Institute of Hydrology

Natural Environment Research Council

A modification to the FSR rainfall-runoff method for deriving design flood hydrographs for the Rivers Kenwyn and Allen at Truro

September 1991

Report to the National Rivers Authority, South West Region.

Institute of Hydrology
Maclean Building
Crowmarsh Gifford
Wallingford
Oxon OX10 8BB

Executive Summary

1. The city of Truro experienced serious flooding in January and October 1988 from the River Kenwyn. Analysis of these and previous events undertaken by the Institute of Hydrology (IH) suggested that the floods had return periods of around 50 and 100 years respectively. The results were used in the design of the first phase of a flood alleviation scheme for Truro centred on a control dam on the River Kenwyn. The study also demonstrated that the standard FSR rainfall-runoff method was not wholly appropriate for this catchment since the resulting flood frequency curve was too shallow. The National Rivers Authority was also concerned that the volumes of the design hydrographs were too great.

2. As part of further investigations into potential flooding in Truro, Hydraulics Research Limited was invited to assess the likelihood of inundation from the River Allen and from the combination of fluvial flows and high tides in the Truro estuary. The fluvial model chosen by HRL for this study, RBM-DOGGS, incorporated the FSR rainfall-runoff method. IH was contracted to provide advice on modifying the method to model the Kenwyn catchment up to the 100 year return period and to recommend how to apply the method to the Allen.

3. To improve the shape and volume of the design hydrographs a unit hydrograph close to that observed in the October event was used in place of the standard triangular shape.

4. To model the significance of antecedent conditions apparent on the Kenwyn, the catchment wetness index, CWI, was set to vary with return period, in contrast to the standard method in which CWI is constant. Values of CWI were chosen such that, when applied to 30% SPR, the design hydrograph peaks coincided with the preferred flood frequency curve.

5. An estimate of $\bar{Q}$ was made for the Allen from it's catchment characteristics and adjusted using the ratio of observed to estimated $\bar{Q}$ on the Kenwyn. A flood frequency curve up to the 100 year return period was derived for the Allen using the $Q/\bar{Q}$ growth factors calculated for the Kenwyn.

6. A unit hydrograph was derived for the Allen based on that defined for the Kenwyn and an adjustment factor given by the ratio of Tp estimates made for the two catchments from their physical characteristics. This factor was applied to all the time ordinates and its reciprocal was applied to the magnitude of each ordinate.

7. The RBM-DOGGS model required design inputs for a number of sub-catchments. CWI for the main catchment was assumed to be appropriate for each sub-catchment, and that unit- hydrographs for sub-catchment could be derived in the same way that the transfer from the Kenwyn to Allen was undertaken.

8. This method was felt to be applicable to the Rivers Kenwyn and Allen only and should not be applied generally.

9. Annex 1 contains estimates of Probable Maximum Floods for the Allen catchment.

1. Background

The city of Truro experienced serious flooding in January and October 1988 from the River Kenwyn. Analysis of these and previous events undertaken by the Institute of Hydrology (IH; Acreman, 1989) enabled definition of the flood frequency curve for the Kenwyn up to a return period of 100 years. This indicated that the 1988 floods had return periods of approximately 50 and 100 years respectively. The curve resulted from the statistical analysis of flood peaks from the continuous flow record and from evidence of historical floods from newspapers and journals going back to 1870. This therefore represented the preferred flood frequency curve.

The study also demonstrated that the standard rainfall-runoff method, the alternative to the statistical method recommended in the Flood Studies Report (FSR; NERC, 1975) and its Supplementary Reports (IH, 1976-1989), was not wholly appropriate to this catchment since the resulting flood frequency curve was rather less steep than the preferred curve based statistical analysis. In addition the design hydrographs produced by the rainfall-runoff method had volumes greater than observed during historical flood events.

The results of the 1989 study were used in the design of the first phase of a flood alleviation scheme for Truro. The scheme centred on construction of a control dam on the River Kenwyn at New Mills, upstream of the city limits.

As part of further investigations by the National Rivers Authority into potential flooding in Truro, Hydraulics Research Limited (HRL) was invited to assess the likelihood of inundation from the River Allen and from the combination of fluvial flows and high tides in the Truro estuary. The model chosen by HRL for this study was RBM-DOGGS. This treated the catchment as a number of sub-catchments and models each using the FSR rainfall-runoff method.

IH was contracted to provide:

(1) a modification to the standard method which would generate design flood hydrographs for the River Kenwyn with return periods between 5 and 100 years whose peak flows would be consistent with the preferred flood frequency curve for the catchment and whose volumes would be consistent with those typically observed;

(2) a technique for transferring the method to the neighbouring but ungauged River Allen; and

(3) a technique for applying the method to sub-catchments of the Kenwyn and Allen within the RBM-DOGGS model.

2. Introduction

The hydrology of the catchment is described in detail by Acreman (1989) and only a few key details are reproduced here.

Flows on the River Kenwyn are measured just inside the city limits. The hydrographs investigated were dominated by a slow rise in base flow which lasted for a number of days before recessing slowly to a residual level. Superimposed on this were short-term steep rises followed, within a few hours, by a quick recession to a slightly higher base flow level. The 1:25,000 OS map of the area shows a number of wells and springs along the water course. The hydrogeology of the catchment is not well understood, but there is no evidence of a deep aquifer. Nevertheless sub-surface storage is clearly sufficient to delay a proportion of the runoff for several days.

Analysis of flood events selected by Boorman (1985) showed that the quick response hydrographs (as defined by the FSR separation technique) contained only a small percentage (less than 20%) of the rainfall volume. Acreman (1989) calculated the percentage runoff for the 1988 events as 37% and 42% respectively for January and October. Thus it is evident that even in rare events (up to 100 year return period) the majority of rainfall supplied the slowly responding flow component. These results implied that the magnitude of the flood peak was controlled by a combination of the quick response from immediately preceding rainfall and the slower response from rainfall up to several days earlier. The significance of antecedent rainfall is exemplified by the 1988 events. The rainfall total for the January event (52 mm) exceeded that for the October event (49 mm) even though the peak flow in October was much greater (30.4 cumecs) than in January (22.5 cumecs) due to wetter antecedent conditions (API5 for January was 8.8, whereas for October it was 11.5). It is also noteworthy that the return periods of the January and October event rainfalls were only 12 and 7 years respectively, whereas they generated floods with 50 and 100 year return periods. As further evidence, the rainfall of 13 September 1975 exceeded both 1988 storm totals (60 mm in 20 hours) but only resulted in a peak flow of 3.7 cumecs due to dry antecedent conditions

Figure 1.1 shows the observed flood hydrograph for the January 1988 event. It can be seen that the first burst of rainfall produced very little runoff response. Presumably this rainfall fell when soil moisture levels were low and so runoff was delayed. This implies that a constant percentage model for determining effective rainfall, as used in the FSR rainfall-runoff method for hydrograph generation, is not wholly appropriate.

The flood frequency curve produced by the FSR rainfall-runoff model, derived by Acreman (1989), estimated flood magnitudes lower than the preferred curve which resulted from applying the statistical method for return periods less than 100 years, although the curves coincided at about the 100 year level (Figure 1.2).

The rainfall-runoff method has the advantage that it produces complete design flood hydrographs. However, the 100 year design flood hydrograph generated by the standard method was found to have a volume somewhat greater than the observed hydrograph from the October flood event (whose return period was approximately 100 years).

In its assessment of the likelihood of inundation from the River Allen and from the combination of fluvial flows and high tides in the Truro estuary, HRL chose to use RBM-DOGGS for modelling fluvial flows. This is a semi-distributed model which treated the catchment as a number of sub-catchments and models each using the FSR rainfall-runoff method.

This report describes adaptions to the FSR rainfall-runoff method such that:

1. the design flood hydrographs contain realistic volumes;
2. the flood frequency curve matches the preferred statistical curve;
3. the method can be applied to the River Allen; and
4. the method can be applied to the sub-catchments of the Kenwyn and Allen.

3. Methodology

The FSR recommends that, where available, unit hydrographs derived from flood events recorded on the catchment should be used in place of the triangular shape used in the standard method. Consequently, it was decided that unit hydrographs from the January and October events would be considered with a view to generating design hydrographs with reduced volumes.

As described above, antecedent catchment conditions clearly play an important role in defining the magnitude of flood peaks on the River Kenwyn. To model this behaviour the catchment wetness index CWI was set to vary with return period.

The physical characteristics of the Allen catchment were compared with those from the Kenwyn to define an adjustment factor for transfering model parameters to the River Allen.

A simple scaling algorithm is recommended for applying the method to the sub-catchments of the Rivers Kenwyn and Allen.

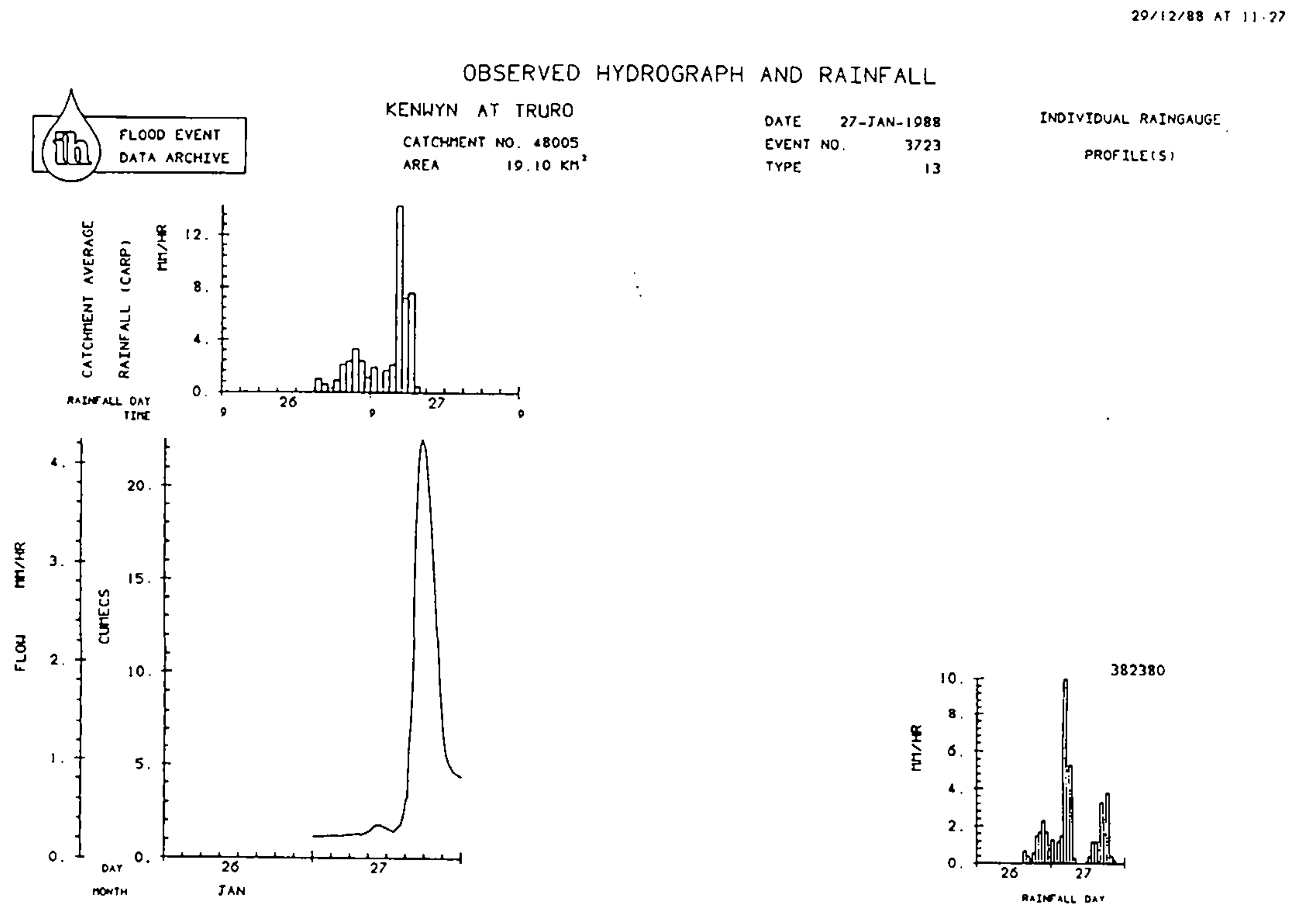

Figure 1.1 Rainfall hyetograph and flood hydrograph - January 1988

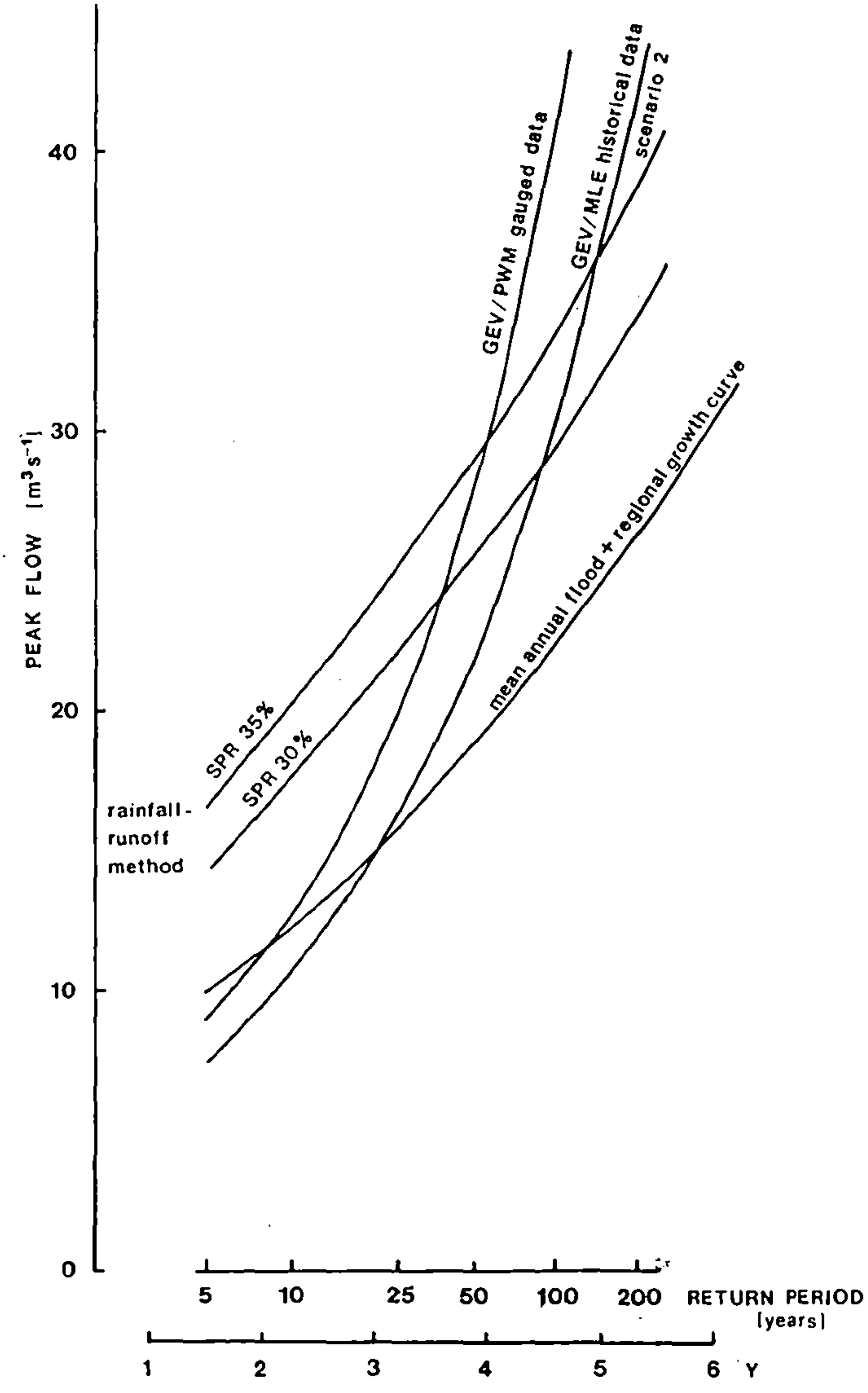

Figure 1.2 Flood frequency curves for the River Kenwyn (after Acreman, 1989)

4. Adjusting the volumes of the design hydrographs for the River Kenwyn by using an observed unit hydrograph

The unit hydrograph derived from the October 1988 event using the rainfall profile from weather radar data is shown in Figure 4.1, both before and after initial smoothing. It is noteworthy that the pre-smoothed version displays large oscillations with negative ordinates. Figure 4.2 shows the smoothed October unit hydrograph together with that for January and the FSR triangular unit hydrograph. Also shown is a 'representative' unit hydrograph (labelled "average"). It can be seen that both observed unit hydrographs are more peaky than the FSR triangle but have markedly different shapes. Thus a true average would not be reprentative of either.

Figure 4.3 shows the observed flood hydrograph for January 1988 together with the hydrograph produced by applying the observed rainfall to the smoothed unit hydrograph for January. As expected the model predicted too great a response from the first rainfall burst and resulted in underestimation of the peak and volume of the main hydrograph. The same behaviour resulted when synthesising the October event. This results primarily from the use of a constant percentage rainfall separation in the FSR method, whereas in the derivation of the unit hydrograph, a decreasing percentage is used. For this reason it is unrealistic to expect the FSR method to reproduce observed flood events acurately. Consequently in the remainder of the anaylsis the design floods were used for comparative purposes to optimise model variables.

Figure 4.4 shows the October 1988 flood hydrograph (whose return period was approximately 100 years) compared with the 100 year design flood hydrograph from the FSR method using a representative observed unit hydrograph (obs) and the FSR triangle (FSR). The observed unit hydrograph is that labelled "average" in Figure 4.2. In both cases percentage runoff had been increased until the design peak flow reached that observed in October. It can be seen that using a more peaky unit hydrograph produces a slightly more peaky response hydrograph. However, it was not possible to reproduce the October 1988 event hydrograph shape by making the unit hydrograph increasingly peaky since the resulting hydrograph shape is constrained somewhat by the other input variables including the design rainfall profile.

Figure 4.5 shows the January flood hydrograph (whose return period was around 50 years) together with the 50 year design hydrograph utilising the same representative observed unit hydrograph. As before the percentage runoff in the model had been selected such that the peak flow equalled that observed in January. It is evident that the modelled hydrograph shape is very close to that observed.

Figure 4.6 shows the flood hydrograph from December 1979, the third largest flood recorded (whose return period was approximately 17 years) together with the 17 year design hydrograph. Again the representative observed unit hydrograph was used and

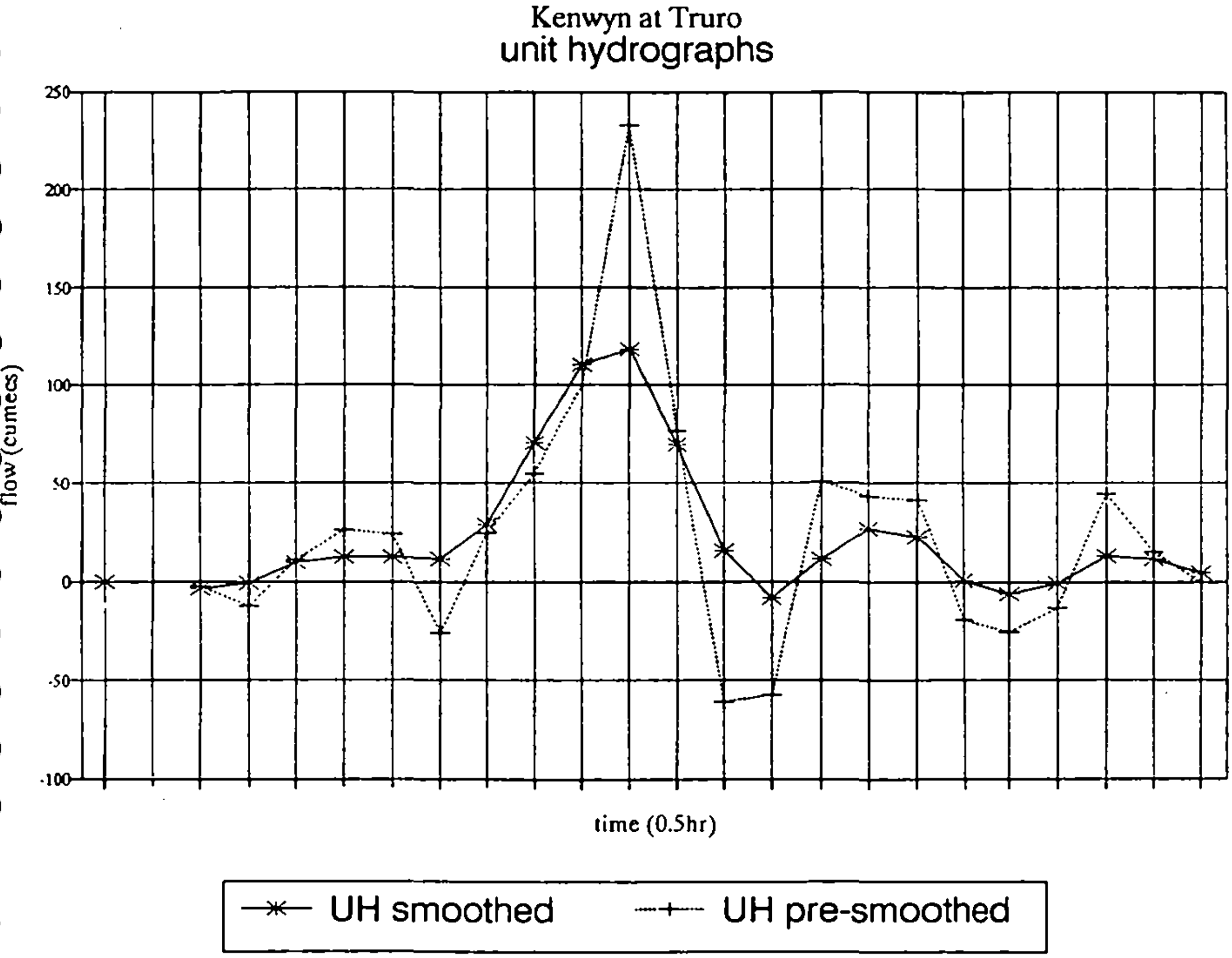

Figure 4.1 Unit hydrograph for the October 1988 flood

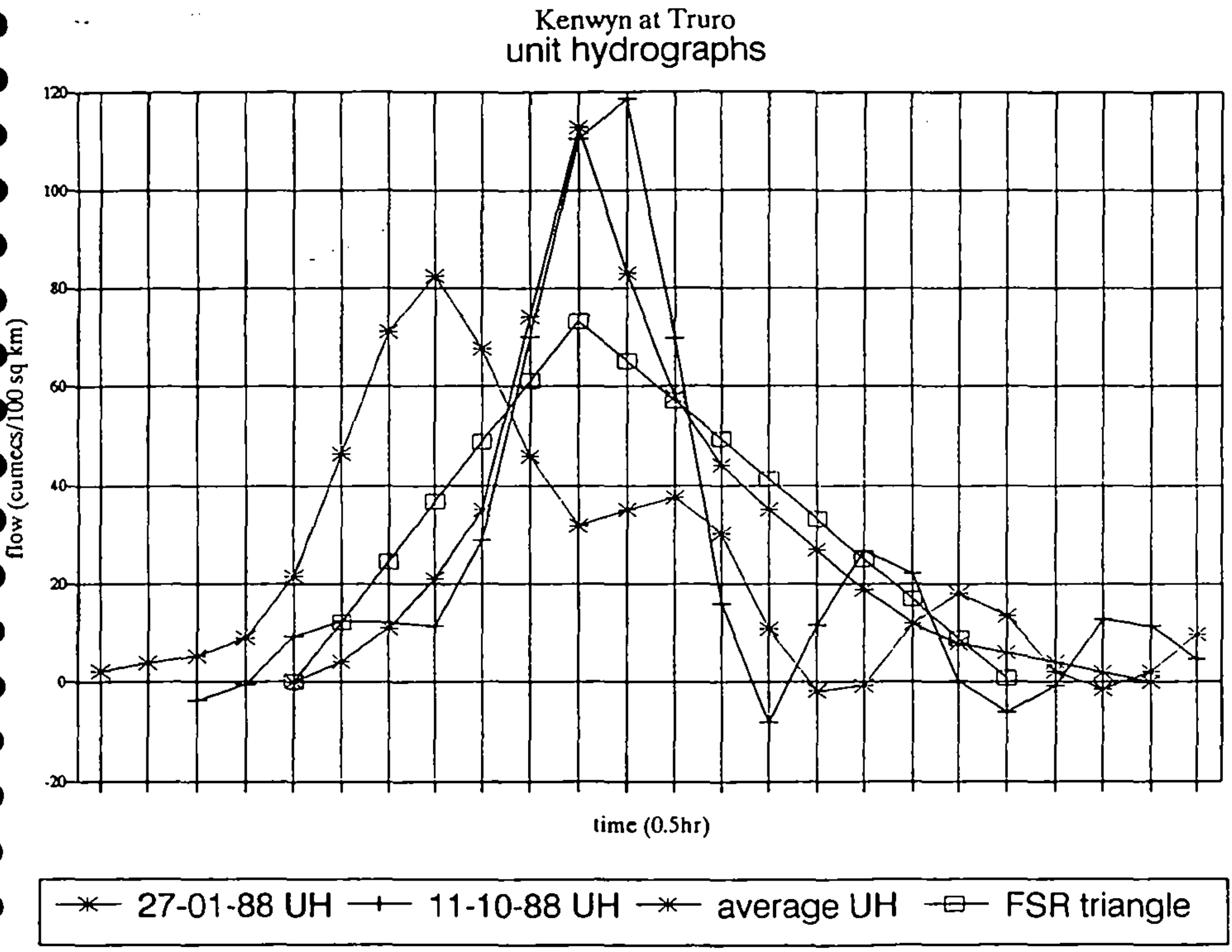

Figure 4.2 Unit hydrographs for October (smoothed) and January 1988 together with the FSR triangle

the percentage runoff in the model was fixed to ensure equal peak flows. The modelled hydrograph shape is close to that observed above 6 cumecs. This would seem adequate since it is unlikely that any flood allevaition scheme would need to operate below this level.

As a result of the performance of the representative unit hydrograph on these three historical events, it was recommended for use in the RBM-DOGGS model for the Kenwyn catchment. The ordinates are given in Table 4.1.

Table 4.1 0.5 hour 10 mm unit hydrograph ordinates for the Kenwyn (m^3s^{-1} $100km^{-2}$)

Hours	Flow				
0.5	4.0	4.0	58.0	7.5	6.0
1.0	11.0	4.5	44.0	8.0	4.0
1.5	21.0	5.0	45.0	8.5	2.0
2.0	35.0	5.5	27.0		
2.5	74.0	6.0	19.0		
3.0	113.0	6.5	12.0		
3.5	83.0	7.0	8.0		

5. Adjusting the flood frequency curve by allowing CWI to vary with return period

Employing the unit hydrograph given in Table 4.1, iterations of the FSR model were performed with the Institute of Hydrology's software package micro-FSR to optimise percentage runoff (PR) such that the design flood hydrographs had peak flows equivalent to those given by the preferred statistical flood frequency curve. In the FSR method PR is calculated from

$$PR = SPR + DPRcwi + DPRrain$$

where SPR (standard percentage runoff) is constant for any catchment and DPRcwi and DPRrain are dynamic terms which vary with the catchment wetness index (CWI) and storm rainfall respectively. CWI indicates the soil moisture status immediately prior to the event. PR was varied in each model run by fixing SPR at 30% and changing the value of CWI. The values of CWI required to produce the desired peak flows are given in Table 5.1 and shown graphically in Figure 5.1.

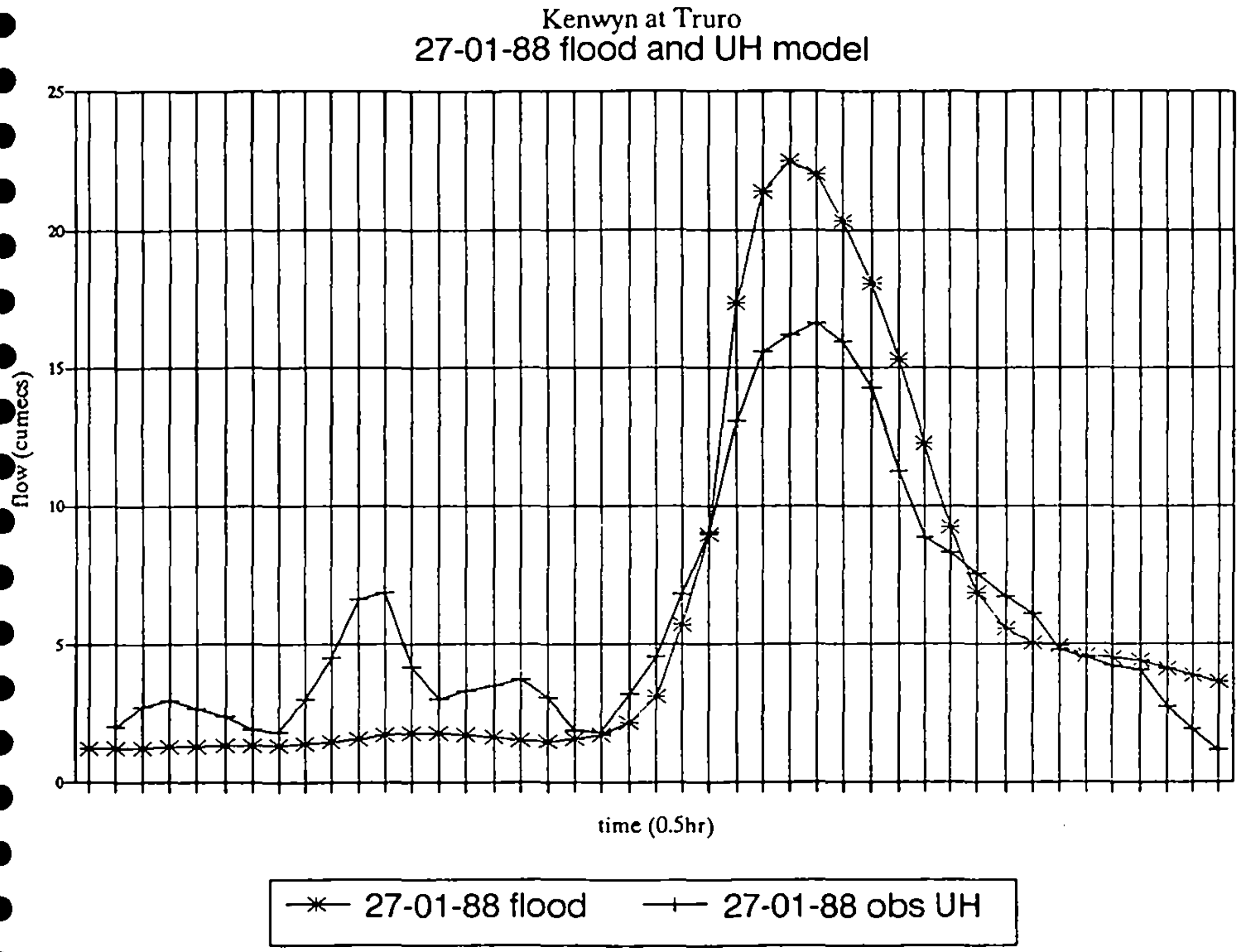

Figure 4.3 Observed flood hydrograph for January 1988 together with the hydrograph produced by applying the observed rainfall to the smoothed unit hydrograph for January.

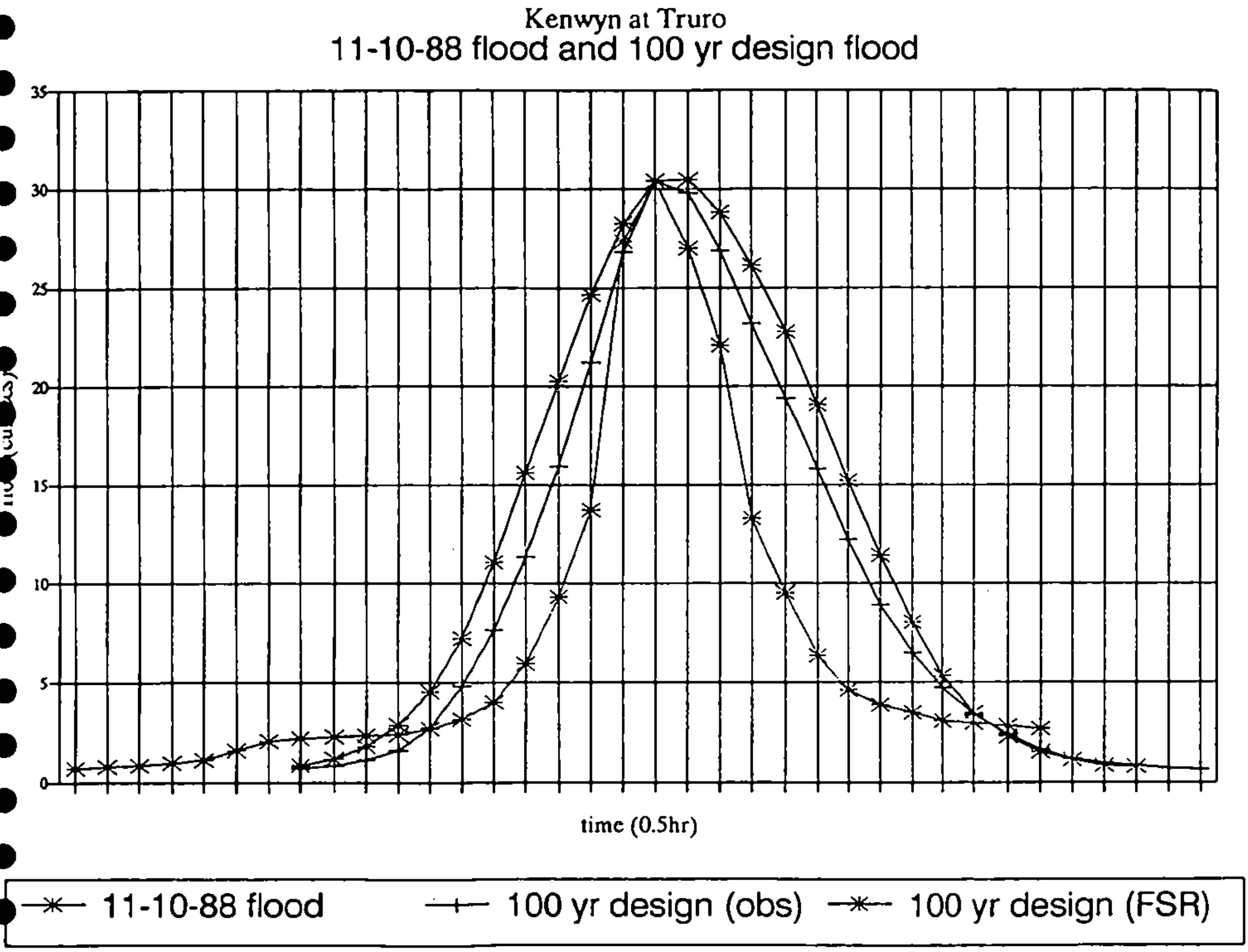

Figure 4.4 Flood hydrograph for October 1988 compared with the 100 year design flood hydrograph from the FSR method using a representative observed unit hydrograph (obs) and the FSR triangle (FSR).

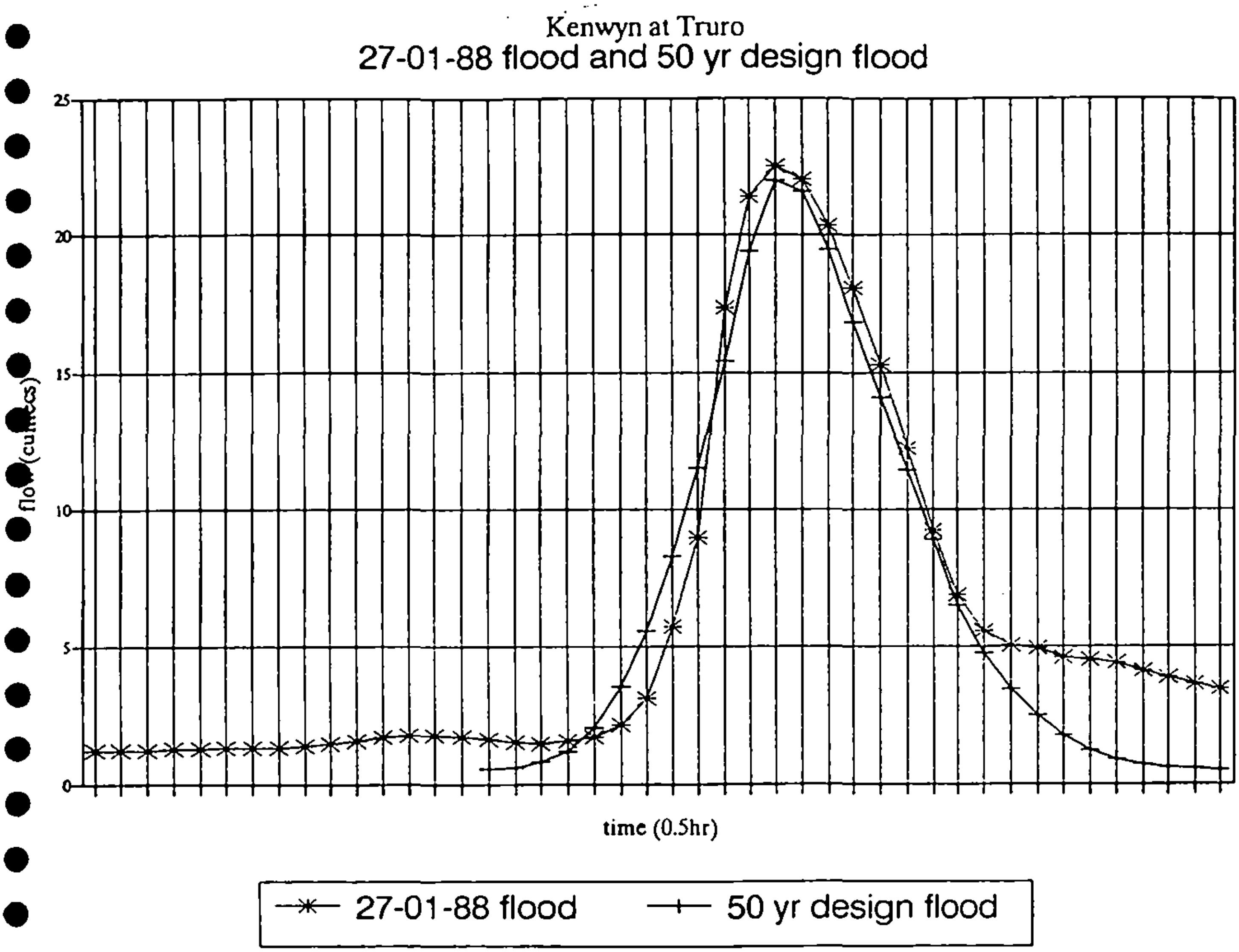

Figure 4.5 Flood hydrograph for January 1988 compared with the 50 year design flood hydrograph from the FSR method using a representative observed unit hydrograph.

Kenwyn at Truro

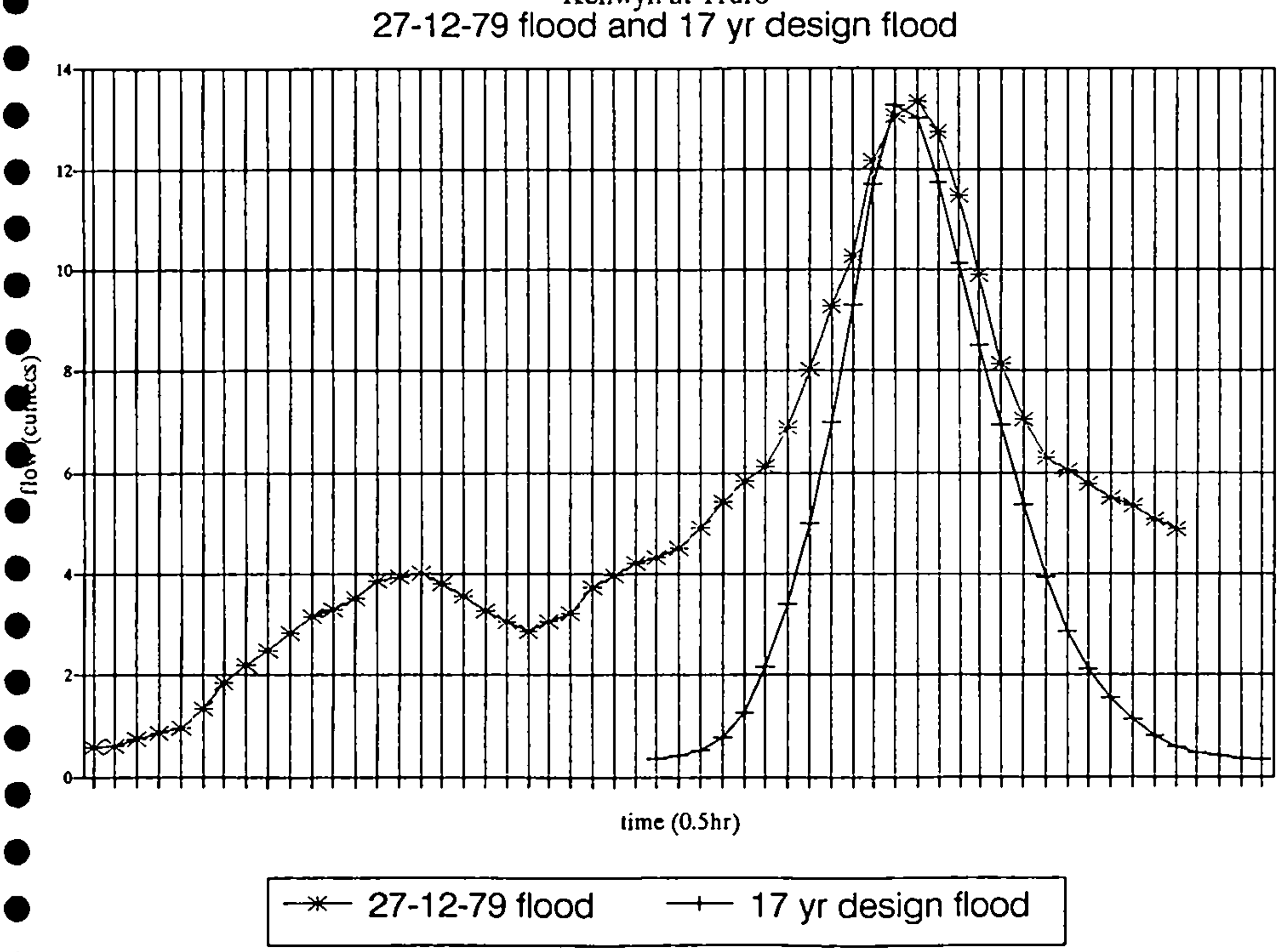

Figure 4.6 *Flood hydrograph for December 1979 compared with the 17 year design flood hydrograph from the FSR method using a representative observed unit hydrograph.*

Table 5.1 Variation in discharge and CWI with return period for the Kenwyn

Return period (yr)	Peak discharge (cumecs)	Required CWI
100	30.6	127
90	29.1	123
80	27.6	119
70	25.9	114
60	24.1	109
50	22.1	103
40	19.9	97
30	17.5	91
25	16.1	87
20	14.5	82
15	12.8	77
10	10.6	71
5	7.8	67

6. Transfering model parameters to the River Allen

The River Allen drains through the eastern side of Truro and has caused flooding on a number of occasions including 27 December 1979. Flows on the river are not measured, so an arbitrary location, the railway viaduct near to city limits (SW 453 825), was chosen to define a reference catchment. At this point the drainage area is 27.1 km2.

The Allen catchment is immediately adjacent to that of the Kenwyn lying to the northeast (Figure 6.1). The physical characteristics of the two catchments are very similar (Table 6.1). Both catchments are underlain by rocks of Devonian age, predominantly slates and greywackes which have weathered to form predominantly brown earths of the Denbigh association (Figure 6.1). Springs are evident in many locations throughout the area. Topography and land use are also very similar, although the Allen is around 40% larger.

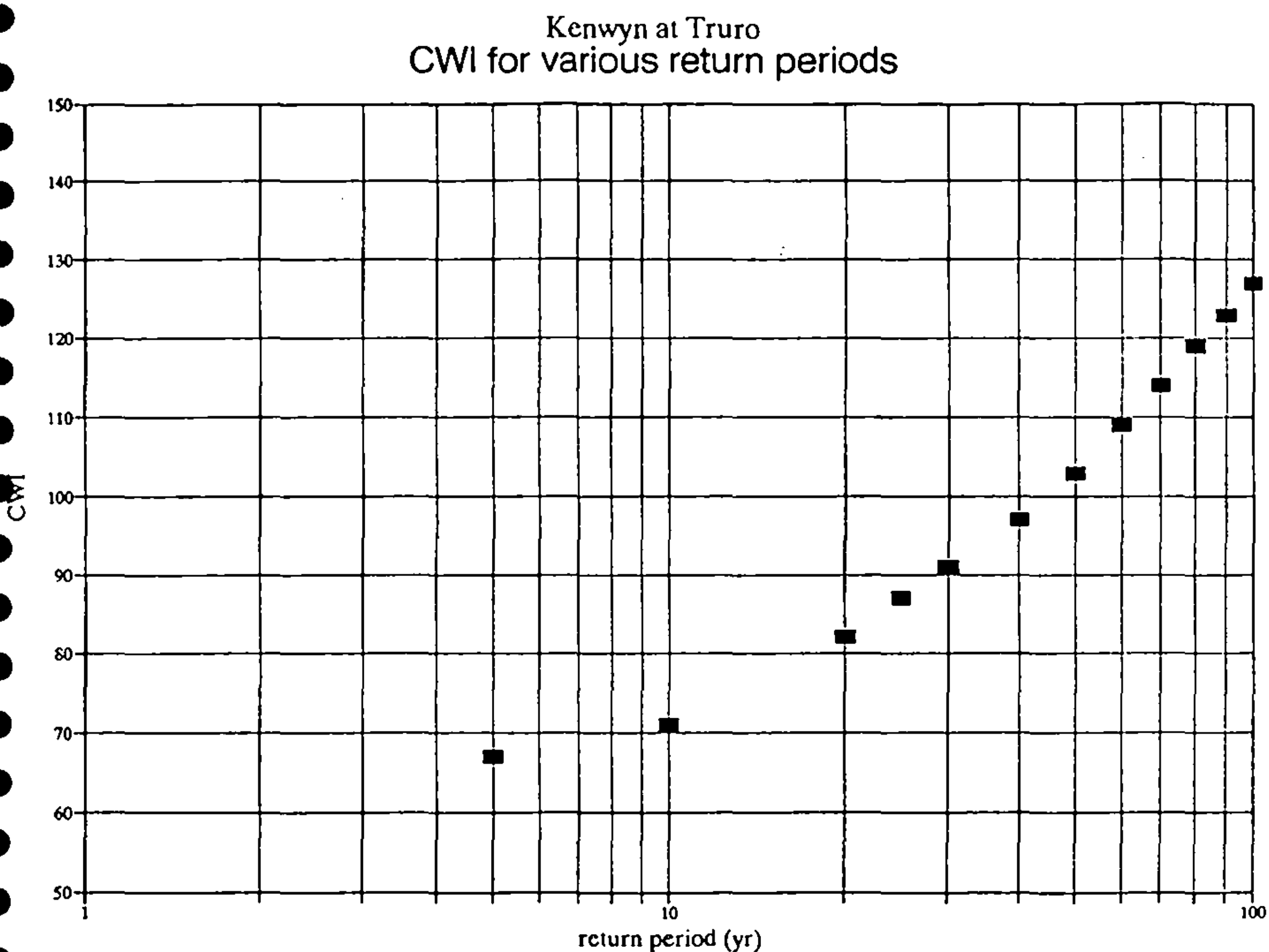

Figure 5.1 Variation in CWI with return period for the Kenwyn

Table 6.1 Physical characteristics of Kenwyn and Allen catchments

	Kenwyn	Allen
Drainge area (km^2)	19.1	27.1
Average annual rainfall SAAR (mm)	1121.	1105.
Main stream length (km)	7.18	9.1
Main stream slope S1085 ($m\ km^{-1}$)	13.1	10.07
Urban fraction	0.06	0.04
Stream frequency (junctions km^{-1})	0.94	0.66
Soils (%)	100.	100.
WRAP class 2	15.8	14.8
Denbigh 1	63.2	66.8
Denbigh 2	15.8	5.5
Sportsman		5.5
Manod		3.7
Yeollandpark		3.7
Unclassified (urban)	5.3	

The similarity between the Kenwyn and Allen suggests that any departure from the standard FSR procedure could be assumed to be the same on both catchments. When no flow records are available
an estimate of the mean annual flood, $\bar{Q}$, can be made using the six variable FSR equation:

$$\bar{Q} = 0.0315\ AREA^{0.94}\ STMFRQ^{0.27}\ S1085^{0.16}\ SOIL^{1.23}\ RSMD^{1.03}\ (1+LAKE)^{-0.85} \qquad (6.1)$$

Application of equation (6.1) to the Kenwyn gave an estimated of $\bar{Q}$ of 8.34 m^3s^{-1}. However, the recorded flow data suggested a value of 7.7 m^3s^{-1}, ie 92% of 8.3. For the River Allen, $\bar{Q}$ from catchment characteristics was 9.44 m^3s^{-1}, but assuming the two catchments are similar in terms of their flood hydrology, the best estimate was taken to be 92% of 9.44, ie. 8.7 m^3s^{-1}.

The flood frequency curve for the Kenwyn was standardised by dividing each flood peak, Q(T), by $\bar{Q}$. This produced a suite of growth factors which could be applied to $\bar{Q}$ on the Allen. The results of this analysis are given in Table 6.2.

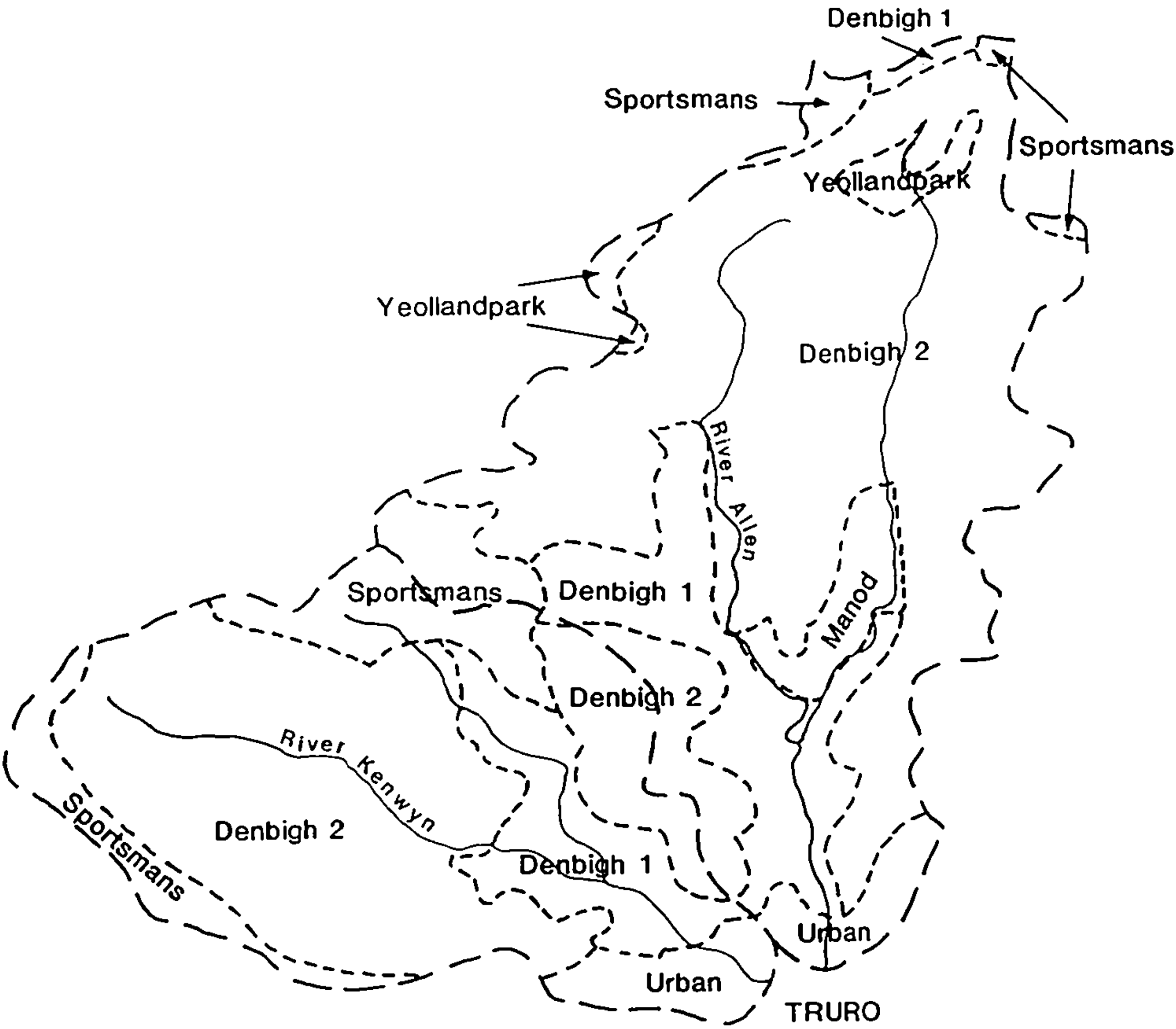

Figure 6.1 Soil types underlying Kenwyn and Allen catchments

Table 6.2 Flood frequency curve for the RiverAllen

$\bar{Q}$ for Allen from equation 7.1	= 9.44	
Scaling factor from Kenwyn	= 0.92	
Best estimate $\bar{Q}$ for Allen	= 8.72	
Return period (yr)	**Growth factor**	**Peak discharge (cumecs)**
100	3.97	127
90	3.77	32.7
80	3.57	31.0
70	3.36	29.2
60	3.13	27.2
50	2.88	25.0
40	2.59	22.5
30	2.27	19.7
20	1.89	16.4
10	1.38	12.0
5	1.01	8.8

Transfer of the unit hydrograph derived Kenwyn to the Allen was undertaken in a similar manner. When no flow records are available the time to peak of the instantaneous unit hydrograph, Tp(0), can be estimated using the equation given in FSSR16:

$$Tp(0) = 283 \ S1085^{-0.33} \ MSL^{0.23} \ (1+URBAN)^{-2.2} \ SAAR^{-0.54} \qquad (6.2)$$

Application of equation (7.2) to the Kenwyn gave Tp(0) = 3.78 hours. The Tp of the preferred unit hydrograph which has time ordinates of 0.5 hours, Tp(0.5), was 3.0 hours. Using

$$Tp(T) = Tp(0) + T/2 \qquad (6.3)$$

Tp(0) = 2.75 hours, ie 73% of that given by the catchment characteristic equation (6.2).

For the Allen equation (6.2) gave Tp(0) = 4.58 hours. It was assumed that the relationship between the preferred Tp(0) and that given by equation (6.2) was the same as that for the Kenwyn. Applying the correction factor to the Allen catchment gave Tp(0) adjusted (4.58 x 0.73) = 3.34 hours and using equation (6.3) gave a preferred Tp(0.5) = 3.59 hours; approximately 3.5 hours.

Next the ordinates of the 0.5 hour unit hydrograph for the Kenwyn were adjusted such that Tp = 3.5 hours. To preserve unit volume each time ordinate was multiplied by 1.17 (3.5/3.0) and each flow ordinate was multiplied by 0.86 (3.0/3.5). The resulting unit hydrograph for the Allen was interpolated to produce ordinates at 0.5 hour time intervals. These are given in the final column of Table 6.3 and are shown in Figure 6.2 together with the unit hydrograph for the Kenwyn.

Table 6.3 0.5 hour 10 mm unit hydrograph ordinates for the Allen (m^3s^{-1} $100km^{-2}$)

Kenwyn		Adjustment		Allen interpolated	
Time (hr)	Flow (cumes)	Time x 3.5/3.0 (hr)	Flow x 3.0/3.5 (cumecs)	Time (hr)	Flow (cumecs)
0.5	4.0	0.6	3.4	0.5	2.9
1.0	11.0	1.2	9.4	1.0	7.7
1.5	21.0	1.8	18.0	1.5	14.3
2.0	35.0	2.3	30.0	2.0	23.1
2.5	74.0	2.9	63.4	2.5	39.6
3.0	113.0	3.5	96.9	3.0	68.2
3.5	83.0	4.1	71.1	3.5	96.9
4.0	58.0	4.7	49.7	4.0	74.8
4.5	44.0	5.3	37.7	4.5	55.8
5.0	35.0	5.8	30.0	5.0	42.9
5.5	27.0	6.4	23.1	5.5	34.4
6.0	19.0	7.0	16.3	6.0	28.0
6.5	12.0	7.6	10.3	6.5	22.2
7.0	8.0	8.2	6.9	7.0	16.3
7.5	6.0	8.8	5.1	7.5	11.1
8.0	4.0	9.3	3.4	8.0	7.8
8.5	2.0	9.9	1.7	8.5	5.9
9.0	0.0	10.0	0.0	9.0	4.4
				9.5	2.9
				10.0	1.5
				10.5	0.0

As for the Kenwyn, SPR was fixed at 30% and iterations of the model were performed using micro-FSR to optimise CWI such that the design flood hydrographs had peak flows equivalent to those given by the preferred flood frequency curve given in Table 6.2. The resulting values of CWI are given in Table 6.3 and shown graphically in Figure 6.3.

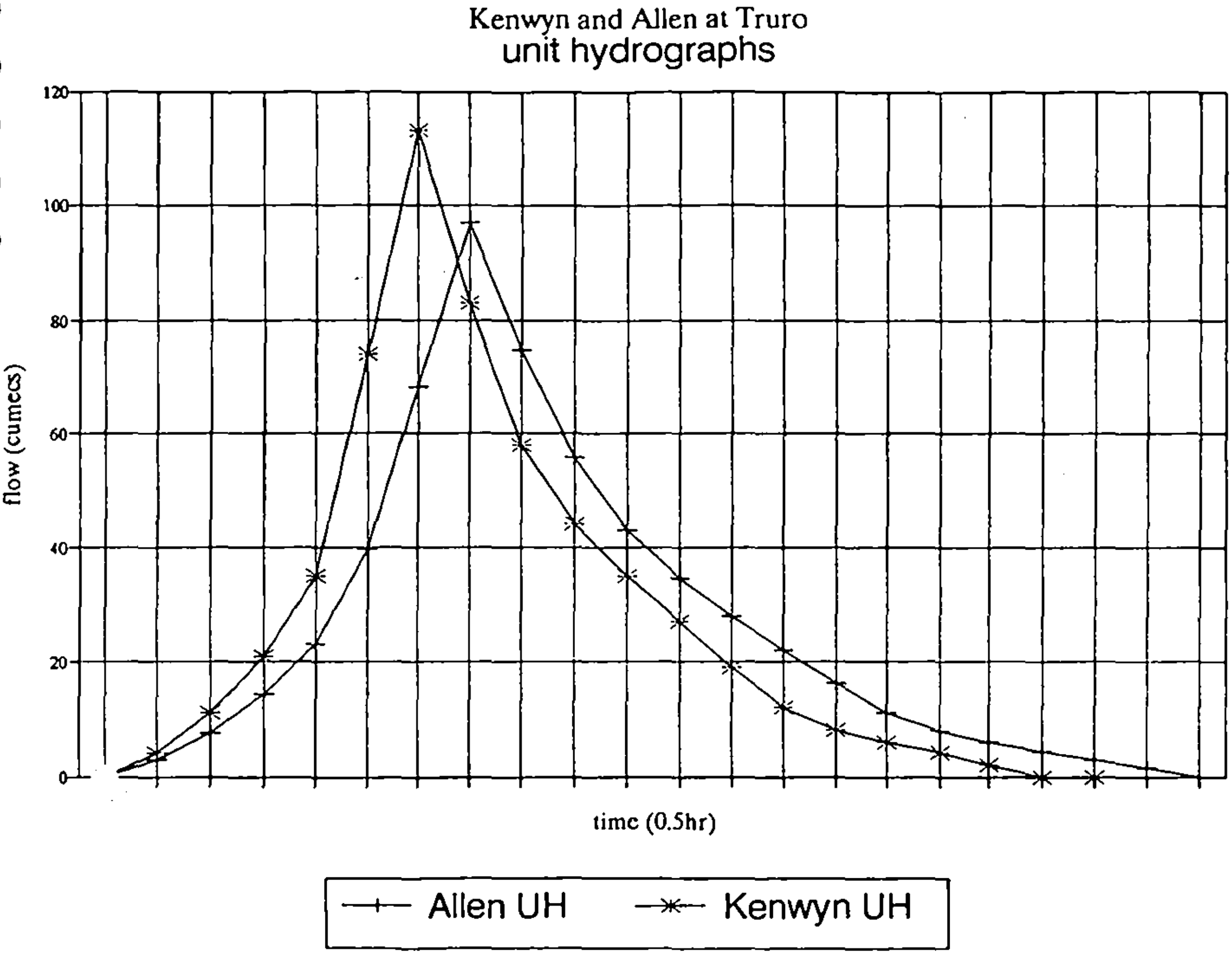

Figure 6.2 Unit hydrographs for the Kenwyn and Allen catchments

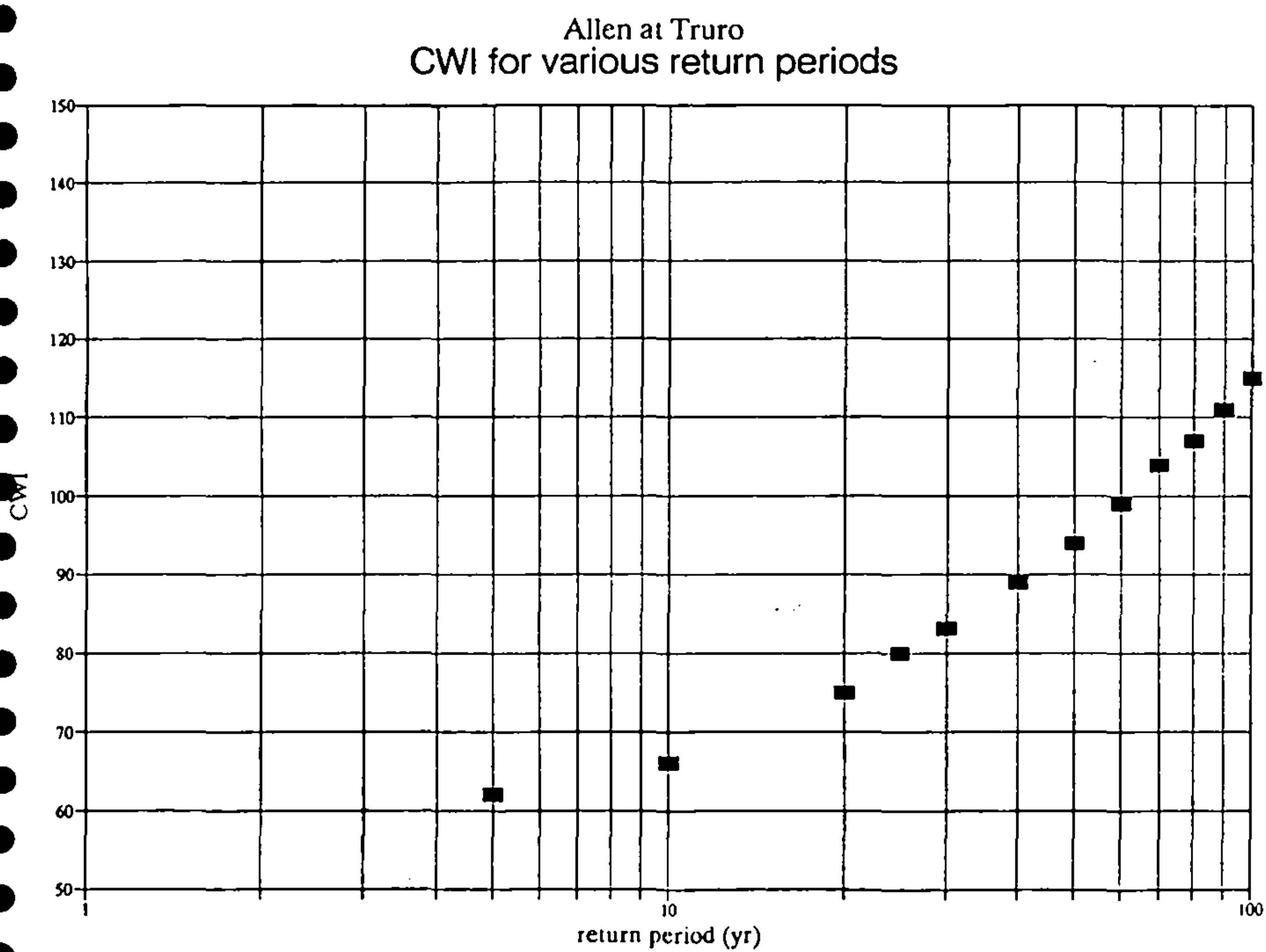

Figure 6.3 Variation in CWI with return period for the Allen

Table 6.4 Variation in discharge and CWI with return period for the Allen

Return period (yr)	Peak discharge (cumecs)	CWI
100	34.5	115
90	32.7	111
80	31.0	107
70	29.2	104
60	28.2	99
50	25.0	94
40	22.5	89
30	19.7	83
25	18.2	80
20	16.4	75
10	12.0	66
5	8.8	62

7. Transfering model parameters to the sub-catchments

The same methodology used to transfer the preferred Kenwyn unit hydrograph to the Allen can be employed for scaling to sub-catchments.

Estimates of Tp(0) are made using Equation (6.2), these are reduced by 73% and Tp(T) is derived using Equation (6.3). To define the entire unit hydrograph each flow ordinate is multiplied by Tp(T)/3.0 and each time ordinate by 3.0/TP(T).

SPR of 30% and values of CWI from the full catchment are applicable for sub-catchments.

8. Conclusions

The study of 1988 floods by Acreman (1989) had concluded that the standard FSR rainfall-runoff method was not appropriate for the Kenywn catchment. The rainfall-runoff method was found to underestimated flood peak magnitudes defined by a preferred flooding frequency curve based on statistical analysis of historical events. Furthermore, the NRA had been concerned that the method produced design hydrographs whose volumes were too great.

In this study the rainfall-runoff method was modified for application with RBM-DOGGS for an assessment of the likelihood of inundation from the combination of fluvial flows from the Kenwyn and Allen and high tides in the Truro estuary.

To reduce the volume of design hydrographs a unit hydrograph close to that observed in the October event was used in place of the standard triangular shape.

Design flood peaks were increased by allowing CWI to vary with return period, in contrast to the standard method in which CWI is constant. Values of CWI were chosen such that the design hydrograph peaks coincided with the preferred flood frequency curve for the Kenwyn.

A flood frequency curve up to a return period of 100 years was derived for the Allen using the Q(T)/Q growth factors calculated for the Kenwyn and an estimate of $\bar{Q}$ from catchment characteristics adjusted by reference to the ratio of observed to estimated $\bar{Q}$ on the Kenwyn.

A unit hydrograph was derived for the Allen based on that defined for the Kenwyn and an adjustment factor given by the ratio of Tp estimates made for the two catchments from their physical characteristics. This factor was applied to all the time ordinates and its reciprocal was applied to the magnitude of each ordinate.

It is recommended that unit hydrographs for sub-catchment within RBM-DOGGS are derived in the same way that the transfer from the Kenwyn to Allen was undertaken.

It is recommended that the values of CWI for the Kenywn and Allen are used for their respective subcatchments and that 30% SPR is used for all.

This method is applicable up to a return period of 100 years only and to the Rivers Kenywn and Allen only. It should not be applied to other catchments.

9. References

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ANNEX 1

Supplementary Report

Estimation of the Probable Maximum Flood design hydrographs on the River Allen at the proposed dam site

October 1991

1. As a further part of the hydrological investigations for the design of flood alleviation scheme for Truro the Institute of Hydrology (IH) was contracted to estimate the design hydrograph for the Probable Maximum Flood on the River Allen at the proposed site of the flood storage reservoir.

2. A unit hydrograph was derived for the Allen based on that defined for the Kenwyn and an adjustment factor given by the ratio of Tp estimates made for the two catchments from their physical characteristics. This factor was applied to all the time ordinates and its reciprocal was applied to the magnitude of each ordinate.

3. As part of the main study for the Truro flood alleviation scheme the significance of antecedent conditions apparent on the Allen, the catchment wetness index, CWI, was set to vary with return period in contrast to the standard method in which CWI is constant. However, the variation in CWI was only specified for floods up to a return period of 100 years. In the terms of reference for the PMF part of the study the National Rivers Authority specified that standard FSR approach to percentage runoff estimation with fixed CWI should be adopted.

4. Probable Maximum Flood estimates were derived for summer and for winter conditions. Peak flows of 224.9 m^3s^{-1} and 230.8 m^3s^{-1} respectively were produced. Full results are presented below.

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UK DESIGN FLOOD ESTIMATION

Description : Allen at Idless PMF estimate
Printed on 22 10 1991 at 16:43                    Run Reference : IDLES
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Summary of estimate using Flood Studies Report rainfall-runoff method
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Estimation of Probable Maximum Flood
====================================
Summer season rainfall
Includes Tp scaling factor      :     0.67

Design storm duration           :     5.50  hours
No snowmelt contribution to precipitation input
Design storm depth              :   199.64  mm.

Design CWI                      :   170.50

Standard Percentage Runoff      :    30.00
Percentage runoff               :    57.06  %


Response hydrograph peak        :   222.79  cumecs  (Max ordinate)
                                :   223.72  cumecs  (Interpolated)
Baseflow                        :     1.13  cumecs
Hydrograph peak                 :   223.92  cumecs  (Max ordinate)
                                :   224.85  cumecs  (Interpolated)

Options
=======
Unit hydrograph option            :   0 - Specified by user
Tp option                         :   5 - From user entered UH
Rainfall option                   :   5 - Max precipitation
Rainfall duration option          :   1 - Calculated from Tp
PR option                         :   1 - FSSR 16 equation
SPR option                        :   2 - from SOIL
Baseflow option                   :   1 - FSSR 16 equation
Flow/Rainfall return periods      :  -1 - Unset
CWI option                        :   1 - Design standard

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UK DESIGN FLOOD ESTIMATION

Description : Allen at Idless PMF estimate
Printed on 22 10 1991 at 16:43 Run Reference : IDLES

Time series data from Flood Studies Report rainfall-runoff method

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Time	Total Rain	Net Rain	Unit Hydrograph		Flow
hours	mm	mm	cumecs/cm /100sq km	%	cumecs
0.50	6.7	3.8	5.80	1.04	1.65
1.00	8.4	4.8	17.00	3.06	3.31
1.50	11.1	6.3	32.80	5.90	6.84
2.00	12.7	7.3	78.20	14.07	15.34
2.50	20.9	11.9	133.40	24.01	31.25
3.00	79.9	45.6	94.20	16.95	52.68
3.50	20.9	11.9	62.20	11.20	79.35
4.00	12.7	7.3	46.20	8.32	111.60
4.50	11.1	6.3	34.20	6.16	168.44
5.00	8.4	4.8	22.40	4.03	223.92
5.50	6.7	3.8	12.80	2.30	193.69
6.00			8.30	1.49	157.70
6.50			5.50	0.99	132.15
7.00			2.50	0.45	107.65
7.50					80.35
8.00					52.81
8.50					35.19
9.00					23.51
9.50					14.23
10.00					7.44
10.50					4.45
11.00					2.86
11.50					1.90
12.00					1.35

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UK DESIGN FLOOD ESTIMATION

Description : Allen at Idless PMF estimate
Printed on 22 10 1991 at 16:43 Run Reference : IDLES

Summary of estimate using Flood Studies Report rainfall-runoff method

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Estimation of Probable Maximum Flood

Winter season rainfall

Includes Tp scaling factor	:	0.67		
Design storm duration	:	5.50	hours	
Pre-event snow depth	:	100.00	mm.	
Melt rate	:	1.75	mm/hr	
Design storm depth	:	166.32	mm.	
Design CWI	:	186.76		
Standard Percentage Runoff	:	30.00		
Percentage runoff	:	81.75	%	

Assumes frozen ground

Response hydrograph peak	:	228.33	cumecs	(Max ordinate)
	:	229.53	cumecs	(Interpolated)
Baseflow	:	1.26	cumecs	
Hydrograph peak	:	229.58	cumecs	(Max ordinate)
	:	230.79	cumecs	(Interpolated)

Options

Unit hydrograph option	:	0 - Specified by user
Tp option	:	5 - From user entered UH
Rainfall option	:	5 - Max precipitation
Rainfall duration option	:	1 - Calculated from Tp
PR option	:	1 - FSSR 16 equation
SPR option	:	2 - from SOIL
Baseflow option	:	1 - FSSR 16 equation
Flow/Rainfall return periods	:	-1 - Unset
CWI option	:	1 - Design standard

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Institute of Hydrology Software

UK DESIGN FLOOD ESTIMATION

Description : Allen at Idless PMF estimate
Printed on 22 10 1991 at 16:43 Run Reference : IDLES

Time series data from Flood Studies Report rainfall-runoff method

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Time hours	Total Rain mm	Net Rain mm	Unit Hydrograph cumecs/cm /100sq km	Unit Hydrograph %	Flow cumecs
0.50	7.4	6.1	5.80	1.04	2.08
1.00	9.0	7.4	17.00	3.06	4.68
1.50	11.7	9.5	32.80	5.90	10.16
2.00	13.1	10.7	78.20	14.07	23.31
2.50	18.9	15.4	133.40	24.01	47.45
3.00	46.2	37.7	94.20	16.95	74.71
3.50	18.9	15.4	62.20	11.20	104.79
4.00	13.1	10.7	46.20	8.32	137.90
4.50	11.7	9.5	34.20	6.16	186.40
5.00	9.0	7.4	22.40	4.03	229.58
5.50	7.4	6.1	12.80	2.30	210.86
6.00			8.30	1.49	182.94
6.50			5.50	0.99	159.25
7.00			2.50	0.45	133.51
7.50					102.55
8.00					68.67
8.50					45.94
9.00					30.73
9.50					19.14
10.00					10.79
10.50					6.37
11.00					3.95
11.50					2.47
12.00					1.61

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