INSTITUTE of HYDROLOGY

RUFFORD PARK FLOOD STUDY:

a hydrological assessment

Report to Elliott and Brown Consulting Engineers
and Browne Jacobson Solicitors

Dr Duncan W Reed
Institute of Hydrology, Wallingford, OX10 8BB

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1 INTRODUCTION

1.1 Context

A damaging flood incident occurred at Maylodge Drive, Rufford Park in Nottinghamshire on 1/2 June 1983 which became the subject of a legal dispute between a group of property insurers, Nottinghamshire County Council and British Coal. Nottinghamshire County Council manage land and a reservoir immediately downstream of the flooded site. British Coal carry out deep mining in the area which leads to subsidence.

The Institute of Hydrology (IH) was approached by Elliott & Brown Consulting Engineers on behalf of the property insurers' solicitor, Browne Jacobson. Initially, IH was asked only to assess the rarity of the flood-producing rainfall. This led to two short studies in 1988. Following legal developments in the case, Elliott & Brown approached IH for further advice on 31 October 1989. A comprehensive hydrological assessment began in mid-November.

1.2 Status of report

This report presents the preliminary results of the main study. The analysis supersedes that presented in two earlier IH reports to Elliott & Brown. The conclusions are broadly in line with the first report (Stewart, 1988a). However, in the second report (Stewart, 1988b) an assessment was made of the rarity of the combination of storm depth and antecedent wetness experienced on 1 June 1983, based on the assumption of independence and without reference to a rainfall-runoff model of flood response. That shortcut to flood rarity assessment has shortcomings and has not been followed in the present study.

1.3 Scope of study

The study has two objectives. The primary objective is to assess the rarities of the flood runoff events that occurred following storms on 22 April and 1 June 1983. The secondary objective is open-ended; this is to comment on hydrological aspects of the dispute.

1.4 General approach

Assessing the rarity of a given flood peak poses a statistical problem similar to, but not identical to, that of assessing the magnitude of a flood of a given rarity. Several techniques are applicable to either problem if extensive river flow and rainfall data are available at, or near to, the subject site. However, where no formal flow data are available, it is necessary to estimate the flood potential by reference to the physical characteristics of the catchment. Standard methods are available to do this (NERC, 1975; Institute of Hydrology, 1985) but are known to be inherently uncertain. Consequently it is recommended that reference is also made to such additional information as can be found (Institute of Hydrology, 1983; Reed, 1987). The additional information can take many forms. More detailed soil maps and historical flood information are two examples of additional data that may be relevant.

1.5 Hydraulic aspects

Local features of a drainage system will influence the way in which a given flood runoff event leads to inundation and damage to property. The relationship between flow rates and water levels is largely a matter of site conditions and hydraulics; relevant factors will be the design and maintenance of channels, culverts, bridge waterways and embankments, and also the design, maintenance and operation of variable control devices, such as sluice gates. In this instance it appears that differential subsidence due to mining may have been an important factor affecting the river flow at which unwanted inundation begins and the severity and extent of subsequent damage to property.

These hydraulic considerations are largely outwith the present study. Reference to land levels is only made to establish the possible significance of groundwater contributions to the flooding incidents at Maylodge Drive. It is for others to determine the effect that subsidence may have had on diminishing the level of protection against inundation provided by the various embankments at Rufford Park.

1.6 Why the interest in flood rarity?

Here the concern is to assess the rarity of the peak flood runoff from the catchment. If the hydrological assessment indicates that flood runoff on 1/2 June 1983 was exceptionally rare, there might be ground to argue that <u>some degree of damage</u> was inevitable, that a particular flood protection structure was not designed to withstand such an extreme event, and/or that such an occurrence could not reasonably have been expected. On the other hand, if the assessment shows that the peak flow on 1/2 June 1983 was not exceptionally rare, such arguments may be found wanting.

While the rarity of the peak flood runoff may well be relevant to the case, the qualification "some degree of damage" may also be important. Even if the hydrological conditions giving rise to the flooding on 1/2 June 1983 were shown to be exceptionally rare, the actions or inactions of the Defendants may nevertheless have strongly influenced the <u>extent</u> of flooding experienced, and the <u>extent</u> of consequential damage to property.

1.7 Flood protection design standards

Such arguments will depend partly on what is deemed to be exceptionally rare. This is also outwith the hydrology. However, it is noted that nominal designs standards adopted in land drainage design on main rivers are typically in the 30 to 50-year event range for rural areas and the 50 to 150-year event range for urban areas. The Severn-Trent Region of the National Rivers Authority might be a source of more specific guidance; however, neither the Rainworth Water nor the Gallow Hole Dyke is an adopted "main river". It is believed that any responsibility for prescribing drainage standards at Rufford Park therefore rests with the Newark and Sherwood District Council.

It may be relevant to distinguish drainage "levels of service" expected generally from those expected when specific works have been undertaken to reduce the frequency of flooding. It might be argued that, through mining subsidence, British Coal have imposed an additional flood risk. It is well known (eg. Royal Society, 1983) that judgements of acceptable risk are strongly influenced by whether exposure to the hazard is chosen or imposed.

1.8 Structure of report

Study catchments are defined and their characteristics reviewed (Section 2). The flood-producing storms are considered in Sections 3 and 4 and rarity assessments made. Standard procedures for estimating design floods are applied in Section 5 to provide a yardstick against which to measure the rarity of the 22 April 1983 and 1/2 June 1983 floods, which are simulated in Sections 6 and 7. Finally, conclusions are summarized in Section 8, and a reminder given that the hydrological assessment provides only one input to resolving why the damaging floods occurred.

2 CATCHMENT CHARACTERISTICS

2.1 Catchments of interest

In many flood assessments it is sufficient to consider only one catchment, ie. all land that drains to the subject site. However, the circumstances at Rufford Park are unusual and it is advisable to consider several catchments. The important ones are illustrated in Fig. 2.1, which is an agreed plan.

First, it is appropriate to consider the Rainworth Water catchment to Rufford Park. This is defined here as the topographic catchment of the Rainworth Water to its confluence with the Gallow Hole Dyke. The catchment, coded RW, extends from Cox Moor (near Kirby in Ashfield) in the southwest to Rufford Park in the northeast, with an area of 59.0 km^2. At first sight this appears to be the only area relevant to flooding at Maylodge Drive. However, because of the proximity of Maylodge Drive to the Rainworth Water/Gallow Hole Dyke confluence, it is appropriate to consider also the combined Rainworth Water and Gallow Hole Dyke catchment to their confluence at Rufford Park, referred to as the RW+GHD catchment (74.2 km^2).

For special reasons discussed below, it is also relevant to consider the Gallow Hole Dyke (GHD) catchment alone.

Because of the presence of an impounding reservoir (Rufford Lake) just downstream of the Rainworth Water confluence with the Gallow Hole Dyke, it is relevant to consider the entire catchment draining to that site also. Flood assessments there may be relevant to those interpreting the hydraulic performance of the discharge control structures at Rufford Lake. This catchment is referred to as the Rufford Lake (RL) catchment (75.7 km^2).

Finally, for completeness, that part of the Rainworth Water catchment that drains through the "L" Lake at Rainworth town has also distinguished. This is referred to as the Upper Rainworth Water (URW) catchment.

2.2 Standard characteristics

Standard characteristics (NERC, 1975) of these five catchments are given in Table 2.1. The Flood Studies Report (FSR) nomenclature is defined in Appendix 1.

Values of stream frequency, STMFRQ, were derived from 1st Series 1:25000 maps (as recommended in the FSR). The urban fractions (URBAN) were derived by reference to a 1:50000 map published in 1987. Neither the extent nor rate of urbanization of any of the five catchments is sufficient to make the flood rarity assessments significantly dependent on the date of survey. Although 36% of the RW catchment drains through the "L" Lake at Rainworth, the lake area is too small to qualify as a significant lake according to the FSR standard.

TABLE 2.1 Catchment characteristics

Characteristic		URW	RW	GHD	RW+GHD	RL
AREA	km^2	21.3	59.0	15.2	74.2	75.7
SAAR	mm	720	691	640	681	680
M5-2D	mm	56.0	55.5	54.0	55.0	55.0
r	-	.394	.400	.408	.402	.402
SMDBAR	mm	10.0	10.1	10.1	10.1	10.1
MSL	km	4.8	15.5	5.9	15.5	16.5
S1085	m/km	6.5	5.2	3.8	5.2	5.0
STMFRQ	junc'ns/km^2	.09	.14	.59	.23	.23
SOIL1	-	1.00	.92	.00	.73	.73
SOIL4	-	.00	.08	1.00	.27	.27
URBAN	-	.09	.07	.01	.06	.055
LAKE	-	.00	.00	.00	.00	.00

Comment is warranted on the values shown for M5-2D, which have been adjusted by direct analysis of local rainfall data.

2.3 Adjustment of M5-2D values

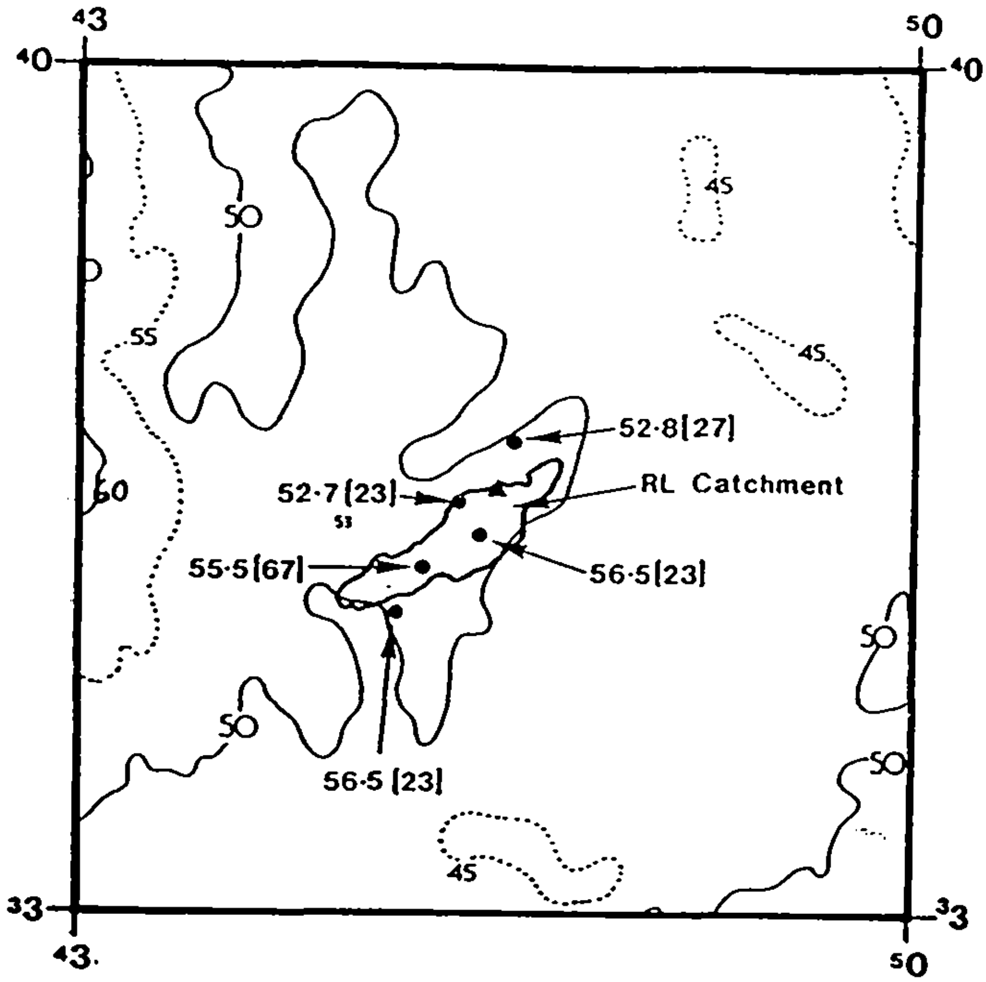
M5-2D denotes the 2-day rainfall depth of 5-year return period.* A value of M5-2D rainfall is normally read by superimposing the catchment boundary drawn at 1:625000 scale on to a standard map given in Volume V of the FSR. However, long-term research at IH on rainfall frequency estimation has demonstrated that some rainfall statistics given in the FSR are over-generalized (eg. Dales and Reed, 1989). Estimates of M5-2D were therefore verified by direct analysis of daily rainfall records for gauges in or near the RL catchment. These gauges are shown in Fig. 2.2. M5-2D values were derived as the geometric mean of the upper half of annual maximum 2-day rainfall depths, ie. by the method used in Volume II of the FSR. The direct analysis checks for any local error in the M5-2D map and exploits the longer periods of record now available.

From Fig. 2.2 it is seen that the standard map underestimates the M5-2D rainfall statistic. The catchment values adopted for M5-2D are those shown in Table 2.1.

* Return periods quoted in this report are those measured on the annual maximum scale, in which return period represents the average interval between years containing an exceedance rather than between all exceedances. Where return periods on the "peaks over threshold" scale are required, these are termed mean recurrence intervals between exceedances.

Fig. 2.2 Map and gauged values of M5-2D rainfall statistic

[numbers in parentheses denote number of years of record used in calculation of gauged values]



2.4 Geology

In the standard FSR flood estimation methods, the solid and drift geologies have an influence only in so much as they affect the Winter Rainfall Acceptance Potential (WRAP) classification (see Appendix 1). However, partly because of the limited spatial resolution of the 1:625000 WRAP map, it is relevant to examine more detailed maps where these are available. The catchments lie on one-inch "solid and drift" maps nos. 112 and 113.

The dominant geology on the RW catchment is Bunter Sandstone, now generally termed Sherwood Sandstone. On the eastern margins of the catchment the Green Beds and Keuper Waterstones appear. Drift deposits are not extensive, being limited to small patches of Glacial Sands & Gravels, Boulder Clay and Head.

In contrast, most of the GHD catchment lies on the Keuper Waterstones and Green Beds. Some superficial clays are marked, particularly in the west of the catchment.

In the RW catchment, alluvium is limited to the main course of the Rainworth Water. In the GHD catchment, alluvial deposits are shown on both the northern and southern branches of the Gallow Hole Dyke.

2.5 Hydrogeology

The Sherwood Sandstone is a major aquifer of regional importance. Extensive abstractions for public water supply are made at sites within and close to the topographic catchment. These abstractions have a strong local influence on groundwater levels. In most cases, because the rates of abstraction are relatively uniform, a characteristic spatial profile of groundwater levels is maintained. The aquifer responds relatively slowly to effective rainfall, the main period of recharge generally being in late winter and spring (January to April).

A 1:100000 hydrogeological map is available (Institute of Geological Sciences, 1981) and shows approximate groundwater contours derived from borehole data for March 1978. Believed to be typical, this snapshot confirms that the groundwater catchment is markedly different from the topographic catchment. At times when the Rainworth Water is in hydraulic continuity with the aquifer, the contibuting groundwater catchment extends principally to the west. While it is always less extensive than the topographic catchment, the variable nature of the groundwater catchment is one factor which accounts for the unusual flow regimes of the Rainworth Water. In particular, at times of high groundwater levels, levels in the Sherwood Sandstone aquifer undoubtedly influence groundwater levels at Maylodge Drive.

Neighbouring rivers in the region, such as the Poulter, Meden, Maun, (and the Trent), have their headwaters on less permeable geology. Where these other rivers pass over the

Sherwood Sandstone outcrop, they are generally held to be influent (influent to the aquifer), with some river water passing to the aquifer. However, above its confluence with the Gallow Hole Dyke, the Rainworth Water catchment lies almost exclusively on the highly permeable Sherwood Sandstone.

In these circumstances it is likely that much of the flow in the Rainworth Water is contributed by riparian areas close to the watercourse. There appears to be no evidence to suggest that the urbanized area at the head of the catchment is well connected to the river system. However, it appears likely that urban areas close to the Rainworth Water (ie. at Rainworth and in the western fringes of Bilsthorpe) will contribute significantly to the flood response of the RW catchment. Analogously, while there appears to be no evidence that drainage from Clipstone Forest is well connected to the river system, it appears likely that mineral extraction activities may contribute some waters. There is some evidence for this in the typical blackness of the river water.

A combination of factors suggests that flows in the Rainworth Water are partly supported by groundwater. The 1st Series 1:25000 map shows a number of springs close to Rufford Park. Eye-witness evidence of the June 1/2 1983 flooding incident refers to the difficulties that the Fire Authority had in pumping the Maylodge Drive residences and gardens dry (Statement of Mrs Storer). This again suggests that "natural" groundwater discharges in the area contribute seasonally to Rainworth Water flows when regional groundwater levels are high. Long-term well records, for example at Bilsthorpe, indicate that groundwater levels were higher in 1982 and 1983 than they had been since 1977.

Very little of the Sherwood Sandstone outcrops in the Gallow Hole Dyke catchment. There the aquifer is confined by the much less permeable Green Beds and Keuper Waterstomes. However, the cone of depression, produced by groundwater abstraction for public water supply close to Ompton, probably leads to some reductions in low flows in the adjacent course of the Gallow Hole Dyke. A check revealed that regional and temporal patterns of groundwater abstraction in 1983 were not unusual.

2.6 Soils

The 1:625000 WRAP map broadly distinguishes the generally very permeable soils associated with the Sherwood Sandstone of the Rainworth Water catchment from the much less permeable soils overlying the Green Beds and Keuper Waterstones of the GHD catchment. Additional detail is now provided by universal 1:250000 soil maps (Soil Survey of England and Wales, 1983). Their interpretation in terms of Winter Rainfall Acceptance Potential requires skill, standard categorizations not yet being available. However they are useful to the hydrologist because they provide greater spatial detail. This is not too informative for the

59.0 km^2 RW catchment which is shown to be dominated by two soil associations: the Cuckney and Delamere, both of them highly permeable. However, the smaller 15.2 km^2 Gallow Hole Dyke catchment has more contrasting soils, the Hodnet association being rather more permeable than the surface water gleys of the Brockhurst associations.

An altogether more detailed mapping of soils is provided by 1:25000 maps, where available. Few districts have been mapped at this scale but the SK66 grid square "Ollerton" is one of them (Robson and George, 1971). The map and associated monograph provide exceptionally detailed information about the soils of both the Gallow Hole Dyke catchment and much of the lower part of the Rainworth Water catchment.

In addition to the greater detail, two specific mappings from the 1:25000 map are of special interest. First, the 1:250000 soil map and maps derived therefrom - such as the 1:100000 groundwater vulnerability map (Soil Survey and Land Research Centre, 1987) - show a riparian area immediately north of Bilsthorpe and east of the Rainworth Water as possessing typical stagnogley soils. This contradicts the 1:25000 map, which shows the same typical brown sands that are characteristic of much of the Rainworth Water catchment. An enquiry to the Soil Survey met the response that the more detailed 1:25000 map is correct.

The second feature of note is that the 1:25000 map clearly indicates that the soils at, and immediately upstream of, Rufford Park are of the Compton series. The monograph (Robson and George, 1971) defines the parent material to be "clayey alluvium and hill-wash mainly from Keuper Marl or Waterstones". This provides geomorphological evidence that, the Gallow Hole Dyke has been as influential as (or more influential than) the Rainworth Water in the historical flooding of land at Rufford Park. Both the name "dyke", and the presence on the 1st Series 1:25000 of embankments along the southern bank of the Gallow Hole Dyke add weight to the suggestion that, in its natural state, the Rufford Park area was as sensitive to inundation by floods from the Gallow Hole Dyke catchment as from the Rainworth Water catchment.

2.7 Land use

HISTORY

A feel for the history of the area can be gained from Wild's historical description of the Rainworth area (Wild, 1972). It is apparent that man has influenced flows in the Rainworth Water from at least the early 19th Century. Around the time of Waterloo, a number of reservoirs were constructed upstream of Rainworth to improve cropping through irrigation. Some of these reservoirs remain. In the lower course of the Rainworth Water close to Rufford Park, there is some evidence that the watercourse was diverted to permit irrigation of the most fertile flood plain land.

Ultimately, this diversion has served to permit development of the flood plain at Rufford Park for housing.

The 20th Century has seen man's influence in the increased exploitation of groundwater for public water supply. There has been disruption to drainage by mining, most notably where subsidence has led to differential settlement of sections of watercourses and fissuring.

MINERAL EXTRACTION

Two major collieries lie in the study area: Bilsthorpe Colliery (mainly draining to the Gallow Hole Dyke catchment) and Rufford Colliery, adjacent to the Rainworth Water. The quantities of water abstracted from groundwater for coal-washing and discharged to the Gallow Hole Dyke and Rainworth Water are of no direct consequence to flood flows. It is presumed that any pumped drainage of minewater is likewise insignificant in terms of flood flows in the receiving watercourses.

A major Coal Stocking Site appears to extend over the natural course of the Rainworth Water. I am not aware of any suggestion that this situation, or those of various wastewater settling lagoons, had an appreciable effect on flood flows in the Rainworth Water in the 1983 events. However, given that new settling lagoons were planned at the time (Discharge Consent No. WQ/7/1889, dated 14 September 1982), it would be helpful to have confirmation that no untoward incidents occurred at these sites which might have led to a sudden increase in flows in the Rainworth Water in the 1/2 June 1983 event.

FORESTRY

The Rainworth Water catchment lies in what was once a natural deciduous woodland: Sherwood Forest. A substantial part of the catchment continues this tradition with conifer plantations at Thieves Wood and Clipstone Forest (see Fig. 2.3). Given the very permeable soils, this land use is not thought to aggravate flood risk. (On less permeable soils pre-afforestation drainage may give rise to a temporary increase in flood risk.)

A major tourist attraction, the Sherwood Forest Country Park is now sited in the Clipstone Forest part of the catchment. However, this development post-dates the flooding incidents under investigation.

GROUNDWATER ABSTRACTION

There are a number of major groundwater pumping stations in or close to the topographic catchment. These abstractions for public water supply are significant insomuch as they lower the natural groundwater table for prolonged periods. However, in Spring 1983, groundwater levels in the Sherwood Sandstone were already relatively high. Thus the particular

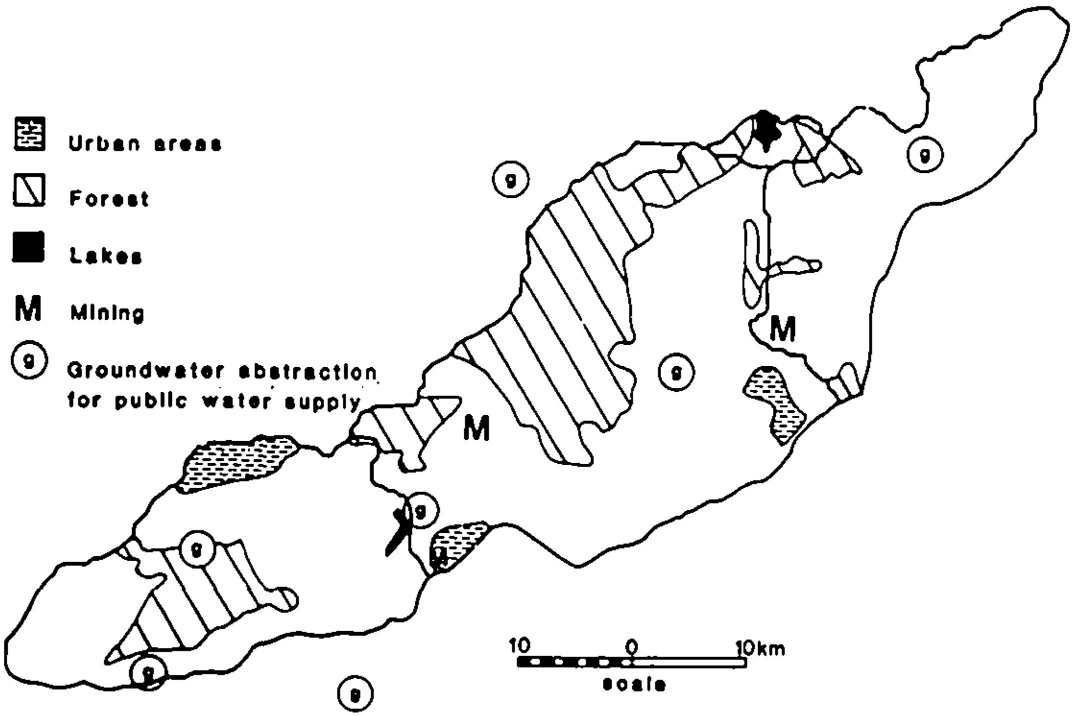

Urban areas
Forest
Lakes
M Mining
g Groundwater abstraction for public water supply
M
M
10 0 10km
scale

Fig. 2.3 Land use

DIAGRAM IN PREPARATION

abstractions being made at the time of the flooding incidents are not thought to be of significance.

A PECULIARITY

During the second half of the 1970s, the Rainworth Water came under particular scrutiny for its lack of water. This coincided with a period where regional groundwater levels in the Sherwood Sandstone were declining persistently, primarily in response to low winter rainfall but possibly also in response to over-abstraction. Particular difficulties were, and to some extent still are, experienced in the public water supply abstraction at Rufford Pumping Station. Sited close to the Rainworth Water (see Fig. 2.1), it was suspected that adverse borehole water quality was related to poor river water quality. Research demonstrated (Finch, 1979) that the presence of a very large fissure gave rise to a loss of river water to the aquifer, and to one production borehole in particular. One theory for the fissuring was that, at the time, it was customary in mineral extraction for a supporting pillar to be left under pumping stations; while this protected the pump installation, differential settlement may have led to fissuring.

The relevance of this to the flood behaviour of the Rainworth Water is that subsidence due to mineral extraction may have increased the tendency for the Rainworth Water to be influent (to the aquifer), particularly in its middle reaches. Coupled with the declining regional groundwater levels throughout the 1970s, this may have disguised the flow regime of the Rainworth Water and led to a lack of attention to, or underestimation of, potential drainage problems.

OTHER

According to MAFF records studied by Robinson (pers. comm., 1989), there were few grant-aided field drainage schemes in the catchment in the 1970s. The heavier soils of the Keuper Waterstones might be expected to have attracted some works and the records suggest that this has been the case to the south, in the parish of Eakring. For administrative reasons - partly related to confidentiality - it is not possible to be specific about the location and timing of drainage works. It would seem likely that drainage improvements carried out in the area are those typically used on the various soils. Thus no special allowance is warranted.

2.8 Caveat

While the characteristics of the catchments have been discussed in considerable detail, the information could be refined by further reference to the various sources.

The standard methods of flood estimation applied in Section 5 take explicit account only of a limited number of catchment characteristics. In the case of the Winter

Rainfall Acceptance Potential classification, the standard method uses soils information mapped at a very coarse scale.

Improved flood estimates could be obtained by making use of the additional detailed information presented above. However, this would require the exercising of considerable judgement, which experts might not readily agree on.

There would have been more to be gained by close scrutiny of the catchment had subsequent analysis (Sections 3, 4, 6 and 7) shown the flood events to be very rare. It is well known that the estimation of very rare floods on highly permeable catchments (such as the RW catchment) is problematic; it might be argued that extreme events on such catchments are produced by infrequent combinations of factors - such as heavy rain falling while topsoils are frozen. In such cases, the normal flood behaviour may not be a good guide to the supranormal.

The requirement for more detailed analysis became largely academic when it was confirmed that the storm and flood incidents were by no means exceptionally rare, and it was learnt that this might be readily agreed by the Defendants. In promoting such an agreement, there appeared to be nothing to be gained by refining flood estimates in a non-standard manner. Thus much of the information gathered and scrutinized in the study has not been used in the assessments of event rarity that follow.

3 RARITY OF 22 APRIL 1983 STORM

Four sources of information are discussed separately before being brought together in Section 3.5.

3.1 General conditions

According to the proof of evidence by Mr Meadows: "During the evening of Friday 22 April 1983 the area was subjected to torrential thunderstorms".

3.2 Daily raingauge data

An agreed set of daily rainfall totals is reproduced as Appendix 2 to this report. The values are keyed to raingauge locations shown on Fig. 2.1 (appended), which is also an agreed document.

Rainfall totals recorded for the 24-hour period ending at 09.00 on 23 April 1983 ranged from 7.8 mm at Sutton Sewage Works (gauge A) to 35.3 mm in west Farnsfield (gauge J). The relevant rainfall readings are given in Table 3.1.

TABLE 3.1 Daily rainfall readings - 22 April 1983

Gauge	depth (mm)	Thiessen weight	Gauge	depth (mm)	Thiessen weight
A	7.8	0.03	I	21.0	0.135
C	14.4	0.15	J	35.3	0.01
D	16.0	0.12	L	16.0e	0.135
F	28.2	0.07	N	22.2e	0.05
G	20.9e	0.04	O	13.0	0.02
H	21.8e	0.24			

Values with suffix "e" are estimates which derive from gauge readings made less frequently than daily. These apportionments were made by the Met. Office in the normal course of their quality control of daily rainfall data; they appear to be reasonable.

The gauge readings suggest that the rainfall was somewhat more intense in the Lower Rainworth Water and Gallow Hole Dyke catchments than in the Upper Rainworth Water catchment. Gauge H at Rufford Pumping Station is relatively central to the combined Rainworth Water and Gallow Hole Dyke catchments (RW+GHD), and had an apportioned depth of 21.8 mm.

3.3 Recording raingauge data

Rain recorder charts were examined for Mansfield Sewage Works (gauge B), Gleadthorp Experimental Husbandry Farm near Warsop (gauge M), Markham Clinton Pumping Station (Met. Office gauge no. 123376, sited about 2km north of gauge K) and Brackenhurst (gauge P). None of the gauges is within the catchment.

These data suggest that the storm moved approximately Southwest to Northeast across the area, rainfall occurring slightly earlier at Brackenhurst and Mansfield than at Gleadthorp, and much earlier than at Markham Clinton.

At Mansfield, all but 2.5 mm of the daily total of 14.6 mm fell between 17.25 and 19.40 hr GMT. Rainfall was intense between 17.30 and 17.45, slackened between 17.45 and 18.50, then moderately intense until 19.40. At Gleadthorp, which received a daily total of 19.8 mm, all but 2.5 mm fell between 17.45 and 19.45 hr GMT, with the most intense rainfall between 17.45 and 18.00 but moderately intense rainfall between 18.55 and 19.45.

3.4 Radar data

Weather radar data are available for this date from the Hameldon Hill station in Northwest England. The format of data is hourly readings over grid squares of side 5 km. It is well known that radar data are useful in representing where and when it rains, but less good at determining intensities. "Adjustment factors" applied by the Met. Office can differ by more than a factor of ten. Because the study area is a long way (about 100 km) from the radar site, the quality of rainfall estimates derived from radar data is likely to be further degraded.

The radar data indicate that heavy rainfall on 22 April 1983 was mainly confined to the period 17.00 to 20.00 hr GMT. The data demonstrate that rainfall was widespread throughout a 35 by 35 km area centred on Clipstone Forest. The temporal and spatial resolutions of the data are insufficient to define the movement of individual storm cells with confidence. However, the wider field of radar data is consistent with a possible general movement from Southwest to Northeast. A notable feature in the radar data is a North-South band of higher values over Boughton, Eakring and Halam.

3.5 Estimate of catchment rainfall

An estimate of the average rainfall over the 75.7 km^2 catchment to Rufford Lake was obtained as a weighted average of 11 daily gauge readings, based on the method of Thiessen polygons. The weights are given in Table 3.1. This scheme yields a depth of 19.1 mm for 22 April 1983.

The correspondence between radar data and gauge data is rather poor. For this event the radar data underestimate depths appreciably. In terms of spatial variation, the radar data indicate that the greatest depths were experienced in a North-South alignment over Boughton, Eakring and Halam; the gauge data support this general alignment but suggest that the greatest depths were experienced further west, over Edwinstowe and west Farnsfield. Without a very detailed investigation of the general characteristics of Hameldon radar estimates for the study area, it would appear inadvisable to place any great reliance on the radar data for this storm.

From the recording raingauge data - giving prominence to the Gleadthorp gauge (which experienced a daily depth similar to the estimated catchment average) - it is judged that 17 mm of the 19.1 mm fell in the main storm period, and that, at the catchment centroid, this would have lasted from 17.30 to 19.45 hr GMT.

The temporal distribution of rainfall seen at the recording raingauges indicates that the most intense rainfall occurred in the first 15 minutes, followed by intermittent intense rainfall for the next 75 minutes, with moderately intense and fairly uniform rainfall in the final 45 minutes. A representation of the temporal profile is given in Table 3.2, for later use in Section 6.

TABLE 3.2 Estimated temporal profile for 22 April 1983 storm

index to 30-minute period	% of storm depth
1	30
2	10
3	15
4	30
5	15
total:	100

Index 1 refers to 17.30-18.00 hr GMT

3.6 Assessment of rarity of flood-producing rainfall

From Section 3.5 it is concluded that the flood-producing storm comprised a catchment rainfall of 17 mm in 2.25 hours. Using the standard Flood Studies Report procedure - but the preferred estimate of the M5-2D statistic (see Section 2.3) - this corresponds to a 1.8-year rainfall event on the annual maximum scale. Put another way, the annual exceedance probability of a 2.25-hour catchment of 17 mm on the Rufford Lake catchment is 0.56. For such a frequent event it is appropriate to convert the return period to the "peaks over threshold" scale. Application of Langbein's formula yields an estimated mean interval between exceedances of 15 months for this 2.25 hour catchment rainfall depth. Calculation details are given in Appendix 3.

Thus the storm event is judged to be unexceptional.

4 RARITY OF 1 JUNE 1983 STORMS

The sources of information available for the 1 June 1983 storms are broadly as before, and are discussed in turn. It should be noted that only partial radar data are available for this event.

However, the main difficulty faced in assigning a rarity to the flood-producing rainfall is that two separate storms occurred on 1 June 1983. Whether the two storms were sufficiently separated in time to represent two independent flood-producing events is doubtful. For this reason, the catchment rainfall assessment that follows is helpful more for later use in Section 7 than for assigning simple rarities (or a complex combined rarity) to the 1 June 1983 storms.

The storms fell on the same day (1 June 1983) but on separate "rainfall days": 31 May and 1 June 1983.

4.1 General information

1ST STORM

The first storm occurred in the early hours of 1 June 1983. The statement of Mr Bellamy indicates that heavy rainfall commenced at 5 am and ceased at 9 am. British Summer Time was in force and timings given by witnesses are therefore one hour later than GMT timings.

2ND STORM

There appears at first sight to be some contradiction in accounts of the timing of the second storm. Statements taken from Mr Lieber and Mr Ketchell on 9 June 1983 refer to torrential rain from 7.15 pm until 8 pm; Mr Ketchell adds: "but not to an extent of being greater than previous experiences". Later statements by Mr Lieber and Mr Bellamy (taken in July 1987?) say that the rainstorm began at 6 pm and lasted until 7 pm. The proof of evidence by Mr Meadows states that "About 8 pm a further downpour of rain began". A possible explanation for these different perspectives is given in Section 4.3.

4.2 Daily raingauge data

1ST STORM

Rainfall totals (see Appendix 2 and Table 4.1) recorded for the 24-hour period ending at 09.00 on 1 June 1983 ranged from 25.5 mm at Edwinstowe (gauge E) and 26.6 at Mansfield (gauge O) to 37.1 mm at Sutton Sewage Works (gauge A). The gauge most central to the catchment (gauge H at Rufford Pumping Station) registered 28.1 mm. The spatial uniformity of these readings would seem remarkable given the likely convective nature of the storm that these totals largely represent.

TABLE 4.1 Daily rainfall readings - 31 May 1983

Gauge	depth (mm)	Thiessen weight	Gauge	depth (mm)	Thiessen weight
A	37.1	0.03	I	27.7	0.135
C	28.3	0.15	J	30.0	0.01
D	30.3e	0.12	L	28.1e	0.135
E	25.5	0.01	N	33.9e	0.05
F	46.1e	0.06	O	26.6	0.02
G	28.8e	0.04			
H	28.1	0.24			

Amongst gauges not read on a regular basis, a higher value was inferred by the Met. Office for Edwinstowe Water Reclamation Works (122939, 46.1 mm). However, this apportionment was made in routine quality control of data without reference to the observations at Edwinstowe (122928), which is the next nearest gauge. The Met. Office ceased to use data from Edwinstowe in 1977, presumably because readings were not being taken sufficiently regularly.

Examination of rainfall measurements for the entire period 27 May to 2 June 1983 reveals what appear to be anomalies in the Edwinstowe and Edwinstowe WRW readings. The 4-day reading at Edwinstowe for the 27-30 May suggests that heavy rainfall was experienced in this period as well as in the 31 May to 2 June period. Cross-reference to the Edwinstowe WRW readings suggests that both sites experienced heavy rainfall on 30 May 1983, over and above that experienced at other stations in the study area. This is not reflected in the Met. Office apportionment for Edwinstowe WRW and the latter is therefore in doubt. A preferred apportionment is that 20 mm fell on 30 May and 36.5 mm on 31 May, and this is assumed in subsequent analysis.

2ND STORM

An additional worry concerns the Edwinstowe WRW reading for 1 June 1983. Two sources, one the Met. Office computerized data set, show 8.3 mm but a Severn-Trent Water Authority source shows an unequivocal 28.3 mm. The latter value has therefore been adopted.

Rainfall totals for the 24-hour period commencing 09.00 on 1 June 1983 were generally smaller and more variable than for 31 May 1983. They ranged from 1.5 mm at Sutton Sewage Works (gauge no. 122707) to 28.0 mm in west Farnsfield (118731) and 28.3 mm at Edwinstowe WRW (122939). The Rufford Pumping Station gauge registered 21.0 mm.

The relevant raingauge readings are given in Table 4.2.

TABLE 4.2 Daily rainfall readings - 1 June 1983

Gauge	depth (mm)	Thiessen weight	Gauge	depth (mm)	Thiessen weight
A	1.5	0.03	I	9.0	0.135
C	15.6	0.15	J	28.0	0.01
D	8.7e	0.12	L	10.2e	0.135
E	7.0	0.01	N	4.5e	0.05
F	28.3	0.06	O	3.3	0.02
G	7.3	0.04			
H	21.0	0.24			

4.3 Recording raingauge data

Rain recorder charts were examined for gauges at Mansfield Sewage Works (gauge B), Gleadthorp (gauge M), Markham Clinton (about 2 km north of gauge K) and Brackenhurst (gauge P). The records for Brackenhurst were incomplete while the record at Gleadthorp was affected by a partial blockage in the raingauge on the first day. Because of the absence of radar data for this day, additional recording raingauge data were examined for sites further afield, at Watnall (Met. Office gauge no. 117626) and Torksey Pumping Station (122084).

1ST STORM

These data indicate that, apart from negligible amounts around 20.00 hr GMT, the daily totals for 31 May 1983 represent rainfall between about 03.00 and 08.00 hr GMT on 1 June. It appears that heavy rainfall at any one site lasted for 3.5 to 4 hours, with rainfall commencing earlier in the southwest (eg. Watnall) and later in the northeast (eg. Markham Clinton and Torksey). At all sites the rainfall was generally heavy and continuous, but with particularly intense bursts evident towards the beginning and end of the storm period.

2ND STORM

Recording raingauge charts for the 1 June 1983 indicate that there were three periods of rainfall: generally negligible amounts around 10.00 hr GMT, and two intense periods of rainfall in the early evening, each lasting between 20 and 35 minutes, and separated by a 90 minute rainless intermission. An exception is the Brackenhurst gauge which indicates a much longer intermission; however, the chart record there is incomplete.

Chart timings are thought to be fairly reliable for the Mansfield Sewage Works and Gleadthorp records. These indicate that each burst commenced synchronously at both sites, at about 16.15 and 18.10 hr GMT respectively. That there were two bursts may account for the apparent confusion in witnesses' statements (see Section 4.1).

4.4 Radar data

1ST STORM

No radar data were available.

2ND STORM

For this flooding incident, radar data are available only for the period from 17.00 hr GMT on 1 June 1983. Their temporal pattern agrees well with the recording raingauge data. The radar data indicate that there was considerable spatial variability in the rainfall experienced in the evening of 1 June. Interestingly the heaviest rainfall depicted by radar is again oriented in a North-South direction over Boughton, Eakring and Halam, whereas gauge data again suggest that the heaviest falls were further west, over Edwinstowe WRW and west Farnsfield.

4.5 Estimate of catchment rainfall

The Thiessen weighting procedure was used to obtain an estimate of catchment average rainfall over the 75.7 km^2 catchment to Rufford Lake. The Thiessen weights (Tables 4.1 and 4.2) differ slightly from those used in Section 3.4 because rainfall readings were available from gauge E for these storms.

The procedure yielded depths of 29.4 and 14.1 mm respectively for the 24-hour periods ending and beginning at 09.00 GMT on 1 June 1983.

1ST STORM

From the recording raingauge data it is judged that 29.2 mm of the 29.4 mm fell in the main storm period, and that, at the catchment centroid, this would have lasted from 03.30 to 07.30 hr GMT on 1 June 1983. Weight was given to the data recorded at Mansfield and Markham Clinton.

There is evidence that this storm passed from Southwest to Northeast, affecting the Gallow Hole Dyke catchment a little later than the Rainworth Water catchment.

2ND STORM

From the recording raingauge data it is judged that 7.7 mm of the 14.1 mm daily total for 1 June 1983 fell between 16.15 and 16.45 hr GMT and 6.1 mm fell between 18.15 and 19.00 hr GMT. The latter assessment tallies with the contemporary statements of Messrs. Lieber and Ketchell. Evidence for significant storm movement associated with these bursts of rainfall is weak.

Approximate temporal profiles for the catchment average rainfall in these storms are given in Table 4.3.

TABLE 4.3 Estimated temporal profiles for storms on 1 June 1983

1ST STORM

index to 30-minute period	% of storm depth
1	18
2	15
3	6
4	12
5	13
6	16
7	16
8	4
total:	100

Index 1 refers to 03.30-04.00 hr GMT

2ND STORM

index to 30-minute period	% of storm depth
1	18
2	38
3	0
4	0
5	11
6	33
total:	100

Index 1 refers to 16.00-16.30 hr GMT

4.6 Assessment of rarity of flood-producing rainfalls

The first storm includes a period in which 28.0 mm fell in 3.5 hours. Such a catchment average fall has an assessed rarity of 5.33 years on the annual maximum scale, corresponding to a mean recurrence interval of 58 months.

The second storm did not represent a notable fall in itself. A catchment average fall of 13.8 mm has a return period of 1.20 years on the annual maximum scale. This corresponds to a mean recurrence interval of 7 months.

The two storms together yielded a catchment average fall of 43.3 mm in 15.5 hours, corresponding to a 5.79-year event for this duration. The equivalent mean recurrence interval is 63 months.

The calculation details are given in Appendix 3.

5 DESIGN FLOOD ESTIMATES

5.1 Introduction

As discussed in Section 1.4, standard methods are available (NERC, 1975; Institute of Hydrology, 1985) to estimate flood potential by reference to physical characteristics of the catchment. Application of these standard methods is considered first, for the "statistical" approach (Section 5.2) and the "rainfall-runoff" approach (Section 5.3). The estimates are compared in Section 5.4.

5.2 The statistical approach

Estimates of the T-year peak flow are obtained by first estimating an "index" flood and then applying regional floood "growth factors".

The Flood Studies Report (NERC, 1975) uses the mean annual flood, QBAR, as the index flood. It is defined as the arithmetic mean of annual maximum instantaneous flows. typically it has a return period, on the annual maximum scale, of about 2.33 years. The standard equation for estimating QBAR on "ungauged" catchments is:

$$QBAR = c\ AREA^{.94}\ STMFRQ^{.27}\ SOIL^{1.23}\ RSMD^{1.03}\ (1+LAKE)^{-.85}$$

where c=0.0213 for the Central Region (which includes the Trent basin). This gives an estimate of the mean annual flood, QBAR, in m^3s^{-1}; see Section 2.2 and Appendix 1 for definition of the other terms.

Estimates of QBAR are given in Table 5.1 for the various catchments considered in this study.

A design flood of lower frequency (and therefore higher return period) is estimated by multiplying QBAR by an appropriate growth factor. This factor is used to "scale up" the mean annual flood (QBAR) to the T-year flood (Q_T). For example, the Severn-Trent regional flood growth factor for the 50-year return period event is:

$$Q_T \ /\ QBAR = 2.20.$$

These estimates suggest that the small (15.2 km^2), but relatively impermeable, Gallow Hole Dyke catchment presents a higher flood potential than the 59.0 km^2 Rainworth Water catchment to their joint confluence near Maylodge Drive.

TABLE 5.1 Flood estimates - "statistical" approach

(all figures are in m^3s^{-1})

	URW 21.3 km^2	RW 59.0 km^2	GHD 15.2 km^2	RW+GHD 74.2 km^2	RL 75.7 km^2
QBAR	0.96	3.18	3.95	6.27	6.35
Q_2	0.86	2.83	3.52	5.58	5.65
Q_5	1.18	3.91	4.86	7.72	7.81
Q_{10}	1.43	4.73	5.89	9.35	9.46
Q_{20}	1.71	5.65	7.03	11.15	11.29
Q_{30}	1.88	6.22	7.74	12.28	12.43
Q_{50}	2.11	6.99	8.70	13.80	13.97
Q_{100}	2.47	8.17	10.16	16.12	16.32

5.3 The rainfall-runoff approach

Because the estimation of design floods from physical characteristics is inherently error prone, it is inadvisable to rely on estimates by a single method. In addition to providing alternative estimates of peak flows, the rainfall-runoff method can provide a representation of the flood hydrograph. This is of particular interest in this case to check that the Rainworth Water and Gallow Hole Dyke catchments are broadly sensitive to the same kind of flood-producing storms, despite their diverse physical characteristics.

Summary results from application of the FSR rainfall-runoff method, as modified in Flood Studies Supplementary Report No. 16, are given in Table 5.2. D is the design storm duration and Q_{BASE} denotes the baseflow allowance. The standard method suggests that the catchments will be generally sensitive to prolonged periods of rainfall of many hours.

That the Gallow Hole Dyke catchment is represented as being no more quickly responding than the Rainworth Water catchment is slightly surprising. It is explained by a combination of factors. Firstly, although the GHD catchment has steeper overland slopes, the average slope of its main channel is significantly less than that of the RW catchment. Secondly, the GHD catchment is almost entirely rural whereas the RW catchment has a significant urban fraction. Finally, the GHD catchment has a slightly lower average annual rainfall than the RW catchment. These characteristics (S1085, URBAN and SAAR) all appear in the estimation equation for the characteristic response time, Tp(0), and hence influence the design storm duration, D.

TABLE 5.2 Flood estimates - "rainfall-runoff" approach

(figures are in m^3s^{-1} except where indicated)

	URW 21.3 km^2	RW 59.0 km^2	GHD 15.2 km^2	RW+GHD 74.2 km^2	RL 75.5 km^2
D (hr)	9.0	15.0	15.0	15.0	15.0
Q_{BASE}	0.33	0.51	0.13	0.91	0.92
Q_2	1.55	2.73	3.63	7.44	7.26
Q_5	2.49	4.98	5.92	12.36	12.04
Q_{10}	3.35	6.58	7.16	15.41	15.02
Q_{20}	4.20	8.21	8.38	18.46	17.99
Q_{30}	4.68	9.13	9.04	20.15	19.65
Q_{50}	5.47	10.67	10.13	22.94	22.38
Q_{100}	6.53	12.71	11.52	26.58	25.94

5.4 Comparison of estimates

Agreement between the statistical and rainfall-runoff estimates is generally good for the GHD catchment, with the rainfall-runoff approach giving only slightly larger estimates. However, for the other catchments considered, the estimates by the rainfall-runoff approach are much larger than those by the statistical approach.

Whether the standard methods provide an adequate representation of the catchments is doubtful. In the rainfall-runoff method, the estimation equation for Tp(0) does not represent the likely scenario that runoff contributions from non-riparian parts of the catchment overlying the Sherwood sandstone will travel both more slowly and over greater distances than those from riparian areas sited on alluvium or less permeable soils derived from hillwash. In contrast, in the statistical approach, the stream frequency term, STMFRQ, provides some representation of the slower response expected from the Sherwood sandstone areas.

It is instructive to compare the flood estimates for the URW and RW catchments. Visual inspection of the stream channel at Rainworth following heavy rainfall, confirmed in discussion with a long-term local resident, indicates that the flood potential of the Upper Rainworth Water is very modest; runoff is heavily controlled by natural groundwater storage and - to a lesser extent - by routing through the "L" Lake. In contrast, visual inspection of the lower Rainworth Water (eg. at the Manor Farm culvert immediately upstream of Rufford Park) indicates a much more appreciable response. The statistical approach (typical ratio: RW = 3.3 URW) represents the different response characteristics of the URW and RW catchments more realistically than does the rainfall-runoff method (typical ratio: RW = 2.0 URW).

A further unsatisfactory feature of the flood estimates by the rainfall-runoff method is that those for the combined Rainworth Water and Gallow Hole Dyke catchment exceed the sum of the corresponding flood estimates for the indivivdual catchments. This is illogical. Given the diverse nature of the catchments, it seems unlikely that they will be sensitive to precisely the same flood-producing conditions. In such circumstances one would therefore expect the design floods for the combined catchment to be somewhat less than the sum of the individual design floods.

6 SIMULATED RESPONSE TO 22 APRIL 1983 STORM

6.1 Method

Flood Studies Supplementary Report No. 12 (Institute of Hydrology, 1983) sets out a method for assessing the return period of a notable flood using the rainfall-runoff approach. The method is suitable where ample rainfall data are available.

There are two important principles. Firstly, the rarity of a given rainfall occurrence (eg. 30 mm in 4 hours) is not necessarily a good guide to the rarity of the resultant flood. This is because a given catchment may not be in tune with the particular character of the extreme rainfall. For example, flooding in heavily urbanized catchments is generally sensitive to short-duration high-intensity rainfall whereas flooding in large (usually slowly-responding) river basins generally arises from prolonged and widespread heavy rainfall. Also, the severity of the resulting flood may be influenced by other factors such as the dryness (or wetness) of the catchment prior to the main storm. Use of a rainfall-runoff method can allow for this.

The second guiding principle of the FSSR12 method is that the same rainfall-runoff model is used to simulate the notable flood as is used in calculating design flood estimates. The merit of this is that there will be some tendency for errors to cancel out. For example, if the rainfall-runoff method overestimates the volume of runoff response (eg. through misclassification of the Winter Rainfall Acceptance Potential of the soils), this calibration error will inflate both the design flood estimates and the simulated notable flood. Thus the assessment of flood rarity is less sensitive to error than is the flood peak estimate itself.

6.2 Data

An estimate of antecedent catchment wetness is obtained from routine mapped values of Soil Moisture Deficit (SMD) and calculated values of the 5-day Antecedent Precipitation Index (API5) using the standard definition:

$$CWI = 125 - SMD + API5$$

where CWI denotes Catchment Wetness Index. The daily rainfall readings at Rufford Pumping Station (gauge H) were used in the calculation of API5. Estimates of SMD were taken by reference to routine mapped values provided by the MORECS service operated by the Met. Office.

The calculation for the 22 April 1983 storm is summarized in Table 6.1.

TABLE 6.1 Antecedent catchment wetness - 22 April 1983

Time (GMT)	SMD mm	API5 mm	CWI mm	
09.00	0.0	6.6	131.6	
17.30	0.0	6.1	131.1	(say 131)

6.3 RL catchment

Using the storm depth of 17.0 mm derived in Section 3.5, the temporal profile given in Table 3.2, and the CWI value from Table 6.1, the simulated hydrograph for the 22 April 1983 flood to Rufford Lake had a peak of 8.54 m^3s^{-1} (see Appendix 4). Comparison with the design flood estimates given in Table 5.2 yields an assessment of a 2.55-year flood on the annual maximum scale, corresponding to a mean recurrence interval of 24 months. This is not very different from the estimate of rainfall rarity as a 2.33-year storm.

6.4 GHD and RW catchments

Rainfall was rather heavier over the GHD catchment (20 mm) than the RW catchment (16 mm). Separate hydrograph simulations are included in Appendix 4. These suggest that, in terms of flood runoff at Rufford Park, the RW and GHD catchments contributed similar quantities of flow in this event.

7 SIMULATED RESPONSE TO 1 JUNE 1983 STORMS

7.1 Calculations

Antecedent catchment wetness is summarized in Table 7.1.

TABLE 7.1 Antecedent catchment wetness 31 May/1 June 1983

Date	Time (GMT)	SMD mm	API5 mm	CWI mm	
31 May	09.00	0.0	4.5	129.5	
1 June	03.30	0.0	2.8	127.8	(say 128)
1 June	16.00	0.0	23.8	148.8	(say 149)

Because of the distinct antecedent wetness conditions, it is necessary to simulate the flood response to the second storm separately from that to the first storm; these are given in Appendix 4.

Simulations for the two storms have been combined in Fig. 7.1 to indicate the combined response of the Gallow Hole Dyke and Rainworth Water to Rufford Park, taking account of both storms. The simulations suggest that the second storm led to a "shoulder" on the hydrograph recession from the main peak.

7.2 Flood rarity

The combined hydrograph has an estimated peak of 12.7 m^3 s^{-1} occurring at about 14.00 hr GMT on 1 June, ie. about two hours prior to commencement of the second storm. Using the RW+GHD design flood estimates given in Table 5.2, this combined peak flow is assessed to be a 5.4-year event on the *annual maximum scale, corresponding to a mean recurrence* interval of 59 months.

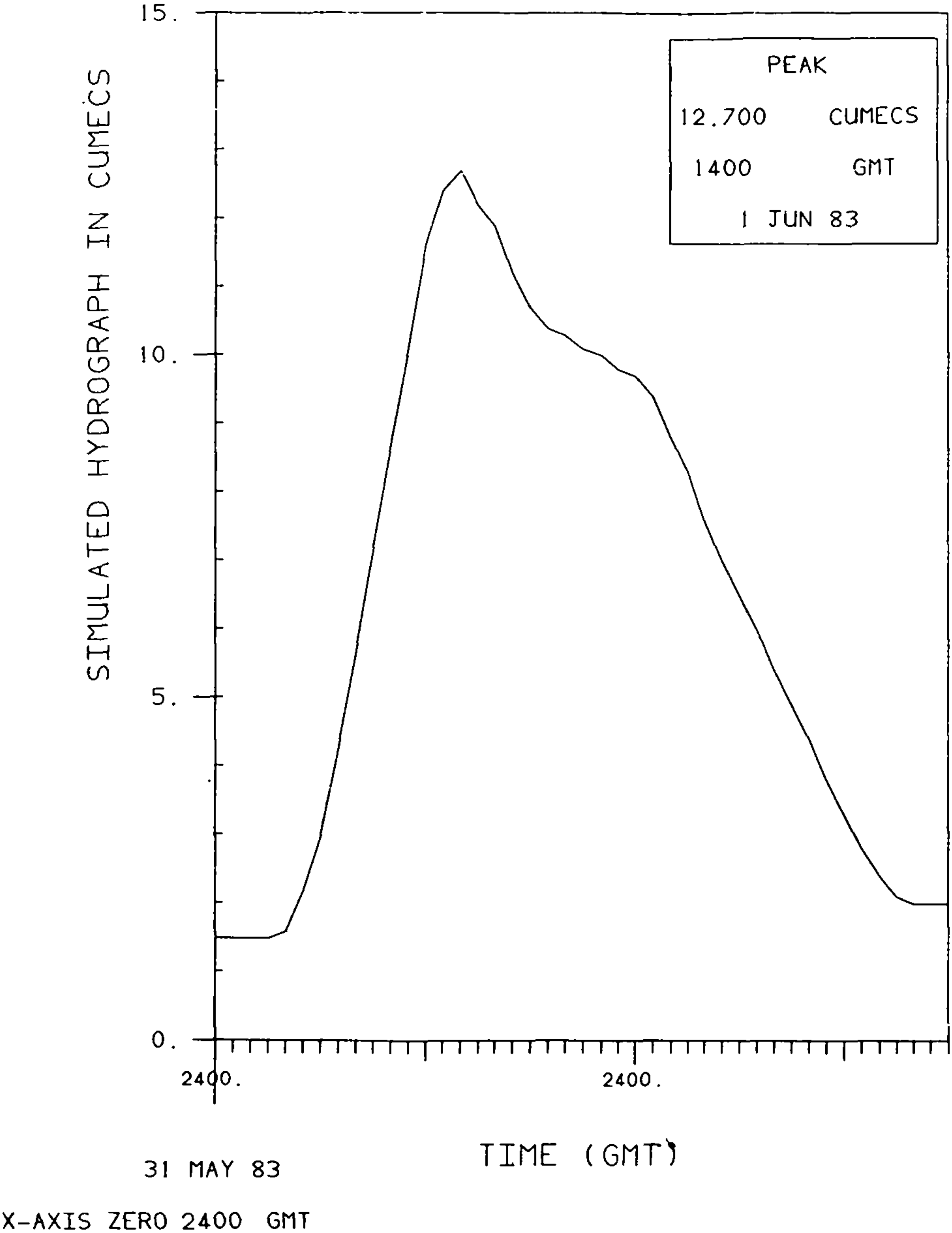
Thus, for this event, the flood peak rarity is assessed to be very similar to that of the flood-producing rainfall (see Section 4.6).

7.3 A check

For reasons discussed earlier (see Sections 2.4 to 2.7 and Section 5.4) there is doubt that the rainfall-runoff method provides a faithful representation of the flood response of the very permeable Rainworth Water catchment, particular in terms of its relative timing to that of the Gallow Hole Dyke.

At an early stage of the study a search was made for a nearby gauged catchment with similar characteristics. While there are some geological and soils differences, the most nearly analogous catchment with formal flow records is judged to be the Greet at Southwell (gauging station no. 28072).

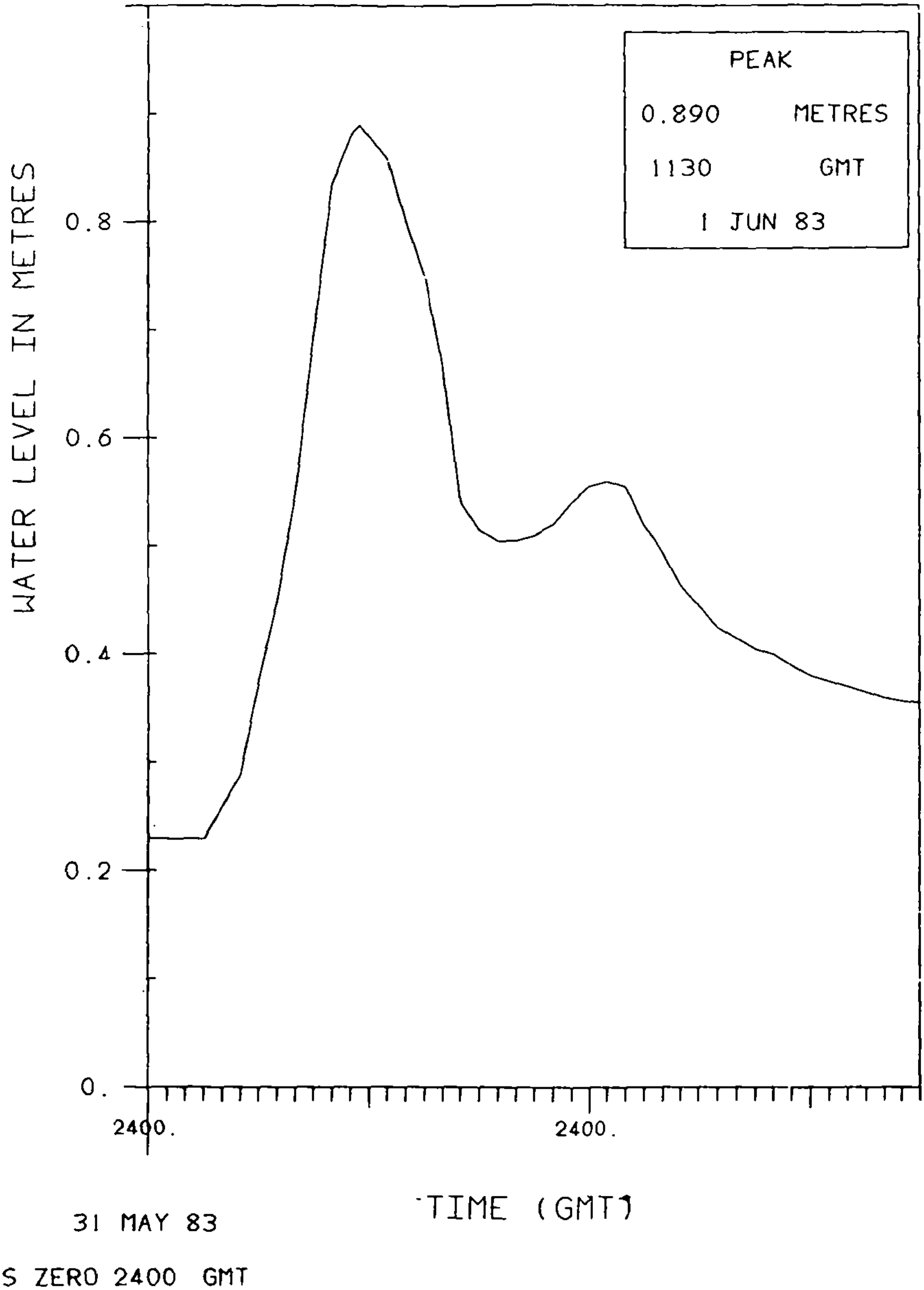
Fig. 7.1 Simulated hydrograph for 1/2 June 1983: combined RW and GHD flows at Rufford Park



Resources did not permit a detailed investigation. However, the water level record for 31 May / 2 June 1983 shown in Fig. 7.2 provides some corroboration that the hydrograph simulation (Fig. 7.1) is reasonable.

It is possible that the simulated flood hydrograph at Rufford Park is rather too uniform. Eye-witness accounts suggest that the temporal pattern of response may have been rather more like that seen at Southwell, with the second storm producing a subsidiary peak in the early hours of 2 June 1983.

Fig. 7.2 Observed level hydrograph for 1/2 June 1983: Greet at Southwell



8 SUMMARY AND ADDITIONAL REMARKS

8.1 Event rarities

The rarities of the flood-producing events on 22 April 1983 and 1/2 June 1983 have been assessed.

22 APRIL 1983

The storm depth of 17.0 mm in 2.25 hours on 22 April 1983 has a mean recurrence interval of about 1.25 years. Thus it was not a very rare event. The resultant flood peak at Rufford Lake is estimated to be 8.5 $m^3 s^{-1}$, with an assessed mean recurrence interval of 2.5 years. Simulation of the event suggests that about half the flood runoff emanated from the Gallow Hole Dyke and half from the Rainworth Water.

1/2 JUNE 1983

Two storms occurred on 1 June 1983. The first storm was much the larger, with a mean depth of 28.0 mm falling in 3.5 hours; this has a mean recurrence interval of about 5 years. The second storm was characterized by two intense but localized bursts of rain. A mean depth of 13.8 mm fell in 2.75 hours in this second storm; this has a mean recurrence interval of about 7 months.

Taken together, the two storms yielded 43.3 mm in 15.5 hours. This longer duration fall has a mean recurrence interval of about 5.25 years. However, because the rainfall was not uniformly distributed over the 15.5 hour period, this assessment may be misleading.

In terms of their individual contributions, the simulated hydrograph for the Rainworth Water has a peak of 7.3 $m^3 s^{-1}$ with a mean recurrence interval of about 10 years; that for the Gallow Hole Dyke has a peak of 5.3 $m^3 s^{-1}$, with a mean recurrence interval of about 3.5 years.

It has been possible to simulate the flood runoff resulting jointly from the two storms which occurred on 1 June 1983. The estimated flood hydrograph is shown in Fig. 7.1.

The simulation suggests that the peak combined flow of the Rainworth Water and Gallow Hole Dyke was 12.7 $m^3 s^{-1}$, occurring at about 14.00 hr GMT on 1 June, ie. about two hours prior to commencement of the second storm. This combined peak flow has a mean recurrence interval of about 5 years. The synthesis indicates that the total volume of event runoff was about 728,000 m^3, with the Rainworth Water supplying about 60% and the Gallow Hole Dyke about 40%.

It can be seen that, while the peak flow was not exceptionally large, relatively high flows were maintained for a prolonged period. Partial corroboration of the hydrograph shape for the composite event is provided by the gauged record for the adjacent Greet at Southwell catchment (Fig. 7.2). This shares some geological characteristics with the combined Rainworth Water and Gallow Hole Dyke catchments.

It is possible that the simulated flood hydrograph at Rufford Park is rather too uniform. Eye-witness accounts suggest that the temporal pattern of response may have been rather more like that seen at Southwell, with the second storm producing a subsidiary peak in the early hours of 2 June 1983.

8.2 Historical notes

Authoritative mapping of soils for the Ollerton district suggests that, historically (ie. prior to drainage works, subsidence, etc.), land in the vicinity of Maylodge Drive has been prone to flooding from the Gallow Hole Dyke as well as from the Rainworth Water. This is because the former catchment is relatively impermeable and typically produces a greater flood response than the much more permeable Rainworth Water catchment.

As part of the study, a historical review of large rainfall events was carried out by reference to gauged rainfall records and back-copies of the Mansfield CHAD newspaper. This revealed little evidence of past serious flooding incidents in the Rainworth Water catchment.

It was noted that the Rainworth Water came under close scrutiny in the mid to late 1970s because of the smallness of its flows. The period coincided with a largely natural lowering of groundwater levels in the region. However, the loss of river water to the underlying aquifer was held by contemporary research to be attributable to fissures in the superficial soils. Deep mining is the most likely cause of such fissures. The absence of large flows in the Rainworth Water during the mid and late 1970s may have engendered a false sense of security in terms of flood risk at Rufford Park.

8.3 Other factors

It is concluded that the meteorological conditions alone do not explain the very serious flooding incidents experienced at Rufford Park on 22 April 1983 and 1 June 1983. Exceptional contributing factors must therefore be sought, of which differential land subsidence appears to be the most likely root cause.

Resolution of liability may rest on the sizing, construction, maintenance and integrity of engineered structures, notably the embankments which intervene between Maylodge Drive, the various watercourses, and Rufford Lake. Surveys of land, watercourse and embankment levels, investigation of mining subsidence, assessments of hydraulic characteristics of the watercourses and structures (including the outflow weir at Rufford Lake) may all be highly relevant. These are matters to which professional hydrological advice is peripheral.

The hydrological assessment is that the 22 April 1983 and 1 June 1983 flood events were unexceptional. Other factors must have been highly influential in allowing these moderate events to cause flooding and, in the case of the 1 June 1983 event, to produce such disastrous consequences.

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APPENDIX 1 Flood Studies Report nomenclature

API5	antecedent precipitation index over 5 days, mm
AREA	catchment area, km^2
CWI	catchment wetness index (CWI=125-SMD+API5), mm
D	design storm duration, hr
LAKE	fraction of catchment draining through a significant lake or reservoir
MSL	main stream length, km
M5-2D	2-day rainfall of 5-year return period, mm
QBAR	mean of annual maximum instantaneous flood series, known as the mean annual flood, $m^3\ s^{-1}$
Q_{BASE}	baseflow allowance, $m^3\ s^{-1}$
Q_T	flood peak of return period T, $m^3\ s^{-1}$
r	ratio of 60-minute rainfall of 5-year return period to M5-2D, known as Jenkinson's "r"
RSMD	1-day catchment rainfall of 5-year return period less SMDBAR, mm
SAAR	(standard period) average annual rainfall, mm
SMD	soil moisture deficit
SMDBAR	effective mean value of SMD
SOIL1	fraction of catchment having soil in class 1
SOIL4	fraction of catchment having soil in class 4
STMFRQ	stream frequency, junctions km^{-2}
S1085	10-85% stream slope, m km^{-1}
T	average interval between years with a flood exceeding a given magnitude, known as return period (on annual maximum scale), yr
Tp(0)	time-to-peak of an equivalent instantaneous unit hydrograph, hr
URBAN	fraction of catchment urbanized (measured from 1:50000 scale map)

APPENDIX 2 Agreed rainfall values

RUFFORD COUNTRY PARK -- HIGH COURT -- MEADOWS etc -v- NOTTS COUNTY COUNCIL & BRITISH COAL CORPORATION

MEETING OF EXPERTS -- AGENDA ITEM D1

Daily Rainfall Totals at Various Stations Within & Around the Rufford Lake Catchmennt Area on the Specified Dates in April, May & June 1983

Station Ref.	Station Name	Met.Off. Ref. No.	National Grid Ref.	22 Apr	23 Apr	18 May	19 May	20 May	29 May	30 May	31 May	1 June	2 June
				Rainfall in millimetres on:									
	Sutton-in-Ashfield S.Wks	122707	45103595	7.8	0.0	3.3	0.8	0.9	1.2	8.8	37.1	1.5	2.7
B	Mansfield S. Works	122775	45483622	14.6	0.0	1.5	1.2	0.2e	0.4e	3.0	26.3	4.4	3.9
C	Blidworth,Ravenshead	118317	45623553	14.4	0.0	3.8	4.6	4.2	0.6	4.1	28.3	15.6	6.2
D	Rainworth Spring Hill S.Wks	123028	45973593	16.0	0.0	2.9	0.7	1.6	0.3e	3.4e	30.3e	8.7e	3.8e
E	Edwinstowe	122928	46243667			8.3	20.9	(3.8)		(34.0)	25.5	7.0	2.1
	Edwinstowe W.R.Wks	122939	46413669	28.2	0.1	7.0	23.2	1.3	0.0e	10.7e	46.1e	28.3	4.6
G	Boughton P.S.	123261	46673692	20.9e	0.1e	16.2	14.3	0.7e	0.3e	6.4e	28.8e	7.3	3.2
T	Rufford P.S.	123094	46323611	21.8e	0.0e	5.9	0.6	2.0e	5.7e	2.4e	28.1	21.0	4.0
	Eakring	120801	46733614	21.0	0.0	14.8	4.3	2.1	0.0	3.2	27.7	9.0	3.0
	Farnsfield	118731	46393561	35.3	0.0	3.4	13.5	8.4	8.0	2.3	30.0	28.0	3.9
I	Tuxford, Westwood	121862	47143707	5.9	0.2	9.5	21.5	0.3	0.3	9.3	36.5	11.5	1.2
L	Rainworth W.W.	123017	45873586	16.0e	0.0	3.1e	1.4e	1.7e	0.6e	3.3e	28.1e	10.2e	3.6e
M	Warsop Gleadthorpe EHF	123712	45913699	19.8	0.0	8.8	6.7	0.5	-0.5	1.8	24.7	2.5	2.2
N	Clipstone W.W.	122891	46033644	22.2e	0.1e	5.5e	18.0e	0.6e	0.1e	2.0e	33.9e	4.5e	4.1e
O	Mansfield	122777	45433619	13.0	0.0	1.5	1.0	0.3	0.4	2.8	26.6	3.3	3.4
P	Brackenhurst, S'well Notts Coll of Agric	118920	46963524	6.2	0.1	3.3	5.4	0.5	0.5	0.3	22.6	0.3	8.5

NOTES:

1) The Daily Rainfall Values represent the amount of rainfall in millimetres which fell between 0900 hrs GMT on the day indicated & 0900 hrs GMT on the following day;

2) The Measuring Station locations are shown with their respective Reference Letters on Drawing D/00300/126;

3) Estimated daily values apportioned by the Met Office from multiday readings are shown suffixed 'e';

4) The values in parentheses for Station E were accumulated over the 3 days 20-22 May & the 4 days 27-30 May respectively.

APPENDIX 3 Rainfall rarity assessments

A3.1 General

The rainfall rarity assessments are made for the 75.7 km^2 catchment to Rufford Lake (catchment RL). For each storm, the rarity assessment (Section A3.3) is made by comparing an equivalent point rainfall (derived in Section A3.2 using the storm depths and durations found in Sections 3 and 4) with "design" point rainfall depths of the same duration derived for a range of return periods.

A3.2 Calculation of equivalent point rainfall

Storm date [no.]	Catchment average rainfall (mm)	Storm duration (hr)	Areal reduction factor (-)	Equiv. point rainfall (mm)
22 April 1983	17.0	2.25	0.868	19.6
1 June 1983:				
[1]	28.0	3.5	0.890	31.5
[2]	13.8	2.75	0.878	15.7
["1+2"]	43.3	15.5	0.939	46.1

A3.3 Rarity assessments

Design rainfall statistics:
M5-2D = 55 mm (see Section 2.3)
r = 0.402 (see Section 2.2)

Calculation table:

Storm	[A] Depth (typ'l point) (mm)	Storm dur'n D (hr)	[B] M5-Dhr point depth (mm)	Ratio [A] : [B]	Return period (yrs)	Mean recurrence (months)
22 Apr	19.6	2.25	27.6	0.710	1.81	15
1 Jun:						
[1]	31.5	3.5	30.9	1.019	5.33	58
[2]	15.7	2.75	29.0	0.541	1.20	7
["1+2"]	46.1	15.5	44.5	1.036	5.79	63

A3.4 Sensitivity to value of M5-2D

Locally adjusted estimates of the M5-2D rainfall statistic were recommended In Section 2.3. The calculation table below uses an "as mapped" value of M5-2D, to provide a check that the rarity assessments are relatively insensitive to this adjustment.

M5-2D for Rufford Lake:

Preferred estimate (used in Section A3.3): 55 mm
"As mapped" estimate (used below): 50.5 mm

Storm	[A] Depth (typ'l point) (mm)	Storm dur'n D (hr)	[B] M5-Dhr point depth (mm)	Ratio [A] : [B]	Return period (yrs)	Mean recurrence (months)
22 Apr	19.6	2.25	25.3	0.775	2.33	21
1 Jun:						
[1]	31.5	3.5	28.3	1.113	7.22	81
[2]	15.7	2.75	26.6	0.590	1.33	9
["1+2"]	46.1	15.5	40.8	1.130	8.29	93

It is seen that the rarities assessed using the "as mapped" estimates of M5-2D are rather greater than those obtained earlier.

However, for the reasons given in Section 2.3, the locally adjusted M5-2D values are preferred and the assessments of Section A3.3 therefore stand.

APPENDIX 4 Computer listings for hydrograph simulations

22 APRIL 1983

A4.1

Description : Rainworth Water at Rufford Lake
Printed on 25- 1-1990 at 14.40 Run Reference - RLAKE

Convolution of user defined rainfall

			(UH option	1)
Unit hydrograph time to peak	8.7	hours	(TP option	0)
Data interval	0.50	hours		
Design storm duration	2.5	hours	(Dur option	0)
Design storm depth	17.00	mm.	(P option	0)
Design CWI	131.00		(CWI option	0)
Standard Percentage Runoff	19.99		(SPR option	2)
Percentage runoff	22.22	%	(PR option	1)
Response hydrograph peak	6.84	cumecs		
Baseflow	1.70	cumecs		
			(Baseflow option :	
Design hydrograph peak	8.54	cumecs		

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I n s t i t u t e o f H y d r o l o g y

UK DESIGN FLOOD ESTIMATION

Time Series data from estimate using the
Flood Studies Report rainfall-runoff method

Description : Rainworth Water at Rufford Lake
Printed on 25- 1-1990 at 14.40 Run Reference - RLAKE

Time hours	<-- Rainfall Total mm	Profile % -->	Net mm	Unit Hydrograph cumecs/cm per 100sq km	%	ANSF	<---- Flow Response cumecs	----> Total
								1.70 ← 17.30 hr GMT
0.50	5.1	30.0	1.1	1.47	0.26	1.70	0.13	1.82
1.00	1.7	10.0	0.4	2.93	0.53	1.70	0.29	1.99
1.50	2.5	15.0	0.6	4.40	0.79	1.70	0.52	2.22
2.00	5.1	30.0	1.1	5.87	1.06	1.70	0.88	2.58
2.50	2.5	15.0	0.6	7.33	1.32	1.70	1.30	3.00
3.00				8.80	1.58	1.70	1.72	3.42
3.50				10.27	1.85	1.70	2.14	3.84
4.00				11.73	2.11	1.70	2.56	4.26
4.50				13.20	2.38	1.70	2.98	4.68
5.00				14.67	2.64	1.70	3.40	5.10
5.50				16.13	2.90	1.70	3.82	5.51
6.00				17.60	3.17	1.70	4.24	5.93
6.50				19.07	3.43	1.70	4.66	6.35
7.00				20.53	3.70	1.70	5.07	6.77
7.50				22.00	3.96	1.70	5.49	7.19
8.00				23.47	4.22	1.70	5.91	7.61
8.50				24.93	4.49	1.70	6.33	8.03
9.00				24.75	4.45	1.70	6.61	8.31
9.50				23.78	4.28	1.70	6.77	8.47
10.00				22.82	4.11	1.70	6.84	8.54
10.50				21.85	3.93	1.70	6.74	8.44
11.00				20.89	3.76	1.70	6.50	8.19
11.50				19.92	3.59	1.70	6.22	7.92
12.00				18.96	3.41	1.70	5.94	7.64
12.50				17.99	3.24	1.70	5.67	7.37
13.00				17.03	3.06	1.70	5.39	7.09
13.50				16.06	2.89	1.70	5.12	6.82
14.00				15.10	2.72	1.70	4.84	6.54
14.50				14.13	2.54	1.70	4.57	6.26
15.00				13.17	2.37	1.70	4.29	5.99
15.50				12.20	2.20	1.70	4.01	5.71
16.00				11.24	2.02	1.70	3.74	5.44
16.50				10.27	1.85	1.70	3.46	5.16
17.00				9.31	1.68	1.70	3.19	4.88
17.50				8.34	1.50	1.70	2.91	4.61
19.00				7.38	1.33	1.70	2.63	4.33
18.50				6.41	1.15	1.70	2.36	4.06
19.00				5.45	0.98	1.70	2.08	3.78
19.50				4.48	0.81	1.70	1.81	3.50
20.00				3.52	0.63	1.70	1.53	3.23
20.50				2.55	0.46	1.70	1.25	2.95
21.00				1.59	0.29	1.70	0.98	2.68
21.50				0.62	0.11	1.70	0.70	2.40
22.00						1.70	0.46	2.15
22.50						1.70	0.27	1.97
23.00						1.70	0.12	1.82
23.50						1.70	0.03	1.73

22 APRIL 1983

Description : Gallow Hole Dyke to confluence with Rainworth Wate
Printed on 3- 1-1990 at 17.51 Run Reference - GHDDD

A4.2

Convolution of user defined rainfall

			(UH option : 1)
Unit hydrograph time to peak	8.4	hours	(TP option : 0)
Data interval	0.50	hours	
Design storm duration	2.5	hours	(Dur option : 0)
Design storm depth	20.00	mm.	(P option : 0)
Design CWI	131.00		(CWI option : 0)
Standard Percentage Runoff	47.00		(SPR option : 2)
Percentage runoff	48.56	%	(PR option 1)
Response hydrograph peak	3.62	cumecs	
Baseflow	0.32	cumecs	
			(Baseflow option :
Design hydrograph peak :	3.94	cumecs	

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I n s t i t u t e o f H y d r o l o g y

UK DESIGN FLOOD ESTIMATION

Time Series data from estimate using the
Flood Studies Report rainfall-runoff method

Description : Gallow Hole Dyke to confluence with Rainworth Wate
Printed on 3- 1-1990 at 17.52 Run Reference - GHDDD

Time hours	<-- Rainfall Total mm	Profile % -->	Net mm	Unit Hydrograph cumecs/cm per 100sq km	%	ANSF	<---- Flow Response cumecs	----> Total
								0.32 ← 17.30hr GMT
0.50	6.0	30.0	2.9	1.55	0.28	0.32	0.07	0.39
1.00	2.0	10.0	1.0	3.10	0.56	0.32	0.16	0.48
1.50	3.0	15.0	1.5	4.64	0.84	0.32	0.29	0.61
2.00	6.0	30.0	2.9	6.19	1.11	0.32	0.48	0.80
2.50	3.0	15.0	1.5	7.74	1.39	0.32	0.71	1.03
3.00				9.29	1.67	0.32	0.94	1.26
3.50				10.84	1.95	0.32	1.17	1.49
4.00				12.38	2.23	0.32	1.39	1.72
4.50				13.93	2.51	0.32	1.62	1.95
5.00				15.48	2.79	0.32	1.85	2.17
5.50				17.03	3.06	0.32	2.08	2.40
6.00				18.57	3.34	0.32	2.31	2.63
6.50				20.12	3.62	0.32	2.54	2.86
7.00				21.67	3.90	0.32	2.77	3.09
7.50				23.22	4.18	0.32	2.99	3.32
8.00				24.77	4.46	0.32	3.22	3.54
8.50				25.95	4.67	0.32	3.43	3.76
9.00				24.94	4.49	0.32	3.54	3.87
9.50				23.92	4.30	0.32	3.61	3.94
10.00				22.90	4.12	0.32	3.62	3.94
10.50				21.88	3.94	0.32	3.52	3.84
11.00				20.86	3.76	0.32	3.37	3.69
11.50				19.84	3.57	0.32	3.22	3.54
12.00				18.83	3.39	0.32	3.07	3.39
12.50				17.81	3.21	0.32	2.91	3.24
13.00				16.79	3.02	0.32	2.76	3.09
13.50				15.77	2.84	0.32	2.61	2.94
14.00				14.75	2.66	0.32	2.46	2.79
14.50				13.73	2.47	0.32	2.31	2.64
15.00				12.72	2.29	0.32	2.16	2.49
15.50				11.70	2.11	0.32	2.01	2.34
16.00				10.68	1.92	0.32	1.86	2.19
16.50				9.66	1.74	0.32	1.71	2.03
17.00				8.64	1.56	0.32	1.56	1.88
17.50				7.62	1.37	0.32	1.41	1.73
18.00				6.61	1.19	0.32	1.26	1.58
18.50				5.59	1.01	0.32	1.11	1.43
19.00				4.57	0.82	0.32	0.96	1.28
19.50				3.55	0.64	0.32	0.81	1.13
20.00				2.53	0.46	0.32	0.65	0.98
20.50				1.51	0.27	0.32	0.51	0.83
21.00				0.50	0.09	0.32	0.36	0.68
21.50						0.32	0.23	0.55
22.00						0.32	0.13	0.46
22.50						0.32	0.06	0.38
23.00						0.32	0.01	0.33

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22 APRIL

Description : Rainworth Water at confluence with Gallow Hole Dyk
Printed on 3- 1-1990 at 17.15 Run Reference - RWWWW

A4.3

Convolution of user defined rainfall

			(UH option 1)
Unit hydrograph time to peak	8.4	hours	(TP option 0)
Data interval	0.50	hours	
Design storm duration	2.5	hours	(Dur option 0)
Design storm depth	16.00	mm.	(P option 0)
Design CWI	131.00		(CWI option : 0)
Standard Percentage Runoff	12.96		(SPR option : 2)
Percentage runoff	15.63	%	(PR option : 1)
Response hydrograph peak	3.64	cumecs	
Baseflow	1.25	cumecs	
			(Baseflow option :
Design hydrograph peak	4.89	cumecs	

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I n s t i t u t e o f H y d r o l o g y

UK DESIGN FLOOD ESTIMATION

Time Series data from estimate using the
Flood Studies Report rainfall-runoff method

Description : Rainworth Water at confluence with Gallow Hole Dyk
Printed on 3- 1-1990 at 17.16 Run Reference - RWWWW

Time hours	<-- Rainfall Total mm	Profile %	--> Net mm	Unit Hydrograph cumecs/cm per 100sq km	%	ANSF	<---- Flow Response cumecs	----> Total
								1.25 ← 17.30hr GMT
0.50	4.8	30.0	0.8	1.57	0.28	1.25	0.07	1.32
1.00	1.6	10.0	0.3	3.14	0.57	1.25	0.16	1.41
1.50	2.4	15.0	0.4	4.71	0.85	1.25	0.29	1.54
2.00	4.8	30.0	0.8	6.28	1.13	1.25	0.49	1.74
2.50	2.4	15.0	0.4	7.85	1.41	1.25	0.72	1.97
3.00				9.42	1.70	1.25	0.95	2.20
3.50				10.99	1.98	1.25	1.18	2.43
4.00				12.56	2.26	1.25	1.41	2.67
4.50				14.13	2.54	1.25	1.64	2.90
5.00				15.70	2.83	1.25	1.88	3.13
5.50				17.27	3.11	1.25	2.11	3.36
6.00				18.84	3.39	1.25	2.34	3.59
6.50				20.41	3.67	1.25	2.57	3.82
7.00				21.98	3.96	1.25	2.80	4.06
7.50				23.55	4.24	1.25	3.03	4.29
8.00				25.12	4.52	1.25	3.27	4.52
8.50				26.02	4.68	1.25	3.47	4.72
9.00				24.98	4.50	1.25	3.57	4.83
9.50				23.95	4.31	1.25	3.64	4.89
10.00				22.92	4.12	1.25	3.63	4.88
10.50				21.88	3.94	1.25	3.52	4.77
11.00				20.85	3.75	1.25	3.37	4.62
11.50				19.82	3.57	1.25	3.21	4.47
12.00				18.78	3.38	1.25	3.06	4.31
12.50				17.75	3.20	1.25	2.91	4.16
13.00				16.72	3.01	1.25	2.76	4.01
13.50				15.69	2.82	1.25	2.60	3.86
14.00				14.65	2.64	1.25	2.45	3.70
14.50				13.62	2.45	1.25	2.30	3.55
15.00				12.59	2.27	1.25	2.15	3.40
15.50				11.55	2.08	1.25	1.99	3.25
16.00				10.52	1.89	1.25	1.84	3.09
16.50				9.49	1.71	1.25	1.69	2.94
17.00				8.46	1.52	1.25	1.54	2.79
17.50				7.42	1.34	1.25	1.38	2.64
18.00				6.39	1.15	1.25	1.23	2.48
18.50				5.36	0.96	1.25	1.08	2.33
19.00				4.32	0.78	1.25	0.93	2.18
19.50				3.29	0.59	1.25	0.77	2.03
20.00				2.26	0.41	1.25	0.62	1.88
20.50				1.22	0.22	1.25	0.47	1.72
21.00				0.19	0.03	1.25	0.32	1.57
21.50						1.25	0.20	1.46
22.00						1.25	0.11	1.36
22.50						1.25	0.04	1.29
23.00						1.25	0.00	1.26

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1 JUNE 1983 [1]

Description : Rainworth Water at Rufford Lake
Printed on 25- 1-1990 at 14.31 Run Reference - RLAKE

A4.4

Convolution of user defined rainfall

			(UH option	1)
Unit hydrograph time to peak	8.7	hours	(TP option	0)
Data interval	0.50	hours		
Design storm duration	4.0	hours	(Dur option	0)
Design storm depth	29.20	mm.	(P option	0)
Design CWI	128.00		(CWI option	0)
Standard Percentage Runoff	19.99		(SPR option	2)
Percentage runoff	21.48	%	(PR option	1)
Response hydrograph peak	10.97	cumecs		
Baseflow	1.62	cumecs		
			(Baseflow option :	
Design hydrograph peak	12.59	cumecs		

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I n s t i t u t e o f H y d r o l o g y

UK DESIGN FLOOD ESTIMATION

Time Series data from estimate using the
Flood Studies Report rainfall-runoff method

Description : Rainworth Water at Rufford Lake
Printed on 25- 1-1990 at 14.32 Run Reference - RLAKE

Time hours	<-- Rainfall Total mm	Profile %	--> Net mm	Unit Hydrograph cumecs/cm per 100sq km	%	<---- Flow ANSF	Response cumecs	----> Total
								1.62← 03.30hr GMT
0.50	5.3	18.0	1.1	1.47	0.26	1.62	0.13	1.75
1.00	4.4	15.0	0.9	2.93	0.53	1.62	0.36	1.98
1.50	1.8	6.0	0.4	4.40	0.79	1.62	0.63	2.25
2.00	3.5	12.0	0.8	5.87	1.06	1.62	0.98	2.61
2.50	3.8	13.0	0.8	7.33	1.32	1.62	1.43	3.05
3.00	4.7	16.0	1.0	8.80	1.58	1.62	1.98	3.61
3.50	4.7	16.0	1.0	10.27	1.85	1.62	2.65	4.28
4.00	1.2	4.0	0.3	11.73	2.11	1.62	3.35	4.97
4.50				13.20	2.38	1.62	4.05	5.67
5.00				14.67	2.64	1.62	4.74	6.37
5.50				16.13	2.90	1.62	5.44	7.06
6.00				17.60	3.17	1.62	6.14	7.76
6.50				19.07	3.43	1.62	6.83	8.45
7.00				20.53	3.70	1.62	7.53	9.15
7.50				22.00	3.96	1.62	8.22	9.85
8.00				23.47	4.22	1.62	8.92	10.54
8.50				24.93	4.49	1.62	9.62	11.24
9.00				24.75	4.45	1.62	10.17	11.80
9.50				23.78	4.28	1.62	10.54	12.17
10.00				22.82	4.11	1.62	10.81	12.43
10.50				21.85	3.93	1.62	10.96	12.59
11.00				20.89	3.76	1.62	10.97	12.59
11.50				19.92	3.59	1.62	10.80	12.42
12.00				18.96	3.41	1.62	10.45	12.07
12.50				17.99	3.24	1.62	10.00	11.63
13.00				17.03	3.06	1.62	9.55	11.17
13.50				16.06	2.89	1.62	9.09	10.71
14.00				15.10	2.72	1.62	8.63	10.25
14.50				14.13	2.54	1.62	8.17	9.80
15.00				13.17	2.37	1.62	7.71	9.34
15.50				12.20	2.20	1.62	7.26	8.88
16.00				11.24	2.02	1.62	6.80	8.42
16.50				10.27	1.85	1.62	6.34	7.96
17.00				9.31	1.68	1.62	5.88	7.50
17.50				8.34	1.50	1.62	5.42	7.05
18.00				7.38	1.33	1.62	4.96	6.59
18.50				6.41	1.15	1.62	4.51	6.13
19.00				5.45	0.98	1.62	4.05	5.67
19.50				4.48	0.81	1.62	3.59	5.21
20.00				3.52	0.63	1.62	3.13	4.76
20.50				2.55	0.46	1.62	2.67	4.30
21.00				1.59	0.29	1.62	2.22	3.84
21.50				0.62	0.11	1.62	1.76	3.38
22.00						1.62	1.33	2.95
22.50						1.62	0.98	2.60
23.00						1.62	0.68	2.30
23.50						1.62	0.42	2.04
24.00						1.62	0.22	1.84
24.50						1.62	0.08	1.70
25.00						1.62	0.01	1.64

Description : Gallow Hole Dyke to confluence with Rainworth Wate
Printed on 25- 1-1990 at 12.10 Run Reference - GHDDD

A4.5

Convolution of user defined rainfall

			(UH option	1)
Unit hydrograph time to peak	8.4	hours	(TP option	0)
Data interval	0.50	hours		
Design storm duration	4.0	hours	(Dur option	0)
Design storm depth	29.20	mm.	(P option	0)
Design CWI	128.00		(CWI option	0)
Standard Percentage Runoff	47.00		(SPR option	2)
Percentage runoff	47.82	%	(PR option	1)
Response hydrograph peak	5.03	cumecs		
Baseflow	0.31	cumecs	(Baseflow option :	
Design hydrograph peak	5.34	cumecs		

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UK DESIGN FLOOD ESTIMATION

Time Series data from estimate using the
Flood Studies Report rainfall-runoff method

Description : Gallow Hole Dyke to confluence with Rainworth Wate
Printed on 25- 1-1990 at 12.10 Run Reference - GHDDD

Time	<-- Rainfall	-->		Unit		<---- Flow	---->	
	Total	Profile	Net	Hydrograph		ANSF	Response	Total
hours	mm	%	mm	cumecs/cm per 100sq km	%		cumecs	
								0.31 ← 03.30hr GMT
0.50	5.3	18.0	2.5	1.55	0.28	0.31	0.06	0.37
1.00	4.4	15.0	2.1	3.10	0.56	0.31	0.17	0.48
1.50	1.8	6.0	0.8	4.64	0.84	0.31	0.30	0.60
2.00	3.5	12.0	1.7	6.19	1.11	0.31	0.46	0.77
2.50	3.8	13.0	1.8	7.74	1.39	0.31	0.67	0.98
3.00	4.7	16.0	2.2	9.29	1.67	0.31	0.94	1.24
3.50	4.7	16.0	2.2	10.84	1.95	0.31	1.25	1.56
4.00	1.2	4.0	0.6	12.38	2.23	0.31	1.58	1.89
4.50				13.93	2.51	0.31	1.91	2.22
5.00				15.48	2.79	0.31	2.24	2.54
5.50				17.03	3.06	0.31	2.57	2.87
6.00				18.58	3.34	0.31	2.89	3.20
6.50				20.12	3.62	0.31	3.22	3.53
7.00				21.67	3.90	0.31	3.55	3.86
7.50				23.22	4.18	0.31	3.88	4.19
8.00				24.77	4.46	0.31	4.21	4.52
8.50				25.95	4.67	0.31	4.52	4.83
9.00				24.94	4.49	0.31	4.74	5.05
9.50				23.92	4.30	0.31	4.89	5.19
10.00				22.90	4.12	0.31	4.99	5.30
10.50				21.88	3.94	0.31	5.03	5.34
11.00				20.86	3.76	0.31	5.00	5.31
11.50				19.84	3.57	0.31	4.88	5.19
12.00				18.83	3.39	0.31	4.68	4.99
12.50				17.81	3.21	0.31	4.47	4.78
13.00				16.79	3.02	0.31	4.25	4.56
13.50				15.77	2.84	0.31	4.04	4.34
14.00				14.75	2.66	0.31	3.82	4.13
14.50				13.74	2.47	0.31	3.60	3.91
15.00				12.72	2.29	0.31	3.39	3.70
15.50				11.70	2.11	0.31	3.17	3.48
16.00				10.68	1.92	0.31	2.96	3.26
16.50				9.66	1.74	0.31	2.74	3.05
17.00				8.64	1.56	0.31	2.52	2.83
17.50				7.63	1.37	0.31	2.31	2.62
18.00				6.61	1.19	0.31	2.09	2.40
18.50				5.59	1.01	0.31	1.88	2.18
19.00				4.57	0.82	0.31	1.66	1.97
19.50				3.55	0.64	0.31	1.44	1.75
20.00				2.53	0.46	0.31	1.23	1.53
20.50				1.51	0.27	0.31	1.01	1.32
21.00				0.50	0.09	0.31	0.79	1.10
21.50						0.31	0.60	0.91
22.00						0.31	0.44	0.75
22.50						0.31	0.30	0.61
23.00						0.31	0.18	0.49
23.50						0.31	0.09	0.40
24.00						0.31	0.03	0.34
24.50						0.31	0.00	0.31

1 JUNE 1985L'4

A4.6

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Description : Rainworth Water at confluence with Gallow Hole Dyk
Printed on 25- 1-1990 at 12.22                     Run Reference - RWWWW
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Convolution of user defined rainfall
====================================
                                                   (UH option        1)
Unit hydrograph time to peak          8.4   hours (TP option        0)
Data interval                         0.50  hours

Design storm duration                 4.0   hours (Dur option       0)
Design storm depth                   29.20  mm.   (P  option        0)
Design CWI                          128.00        (CWI option       0)
Standard Percentage Runoff           12.96        (SPR option       2)
Percentage runoff                    14.89  %     (PR option        1)


Response hydrograph peak              6.12  cumecs
Baseflow                              1.19  cumecs
                                                  (Baseflow option :
                                    -------
Design hydrograph peak                7.32  cumecs
                                    =======
************************************************************************
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                         I n s t i t u t e   o f   H y d r o l o g y
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UK DESIGN FLOOD ESTIMATION

Time Series data from estimate using the
Flood Studies Report rainfall-runoff method

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************************************************************************

Description : Rainworth Water at confluence with Gallow Hole Dyk
Printed on 25- 1-1990 at 12.23                     Run Reference - RWWWW
------------------------------------------------------------------------
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1·19 ← 03·30 hr GMT

Time hours	<-- Rainfall Total mm	Profile %	--> Net mm	Unit Hydrograph cumecs/cm per 100sq km	%	<---- Flow ANSF	Response cumecs	----> Total
0.50	5.3	18.0	0.8	1.57	0.28	1.19	0.07	1.27
1.00	4.4	15.0	0.7	3.14	0.57	1.19	0.21	1.40
1.50	1.8	6.0	0.3	4.71	0.85	1.19	0.36	1.56
2.00	3.5	12.0	0.5	6.28	1.13	1.19	0.57	1.76
2.50	3.8	13.0	0.6	7.85	1.41	1.19	0.83	2.02
3.00	4.7	16.0	0.7	9.42	1.70	1.19	1.15	2.34
3.50	4.7	16.0	0.7	10.99	1.98	1.19	1.53	2.73
4.00	1.2	4.0	0.2	12.56	2.26	1.19	1.94	3.13
4.50				14.13	2.54	1.19	2.34	3.53
5.00				15.70	2.83	1.19	2.74	3.94
5.50				17.27	3.11	1.19	3.15	4.34
6.00				18.84	3.39	1.19	3.55	4.74
6.50				20.41	3.67	1.19	3.95	5.15
7.00				21.98	3.96	1.19	4.35	5.55
7.50				23.55	4.24	1.19	4.76	5.95
8.00				25.12	4.52	1.19	5.16	6.35
8.50				26.02	4.68	1.19	5.53	6.73
9.00				24.98	4.50	1.19	5.79	6.98
9.50				23.95	4.31	1.19	5.96	7.16
10.00				22.92	4.12	1.19	6.08	7.28
10.50				21.88	3.94	1.19	6.12	7.32
11.00				20.85	3.75	1.19	6.07	7.26
11.50				19.82	3.57	1.19	5.91	7.10
12.00				18.78	3.38	1.19	5.66	6.86
12.50				17.75	3.20	1.19	5.40	6.59
13.00				16.72	3.01	1.19	5.13	6.33
13.50				15.69	2.82	1.19	4.87	6.06
14.00				14.65	2.64	1.19	4.60	5.80
14.50				13.62	2.45	1.19	4.34	5.53
15.00				12.59	2.27	1.19	4.07	5.27
15.50				11.55	2.08	1.19	3.81	5.00
16.00				10.52	1.89	1.19	3.54	4.74
16.50				9.49	1.71	1.19	3.28	4.47
17.00				8.46	1.52	1.19	3.01	4.21
17.50				7.42	1.34	1.19	2.75	3.94
18.00				6.39	1.15	1.19	2.48	3.68
18.50				5.36	0.96	1.19	2.22	3.41
19.00				4.32	0.78	1.19	1.95	3.15
19.50				3.29	0.59	1.19	1.69	2.88
20.00				2.26	0.41	1.19	1.42	2.62
20.50				1.22	0.22	1.19	1.16	2.35
21.00				0.19	0.03	1.19	0.89	2.09
21.50						1.19	0.67	1.86
22.00						1.19	0.48	1.68
22.50						1.19	0.32	1.51
23.00						1.19	0.18	1.38
23.50						1.19	0.08	1.28
24.00						1.19	0.02	1.21
24.50						1.19	0.00	1.20

1 JUNE 1983 [2]

A4.7

Description : Rainworth Water at Rufford Lake
Printed on 25- 1-1990 at 14.36 Run Reference - RLAKE

Convolution of user defined rainfall

			(UH option 1)
Unit hydrograph time to peak	8.7	hours	(TP option 0)
Data interval	0.50	hours	
Design storm duration	3.0	hours	(Dur option 0)
Design storm depth	14.10	mm.	(P option 0)
Design CWI	149.50		(CWI option 0)
Standard Percentage Runoff	19.99		(SPR option 2)
Percentage runoff	26.77	%	(PR option 1)
Response hydrograph peak	6.60	cumecs	
Baseflow	2.16	cumecs	
			(Baseflow option :
Design hydrograph peak :	8.76	cumecs	

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I n s t i t u t e o f H y d r o l o g y

UK DESIGN FLOOD ESTIMATION

Time Series data from estimate using the
Flood Studies Report rainfall-runoff method

Description : Rainworth Water at Rufford Lake
Printed on 25- 1-1990 at 14.37 Run Reference - RLAKE

Time hours	<-- Rainfall Total mm	Profile %	--> Net mm	Unit Hydrograph cumecs/cm per 100sq km	%	ANSF	<---- Flow ----> Response cumecs	Total
								2.16 ← 1600hr GMT
0.50	2.5	18.0	0.7	1.47	0.26	2.16	0.08	2.24
1.00	5.4	38.0	1.4	2.93	0.53	2.16	0.31	2.47
1.50	0.0	0.0	0.0	4.40	0.79	2.16	0.54	2.71
2.00	0.0	0.0	0.0	5.87	1.06	2.16	0.78	2.94
2.50	1.6	11.0	0.4	7.33	1.32	2.16	1.06	3.22
3.00	4.7	33.0	1.2	8.80	1.58	2.16	1.48	3.64
3.50				10.27	1.85	2.16	1.90	4.06
4.00				11.73	2.11	2.16	2.32	4.48
4.50				13.20	2.38	2.16	2.74	4.90
5.00				14.67	2.64	2.16	3.16	5.32
5.50				16.13	2.90	2.16	3.58	5.74
6.00				17.60	3.17	2.16	3.99	6.16
6.50				19.07	3.43	2.16	4.41	6.57
7.00				20.53	3.70	2.16	4.83	6.99
7.50				22.00	3.96	2.16	5.25	7.41
8.00				23.47	4.22	2.16	5.67	7.83
8.50				24.93	4.49	2.16	6.09	8.25
9.00				24.75	4.45	2.16	6.42	8.58
9.50				23.78	4.28	2.16	6.54	8.70
10.00				22.82	4.11	2.16	6.57	8.73
10.50				21.85	3.93	2.16	6.60	8.76
11.00				20.89	3.76	2.16	6.56	8.74
11.50				19.92	3.59	2.16	6.37	8.54
12.00				18.96	3.41	2.16	6.10	8.26
12.50				17.99	3.24	2.16	5.82	7.98
13.00				17.03	3.06	2.16	5.55	7.71
13.50				16.06	2.89	2.16	5.27	7.43
14.00				15.10	2.72	2.16	5.00	7.16
14.50				14.13	2.54	2.16	4.72	6.88
15.00				13.17	2.37	2.16	4.44	6.60
15.50				12.20	2.20	2.16	4.17	6.33
16.00				11.24	2.02	2.16	3.89	6.05
16.50				10.27	1.85	2.16	3.62	5.78
17.00				9.31	1.68	2.16	3.34	5.50
17.50				8.34	1.50	2.16	3.07	5.23
18.00				7.38	1.33	2.16	2.79	4.95
18.50				6.41	1.15	2.16	2.51	4.67
19.00				5.45	0.98	2.16	2.24	4.40
19.50				4.48	0.81	2.16	1.96	4.12
20.00				3.52	0.63	2.16	1.69	3.85
20.50				2.55	0.46	2.16	1.41	3.57
21.00				1.59	0.29	2.16	1.14	3.30
21.50				0.62	0.11	2.16	0.86	3.02
22.00						2.16	0.60	2.76
22.50						2.16	0.41	2.57
23.00						2.16	0.29	2.45
23.50						2.16	0.17	2.33
24.00						2.16	0.06	2.22

Description : Gallow Hole Dyke to confluence with Rainworth Wate
Printed on 25- 1-1990 at 12.06 Run Reference - GHDDD

A4.8

Convolution of user defined rainfall

			(UH option	1)
Unit hydrograph time to peak	8.4	hours	(TP option	0)
Data interval	0.50	hours		
Design storm duration	3.0	hours	(Dur option	0)
Design storm depth	10.00	mm.	(P option	0)
Design CWI	149.50		(CWI option :	0)
Standard Percentage Runoff	47.00		(SPR option :	2)
Percentage runoff	53.18	%	(PR option	1)

Response hydrograph peak	1.91	cumecs	
Baseflow	0.42	cumecs	
			(Baseflow option :
Design hydrograph peak	2.33	cumecs	

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I n s t i t u t e o f H y d r o l o g y

UK DESIGN FLOOD ESTIMATION

Time Series data from estimate using the
Flood Studies Report rainfall-runoff method

Description : Gallow Hole Dyke to confluence with Rainworth Wate
Printed on 25- 1-1990 at 12.06 Run Reference - GHDDD

Time hours	<-- Rainfall Total mm	Profile %	--> Net mm	Unit Hydrograph cumecs/cm per 100sq km	%	ANSF	<---- Flow Response cumecs	----> Total
								0·42 @ 16.00hr GMT
0.50	1.8	18.0	1.0	1.55	0.28	0.42	0.02	0.44
1.00	3.8	38.0	2.0	3.10	0.56	0.42	0.09	0.51
1.50	0.0	0.0	0.0	4.64	0.84	0.42	0.16	0.58
2.00	C.0	0.0	0.0	6.19	1.11	0.42	0.23	0.65
2.50	1.1	11.0	0.6	7.74	1.39	0.42	0.32	0.73
3.00	3.3	33.0	1.8	9.29	1.67	0.42	0.44	0.86
3.50				10.84	1.95	0.42	0.57	0.98
4.00				12.38	2.23	0.42	0.69	1.11
4.50				13.93	2.51	0.42	0.82	1.23
5.00				15.48	2.79	0.42	0.94	1.36
5.50				17.03	3.06	0.42	1.07	1.48
6.00				18.58	3.34	0.42	1.19	1.61
6.50				20.12	3.62	0.42	1.32	1.73
7.00				21.67	3.90	0.42	1.44	1.86
7.50				23.22	4.18	0.42	1.57	1.98
8.00				24.77	4.46	0.42	1.69	2.11
8.50				25.95	4.67	0.42	1.81	2.23
9.00				24.94	4.49	0.42	1.89	2.30
9.50				23.92	4.30	0.42	1.90	2.31
10.00				22.90	4.12	0.42	1.91	2.32
10.50				21.88	3.94	0.42	1.91	2.33
11.00				20.86	3.76	0.42	1.89	2.31
11.50				19.84	3.57	0.42	1.81	2.22
12.00				18.83	3.39	0.42	1.72	2.14
12.50				17.81	3.21	0.42	1.64	2.06
13.00				16.79	3.02	0.42	1.56	1.98
13.50				15.77	2.84	0.42	1.48	1.89
14.00				14.75	2.66	0.42	1.40	1.81
14.50				13.74	2.47	0.42	1.31	1.73
15.00				12.72	2.29	0.42	1.23	1.65
15.50				11.70	2.11	0.42	1.15	1.56
16.00				10.68	1.92	0.42	1.07	1.48
16.50				9.66	1.74	0.42	0.98	1.40
17.00				8.64	1.56	0.42	0.90	1.32
17.50				7.63	1.37	0.42	0.82	1.24
18.00				6.61	1.19	0.42	0.74	1.15
18.50				5.59	1.01	0.42	0.65	1.07
19.00				4.57	0.82	0.42	0.57	0.99
19.50				3.55	0.64	0.42	0.49	0.91
20.00				2.53	0.46	0.42	0.41	0.82
20.50				1.51	0.27	0.42	0.33	0.74
21.00				0.50	0.09	0.42	0.24	0.66
21.50						0.42	0.17	0.58
22.00						0.42	0.12	0.53
22.50						0.42	0.08	0.50
23.00						0.42	0.04	0.46
23.50						0.42	0.01	0.43

1 JUNE 1983 [2]

A4.9

Description : Rainworth Water at confluence with Gallow Hole Dyk
Printed on 25- 1-1990 at 12.19 Run Reference - RWWWW

Convolution of user defined rainfall

			(UH option	1)
Unit hydrograph time to peak	8.4	hours	(TP option	0)
Data interval	0.50	hours		
Design storm duration	3.0	hours	(Dur option :	0)
Design storm depth	15.00	mm.	(P option :	0)
Design CWI	149.50		(CWI option :	0)
Standard Percentage Runoff	12.96		(SPR option	2)
Percentage runoff	20.15	%	(PR option	1)
Response hydrograph peak	4.25	cumecs		
Baseflow	1.61	cumecs		
			(Baseflow option :	
Design hydrograph peak	5.86	cumecs		

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Institute of Hydrology

UK DESIGN FLOOD ESTIMATION

Time Series data from estimate using the
Flood Studies Report rainfall-runoff method

Description : Rainworth Water at confluence with Gallow Hole Dyk
Printed on 25- 1-1990 at 12.20 Run Reference - RWWWW

Time hours	<-- Rainfall Total mm	Profile %	--> Net mm	Unit Hydrograph cumecs/cm per 100sq km	%	ANSF	<---- Flow ----> Response cumecs	Total
								1.61←16.00 hr GMT
0.50	2.7	18.0	0.5	1.57	0.28	1.61	0.05	1.66
1.00	5.7	38.0	1.1	3.14	0.57	1.61	0.21	1.82
1.50	0.0	0.0	0.0	4.71	0.85	1.61	0.36	1.98
2.00	0.0	0.0	0.0	6.28	1.13	1.61	0.52	2.13
2.50	1.6	11.0	0.3	7.85	1.41	1.61	0.71	2.32
3.00	5.0	33.0	1.0	9.42	1.70	1.61	0.99	2.60
3.50				10.99	1.98	1.61	1.27	2.88
4.00				12.56	2.26	1.61	1.55	3.16
4.50				14.13	2.54	1.61	1.83	3.44
5.00				15.70	2.83	1.61	2.11	3.72
5.50				17.27	3.11	1.61	2.39	4.00
6.00				18.84	3.39	1.61	2.67	4.28
6.50				20.41	3.67	1.61	2.95	4.56
7.00				21.98	3.96	1.61	3.23	4.84
7.50				23.55	4.24	1.61	3.51	5.12
8.00				25.12	4.52	1.61	3.79	5.40
8.50				26.02	4.68	1.61	4.05	5.66
9.00				24.98	4.50	1.61	4.20	5.81
9.50				23.95	4.31	1.61	4.22	5.83
10.00				22.92	4.12	1.61	4.24	5.85
10.50				21.88	3.94	1.61	4.25	5.86
11.00				20.85	3.75	1.61	4.17	5.79
11.50				19.82	3.57	1.61	3.99	5.60
12.00				18.78	3.38	1.61	3.81	5.42
12.50				17.75	3.20	1.61	3.62	5.23
13.00				16.72	3.01	1.61	3.44	5.05
13.50				15.69	2.82	1.61	3.25	4.87
14.00				14.65	2.64	1.61	3.07	4.68
14.50				13.62	2.45	1.61	2.88	4.50
15.00				12.59	2.27	1.61	2.70	4.31
15.50				11.55	2.08	1.61	2.52	4.13
16.00				10.52	1.89	1.61	2.33	3.94
16.50				9.49	1.71	1.61	2.15	3.76
17.00				8.46	1.52	1.61	1.96	3.58
17.50				7.42	1.34	1.61	1.78	3.39
18.00				6.39	1.15	1.61	1.59	3.21
18.50				5.36	0.96	1.61	1.41	3.02
19.00				4.32	0.78	1.61	1.23	2.84
19.50				3.29	0.59	1.61	1.04	2.65
20.00				2.26	0.41	1.61	0.86	2.47
20.50				1.22	0.22	1.61	0.67	2.29
21.00				0.19	0.03	1.61	0.49	2.10
21.50						1.61	0.33	1.95
22.00						1.61	0.24	1.85
22.50						1.61	0.16	1.77
23.00						1.61	0.08	1.69
23.50						1.61	0.01	1.62


GALLOW HOLE DYKE CATCHMENT BOUNDARY
RAINWORTH WATER CATCHMENT BOUNDARY
GALLOW HOLE DYKE
RAINWORTH WATER
RUFFORD LAKE
LOCAL BOUNDARY
NEWARK DISTRICT
MANSFIELD
MANSFIELD WOODHOUSE
SOUTHWELL
Rainworth
Bilsthorpe
Edwinstowe
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The **Institute of Hydrology** is a component establishment of the UK Natural Environment Research Council, grant-aided from Government by the Department of Education and Science. For over 20 years the Institute has been at the forefront of research exploration of hydrological systems within complete catchment areas and into the physical processes by which rain or snow is transformed into flow in rivers. Applied studies, undertaken both in the UK and overseas, ensures that research activities are closely related to practical needs and that newly developed methods and instruments are tested for a wide range of environmental conditions.

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● FRESHWATER BIOLOGICAL ASSOCIATION
The Ferry House, Far Sawrey
Ambleside, Cumbria LA22 0LP
Tel: 09662 2468 Fax: 6914
Telex: 8950511 ONEONE G
REF 16173001

○ The River Laboratory
East Stoke, Wareham
Dorset BH20 6BB
Tel: 0929 462314 Fax: 462180
Telex: 8950511 ONEONE G
REF 16174001

■ INSTITUTE OF HYDROLOGY
Wallingford, Oxon OX10 8BB
Tel: 0491 38800 Fax: 32256 Telex: 849365

□ Plynlimon Office
Staylittle, Llanbrynmair
Powys SY19 7DB
Tel: 05516 652

INSTITUTE OF TERRESTRIAL ECOLOGY

▲ Edinburgh Research Station
Bush Estate, Penicuik, Midlothian EH26 0QB
Tel: 031-445 4343 Fax: 3943 Telex: 72579

△ Banchory Research Station
Hill of Brathens, Glassel
Banchory, Kincardineshire AB3 4BY
Tel: 03302 3434 Fax: 3303 Telex: 739396

△ Merlewood Research Station
Grange-over-Sands, Cumbria LA11 6JU
Tel: 04484 2264 Fax: 4705 Telex: 65102

▲ Monks Wood Experimental Station
Abbots Ripton, Huntingdon, Cambs PE17 2LS
Tel: 04873 381 Fax: 467 Telex: 32416

△ Bangor Research Station
Penrhos Road, Bangor, Gwynedd LL57 2LQ
Tel: 0248 364001 Fax: 355365 Telex: 61224

△ Furzebrook Research Station
Wareham, Dorset BH20 5AS
Tel: 0929 51518 Fax: 51087

♦ INSTITUTE OF VIROLOGY
Mansfield Road, Oxford OX1 3SR
Tel: 0865 512361 Fax: 59962 Telex: 83147

★ UNIT OF COMPARATIVE PLANT ECOLOGY
Dept of Plant Sciences, Sheffield University, Sheffield S10 2TN
Tel: 0742 768555 Fax: 760159 Telex: 547216

◆ UNIT OF WATER RESOURCES SYSTEMS RESEARCH
Dept of Civil Engineering
Newcastle University
Newcastle upon Tyne NE1 7RU
Tel: 091-232 8511 Fax: 261 0191 Telex: 53654

▼ DIRECTORATE OF TERRESTRIAL & FRESHWATER SCIENCES
Natural Environment Research Council
Polaris House, North Star Avenue
Swindon SN2 1EU
Tel: 0793 40101 Fax: 511117 Telex: 444293

DIRECTORATE OF TERRESTRIAL & FRESHWATER SCIENCES

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