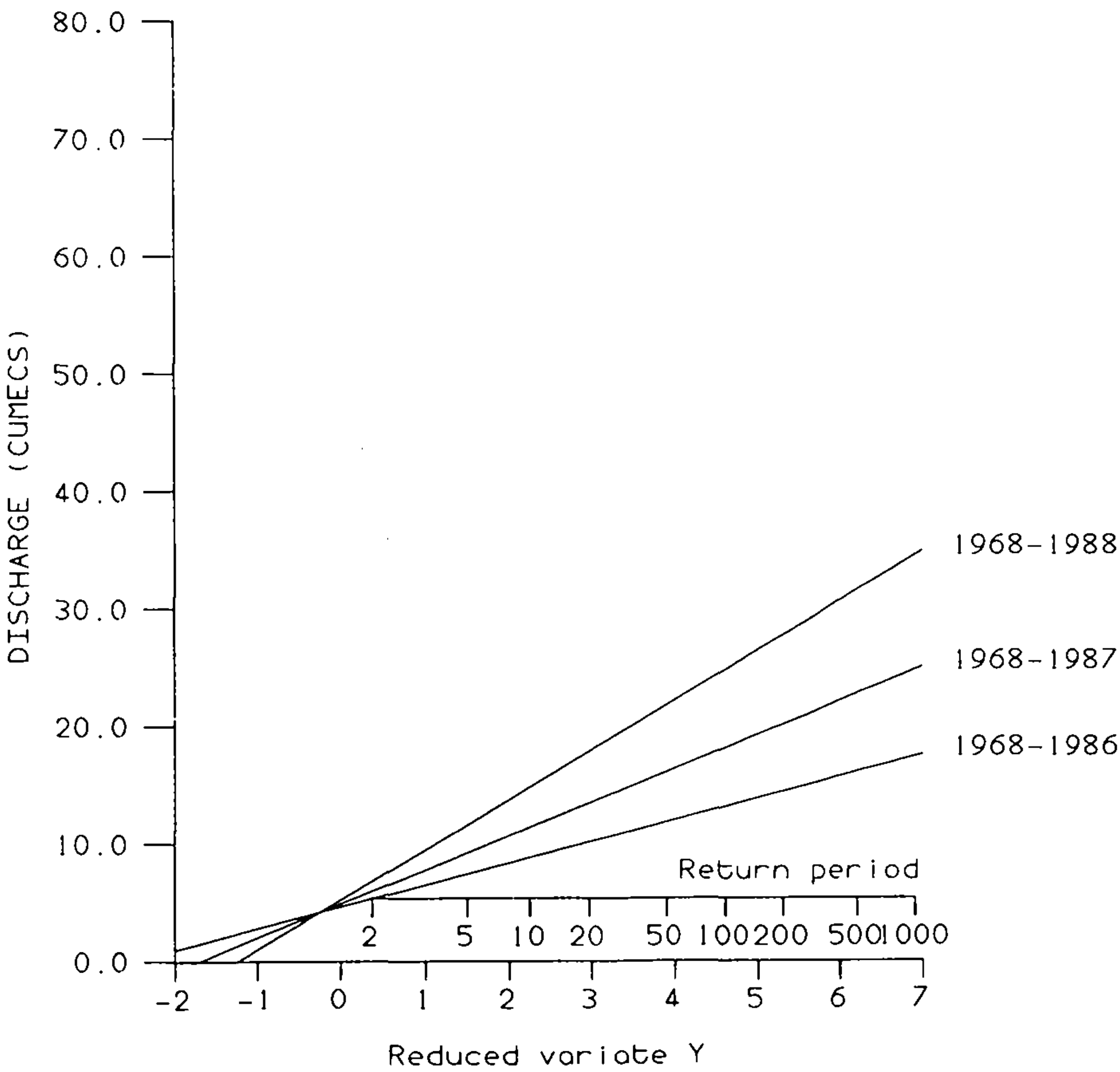
A complete series of flood events is available for the 21 years of operation of the Truro gauging station (1968-present). The *Flood Studies Report* (NERC, 1975) recommends that when between 10 and 25 years of data are available, floods up to return periods of twice the length of record may be estimated by fitting an extreme value type 1 (EV1) distribution to the annual maximum flood series. These annual maxima are given in Table 5.1 (both the January and October floods are included since they occurred in different water years).

Table 5.1 Annual maximum flood series for the Kenwyn

Water year	peak flow (m^3s^{-1})	date of flood	Water year	peak flow (m^3s^{-1})	date of flood
1968	4.58	12/ 1/69	1979	13.35	27/12/79
1969	4.94	17/ 1/70	1980	8.61	17/11/80
1970	3.08	22/11/70	1981	6.11	13/12/81
1971	6.74	29/11/71	1982	9.74	7/11/82
1972	5.36	19/ 1/73	1983	3.48	20/12/83
1973	5.74	10/ 2/74	1984	3.70	8/12/84
1974	4.79	19/ 1/75	1985	4.74	7/ 1/86
1975	5.74	21/ 3/76	1986	5.31	11/12/86
1976	3.31	5/12/76	1987	22.50	27/ 1/88
1977	6.97	9/12/77	1988	30.37	11/10/88
1978	3.35	6/ 2/79			

For greater return periods the mean annual flood should be calculated from the data and regional growth factors applied. Table 5.2 shows the variations resulting from applying these recommendations before, between and after the two floods. The growth factors are those produced by Whiter (1984) as part of a revision of the flood frequency estimation procedures for the South West region using the *Flood Studies Report* methodology. Graphs of the EV1

Figure 5.1 *Extreme value type 1 distributions fitted to annual maximum data for periods shown.*



quantiles are shown in Figure 5.1.

Table 5.2 Statistical analysis of annual maximum floods

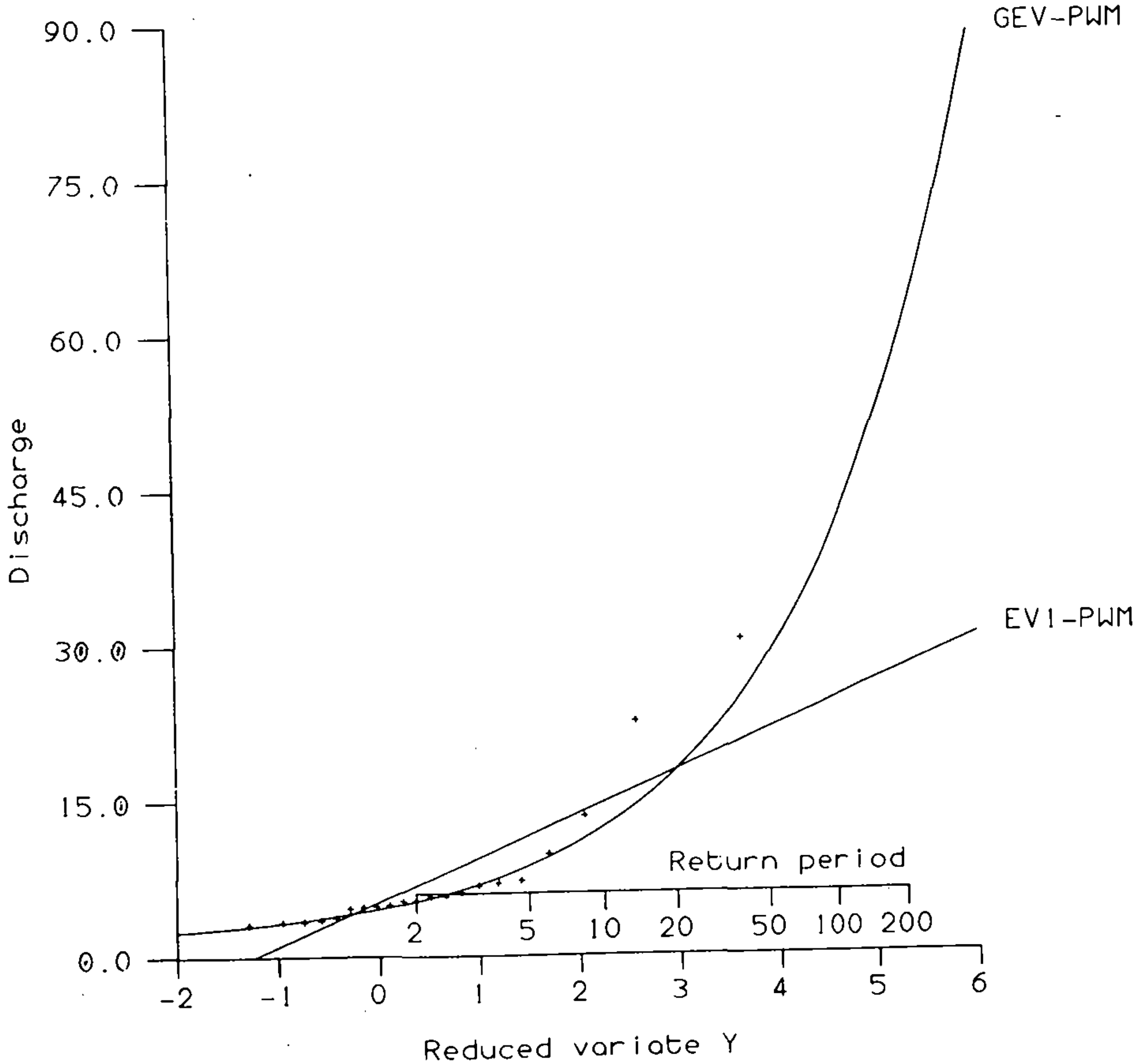
	before January flood	after January flood	after October flood
Record length (years)	19	20	21
Maximum flood (m^3s^{-1})	13.35	22.50	30.37
Mean (m^3s^{-1})	5.70	6.54	7.67
Median (m^3s^{-1})	4.94	5.12	5.31
CV	0.41	0.65	0.84
Skewness	1.30	1.78	2.07

return period	growth factor	mean + growth	EV1	mean + growth	EV1	mean + growth	EV1
2	0.93	5.3	5.3	6.1	5.9	7.1	6.8
5	1.28	7.3	7.4	8.4	9.2	9.8	11.6
10	1.58	9.0	8.8	10.3	11.3	12.1	14.8
25	2.03	11.6	10.5	13.3	14.1	15.6	18.8
50	2.45	14.0	11.8	16.0	16.1	18.8	21.7
100	2.93	16.7		19.2		22.5	
200	3.41	19.4		22.3		26.2	
500	4.13	23.5		27.0		31.7	

The *Flood Studies Report* also stipulates that if any flood is greater than three times the medians (as is the case for both the 1988 floods) it should be considered as an outlier. In which case the conventional estimate of the mean, the arithmetic average, should be replaced by 1.07 times the median, since this is not influenced by the outlier. The value of 1.07 is the average ratio of the median to the mean for all stations in the UK which do not contain outliers in their annual flood series. However, if the period of record is considered to be representative of the long-term flood regime the arithmetic average should be retained.

Arguments for and against the outlier categorisation can be circular; if the weighted median is used the return period of the event increases, thus the justification for declaring the flood as an outliers also improves. Contrarily, if the arithmetic average is used the assessed return periods is less extreme and the flood may not be seen as an outlier.

Figure 5.2 Comparison of EV1 and GEV distributions fitted to annual maximum data 1968-1988



The flow regime on the Kenwyn is somewhat similar to those of catchments underlain by chalk. Percentage runoff is low during most events, but occasionally a heavy rainfall coincides with a responsive, saturated - or frozen as in the case of the Great Till flood (Cross, 1967) - catchment and a large flood results. Thus, the occurrence of one or two events in the flood series which are much greater than the remainder does not necessarily render them outliers. not in Refs.

On balance is was considered reasonable to use the arithmetic mean annual flood. In this case the return periods of the January and October floods using the mean annual flood/regional growth curve method would be 100 and 400 years respectively. Use of the EV1 distribution implies that, for the January flood, it should be closer to 50 years, whereas the October flood is beyond safe extrapolation of the method.

If the period of record is considered to be representative of the long term flow regime, an improved estimate of the return period of the floods may be calculated by fitting a generalised extreme value (GEV) distribution to the annual floods. The results from fitting this distribution by the method of probability weighted moments (PWM) are given in Table 5.3, and shown graphically in Figure 5.2 together with the results from fitting the EV1 distribution.

Table 5.3 Flood quantiles from fitting GEV by PWM (1968-1988)

return period	peak flow (m^3s^{-1})	return flow	peak flow (m^3s^{-1})
5	8.67	50	28.82
10	12.41	100	41.72
25	19.99		

Analysis of historical peak flows.

The history of flooding in Truro, described in Section 3, provides information which can be used to make additional estimates of flood frequency. Unfortunately data pertaining to previous floods were not collected in an objective manner, such as referencing peak water levels to a fixed datum, and therefore individual events may not be strictly comparable. Nevertheless techniques are available which can utilise historical information to refine estimates of the long-term flood frequency distribution. Several assumptions need to made when analysing the data. Firstly, all floods above a given threshold flow or level would have been recorded in some way. This is not unreasonable in a city such as Truro where flooding makes news in the local paper. An exhaustive search would involve scanning every page of every newspaper - but, as described in Section 3, rainfall data were used to indicate potential dates. Clearly the historical data collected must be restricted to floods caused by excess river flows. Unfortunately newspaper accounts do not always differentiate between flooding from blocked or inadequate surface drains and river flooding. The second assumption is that there is a consistent relationship between level and flow so that the events are hydrologically comparable. Clearly, the dredging of the culvert in 1956 and the improvements carried out in 1971 will have increase its capacity; thus similar events before and afterwards would have resulted in different levels of flooding. A summary of the history of flooding in Truro, described in Section 3, is given in Table 5.4.

Table 5.4 Summary of flooding history in Truro 1830-1987

Date	Subjective assessment
c 1830-1870	Development of River Street, construction of St Georges Road and culvert.
13 November 1875	Gales and floods. High tide.
4/5 October 1880	Heavy rain. Surface water ?
28 September 1882	High tide.
2 February 1885	Extreme tide.
12 November 1894	Serious flood. Wet catchment.
6 February 1899	Heavy rain. Surface water ?
7/8 October 1924	Heavy rain. Mainly River Allen.
1954-1955 ?	Reference to floods, details yet to be confirmed
1956	Improvements to culvert, removal of silt.
25 December 1956	Flooding St Georges Villas.
10/11 August 1959	Heavy rain. Surface water ?
1971	Hydraulic improvements, culvert capacity increased
29 November 1971	Heavy rain. Surface water.
8 August 1975	Thunderstorm. Surface water.
? August 1977	Heavy rain. Surface water.
? October 1977	Heavy rain. Surface water.
27/28 December 1979	Flooding of River Allen.

A number of possible interpretations can be placed on the worst floods which have occurred on the River Kenwyn since the C19th.

1) Between 1870 and 1967 only one event, that of 1894, exceeded 18 m^3s^{-1},
2) Between 1870 and 1967 there were only two events, 1894 and 1955, which exceeded 18 m^3s^{-1}.

3) Between 1870 and 1967 there were only three events, 1894, 1955 and 1956, which exceeded 15 m^3s^{-1}.

4) Between 1870 and 1967 there were only two events, 1894 and 1955, which exceeded 20 m^3s^{-1}.

5) Between 1850 and 1967 there were only two events, 1894 and 1955, which exceeded 18 m^3s^{-1}.

The hydrological consequences of each of these scenarios can be investigated by fitting a GEV distribution to the historical data combined with the annual maximum flood peaks recorded at the gauging station by the method of maximum likelihood. The methodology is similar to that described by Leese (1976). The information required comprises a threshold flow value above which all floods are recorded, the number of floods which exceeded the threshold and the length of the historical period. The exact magnitudes of the historical flood peaks are not required. The results are given in Table 5.5.

Table 5.5 Estimates of flood quantiles (m^3s^{-1}) using historical flood data

Return period	Scenario 1	2	3	4	5
	1 1870	2 1870	3 1870	2 1870	2 1850
	> 18	> 18	> 15	> 20	> 18
10	10.0	10.6	10.4	11.1	10.3
25	14.6	16.1	15.7	17.1	15.3
50	19.4	22.1	21.5	24.0	20.7
100	25.9	30.6	29.6	33.7	28.4

The sensitivity of the historical data method to changing the threshold, length of historical record and number of exceedences can be seen in Table 5.5. Scenarios 2 and 3 are perhaps the most likely, suggesting that the return period of the January flood is approximately 50 years and that for the October flood is around 100 years. Because of the form of the resulting distribution (the estimated value of the GEV parameter k is -0.49) the return period of the mean annual flood is around 1.1 years.

6. Rainfall-runoff analysis

An alternative approach to the purely statistical method of flood frequency analysis described above is the rainfall-runoff technique. This involves applying design rainfall inputs to a rainfall-runoff model of the catchment in order to produce floods of various return periods. This approach is often favoured by engineers, since the model parameters have a physical meaning, thus allowing easier application of hydrological knowledge of the catchment. Full details of the method are given in the *Flood Studies Report* and *Flood Studies Supplementary Report* 16 The model has two fundamental parameters, percentage runoff (PR), which controls the volume of rainfall which runs off as the flood flow, and the time-to-peak (Tp) of the unit hydrograph, which controls the relative rates of runoff through the event. The percentage runoff part of the model consists of two components (i) a constant term for the catchment (SPR) and (ii) two dynamic terms which increase PR with storm rainfall depth (DPR_{CWI}) and antecedent catchment wetness (DPR_{RAIN}).

$$PR = \underbrace{(\ SPR\ )}_{\text{constant component}} + \underbrace{(\ DPR_{RAIN} + DPR_{CWI}\ )}_{\text{dynamic component}} \tag{6.1}$$

where

$$DPR_{CWI} = 0.25\ (CWI-125)$$

$$DPR_{RAIN} = 0.45\ (P-40)^{0.7} \quad \text{for } P > 40 \text{ mm}$$

$$DPR_{RAIN} = 0 \quad \text{for } P \leq 40 \text{ mm}$$

In the absence of flow data, SPR can be estimated from the proportions of the catchment underlain by soil of five classes (S1 ... S5, Figure 6.1) based on their winter rain acceptance potential (WRAP).

$$SPR = 10\ S1 + 30\ S2 + 37\ S3 + 47\ S4 + 53\ S5 \tag{6.2}$$

P is the total precipitation and CWI is an antecendent catchment wetness index

$$CWI = 125 + API5 - SMD \tag{6.3}$$

SMD is the soil moisture deficit at the start of the storm and API5 is an antecendent precipitation index of the previous five days rainfall. It is usually preferable to use estimates of SPR and Tp from events recorded on the catchment of interest. As part of a revision of the parameter estimation equations, Boorman (1985) presents results for the analysis of 10 events on the Kenwyn. The flow hydrographs and rainfall hyetographs are given in Appendix I. Seven of these events and the two floods of 1988 were chosen for further analysis. Those discarded were found to have poor quality data. Details of the updated results from the analysis of the nine events are given in Table 6.1.

It can be seen that PR is less than 20% for all events except the 1988 floods.

These findings are comparable with values of percentage runoff evaluated for five events by MacGregor and Cameron (1977), as part of a unit hydrograph study of five Cornish catchments, which ranged from 6% for a July event to 20% for a January event. It is important to note that all these events were small, in terms of peak flow, when compared with the 1988 events; see the peak flow column in Table 6.1.

Table 6.1 Results of event analysis

Date	Rainfall Dur	Rainfall Tot (mm)	Flow Peak ($m^3 s^{-1}$)	Lag (hr)	PR	SMD (mm)	AP15	SPR	TpO (hr)
25-Apr-69	23	21.1	2.3	4.2	10.1	0.0	3.1	9.3	1.4
18-Dec-71	9	18.3	1.6	2.9	5.7	0.0	1.8	5.3	1.5
18-Jan-73	35	44.5	4.3	3.2	17.9	0.0	2.1	16.1	4.5
10-Nov-74	10	19.1	2.5	3.2	11.3	0.0	2.5	10.7	2.2
20-Jan-75	8	12.3	4.4	2.8	19.1	0.0	8.1	17.1	0.7
16-Aug-75	17	23.6	1.2	1.6	5.4	95.3	11.2	26.4	1.5
13-Sep-75	20	59.5	3.7	3.3	7.4	75.9	5.2	21.5	2.7
27-Jan-88	18	52.0	22.5	3.1	37.2	0.0	8.8	32.4	1.2*
27-Jan-88	17	49.3	22.5	5.6	42.1	0.0	9.0	37.7	3.4
10-Oct-88	14	44.8	30.4	4.3	42.2	0.0	11.5	38.0	3.3*
10-Oct-88	14	44.3	30.4	6.4	45.3	0.0	11.9	41.1	

* Rainfall profile from weather radar data

The 1988 floods were not particularly extreme in terms of rainfall intensity. The critical duration of rainfall for this catchment is about five hours. The *Flood Studies Report* gives the 5 year return period, 5 hour rainfall as 31 mm, the 10 year as 37 mm and the 20 year as 44 mm. The January storm, for which the maximum five hour rainfall was 38.2 mm, thus has a return period of around 12 years whilst the October storm (32.5 mm) would occur once, on average, about every 7 years. Both are considerably more frequent than the resulting floods. A further contradiction is that the peak flow for the January event was less than that for the October flood. Thus 5-hour storm rainfall intensity is not the only important flood producing mechanism. This is clear from the event of 13th September 1975 which exceeded both 1988 events in terms of rainfall but only resulted in a peak flow of 3.7 m^3s^{-1} due to a high SMD and low API.

The hydrological description of the catchment (Section 2) and the accounts of historical flooding (Section 3) emphasise the role of antecedent rainfall, an index of which is API (given in Table 6.1), in percentage runoff and flood generation.

The *Flood Studies Report* rainfall-runoff method was applied to the catchment using the microcomputer package micro-FSR (Boorman, 1988). A value of 2.4 was used for Tp with the time interval, T, equal to 0.5 where

$$Tp = Tp0 + T/2 \qquad (6.4)$$

Two values of SPR where employed. The parameter estimation equation (6.2) gives SPR as 30%. This value provides a compromise between lower values for the small floods analysed and the two events of 1988 (see Table 6.1). Flood quantiles were also evaluated using an SPR value of 35 which is an average of the two 1988 events, and perhaps more representative of the floods of higher return periods. The results are given in Table 6.2.

Table 6.2 Estiumates of flood quantiles (m^3s^{-1})*from rainfall-runoff method*

Return period	Tp 2.4 hr SPR 30%	Tp 2.4 hr SPR 35%
5	14.3	16.5
10	17.4	20.1
20	20.8	23.8
30	22.6	25.8
50	25.6	29.2
100	29.4	33.5

Full details of the calculations for the 50 year return period floods are given in Appendix III. A value of 6% was used for the urban area, even an increase of 1% would only increase the 1000 year flood by 0.5 m^3s^{-1}. It is concluded that the degree of recent urban development in the catchment is not sufficient to significantly affect flood flows. These results suggest that the January flood had a return period of around 17 to 30 years whilst the October flood would be exceeded once, on average, every 70 to 110 years.

7 Analysis of daily rainfalls

Daily rainfall depths are available for Truro from the 1890's to the present. If some index of flood producing rainfall could be derived then the return period of the 1988 floods could be estimated in terms of this index. As discussed earlier in several places, antecedent rainfall is clearly important given the pervious nature of the catchment. However, there is no obviously simple relationship between rainfall and flood magnitude. To examine the kind of relationship which might be suitable, an antecedent rainfall index, ARI, was calculated for each day of the flow gauging record from the daily rainfall data using the equation

$$ARI_d = P_d + k.P_{d-1} + k^2.P_{d-2} + k^3.P_{d-3} \ldots \qquad (7.1)$$

$$= P_d + k.ARI_{d-1}$$

Three trials were undertaken using values of k equal to 0.8, 0.85 and 0.9. The 45 largest ARIs in each run were assembled in rank order. The dates of all flood peaks recorded at the gauging station before 1988 which reached over

4.0 m^3s^{-1} were also assembled and ranked according to peak flow. In each of the three trials only five of the 10 largest floods appeared in the top 45 ARIs. The poor performance of this method may be due to the fact that although the daily rainfall totals are suitable for antecedent rainfall indices up to the beginning of the day of the flood, the event itself may be generated by a short duration, high intensity rainfall which is not significant as a daily fall. As mentioned in Section 6, the critical rainfall duration for the Kenwyn is around five hours. Therefore, the most suitable antecedent rainfall index may consist of a combination of the several days rainfall previous to the day of the event and the maximum five hour rainfall during the event. Unfortunately, hourly rainfalls are not available for a sufficiently long period on the Kenwyn to be able to test this hypothesis.

DISCUSSION

The most recent recorded event which caused river flooding prior to 1988 was, most likely, in 1956. The highest flow accurately measured before 1988 was 13.6 m^3s^{-1}, well within the capacity of the city centre culvert. Consequently, residents of the city, the many of whom will have moved into the area since 1956 would, before January 1988, have assumed that Truro had no river flooding problem, and others may simply have forgotten. It is not surprising, therefore, that many residents were somewhat alarmed to experience two large floods with 10 months. The small degree of urbanisation of the catchment is not sufficient to have caused a significant change in its response. Other characterisitics of the catchment, such as land use practices do not appear to have altered for many years; there is little evidence of wide spread artificial drainage, afforestation or mining. Despite evidence for global temperature changes, it is unlikely to have been sufficient to have altered the climate of Cornwall to such an extent as to radically change the flood frequency. Thus, there is no reason to suppose that the two 1988 floods were not simply chance occurrences. Indeed, the historical evidence indicates that flooding has been a problem in the past, with at least one (1894), and maybe two or more (1955 and/or 1956), major floods in the last 100 year. The likelihood that these events may be equalled or exceeded in the future has been assessed by a frequency analysis of the available information.

Table 7.1 Summary of return period estimates

Method	January	October
Statistical; mean annual flood/growth curve	100	380
Statistical; EV1	50	
Statistical; GEV	30	60
Statistical; historical record	50	100
Rainfall-runoff	17-30	70-110

Table 7.1 summarises the results from the different methods employed, these are displayed graphically in Figure 7.1. Each of the methods has its advantages and drawbacks. The GEV distribution fitted to the annual maximum data recorded at the gauging station produces the steepest curve. It is likely that these data are broadly, but not entirely, representative of the long term flood regime.

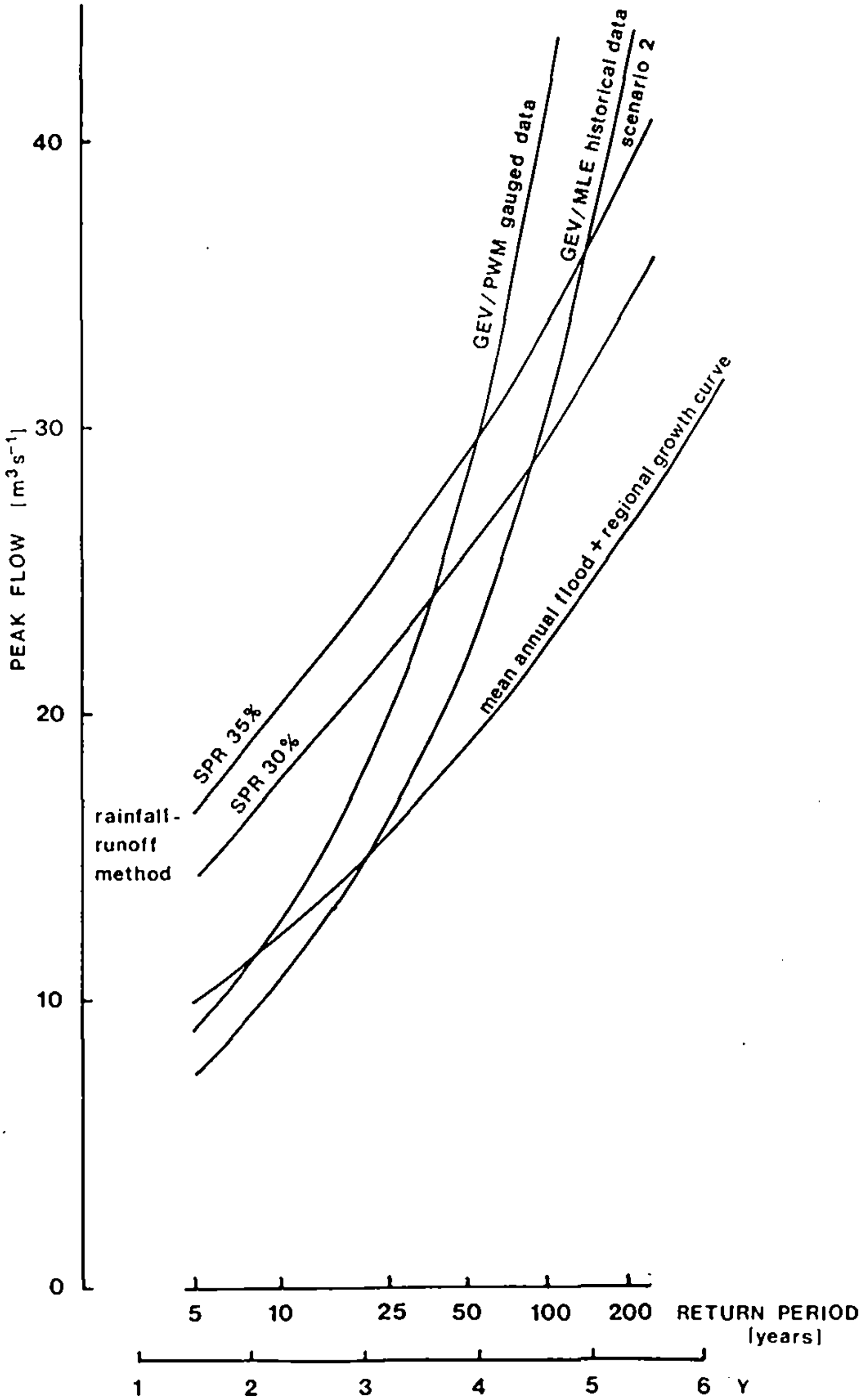
The rainfall-runoff method produces flood frequency curves which are much shallower. This is probably due to an inadequate API term in the percentage runoff model (Eq 6.1). It appears that this catchment is particularly sensitive to the antecedent conditions. The curve in Figure 7.1 results from employing a fairly high SPR. It may be more reasonable to use a lower SPR and a higher multiplying factor than 0.25 in the DPR_{CWI} term. This would reduce the magnitude predicted for the more frequent floods but increase the steepness of the flood frequency curve. Unfortunately, there are insufficient data for the catchment to justify recalibration of the CWI model.

Use of the regional growth curve/at-site mean annual flood method relies on the other catchments in the South West region being similar to the Kenwyn in terms of their flood frequency distributions. However, there is considerable variation in other hydrological parameters within the region, such as BFI (0.27-0.72, Institute of Hydrology, 1988) which is closely (inversely) related to percentage runoff. BFI for the Kenwyn is given as 0.66. The Kenwyn perhaps has a steeper, than regional average, growth curve due to flood generation resulting from the joint occurrence of a wet catchment and intense rainfall. Another problem is that the method is sensitive to the classification of the 1988 floods as outliers, or not, which significantly affects the at-site estimate of the mean.

A major problem with using the historical data for flood frequency analysis is that there have been changes in the hydraulic properties of the culvert to increase its capacity. Thus all historical events are not strictly comparable. Nevertheless, the 2nd and 3th scenarios presented in Table 5.5 are not unreasonable and provide the best estimates of the return periods for the two floods.

The flood hazard, as far as it is perceived by the riparian inhabitants is a result of the interaction of the hydrology, hydrgeology and the hydraulics of the catchment. Clearly, however great the the river flow is, if it stays within the channel it poses no risk, and is not classified as a flood. Flooding in St Georges Road may be decreased by strengthening the wall. The solution for the city centre is not so easy. Increasing the size of the culvert would not be financially feasible. A suitable option for a flood alleviation scheme would be a storage area for flood waters upstream of Truro. This would give a level of protection up to the chosen design standard, which may be the 200 year flood, or perhaps the October flood.

Figure 7.1 Summary of Flood return period estimates



8. Application of results to River Allen

The River Allen has also been known to cause flooding in Truro. Notable examples are the events of 7/8th October 1924 and 28th December 1979 (see Section 3 for details). Clearly, results from the analysis of floods on the River Kenwyn can be useful in estimating the flood frequency distribution of the Allen; they are geographically proximate and have similar land use and rainfall regimes. *Flood Studies Supplementary Report 13* details how best to approach the use of this local data.

Table 8.1 Comparison of soil types between the Rivers Kenwyn and Allen

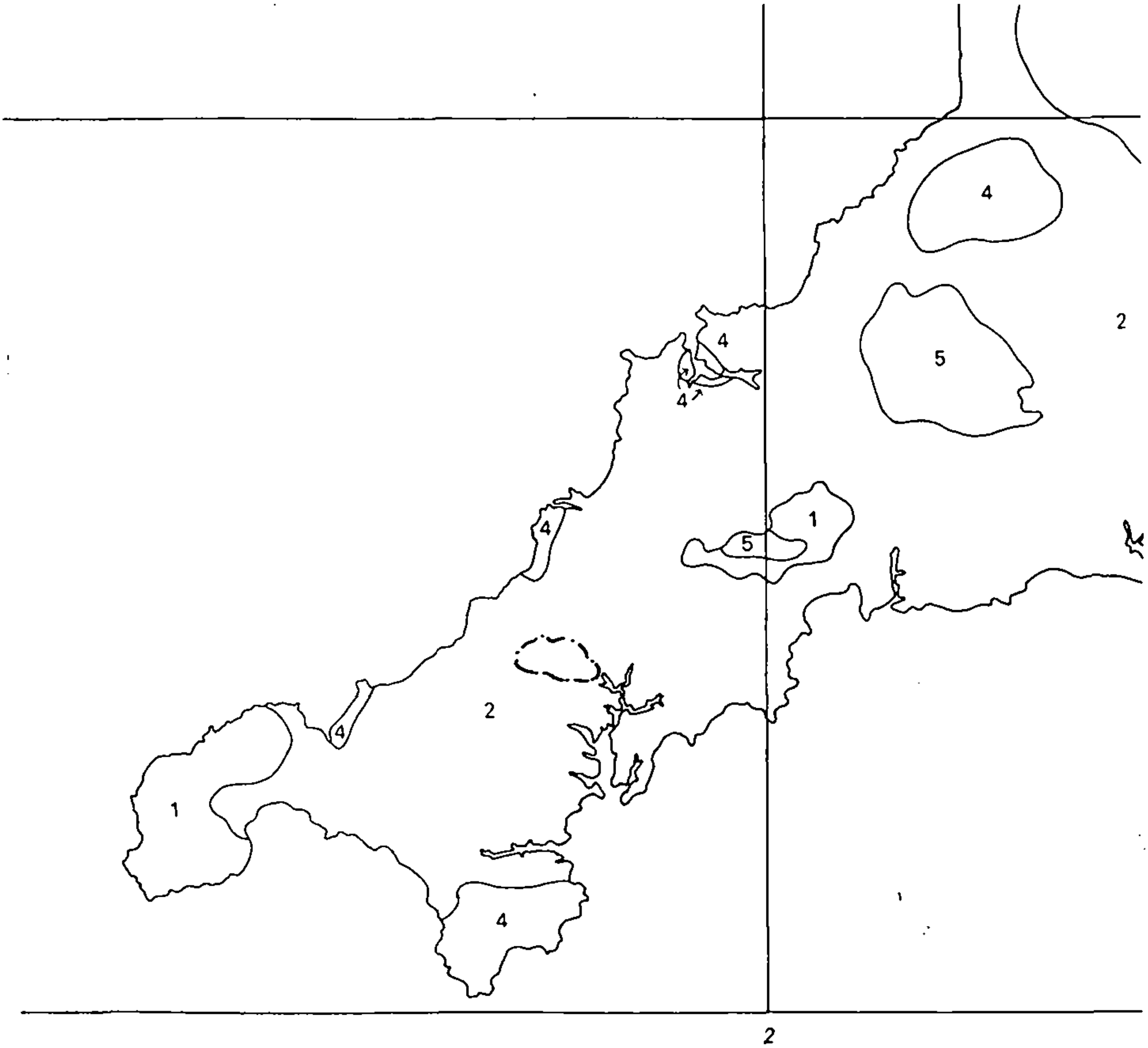
	River Kenwyn		River Allen	
	km^2	%	km^2	%
Denbigh 1	3.	15.8	4.	14.8
Denbigh 2	12.	63.2	18.	66.7
Sportsman	3.	15.8	1.5	5.5
Manod			1.5	5.5
Yeollandpark			1	3.7
Unclassified (Urban)	1.	5.3	1	3.7

The drainage area of the Allen near to Truro city centre is around 27 km^2 (depending on the exact location). Table 8.1 shows the extent and percentage of the catchment underlain by soils of different associations, as given by Findlay *et al* (1984). A map depicting their spatial extent is shown in Figure 2.2. The most striking aspect is that both catchments are dominated by approximately equal percentages of soils of the Denbigh type. This supports the information in Figure 6.1 which shows that both catchments have similar WRAP class soils according to that classification. Given the similarity in both soils and geology, it is likely that the flow regimes are similar in terms of sub-surface storage and percentage runoff.

Since the rainfall-runoff model is felt to be inadequate to model the flood frequency behaviour on the Kenwyn, it is perhaps advisable to use a statistical method of analysis on the Allen. The *Flood Studies Report* gives an equation for estimating the mean annual flood, $\bar{Q}$, from catchment characteristics.

$$\bar{Q} = 0.0284\ \mathrm{AREA}^{0.94}\ \mathrm{STMFRQ}^{0.27}\ \mathrm{SOIL}^{1.23}\ \mathrm{RSMD}^{1.03}\ (1+\mathrm{LAKE})^{-0.85}\ \mathrm{S1085}^{0.16} \quad (8.1)$$

Figure 6.1 WRAP classification of soils in Cornwall



Using this equation, together with the catchment characteristics given in Appendix 2, gives a $\bar{Q}$ estimates of 8.1 m^3s^{-1} for the Kenwyn. The annual maximum flow data (Table 5.2) suggests that this figure should be nearer to 7.7, thus the equation is overpredicting by a factor of 1.05. Once the location has been chosen on the Allen at which flood estimates are required, the physical characteristics of the catchment, including slope and stream frequency can be calculated . Equation (8.1) can then be used to provide a first estimate of $\bar{Q}$. This figure can then be divided by the scaling factor (1.05) if it is felt that the catchments are fairly similar in terms of their other physical characteristics. To estimate floods of less frequent occurrence the best estimate of $\bar{Q}$ should be increased by multiplying it by the appropriate growth factor. This growth factor can be selected either from the South West regional growth curve or from a growth curve derived by dividing the flood quantiles for the Kenwyn catchment by 7.7. The choice will again depend on the similarity between the catchments indexed by their physical characteristics. It is recommended that the Kenwyn growth curve is only used for floods up to a return period of 100 years.

9 Conclusions

The city of Truro experienced two large floods in 1988 from the River Kenwyn. Evidence is available to be able to assign a wide range of return periods to the two floods. Statistical analysis of the historical information probably provides the best estimate of the flood frequency curve.

This assigns return periods of 50 and 100 years to floods of 22.5 and 30.37 m^3s^{-1} which are the estimated peak flows for the January and October floods respectively (Table 9.1). The probability of getting a 100 year and a 50 year flood in any two consecutive water years is 0.004 (or 1 in 2500). Thus the occurrences in 1988 were exceptional but not implausibly so.

Knowledge of the Kenwyn's flood regime can be useful for flood frequency estimation on nearby catchments such as the Allen which also drains through Truro.

Table 9.1 Estimates of flood quantiles and growth factors of the River Kenwyn

Return period years	Peak flow $m^3 s^{-1}$	Growth factor based on $\bar{Q}$ = 7.7
10	10.6	1.38
25	16.1	2.09
50	22.1	2.87
100	30.6	3.97

10 Acknowledgements

Invaluable comments and criticism were provided by Dr D W Reed of the Institute of Hydrology. Richard Horrocks of South West Water researched the historical data and contributed his personal knowledge of the catchment and its problems.

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Appendix 1

FLOW HYDROGRAPHS AND RAINFALL HYETOGRAPHS
FOR EVENTS EVENTS ANALYSED

OBSERVED HYDROGRAPH AND RAINFALL

FLOOD EVENT
DATA ARCHIVE

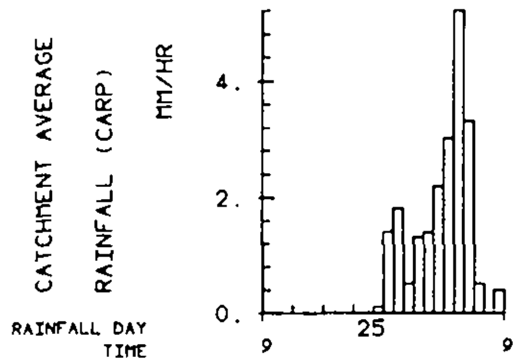
KENWYN AT TRURO

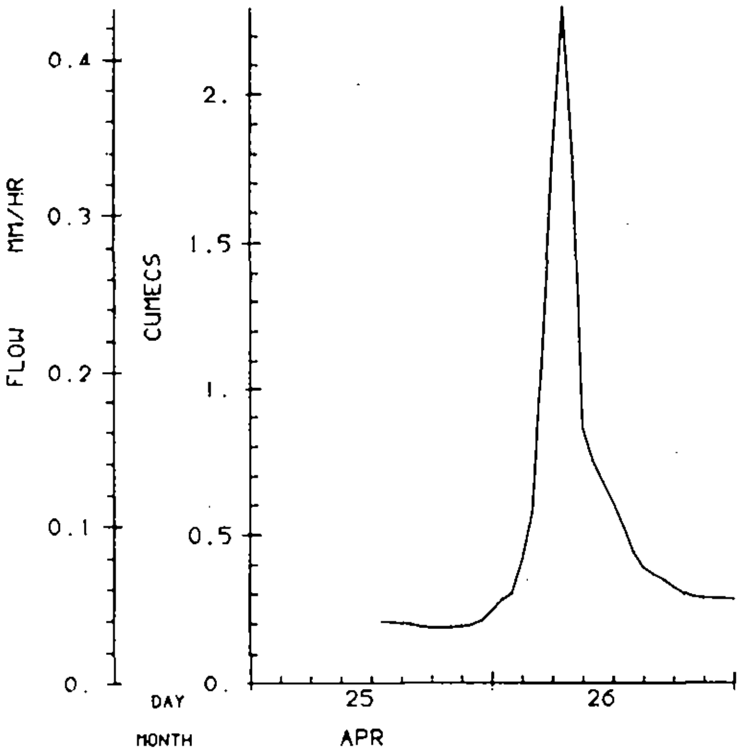
CATCHMENT NO. 48005
AREA 19.10 KM^2

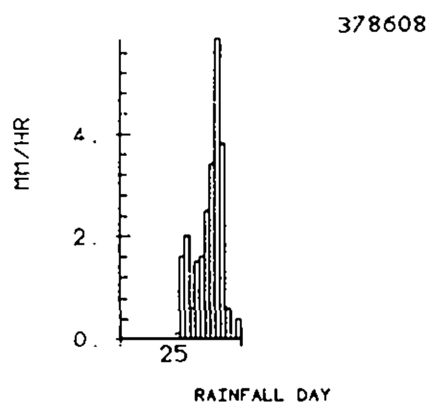
DATE 25-APR-1969
EVENT NO. 1388
TYPE 12

INDIVIDUAL RAINGAUGE

PROFILE(S)







OBSERVED HYDROGRAPH AND RAINFALL

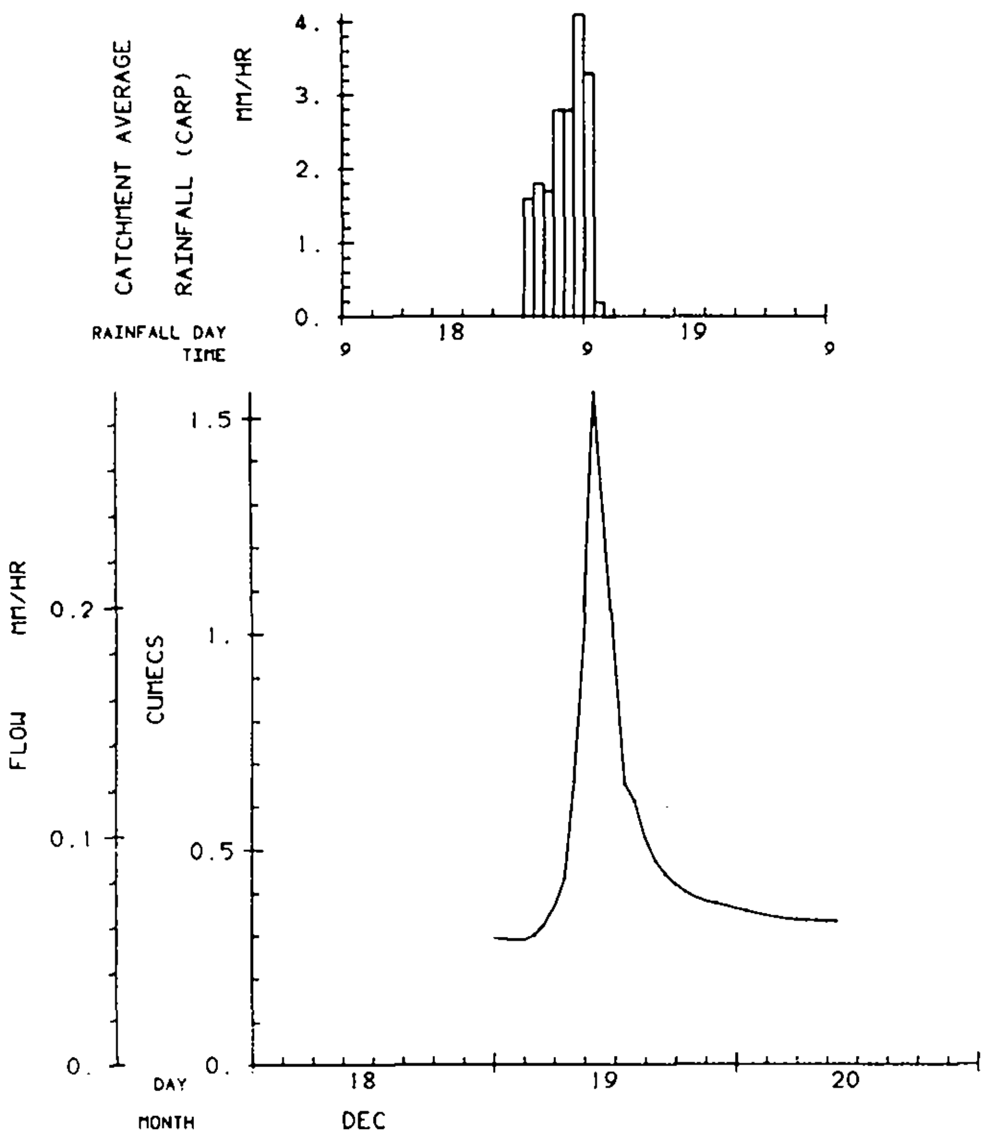
FLOOD EVENT
DATA ARCHIVE

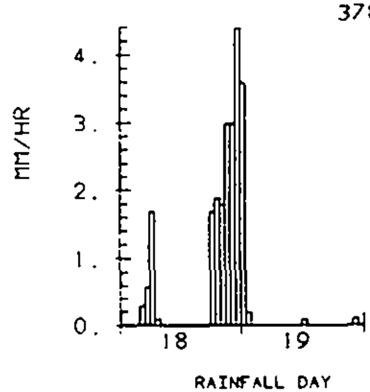
KENWYN AT TRURO

CATCHMENT NO. 48005
AREA 19.10 KM²

DATE 19-DEC-1971
EVENT NO. 1393
TYPE 12

INDIVIDUAL RAINGAUGE
PROFILE(S)





23/12/88 AT 12:05

OBSERVED HYDROGRAPH AND RAINFALL

FLOOD EVENT
DATA ARCHIVE

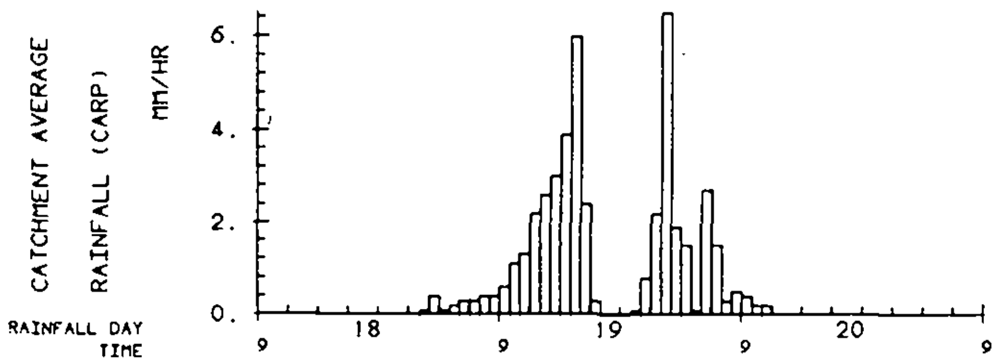
KENWYN AT TRURO

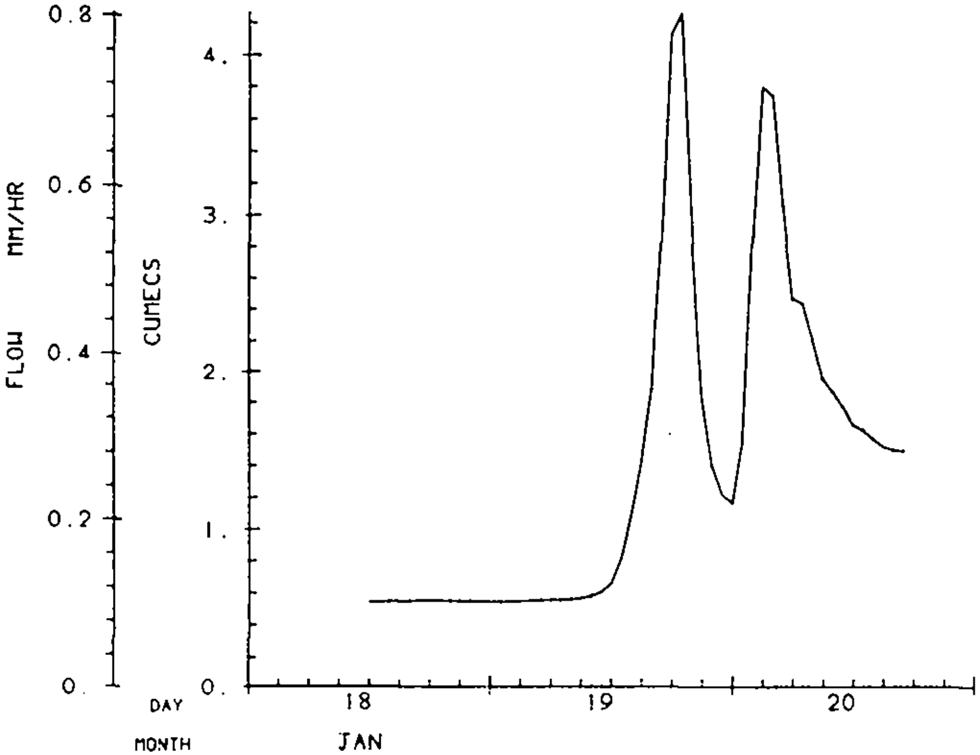
CATCHMENT NO. 48005
AREA 19.10 KM^2

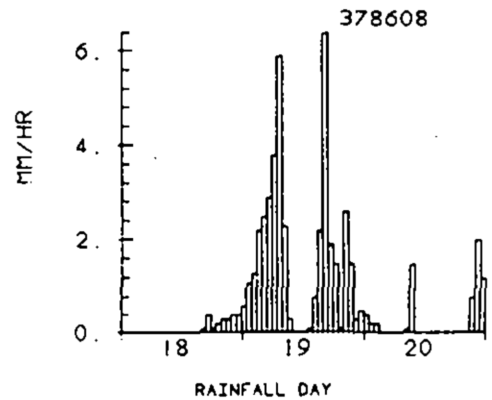
DATE 18-JAN-1973
EVENT NO. 1395
TYPE 12

INDIVIDUAL RAINGAUGE

PROFILE(S)







23/12/88 AT 12:09

OBSERVED HYDROGRAPH AND RAINFALL

FLOOD EVENT
DATA ARCHIVE

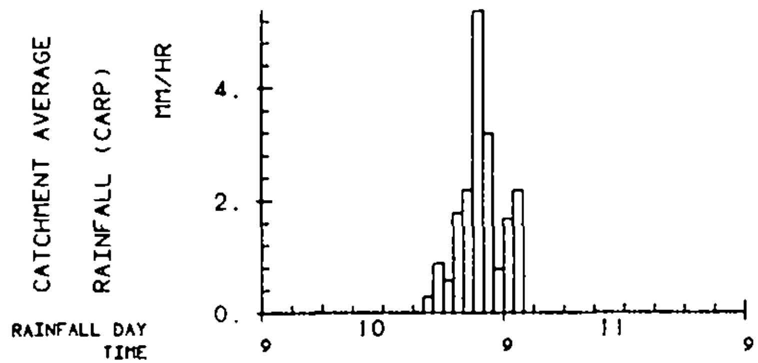
KENWYN AT TRURO

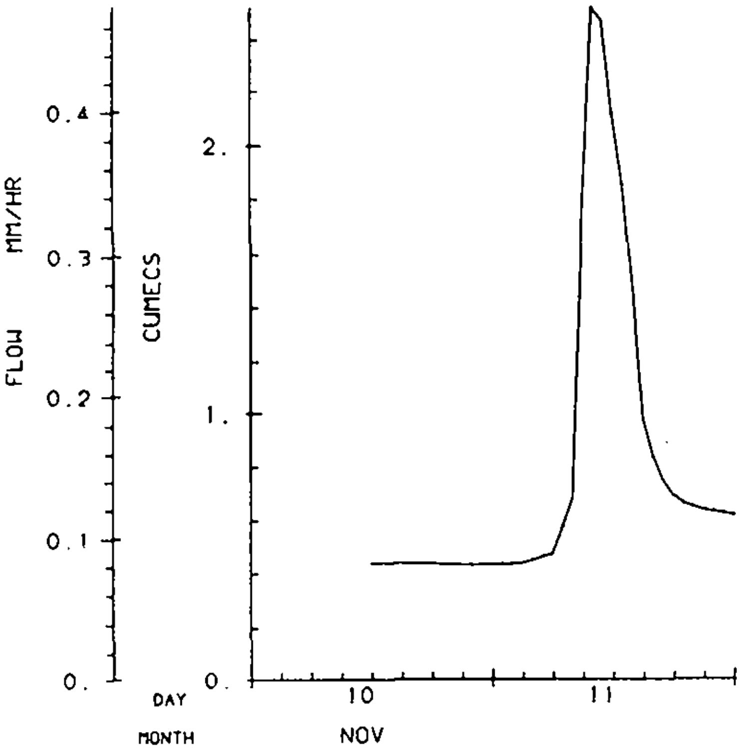
CATCHMENT NO. 48005
AREA 19.10 KM^2

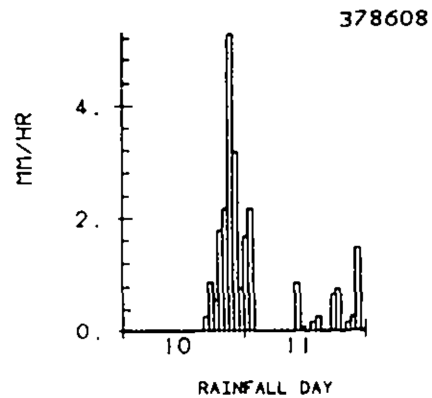
DATE 10-NOV-1974
EVENT NO. 1397
TYPE 12

INDIVIDUAL RAINGAUGE

PROFILE(S)







OBSERVED HYDROGRAPH AND RAINFALL

FLOOD EVENT
DATA ARCHIVE

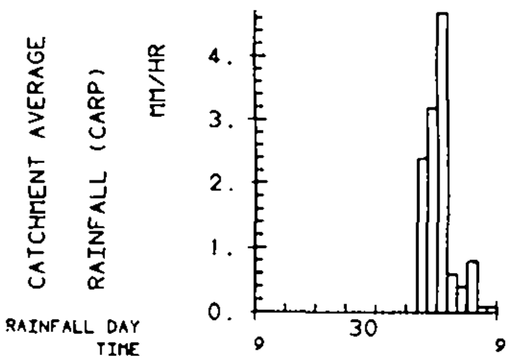
KENWYN AT TRURO

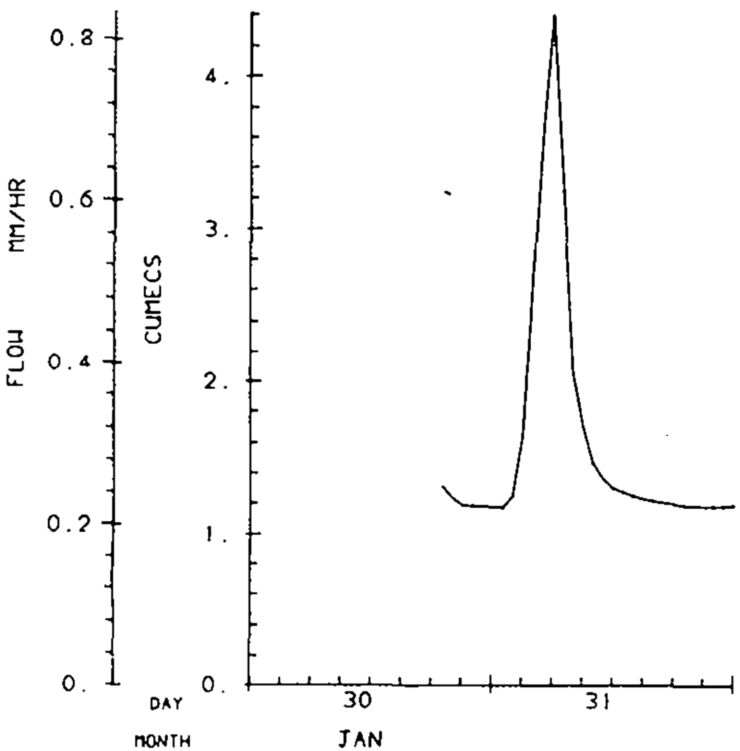
CATCHMENT NO. 48005
AREA 19.10 KM^2

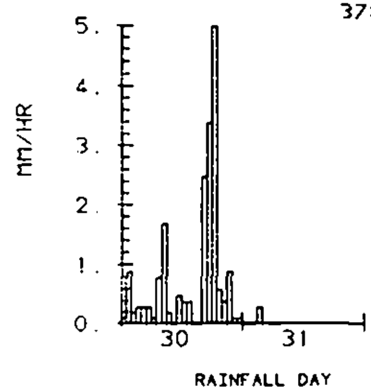
DATE 30-JAN-1975
EVENT NO. 1399
TYPE 12

INDIVIDUAL RAINGAUGE

PROFILE(S)







OBSERVED HYDROGRAPH AND RAINFALL

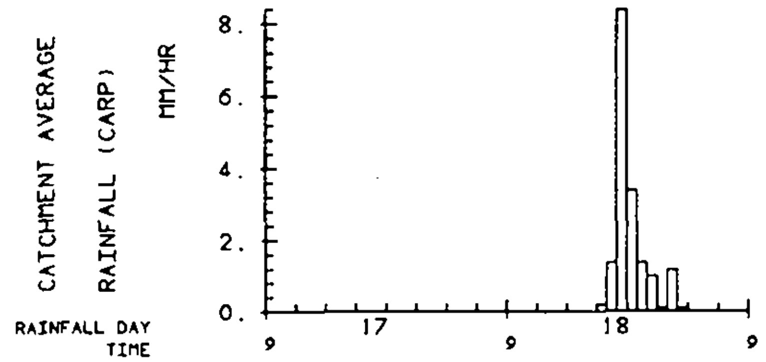
FLOOD EVENT
DATA ARCHIVE

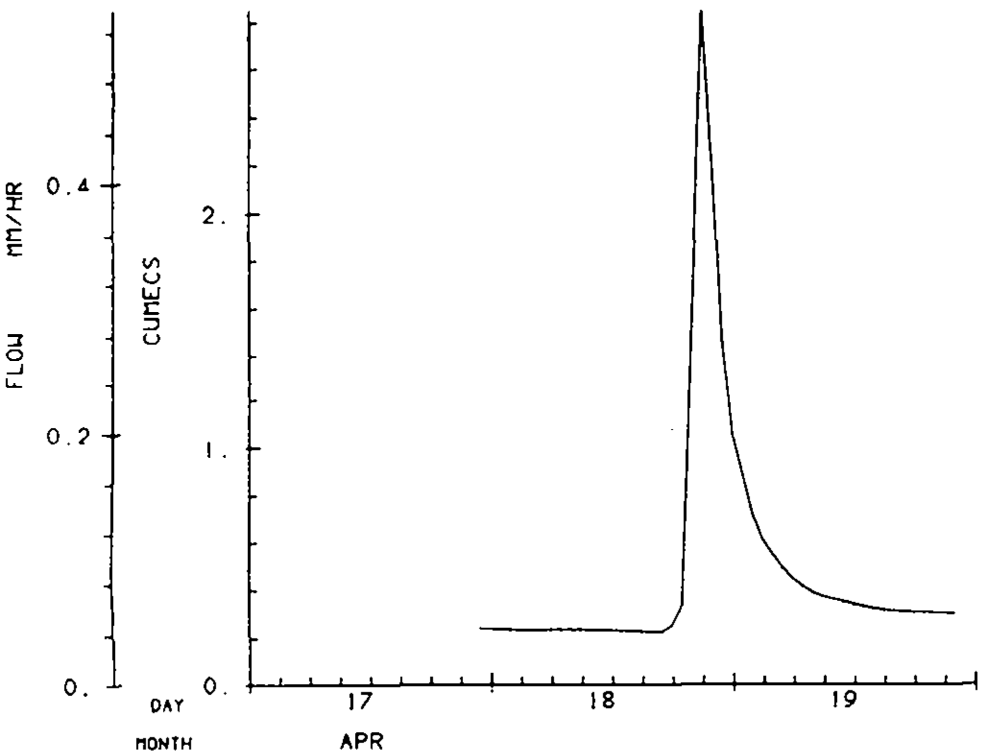
KENWYN AT TRURO

CATCHMENT NO. 48005
AREA 19.10 KM²

DATE 17-APR-1975
EVENT NO. 1400
TYPE 12

INDIVIDUAL RAINGAUGE
PROFILE(S)





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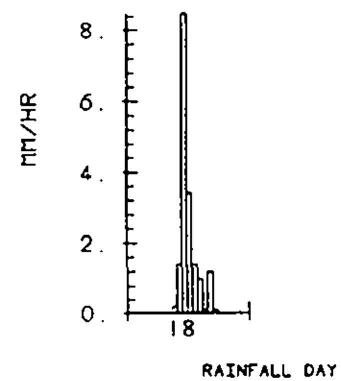


22/12/88 AT 13:07

OBSERVED HYDROGRAPH AND RAINFALL

FLOOD EVENT
DATA ARCHIVE

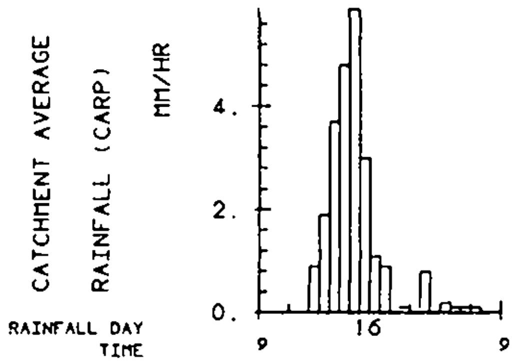
KENWYN AT TRURO

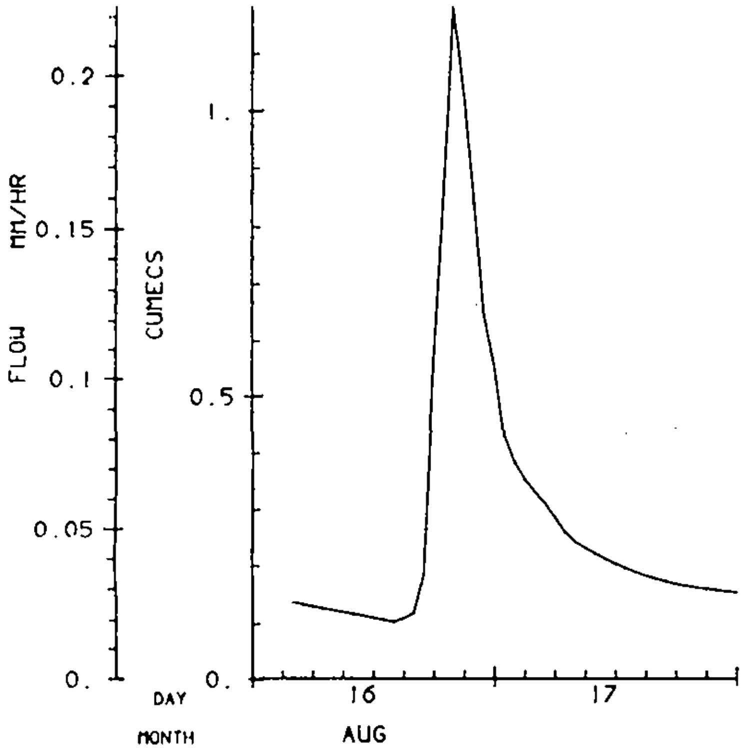
CATCHMENT NO. 48005
AREA 19.10 KM^2

DATE 16-AUG-1975
EVENT NO. 1401
TYPE 12

INDIVIDUAL RAINGAUGE

PROFILE(S)





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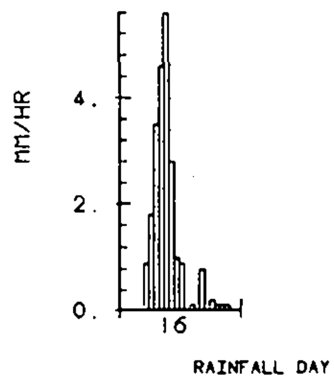


22/12/88 AT 13:08

OBSERVED HYDROGRAPH AND RAINFALL

FLOOD EVENT
DATA ARCHIVE

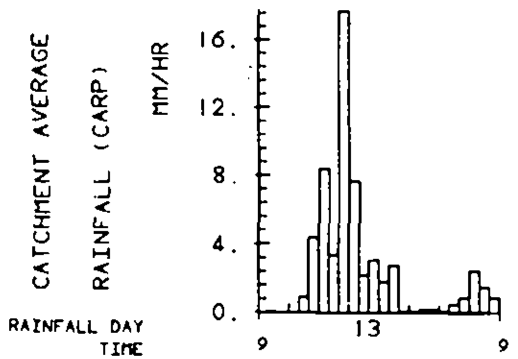
KENWYN AT TRURO

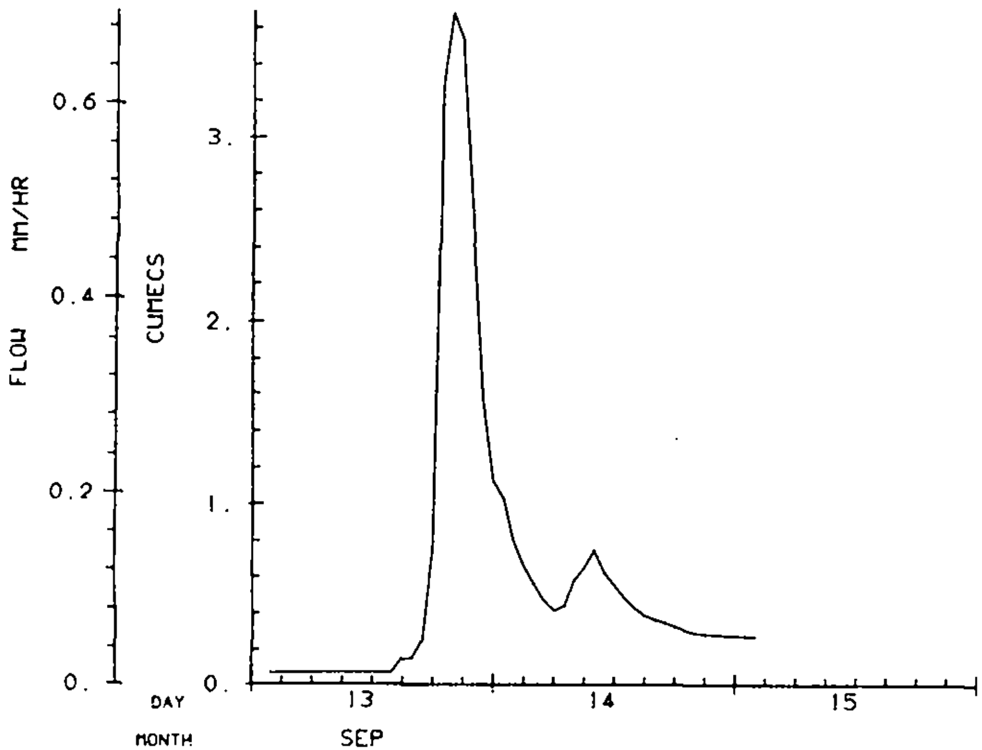
CATCHMENT NO. 48005
AREA 19.10 KM^2

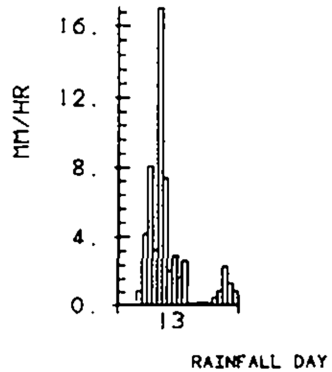
DATE 13-SEP-1975
EVENT NO. 1402
TYPE 12

INDIVIDUAL RAINGAUGE

PROFILE(S)







29/12/88 AT 11:27

OBSERVED HYDROGRAPH AND RAINFALL

FLOOD EVENT
DATA ARCHIVE

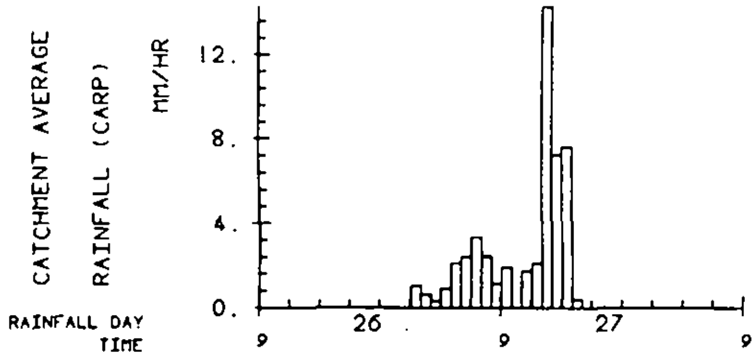
KENWYN AT TRURO

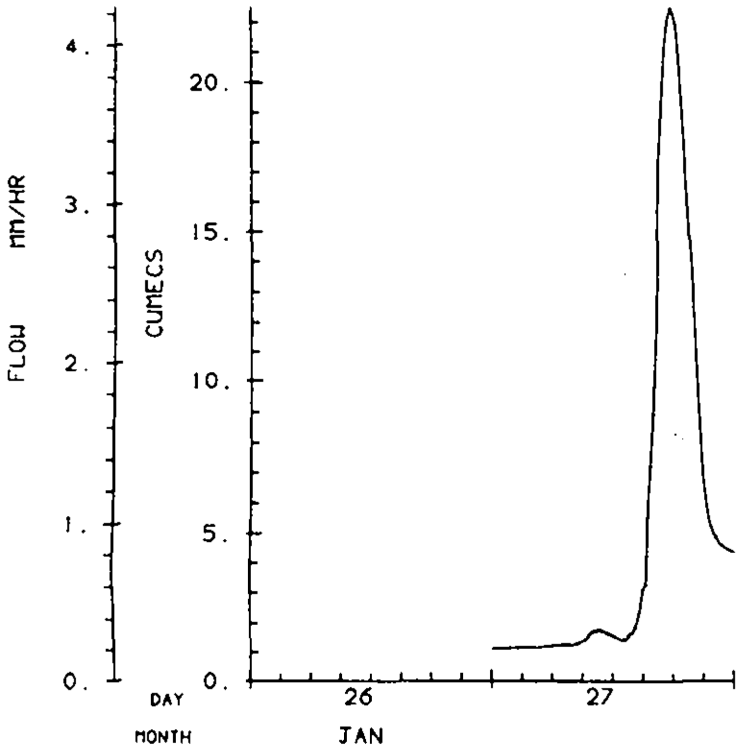
CATCHMENT NO. 48005
AREA 19.10 KM^2

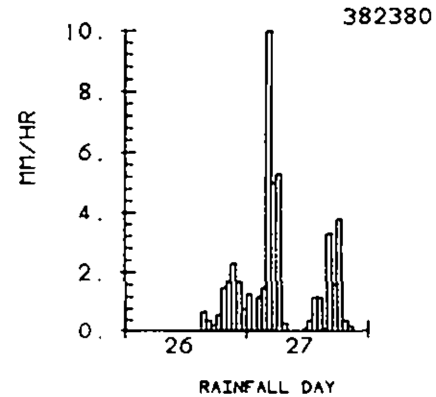
DATE 27-JAN-1988
EVENT NO. 3723
TYPE 13

INDIVIDUAL RAINGAUGE

PROFILE(S)







29/12/88 AT 11:26

OBSERVED HYDROGRAPH AND RAINFALL

FLOOD EVENT
DATA ARCHIVE

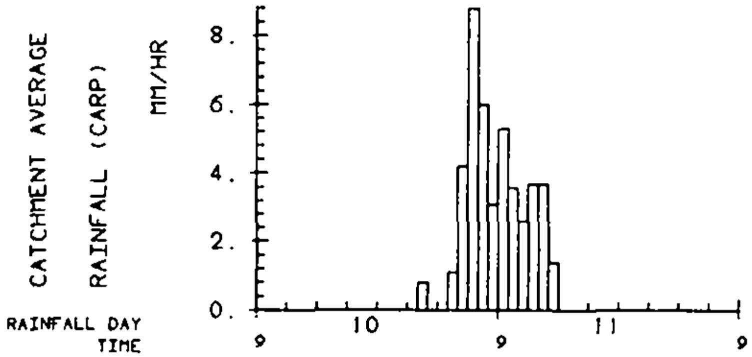
KENWYN AT TRURO

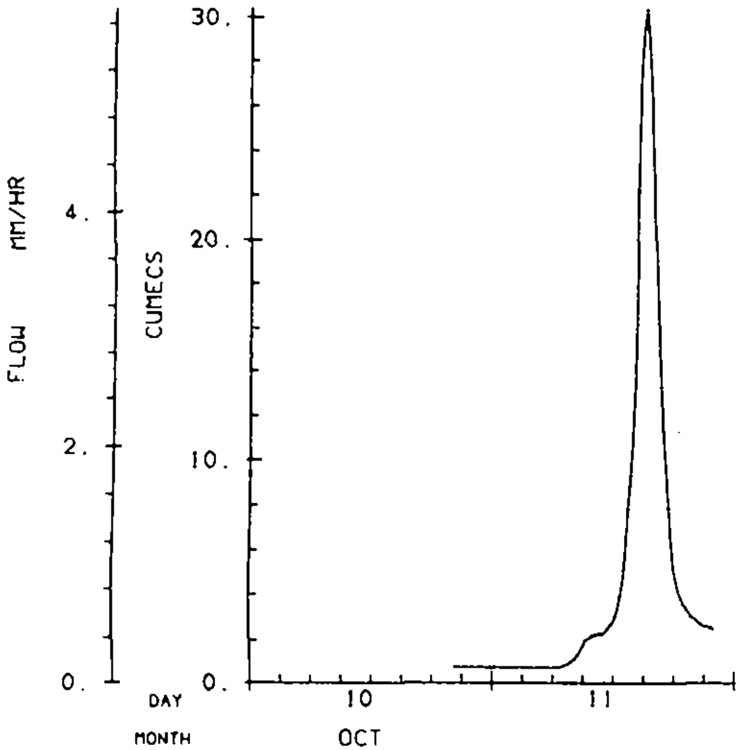
CATCHMENT NO. 48005
AREA 19.10 KM^2

DATE 10-OCT-1988
EVENT NO. 3724
TYPE 13

INDIVIDUAL RAINGAUGE

PROFILE(S)





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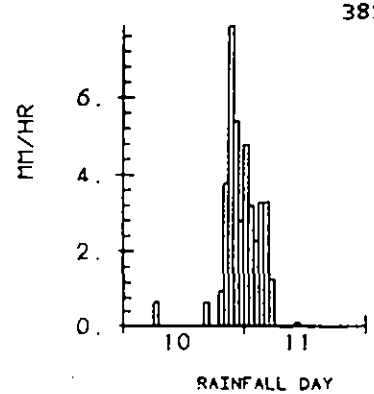

Appendix 2

RAINFALL-RUNOFF ANALYSIS FOR 50 YEAR RETURN PERIOD FLOODS

****

UK DESIGN FLOOD ESTIMATION

****

Description : Flood estimation for Kenwyn at Truro

Printed on 2-11-1988 at 11.30 Run Reference - TRURO

Catchment Characteristics

Area	: 19.10 sq.km.	Soil 1	:	0.000
Length	: 7.18 km.	Soil 2	:	1.000
Slope	: 13.10 m./km.	Soil 3	:	0.000
SAAR	: 1121 mm.	Soil 4	:	0.000
M5-2D	: 67.0 mm.	Soil 5	:	0.000
M5-25D	: -1.0 % of SAAR			
Jenkinson's r	: 0.27			
Urban	: 0.06			
Smdbar	: 1.6 mm.	RSMD	:	47.177 mm.
Stmfrq	: 0.94 junctions/sq.km.			
Lake	: 0.00			
EMP 2 hour	: -1.00 mm.	BFI	:	-1.00
EMP 24 hour	: -1.00 mm.	LAG	:	-1.00 hr.

****

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UK DESIGN FLOOD ESTIMATION

Summary of estimate using Flood Studies Report rainfall-runoff method

Description : Flood estimation for Kenwyn at Truro
Printed on 2-11-1988 at 11.39 Run Reference - TRURO

Estimation of T-year flood

```
                                                    (UH option      :  1)
Unit hydrograph time to peak   :     2.4   hours (TP option      :  0)
Data interval                  :     0.50  hours

Design storm duration          :     5.5   hours (Dur option     :  1)

Using rainfall statistics for England and Wales

Return period for design flood :    50.0   years
 requires rain return period   :    81.0   years
M5- 5.5 hour/M5-2day           :     0.501 mm.
M5- 5.5 hour                   :    33.6   mm.
M   81.0/M5                    :     1.85
M   81.0- 5.5 hour             :    62.3   mm. (point)
ARF                            :     0.94
M   81.0- 5.5 hour             :    58.7   mm. (area)

Design storm depth             :    58.68  mm.     (P  option       :  1)
                                                   (Profile  option :  4)
                                              (which is 75% Winter Profile)
Design CWI                     :   123.61          (CWI option      :  1)
Standard Percentage Runoff     :    30.00          (SPR option      :  0)
Percentage runoff              :    33.81  %       (PR option       :  1)


Response hydrograph peak       :    24.93  cumecs
Baseflow                       :     0.63  cumecs
                                                   (Baseflow option :  1)
                                   -------
Design hydrograph peak         :    25.56  cumecs
                                   =======
```

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```
*****************************************************************************
                                                   Institute of Hydrology
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UK DESIGN FLOOD ESTIMATION

Summary of estimate using Flood Studies Report rainfall-runoff method
*****************************************************************************

Description : Flood estimation for Kenwyn at Truro
Printed on  2-11-1988 at 11.43                    Run Reference - TRURO
-----------------------------------------------------------------------------

Estimation of T-year flood
==========================
                                                    (UH option        :  1)
Unit hydrograph time to peak    :    2.4   hours (TP option        :  0)
Data interval                   :    0.50  hours

Design storm duration           :    5.5   hours (Dur option       :  1)

Using rainfall statistics for England and Wales

Return period for design flood :   50.0   years
 requires rain return period    :   81.0   years
M5- 5.5 hour/M5-2day            :    0.501 mm.
M5- 5.5 hour                    :   33.6   mm.
M   81.0/M5                     :    1.85
M   81.0- 5.5 hour              :   62.3   mm. (point)
ARF                             :    0.94
M   81.0- 5.5 hour              :   58.7   mm. (area)

Design storm depth              :   58.68  mm.      (P  option        :  1)
                                                    (Profile  option  :  4)
                                             (which is 75% Winter Profile)
Design CWI                      :  123.61           (CWI option       :  1)
Standard Percentage Runoff      :   35.00           (SPR option       :  0)
Percentage runoff               :   38.72  %        (PR option        :  1)


Response hydrograph peak        :   28.55  cumecs
Baseflow                        :    0.63  cumecs
                                                    (Baseflow option  :  1)
                                  -------
Design hydrograph peak          :   29.18  cumecs
                                  =======
*****************************************************************************
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```