THE OCTOBER 1987 FLOOD ON THE RIVER TYWI

J.R.FROST and E.C.JONES

Welsh Water ***Consultant***

Introduction

October 1987 will be remembered for several remarkable hydrometeorological events – the 'hurricane' during the night of the 15/16th and the widespread flooding associated with the passage of a series of vigorous low pressure systems which affected various parts of the United Kingdom. Flooding was particularly severe in south-west Wales where media attention focused on the overtopping of flood defences in Carmarthen (Caerfyrddin) and the fatalities resulting from the collapse of a railway bridge over the River Tywi. This article draws on a number of contemporary reports – particularly those completed on behalf of the Welsh Water Authority – to examine the development of the flood event and to consider its impact on the community. Attention is directed to the problems of assessing the peak discharge rate and of estimating the rarity of events of such a notable magnitude.

The Tywi Catchment

The River Tywi is the sixth longest river in the British Isles. It rises in the Cambrian Mountains of central Wales and flows, eventually, into Carmarthen Bay (see Figure 9). From its headwaters, the Tywi flows south through the Tywi Forest and thence to Llandovery where it trends south-west picking up tributaries draining from the Caeo Forest to the north and from the Black Mountains which form the south-eastern watershed. Its course is well defined and flooding in the upper reaches is not generally a problem. Below Llandeilo, the river strikes westwards and meanders gently across a floodplain which achieves its maximum width – about 1.5 km – near Nantgaredig just upstream of Carmarthen. Most of the Tywi's tributaries are short and fast flowing but a major tributary – the Cothi – joins the main river a few kilometres upstream of the flow measurement station at Ty-Castell where the floodplain narrows to little more than river width as a result of a geological constriction. There has been development over the years on the floodplain in and around Carmarthen; the Pensarn district has been heavily exploited with a significant growth of service and light engineering industry. This development, together with the bridges over the Tywi constitutes an artificial constriction which impedes flow especially during periods of high discharge.

The catchment area of the Tywi above Carmarthen is 1300 km^2 with a maximum altitude of 792 metres on the summit of The Black Mountain. The relief is generally rugged with steep slopes descending to the Tywi and Cothi valleys. Average annual rainfall closely reflects the relief and exceeds 2000 mm in the northern headwaters with a maximum of approximately 2500 mm in the Black Mountains. Even at the catchment outfall – about 3 m aOD – the average annual rainfall exceeds 1200 mm. Precipitation is well distributed throughout the year with a discernible winter maximum, a consequence of the predominant maritime influence on the regional climate. The long term catchment average rainfall is 1560 mm, 70 per cent greater than the England and Wales mean. In relation to large river basins – those exceeding 1000 km^2 – the Tywi catchment is the wettest in England and Wales of those for which flow records are held on the Surface Water Archive.

Geologically, the Tywi catchment is dominated by impervious metamorphosed sediments of Ordovician and Silurian age. Some younger series outcrop in the south of the basin but natural storage is

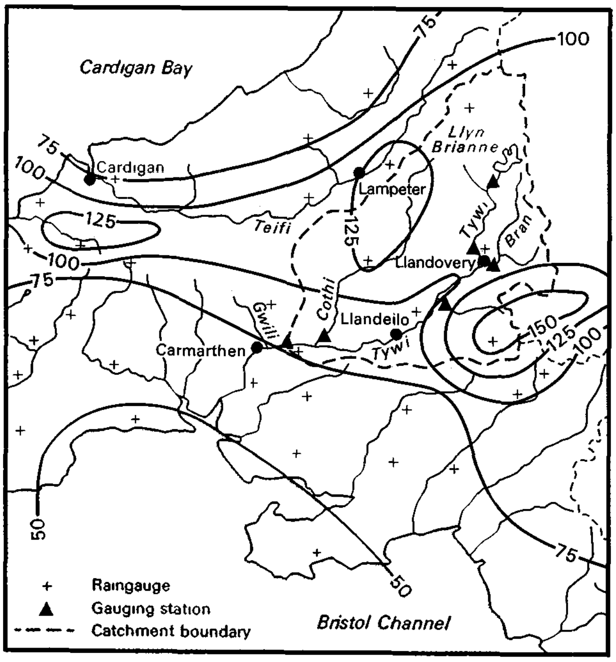

Figure 9. The catchment of the River Tywi – location details and 2-day rainfall totals for October 17–18th 1987.

generally limited to valley gravels and alluvium and peaty soils in the headwaters. The principal land use is hill farming with dairying practised in the valleys and on the gentler slopes. Forestry is important in the headwaters and, overall, coniferous forest comprises about 15 per cent of the catchment. Llandovery, Llandeilo and Carmarthen are the only substantial settlements and the population is generally sparsely distributed. The flow regime of the Tywi is natural apart from the effect of regulation releases from Llyn Brianne Reservoir in the headwaters (see page 26).

Overture to the Flood

Following below average summer rainfall, rivers throughout much of Wales were close to or below the mean, for the time of year, by the end of August 1987. The Tywi flows – at Nantgaredig – had declined to 3 m^3s^{-1} by the 30th of August, the lowest flow for three years, and soil moisture deficits, at least in the lower catchment, were substantially above the long term average. Runoff rates climbed steadily throughout September in response to a series of rain-bearing low pressure systems which crossed the British Isles. The sustained rainfall saw the virtual elimination of soil moisture deficits by the 22nd but some modest deficits became re-established during the dry spell which lasted from the 23rd of September to the 2nd of October. This interlude was terminated by belts of thundery rain moving up from the Western Approaches and, on the 5th, longer outbreaks of rain occurred as a sequence of cold fronts crossed the country. Weather patterns over the subsequent fortnight were influenced by a stationary high pressure zone over western Siberia; a series of depressions tracking along its western flank brought remarkably heavy and sustained precipitation to the British Isles. During the 14th a deepening low swung north-eastwards across central Britain and gave rainfall amounts exceeding 20 mm over wide areas. As a consequence of a fortnight of exceptionally unsettled conditions catchments in South Wales had become saturated with minimal potential for any further infiltration. The situation was then exacerbated by the rainfall associated with the intense low pressure system which brought devastation to much of southern England on the night of the 15/16th October. Although South Wales escaped relatively lightly, many rivers were in spate and the catchments were dangerously vulnerable to any further precipitation.

The northward drift of the 'hurricane' presaged the arrival of another intense system which skirted the western seaboard on the 17th and 18th. As the associated cold front became slow moving over western Britain, a rainfall warning was received on the 17th from Cardiff Weather Centre which indicated that 25 mm of rain could be expected over higher ground between midnight and 09.00 on the 18th. In the event, between 75 and 200 mm of rain fell over the Tywi catchment within two days (Figure 9) and, for short periods, intensities of 17 mm/hr were registered. The highest accumulated rainfall totals were reported to the north of the Preselis massif, in the Upper Cothi catchment extending into the Teifi basin, and on the Black Mountains. Most of the rain was recorded over a 27-hour period commencing on Saturday the 17th October and the prevailing soil conditions ensured that the precipitation was very hydrologically effective.

The Flood

The network of flow measurement stations in the central Welsh uplands is relatively sparse but, by the evening of the 18th, it was evident that a major flood event was developing. Runoff rates in many headwater tributaries increased immediately in response to rainfall especially where the higher intensities were experienced. For instance, the secondary flow measurement station at Llangadog on the Sawdde, which drains westwards from the Black Mountains, recorded a peak flow rate of 230 m^3s^{-1} at 15.30 (BST); this discharge is unprecedented in a 20-year record. At 18.00 the River Gwili, which joins the Tywi near Carmarthen, peaked at a flow of about 114 m^3s^{-1} – the highest flow since 1981 (although the November 1986 flood was of a similar magnitude). In the northern headwaters, the Dolau Hirion gauging station registered a peak at 21.00 and, one hour later, the Bran – which drains a heavily forested catchment away from the most intense rainfall episodes – recorded 62 m^3s^{-1}; a flow rate exceeded on only three occasions in a 20-year record. Elevated discharge rates were not confined to the Tywi. Unprecedented flows occurred in the upper reaches of the neighbouring River Teifi where an examination of wrack marks revealed a peak 0.26 m higher than the previous maximum (see cover) and, to the east, rivers flowing into the Bristol Channel were in spate. In this latter region flows were, however, substantially less than those associated with the flood of December 1979. Noteworthy, rather than remarkable, discharge rates also characterised rivers in North Wales.

By the early hours of the 19th, the Cothi and Tywi were both flowing bankfull and a number of bridges across smaller tributaries were washed away. Floodwaters blocked many minor roads and inundated low lying sections of the railway between Llandovery and Llandeilo. A major tragedy occurred when the 05.27 Swansea to Shrewsbury train was brought to a stop on the bridge over the Tywi at Glanrhyd; a partial collapse had resulted from the undermining of the bridges foundations by the river in spate prior to the train's arrival. Four lives were lost when the leading coach fell into the river and became submerged.

Damage to roads, bridges and other structures was widespread; many were rendered unsafe as foundations became undermined by the fast flowing floodwaters. Fallen trees, and other debris, were a danger in themselves and choked some waterways giving rise to further localised flooding. The Dyfed County Surveyor estimated the cost of repairs to be borne by the County Highways Department at £1.5 million most of which is attributable to bridge repair and reconstruction.

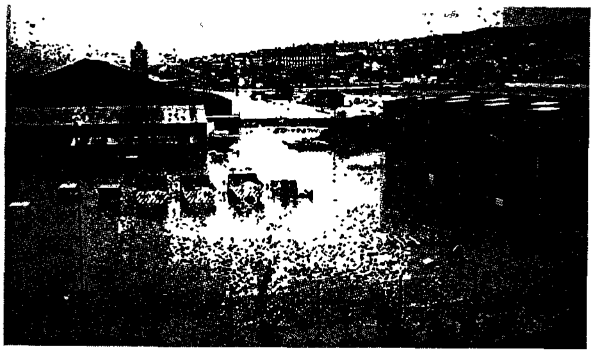

Plate 1. Flooding in the Pensarn district of Carmarthen - 19/10/87. Photo: Elwyn Jones.

Below the confluence with the Cothi the peak discharge estimated for the Ty-Castell monitoring site was significantly greater than the design capacity of the Carmarthen Flood Alleviation Scheme which was completed in 1984. As a consequence, the Pensarn flood defence wall was overtopped for a period of fourteen hours. An early casualty of this inundation was the post office. Mail services were suspended after floodwaters swamped the site housing the main sorting office, transport workshops and vehicle depots. The sorting office had been built only 3 years previously with a ground floor level 0.6 m above the previous maximum recorded level at that location. On the north bank, damage to vital equipment in the Carmarthen telephone exchange caused widespread and serious disruption of communications and hampered the implementation of flood emergency procedures throughout the stricken region. Routine data gathering in the Tywi catchment is similar to that throughout the rest of the Welsh Water Authority area. It is based upon strategically placed recording raingauges and gauging stations which are linked to processing centres by telemetry systems relying on rented telephone lines. With the Carmarthen exchange disabled, operational control during the flood event was severely limited by the absence of on-line data. The main route for the dissemination of flood warnings is via the police at Carmarthen - they are responsible for passing on information to the media. At one stage, on the 19th October, the only means of communication was via the Radio Amateurs Emergency Network.

Plate 2. Inundation of Carmarthen Station - 19/10/87. Photo: The Western Mail.

Throughout the Tywi catchment the number of properties flooded was limited - about 250 overall. However, because of the nature of the development on the floodplain south of the river in Carmarthen, flood damage was very substantial in financial terms; the overall cost approached £7 million in the Pensarn Industrial Estate (see Plate 1). Road and rail communications throughout the Tywi, and adjacent valleys, were severely disrupted and access to and from Carmarthen was particularly difficult - inundation of the railway station echoed the flooding during the 1931 event (see Plate 2). Apart from the

Plate 3. Pumping floodwaters back to the River Tywi over the flood retention wall. Photo: Jeff Tucker.

Industrial Estate, the Johnstown district of Carmarthen was most severely effected as the Tawelan Brook backed up and overflowed its banks. Following the steep decline in river levels after the passage of the flood peak, considerable inconvenience was caused in some low-lying districts by the limited ability of floodwaters to drain back to the main channel; pumps were deployed close to the flood retention wall in order to accelerate this process (see Plate 3).

Less tangible, but nonetheless of substantial importance, was the shock to a community which assumed itself safe from the threat of flooding following the construction of the floodwall. Inevitably, the general perception of the security associated with a scheme providing protection against a flood with a return period assessed at 100 years pays limited regard to the strict statistical implications of such a design objective. A series of public meetings were arranged to provide information concerning the flood, explain the particular difficulties experienced with regard to flood warning and to discuss the broader issues raised by floodplain development generally.

The Effect of Llyn Brianne

One of the topics addressed at the public meetings, and in the media, was the contribution, if any, of the outflow from Llyn Brianne Reservoir on the degree of flooding experienced downstream, particularly in Carmarthen. Llyn Brianne Reservoir was constructed in 1972 as an integral part of the River Tywi water supply scheme. Its function is to act as a regulating reservoir, conserving water for release during dry periods and droughts in order to supplement the natural river flow and thereby permit abstraction at Nantgaredig to continue. The control rules for the reservoir are designed to optimise its role for water supply purposes, no allowance has been made for flood storage.

From October, the reservoir was at full capacity and overspilling continuously. The outflow from Llyn Brianne was therefore closely equivalent to the natural runoff resulting directly from the rainfall in the catchment above the reservoir; the effect of the lake is to reduce the flow rate and attenuate the flood hydrographs of the tributary streams. A study undertaken by Welsh Water concluded that the reservoir delayed the peak, at the outlet, by about three hours and reduced it by over 20 per cent. Nonetheless the overspill itself was a significant component in the flood flows in the upper Tywi. At Dolau Hirion, for instance, it accounted for 33 per cent of the discharge at the peak of the flood. The relatively small size of the reservoired catchment meant, however, that the overspill could have only a minor impact on the flooding experienced in Carmarthen. Calculations show that water level increases in the lower Tywi of six or seven centimetres only are attributable to reservoir outflows. This increase is placed in appropriate perspective by the 70 cm overtopping of the flood wall in Pensarn and by the fact that a slightly higher discharge rate could have been expected had the reservoir not been built.

Assessing the Peak Flow

For planning purposes and especially for the design of flood alleviation schemes a knowledge of the peak flow and its rarity is essential. Unfortunately, considerable practical difficulties attend the precise measurement of maximum discharge rates during flood events. Direct measurement is often precluded by the urgent need to assign field personnel to other tasks designed to ameliorate the impact of the flood. Access to the gauging section may also be difficult or hazardous during rare runoff events. Recourse is therefore normally made to the stage-discharge relation in order to derive flows based upon a record of water levels. The stage-discharge relation is developed over a period of years using a series of current meter gaugings to define a sensibly unique relationship. This 'rating' may be assumed to remain valid whilst the factors which influence the association between stage and flow (for instance the slope and roughness of the channel bed) remain unchanged. Scour and fill during the passage of a flood may alter the stage discharge relation and other factors, such as bridges and floodplain development, may exert an increasingly important influence in the extreme flow range. The change in rating consequent upon a rare event may be immediately evident after several further gauging results but the development of a revised stage-discharge relation can be a lengthy process. It will be appreciated that considerable uncertainty may often be associated with estimates of the highest floods. This uncertainty can have serious implications in connection with engineering design procedures.

The principal gauging station on the River Tywi is at Ty-Castell, 6 km upstream of Carmarthen – low flows are measured at the nearby Nantgaredig gauging station. The measuring section is sited about 200 m downstream of Pont Llandeilo-yr-ynys at a reach where most flows are contained within the channel. At stages above 5.2 m, however, water begins to spill onto the narrow floodplain – most of the inundation occurs over the right hand bank. The peak staff gauge reading during the October 19th flood was 6.76 m (13.99 m aOD). Considerable extrapolation of the stage discharge relation is thus necessary to assess the maximum rate. However, some confidence may be placed in the below bankfull component; the maximum gauging corresponds to a stage of 5.09 m and the rating may be considered well defined below this level. By extrapolation, the peak between-bank flows were assessed at approximately 1200 m^3s^{-1}. Floodplain discharge tends to be rather more difficult to assess – direct measurement of velocities being rare – but in the case of the Tywi a reasonable estimation could be attempted since a major proportion of the overspill was confined to a 100 m wide channel. The flow rate was sufficient to flatten hedges and an assumed average of velocity of 1.0 to 2.0 metres per second would place the floodplain discharge in the range 100–200 m^3s^{-1} and the total discharge of the order of 1300–1400 m^3s^{-1}. As with many assessments of extreme discharge rates, the uncertainty band is wide; ± 20 per cent is not exceptional where significant overbank flow is involved. It is necessary to stress also that the potential systematic error in peak flow assessment is considerable where few gaugings exist to define the stage-discharge relation in the high flow range.

On the Tywi, as elsewhere, a continuing programme of current metering represents the only way to maintain and improve the precision of flood discharge data. Nonetheless the October peak flow estimate may be expected to compare favourably with many instantaneous maxima registered for historically noteworthy floods – in a substantial proportion of cases the required flow rate would, of necessity, be based on the cross sectional area at the target site, the assumed water surface slope (commonly approximated using wrack mark evidence) and an informed guess at the frictional resistance of the channel. Preliminary results from a physical model of the Carmarthen reach (see below) suggest that the maximun flow rate during the 1987 Tywi flood has been realistically estimated, although a downward adjustment of approximately $100 m^3 s^{-1}$ may be warranted.

Flows in excess of 1000 $m^3 s^{-1}$ are very rarely exceeded in England and Wales and some measure of the extreme nature of the October flood may be gauged by the fact that a flow rate of 1350 $m^3 s^{-1}$ would represent the greatest flow registered on the Surface Water Archive for any river south of the Tyne.

Assessing the Rarity of the Flood

Whilst a number of standard procedures exist for the estimation of the rarity of extreme events – most based on the Floods Study (FS) proposals[1] – in practice the most appropriate methodology is often largely determined by the availability of data and the results are clearly sensitive to the quality of the hydrometric and other data which are employed. The difficulty of precisely establishing the flow has already been considered but uncertainties in the assessment of storm rainfall are equally important. Raingauge distribution throughout the Tywi catchment is relatively sparse – less than one per 100 km^2. With such a network density the potential for under or over-estimation is considerable. Figure 9 suggests that the scope for error may be greatest in the high rainfall zones along the north-west catchment divide and to the south-west of the Black Mountains. Thus the results given below should be treated with caution. This is especially true at a time when the hydrological impact of climatic change may shed further doubt on inferences drawn on the basis of historical associations between rainfall and runoff (but see page 12).

Table 5 lists the series of annual maximum flows for the River Tywi from 1958. By analysing this series it is possible to derive a relation between flood magnitude and return period – the average interval between years with a flood exceeding a given magnitude. The selection of an appropriate statistical distribution to fit to the annual maxima series has important implications. On the basis of an assumed GEV-PWM distribution which gives particular weight to extreme events[2], for instance, a very long return period might be proposed for the Tywi flood (see Figure 10); incorporating the October 19th flow in the analysis would reduce the rarity significantly. In the absence of a long series of good quality annual maxima for the target site, it is often better to base the choice of distribution upon an examination of the flood data from a number of stations in a region. The Flood Studies Report divided Great Britain into nine regions one of which corresponds to the Welsh Water area. For each region a growth curve associates a return period with the ratio of a flood discharge to the mean annual flood (MAF) at that location[1,3]. A flow rate of 1378 $m^3 s^{-1}$ comfortably exceeds three times the MAF and reference to the growth curve for Wales (FS Vol I, page 174) suggests a return period in excess of 500 years – see Figure 10.

Even by exploiting the additional information provided by regional flood data the estimated return period represents an initial appraisal only and further information merits consideration before a judgement is made regarding the most realistic return period to assign to the 1987 event. Evidence

TABLE 5 ANNUAL MAXIMUM SERIES FOR THE RIVER TYWI AT TY-CASTELL

Water Year (Oct-Sep)	Date	Max. Stage (Metres)	Peak Flow (cumecs)
1958	19/01/59	4.08	272.8
1959	03/02/60	4.94	456.4
1960	04/12/60	5.21	526.6
1961	12/09/62	4.41	336.3
1962	09/03/63	4.08	272.8
1963	19/11/63	4.08	272.8
1964	13/12/64	5.36	568.4
1965	18/12/65	5.36	568.4
1966	13/12/66	4.60	376.7
1967	17/10/67	5.12	502.5
1968	21/01/69	4.40	334.2
1969	11/11/69	4.31	316.2
1970	02/11/70	3.87	237.8
1971	19/10/71	4.18	291.2
1972	06/08/73	4.50	355.1
1973	30/01/74	4.75	410.7
1974	22/12/74	4.37	328.2
1975	01/12/75	4.04	265.7
1976	03/02/77	4.15	285.6
1977	31/10/77	4.71	401.4
1978	01/02/79	4.20	294.9
1979	28/12/79	5.89	779.8
1980	22/03/81	5.62	645.7
1981	09/10/81	4.65	387.8
1982	06/01/83	4.12	280.1
1983	16/10/83	4.30	314.2
1984	23/11/85	4.02	262.1
1985	22/12/85	4.57	370.1
1986	27/03/87	4.84	431.9
1987	19/10/87	6.76	1378.0

Note: Llyn Brianne began to fill in March 1972 and was full by December 1972.

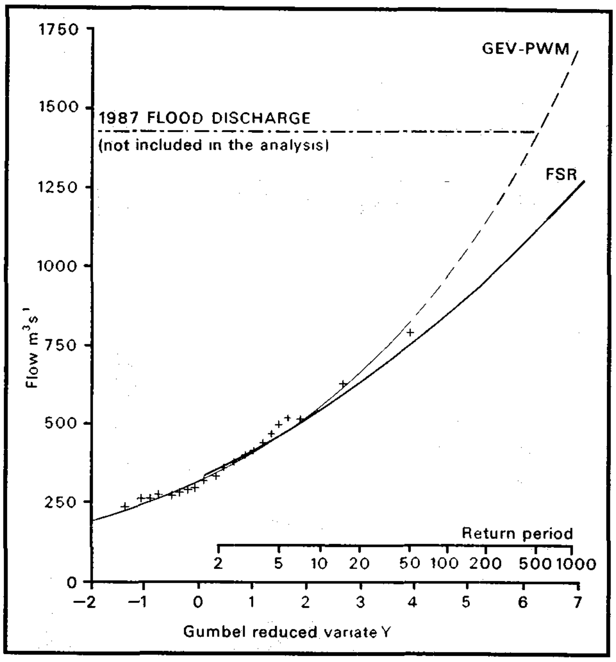

Figure 10. Flood frequency diagram for the River Tywi at Ty-Castell based on data for the period 1958-86.

assembled following a major flood on the Tywi in 1931 suggests that the maximum flow on that occasion approached that experienced during the 1987 flood; an estimated flow of 1270 m^3s^{-1} is quoted in the Interim Report on Floods published in 1933[4]. With a far greater measure of uncertainty, anecdotal evidence indicates that the 1894 flood – which affected wide areas of southern Britain – was also a flood of greater magnitude than is represented in the record of gauged flows (from 1958). The presence of three such notable events in a hundred year period raises questions about how representative the recent data can be considered to be and confirms that great care needs to be exercised regarding certain of the very long return periods ascribed to the 1987 flood. More detailed investigation of other historical floods – for example, those which occurred in 1852 and 1875[5] – allowing useful estimates of the peak flow rates to be determined – may further emphasise the need for caution. The significance of this early data may be appreciated by assuming that both the 1894 and 1931 events produced maximum discharge rates in excess of 1000 m^3s^{-1}; under such circumstances the return period of the 1987 flood would be closer to 100 years.

An alternative and more deterministic approach to the assessment of the return period is recommended for very rare events when regional curves become increasingly poorly defined. The Unit Hydrograph (UH) technique is widely used where the record of actual annual maxima is relatively short. A detailed explanation of the methodology is given in the Flood Studies Report. In essence, the technique involves the assessment of the rainfall input – for a particular catchment – corresponding to a given return period followed by the estimation of several parameters in a rainfall-runoff model to facilitate the conversion of storm rainfall into the consequent runoff. That proportion of the rainfall contributing immediately to runoff (the Percentage Runoff) is one of these parameters; it comprises two components: a constant depending on the soil type and a second factor relating to the magnitude and duration of the storm together with a measure of antecedent catchment wetness. The unit hydrograph, from which the duration of the design storm is derived, may be developed using actual event data or, with less precision, from catchment characteristics.

The Consultants for the design of the Carmarthen Flood Alleviation Scheme derived a unit hydrograph from the rainfall and runoff data associated with the floods of December 1979 and March 1981 and – on this basis – ascribed a flow of the order of 800 m^3s^{-1} to the 100-year flood at Ty-Castell; this analysis was central to the design of the flood retention wall in Carmarthen. Following the 1987 flood, an initial analysis suggested that under certain conditions some of the assumptions inherent in the UH approach require further examination. The peak flow, for instance, occurred some eight hours earlier – and was consequently substantially greater – than would be expected on the basis of unit hydrograph analysis discussed above; a time to peak of about 24 hours was used by the Consultants. This discrepancy may be partially explained by the decline in the rate of storage which results when all of the floodplain has been inundated, but the percentage runoff appears to have been appreciably greater during the October 1987 flood than would be expected on the basis of the FSR equations model (and in relation to earlier flood events on the Tywi when, typically, percentage runoffs were below 50). Analysis of a series of high flow events in the Cothi catchment indicated that the difference between the observed runoff rate and that estimated using standard values (following Flood Studies recommendations) may be greatest for the rarer floods. Such differences may, of course, reflect limitations in the accuracy of the basic rainfall and/or the runoff data. It is also possible that the occurrence of the highest rainfall intensities towards the end of a storm – a feature of the October 18/19th rainfall distribution – may exert an important influence. Accepting that one or more of these factors may justify a later review of the analytical procedure, a departure from the standard method was adopted and the percentage runoff value increased to equate more closely with the observed value (about 65 per cent). The Cothi catchment was also considered separately from the Tywi catchment in this revised treatment. The associated computation revealed that storms of about 41 hours duration were critical in relation to the production of very high discharge rates at Ty-Castell. This analysis ascribed a flow of around 1040 m^3s^{-1} to the 100 year flood and associated a return period of approximately 250 years with the October 1987 event. The assumptions involved, together with uncertainties in the rainfall and runoff data, imply that a wide error band should be associated with this, and the other, return period estimates.

It is important to recognise that water levels in the vicinity of Carmarthen may be influenced by factors other than the upstream discharge as measured at Ty-Castell. Tidal effects, local tributaries and the hydraulic characteristics of the river and its floodplain (which has undergone significant changes over the last century) can all contribute to the scale of any inundation. A provisional examination of water levels recorded at the Quay in Carmarthen suggests that, although the tidal influence was negligible, the 1987 October peak appreciably exceeds all previous maxima; the data series extends back to the beginning of the nineteenth century[6]. The construction of the 1984 flood retention wall will have increased water levels at the Quay somewhat but its submergence by almost two metres confirms the singular nature of the 1987 flood.

Conclusion

The perverse nature of the British climate may be held principally responsible for a major flood event occurring within three years of the completion of a retention wall designed to give a measure of protection which, to the layman, must have seemed very comforting prior to the October 1987 inundation. Important lessons of general significance have been learnt as a result of this exceptional flood. These range from a fuller appreciation of the vulnerability of emergency communication systems in flood conditions to a demonstration of the critical importance of hydrometric data in the development and application of engineering design procedures.

In the short term, river improvement works in Carmarthen will increase the river's carrying capacity but, more significantly, the investment in a physical model of the Carmarthen reach – commissioned by Welsh Water – together with further research into the flood generating and routing processes should provide a firm basis upon which to develop a comprehensive flood alleviation strategy for the lower Tywi.

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