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The Use of Local Data in Estimating and Predicting Extreme Floods

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ABSTRACT: Worldwide floods continue to cause the most damage of all natural hazards. Estimating floods can involve the use of estimates of extreme rainfall. In the UK, the Flood Estimation Handbook (FEH) has been shown to underestimate both rare rainfall depths and the Probable Maximum Precipitation (PMP) simply through a lack of use of local rainfall and historic storm information. Although the FEH encourages the use of historic flood data to improve estimates of extreme floods, it is dominated by desktop procedures. One consequence of this approach is that few practitioners now have the skills and experience needed to investigate floods in the field. This should be incorporated into national methodology for flood estimation in ungauged catchments. Its absence has resulted in upto an eight-fold difference in the estimate of the 100 year flood on a small chalk catchment. On clay catchments such as the Upper Brue, the 100 year flood has been underestimated by a factor of 2, and the Probable Maximum Flood (PMF) was underestimated by a similar margin. Local historic flood data can also be used to estimate flood volumes; this data is less sensitive to errors than for flood peaks. Historic floods can also be used to produce flood inundation maps or to test the reliability of existing maps and of dam-break floods.

Predicting floods in real time requires accurate rainfall data, a reliable estimate of Soil Moisture Deficit (SMD), and a well calibrated runoff model that uses local soil hydraulic conductivity measurements. There can be serious underestimates of rainfall by the UKMO Nimrod radar based system. For one 5 km × 5 km grid square in East Somerset for the period 2004–2005 the error on daily rainfall is 40% at a depth of 10 mm, increasing to 64% at 28 mm. The errors are greatest at a time when floods may take place. Measurement of actual evaporation using weighing lysimeters also allows a reliable estimate of SMD to be made at low cost. In contrast to this both the UKMO MORECS (Meteorological Office Rainfall and Evaporation Calculation System), and MOSES (Meteorological Office Soil Exchange System) methods have errors upto 50 mm too high. This will prevent timely flood warnings. Locally measured soil hydraulic conductivity has produced higher estimates of percentage runoff than the FEH, while at low rainfall intensities there is an overestimate. Local soils data combined with local observed time to peak have been used to produce a real-time flood warning system for the upper Brue, operational now for three years.

INTRODUCTION

Floods continue to cause considerable storm damage and death worldwide: for reviews see Smith and Ward (1998), Ashley *et al.*, (2007). Whilst much progress has been made in modelling (Bevan, 2001) and instrumentation (Strangeways, 2003), much uncertainty still exists in the estimates of extreme floods (Pappenbergar, 2006, Hutchins, 2006). Much of this uncertainty comes about through a basic lack of data, it is made worse by the increasing dependence upon models to provide estimates of SMD, soil hydraulic conductivity (Ksat), and even rainfall. In many areas of the world the situation could be vastly improved by better cooperation between government, academia, industry, and the public (Singh and Yadava, 2003). In the UK, much uncertainty remains regarding maximum flood estimation, while the lessons of the past have not been learnt (Clark, 2006). Although the use of local data, especially flood event data, was encouraged in the FEH (IOH, 1999), its use has been very limited mainly through a lack of explanation of its importance and because of the absence of detailed guidelines to search for and deal with historic data. This is essentially local in character and it demands a local approach. The experience gained in computer methods has, to some extent, been at the expense of field experience. Hydrology remains a field based science and the answers to critical questions will be obtained in the field. There have been improvements in the data base of floods at gauging stations http://www.environment-agency.gov.uk/hiflowsuk/, but the magnitude and frequency of extreme floods which are out of bank is much less certain. Unless greater use is made of local historic flood information it may be decades before the level of uncertainty can be reduced to acceptable levels.

It is against the background of these concerns that this paper has been prepared. It has the following structure. First, the use of local rainfall data and historic storm data are described in relation to rainfall frequency analysis. Second, examples of the use of historic flood information are described and a comparison made with the results of using the FEH with regard to flood frequency, flood volume, and inundation. Third, the use of locally measured rainfall, SMD and Ksat data are described and how they will improve real time flood warnings in the future.

ESTIMATING EXTREME RAINFALL AND FLOODS

Although the estimation of extreme rainfall and floods has a long history (Maidment, 1993) much controversy still exists (Klemes, 2000; Gaume, 2006; Koutsoyiannis, 2007). The basic problem stems from a lack of long term data, yet by 1960 Tate Dalrymple told us: "Historic floods provide probably the most effective flood data available on which to base flood-frequency determination, and where the data are reliable this information should be given the greatest weight in constructing the flood-frequency graph. Effort should be expended to search out historic data from newspapers, local history society records, local history reports and other sources." (Dalrymple, 1960). One might add to this list eye-witness accounts, photographs, town records, and flood markers. In the UK the use of historic records has lagged behind by about 40 years, while in Europe the situation is much better (Brazdil and Kundzewicz, 2006). For flood risk mapping the use of local Ordnance Survey maps was only proclaimed to the civil engineering profession in 2002 by Thompson and Clayton (2002).

More widely accepted methods of extreme flood estimation in the UK include statistical analysis of gauging station data; the application of prediction equations; rainfall-runoff methods based on UH methodology (IOH, 1999); and continuous simulation (Calver *et al.*, 1999). The use of historic flood data is very sparse but includes Archer (1999) Clark, (1986), Williams and Archer (2002) McDonald, Black, and Werrity (2003) and is growing in importance Thorndycraft *et al.*, (2003). The PMF is normally estimated using the PMP and a runoff model. Estimation of PMP usually involves the use of regional storm data which can be maximised by hydrometeorological methods (WMO, 1986). This approach is not without its critics (Papalexiou and Koutsoyiannis, 2006; Koutsoyiannis, 2007), but should not be dismissed since a probability has been assigned to PMP (Bureau of Meteorology, 2003; Austin *et al.*, 1995) showing that rainfall is not unbounded. Furthermore, it can help to produce maps of PMP especially when combined with rainfall frequency analysis using a modified Gumbel distribution (Clark, 2002a).

Local Data versus Standard Methodology

It is instructive to compare the results of standard flood estimation methods in the UK with those based on local data. In both the Flood Studies Report (NERC, 1975) and the FEH (IOH, 1999) the use of local data is discouraged. However, Bootman and Willis (1977) showed that for parts of Somerset UK, this can lead to serious underestimation of extreme rainfall. Since 1999 the FEH has replaced the FSR for rainfall and flood estimation, but MacDonald and Scott (2000) have shown serious anomalies in some of the rainfall estimates.

Since heavy rainfall causes floods its proper estimation is crucial. The analysis of annual maximum values uses the modified Gumbel scale (Rakhecha and Clark, 1999, Clark, 2007), where the modified reduced variate,

$$Y = [(-\ln \ln (1 - 1/T) - 3.3842 * 1.09348 * T^{-0.046518}] + 3.3842 \qquad \dots (1)$$

Where T = return period (years)

Annual maxima are ranked and the return period calculated using,

$$Rp = N/(M - 0.7) \qquad \dots (2)$$

Where M = rank order, N = length of record (Clark, 1983). This formula was tested using Monte Carlo simulation and the results were consistent with the formula. Rainfall quantiles are converted to logarithms and this results in unbounded estimates of rainfall, even though PMP implies a maximum with finite probability, but is here assigned a probability of 0.000001 or 10^6 years, which in is line with Australian practice (Bureau of Meteorology, 2003). Estimates of 24 hour PMP were described by Clark (2002a), based on historic storms. One-day rainfall was converted to 24 hour depths by the factor 1.18 (IOH, 1999). For 1 hour rainfall the most severe 1 hour storms in southern England are here maximised using the same methodology for 24 hour rainfall namely the moisture maximisation method,

$$Mr = R\ (MTd/STd) \qquad \dots (3)$$

Where R = storm rainfall; MTd = maximum 12 hour persisting dewpoint at the time of the storm; STd = storm 12 hour persisting dewpoint. The ratio of the storm and maximum dew points is called the Moisture Maximisation Factor (MMF). Maximum 12 hour persisting dewpoints for 21 years were extracted from the nearest suitable local climate station at Cardington, Bedfordshire. Table 1 shows the results.

Table 1: Maximisation of One-hour Rainfall

Location	*Date of Storm*	*Rainfall (mm)*	*MMF*	*Maximised Rainfall (mm)*
Henley in Arden	13/7/1889	85.3	1.92	164
Maidenhead	12/7/1901	92.2	1.74	160

Use of 6 hour persisting dew point data for the storms made no difference to the maximised rainfall. No one-hour dewpoint data are available for the two storms in Table 1 but it is unlikely that such information would change significantly the maximised rainfall depth.

Figure 1 shows the results of rainfall frequency analysis for North Brewham, (average annual rainfall = 850 mm). Also shown are the results from the FEH. There is an excellent linkage between the observed annual maximum (AMAX) data for 24 hour rainfall and the PMP. In contrast to this the FEH estimate has a variable rate of growth with return period. More significantly the 100 year 24 hour rainfall is underestimated by 35 mm. The FEH PMP for the Brewham area is 300 mm. However, this was exceeded in 1955 when 355 mm were recorded at Martinstown, some 40 km SSW of North Brewham. According to the FEH the growth rate for 1 hour rainfall is even more variable, giving a 10000 year 1 hour rainfall in excess of 1 and 2 hour FEH PMP. Such a pattern of growth rates is very unlikely since all sub-daily rainfall frequency analyses have similar growth rates irrespective of duration (Clark, 1991; Hershfield, 1961). The increasing growth rate of the FEH has come about by the upward extension of the intensity duration model (Faulkner, 1999) above the observed data (MacDonald and Scott, 2001).

For wet sites like Dale Head (AAR = 2259 mm), the estimates of extreme rainfall need to take account of all events during the year—the so-called peaks over a threshold (POT). Omission of this local data will tend to an underestimate of rainfall depth of moderate frequency (Table 2).

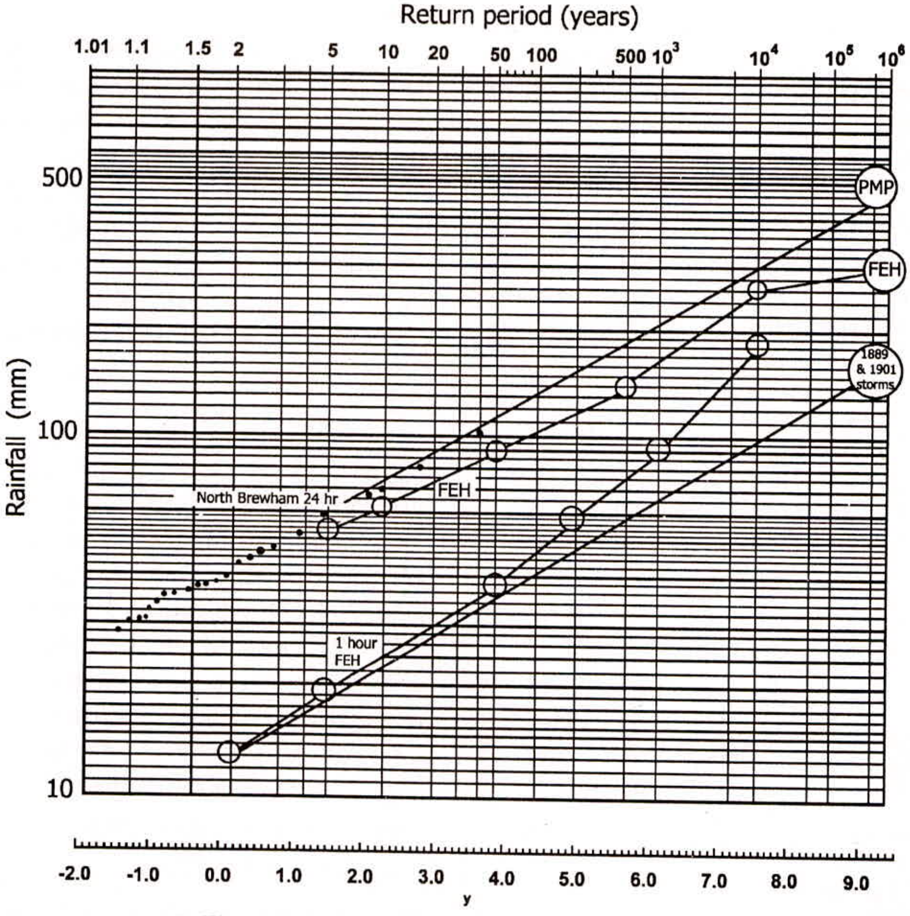

Fig. 1: Rainfall estimates for North Brewham

Table 2: Frequency of Rainfall Events from AMAX, POT, and FEH Estimates for Dale Head, NGR: NY313475

Rainfall (mm)	*Number of Events (AMAX)*	*Number of Events (POT)*	*FEH*
60	23	68	21
70	17	20	13
80	11	16	8
90	7	9	5

Rainfall events in excess of 60 mm have a threefold difference between the recorded frequency and the FEH estimate. These differences rapidly decrease for higher depths of rainfall but are still significant at 80 mm. These examples, although limited in extent, show how the analysis of local rainfall can lead to higher estimates of extreme rainfall for 24 hour totals, while the *1-hour* rainfall at high return periods appears to be overestimated. There is a need to homogenize estimates of rainfall over the complete range of rarity *upto* 10^6 years.

ESTIMATES OF FLOOD FREQUENCY USING LOCAL HISTORIC FLOOD INFORMATION

While the use of unsuitable rainfall estimates can contribute to errors in flood frequency estimates, so too can the percentage of runoff and time to peak of the unit hydrograph lead to further errors. It is beyond the scope of this paper to investigate in more detail the relative contribution of each of these variables, suffice to say that where they have the same lowering effect on flood estimates then the overall effect can be startling. This part of the paper will compare the results from six locations in the UK. Figure 2 shows their location.

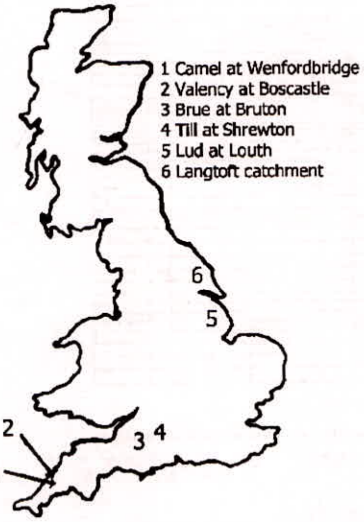

Fig. 2: Location of study areas

River Camel at Wenfordbridge

This upland river drains an area of 59.2 km^2 at Wenfordbridge. At the old Inn close by the two arch medieval bridge are a series of flood marks carved onto the wall whose heights above sea level are given in Table 3.

Table 3: Flood Levels (m OD) on the River Camel at Wenfordbridge UK

River bed level	67.39
30/8/1950	69.77
27/12/1979	69.98
12/6/1993	70.16
8/6/1957	70.53
8/7/1847	71.99

In order to convert these flood levels to an estimated discharge a channel and floodplain cross section was surveyed. The water surface slope at low flow was also surveyed and found to be 0.0066. Friction values of 0.025 for the cemented stone arches and 0.055 for the floodplain which is covered by grassland were chosen. Whilst the lowest four floods were marked on a wall at the old Inn, the flood level for the 1847 flood event was inferred from:

"At Wenford Bridge, about 5 miles from Camelford, the body of water was immense. The Wenford Inn and Stables, standing about 3 or 4 feet only beyond the bed of the river, filled with water…The Stables in which was a horse, filled, and strange to say the horse (which rose with the water to the roof that was carried away) was washed over the wall and luckily saved." (Royal Cornwall Gazette, 16/7/1847.

In order to estimate the peak discharge the Manning equation was used,

$$Q = A\,R^{0.666}\,S^{0.5}\,n^{-1} \qquad \dots (4)$$

Where Q = discharge; A = channel area; S = water surface slope; n = Manning's roughness factor. The return periods of the four lowest floods were calculated using equation (3) and a length of record 1950–2006. There are no flood marks for the period 1848–1949 even though on the adjacent Valency at least seven floods are recorded for the same time period (Clark, 2006). The return period of the 1847 flood was calculated using the new method proposed by Clark (2007), based on the joint probability of the effective rainfall and antecedent SMD,

$$Frp = ERrp * SMDrp \qquad \dots (5)$$

Where Frp = return period of the flood; ERrp = return period of the effective rainfall; SMDrp = return period of the antecedent SMD. In the case of the 1847 flood application of the new method involved an estimation of the storm rainfall based on a water balance check of the flood event, itself based on the description of the flood duration and the storm (Royal Cornwall Gazette, 16/7/1847; West Briton, 16/7/1847), and weather reports during the year in order to give an estimate of the antecedent SMD. The results of these methods are shown in Table 4.

Table 4: Magnitude and Rarity of five Floods on the River Camel at Wenford Bridge

Year of Flood	*Peak Discharge (cumecs)*	*Return Period*
1847	290	34800
1957	76	81
1993	54	34
1979	47	21
1950	41	15

These results are presented in Figure 3 as is the result using the Revitalised rainfall-runoff method (Kjeldsen *et al.*, 2005) which has been calibrated upto a return period of 150 years and thereafter linked to the FEH PMF of 365 cumecs. In addition, the PMF using local soil hydraulic conductivity and a non-linear flow model (Clark, 2004), was calculated as 437 cumecs.

As part of the flood frequency analysis, it can be shown for impermeable catchments that where the channel has not been modified by human activity, bankfull discharge has a return period of about 2 years. In the present case a channel depth of 1.2 m gives a bankfull discharge of 17 cumecs which is very close to the estimate of 18 cumecs from the historic flood analysis. The Flood Frequency Curve (FFC) based on the present analysis was calculated using probability weighted regression. Excluding the flood of 1847 the PMF is estimated as 425 cumecs, very close to the estimate based on PMP of 437 cumecs.

These results are clearly much higher than those given by the ReFH and FEH which raises the question as to which is more realistic. First, the historic FFC gives a median flood which is close to the estimated bankfull flow. Second, the ReFH flood growth rate Q50/Q2 = 2.25 while the measured growth rate on the Camel at Denby = 3.98, where the catchment area is 209 km^2. These compare with a value of 3.55 from the historic FFC. The growth rate of rainfall at nearby Lesnewth = 2.19. The ratio growth rate of floods: growth rate of rainfall is greater than unity since the hydraulics of overland flow are non-linear.

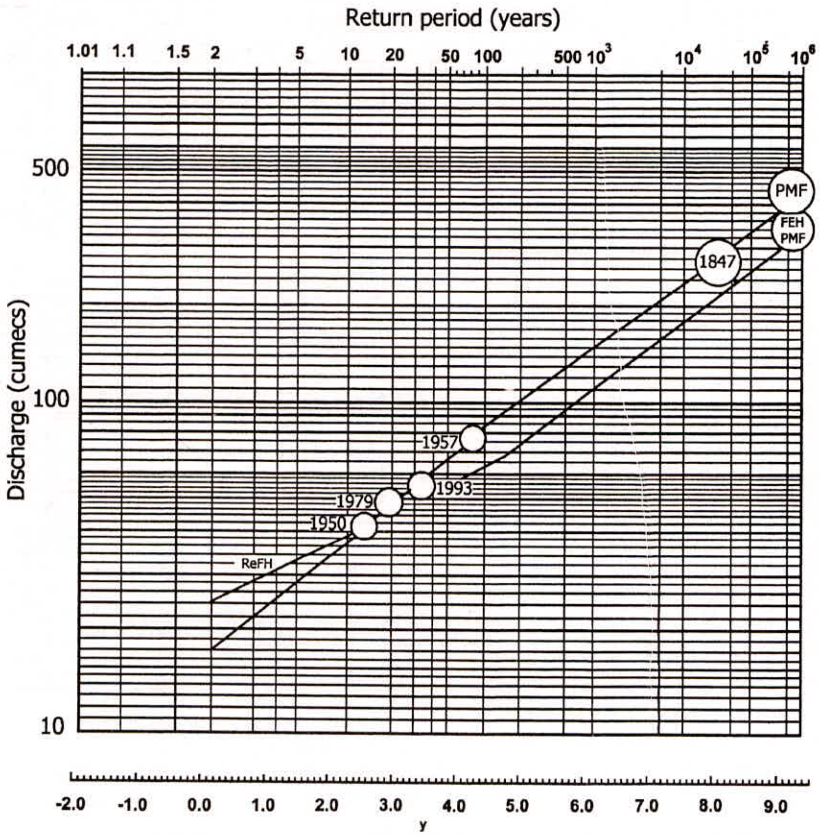

Fig. 3: Flood frequency for the Camel at Wenfordbridge

Although the ReFH gives a reasonable comparison with the median flood the expected growth rate of rarer floods is too low. In addition the flood of 1847, however imperfect the estimate may be, was produced by an estimated rainfall below the PMP for this area, and certainly below that measured during the Martinstown storm of 1955.

River Valency at Boscastle

The Valency at Boscastle drains an area of 19.8 km^2 and has already been the subject of investigation (Clark, 2005, 2006; Environment Agency, 2005). The results of both studies are shown in Figure 4. The four flood frequency estimates in Figure 4 require explanation. The one chosen by the Environment Agency in order to design the flood alleviation scheme for Boscastle, marked EX5160 is a fine example of the results of a misused technique and a reminder that historic flood frequency is not without its own pitfalls. First, the return periods which their consultants used included the period 1828–1931 as part of the complete flood record *even though there were no floods during this time period in their analysis.* This approach ignores the advice given in Bayliss and Reed (2001) and standard practice elsewhere. Second, the growth rate Q50/Q2 for EX5160 = 5.25 which is far in excess of the rainfall growth rate at Lesnewth, located in the Valency valley. The result using the FEH rainfall-runoff method gives a realistic flood growth ratio of 2.91 but the 100 year flood discharge has been exceeded nine times since 1882, showing how badly the hazard has been underestimated at this site. Also included in Figure 4 is the gauging station data for the Horner Water catchment of 20.8 km^2 with similar basin characteristics. This has a Q50/Q2 flood growth rate of 3.58, close that of Clark (2006) of 3.31 for the Valency, but with lower discharges. This can be explained by the presence of 17% woodland in Horner Water as compared with 5% in the Valency, a longer mainstream *channel* length of 11km as compared with 7 km; the presence of Nutscale reservoir in Horner Water which affects the runoff from 5.5 km^2 of the headwater area.

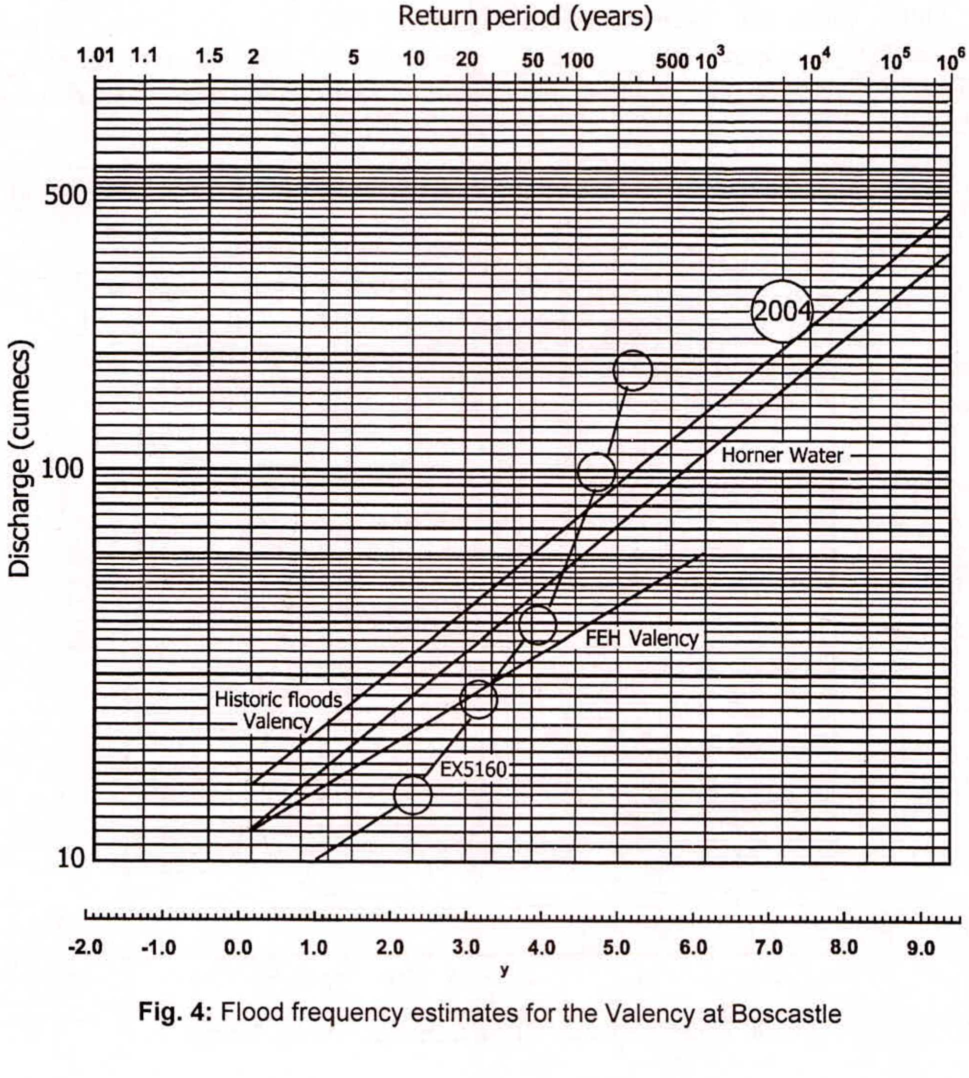

Fig. 4: Flood frequency estimates for the Valency at Boscastle

Several points emerge from the evidence discussed. First, the search for historic floods has to be thorough and not merely guided by records of rainfall which were not collected in the catchment area. Second, return periods must be based on a record length that does not have large time gaps. This will lead to inflated return periods and could also involve the loss of important flood events – in this case at least six events were missed out. Third, the resulting flood frequency curve must produce estimates of the median flood and the PMF which are realistic. In the case of the Valency at Boscastle the pre-flood channel could convey about 16 cumecs, close to the estimated 2 year flood of 17 cumecs. Fourth, the flood growth rate should be consistent with the growth rates of local rainfall and of other nearby sites or hydrologically similar catchments.

The Rivers Brue, Till, Lud, and Langtoft Catchment

Whilst the behavior of the river Brue is similar to that of the Camel and Valency the remaining three examples are on chalk which is very permeable, resulting in problems of fieldwork, analysis and flow modelling. Many chalk catchments are without any signs of surface drainage in their upper reaches, where the water table must be well below the surface, only to appear, if at all, during the winter. Yet in many parts of England these valleys are the site of villages which may be at risk from flooding in summer and winter. The problem is to assess the flood hazard when there is no riverflow data and in many cases where there is no river channel available to give an estimate of the median flood. When floods do occur they are often rare events, possibly greater than 1 in 50 years, although this is below the 1 in 70 year threshold for house insurance in the UK. At this level of rarity, it is not possible to assess if the recent past is representative of a much longer time period. The results of these studies are given in Table 5, where the result using the FEH is given for comparison.

In all cases the use of local data has produced estimates of floods considerably in excess of those using the FEH. There are two main reasons for this result. The first is the underestimation of extreme rainfall especially at the scale of the catchments investigated; the second is the underestimation of percentage runoff. One example is shown in Figure 5 where the field measurements of Ksat suggest higher rates of runoff at most intensities than the FEH. The Till, Lud and Langtoft catchments are underlain by chalk where the differences in estimates of floods are the greatest. Greater weight should be given to the historic record where it can be proven that serious and damaging floods have taken place such as at Langtoft with floods in 1888 and 1892 (Hood, 1892). The flood of 1892 exceeded the FEH PMF. Although that flood was a very rare event, its existence alone casts doubt on the standard method of flood estimation in the UK.

Table 5: Flood Quantiles for the Brue, Till, Lud, and Langtoft Catchment (Hist), as Compared with Results using the Flood Estimation Handbook (FEH)

River	*Area (km^2)*	*Q2*		*Q50*		*Q100*		*Q500*	
		Hist.	*FEH*	*Hist.*	*FEH*	*Hist.*	*FEH*	*Hist*	*FEH*
Brue	31	19	18	64	36	86	41	128	52
Till	71	0.6	1.0	11	2.9	19	3.5	56	5
Lud	51	2.8	1.0	17	6.0	21	8	41	17
Langtoft	6.6	–	–	3.2	0.6	4.2	1.0	8.5	2.8

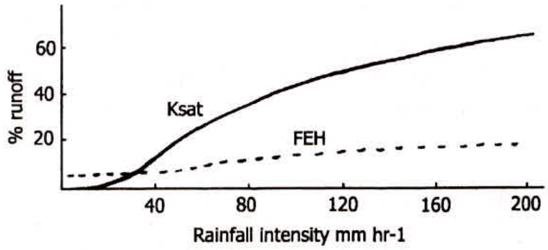

Fig. 5: Rainfall intensity in relation to % runoff at Langtoft

Flood Volumes from Historic Flood Reports

Locally reported historic floods can give valuable information regarding the frequency of flood volumes. Such information can be very useful for the design of flood storage reservoirs or the assessment of the design standard of an existing structure.

On the river Brue UK descriptions of the floods in 1882, 1888, 1917, 1974, 1979, and 1982 are available. Estimation of the flood volume required for storage needs a good estimate of the duration of overbank discharge and the peak discharge. The estimated triangular hydrograph then gives the estimated flood volume. If there is more detailed evidence for hydrograph shape then it should be used. As an example, the report of the 1917 flood tells us:

"The inmates of the houses noticed the water coming into their homes about nine o'clock on Thursday evening…the water rose to the bedroom floors and the unfortunate dwellers cried for help, which could not reach them till 12 o'clock on Friday." (Western Gazette, 6/7/1917). The results for the floods of 1974, 1979, and 2005 were based on the author's own observations. Figure 6 shows the results. Also shown are the measured values of overbank flood volume at the Bruton flood detention dam site which is 2 km upstream of Bruton. The good comparison of the measured excess flood volumes with the historic flood record gives confidence in the method of analysis. In contrast to this the estimates made for the Environment Agency (Black and Veatch, 2005) are considerably in excess of the lower historic estimates but much lower than the extreme values. This is to be expected on account of the differences in percentage runoff at both low and high rainfall intensities between Ksat data and those of the FEH. Even for small floods the standard percentage runoff of the FEH for this area is 42% which is far in excess of what happens in the field.

Flood Inundation Maps and Local Flood Data

As part of the investigation into the safety of Bruton dam, the Environment Agency commissioned a dam-break study (Babtie, Brown, and Root, 2004). A flood inundation map for the town of Bruton was produced based on the 1 in 10000 year event, the PMF, and the PMF and dam break flood. The resulting maps, not shown here, show wholesale inundation of the town. Unfortunately, there was no check made with what happened during the major floods of 1917 and 1768. Table 6 gives the flood levels at Church Bridge, Bruton.

There is simply no comparison of the modelled flood levels with what has happened in the past. Should the dam be overtopped by the estimated PMF of about 500 cumecs then the resulting flood will substantially exceed that in 1768 resulting in wholesale destruction and loss of life. For example the BBR dam-break flood was exceeded by the natural floods in 1917 and 1768.

Table 6: Flood Levels Based on BBR (2004) Compared with Historic Flood Levels from Local Reports

Source and Flood Standard/Event	*Flood Level m OD*
BBR 1 in 10000	60.9
BBR PMF	61.1
BBR PMF & dam break	61.3
1982 flood	60.9
1917 flood	62.3
1768 flood	63.6

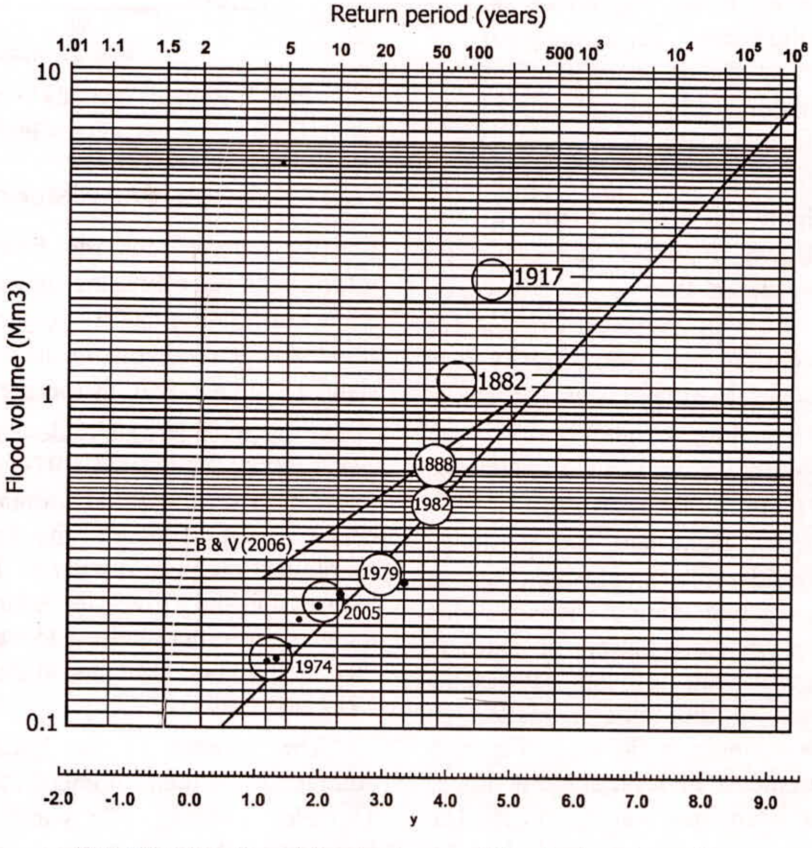

Fig. 6: Estimates of flood volumes at the Bruton dam site

FLOOD PREDICTION IN REAL TIME

Flood warnings are just as essential for areas which already have flood alleviation measures in place as for those which remain unprotected. This is because the existence of control measures can lead to a false sense of security over time and a reduction of flood experience by those who remain long after the measures have been implemented. The issuing, dissemination, and action taken on receiving a flood warning are not considered here. A real time flood warning system needs to have:

1. Accurate rainfall data in real time
2. A good estimate of the SMD
3. A realistic percentage runoff function
4. A flow model which has been calibrated against extreme events and which can be run in time to produce a flood warning.

Rainfall and SMD Measurement

Since the mid 1990's the UKMO (Golding, 1998) has developed the Nimrod nowcasting system. Nimrod was designed to give estimates of rainfall based on its radar installations at a resolution of 5 km × 5 km. This data is used in the MOSES system in order to produce estimates of SMD (Smith *et al*., 2006). The radar data are available at 15 minute time intervals and SMD hourly. To date no empirical evaluation at the local scale of either rainfall or SMD has been made. At CHRS daily rainfall are measured at a UKMO registered site using a standard 5 inch gauge and a ground level gauge. Also measured are open pan evaporation from a 0.7 m sunken pan operational since 1985, and actual evaporation from two grass weighing lysimeters which have been operational for 13 years. These lysimeters are weighed daily and with measurements of any drainage allow the full water balance to be obtained as well as a measure of SMD. Both the rainfall and SMD data allow a comparison to be made with the MOSES data.

Figure 7 shows a comparison of the daily rainfall totals for the year August 2004 – July 2005 where the sloping line gives the 1:1 comparison. Below rainfall depths of 8mm there is a reasonable comparison but above this the raingauge totals are often double than that given by the radar and above 20 mm the errors are in excess of a factor of 3. On one day the standard gauge measured 27 mm while the radar estimate was only 8mm. To this error must be added the 3% difference between the standard MO gauge and the ground level gauge. Since CHRS is close to the edge of one 5 × 5 km grid square a comparison was made with the adjoining square, but this gave even bigger differences. The mean rainfall at two other sites was then compared with the MOSES rainfall. For the same time period there was a difference of 363mm for the whole year, with the largest monthly differences being observed during the wettest months.

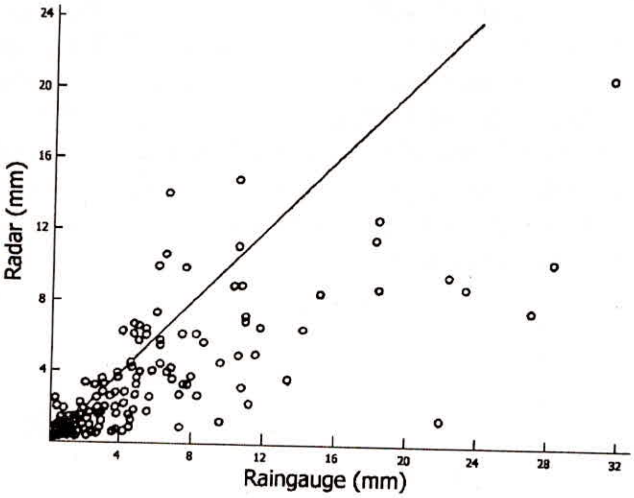

Fig. 7: Radar and rainfall estimates of one-day rainfall, 2004–2005

Figure 8 shows the estimates of SMD from the lysimeter and MOSES. During the summer of 2004, MOSES gave estimates of SMD typically 30–40 mm higher than the lysimeter. During the winter when the ground is normally at field capacity and zero SMD as shown by the lysimeter, MOSES gave the SMD around 50 mm. During the spring of 2005 the differences between the two datasets were as much as 60 mm.

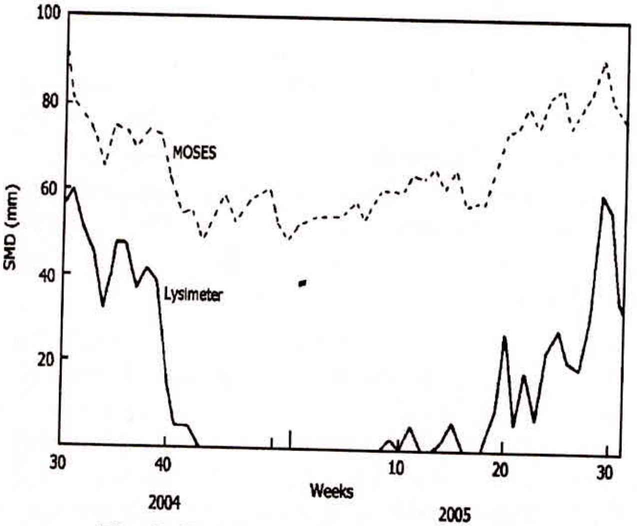

Fig. 8: Estimated and measured SMD at CHRS

These results are typically worse than those produced by the predecessor system MORECS, (Clark, 2002b). Taken as a whole the results were typical of the upper Brue catchment and not just confined to the local grid square of CHRS. Clearly these results call for an explanation. First is the underestimation of rainfall by the radar system (Figure 7). Second is the overestimation of the actual evaporation. Figure 9 shows the monthly estimates and measurements of evaporation from grass. In seven of the months MOSES gave higher estimates of actual evaporation than the lysimeter. The year totals were lysimeter 437 mm, MOSES 482 mm. The higher SMD and lower rainfall than occurs in real life can only mean that a timely flood warning on small catchments will be more difficult to achieve.

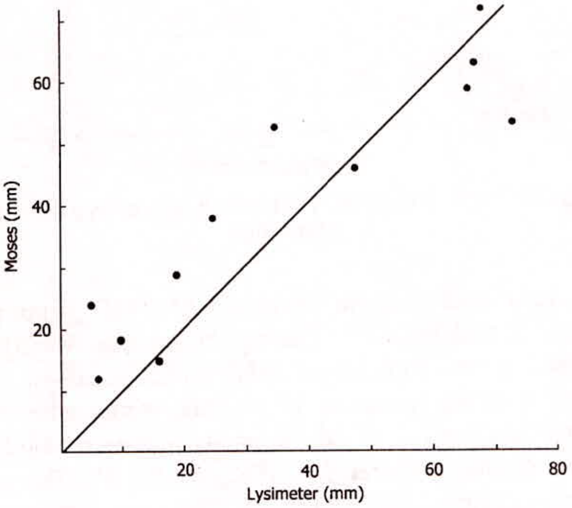

Fig. 9: Monthly measured and estimated evaporation 2004–2005

Percentage Runoff

When rainfall meets the ground the nature of the soil surface and its hydraulic properties will influence how much rainfall is converted into runoff. Early work on heavily wooded and pasture catchments confirmed the role of soil in the generation of runoff (Clark, 1987). Figure 10 shows the measurements of Ksat in the Langtoft catchment area.

A wide range of values were obtained which is a reflection of the great variety of soil physical properties. When these data are combined with a range of rainfall intensities it is possible to estimate the effect of rainfall on percentage runoff (Figure 5). Also shown is the FEH percentage runoff in relation to rainfall intensity lasting for one hour so as to make the comparison possible.

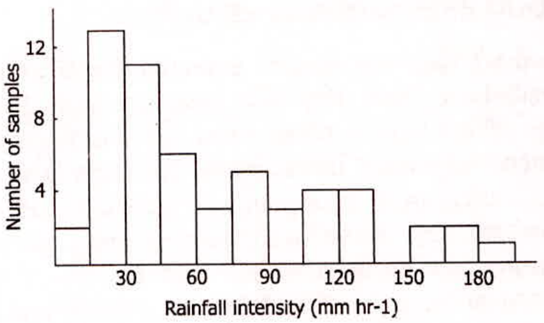

Fig. 10: Saturated hydraulic conductivity for soils in the Langtoft catchment

Local soils data show much more variability in percentage runoff than what the FEH suggests. Although the FEH rainfall runoff method has recently been revised and includes a percentage runoff scheme based on a probability density function, when applied to the catchments described earlier in this paper, gave results that were at odds with reality. Whether this was partly due to the percentage runoff formulation is not clear.

Comparison of local data for percentage runoff with that from the FEH is even more startling for the upper Brue (Figure 11). The soils data suggest that at low rainfall intensities there will be low rates of runoff. As the intensity increases the runoff rate will rapidly increase. This is what the flood frequency analysis shows and what observations in the field made during storm events also show. However, in contrast to this the FEH percentage runoff starts at a relatively high rate of 42% irrespective of the low rainfall intensity. But then this does not increase further until the rainfall depth over one hour or the rainfall over the whole storm exceeds 40mm. Even at a depth of 150 mm the percentage runoff does not exceed 60%. The relevance to flood volumes as shown in Figure 6 should now be apparent.

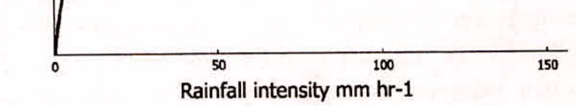

Fig. 11: Rainfall intensity and % runoff for the upper Brue

The Non-linear UH Flow Model

Following false flood warnings given by the Environment Agency, especially in November 2000, a real time flow model for flood warning at Bruton was devised by the author (Clark, 2004). Its features are:

1. The use of telemetered tipping bucket rainfall data.
2. Lysimeter based SMD measurements that are uploaded onto a website daily.
3. Percentage runoff based on a formulation of Figure 11.
4. Time to peak based on local observations made during floods.
5. Calibration against historic floods that gives a wide range of flood producing conditions.

The advantages of the system, now in operation for three years, are first, that the measured local rainfall data is used directly in the model. Second, the SMD or state of the soil is measured locally on a daily basis. Third, the percentage runoff has a physical meaning being measured in the field. Fourth, using a local time to peak which is related to rainfall intensity gives faster response times and hence higher peak discharges. Fifth, the use of major historic floods, two of which would have led to overtopping of the dam and flooding downstream, means that the model is able to deal with major events. Sixth, the physical processes which are modelled are essentially non linear. The non-linear UH ordinates were introduced because classical linear ordinates could not simulate the detailed pattern of runoff observed during the floods of 1979 and 1982. Since the model became operational there has been one storm of 46 mm during December 2005. The model predicted the water level behind the flood detention dam to within 0.1 m, the error being due to instrumental error and some partial blockage of the inlet culvert. The entry grill is due to be replaced by a bigger structure in order to reduce this problem.

DISCUSSIONS

It has been the object of this paper to show the value of local data in estimating rainfall and flood frequency and flood inundation. In addition, local data has been shown to be superior to remotely sensed rainfall data and derived estimates of SMD. In all cases, the outcome is a more severe estimate of the hazard posed by floods and the rapidity with which floods can occur in real life. The use of sophisticated equipment and computer models will not necessarily produce more reliable results if the basic input data are themselves in error. The price paid by the public for a flood free existence and a timely warning when flood defences fail, is considerable.

In recent years there has been a belief that climate change will lead to more serious and frequent flooding and other extreme weather conditions. In certain cases just the opposite has been *demonstrated.* This finding can only come about with careful analysis of past events. Land use planning must take account of the higher estimates of extreme floods as described in this paper and elsewhere. Unfortunately there has been a reluctance on the part of some authorities, especially the UK Environment Agency, to discuss these and related issues. Trying to produce a one size fits all approach to flood estimation as in the FEH has resulted in a plethora of models each with its own uncertainty, a variety of results and not enough local data either to confirm or refute these results. Coincidence is not a synonym for confirmation, a mistake often made during reporting research findings. At present we lack the long term data needed to give realistic estimates of say the 200 year flood. The present is not the key to the past or the future. The long experience of flooding sometimes recorded in the National Archives, private diaries and the memories of people, is giving a clearer picture of the medium term past which can be used as a realistic guide for the future. At present in the UK and elsewhere, there are not enough flood chronologies to convince the modelling community to investigate flood problems on a case-by-case basis. The catastrophic floods of the future can be placed in their proper context when we have a better knowledge of the past. There is a need to train more people in the field so making that type of evidence easier to measure, analyse, and interpret.

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