INSTITUTE of
HYDROLOGY

The effects on flood risk at Elsworth, Cambridgeshire of the building of the proposed settlement of Belham Hill.

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Report to Bryant Homes Ltd,

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1. INTRODUCTION

An application was made to South Cambridgeshire District Council by Bryant Homes Ltd to develop a 16.2 hectare site some 12 km South-East of Huntingdon for residential, commercial and industrial usage. Anglian Water objected to the application on the basis that it 'does not show satifactory means of disposal of surface water from the proposed development'*. Furthermore they felt that 'the use of balancing reservoirs would not be acceptable at the site as the area drains towards Elsworth, and any failure would result in flooding of the settlement'*. They also felt that 'it may not be practical to improve the watercourse through Elsworth'*. The Institute of Hydrology were commissioned on 30th June 1987 to make preliminary assessments of flood frequency at Elsworth, both before and after the above development and to assess the impact on the flood risk. The study was to include evaluation of catchment characteristics and flood estimates (both by statistical and rainfall-runoff methods) for two sites: one close to Elsworth and one just downstream of the development, the precise locations to be agreed following site inspection. The commission would also include searching for, and use of, local data.

2. CATCHMENT DESCRIPTION

The unnamed stream (referred to hereafter as the Elsworth brook) at the village of Elsworth drains a 8.6 km^2 catchment of low relief some 11 km to the south-east of

* letter to Bryant Homes from South Cambridgeshire District Council dated 7/5/87

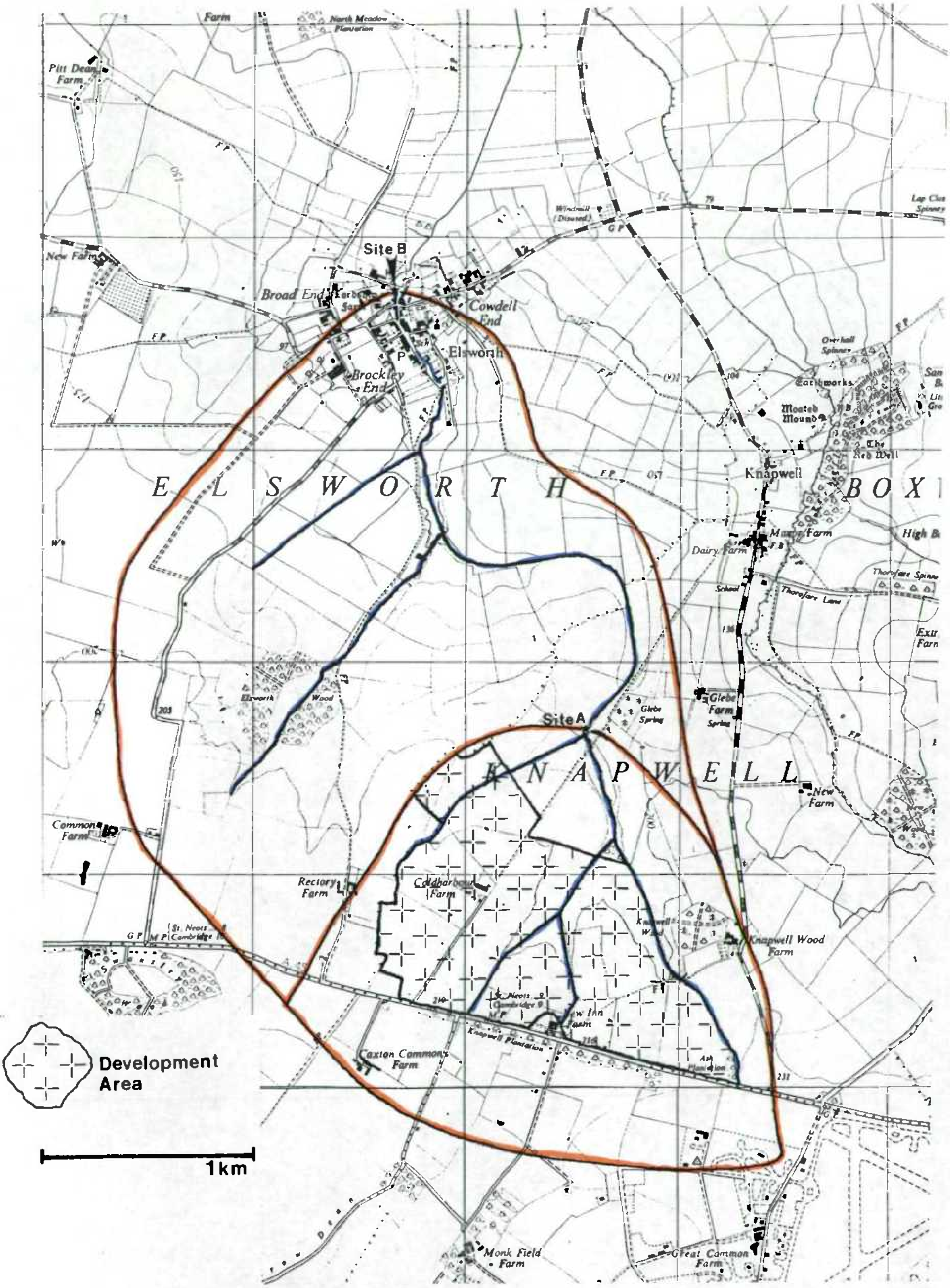

Figure 1 Location map

Huntingdon in Cambridgeshire (Figure 1). The upper parts of the catchment are underlain by soils of the Hanslope series whilst around Elsworth they are classed as Evesham 3 (Soil Survey, 1986). Landuse in the area is predominantly arable agriculture. On 2nd July 1987 most of the land was under barley. Trees are restricted to a few hedgerows and several small areas of woodland each not greater than 2 hectares in extent. Apart from few farms and isolated houses, building has been restricted to Elsworth village. There is a small pond in the centre of the catchment through which 2.4 km^2 of the catchment drains.

All open channels within the catchment were severely congested with weeds and contained little water at the time of the site visit. The only exception was a small reach at the upstream end of the village where the channel had been dredged and a new footbridge installed. For part of its course within the village the stream is contained within three underground pipes of about 0.6 m in diameter. At the upstream end of these pipes there is a pair of sluice gates, one without workings. The stream is also culverted under two road bridges. Below the downstream bridge the channel is deep and mostly weed-free. It was recognised from the site inspection and the comments from Anglian Water that the critical site is Elsworth which is clearly susceptible to flooding in Water Street which runs adjacent to the stream. Property is generally set some distance above the road level and it appears that serious flooding is a potential hazard rather than a regular occurrence.

3. PHYSICAL CATCHMENT CHARACTERISTICS

Two sites were chosen for flood frequency analysis (see Figure 1)

Site A: immediately below the confluence of two tributaries which would drain the proposed development

Site B: in Elsworth at the most downstream bridge culvert.

For these two sites, and the intervening drainage area, estimates of the physical characteristics of the catchments were made from maps given in the Flood Studies Report (NERC, 1975). Values for these characteristics are given in Appendix 1 together with those for four nearby catchments which have records of river flows.

4. FLOOD FREQUENCY ANALYSIS

The Flood Studies Report (NERC, 1975) and Flood Studies Supplementary Reports (Institute of Hydrology, 1976-1986) provide methods of estimating the flooding behaviour of a stream either from past records of river flows or from the physical characteristics of the catchment. The latter methods are used when flow data are inadequate or unavailable. The instantaneous peak discharge of a given design flood can be estimated directly by the 'statistical' method. Alternatively, the entire flood hydrograph resulting from a design rainfall can be derived by the 'rainfall-runoff' method.

4.1 Statistical method

In the recommended method an index of the typical size of the annual maximum flood is estimated, in this case the mean annual flood, $\bar{Q}$. $\bar{Q}_{obs}$ is calculated from the set of observed flood peaks. When adequate flow records are not available $\bar{Q}_{cc}$ may be estimated from the physical characteristics of the catchment. $\bar{Q}$ is then scaled by appropriate growth factors to estimate floods of less frequent occurrence. These factors are available for all regions of the U.K.

4.1.1 $\bar{Q}$ adjustment

Values of $\bar{Q}_{cc}$ and $\bar{Q}_{obs}$ for the Flore and Bury Brook (see Appendix 1 for details) are given below together with the discrepancy between the two methods expressed as a proportion of $\bar{Q}_{cc}$.

catchment	$\bar{Q}_{obs}$ m^3s^{-1}	$\bar{Q}_{cc}$ m^3s^{-1}	$\bar{Q}_{obs}/\bar{Q}_{cc}$
Flore	2.40	1.38	1.74
Bury Brook	9.71	5.80	1.67

These results suggest that, in this locality, the observed $\bar{Q}$ is around 1.7 times that estimated from catchment characteristics. Estimates of $\bar{Q}$ for the Elsworth brook were therefore scaled by 1.72, a weighted average of these two.

Weights were calculated from the physical similarity between the catchments. This yielded preferred pre-development estimates, $\bar{Q}$

catchment	$\bar{Q}_{cc}$ $m^3 s^{-1}$	scaling factor	$\bar{Q}_{rural}$ $m^3 s^{-1}$
Site A	0.50	1.72	0.86
Site B	1.22	1.72	2.10

4.1.2 Urban adjustment

The Flood Studies Supplementary Report 6 provides a further correction factor to estimate $\bar{Q}$ for the period after urban development. This factor depends upon the extent of urbanisation and the characteristics of the rural catchment.

catchment	$\bar{Q}_{rural}$ $m^3 s^{-1}$	urban factor	$\bar{Q}_{urban}$ $m^3 s^{-1}$
Site A	0.86	2.16	1.86
Site B pre	2.10	1.04	2.17
Site B post	2.10	1.41	2.96

4.1.3 Flood quantiles

The estimates of $\bar{Q}$ are scaled to derive the specified design flood discharge using growth factors appropriate to the region for the rural and urbanised cases.

	Site A		Site B	
T yr	$Q(T)_{pre}$ $m^3 s^{-1}$	$Q(T)_{post}$ $m^3 s^{-1}$	$Q(T)_{pre}$ $m^3 s^{-1}$	$Q(T)_{post}$ $m^3 s^{-1}$
5	1.11	2.51	2.80	3.82
10	1.42	2.92	3.59	4.74
50	2.43	3.40	6.15	6.96
100	3.06		7.74	
500	4.31		10.91	

4.2 Rainfall-runoff method

To apply this method two important parameters must be estimated. Firstly the response of the catchment to a unit amount of rainfall is required. single parameter, time-to-peak (Tp), is sufficient to describe all aspects of this response. second parameter (PR) defines the percentage of the design storm depth which contributes to the flood hydrograph. This is the most influential factor in determining the flood response since the resulting hydrograph is scaled directly by PR.

4.2.1 Tp adjustment

Tp may be expressed in various forms according to the standard duration of rainfall considered; thus Tp(0) defines the response to unit rainfall falling instantaneously over the catchment. Tp may be derived by using observed rainfall sequences together with the resulting catchment response. An average Tp(0) has been defined in this way for the Flore and West Glen catchments. Data from the Bury Brook were not used because its catchment area is much larger and slope much lower. When only records of river level are available, with no stage-discharge calibration, catchment lag between rainfall centroid and peak river level may be used to estimate Tp indirectly. Data for the Beck Brook (see Appendix 1) were used in this way. Despite having a much larger catchment area its geographical proximity to Elsworth made it worth considering. Tp(0) can also be estimated from the physical characteristics of the catchment. Estimates of Tp from hydrometric data and catchment characteristics for these three catchments are

catchment	$Tp(0)_{obs}$ hr	$Tp(0)_{cc}$ hr	$Tp(0)_{obs}/Tp(0)_{cc}$
West Glen	3.80	4.57	0.83
Flore	4.03	5.52	0.73
Beck Br.	11.11	7.01	1.58

The relationship between $Tp(0)_{obs}$ and $Tp(0)_{cc}$ is not consistent between these catchments. Data from the Flore and West Glen suggest that the catchment characteristic equation over-estimates Tp(0), whereas data from the Beck Brook imply underestimation. Although the Beck Brook is geographically nearer to Elsworth its catchment is much larger, flatter and at present more heavily urbanised. Furthermore river levels are recorded on monthly charts and accurately defining the timing of peak flows is therefore difficult. The Flore and West Glen catchments are more similar to that at Elsworth in terms of size and slope although the soils are slightly more impervious. A factor of 0.8 was therefore chosen to adjust $Tp(0)_{cc}$ at Elsworth.

	$Tp(0)_{cc,pre}$ hr	scaling factor	$Tp(0)_{pre}$ hr
Site A	5.87	0.8	4.70
Site B	5.91	0.8	4.73
Intervening area	4.93	0.8	3.94

4.2.2 PR adjustment

The percentage runoff, PR, is closely related to the type of soil in the catchment. The soils underlying the catchment of the Bury Brook have a similar classification to those at Elsworth in terms of their winter rain acceptance potential, WRAP (see Appendix 1). Analysis of several flood events on this catchment suggests that the standard percentage runoff, SPR, is around 55%. The relevant catchment characteristic equation implies an SPR of 38% for both catchments. A figure of 55% is consistent with soils of WRAP class 5. The 1:250,000 soil map classifies as Hanslope (also present at Elsworth) and Cannamore for the Bury Brook catchment. The Cannamore soils contain a higher proportion of clay than found at Elsworth implying a higher SPR. Using this evidence the soil type on the Elsworth catchment was reclassified as WRAP class 4, yielding an SPR of 47%.

4.2.3 Urban adjustment

Since the Tp estimation equation contains the parameter URBAN, the effect of increasing the proportion of the catchment under urban development is readily calculated.

	$Tp(0)_{cc,post}$ hr	scaling factor	$Tp(0)_{post}$ hr
Site A	2.55	0.8	2.04
Site B	4.09	0.8	3.27
Intervening area	4.93	0.8	3.94

PR may be adjusted to allow for impervious surfaces in urban areas. In most urban developments around 30% of the surface area is impervious, from which 70% of the rainfall runs off directly. A detailed plan of the site suggests that 40% of the developed area of 12.2 hectares may be impervious, since this will include large factory units and associated car parks. This area does not include recreational open space around the housing. In fact 30% of the entire site of 16.2 hectares is approximately equal to 40% of the 12.2 hectare developed area. The standard urban correction for PR was therefore retained and applied to the whole site.

4.2.4 Flood quantiles

Site A

To estimate the flood frequency relationship for Site A a series of design rainfalls of varying return periods were transformed into runoff hydrographs using the rainfall-runoff model. Two sets of flood estimates resulted corresponding to the pre and post development cases.

Site A

T yr	$Q(T)_{pre}$ $m^3 s^{-1}$	$Q(T)_{post}$ $m^3 s^{-1}$
5	1.60	3.35
10	1.97	4.01
50	2.89	5.89
100	3.33	6.77
500	4.66	9.43

Site B

To estimate flood frequency at Site B two strategies were adopted. The first involved a similar analysis to that applied to site A, treating the whole catchment as a single lumped system. In the second approach a semi-distributed model was adopted utilising the response hydrographs from site A. For each design flood estimate the hydrograph from Site A was routed along the channel to the Site B, where it was combined with the response from the intervening catchment area which had been calculated separately. This latter method is useful since the effects of balancing areas may be easily included in the modelling. The major problem with this approach is estimating the wave speed to be used in the channel routing. The characteristics of the channel are:

length	2.85	km
slope	0.0095	$m\ m^{-1}$
mean width	1.2	m

The Manning equation may be used to provide an estimate of velocity. Assuming a hydraulic radius for the channel of 0.75 m and n=0.1, a velocity of around 0.8 $m\ s^{-1}$ results. As a check on this estimate, a travel time from Site A to Site B was inferred by combining weighted estimates of Tp(0). This yielded a velocity of 0.66 $m\ s^{-1}$. Using a flood wave speed of 0.8 $m\ s^{-1}$ and a fixed parameter

Muskingum flood routing model yields a travel time of one hour with no significant attenuation of the flood wave. The solution adopted was simply to delay the hydrograph from Site A by one hour without changing its discharge ordinates. Each ordinate of the routed hydrograph was then added to the corresponding ordinate of the response hydrograph from the intervening catchment area.

The following results were obtained from the flood frequency analysis

	lumped		semi-distributed	
T yr	$Q(T)_{pre}$ m^3s^{-1}	$Q(T)_{post}$ $m^3 s^{-1}$	$Q(T)_{pre}$ m^3s^{-1}	$Q(T)_{post}$ $m^3 s^{-1}$
5	3.72	5.51	4.06	6.00
10	4.58	6.58	5.00	7.17
50	6.71	9.77	7.34	10.61
100	7.72	11.25	8.43	12.20
500	10.80	15.77	11.80	17.11

5. FLOOD FREQUENCY CURVES

Flood frequency relationships derived by the three method described above for Site B are shown in Figure 2. Note that there is close agreement between the results for the catchment prior to urbanisation. However, estimates for the post-urbanisation case are rather different. The statistical procedure results in a flood frequency curve which is less steep than for the pre-urban case, thus implying that at high return periods estimates of flood peaks before and after urbanisation are similar. There is some theoretical justification for this. Very large floods

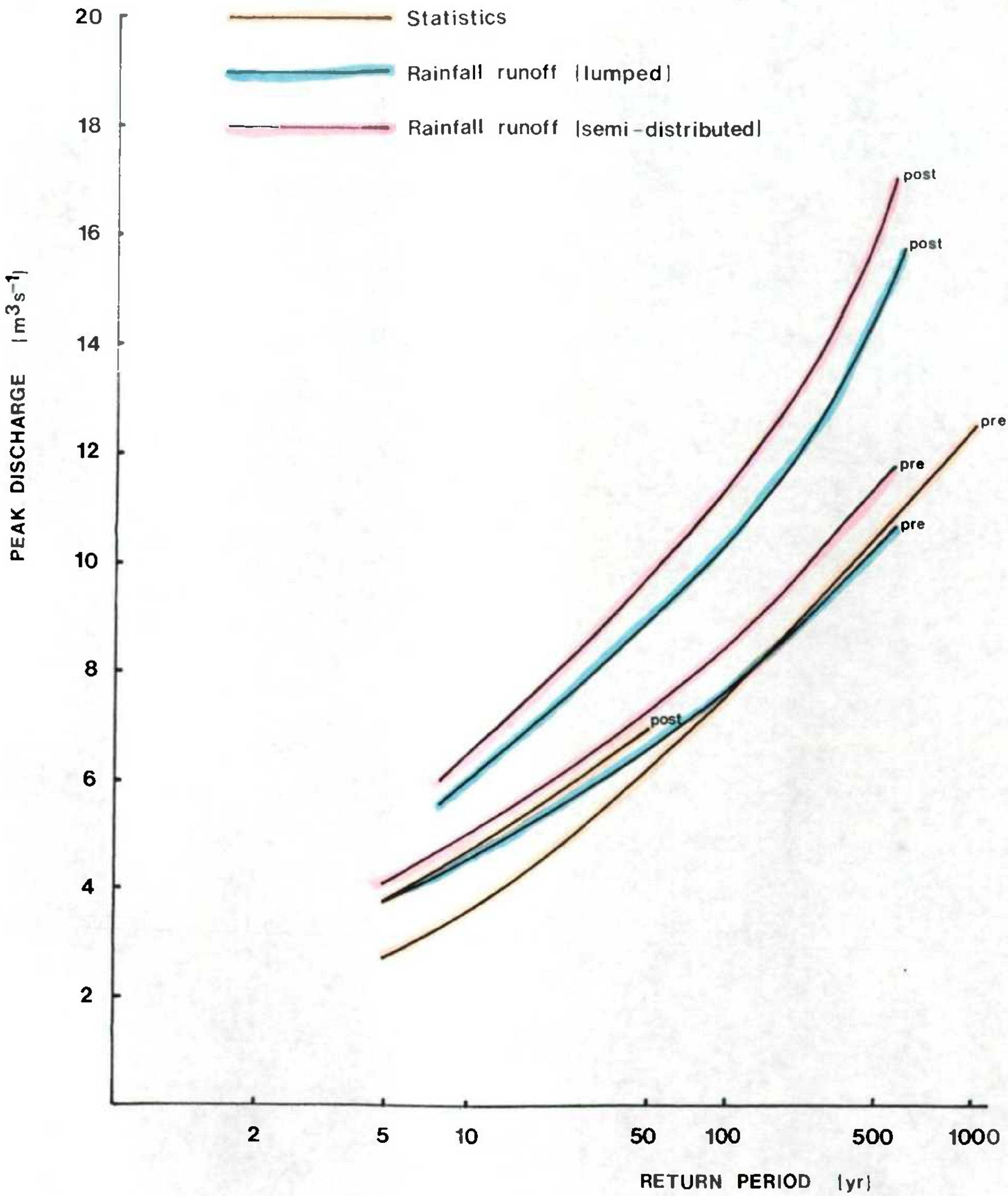

Figure 2 Flood frequency curves

on rural catchments are usually associated with a high precentage runoff, thus they are acting somewhat like an urbanised catchment. However the growth factors for urbanised catchments are based on few data and so are only given up to the 50 year level. At the 10 year flood level the curves suggest a 30% increase in peak flows following urbanisation, which is consistent with the increase predicted by the rainfall-runoff methods. The rainfall-runoff methods predict steeper flood frequency curves with an increase peak flows of around 30% for all return periods. Results from the semi-distributed rainfall-runoff method are to be preferred overall since this model allows specifically for the spatial distribution of the urbanisation. The increase in peak flows is due both to an increased volume of runoff and also to an increased speed of runoff so that flood peaks from the upper and lower subcatchments coincide after urbanisation. In the pre-urban case the peak from the lower subcatchment had passed by the time the peak from the upper subcatchment reached Elsworth.

6. CONCLUSIONS

The effect of the proposed development at Belham Hill will be to increase flood peak discharge at Elsworth by around 30% for all return periods. Another way of interpreting the results is that the pre-development 50 year flood will probably occur once, on average, every 15 years after development and the previous 100 year flood will become the new 25 year flood. This constitutes significant increase in flood risk in the village.

7. FLOOD ALLEVIATION

The watercourse through Elsworth is heavily culverted and major upgrading of the discharge capacity through the village would be both expensive and disruptive. Provision of balancing storage at Site A possibly offers cost-effective solution and is particularly suitable because of the relative locations of the urban and rural areas. Any scheme must, however, satisfy two criteria. Firstly, it must balance the increased and accelerated runoff from the development such that the flood frequency at Elsworth is not increased. The specification of design criteria is important since storage that balances at the 100-year level will reduce flood flows for lower recurrence intervals. Secondly, the structure of the balancing storage must be able to withstand a very rare design flood to ensure public safety against damburst. This spillway design flood might be the Probable Maximum Flood (PMF), given its location above Elsworth. However, the choice would be a matter for a panel engineer appointed under the Reservoirs Act 1975.

Producing the optimum design solution requires assessment of a combination of several processes within the catchment. Because the balancing storage attenuates and delays the runoff response, the flood frequency is based on longer (less intense) design storm. The adjustment in design storm duration is based on the lag effect imposed by the balancing storage. The lag is dependent on the storage/discharge characteristics of the reservoir which in turn depend on the balancing effect required. The problem is thus solved by design iteration in which scheme is proposed, tested and refined. It is also important to remember that the balancing storage has dual effect, reducing the flood peak and delaying its arrival time at Elsworth. Since the flood frequency relationship is obtained by combining the response of the lower part of the catchment with that routed from Site A, delaying the peak in the reservoir may result in it arriving at Elsworth after the downstream response has passed, thus the combined response will be greatly reduced.

The above balancing design will enable an appropriate control structure, such as a throttle pipe, to be sized to achieve the required balancing. Estimation of the PMF, for design of the spillway will require design iterations since the duration of the design storm, in this case the Probable Maximum Precipitation, will also need to account for the reservoir lag.

8. RECOMMENDATIONS FOR FUTURE WORK

8.1 Data collection

Analysis of local data from different sites suggests that in this region the true Tp varies from that predicted by the catchment characteristic equation but that the magnitude and direction of the variation is locally uncertain. Data from the Bury Brook catchment suggest local difference between observed and estimated SPR. However since this catchment is not a perfect analogy with that at Elsworth a compromise SPR was accepted. These problems reinforce the need for collection of data on the catchment concerned. Only in this way can the accuracy of the parameter estimates be substantially improved. Records of water level during several floods, combined with short duration rainfall records, would allow estimation of catchment lag time and hence Tp. Records of stream discharge would allow estimation of SPR and Tp directly. A good site for monitoring stream flow would be beneath the footbridge at the upstream edge of the village, whilst the recording raingauge could be sited at Coldharbour Farm.

8.2 Feasibility of balancing storage

Before deciding on a flood alleviation scheme an engineer would need to be consulted on the feasibility of providing sufficient balancing storage at Site A. If this solution is appropriate, detailed calculations for sizing the balancing pond control structure and spillway would be required. For this purpose at-site data would be very valuable.

9. ACKNOWLEDGEMENTS

Data from the Beck Brook at Westwick were kindly supplied by Anglian Water, Cambridge Division.

10. REFERENCES

Institute of Hydrology (1976-1986) Flood Studies Supplementary Reports, IH, Wallingford, Oxfordshire.

Natural Environment Research Council (1975) Flood Studies Report, NERC, London. 5 vols.

Soil Survey of England and Wales (1983) Soils of Eastern England, 1:250,000 Map, Ordnance Survey, Southampton.

APPENDIX 1 CATCHMENT DETAILS

	Site A	Site B	inter. area	W. Glen Easton W.	Flore Exper	Bury Br. Bury Weir	Beck Br. Westwick
GRID REF.	TL326616	TL317637	TL317637	SK965258	SP660610	TL286837	TL419650
AREA	3.44	8.55	5.11	4.40	6.81	65.30	44.60
MSL	2.80	4.60	2.62	2.80	3.28	19.00	9.55
S1085	8.24	10.06	13.30	14.60	8.59	1.65	6.33
STMFRQ	1.16	0.70	1.16		0.86	1.35	
URBAN PRE	0.00	0.02	0.03	0.00	0.00	0.00	0.09
POST	0.47	0.21	0.03				
SOIL1							
SOIL2							
SOIL3	1.00	0.90				0.85	
SOIL4		0.1		1.0	1.0	0.15	
SOIL5							
SAAR	560.0	560.0	560.0	627.0	654.0	554.0	560.0
RSMD					24.0	17.7	
Jenk.'s r	44.0	44.0	44.0				
Max 2 hr	165.0	165.0	165.0				
Max 24 hr	240.0	240.0	240.0				
LAKE	0.0	0.0	0.0		0.0	0.0	