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Sandpool Farm Flood Study

A report to Hills Aggregates Ltd

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Executive Summary

1 The proposed development of Sandpool Farm involves the infilling of a series of gravel pits, some of which are located within the Flagham Brook floodplain as defined by the March 1947 flood. This study has investigated the extent to which this development may be detrimental to floodplain storage throughout the Flagham Brook catchment as a whole.

2 The March 1947 flood in the Flagham Brook catchment has an estimated return period of between 50 and 100 years. Smaller floods, of around 20 years return period, would have probably resulted in minor flooding of the site as it was prior to gravel extraction whilst lesser floods than this may have been contained within the stream channel.

3 Since the March 1947 flood Sandpool Farm has been worked for gravel and a site access road built up alongside the Flagham Brook. This road appears to be elevated above the flood level associated with the 1947 flood. It is likely that the frequency of flooding at Sandpool Farm has fallen since the construction of the access road, with flood waters constrained to overflow mainly on the southern side of the channel.

4 It is extremely difficult to estimate the magnitude of the flood which would cause flooding of Sandpool Farm in its present condition although it is reasonable to say that an extreme event similar to the 1947 flood would probably result in some flooding, if not from water overtopping the access road then from flow through weak points in the road or overspilling from adjacent land to the north and east. It has therefore been assumed that the site remains within the floodplain defined by the 1947 flood.

5 Extensive gravel extraction in the Flagham Brook catchment has resulted in a series of pits, some of which are now artificial lakes and others which remain dry. These pits represent an estimated increase in potential flood storage of 370 000 m^3, considerably more than the estimated volume of floodplain storage associated with the 1947 flood. A repeat of the 1947 flood, with an estimated volume of approximately 275 000 m^3, would be likely to have a significantly reduced impact on surface land use within the Flagham Brook catchment with a large proportion of flood water entering storage in gravel pits excavated within the area of the floodplain.

6 The infilling of gravel pits under the proposed development of Sandpool Farm would result in an estimated reduction in potential floodplain storage of 70 000 m^3. The development would therefore be of relatively little significance when taken in the context of changes to the floodplain as a whole since the 1947 flood, with only a 70 000 m^3 reduction in potential storage out of an overall increase of 370 000 m^3. The remaining 300 000 m^3 additional storage in the Flagham Brook catchment would still be sufficient to accommodate a repeat of the 1947 flood.

7 The proposed development at Sandpool Farm is not likely to increase flood risk in the Flagham Brook catchment. Given the availability of gravel pits for flood storage elsewhere in the catchment a repeat of the 1947 flood would be likely to cause flooding over a significantly smaller area of the catchment than was the case in 1947.

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1 Introduction

This report describes the assessment of the impact of proposed developments at Sandpool Farm on floodplain storage in the Flagham Brook catchment. Sandpool Farm is an area of former gravel extraction near South Cerney in Gloucestershire. The proposed development of the site involves the infilling of gravel pits, some of which lie within the floodplain defined by the March 1947 flood. This study has investigated the extent to which this development may be detrimental to floodplain storage throughout the Flagham Brook catchment as a whole.

The study has focused on two central issues. Firstly, an assessment has been made as to whether Sandpool Farm in its current condition still forms part of the floodplain defined by the March 1947 flood. Secondly, an attempt as been to evaluate the extent to which changes to the floodplain since 1947 may have increased potential flood storage in the catchment. The impact of the proposed development at Sandpool Farm has then been assessed in the light of findings relating to each of these issues.

Although relevant data for the site and catchment is scarce the approach adopted here has aimed to utilise the available information as fully as possible. Flow records from gauging stations on the nearby Swill Brook and River Thames were used to guide flood estimation on the Flagham Brook for which no flow data exists. Flood maps and levels in conjunction with a topographic survey provided a basis from which to estimate floodplain storage. Ordnance Survey maps of the area were consulted to evaluate several factors, including the way in which the Flagham Brook catchment has changed over the latter half of the century.

Despite the best use of the available data it should be noted that the estimates of flood magnitudes and floodplain storage presented in this report are surrounded by a degree of uncertainty. They should therefore be viewed as giving an indication of likely magnitudes rather than in terms of their absolute values.

2 Background

2.1 Site Description

The Sandpool Farm site comprises two areas of land previously worked for gravel extraction near South Cerney, Gloucestershire (see figure 2.1). In this study attention is focused solely on the western area, also known as Sandpool Farm, and all further reference is to this area of land rather than to the site as a whole.

The site was visited in July 1994 to gain familiarity with the general condition of the land and to inspect local water courses. Nearby river gauging stations on the River Thames at Cricklade and the Swill Brook at Oaksey were also examined. A return visit to Sandpool Farm was made in August 1994 in order to survey relevant aspects of the site topography.

Sandpool Farm covers an area of approximately 0.25 km^2. The site geology comprises Oxford Clay overlain by alluvial gravels. The character of the site has undergone considerable change since the cessation of mining operations around 20 years ago although evidence of the former gravel workings remains in the form of pits, residue heaps and works tracks. An access road, built above the general ground level, surrounds the site. The site is now covered with a varied and, in places, relatively dense vegetation dominated by willow scrub. In addition areas of more mature vegetation and grassland exist which are recognised for their ecological interest (Land and Mineral Management Ltd, 1993).

The main hydrological feature of Sandpool Farm is the Flagham Brook which forms the border of the site to the west and south. The stream is a small one, having an estimated mean discharge of the order 0.1 m^3s^{-1}. At the time of the site visit the stream channel was overgrown by relatively dense vegetation which was impeding the free flow of water.

Within the site itself a number of small ponds have formed in depressions left by the extraction of gravel. It is likely that a significant proportion of rainfall at the site collects in these ponds from which groundwater recharge may occur. A number of ditches are also in evidence at the site although they do not all appear to be linked to Flagham Brook.

Sandpool Farm lies within the wider context of the upper Thames basin, the river rising in the Cotswold Hills to the west (see figure 2.2). The geology of the area is dominated by two lithologies; the Oolitic limestone of the Cotswolds and a broad belt of Oxford Clay underlying the lower lying land in the east. The permeability of soils therefore varies significantly across the region. The Swill Brook flows to the south of Sandpool Farm and is joined by the Flagham Brook approximately 1 km east of the site. A further 4 km downstream the Swill Brook meets the River Thames which flows to the north of the Sandpool Farm site. The uppermost gauging station on the Thames is at Cricklade, about 8 km east of Sandpool Farm. The catchment draining to this point on the river was taken to define the extent of the area of interest to this study.

Land use in this catchment is dominantly agricultural although a significant area around Sandpool Farm has been worked for gravel extraction. The vast majority of this extraction

Map of Sandpool Farm site

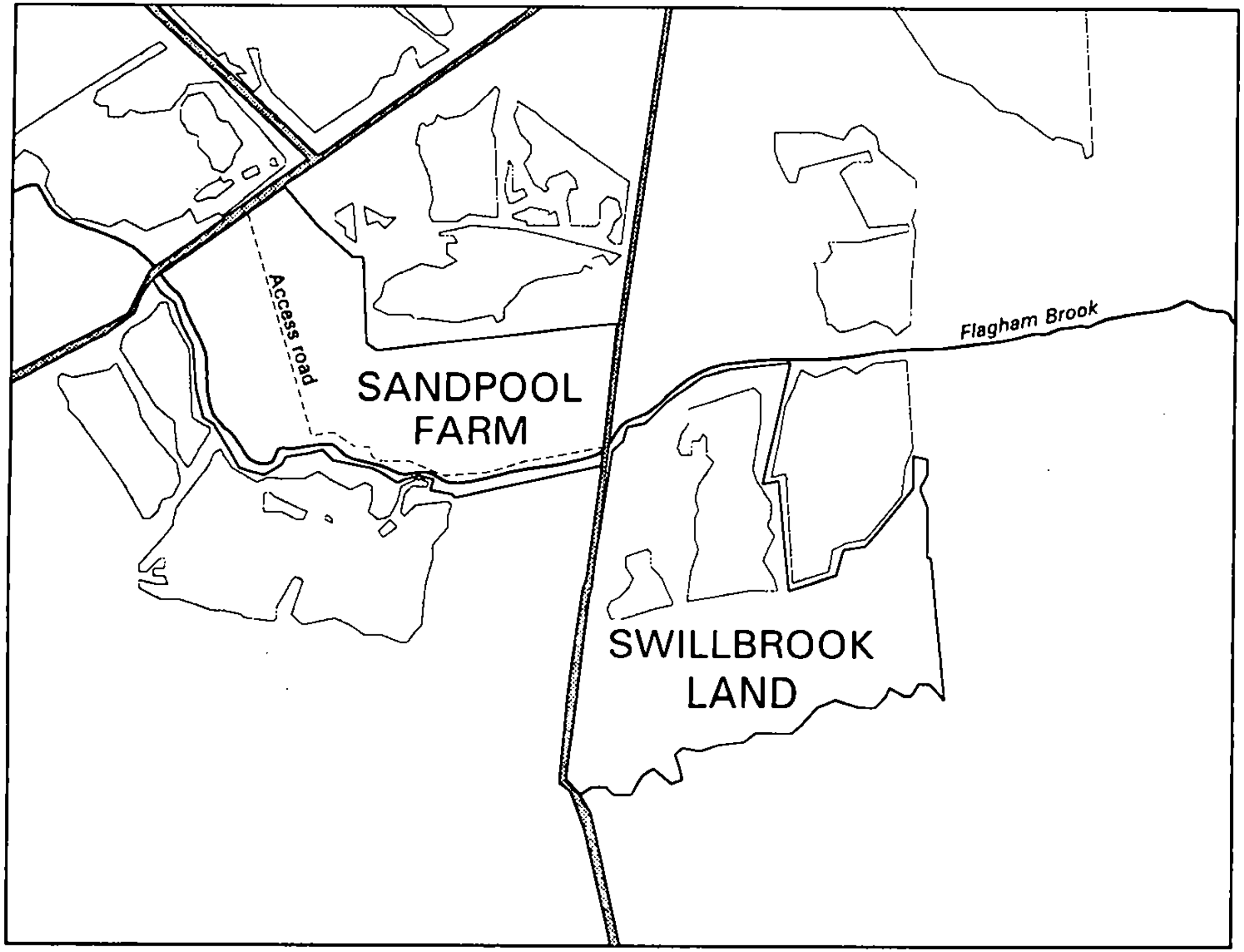


Figure 2.1

Location map of Sandpool Farm showing geology and main rivers

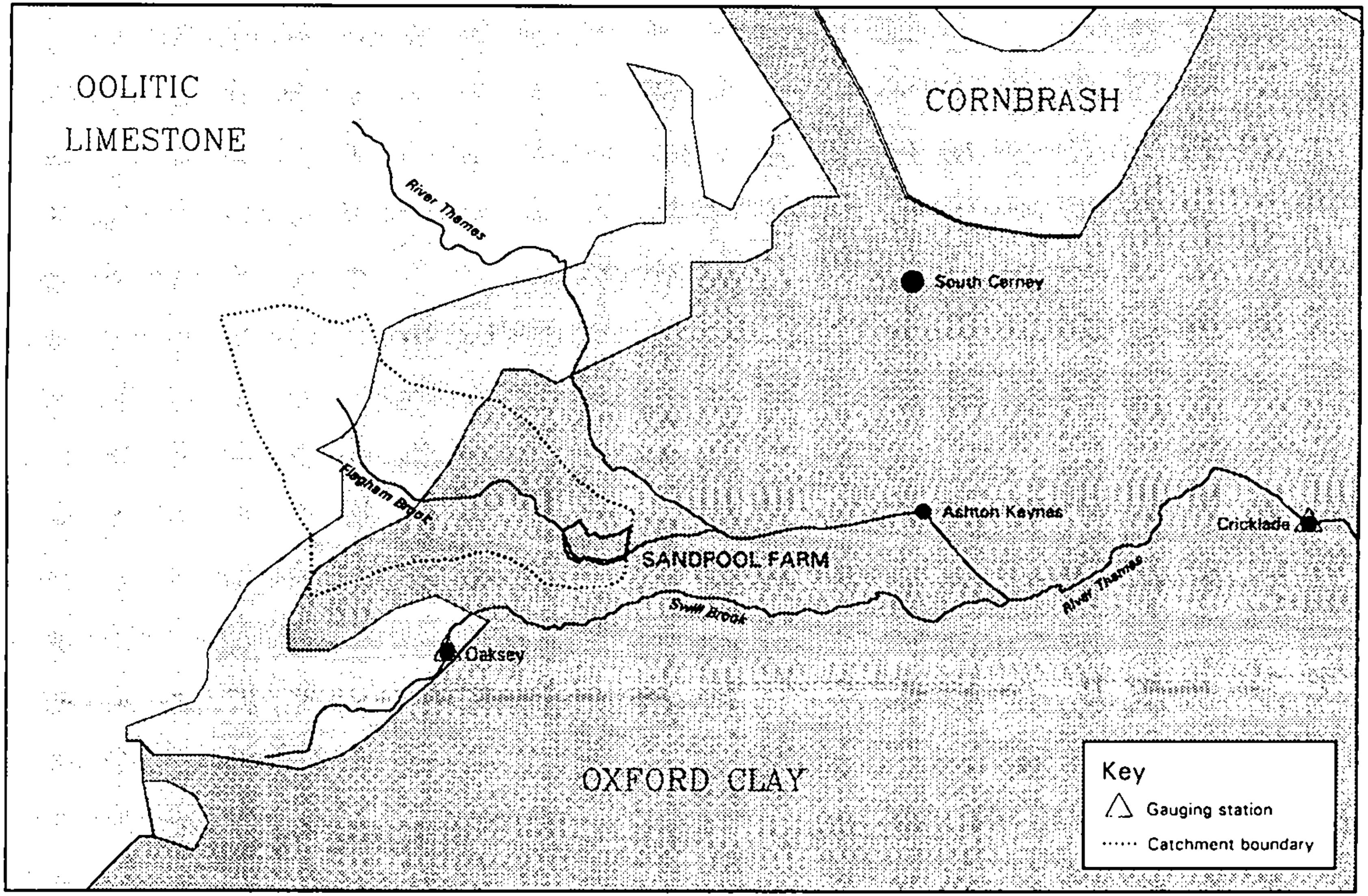


Figure 2.2

occurred between the 1950s and 1970s and many of the former gravel pits are now under water forming a series artificial lakes. The depth of these lakes is generally no more than 2 to 3 metres. The combined surface area of the lakes is estimated to be over 3.0 km^2 (2% of the total Cricklade catchment area) although only 30% of this total lake area appears to be directly linked to the natural channels of the catchment.

2.2 Proposed Development

The proposed development of Sandpool Farm will occur in two phases. Phase I involves the infilling of remnant gravel pits with inert, non-toxic, non putrescible waste (Land and Mineral Management Ltd, 1993). The landfill will store an estimated 250,000 m^3 of waste in two areas of the site. It is proposed that the waste will be mounded several metres above the current elevation of the site.

Phase II of the proposed development involves the construction of a nine hole golf course. It is envisaged that a period of grassland management will precede phase II and that other areas of ecological interest on the site will be managed throughout both phases I and II.

2.3 Outline of Methodology

The aim of this study was to assess the impact of the proposed developments at Sandpool Farm on floodplain storage in the Flagham Brook catchment given that the site lies within the floodplain boundaries defined by the 1947 flood. In assessing the extent to which the area of potential flood storage may be reduced by the infilling of gravel pits and the construction of landfills above the current ground level the following issues are raised:

1 Does the site currently represent an area of floodplain storage ? It has been suggested that the raised access road surrounding the site has already taken the site out of the floodplain, in which case the development will have no impact on the local pattern of flood storage.

2 To what extent has available flood storage in the Flagham Brook changed since the 1947 flood ? How does this compare with the expected reduction in floodplain storage resulting from the developments at Sandpool Farm ?

The approach adopted to address these issues consists of two parts. The first of these involved the assessment of past, present and possible future floodplain storage. This evaluation involved calculations based on maps, site visits and the evidence from historical records of the 1947 flood. The second aspect of the analysis involved utilising the Institute's expertise in flood estimation to estimate the frequency and magnitude of flooding in the Flagham Brook catchment.

The assessment of floodplain storage is described in chapter 3 whilst methods of flood estimation employed in this study are outlined in chapter 4. The main findings of the analyses are discussed in chapter 5.

3 Estimation of Floodplain Storage and Channel Capacity in the Flagham Brook Catchment

3.1 Background

The assessment of floodplain storage in the Flagham Brook catchment involved the estimation of the volume of water that was or could be stored under three different conditions:

(1) Floodplain storage during the March 1947 flood.

(2) Potential floodplain storage under present conditions, taking into account the large scale extraction of gravel from the catchment over the past 40 years or so.

(3) Potential floodplain storage under future conditions, assuming the proposed development at Sandpool Farm goes ahead.

The assessment of floodplain storage under each of these three conditions was based on a combination of mapwork for flood areas and topographic survey for flood levels and depths. Surveying techniques were also used to estimate the channel capacity of the Flagham Brook at the eastern boundary of the Sandpool Farm site. The assessment of floodplain storage under each of the three conditions outlined above and the estimation of channel capacity are described in more detail below.

3.2 Estimation of Floodplain Storage During the 1947 Flood

Flood maps of the March 1947 flood are held by the NRA for the whole of the Thames catchment. The relevant maps for the upper Thames catchment show the extent of flooding but do not show any measured flood levels upstream of High Bridge, Cricklade (grid ref SU100940). The flood level at this point is shown as 80.01 m OD. Measured flood levels are given, however, on flood record cards for Oaklake Bridge (grid ref SU 049935) and Waterworks Bridge (SU 041941) near Ashton Keynes. Both levels are given relative to bridge soffit heights and it is not known whether the bridges have been replaced or modified since the 1947 flood. Despite this, the bridge soffits were surveyed to give estimates of the 1947 flood levels of 81.8 m at Oaklake Bridge and 84.78 m at Waterworks Bridge. Although the accuracy of these estimates is somewhat uncertain they do at least provide a check on flood levels estimated upstream on the Sandpool Farm site itself.

Flood levels were surveyed at Sandpool Farm for the flood limits as shown by the NRA flood map. Levels were surveyed at both the eastern and northern ends of the site. In addition the Flagham Brook channel bed and bankfull elevations were surveyed in order to allow the estimation of the depth of flooding at the lowest point of the catchment cross section.

The approach adopted to calculate the volume of floodplain storage during the 1947 flood was first to divide the flooded areas of the catchment into reaches of similar flood width (see figure 3.1). Representative flood and bankfull levels for each reach were then extrapolated

Surveyed and estimated flood and bankfull levels for estimation of flood storage, March 1947 flood

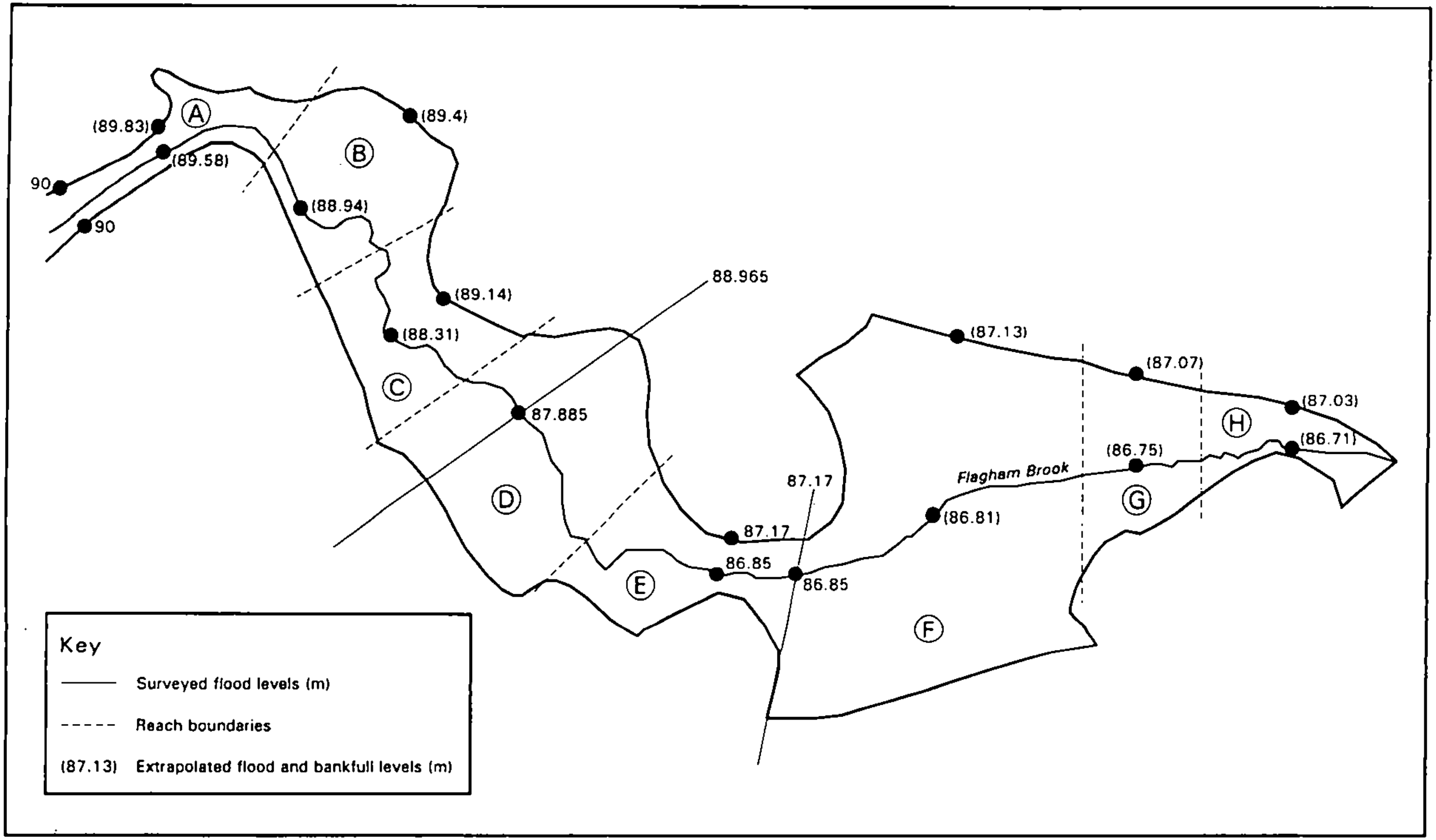


Figure 3.1

from the surveyed elevations on site and spot heights and contours shown on OS maps. These levels are shown in figure 3.1 along with the elevations measured during the site survey. The flood levels noted above in relation to the bridges at Ashton Keynes and Cricklade provided a check on the general gradient of these interpolated levels.

The area of flooding and channel length in each reach was estimated. This allowed the calculation of the mean width of each of the flood reaches. A representative flood cross section for each reach was defined by the mean width and a maximum depth given by the difference between the flood level and the bankfull elevation. For simplicity the cross sections were assumed to be symmetrical triangles with depth varying from zero at the limits of flooding to the maximum at a centrally located stream channel. The volume of flood water in each reach was estimated by simply multiplying the area of this cross section by the channel length. The results of these calculations are given in table 3.1. The total floodplain storage in the Flagham Brook catchment during the March 1947 flood is estimated to be 273 368 m^3.

***Table 3.1** Estimation of Floodplain Storage, March 1947 Flood*

Reach	Area (m^2)	Channel length (m)	Mean width (m)	Maximum depth (m)	Cross-sectional area (m^2)	Volume (m^3)
A	60 000	600	100	0.25	12.5	7 500
B	102 500	450	230	0.46	52.9	23 805
C	95 000	550	170	0.83	77.5	38 803
D	190 000	450	420	1.08	226.8	102 060
E	92 500	550	170	0.32	27.2	14 960
F	410 000	650	630	0.32	100.8	65 520
G	77 500	250	310	0.32	49.6	12 400
H	52 500	400	130	0.32	20.8	8 320
TOTAL						273 368

3.3 Estimation of Potential Floodplain Storage Under Present Conditions

In estimating the potential floodplain storage under present conditions attention was focused on the way in which the character of the floodplain in the Flagham Brook catchment has changed since 1947. The most significant change is clearly the way in which large areas of the catchment have been worked for gravel leaving a series of pits, some of which are now under water. An attempt was made to estimate the increased total volume of gravel pits located in the floodplain since the 1947 flood since this represents additional storage for flood waters.

Both dry and watered pits are shown in some detail on 1:25 000 OS maps. A comparison was made between the total area of pits shown on 1st Series and 2nd Series maps of the area. The 1st series maps were revised in 1956 and therefore give a good indication of the likely extent of gravel workings around the time of the 1947 flood. The 2nd series maps date from 1979 and although gravel extraction has continued since then it is reasonable to assume that the most significant changes to the catchment occurred before this date. The increase in the area of gravel pits in the Flagham Brook catchment between 1956 and 1979 is shown in figure 3.2. The area occupied by both dry and watered pits was estimated from both 1st and 2nd Series maps.

The pits are generally relatively shallow. Following the site visits and consultations with local members of the public the average depth was estimated in the region of 2 to 3 metres. In order to estimate the volume of potential storage space in the pits an average depth of 2.5 metres was assumed for dry pits and a depth of 0.5 metres between bankfull and water level for watered pits.

The estimated total area and volume of gravel pits in the floodplain of the Flagham Brook catchment is presented in table 3.2. The estimated increase in potential flood storage arising from the extraction of gravel between 1956 and 1979 is 370 000 m^3.

Table 3.2 Estimation of increase in potential flood storage due to gravel extraction 1956-79

	Area gravel pits (m^2)		Volume potential flood storage (m^3)		
	Dry	Watered	Dry	Watered	Total
1956	0	23 000	0	11 500	11 500
1979	109 000	218 000	272 500	109 000	381 500
Change	+ 109 000	+ 195 000	+ 272 000	+ 97 500	+ 370 000

3.4 Estimation of Potential Floodplain Storage Following Proposed Development

In estimating the potential floodplain storage following the proposed development of Sandpool Farm attention was focused on the way in which the infilling of pits on the site and mounding of landfill material above the current level of the ground surface may reduce flood storage. The area covered by the proposed landfill was estimated from plans provided with the Pre-Application Study to be 106 000 m^2. Of this an estimated 74 000 m^2 lies within the area under water during the 1947 flood.

It is evident from site visits that the depth to which infilling will take place varies considerably from around 2 metres on some parts of the site to almost zero on parts of the site where little or no gravel extraction has occurred. Taking this variation into account along

Increase in area of gravel pits 1956-1979

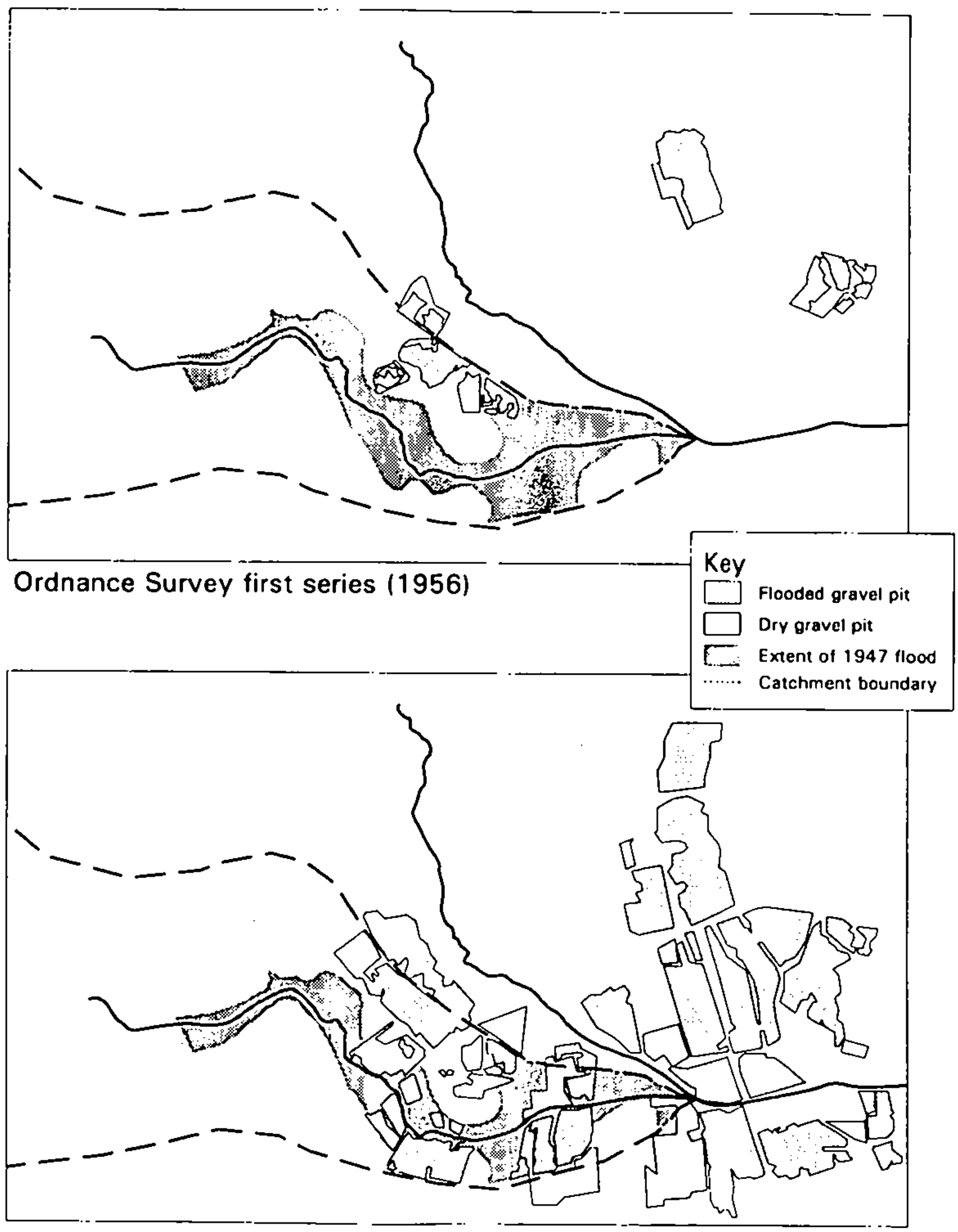


Figure 3.2

with potential flood storage lost due to mounding of material above the ground surface the average depth of floodplain storage lost across the site due to the infilling proposals was estimated to be in the region of 1 metre. The total volume of potential floodplain storage consumed by the development was therefore estimated as 74 000 m^3.

3.5 Estimation of Channel Capacity at Sandpool Farm

As part of the topographic survey performed at Sandpool Farm measurements were made of the Flagham Brook channel cross section at the eastern limit of the site. This involved surveying the elevation of the channel bed and bankfull level and measuring the width of the channel at low flow and bankfull flow elevations. The channel cross section to bankfull height was estimated to be 3.22 m^2 .

An attempt was also made to survey the Flagham Brook at the northern end of the site. However, the density of the vegetation in this part of the site meant that although it was possible to survey channel bed and bank elevations it was not possible to measure the channel width. Visual comparisons at this point and at others along the Flagham Brook suggest that the cross section derived at the eastern limit of Sandpool Farm is reasonably representative of the channel section around the site as a whole.

In order to estimate the channel capacity in terms of a bankfull discharge it was necessary to estimate the likely velocity of flow when the Flagham Brook is in flood. The nearest measurement of flood flow velocity relates to the River Thames at Oaklake Bridge (grid ref SU049935), as recorded on the flood record card for that location. A velocity of 3 ft/sec was recorded on 10 February 1958.

According to the 'laws' of hydraulic geometry velocity varies with discharge. Given the upstream location and hence lower discharge of the site of interest in relation to Oaklake Bridge it can be assumed that a representative flood flow velocity is less than 3 ft/sec. A value of 2 ft/sec or 0.6 ms^{-1} may be appropriate in which case bankfull discharge for the Flagham Brook at Sandpool Farm is estimated to be 1.93 m^3s^{-1}.

In addition to channel bed and bank elevations the elevation of the site access road which runs adjacent to the Flagham Brook was surveyed near to the eastern limit of the site. It is worth noting that the access road, which is built up above the level of the surrounding floodplain, was surveyed as being 0.17 m above the 1947 flood level on this part of the site.

4 Flood Estimation

4.1 Background

The estimation of flood discharge is typically in terms of a magnitude of flow associated with a probability of occurrence. This probability of occurrence is known as the return period (T) of the flood and is expressed in units of time, usually years. A 'T' year flood is estimated to occur, on average, once in every T years. For example, the 50 year flood would be expected to occur, on average, once in every fifty years. Methods of flood estimation aim to estimate the discharge associated with a range of such return periods.

The methods of flood estimation adopted in this study are those recommended in the Flood Study Report (NERC, 1975). Where indicated, reference has also been made to FSR Supplementary Reports 6, 13 and 16 (Institute of Hydrology; 1978, 1983 and 1985) and IH Report 124 (IH, 1994).

The Flood Studies Report describes two sets of techniques for the estimation of floods. The first of these is termed the 'statistical' approach and allows the estimation of an instantaneous flood peak of given return period. The second approach, the rainfall-runoff method, involves a more complicated set of techniques but has the advantage in that it allows the estimation of the timing and total volume of a flood in addition to the peak flow.

Each of the two approaches contains techniques for the estimation of floods for both gauged and ungauged catchments. Floods can be estimated for gauged sites using a variety of methods depending on the length of the flow record. The statistical method involves the fitting of probability distributions to flood peak data or, where records are short, the estimation of floods from the mean annual flood and regional 'growth curves.' The rainfall-runoff approach as applied to gauged sites involves the detailed analysis of a flood peaks and rainfall records to derive a characteristic catchment hydrograph from which flood magnitudes can be estimated.

On ungauged catchments it is possible to estimate flood magnitudes through the use of a set of catchment characteristics, including catchment area, channel slope, stream frequency, soil type and the proportion of the catchment under urban development. These characteristics are derived from both standard Ordnance Survey maps and a series of maps contained in the Flood Studies Report. The catchment characteristics are used to estimate key flood parameters through a series of equations specific to each of the statistical and rainfall-runoff methods.

In some cases flood estimates are required for catchments which, although having no flow records of their own, are in the proximity of one or more gauged catchments. In these instances it is possible to improve upon flood estimates derived for the ungauged catchment by transfer of information from the gauged catchment. It has been possible to adopt this approach in this study.

4.2 Details of Flood Estimation

Flood estimates were derived for the Flagham Brook at the eastern limit of the Sandpool Farm site (grid reference SU017938). With the focus of this study resting on possible changes to floodplain storage it was to necessary to derive estimates of not only flood peaks but also the flood volumes associated with a range of return periods. Flood estimates were therefore derived using both the FSR statistical and rainfall-runoff methods. The statistical method was assumed to provide the best estimate of peak flows of given return period floods. The volumes of flow associated with these peaks was then estimated by the rainfall-runoff method.

Flow records are available for two gauging stations in the vicinity of Flagham Brook. Records from the Thames at Cricklade (gauging station 39040) cover the 21 year period between 1973 and 1993 whilst those collected on the Swill Brook at Oaksey (station 39100) are shorter, the station having been operational only since 1984. Given the availability of this data it was possible to improve on the flood estimates for Flagham Brook which were initially derived from catchment characteristics.

The calculations involved in this analysis were performed using the Institute's MicroFSR software package. Details of the procedure followed in deriving flood estimates are given below.

(1) Estimate mean annual flood (QBAR) for Flagham Brook from catchment characteristics

Catchment characteristics were derived for the Flagham Brook at grid ref SU017938. The area of the catchment is estimated to be 6.9 km^2. The remaining characteristics are listed in Appendix I. An estimate of the mean annual flood (QBAR) was derived for the Flagham Brook from three of these catchment characteristics as recommended in FSSR 6 which gives the following equation for the estimation of QBAR in catchments under 25 km^2.

$$QBAR = 0.00066\ AREA^{0.92}\ SAAR^{1.22}\ SOIL^{2.0}$$

For explanation of catchment characteristics and their derivation from maps reference should be made to the Flood Studies Report. QBAR for the Flagham Brook was also estimated by a slightly modified version of this equation as recommended in the recently published IH Report 124. In both cases QBAR was estimated to be 2.11 m^3s^{-1}.

With the availability of records relating to the nearby gauging stations on the River Thames and the Swill Brook it was possible to improve on this estimate of QBAR as follows.

(2) Estimate mean annual flood (QBAR) for Swill Brook and River Thames from flow records and catchment characteristics

The Flood Studies Report recommends that where 10-25 years of flow data is available QBAR can be estimated by finding the mean of the series of annual maximum flows. QBAR was estimated for both the Swill Brook at Oaksey (grid ref) and the Thames at Cricklade (grid ref) in this way, although the series of annual maxima for the Swill Brook runs to only 9 years and the reliability of estimate from this data is therefore more uncertain.

Catchment characteristics were derived for the catchments of the Swill Brook at Oaksey and the River Thames at Cricklade in and these are also listed in Appendix I. A second estimate of QBAR for each catchment was made from these characteristics. With both catchments greater than 25 km^2 in area QBAR was estimated from the full FSR equation as given below.

$$QBAR = 0.0213\ AREA^{0.94} STMFRQ^{0.27} S1085^{0.16} SOIL^{1.23} RSMD^{1.03} (1 + LAKE)^{-0.85}$$

The estimates of mean annual flood from each of these methods are given in table 4.1 where $QBAR_g$ is the estimate of QBAR from gauged flow records and $QBAR_{cc}$ is the estimate derived from catchment characteristics. Also presented in table 4.1 is the ratio between $QBAR_g$ and $QBAR_{cc}$ for each of the catchments.

Table 4.1 QBAR estimates for Swill Brook at Oaksey and River Thames and Cricklade

	$QBAR_g$ (m^3s^{-1})	$QBAR_{cc}$ (m^3s^{-1})	$QBAR_g/QBAR_{cc}$
Swill Brook	8.24	14.66	0.56
River Thames	3.05	5.46	0.56

The results presented in table 4.1 are of note in that although the record lengths of the two gauging stations differ considerably the $QBAR_g/QBAR_{cc}$ ratio derived for each is identical and can therefore be treated as sufficiently reliable for use in the adjustment of the QBAR estimate for the Flagham Brook.

(3) Adjust QBAR estimate for Flagham Brook using $QBAR_g/QBAR_{cc}$ ratio derived from Swill Brook and River Thames data

The estimate of QBAR derived for the Flagham Brook from catchment characteristics was adjusted by applying the ratio derived from Swill Brook and River Thames data. This method of improving flood estimates on ungauged catchments is as recommended in FSSR 6 which gives the following formula.

$$QBAR_{s,adj} = QBAR_{s,cc} X \frac{QBAR_{g,obs}}{QBAR_{g,cc}}$$

In this equation s is the site of interest, g is the gauged site, cc refers to catchment characteristics, obs to observed and adj to adjusted. The criteria for adjusting estimates of QBAR in this way require that the gauged and ungauged catchments are similar in the following respects:

(i) Less than 50 km between catchment centroids

(ii) Areas differ by less than a factor of 5

(iii) 'Comparable' catchment characteristics

(iv) Less than 20 % urbanised

The three catchments considered here satisfy all but one of these conditions, with both the Thames at Cricklade and the Swill Brook at Oaksey having catchment areas more than 5 times the size of the Flagham Brook catchment. However with the areal difference between the Swill Brook and the Flagham Brook approximately a factor of 7.5 and with the consistency in the $QBAR_g/QBAR_{cc}$ ratio estimated for the two gauged catchments the study was justified in using this method of adjustment.

The $QBAR_{cc}$ estimate of 2.11 m^3s^{-1} for the Flagham Brook was multiplied by the ratio 0.56 to give an adjusted estimate of QBAR of 1.18 m^3s^{-1}.

(4) Estimate flood peaks for a range of return periods

Flood peaks on the Flagham Brook for a range of return periods were estimated by multiplying the adjusted estimate of QBAR by a series of regional growth factors. The derivation of these growth factors is described in the FSR. The growth factors used in this study were those for FSR region 6 of the UK.

Estimated flood peaks for return periods ranging between 10 and 1000 years are presented in table 4.2.

***Table 4.2** Estimated flood peaks, Flagham Brook at SU017938*

Return Period - T (years)	Flood Peak - Q(T) (m^3s^{-1})
10	1.91
20	2.38
30	2.67
50	3.09
100	3.76
250	4.64
500	5.30
1000	6.09

(5) Estimation of flood volumes by rainfall runoff method

Estimates of flood volumes for the Flagham Brook were derived using the rainfall runoff method and catchment characteristics. The equations used are those given in FSSR 16. Before estimating flood volumes a comparison was made of the peak floods calculated by the rainfall-runoff method with those estimated by the statistical method and presented in table 4.2. The flood frequency curves defined by the two alternative sets of flood peak estimates are shown in figure 4.1. It is evident that the estimates derived by each of the two methods agree well.

Although the flood peaks calculated by each method differed only slightly those estimated by the statistical method were taken to be the best set of estimates given that they incorporate information provided from local data. It was therefore assumed that the best estimates of flood volume would be those that were derived from the set of flood profiles having peak floods equal to those derived from statistical method. Flood volumes were therefore estimated by the rainfall-runoff method for a set of flood peaks rather than a set of return periods. The return periods and volumes of floods estimated in this way are presented in table 4.3.

Table 4.3 Estimated flood volumes, Flagham Brook at SU017938

Return Period - T stats method (yrs)	Flood Peak - Q(T) (m^3s^{-1})	Return Period - T rainfall-runoff (yrs)	Flood volume (m^3)
50	3.09	38	225 672
100	3.76	105	271 212
250	4.64	310	329 862
500	5.30	600	374 712
1000	6.09	1120	429 912

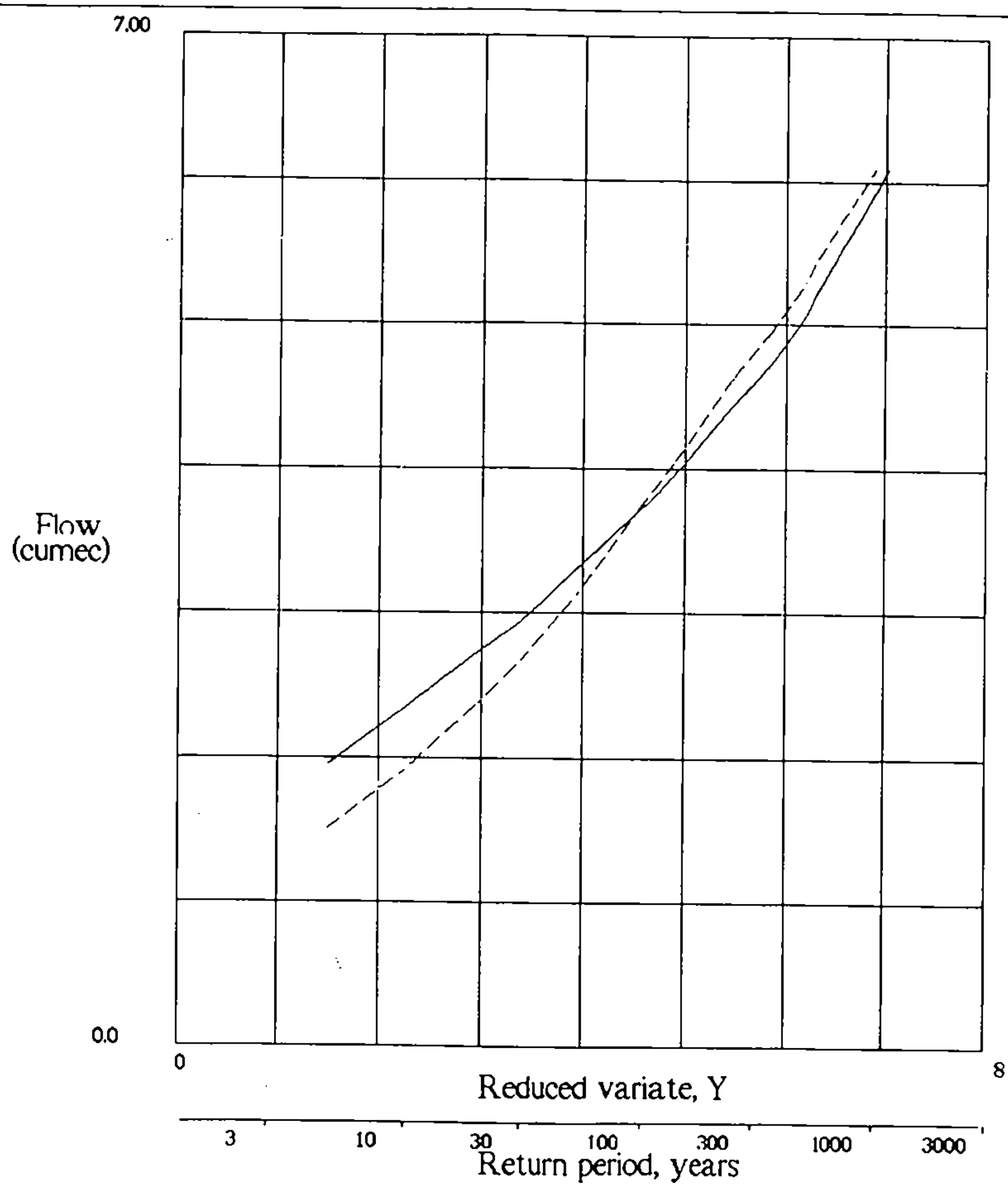
Flood volumes were calculated by multiplying runoff during the flood event by the Flagham Brook catchment area. This was added to a baseflow volume which is constant throughout the range of flood events. Details of the estimation of these floods as provided by MicroFSR are presented in Appendix II.

UK DESIGN FLOOD ESTIMATION
FLOOD FREQUENCY CURVE

Institute of Hydrology

Description: Flagham Brook at SU 017938
Printed on 19 8 1994 at 14:34

Run Reference: FLAG2



Key

— Rainfall runoff method
--- Statistical method

5 Discussion of Results

5.1 Summary of Results

The detailed results of the analysis of floodplain storage and flood estimation are contained in chapters 3 and 4. The more significant of these findings are repeated here for ease of reference with regard to the discussion presented below.

(1) Floodplain storage in the Flagham Brook catchment

(i) Estimated flood storage during March 1947 flood = 273 368 m^3

(ii) Estimated increase in potential floodplain storage 1956-79 = 370 000 m^3

(iii) Estimated decrease in potential flood storage under proposed development = 74 000 m^3

(2) Estimated bankfull discharge, Flagham Brook at grid ref SU017938 = 1.93 m^3s^{-1}

(3) Elevation of site access road above 1947 flood level, Flagham Brook at grid ref SU017938 = 0.17 m

(4) Estimates of flood peaks and flood volumes are presented in table 5.1.

Table 5.1 Estimates of flood peaks and flood volumes, Flagham Brook at grid ref SU017938

Return Period - T (yrs)	Flood Peak - Q(T) (m^3s^{-1})	Flood volume (m^3)
20	2.38	-
50	3.09	225 672
100	3.76	271 212
250	4.64	329 862
500	5.30	374 712
1000	6.09	429 912

It is worth remembering that the reliability of each of the estimates listed above is far from certain, given the sparsity of data from which they have been derived and the rather simple assumptions upon which several of them are based. However, they are none the less derived from a combination of techniques which include relatively robust methods of flood estimation on one hand and the incorporation of historical flood records and field measurements on the other. It is therefore reasonable to draw upon these result in arriving at a general set of conclusions whilst not placing too much significance on the absolute values of individual estimates.

The implications of these results are discussed below.

5.2 Estimate of Return Period of March 1947 Flood

The limits of the March 1947 flood define the floodplain boundary in the Thames catchment. The return period of this flood is estimated to be 56 years, although this figure is based on records at gauging stations in the lower, more populated reaches of the river. This estimate is not necessarily applicable to the flood in the headwaters of the Thames. By comparing estimates of flood volumes and floodplain storage during the 1947 flood it is possible to derive a catchment specific estimate of the return period of this event for the Flagham Brook.

The estimated floodplain storage in the Flagham Brook during the 1947 flood was estimated as 273 368 m^3. This is equivalent to a flood volume with return period of around 100 years (271 212 m^3) assuming that the majority of flood flow enters storage. If this assumption is relaxed so that only a given proportion of flow enters floodplain storage then it can be seen that the return period of the flood required to create this storage is in excess of 100 years. However, it can also be argued that some of the flood water stored in the Flagham Brook catchment represents spill-over from floods the catchments of the larger Swill Brook and River Thames. This would have the effect of reducing the amount of floodwater deriving from the Flagham Brook, possibly to a volume consistent with a 50 year flood (225 672 m^3).

It is clearly difficult to estimate precisely the return period of the 1947 flood in the Flagham Brook catchment. It is, however, reasonable to suggest that the flood return period lies somewhere in the range 50-100 years and that it may well represent a more extreme event than the 1 in 56 years standard employed for the Thames catchment as a whole.

5.3 Frequency of Flooding at Sandpool Farm

The bankfull flow in the Flagham Brook at Sandpool Farm was estimated to be 1.93 m^3s^{-1}. Assuming that this is a reasonable estimate a flood peak of something over 2.0 m^3s^{-1} is therefore likely to produce overbank flooding. This magnitude of flood corresponds to a return period of around 20 years, with Q(20) estimated to be 2.38 m^3s^{-1}. Given the existence of the raised access road adjacent to the Flagham Brook a flood of this magnitude would be likely only to cause flooding south of the stream.

The topographic survey estimated the access road to be approximately 0.5 m above the bankfull level along the southern edge of the site. It is extremely difficult to estimate the magnitude of flood which would be required to overtop the access road. If the bankfull level is assumed to be 0.5 m higher than at present on each side of the channel (ie level with the access road) then bankfull discharge increases to around 3.4 m^3s^{-1}. This discharge corresponds to a flood of approximately 100 years return period. The reality of the situation is that the channel is bounded by the access road only on the northern side. It therefore appears likely that a flood with return period well in excess of 100 years is required in order for flood water to overflow the site access road.

Elsewhere on the site, however, the access road does not appear to be raised significantly above the elevation of the surrounding ground surface. Towards the northern end of the site in particular the access road does not appear to represent the main barrier to flood water from the Flagham Brook. In this part of the site there are several relatively high ridges of deposits which could act as dykes to prevent the intrusion of flood waters. There are, however, discontinuities in these ridges and they cease altogether towards the south west corner of the site. At this point the access road takes over as a relatively elevated strip between the channel and the floodplain.

It is clearly extremely difficult to assess the frequency of flood which would be required to cause flooding at Sandpool Farm in its present condition. The topographic survey of the site revealed that the access road is slightly elevated above the 1947 flood level. However, it is not possible to state with any certainty whether this indicates that the site is no longer within the 1947 floodplain. What is evident, however, is that the construction of the access road is likely to have reduced flooding of Sandpool Farm by all but the more extreme flood events.

5.4 Impact of Gravel Extraction on Floodplain Storage

The estimated increase in potential flood storage due to gravel extraction in the Flagham Brook catchment between 1956 and 1979 is 370 000 m^3. When compared to the estimated flood volumes for the Flagham Brook it appears that this increase in available storage could not only accommodate the flood waters resulting from the 1947 flood but also of more extreme events up to the 500 year flood (with an estimated volume of 374 712 m^3).

It is evident that gravel extraction within the Flagham Brook catchment has had a beneficial effect in terms of providing additional flood storage. This additional storage could reasonably be expected to accommodate flooding on the scale of the 1947 flood, thereby reducing the impact of a repeat event on agriculture and other land use within the catchment.

5.5 Impact of Proposed Development on Floodplain Storage

The estimated reduction in potential floodplain storage due to landfill proposals at Sandpool Farm is 70 000 m^3. A development of this type would be of relatively little significance when taken in the context of changes to the floodplain as a whole since the 1947 flood, with only a 70 000 m^3 reduction in potential storage out of an overall increase of 370 000 m^3. This leaves 300 000 m^3 of flood storage available in floodplain that was not available in 1947.

Despite the proposed development at Sandpool Farm there appears to be sufficient additional storage throughout the Flagham Brook catchment to accommodate a repeat of the 1947 flood. The development is unlikely to significantly increase flood risk elsewhere in the catchment.

6 Conclusions

Sandpool Farm is bordered along its southern perimeter by the Flagham Brook, a tributary of the River Thames. During the 1947 flood much of the site was under water and is therefore classified as floodplain. The proposed development of the site involves the infilling of a series of gravel pits, some of which are located within the floodplain. This study has investigated the extent to which this development may be detrimental to floodplain storage throughout the Flagham Brook catchment as a whole.

The March 1947 flood in the Flagham Brook catchment has an estimated return period of between 50 and 100 years. Smaller floods, of around 20 years return period, would have probably resulted in minor flooding of the site as it was prior to gravel extraction whilst lesser floods than this may have been contained within the stream channel.

Since the 1947 flood Sandpool Farm has been worked for gravel and a site access road built up alongside the Flagham Brook. This road appears to be elevated above the flood level associated with the 1947. It is likely that the frequency of flooding at Sandpool Farm has fallen since the construction of the access road, with flood waters constrained to overflow only on the southern side of the channel. It is extremely difficult to estimate the magnitude of the flood which would cause flooding of Sandpool Farm in its present condition although it is reasonable to say that an extreme event similar to the 1947 flood would probably result in some flooding, if not from water overtopping the access road then from flow through weak points in the road or overspilling from adjacent land to the north and east. It has therefore been assumed that the site remains within the floodplain defined by the 1947 flood on the basis that this can not be ruled out.

Extensive gravel extraction in the Flagham Brook catchment has resulted in a series of pits, some of which are now artificial lakes and others which remain dry. These pits represent an estimated increase in potential flood storage of 370 000 m^3, considerably more than the estimated volume of floodplain storage associated with the 1947 flood. A repeat of the 1947 flood, with an estimated volume of approximately 275 000 m^3, would be likely to have a significantly reduced impact on surface land use within the Flagham Brook catchment with a large proportion of flood water entering storage in gravel pits excavated within the boundaries of the floodplain.

The infilling of gravel pits under the proposed development of Sandpool Farm would result in an estimated reduction in potential floodplain storage of 70 000 m^3. The development would therefore be of relatively little significance when taken in the context of changes to the floodplain as a whole since the 1947 flood, with only a 70 000 m^3 reduction in potential storage out of an overall increase of 370 000 m^3. The remaining additional storage in the Flagham Brook catchment would still be sufficient accommodate a repeat of the 1947 flood.

The proposed development at Sandpool Farm is not likely to increase flood risk in the Flagham Brook catchment. Given the availability of gravel pits for flood storage elsewhere in the catchment a repeat of the 1947 flood would be likely to cause flooding over a significantly smaller area of the catchment than was the case in 1947.

Appendix I - Catchment Characteristics

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UK DESIGN FLOOD ESTIMATION

Description : FLAGHAM BROOK AT DOWNSTREAM END OF SITE
Printed on 17 8 1994 at 13:19 Run Reference : FLAG2

Catchment Characteristics

Area	:	6.90 sq.km.	Soil 1	:	0.000
Length	:	4.92 km.	Soil 2	:	0.050
Slope	:	1.22 m./km.	Soil 3	:	0.780
SAAR	:	780 mm.	Soil 4	:	0.170
M5-2D	:	49.5 mm.	Soil 5	:	0.000
M5-25D	:	-1.0 % of SAAR			
Jenkinson's r	:	0.40			
Urban	:	0.00			
Smdbar	:	9.7 mm.	RSMD	:	29.367 mm.
Stmfrq	:	0.87 junctions/sq.km.			
Lake	:	0.01			
EMP 2 hour	:	-1.00 mm.	BFI	:	-1.00
EMP 24 hour	:	-1.00 mm.	LAG	:	-1.00 hr.
			Hydrometric Area No.	:	39

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UK DESIGN FLOOD ESTIMATION

Description : Swill Brook at Oaksey
Printed on 17 8 1994 at 15:26 Run Reference : SWIL2

Catchment Characteristics

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Area	:	53.30 sq.km.	Soil 1	:	0.161
Length	:	8.90 km.	Soil 2	:	0.000
Slope	:	2.02 m./km.	Soil 3	:	0.466
SAAR	:	785 mm.	Soil 4	:	0.373
M5-2D	:	50.5 mm.	Soil 5	:	0.000
M5-25D	:	-1.0 % of SAAR			
Jenkinson's r	:	0.40			
Urban	:	0.00			
Smdbar	:	9.7 mm.	RSMD	:	29.259 mm.
Stmfrq	:	0.39 junctions/sq.km.			
Lake	:	0.00			
EMP 2 hour	:	-1.00 mm.	BFI	:	-1.00
EMP 24 hour	:	-1.00 mm.	LAG	:	-1.00 hr.
			Hydrometric Area No.	:	39

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UK DESIGN FLOOD ESTIMATION

Description : Thames at Cricklade
Printed on 29 7 1994 at 11:03 Run Reference : CRICK

Catchment Characteristics

Area	: 185.00 sq.km.		Soil 1	: 0.329
Length	: 16.03 km.		Soil 2	: 0.110
Slope	: 1.21 m./km.		Soil 3	: 0.295
SAAR	: 770 mm.		Soil 4	: 0.266
M5-2D	: 52.0 mm.		Soil 5	: 0.000
M5-25D	: -1.0 % of SAAR			
Jenkinson's r	: 0.39			
Urban	: 0.00			
Smdbar	: 9.7 mm.		RSMD	: 29.346 mm.
Stmfrq	: 0.57 junctions/sq.km.			
Lake	: 0.005			
EMP 2 hour	: -1.00 mm.		BFI	: -1.00
EMP 24 hour	: -1.00 mm.		LAG	: -1.00 hr.
			Hydrometric Area No.	: 39

Appendix II - Flood Estimates by Rainfall Runoff Method

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                                                 Institute of Hydrology
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UK DESIGN FLOOD ESTIMATION

Description : FLAGHAM BROOK AT DOWNSTREAM END OF SITE
Printed on 17  8 1994 at 14:00                  Run Reference : FLAG2
-------------------------------------------------------------------------
Summary of estimate using Flood Studies Report rainfall-runoff method
*************************************************************************
Using rainfall statistics for England and Wales
Estimation of T-year flood
=========================

Unit hydrograph time to peak      :    11.49  hours
Data interval                     :     2.00  hours

Design storm duration             :    22.00  hours
Return period for design flood    :    38.00  years
requires rain return period       :    62.40  years
M5-22.00 hour/M5-2day             :     0.878 mm.
M5-22.00 hour                     :    43.48  mm.
M   62.4/M5                       :     1.69
M   62.4-22.00 hour (point)       :    73.49  mm.
ARF                               :     0.98
M   62.4-22.00 hour (area)        :    71.71  mm.
Design storm depth                :    71.71  mm.

Design CWI                        :   114.09

Standard Percentage Runoff        :    38.35
Percentage runoff                 :    40.68  %


Response hydrograph peak          :     2.95  cumec  (Max ordinate)
                                  :     2.95  cumec  (Interpolated)
Baseflow                          :     0.14  cumec
Hydrograph peak                   :     3.08  cumec  (Max ordinate)
                                  :     3.09  cumec  (Interpolated)

Options
=======
Unit hydrograph option              :   1 - FSR-Triangle
Tp option                           :   1 - FSSR 16 Tp equation
Rainfall option                     :   1 - Statistical
Rainfall duration option            :   1 - Calculated from Tp
Rainfall profile option             :   4 - 75% winter profile
Flow/Rainfall return periods        :   1 - Standard
PR option                           :   1 - FSSR 16 equation
SPR option                          :   2 - from SOIL
Baseflow option                     :   1 - FSSR 16 equation
CWI option                          :   1 - Design standard
*************************************************************************
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Institute of Hydrology

UK DESIGN FLOOD ESTIMATION

Description : FLAGHAM BROOK AT DOWNSTREAM END OF SITE
Printed on 17 8 1994 at 14:04 Run Reference : FLAG2

Summary of estimate using Flood Studies Report rainfall-runoff method

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Using rainfall statistics for England and Wales
Estimation of T-year flood

==========================

Unit hydrograph time to peak	:	11.49	hours	
Data interval	:	2.00	hours	
Design storm duration	:	22.00	hours	
Return period for design flood	:	105.00	years	
requires rain return period	:	145.33	years	
M5-22.00 hour/M5-2day	:	0.878	mm.	
M5-22.00 hour	:	43.48	mm.	
M 145.3/M5	:	2.00		
M 145.3-22.00 hour (point)	:	87.10	mm.	
ARF	:	0.98		
M 145.3-22.00 hour (area)	:	84.99	mm.	
Design storm depth	:	84.99	mm.	
Design CWI	:	114.09		
Standard Percentage Runoff	:	38.35		
Percentage runoff	:	42.09	%	
Response hydrograph peak	:	3.61	cumec	(Max ordinate)
	:	3.62	cumec	(Interpolated)
Baseflow	:	0.14	cumec	
Hydrograph peak	:	3.75	cumec	(Max ordinate)
	:	3.76	cumec	(Interpolated)

Options

=======

Unit hydrograph option	:	1 - FSR-Triangle
Tp option	:	1 - FSSR 16 Tp equation
Rainfall option	:	1 - Statistical
Rainfall duration option	:	1 - Calculated from Tp
Rainfall profile option	:	4 - 75% winter profile
Flow/Rainfall return periods	:	1 - Standard
PR option	:	1 - FSSR 16 equation
SPR option	:	2 - from SOIL
Baseflow option	:	1 - FSSR 16 equation
CWI option	:	1 - Design standard

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                                               Institute of Hydrology
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UK DESIGN FLOOD ESTIMATION

Description : FLAGHAM BROOK AT DOWNSTREAM END OF SITE
Printed on 17  8 1994 at 14:10                   Run Reference : FLAG2
-------------------------------------------------------------------------
Summary of estimate using Flood Studies Report rainfall-runoff method
*************************************************************************
Using rainfall statistics for England and Wales
Estimation of T-year flood
=========================

Unit hydrograph time to peak    :    11.49  hours
Data interval                   :     2.00  hours

Design storm duration           :    22.00  hours
Return period for design flood  :   310.00  years
requires rain return period     :   352.80  years
M5-22.00 hour/M5-2day           :    0.878  mm.
M5-22.00 hour                   :    43.48  mm.
M  352.8/M5                     :     2.39
M  352.8-22.00 hour (point)     :   104.03  mm.
ARF                             :     0.98
M  352.8-22.00 hour (area)      :   101.52  mm.
Design storm depth              :   101.52  mm.

Design CWI                      :   114.09

Standard Percentage Runoff      :    38.35
Percentage runoff               :    43.67  %


Response hydrograph peak        :     4.48  cumec  (Max ordinate)
                                :     4.49  cumec  (Interpolated)
Baseflow                        :     0.14  cumec
Hydrograph peak                 :     4.62  cumec  (Max ordinate)
                                :     4.63  cumec  (Interpolated)

Options
=======
Unit hydrograph option              :   1 - FSR-Triangle
Tp option                           :   1 - FSSR 16 Tp equation
Rainfall option                     :   1 - Statistical
Rainfall duration option            :   1 - Calculated from Tp
Rainfall profile option             :   4 - 75% winter profile
Flow/Rainfall return periods        :   1 - Standard
PR option                           :   1 - FSSR 16 equation
SPR option                          :   2 - from SOIL
Baseflow option                     :   1 - FSSR 16 equation
CWI option                          :   1 - Design standard
*************************************************************************
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Institute of Hydrology

UK DESIGN FLOOD ESTIMATION

Description : FLAGHAM BROOK AT DOWNSTREAM END OF SITE
Printed on 17 8 1994 at 14:24 Run Reference : FLAG2

Summary of estimate using Flood Studies Report rainfall-runoff method

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Using rainfall statistics for England and Wales
Estimation of T-year flood
==========================

Unit hydrograph time to peak	:	11.49	hours	
Data interval	:	2.00	hours	
Design storm duration	:	22.00	hours	
Return period for design flood	:	600.00	years	
requires rain return period	:	616.00	years	
M5-22.00 hour/M5-2day	:	0.878	mm.	
M5-22.00 hour	:	43.48	mm.	
M 616.0/M5	:	2.67		
M 616.0-22.00 hour (point)	:	116.31	mm.	
ARF	:	0.98		
M 616.0-22.00 hour (area)	:	113.50	mm.	
Design storm depth	:	113.50	mm.	
Design CWI	:	114.09		
Standard Percentage Runoff	:	38.35		
Percentage runoff	:	44.73	%	
Response hydrograph peak	:	5.13	cumec	(Max ordinate)
	:	5.14	cumec	(Interpolated)
Baseflow	:	0.14	cumec	
Hydrograph peak	:	5.27	cumec	(Max ordinate)
	:	5.28	cumec	(Interpolated)

Options
=======

Unit hydrograph option	:	1 - FSR-Triangle
Tp option	:	1 - FSSR 16 Tp equation
Rainfall option	:	1 - Statistical
Rainfall duration option	:	1 - Calculated from Tp
Rainfall profile option	:	4 - 75% winter profile
Flow/Rainfall return periods	:	1 - Standard
PR option	:	1 - FSSR 16 equation
SPR option	:	2 - from SOIL
Baseflow option	:	1 - FSSR 16 equation
CWI option	:	1 - Design standard

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UK DESIGN FLOOD ESTIMATION

Description : FLAGHAM BROOK AT DOWNSTREAM END OF SITE
Printed on 17 8 1994 at 14:26 Run Reference : FLAG2

Summary of estimate using Flood Studies Report rainfall-runoff method
****
Using rainfall statistics for England and Wales
Estimation of T-year flood
==========================

Unit hydrograph time to peak	:	11.49	hours
Data interval	:	2.00	hours
Design storm duration	:	22.00	hours
Return period for design flood	:	1120.00	years
requires rain return period	:	1120.00	years
M5-22.00 hour/M5-2day	:	0.878	mm.
M5-22.00 hour	:	43.48	mm.
M 1120.0/M5	:	3.01	
M 1120.0-22.00 hour (point)	:	131.08	mm.
ARF	:	0.98	
M 1120.0-22.00 hour (area)	:	127.91	mm.
Design storm depth	:	127.91	mm.
Design CWI	:	114.09	
Standard Percentage Runoff	:	38.35	
Percentage runoff	:	45.95	%

Response hydrograph peak	:	5.94	cumec	(Max ordinate)
	:	5.95	cumec	(Interpolated)
Baseflow	:	0.14	cumec	
Hydrograph peak	:	6.08	cumec	(Max ordinate)
	:	6.09	cumec	(Interpolated)

Options
=======

Unit hydrograph option	:	1 - FSR-Triangle
Tp option	:	1 - FSSR 16 Tp equation
Rainfall option	:	1 - Statistical
Rainfall duration option	:	1 - Calculated from Tp
Rainfall profile option	:	4 - 75% winter profile
Flow/Rainfall return periods	:	1 - Standard
PR option	:	1 - FSSR 16 equation
SPR option	:	2 - from SOIL
Baseflow option	:	1 - FSSR 16 equation
CWI option	:	1 - Design standard

****
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