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The effects of urbanisation on the flood frequency of the River Tinney at Calenick

Report to Strategic Land plc

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Executive summary

1. The River Tinney flows through the village of Calenick, near Truro, in which several properties were flooded in January 1988. Strategic Land plc obtained planning permission to build a residential development within the catchment upstream of the village and agreed to consider flood alleviation measures. The Institute of Hydrology was contracted to assess the flood risk under different levels of development.

2. The methodology adopted was the statistical approach specified in the *Flood Studies Report* and its *Supplementary Reports* which enables estimates of the peak flow during floods of various return periods to be derived given different degrees of catchment urbanisation.

3. The catchment of the River Tinney was found to be sufficiently similar to that of the River Kenwyn such that results of flood frequency analysis on the Kenwyn can be applied to the Tinney.

4. $\bar{Q}$ derived from flow data on the River Kenwyn was found to be 85% of $\bar{Q}$ estimated from the *Flood Studies Report* equation. This factor was applied to $\bar{Q}$ estimated for the Tinney from the *Flood Studies Report*. $\bar{Q}$ estimates for different levels of urbanisation were then derived by the method given in *Flood Studies Supplementary Report No 5*. This gave $\bar{Q}$s of 6.9 and 7.4 m^3s^{-1} for 6% and 10% level of urbanisation respectively.

5. The growth factors (which relate $\bar{Q}$ to floods of higher return period) derived for the Kenwyn were applied to the Tinney. It was not considered justifiable to change the growth factors for different levels of urbanisation. When applied to $\bar{Q}$ values on the Tinney these growth factors gave 100 year flood estimates of 27.3 and 29.3 m^3s^{-1} for 6% and 10% level of urbanisation respectively, an increase of 7%.

6. Estimates were also obtained using the *Flood Studies Report* rainfall-runoff method which suggested an increase in the 100 year flood of 6%, for an increase in urbanisation from 6 to 10%, ie just 1% less than using the $\bar{Q}$/growth factor method.

7. Estimates of peak flow during January 1988, for the Kenwyn from the Truro gauging station and for the Tinney using a hydraulic model at Calenick, were investigated. But possible inaccuracies in measurement and likely difference in rainfall on the two catchments during the storm, meant that it was not reasonable to use the Tinney estimate in the flood frequency analysis.

1. Background

Strategic Land plc obtained planning permission to build a residential development within the catchment of the River Tinney. The Tinney flows through the village of Calenick in which several properties were flooded in January 1988. The National Rivers Authority advised that further development in the valley would increase the flood risk in the village. Consequently, Strategic Land agreed to consider flood alleviation measures for the village.

This report provides estimates of flood magnitude on the River Tinney at Calenick under different levels of urban development within the catchment upstream.

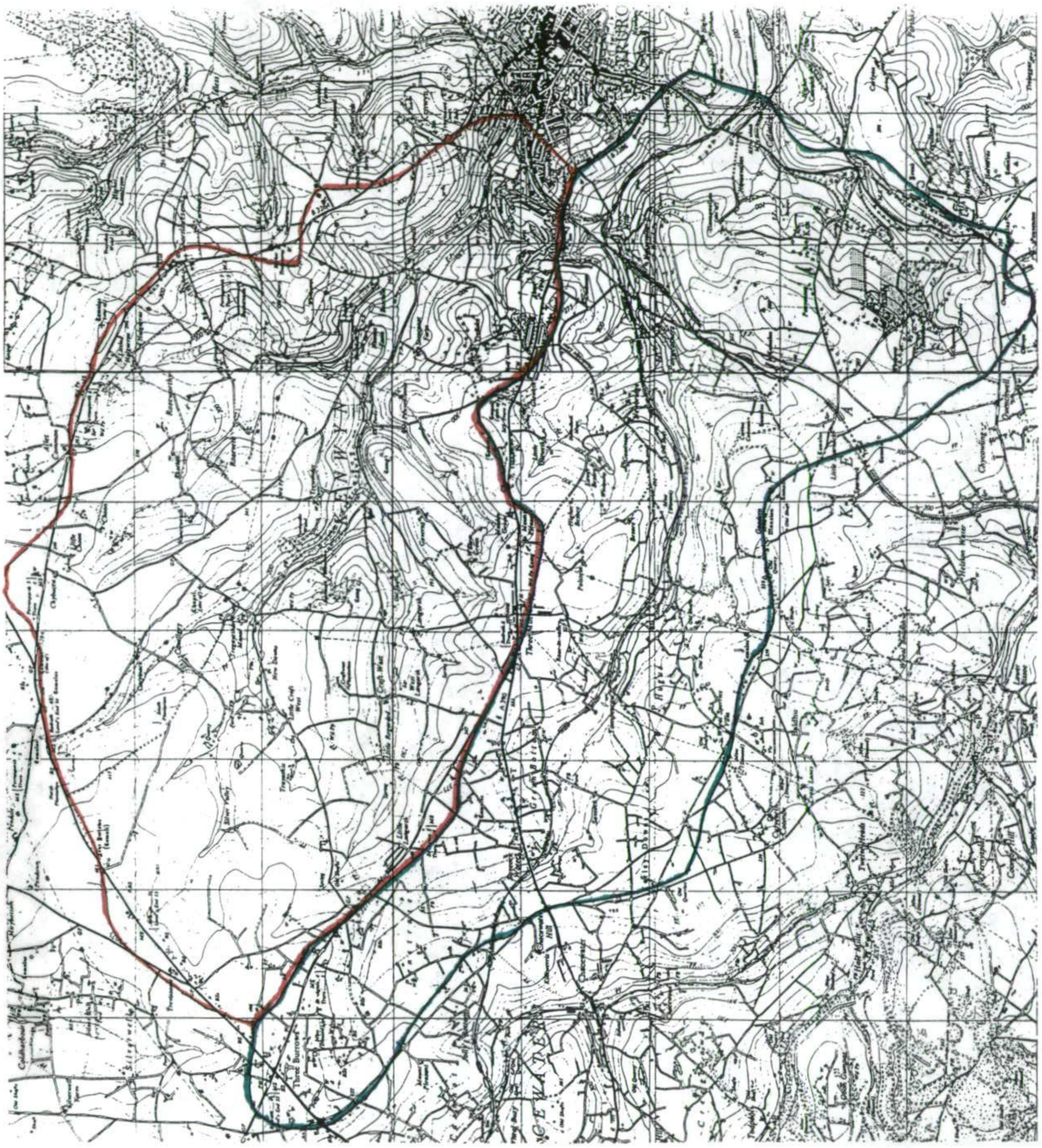
2. Introduction

Following the flooding in Truro from the River Kenwyn in January and October 1988, the Institute of Hydrology was contracted to estimate the flood risk to the city. The report of the study (Acreman, 1989) concluded that the January flood (a peak flow of 22.5 m^3s^{-1}) had a return period of around 50 years and that the October flood (30.4 m^3s^{-1}) had a return period of approximately 100 years. The report also suggested that these growth factors (ie the relative size of floods) derived for the Kewyn could be used to estimate flood frequency on the neighbouring River Allen, since the physical characteristics of its catchment were very similar to that of the Kenwyn.

The River Tinney, at Calenick, drains 17.3 km^2 catchment immediately to the south of the Kenwyn (Figure 2.1), hence its physical characteristics were examined to see if they were sufficiently similar that information on flood frequency from the Kenwyn could be applied.

3. The physical characteristics of the Tinney catchment

Table 3.1 lists the physical characteristics of the Kenwyn and Tinney catchments



Kenwyn ~

Tinney ~

Figure 2.1 Location of Tinney and Kenwyn catchments

Table 3.1 Physical characteristics

	Kenwyn at Truro	Tinney at Calenick
Morphometric characteristics		
Drainage area (km^2)	19.1	17.3
Mainstream length (km)	7.18	8.10
Mainstream slope (m km^{-1})	13.10	13.33
Stream density (junctions/km^{-2})	0.94	0.81
Climatological characteristics		
Mean annual rainfall (mm)	1121.	1130.
5 year - 2 day rainfall (mm)	67.	68.
Rainfall index RSMD (mm)	47.2	48.3
Jenkinson's rainfall factor	0.27	0.28
Mean soil moisture deficit (mm)	1.6	1.6
Land use		
Urban fraction+	0.06	0.05
Lake index	0.0	0.0
Soil type		
Winter rain acceptance potential	class 2	class 2
Denbigh 1&2 (%)	79.0	47.0
Sportsman (%)	15.8	36.0
Manod (%)	0.0	11.0
Unclassified*(%)	5.3	6.0

* mainly urban areas, but their extent does not coincide exactly with urban areas shown on OS1:50,000 map which was used to calculated the urban fraction given above+

which were considered to be important in determining flood frequency in the *Flood Studies Report* (NERC, 1975). The winter rain acceptance potential (WRAP) provides a classification of soils for flood frequency analysis. Denbigh, Sportsman and Manod are soil associations as determined by Findlay *et al* (1984) as part of a comprehensive mapping of the soils of England and Wales by the Soil Survey and Land Research Centre at a scale of 1:250,000 and all have very similar properties.

It is clear that in hydrological terms, the catchments are very similar. A field inspection of the area confirmed this, at which time it was noted that other characteristics of the catchments, including general topography and vegetation, were also similar.

The Ordnance Survey 1:25,000 maps of the area show a number of wells and springs along water courses and both catchments lie within the geological formation, an east-west geosynclinal trough. The area is underlain by rocks of Devonian age, predominantly slates and greywackes, and are known as the Gramseatho beds. It is therefore assumed that the groundwater hydrology of the catchments will be similar.

4. The mean annual flood

The annual maximum flood series, ie the highest instantaneous flow to be reached each year, is the standard data set upon which flood frequency analysis is undertaken, since its statistical properties have been the subject of research for many years.

The mean of the annual flood series, $\bar{Q}$, is a widely quoted statistic which indexes the typical magnitude of floods on a catchment. In general, this can be considered independently of any specific return period (although in a special case it can be shown that Q has a return period of 2.33 years).

When little, poor or no flow data are available on a catchment, an estimate of $\bar{Q}$ can be derived by applying the statistical method specified in the *Flood Studies Report* and its *Supplementary Reports*. The recommended equation is for south west England is:

$$\bar{Q} = 0.0315\ \mathrm{AREA}^{0.94}\ \mathrm{STMFRQ}^{0.27}\ \mathrm{RSMD}^{1.03}\ \mathrm{SOIL}^{1.23}\ \mathrm{S1085}^{0.16}\ (\mathrm{LAKE}+1)^{-0.85} \tag{4.1}$$

where AREA is the drainage area (km^2), STMFRQ is the stream density (junctions km^{-2}), RSMD is an index of flood producing rainfall (mm), SOIL an index of the WRAP class underlying the catchment, S1085 is the slope of the main channel (m km^{-1}) and LAKE is an index of lake storage.

Table 4.1 gives estimates of $\bar{Q}$ for the Kenwyn and Tinney using Equation (4.1) and, in the case of the Kenwyn, $\bar{Q}$ derived from flow data collected at the Truro gauging station. On the Kenwyn the recorded $\bar{Q}$ is some 85% of that predicted by Equation (4.1). Since the two catchments are physically similar, it is reasonable to assume that Q on the Tinney would be 85% of that given by Equation (4.1), ie. 6.89 m^{3}s^{-1} (see Institute of Hydrology, 1983).

Table 4.1 Estimate of the mean annual flood, $\bar{Q}$ (m^{3}s^{-1}).

	Kenwyn at Truro	Tinney at Calenick
1 $\bar{Q}$ Equation (4.1)	9.01	8.10
2 Q from flow data	7.7	N/A
3 scaling factor	0.85	

Equation (4.1) does not contain a variable indexing the portion of the catchment under urban development. About 6% of the River Kenwyn catchment is urbanised[5] (as depicted by the 1984 OS 1:50,000 map), therefore 0.85 is effectively a scaling factor for Equation (4.1) to derive $\bar{Q}$ on a catchment with 6% urbanisation. Measurements from the same map indicate that around 5% of the Tinney is urbanised, although the definition is very subjective.

A flow of 6.9 m^3s^{-1} (85% of 8.1) therefore, can be considered as the best estimate of $\bar{Q}$ for the River Tinney with 6% urbanisation.

The Flood Studies Supplementary Report No 5, *Design flood estimation in catchments subject to urbanisation* (Institute of Hydrology, 1979) provides a method of adjusting estimates of $\bar{Q}$ for different degrees of urbanisation. This is based on the change is percentage runoff, PR, the percentage of rainfall which runs off the catchment as flood flow. For rural catchments this is calculated primarily from the soil type. For partly urbanised catchments it is assumed that 30% of the urban area is impervious (ie roofs, car parks, roads) and that PR from this part equals 70%. Thus the effect of urbanisation on $\bar{Q}$ can be estimated from

$$\bar{Q}u/\bar{Q}r = (1+URBAN)^{1.5}\ (1+0.3URBAN\ 70/PR\ -1) \qquad (4.2)$$

where $\bar{Q}u$ and $\bar{Q}r$ refer to $\bar{Q}$ for urban and rural cases respectively.

Table 4.2 Estimate of $\bar{Q}$ (m^3s^{-1}) for different levels of urbanisation on the River Tinney

urban fraction	0.0	0.02	0.02	0.06	0.08	0.10
estimate of $\bar{Q}$ from Equation (4.2)	6.16	6.39	6.64	6.88	7.14	7.39

The results of applying Equation (4.2) are given in Table 4.2. This method suggests that $\bar{Q}$ for the catchment with 10% of the area under urban development is 20% greater than if it was completely rural and 7% greater than if it were 6% urban.

It is noteworthy that this method does not consider where in the catchment the urban development is taking place. The location will affect the relative timing of flood water from different parts of the catchment. Urbanisation in the upstream areas may result in a rapid response which reinforces the slower response from the rural area downstream, thus producing higher flood peaks. In contrast, urbanisation downstream may cause the urban response to pass before the slow response from upstream arrives; in this case flood peaks may be reduced. Only by constructing a distributed model of the catchment can these spatial effects be considered and this is beyond the scope of the present study.

5. Flood of return periods up to 100 years

Acreman's flood frequency analysis of the River Kenwyn yielded a series of growth factor which related $\bar{Q}$ to estimates of floods of less frequent occurrence, up to the 100 year return period. For example, on the Kenwyn the 100 year flood was found to be 3.97 times greater than $\bar{Q}$. These factors were considerable greater than those published in the *Flood Studies Report* which were based on a regional analysis of flood data across the south west of England (eg the 100 year growth factor was 2.42). However, since the Kenwyn results were based on analysis of recorded flow data and information on historical floods, they were considered to provide the best estimates of growth factors.

Since the Tinney catchment is physically similar to that of the Kenwyn, it can be assumed that the relationship between Q and floods of different return periods will be similar. Table 5.1 and Figure 5.1 show the results of applying the growth factors from the Kenwyn to Q on the Tinney for various levels of urbanisation. These calculations assume that the growth factors are not changes by the level of urbanisation. Thus all return period floods are increased by the same percentage, eg the 100 year flood is increased by 7% when the urban area is increased from 6 to 10%.

Table 5.1 Estimate of floods of return periods 5 to 100 years (m^3s^{-1}) for different levels of urbanisation on the River Tinney using growth factors from the River Kenwyn.

		urban fraction					
		0.0	0.02	0.04	0.06	0.08	0.10
return period	growth factor						
$\bar{Q}$		6.16	6.39	6.64	6.88	7.14	7.39
10 years	1.38	8.5	8.8	9.2	9.5	9.9	10.2
20 years	1.89	11.6	12.1	12.5	13.0	13.5	14.0
50 years	2.88	17.7	18.4	19.1	19.8	20.6	21.3
80 years	3.57	22.0	22.8	23.7	24.6	25.6	26.4
100 years	3.97	24.5	25.4	26.4	27.3	28.3	29.3

The *Flood Studies Supplementary Report No 5* provides a method of adjusting growth factors up to a return period of 50 years for different degrees of urbanisation. It reports that rare floods (eg 50 year flood) increase in magnitude due to urbanisation less severely than frequent floods (eg Q). This has the effect of reducing the size of

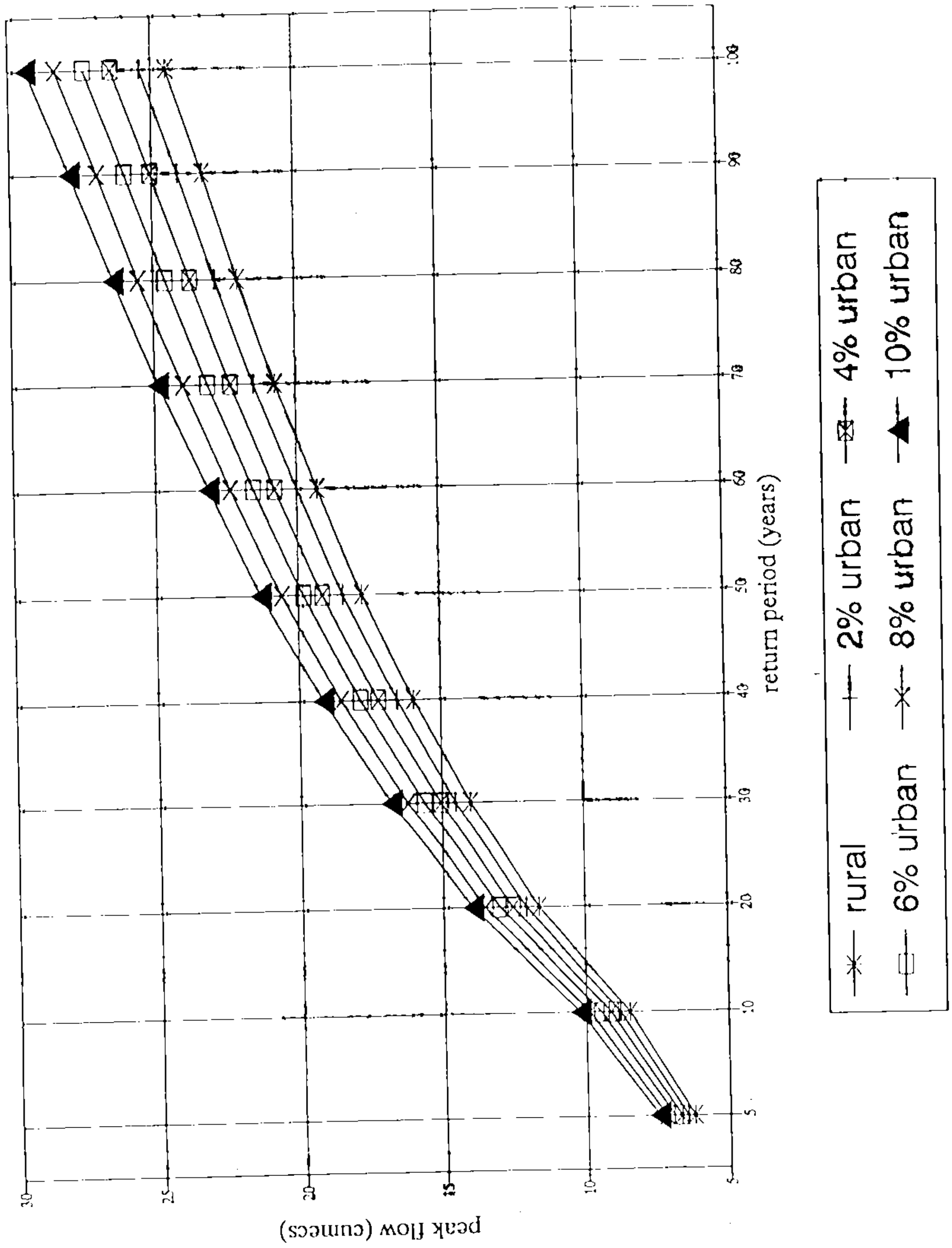


Figure 5.1 Flood frequency curves for the Tinney for different levels of urbanisation

growth factors. Table 5.2 gives the growth factors for the 50 year return period flood for south west England. It can be seen that, for example, the growth factor for 10% urban is slightly lower than the factor for 6% urban. If the same methodology is applied to the growth factors from the Kenwyn, the 50 year flood on the Tinney would be reduced from 21.3 to 21.0 m^3s^{-1}.

Table 5.2 ***Growth factors for the 50 year flood for different levels of urbanisation on catchments in south west England from the Flood Studies Supplementary Report No 5***

urban fraction	0.0	0.02	0.04	0.06	0.08	0.10
50 year growth factors for south west England	2.12	2.11	2.09	2.08	2.06	2.05

Too few data were available to make a strong recommendation in *Flood Studies Supplementary Report No 5* for floods greater than 50 years. However, it was generally considered that the effect on growth curves reduces as urbanisation increases, such that for very rare events, peak flows would be the same for a given catchment regardless of the degree to which it was urbanised.

Strictly, the growth factors derived for the Kenwyn are only appropriate for catchments with a similar level of urbanisation, ie. 6%. However, it is concluded that there was insufficient justification for modifying the growth factors from the Kenwyn to allow for different levels of urbanisation. Nevertheless, for levels of urbanisation greater than 6% the estimates in Table 5.1 can be considered as upper limits.

6. Using the Flood Studies Report rainfall-runoff model

The *Flood Studies Report* and *Flood Studies Supplementary Report No 16* provide an alternative method of flood frequency estimation which uses design rainfalls of particular return period and transforms these to flood flows using a model of catchment behaviour. The model parameters may be changed to allow for different levels of urbanisation. Acreman's study of the River Kenwyn concluded that this method was not appropriate for flood frequency analysis on that river. This was because the response of the catchment is influenced by rain falling prior to a flood-generating storm, to a greater degree than allowed for in the model. However, although it may not be appropriate for defining the exact magnitude of, say, the 100 year flood, it was considered that the model might be used to show the relative effects of urbanisation.

Table 6.2 shows that the 100 year flood for the Tinney increases by 6% when the urban area is increased from 6 to 10%. This compares favourably with the results from the statistical analysis (Table 5.1) which shows an increase in the 100 year flood of 7%. This 1% reduction is consistent with 'intuition' published in *Flood Studies Supplementary Report No 5* that the effect of urbanisation decreases with increasing return period. However, the results based on the $\bar{Q}$/growth factor analysis were preferred for three reasons: (1) the estimates were very close; (2) no data existed to quantify the intuition in *Supplementary Report No 5*; and (3) the rainfall-runoff model had been shown to be not wholly appropriate.

Table 6.2 ***Estimate of the 100 year flood (m^3s^{-1}) for different levels of urbanisation on the River Tinney using the Flood Studies Report rainfall-runoff method.***

urban fraction	0.0	0.02	0.04	0.06	0.08	0.10
100 year growth factors for south west England	18.2	18.8	19.4	20.0	20.6	21.2

7. Using the estimate of peak flow on the Tinney for January 1988

Following the flood of January 1988, which affected both the Rivers Kenwyn and Tinney, the National Rivers Authority undertook a hydraulic study of the Tinney at Calenick bridge to estimate the peak flow. The model produced an estimated of 26 m^3s^{-1}.

Post flood surveys are widely used to reconstruct the conditions during the event in order to calculate the peak flow retrospectively. However, the method suffers from a number of problems. Two basic pieces of information are required: first, the geometry of the river channel and associated structures (such as bridges) and second, the water levels along the reach at the peak of the flood. Clearly the geometry might have been different at the peak due to scour or deposition after the peak. Furthermore, flood marks only provide a rough indication of the water surface profile at the flood peak, since the flow is normally unsteady and may be increased temporarily by debris blockages. In addition most methods require a measure of the roughness of the channel, which is easy to estimate for straight, clean concrete lined reaches but notoriously difficult for natural sections containing trees, bushes, grass, tarmac etc. These problems suggests that the estimate of 26 m^3s^{-1} would only be accurate to within about +/- 10%.

The best estimate of the peak flow recorded on the River Kenwyn for the January 1988 flood was 22.5 m^3s^{-1}, based on a hydraulic model of the river channel. This estimate was used in preference to that from the flow gauging station, since debris had collected across the measuring structure and elevated the peak water level, thus making the stage-discharge relationship invalid (Horrocks, 1988). A flow of 22.5 m^3s^{-1} at the gauging station has a return period of about 50 years (Acreman, 1989). Horrocks suggests that this estimate is accurate to within about 10%.

Rainfall data associated with the January event are sparce. In Truro itself 58.1 mm was recorded between 9:00 on the 27th and 9:00 on the 28th, whilst at Trevince, only 10 km WSW of Truro 91 mm was recorded for the same period. Isohyets published by Acreman (1989), provided by South West Water, consequently show higher rainfall over the Tinney than over the Kenwyn. As described above, the two catchments are similar hydrologically, although the Kenwyn drains an area 10% larger. If the rainfall had been the same on both catchments, a higher flow on the Kenwyn would have been expected. However, since it is likely that rainfall on the Tinney was heavier, a higher peak flow could have been generated despite its smaller area. Also, it is possible that the flow on the Kenwyn was underestimated, which would also mean that the return period of 50 years was underestimated), or that the flow on the Tinney was overestimated. In any case it would not be reliable to assume that the flow estimated for the Tinney, 26 m^3s^{-1}, would have the return period of 50 years attributed to 22.5 m^3s^{-1} as estimated for January on the Kenwyn.

8. Summary and conclusions

The statistical method given in the *Flood Studies Report* and its *Supplementary Reports* provide a methodology for estimating the peak flow during floods of various return periods given different degrees of urbanisation on a catchment.

The catchment of the River Tinney is sufficiently similar to that of the River Kenwyn such that results of flood frequency analysis on the Kenwyn can be applied to the Tinney.

$\bar{Q}$ derived from flow data on the River Kenwyn was found to be 85% of $\bar{Q}$ estimated from the *Flood Studies Report* equation. This factor was applied to $\bar{Q}$ estimated for the Tinney from the *Flood Studies Report*. $\bar{Q}$ estimates for different levels of urbanisation were then derived by the method given in *Flood Studies Supplementary Report No 5*. This gave $\bar{Q}$s of 6.9 and 7.4 m^3s^{-1} for 6% and 10% level of urbanisation respectively.

The growth factors (which relate $\bar{Q}$ to floods of higher return period) derived for the Kenwyn were applied to the Tinney. It was not considered justifiable to change the growth factors for different levels of urbanisation. When applied to $\bar{Q}$ estimates on the Tinney these growth factors gave flood flows of 100 year return period equal to 27.3 and 29.3 m^3s^{-1} for 6% and 10% level of urbanisation respectively, an increase of 7%.

Results from application of the *Flood Studies Report* rainfall-runoff method suggested an the increase in the 100 year flood of 6%, when increasing the level of urbanisation from 6 to 10%, ie just 1% less than using the $\bar{Q}$/growth factor method. This was consistent with 'intuition' published in *Flood Studies Supplementary Report No 5*. Given that the estimates were very close; that no data existed to quantify the intuition; and that the rainfall-runoff model was not wholly appropriate, results from the $\bar{Q}$/growth factor method were retained.

Estimates of peak flow during January 1988, for the Kenwyn from the Truro gauging station and for the Tinney using a hydraulic model at Calenick, were investigated. But possible inaccuracies in measurement and likely difference in rainfall on the two catchments during the storm meant that it was not reasonable to use the Tinney estimate in the flood frequency analysis.

In conclusion it is recommended that flood peaks given in Table 5.1 are used for design purposes.

9. References

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