HYDROLOGICAL ANALYSIS OF THE TRURO FLOODS OF JANUARY AND OCTOBER 1988

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Introduction

On the 27th of January 1988 heavy rainfall over much of Cornwall caused flooding in many places including Helston, Penryn and Perranporth. The most serious flooding occurred in the city of Truro from the River Kenwyn. Fifteen residential and 50 commercial properties were flooded. Using procedures recommended in the Flood Studies Report[1], a return period of 350 years was assigned to the Truro flood; thus most residents considered that it would be unlikely to occur again in their lifetime. On the 10th and 11th of October 1988 further heavy storms occurred. The distribution of rainfall over Cornwall was different to that in January thus, although many properties in Perranporth were again inundated, Penryn did not suffer the same fate. In Truro flooding was even more severe than in January causing further disruption and anxiety. Taken together the two events resulted in damage estimated at over two million pounds.

Given the small probability of experiencing two such extreme floods within 10 months, a major investigation was undertaken to assess the future flood risk in Truro. An important facet of this study was the appraisal of contemporary reports of historical floods in order to refine the assessment of the rarity of the 1988 events.

Truro and the Kenwyn Catchment

The city of Truro is sited on the banks of the Rivers Kenwyn and Allen in central Cornwall. Flow measurement facilities have existed on the Kenwyn since 1968; the gauging station is situated just inside the city limits. Flows are measured by a three-bay compound Crump weir which allows flood flows, up to a stage of 1.98 metres (the height of the piers and wing walls), to be measured accurately. Some 30 metres downstream of the station a low twin-arch bridge carries the main road over the river. It is thought that throttling of flows by the bridge culverts may cause drowning of the gauging structure during extreme floods.

Above the flow measurement station, water levels are controlled by the natural variations in channel geometry and roughness. Within the city, the river flows in an easterly direction and is confined within artificial banks. Some 200 metres 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 high flows to alleviate flooding upstream. Below the sluices, the river flows between a high right-bank retaining wall and a vertical left bank which carries a footpath. The wall protects basement properties in St George's 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 (see Figure 9).

Further downstream the river is culverted under the city centre for about 250 metres. 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 George's 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. Substantial 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. However, its blockage may have contributed to flooding immediately upstream in the Gardens on a few occasions.

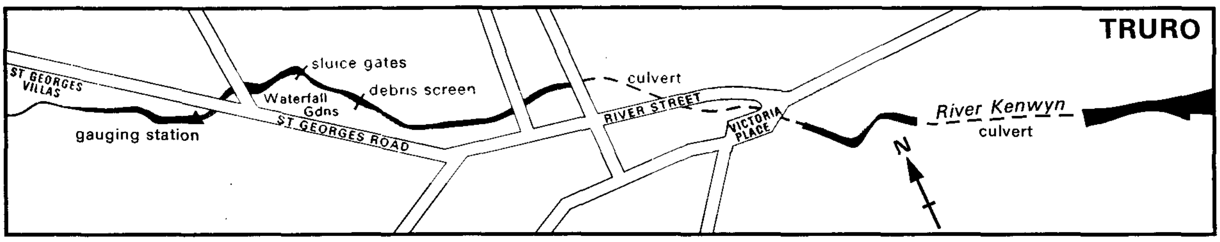

Figure 9. Location details of the River Kenwyn in Truro showing areas inundated during the 1988 floods.

Physical Characteristics

The catchment above the flow measurement station has a drainage area of 19.1 km^2. At present, just over six per cent of the catchment is urbanised. Upstream of the centre of the city the catchment area is 19.4 km^2. The extra 0.3 km^2 is entirely developed and, in total, just over seven per cent 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 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 Kenwyn and Allen catchments are underlain by rocks of Devonian age, predominantly slates and greywackes. Soils are mostly typical brown earths consisting of slightly stony clay loam[2]. These soils are permeable, naturally well drained and accept most rainfall, but temporary water storage capacity is limited by rock or, locally, compact drift at less than 0.8 metre depth which causes some runoff.

Hydrological Characteristics

A typical hydrograph describing the response of the River Kenwyn to rainfall, over a period of a month or so, is dominated by a slow rise in baseflow which lasts for many days before recessing slowly to a residual level. There are a number of wells and springs along the watercourse. 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 subsurface storage is clearly sufficient to delay runoff for several days.

Superimposed on the baseflow are short-lived, fairly steep rises, followed, within a few hours, by a recession to a slightly higher baseflow level. Analysis has shown[3] that the quick response runoff typically comprises only a small percentage (less than 10 per cent) of the rainfall volume, due mainly to the permeable soils. The major proportion of rainfall supplies the slowly responding baseflow 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 less likely to occur in the summer when a significant soil moisture deficit has normally developed. In August 1959, for example, no river flooding occurred even when more than 50 mm of rainfall was recorded in one day.

There is a daily-read raingauge in Truro, but the nearest autographic gauge is at Rosewarne, some 20 km WSW of the city. Until the summer of 1988 a weather radar was operating at Camborne. It was then moved to Predannack. The average annual rainfall for the Kenwyn catchment is around 1120 mm, for the period 1941–70, with the major proportion (over 70 per cent) falling in the months September to March[4]. These are therefore the critical months for flooding.

The Flood of the 27th January 1988

On the afternoon of the 27th January 1988 an occluded front moved very slowly eastwards across Cornwall. The Meteorological Office at Plymouth warned that heavy rainfall was likely over north Devon where the front could become stationary. In the event the heaviest rain fell over central Cornwall with an area of 100 km^2 receiving more than 50 mm (Figure 10) on the 27th. The highest daily fall recorded on the 27th was 91mm at Trevince, 10 km

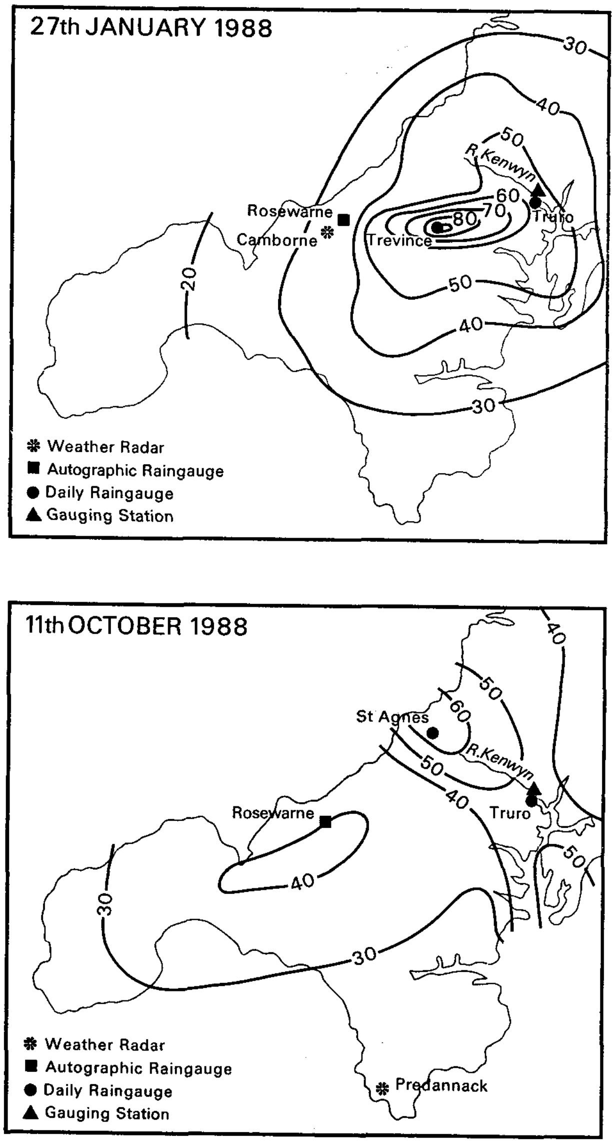

Figure 10. Isohyetal maps for the January and October Truro floods—rainfall totals are in mm.

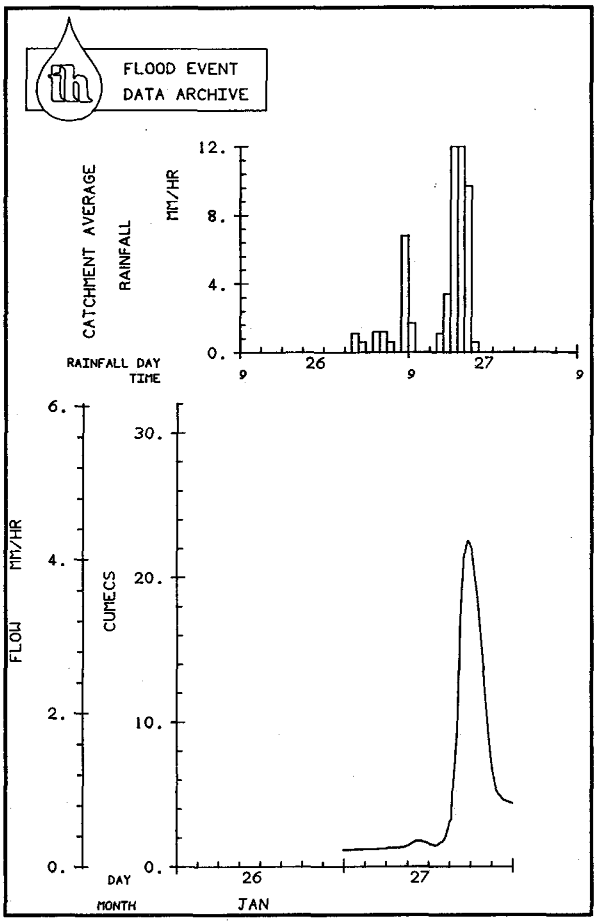

Figure 11(a). Rainfall hyetograph and runoff hydrograph for the January, 1988 flood.

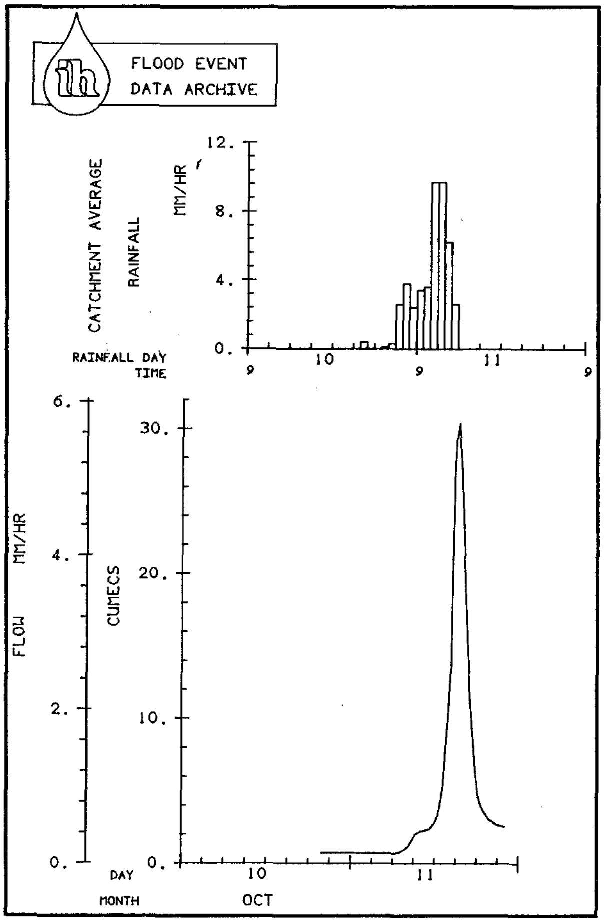

Figure 11(b). Rainfall hyetograph and runoff hydrograph for the October, 1988 flood.

WSW of Truro, whilst 58.1 mm was measured in Truro itself. During the previous five days over 68 mm had fallen in Truro, saturating the Kenwyn catchment. A catchment average rainfall of 67 mm was calculated for the two rainfall-days starting at 09.00 hrs on the 26th. This total was apportioned between the 48 hours using data from the Camborne weather radar. It is noteworthy that, when compared with raingauge data, the weather radar generally underestimated rainfall totals, although it gave a good indication of the relative amounts at different times and of the areas worst affected. The catchment average rainfall hyetograph for the event is shown in Figure 11a. The peak intensity is almost 12 mm hr^{-1}, lasting for two hours. Also shown in Figure 11(a) is the runoff hydrograph for the Kenwyn at the Truro gauging station. After rising at a rate of 10 millimetres per minute, a peak stage of 2.12 m was reached at 17.30 hrs. Extrapolation of the stage-discharge relation 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[5]. This may also have contributed to the flooding which occurred upstream of the gauging station at St George's Villas.

Further downstream, the force of the flood led to the failure of the river retaining wall behind St George's Road. The resultant rapid surge of water flooded several basement flats to a depth of 1.5 m, endangering the life of one of their residents. The leat sluices were already open, perhaps preventing more serious flooding upstream. At around 16.45 hrs the culvert beneath the city centre reached capacity and the excess water flooded approximately 50 commercial properties in River Street and Victoria Place, some to a depth of over half a metre. The total cost of damage exceeded one million pounds. A post-flood survey of the city centre culvert found no evidence of obstructions or debris.

The largest flow previously recorded at the gauging station was only 13.4 m^3s^{-1}, hence a standard assessment by South West Water*, based on the annual maximum flood series from the gauging station and the Flood Studies Report recommended procedures, put the return period of the flood at 350 years. Although flows were high in most other watercourses in the area, the next largest flood recorded was on the River Kennel at Ponsanooth where the return period was of the order of 10 years.

* South West Water had operational responsibility for the gauging station prior to the transfer of hydrometric activities to the National Rivers Authority (see page 188).

The Flood of 11th October 1988

Heavy rainfall returned to Cornwall on the 10th and 11th October, associated with a trough of low pressure, following a week of widespread rain which had saturated the catchment; several gauges in the area recorded over 100 mm in seven days and one, Hessary on Dartmoor, exceeded 200 mm. The highest two-day fall on the 10th and 11th was 68.3 mm recorded at St Agnes. The vast majority of this rain fell between 06.00 and 17.00 hrs on the 11th, thus spanning the two rainfall-days. As in January, all of central Cornwall received more than 30 mm (Figure 10). High flows were again recorded on many rivers with a flood of around the 20-year return period on the River Gannel at Gwills. In Truro, 31.9 mm was recorded for the 24 hours up to 09.00 hrs on the 12th. The average rainfall over the Kenwyn catchment for the two-day period commencing 09.00 hrs on the 10th was 45.1 mm. This total was apportioned amongst the 48 hours using data from the weather radar at Predannack. The catchment average storm rainfall is depicted in Figure 11b. 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 also shown in Figure 11b.

A photograph of the gauging station was taken just after the peak of the flood (Plate 1), showing

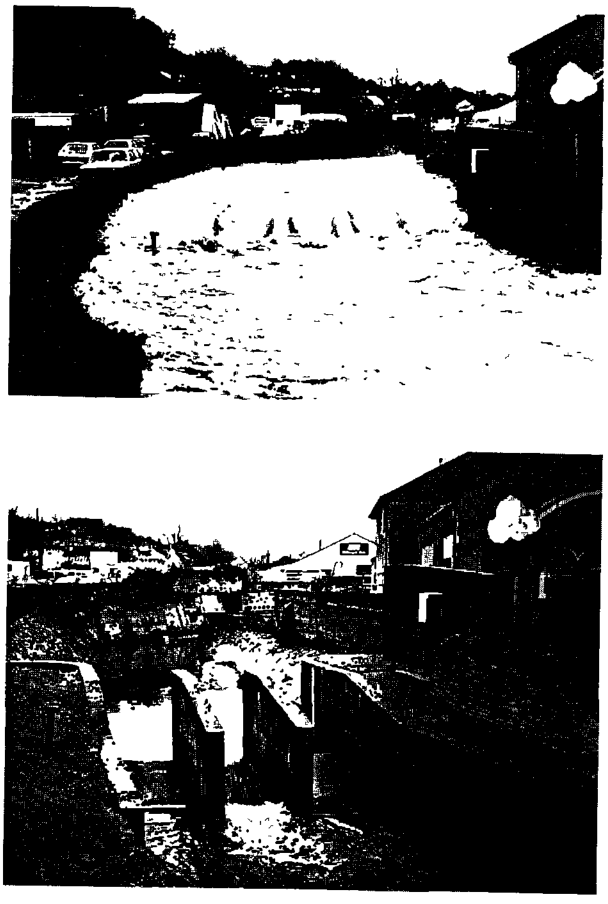

Plate 1. The Truro gauging station—during the October 1988 flood and close to median flow conditions.

Plate 2. Surcharging of manholes in River Street, Truro during the October 1988 flood.

that water levels were very high both upstream and downstream of the measuring structure. However, there appeared to be sufficient drop in head across the structure to assume that the weir was not significantly drowned. The lower photograph shows the same structure at normal flow.

St George's Villas escaped flooding on this occasion due to river maintenance after the January flood. The leat sluices had been raised on the evening of the 10th, after a flood warning was issued, and no major blockages of the channel were reported. Nevertheless, the high river flows led to a further failure of the retaining wall behind St George's Road, immediately downstream of the section re-built following the January event, and one basement property was flooded. However, other flooding in the St George's Road area appears to 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 2 shows the culvert surcharging through access manholes in River Street.

Assessment of Return Period using Annual Maximum Floods

The return period – the average interval between years containing a flood equal to, or greater than, a given discharge rate – can be estimated by analysing records of previous floods.

The Flood Studies Report recommends that for return periods greater than twice the length of record (in this case 42 years) the mean annual flood should be calculated from the flood data and then scaled up to the required return period using an appropriate regional growth factor. New growth factors were produced by Whiter[6] as part of a revision of the flood frequency estimation procedures for the South West region using the Flood Studies Report methodology. Excluding both floods from the calculation of the mean, since they could be considered as outliers, results in the 350-year return period assessment of the January flood obtained by South West Water. However, return periods for the January and October floods of 100 and 400 years respectively are given when these events are included.

If the period of record is considered to be representative of the long-term flow regime, the entire flood frequency curve may be derived directly from the observed flood data. Table 6 shows the results of fitting a generalised extreme value (GEV) distribution to the 21 annual maximum floods from 1968 to 1988. This gives a flood frequency curve much steeper than using the regional average growth factors (see Figure 12). For example the 100-year flood is 5.4 times larger than the mean annual flood (which is 7.7 m^3s^{-1}). The South West area growth curve suggests that the regional average 100-year flood is only 2.93 times the mean.

TABLE 6 FLOOD QUANTILES FROM FITTING A GEV DISTRIBUTION (1968–1988)

Return Period (years)	Peak Flow (m^3s^{-1})	Return Period (years)	Peak Flow (m^3s^{-1})
5	8.67	50	28.82
10	12.41	100	41.72
25	19.99		

The fact that the two 1988 floods are considerably larger than all previously recorded floods strengthens the possibility that they may be considered outliers and therefore the period of flow record may not be representative of the long-term flow regime. Under such circumstances the flood frequency curve based on the regional analysis should normally be adopted. Individual events were analysed in order to check whether there was a physical justification for adopting the steeper curve based on the local data.

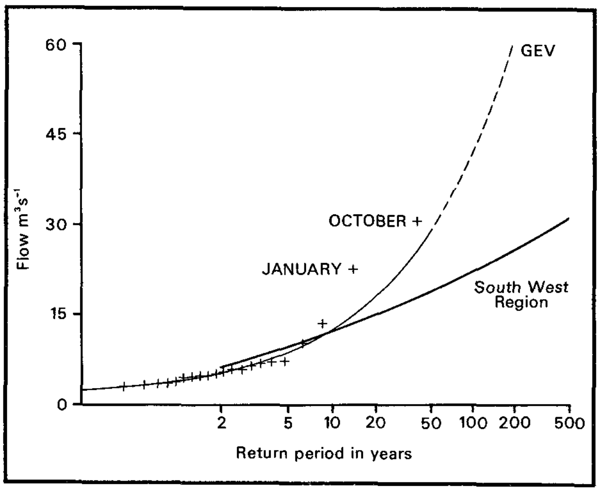

Figure 12. Flood frequency diagram for the River Kenwyn at Truro based on data for the water years 1968/69 to 1988/89.

Analysis of Event Data

Individual flood events on the River Kenwyn have been studied on several occasions, most recently by Boorman[3] as part of a revision of the Flood Studies Report rainfall-runoff model[7]. The percentage runoff (PR) was found to be less than 20 per cent for all events. These findings are comparable with values of PR evaluated for five events by MacGregor and Cameron[8] on the Kenwyn catchment which ranged from six per cent for a July event to 20 per cent for a January event. For both the 1988 events PR was around 40 per cent. It is important to note that relative to the 1988 events all these other events were small in terms of peak flow, the largest being only 4.3 m^3s^{-1}.

Data collected on these individual events showed that the 1988 floods were not particularly extreme in terms of rainfall intensity. The physical nature of the Kenwyn catchment is such that it is particularly susceptible to the amount of rain falling over a 5-hour period. This is thus the critical duration for flood generation. The Flood Studies Report gives the 5-year return period rainfall, of 5 hours duration, 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 seven years. Both are considerably more frequent than the resulting floods. Furthermore, the peak flow for the January event was less than that for the October flood despite the higher rainfall. Thus 5-hour storm rainfall intensity is not the only important flood producing factor. This is clear from the event of the 13th September 1975, in Boorman's data set, which exceeded both 1988 events in terms of rainfall but only resulted in a peak flow of 3.7 m^3s^{-1} because of low antecedent wetness. Percentage runoffs and hence peak flows have a wide range and are strongly influenced by antecedent rainfall. Heavy rainfall alone is rarely sufficient to both satisfy the soil moisture deficit and generate high river flows. Large floods result from the joint occurrence of a saturated catchment and heavy rainfall.

The Flood Studies Report rainfall-runoff model can also be used to estimate floods of various return periods. Results suggest that the January flood has a return period of around 17 to 30 years whilst the October flood would be exceeded once, on average, every 70 to 110 years, supporting the case for adopting a steep flood frequency curve. This suggests that the Kenwyn may not be typical of catchments in the South West region and that the regional growth curve may be inapplicable. To examine this hypothesis further information on historical floods was sought.

Historical information

The 1988 events showed that when flood flows exceed the capacity of the city centre culvert, water overflows into the streets and properties causing obvious damage and distress. It may be assumed, therefore, that if the culvert capacity had been exceeded in the past (a flow of at least 15–18 m^3s^{-1}) the event would have made local news. Truro is fortunate in having an extensive archive containing rainfall records, manuscripts, journals and newspapers. The historical rainfall data were used to indicate potential dates of flooding, and a search of papers was undertaken for reports of flooding in the city on those days. Unfortunately newspaper accounts do not always differentiate between flooding from blocked or inadequate surface drains and river flooding. Another problem is that there has not been a consistent relationship between level and flow, because of changes in the culvert capacity, so that the events are not directly comparable hydrologically. During the search, additional flood events were discovered showing that flooding in Truro is not a new phenomenon. A summary of the history of flooding in Truro described in the newspapers is given in Table 7.

TABLE 7 SUMMARY OF FLOODING HISTORY IN TRURO 1830–1987

Date			Subjective assessment
c 1830–1870			Development of River Street, construction of St George's Road and culvert.
13	November	1875	Gales and floods. High tide.
04/05	October	1880	Heavy rain. Surface water?
28	September	1882	High tide.
02	February	1885	Extreme tide.
12	November	1894	Serious flood. Wet catchment.
06	February	1899	Heavy rain. Surface water?
07/08	October	1924	Heavy rain. Mainly River Allen.
25–30	November	1954	Storms across Cornwall. Flooding from Kenwyn and Allen.
13	January	1955	Serious flooding from Kenwyn. Channel and tunnel capacities exceeded.
		1956	Improvements to culvert, removal of silt.
25	December	1956	Flooding St George's Villas.
10/11	August	1959	Heavy rain. Surface water?
		1971	Hydraulic improvements, culvert capacity increased.
29	November	1971	Heavy rain. Surface water.
08	August	1975	Thunderstorm. Surface water.
23/24	August	1977	Heavy rain. Surface water.
05/06	October	1977	Heavy rain. Surface water.
27/28	December	1979	Flooding of River Allen.

Serious flooding from the River Kenwyn certainly occurred both in November 1894 and again in January 1955, however, the impact of the November 1954 flood is less clear. The most likely interpretation of the history of flooding is that between 1870 and 1967 there were only two events, 1894 and 1955, which exceeded 18 m^3s^{-1} (the present culvert capacity). This historical information, combined with the annual maximum flood peaks recorded at the gauging station, can be used in a statistical analysis to better determine the shape of the flood frequency curve[9]. Results, using this approach, suggest that the return period of the January flood is approximately 50 years and that for the October flood is around 100 years. Various other scenarios were investigated, for example that there were three events in the same period which exceeded 15 m^3s^{-1} (the previous culvert capacity), though this only marginally altered the resulting return period assessments.

Conclusions

The most recent recorded event which caused serious river flooding prior to 1988 would appear to have been in 1956. Consequently, residents of the city, 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 the residents were somewhat alarmed to experience two very serious floods within 10 months. The small degree of urbanisation of the catchment is not sufficient to have caused a significant change in its response. Other characteristics of the catchment, such as land use practices do not appear to have altered for many years; for example there is little evidence of widespread artificial drainage, afforestation or mining. Furthermore, 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 other than chance occurrences.

Assuming that the relative size of floods on the Kenwyn is close to the average for the South West region, implies that the October flood would have a return period in excess of 400 years. Direct analysis of the annual maximum flood series suggests a much lower return period. This is supported by analysis of the historical information which assigns return periods of 50 and 100 years to floods of 22.5 and 30.4 m^3s^{-1} which are the estimated peak flows for the January and October floods respectively. Use of these historical data probably provides the best estimate of flood frequency, although only a lengthy record of accurately measured peak flows would be able to confirm this. Such a steep flood frequency curve is also suggested by an investigation of individual flood events which showed the large range in response to rainfall occurring between events is strongly influenced by antecedent catchment conditions. It is unrealistic to expect all catchments in a region to have identical flood growth curves. However, unless strong evidence is available, it is advisable to use the regional growth curve. In the Truro case, departure from the standard procedure was justified through the analysis of historical data and an understanding of the hydrological response of the catchment during extreme events.

It may be small comfort to the residents of Truro to know that the probability of getting both a 100-year and a 50-year flood in consecutive water years is 0.0004 (or 1 in 2500), but it is important in relation to the development of any future flood alleviation strategy. Thus the occurrences in 1988 were exceptional, but not implausibly so.

Acknowledgements

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The views expressed in this report are those of the author and not necessarily those of South West Water or its successor bodies.

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