Probable Maximum Flood Study for Kielder Dam

Institute of Hydrology
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Probable Maximum Flood Study for Kielder Dam

1. Introduction

In February 1990, Northumbrian Water Ltd commissioned the Institute of Hydrology (IH) to undertake a review of the spillway flood for Kielder dam. Although previous estimates of the spillway flood had been carried out by Babtie, Shaw and Morton, the dam's designers, and by the Northumbrian Water Authority, these studies had not attempted to make full use of all available rainfall and flow data. The aim of the current study was that as much local hydrological data as possible should be utilised in order to derive the best possible estimate of the spillway flood for the reservoir and dam.

A visit was made to the dam by staff of IH on 12 February, and to offices of the NRA on 13 February for discussions on earlier work and for preliminary data collection. An additional visit was made to the NRA at the end of February to collect hourly rainfall and 15 minute stage data for selected events.

The method of flood estimation adopted was that of the Flood Studies Report (FSR) (NERC 1975), following the recommendations of the Institution of Civil Engineers (ICE) report "Floods and Reservoir Safety", second edition (1989). This involves estimation of the spillway flood by means of the unit hydrograph model.

Kielder is classed as a category A reservoir, where a breach would endanger downstream communities. Consequently the appropriate design standard should be the Probable Maximum Flood (PMF). The rainfall input should thus be the Probable Maximum Precipitation, or PMP, from the FSR.

The current study attempted to make full use of all available hydrological data in order to derive the best possible estimate of the Probable Maximum Flood for Kielder.

1.1 PROBABLE MAXIMUM FLOOD ESTIMATION

"Floods and Reservoir Safety", a guide produced by the Institution of Civil Engineers (1989) specifies that for 'Reservoirs where a breach will endanger lives in a community' the dam is classified Category A and the spillway must be capable of passing the Probable Maximum Flood. The term 'Probable Maximum Flood' (PMF) defies precise definition as it is difficult to perceive of an ultimate ceiling on flood magnitude. For practical purposes PMF has been specified by the analysis of major historical UK floods and rainfall.

The Interim Report of the Committee on Floods in Relation to Reservoir

Practice of 1933 included an empirical curve of discharge per unit area against drainage area drawn through the largest floods recorded in the UK. The curve defined the Normal Maximum Flood (NMF). Spillways were often designed to convey twice NMF depending on the risk posed by the dam. The original design for Kielder Reservoir adopted a design flood inflow of approximately 1.4 times NMF, and twice NMF to check the effect on the dam structures of a catastrophic inflow.

As part of the FSR a more physically based method for estimating the maximum flood on UK catchments was developed, founded on the philosophy that the design procedure should define an event which combines the worst possible circumstances. This includes the PMP falling on a saturated or frozen catchment, often combined with melting snow. Excess rainfall is transformed into runoff using a unit hydrograph with a shortened response time.

1.1.1 Probable Maximum Precipitation

The procedure for defining the maximum rainfall was derived by analysis of major historical UK storms of 2 and 24 hours duration. Each storm was assessed in terms of its efficiency ie the ratio of rainfall to amount of precipitable water in a representative column of air. Rainfall depths for each storm were then adjusted upwards to approximate maximum storm efficiency. These revised figures were in turn used to derive maps of maximum 2 and 24 hour rainfalls for the UK. To define maximum rainfalls of other durations, the maximum growth factors resulting from the analysis of rainfalls of 5 year return period were adopted. Thus, although the derived PMP has some theoretical basis, it is based primarily on a few large recorded rainfall events.

The design rainfall profile is symmetrical and contains the maximum rainfall in every duration centred at the peak. To achieve this the central hour of the design storm (where the data interval adopted is one hour) has a depth equal to the maximum one hour rainfall, whilst the central three hours contain the maximum three hour rainfall. Consequently, the two hours on either side of the central hour each contain half the three hour maximum rainfall minus the one hour maximum rainfall ie 0.5(max3hr - max 1hr). This process is continued until the design storm duration has been reached. Clearly the duration must be an odd number of hours (or time ordinates).

The resultant storm thus approximates to a core representative of the maximum rainfall from a summer thunderstorm event embedded inside the maximum rainfall from a winter frontal storm. The method does not attempt to reproduce any observed event but is merely a synthetic design input. It has suffered from the criticism of being unreasonable. To overcome some of these criticisms, with approval from the Meteorological Office, the Institution of Civil Engineers published a refinement to the original procedure, to estimate PMP values separately for summer and winter. To effect this, it was assumed that these seasonal PMPs are in the same ratio as the 100 year rainfalls.

1.1.2 Snowmelt

Although the UK experiences few purely snowmelt floods, melting snow has often combined with heavy rainfall to produce flooding, such as in southern England in 1947. It is therefore necessary to include a snowmelt contribution when combining the worst possible circumstances. A physically derived maximum snowmelt rate was not defined in the FSR, but 42 mm/day (1.75 mm/hr) was felt to be suitable for design purposes. However, the experience of Northumbrian Water has suggested that the melt rate may reach 120 mm/day (5.0 mm/hr).

The probability of there being sufficient snow lying to sustain the maximum rate for long durations was also considered. The FSR contains a map of average annual snow depth exceeded once in two years. Assuming that the ratio of 2 to 100 year snow depths and the average density of snow are self cancelling, this map approximates the 100 year depth of water equivalent. It was recommended that the maximum melt rate combined with a 100 year depth is a suitably rare occurrence for design purposes, particularly when combined with the maximum rainfall. Jackson (1977) provides a refined method of estimating the 100 year water depth equivalent of snow.

1.1.3 Unit Hydrograph

In the PMF method a unit hydrograph is used to transform excess rainfall into response runoff. This is a linear model, and the FSR defines it using one parameter, the time-to- peak, Tp, which indicates the speed of response of the catchment and is found to be closely related to catchment lag time. Tp may be calculated from observed events for which both rainfall and runoff data are available, or from equations linking the instantaneous time to peak, Tp(0), to the physical characteristics of the catchment. The physical characteristics found to be most strongly related to Tp are mainstream length, slope, average annual rainfall and urban fraction:

$$Tp(0) = 283.0\ S1085^{-0.33}\ (1 + URBAN)^{-2.16}\ SAAR^{-0.54}\ MSL^{0.23}$$

The T hour Tp is then given by:

$$Tp(T) = Tp(0) + T/2$$

Length and slope are clearly dominant factors influencing the speed of response of the catchment. Average annual rainfall by contrast is a surrogate variable indexing drainage density and altitude. Tp has an indirect effect on the resulting flood magnitude.

In order to be conservative or cautious, it is recommended that estimates of Tp are reduced to two-thirds of this value for the PMF (where 2/3 is the average ratio of minimum to mean Tp for UK catchments).

1.1.4 Percentage Runoff

The proportion of rainfall which contributes to flood runoff is expressed as the percentage runoff, PR. This is a most important parameter as it has a direct scaling influence over the magnitude of the resulting response runoff flood peak. The design PR is derived from two components of runoff production. Firstly, a catchment is assumed to have associated with it a fixed value called the standard percentage runoff, SPR, which is a function of catchment characteristics, such as soil cover, and which is fixed for all storm types. Secondly, a variable or dynamic runoff component, DPR, which is a function of storm magnitude and antecedent conditions is considered. This DPR is greater for the extreme storms such as the PMF.

Thus the PR is the sum of the fixed SPR and a variable DPR:

$$PR = SPR + DPR$$

When no observed values of SPR are available for a catchment, an indirect method is provided based on soil type. For the FSR soils were divided into five classes on the basis of their ability to accept winter rainfall. Class 1 contains well drained soils such as chalk. Catchments underlain by soils of this type are assumed to have an SPR of 10%. In most upland areas of the UK, where soils are predominantly underlain by impermeable geology, the soil is defined as class 5 and SPR is given as 53%. The value for any catchment is calculated as a weighted average of the different soil types underlying the catchment:

$$SPR = 10S1 + 30S2 + 37S3 + 47S4 + 53S5$$

The catchments around Kielder Reservoir are underlain totally by soils of class 5, thus SPR is constant at 53%.

The variation observed in PR between different events is accommodated by the incorporation of the dynamic component, which itself has two parts. PR would be expected to be high when the antecedent catchment conditions are wet, and lower when they are dry. Hence the parameter DPRcwi varies according to the Catchment Wetness Index, (CWI) of the form:

$$DPRcwi = 0.25\ (CWI-125)$$

PR is also assume to depend on the depth of rainfall (P). To model this the parameter DPRrain is defined as:

$$DPRrain = 0.45\ (P-40)^{0.7} \text{ when } P > 40 \text{ mm}$$

The design PR is then calculated by combining these three components:

PR = SPR + DPRcwi + DPRrain

1.1.5 Frozen Ground

An additional factor which may be included to produce a more severe combination of circumstance is frozen ground. However, in the PMF model, frozen ground is given a value of SPR of 53% ie the same as that for catchments underlain by class 5 soils, such as Kielder. Consequently, in the no data situation, assuming frozen ground would make no difference to estimates of PMF for the Kielder Reservoir catchment and so was not adopted.

As will be shown later, the adopted SPR for the Kielder catchment exceeds the 53% which would be assumed for frozen ground, hence this possible adjustment to SPR is not recommended for the present studies.

1.1.6 Use of Local Data

The FSR recommends that even where no rainfall-runoff data are available for a catchment under study, data from similar catchments nearby should be used to adjust parameter estimates. The suggested method involves evaluating the differences between Tp and SPR derived from observed data, and those derived from the physical characteristics of the catchment. This ratio can then be used to adjust estimates derived for the ungauged study catchment.

The primary aim of the current study was to analyse relevant local rainfall and riverflow data in order to derive the best possible estimates of Tp and SPR.

2. Data available

In this study data were required for several significant storm events. Table 2.1 lists the dates of the events selected. The locations of flow gauging stations and autographic and daily raingauges, from which data records were obtained, are shown in Figure 2.1.

2.1 RAINFALL

Hourly autographic raingauge records were made available by Northumbrian NRA. The records from four gauges were used: Catcleugh Nursery, Kielder

Location map

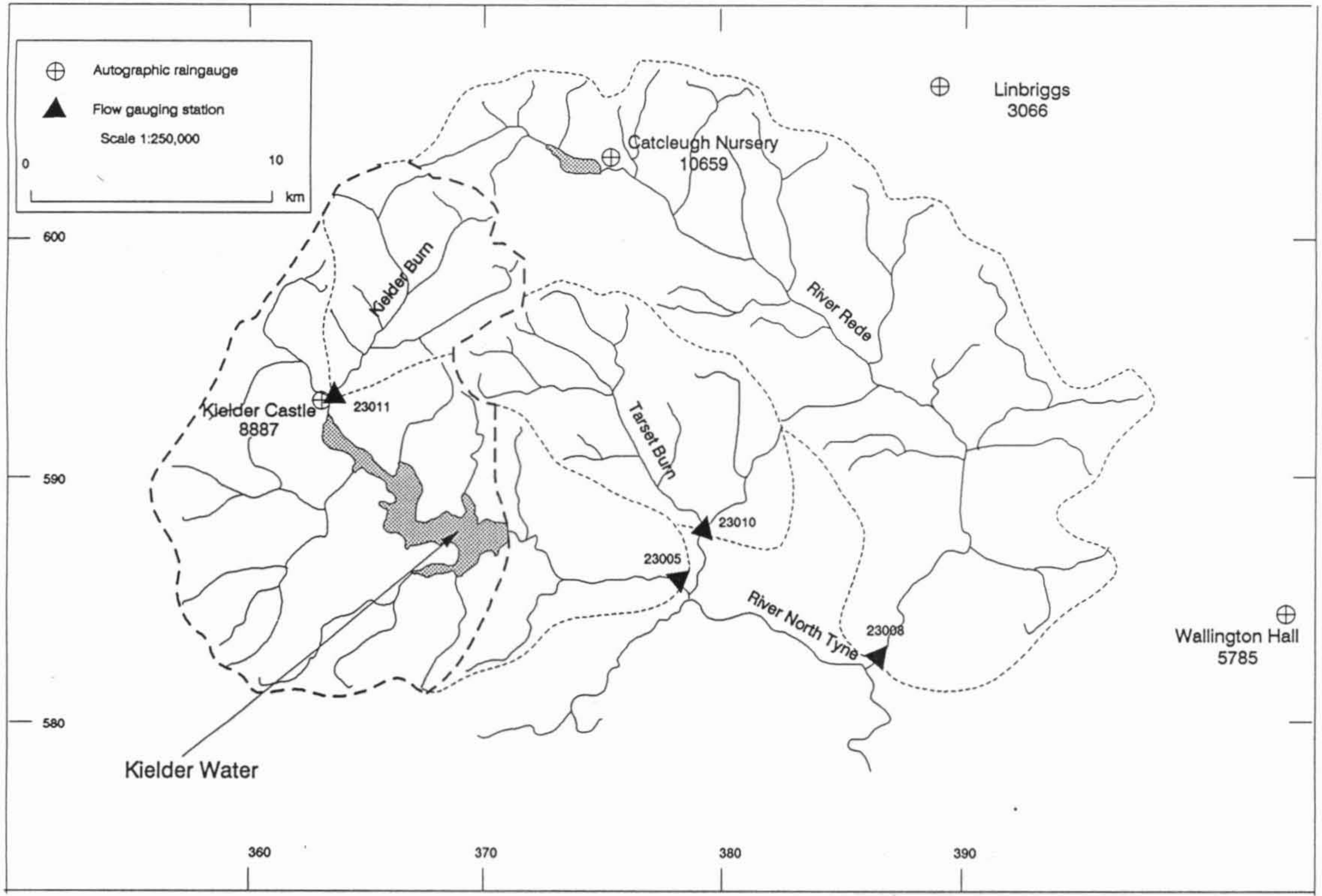

Figure 2.1

Castle, Linbriggs and Wallington Hall. Kielder Castle lies within the Kielder Burn catchment, but data from this gauge were only available until 1980. Catcleugh Nursery lies in the Rede catchment, but being the closest working autographic gauge post-1980, was used as the principle source of hourly rainfall estimates for the Kielder Burn catchment. Linbriggs and Wallington Hall were used together with Catcleugh Nursery for the Rede catchment. Rainfalls for the Tarset Burn at Greenhaugh and North Tyne at Tarset catchments were estimated using the Kielder Castle and Catcleugh Nursery gauges.

Daily rainfall values from raingauges located in or close to the catchments were obtained from the IH archives, with data supplied by the Meteorological Office.

Table 2.1 Events used in the analysis (Date represents the start of the flow data used for the event)

	Catchment			
Date	23005	23008	23010	23011
16.10.67				
01.11.67				
12.09.68				
17.09.68				
30.10.70				
16.03.72				
11.05.72				
08.11.72				
03.05.73				
10.11.74				
22.02.76				
25.12.79				
13.12.80				
22.11.81				
23.12.83				
12.01.84				
25.03.84				
06.05.86				
25.08.86				
18.10.88				
29.11.88				

2.2 RIVERFLOW

Fifteen minute stage values were provided by Northumbrian NRA for four stations: Kielder Burn at Kielder (23011), Tarset Burn at Greenhaugh

(23010), the Rede at Rede Bridge (23008), and the North Tyne at Tarset (23005). The Tarset Burn at Greenhaugh gauge was decommissioned in January 1980. Stages for selected events were converted to hourly flows because the catchment response times did not justify the use of 15 minute data. The conversions were obtained using rating equations from the IH Surface Water Archive, and checked against those used by the NRA. The equations used are listed in Table 2.2.

Table 2.2 Details of Rating Curves used

h(m)	Rating
(i) North Tyne at Tarset (23005)	
0. - 0.315	$Q = 65.715\ h^{2.408}$
0.316 2.000	$Q = 44.088\ (h-0.112)^{1.494}$
2.001 - 4.000	$Q = 33.638\ h^{1.760}$
(ii) Rede at Rede Bridge (23008)	
0. - 0.610	$Q = 44.000\ h^{2.690}$
0.611 1.157	$Q = 33.000\ h^{2.108}$
1.158 - 2.500	$Q = 34.400\ h^{1.923}$
(iii) Tarset Burn at Greenhaugh (23010)	
0. - 0.522	$Q = 28.094\ h^{4.034}$
0.523 - 1.292	$Q = 10.200\ h^{2.4756}$
1.293 - 2.500	$Q = 11.734\ h^{1.9289}$
(iv) Kielder Burn at Kielder (23011)	
0. - 0.303	$Q = 49.500\ h^{2.716}$
0.304 0.608	$Q = 27.050\ h^{2.210}$
0.609 - 2.000	$Q = 22.530\ h^{1.842}$

2.3 SNOWMELT

A record of observations of snow at the NRA's Kielder Ridge End Station, and also the annual snow reports published by the Meteorological Office, were used to ensure that all events were chosen in snow free periods, thus avoiding the complications of snowmelt.

2.4 SOIL MOISTURE DEFICIT (SMD)

Estimates of SMD at the beginning of each event were obtained from the Meteorological Office.

2.5 RESERVOIR LEVELS

A record of reservoir levels measured at 9am each day was available from 1982 onwards. Also available were several short periods of water levels recorded at 15 minute intervals on punched tape. For two periods of this record, which coincided with chosen storm events, hourly reservoir levels were abstracted by hand in an attempt to deduce inflows by the use of the reservoir elevation-volume relationship.

However, it was found that correlation between rainfall and reservoir level rise was not good. This is mainly because the relatively large surface area of the reservoir leads to an insensitive elevation-volume relationship. Hence, this check on reservoir inflows was deemed to be too inaccurate for the current study.

2.6 CATCHMENT CHARACTERISTICS

These were abstracted for the Kielder Reservoir catchment, that is the catchment above the dam, and the Kielder Burn catchment, that is the catchment of the main tributary flowing into the reservoir (see Figure 2.1). Values were obtained in accordance with the methods of the FSR from topographic (1:25000) maps and the FSR maps. Characteristics for the other gauged catchments were obtained from IH Report no. 94 (Boorman, 1985) and the IH Surface Water Archive. The values are listed in Table 2.3.

Table 2.3 Catchment characteristics

Catchment	Area km^2	MSL km	S1085 mkm^{-1}	SAAR mm	SOIL	URB %	LAKE %	M5-2D mm	
North Tyne at Tarset (23005)	285.0	36.3	4.85	1255	0.5	0.0	0.0	69.7	0.24
Rede at Rede Bridge (23008)	343.0	39.9	3.76	1002	0.5	0.0	0.0	61.0	0.30
Tarset Burn at Greenhaugh (23010)	96.0	15.3	16.16	1035	0.5	0.0	0.0	60.4	0.27
Kielder Burn at Kielder (23011)	85.6	16.4	14.88	1370	0.5	0.0	0.0	72.0	0.24
Kielder Reservoir	241.5	31.9	4.36	1370	0.5	0.0	0.0	68.0	0.24

2.7 ADDITIONAL DATA

Additional events, summarised in IH Report no. 94 (Boorman, 1985), were used to supplement the data for the North Tyne at Tarset and Tarset Burn at Greenhaugh catchments. Six events were available for each catchment, all prior to 1978.

3. Reservoir characteristics

3.1 SPILLWAY RATING

Kielder has a side-overflow spillway on the northern abutment of the dam, which flows into a rectangular concrete channel. There were some doubts over the adequacy of the spillway and stilling basin, and a physical model test was carried out by Wimpey Laboratories Ltd and reported on in 1972. As part of this work, the spillway rating was checked, partly because there were doubts about the validity of this rating for high flows, when the spillway was believed to drown.

The spillway rating could be checked fairly directly using records of flow at the Uglydub station just downstream if, and when, the reservoir ever spills. However, to date there has been no significant spill from Kielder reservoir and so this possible check mechanism, using Uglydub, has not been of much practicable use.

The Wimpey report contains a fundamental error in that the spillway sill level is quoted as being at 185.00 m, when it is in fact at 185.20 m for chainage 0 46 m, and at 185.40 m for chainage 46 - 185 m. In the Wimpey report, the spillway rating is presented as an indifferent quality plot of Q against H in Figure 3, and in tabular form in Tables I and II. The first set of results were derived using a 1:50 scale models whilst the second set are from a more accurate 1:5 model, but relate to the higher crest-level spillway only. Thus establishing the true spillway rating from the presented data is far from straightforward. Our best interpretation of the Wimpey results is given on Figure 3.1, which shows the ratings from various sources.

Subsequently, in 1976, a second study of the spillway flow characteristics was undertaken by Prof J. Ellis of the University of Strathclyde, looking primarily at the problems of the performance of the spillway under drowned conditions. Like the earlier Wimpey report, the spillway rating relationship is presented only as a poor quality diagram, which is Figure 3 in the Ellis report. However, the rating derived by Wimpey was essentially shown to be valid by the later Ellis report for flows up to some 800 to 900 $m^3 s^{-1}$, provided the correction of 0.20 m was allowed for. The rating derived by Ellis is reproduced here on Figure 3.1.

The two sets of ratings were studied by Northumbrian Water Authority during their earlier review of the Kielder spillway flood and were converted to logarithmic equations. This re- worked rating is also shown on Figure 3.1 and listed below as Table 3.1. This set of logarithmic ratings was used for the present studies.

Table 3.1 Spillway rating equations used (obtained from NRA)

Headway over Spillway (m)		Equation
0.0	to 0.253	$Q = 274.00\ h^{1.126}$
0.253	to 1.0	$Q = 376.00\ h^{1.356}$
1.0	to 1.2	$Q = 376.00\ h^{1.541}$
1.2	to 1.7	$Q = 365.30\ h^{1.699}$
>1.7		$Q = 748.74\ h^{0.3467}$

Kielder Dam PMF Study - Comparison of spillway ratings

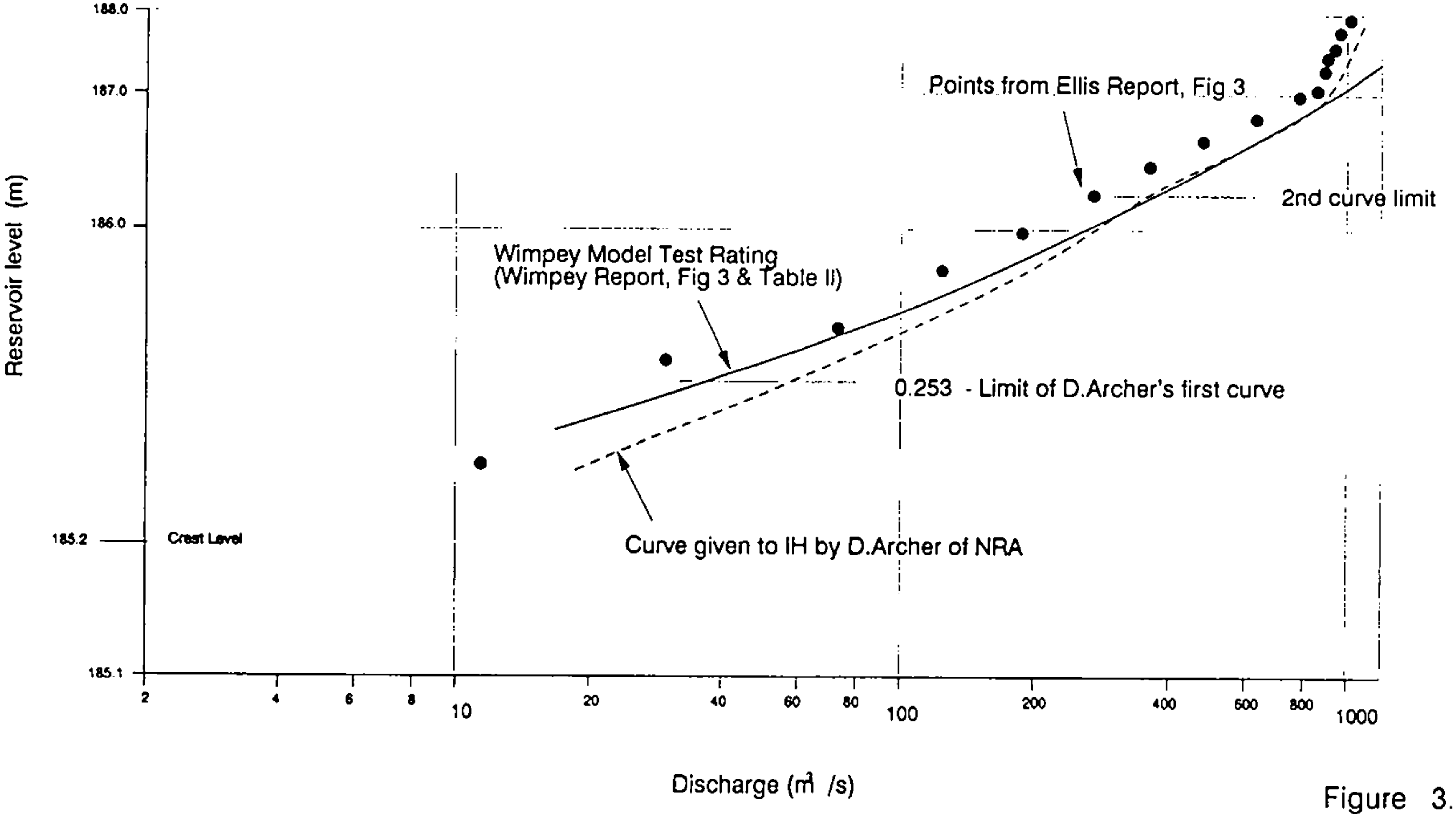

Figure 3.1

3.2 OUTFLOW FACILITIES

In addition to the spillway, water may be released from the reservoir through a range of outflow facilities. These comprise a 2 m diameter draw-off pipe and a 2.9 m diameter scour pipe which are cross-connected at two points and which discharge to the stilling basin via a series of valves. The discharge of these valves is indicated below.

Table 3.2 Assumed discharge of outflow facilities

Outlet Facility	Maximum capacity m^3s^{-1}
FD1	53.5
FD2-1	15.7
FD2-2	14.6
SDV1	3.0
Total	86.8

During a major flood, such as the PMF, it is possible that water might be discharged through some or all of the available low-level outflow facilities to help prevent water level rising excessively in the reservoir. Because of the fact that the spillway appears to drown at high discharges, there may be some merit in utilising these various alternative outflow facilities.

In order to test this option, a number of model runs were undertaken with a controlled outflow of 86.8 m^3 s^{-1}, the maximum theoretical discharge rate, and other runs with an outflow of 68.1 m^3 s^{-1}, assuming releases through valves FD1 and FD2-2 only. Results are presented later.

3.3 LEVEL-CAPACITY RELATIONSHIP

At full capacity the area of Kielder reservoir is 10.86 km^2. A detailed level-capacity curve was not available. However, the increase in surface area for the limited range of level being considered is relatively small and from examination of the 1:25,000 scale maps, an area growth rate of 0.29 km^2m^{-1} was assumed. A level-capacity relationship was developed for reservoir routing studies based on an area of 10.86 km^2 at water level 185.2 m, and with a slope of the level-area curve of 0.29 km^2m^{-1}

It was felt that this assumed level-capacity relationship is sufficiently accurate for the current study.

4. Unit hydrograph analyses on local catchments

In order to run the FSR unit hydrograph-losses derivation programs it is necessary to have for each event:

i) hourly flow data,

ii) hourly rainfall data,

iii) daily rainfall data for the storm (and for the 5 days prior to the event),

iv) measured SMD at 9.00 am on the first day of the event.

4.1 RAINFALL

Each daily rainfall gauge is weighted according to its location with respect to the catchment (Jones, 1983). The hourly gauges are weighted in the same way, and then for each gauge, each hour is expressed as a proportion of the total event rainfall at that gauge. For each hour in turn, the weighted proportions at each gauge are summed across all the gauges to yield an average profile. The weighted daily rainfalls are averaged to give a catchment average event total, which is distributed between the hours of the event, using the average profile calculated from the hourly gauges, to give the catchment average rainfall profile.

In addition, daily rainfall data for the 5 days preceding the start of the event are analysed to give the catchment average API5 (5-day Antecedent Precipitation Index). The CWI (Catchment Wetness Index) at the start of each event is calculated from the API5 and the SMD (Soil Moisture Deficit) value, and used later in fitting the unit hydrograph losses model.

Figure 4.1 shows a typical event. This way of presenting data is useful because it may reveal errors or inconsistencies not apparent from columns of numbers eg. timing errors between rainfall and flow, discrepancies between hourly gauges, or the possible presence of snowmelt. Any one of these things may cause an event to be rejected at this point.

4.2 FITTING THE UNIT HYDROGRAPH LOSSES MODEL

The FSR Unit Hydrograph and losses analysis programs first separate the flow and rainfall, and then derive a smoothed unit hydrograph by the matrix inversion method, as described fully in FSR I.6.4. Each event is inspected and either:

i) rejected,

ii) used for losses only studies ie. PR, or

iii) used for full UH analysis ie. PR and Tp(0).

Only one of the events which reached this stage was rejected: a double-peaked June flood on the Rede Bridge catchment which had a highly suspect percentage runoff of 15.3%. For full UH analysis, smooth single-peaked events as shown in Figure 4.1 are most likely to produce good unit hydrographs, though reasonable ones may sometimes be obtained from double or multi-peaked events. The simple linear unit hydrograph model may often prove to be an inadequate tool for fitting complex runoff events, where limitations on the input rainfall data often limit the fitting process. In most cases, these complex events tend to produce multi-peaked unit hydrographs, making them suitable for estimation of losses only.

4.3 DISCUSSION OF RESULTS

The results of the additional events for the North Tyne at Tarset and the Tarset Burn at Greenhaugh (Boorman, 1985) were included at this stage, and the details are summarised in Appendix II. Table 4.1 shows the numbers of events used and the catchment average values for Tp(0) and SPR, together with those estimated from the catchment characteristics using the FSSR16 regression equations. SPR was calculated for each event using the equations presented in Section 1.1.4. Further results of the unit hydrograph losses derivation procedure are presented in graphical form in Appendix IV.

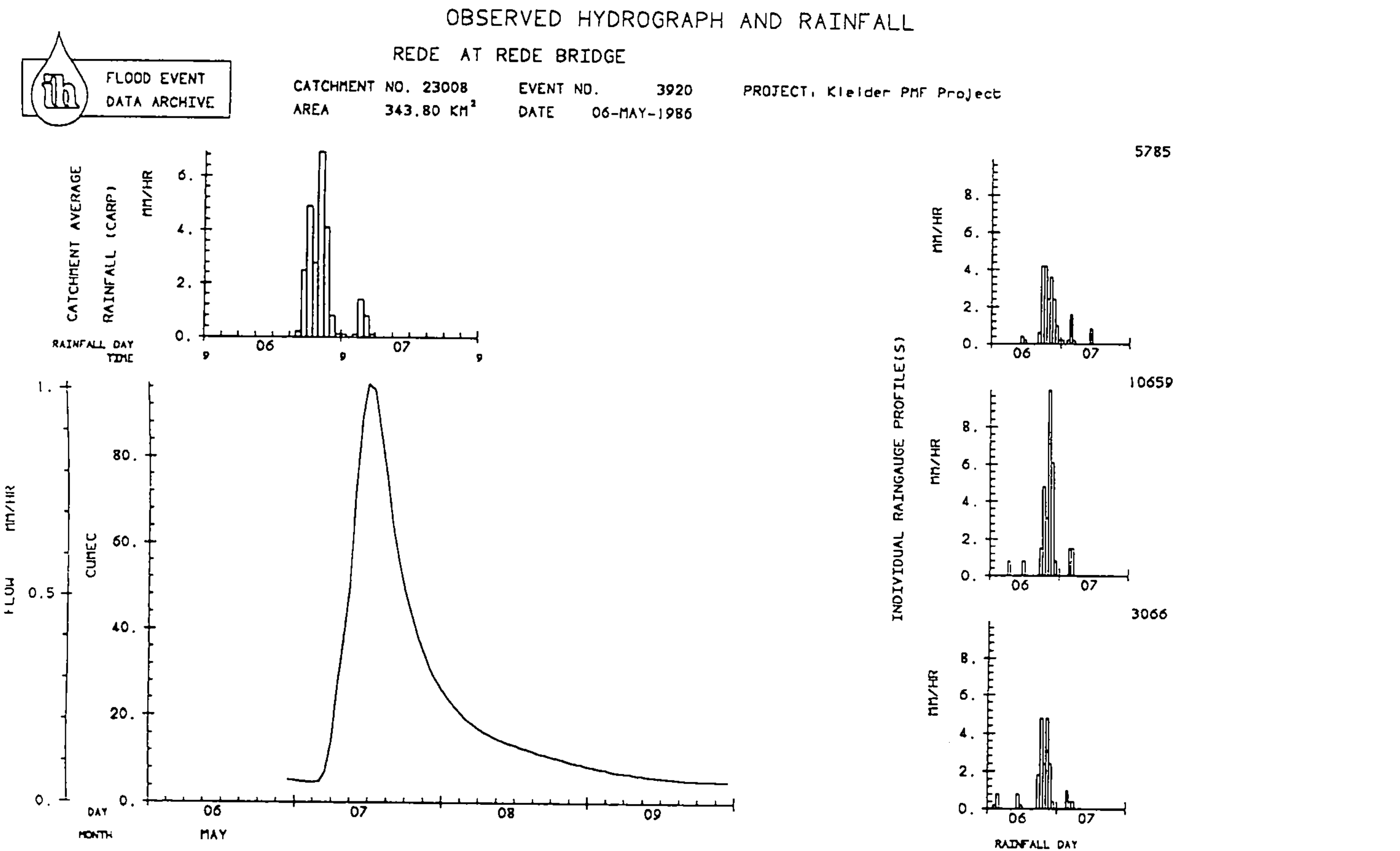

Figure 4.1 Typical unit-hydrograph losses event

Table 4.1 Details of unit hydrograph-losses analysis

Catchment Number	No. of Events Total	Rejected	Losses	Unit Hydrograph	Tp(0) (hr) Catchment Average (Observed)	Estimated (FSSR16)	SPR (%) Catchment Average (Observed)	Estimated (FSSR16)
23005	8	1	2	5	6.18	8.15	55	53
23008	15	6	2	7	8.43	10.23	54.5	53
23010	8	1	7	0		4.98	50.9	53
23011	13	6	7	5	3.40	3.94	61.7	53
Mean					6.00	6.83	55.53	53

A comparison between observed and estimated SPRs and Tp(0)s is presented in Table 4.1. The adjustment factors for the no data estimates were calculated as simple arithmetic means since no valid reasons for weighting any one of the catchments above the others were apparent. The resultant corrections are as follows:

$$Tp(0)_{obs} = 0.815\ Tp(0)_{est}$$

$$SPR_{obs} = 1.05\ SPR_{est}$$

This shows that the FSSR16 regression equations underestimate SPR by some 5% and overestimate Tp(0) by about 19%. Since the Kielder area is now largely forested, which could be expected to decrease SPR and increase Tp(0), this is perhaps not the anticipated result.

For the SPR, only the Kielder Burn at Kielder (23011) has an anomalously high catchment average value, and hence is the main cause of the increase from 53% to 55.53%; the other three catchments have values between 50% and 55%. For Kielder although only 7 events are used to derive the SPR, all are equal to or greater than 53%, suggesting that the catchment value is on average more than 53%. In support of this, SPRs of around 60% are not uncommon for small upland catchments in neighbouring NW England and S Scotland (Boorman, 1985). Alternatively, since the rainfall data are obtained principally from the Catcleugh Nursery gauge on the Rede Bridge catchment some distance away, they may not be wholly representative of the small Kielder Burn catchment ie. if, for instance, the rainfall on the catchment is underestimated, then the runoff will be overestimated. However, since the reservoir catchment is being modelled as having similar characteristics to the Kielder catchment, an increase in SPR from 53% to 55.5% is not considered unreasonable, indeed the agreement between the observed and predicted SPR is very good.

There are perhaps not enough data estimates of Tp(0) to gain a true feeling for the differences between the data and no data figures. However, all three (excluding Tarset Burn at Greenhaugh) observed catchment average values are lower than their corresponding estimated ones by similar amounts. This suggests that the region as a whole may have a slightly lower Tp(0) than anticipated from catchment characteristics, although again the agreement is generally good.

Since the FSR strongly recommends the use of local data wherever possible, adjusted Tp(0)s and SPRs were used in the calculation of the PMF.

5. Rainfall analyses

An analysis of rainfall frequency at Kielder has been undertaken using the IH's newly developed FORGE technique. This stands for Focussed Rainfall Growth curve Estimation, and is an improved means of deriving the rainfall frequency relationship for a point of interest.

The FORGE method combines local, district, regional and national data to provide a single rainfall growth curve focussed on the subject site (Stewart *et al.* (submitted)). The further from the focal point that a gauge is, the greater the number of years of data that this gauge must have to be used in the analysis. The ten largest independent standardised rainfall events from the gauges with the longest records are found and plotted against a function of the equivalent independent station-years (Stewart, 1989). Fuller details of the method are given in Appendix III.

The total number of station-years is divided by four and the required number of gauges needed to get these station-years is calculated; these gauges are chosen as the closest to the focal point. The ten largest independent rainfall events occurring at these gauges are found and these new data points are added to those already calculated. The above process is repeated and more data points added to the focal point data set until the process can go no further. At this stage all the data points for the focal point have been found. To provide FORGE growth curves that are harmonious the technique is applied jointly to a number of focal points in a region.

The first part of this analysis is to determine typical 1 and 2-day mean annual maximum rainfalls (RBAR) for Kielder. Kielder village is on the upstream side of Kielder Water, approximately ten kilometres north west of the dam, and is roughly in the centre of the Kielder Reservoir catchment. Estimation of the RBAR values has been accomplished by interpolating the RBAR data that are available at rainfall gauges within a thirty kilometre radius of Kielder. Only gauges with at least ten years of data have been used. Contours of the interpolated 1 and 2-day RBAR data have been plotted (Figures 5.1 and 5.2) and average RBAR values for the catchment have been estimated. These values are shown in Table 5.1.

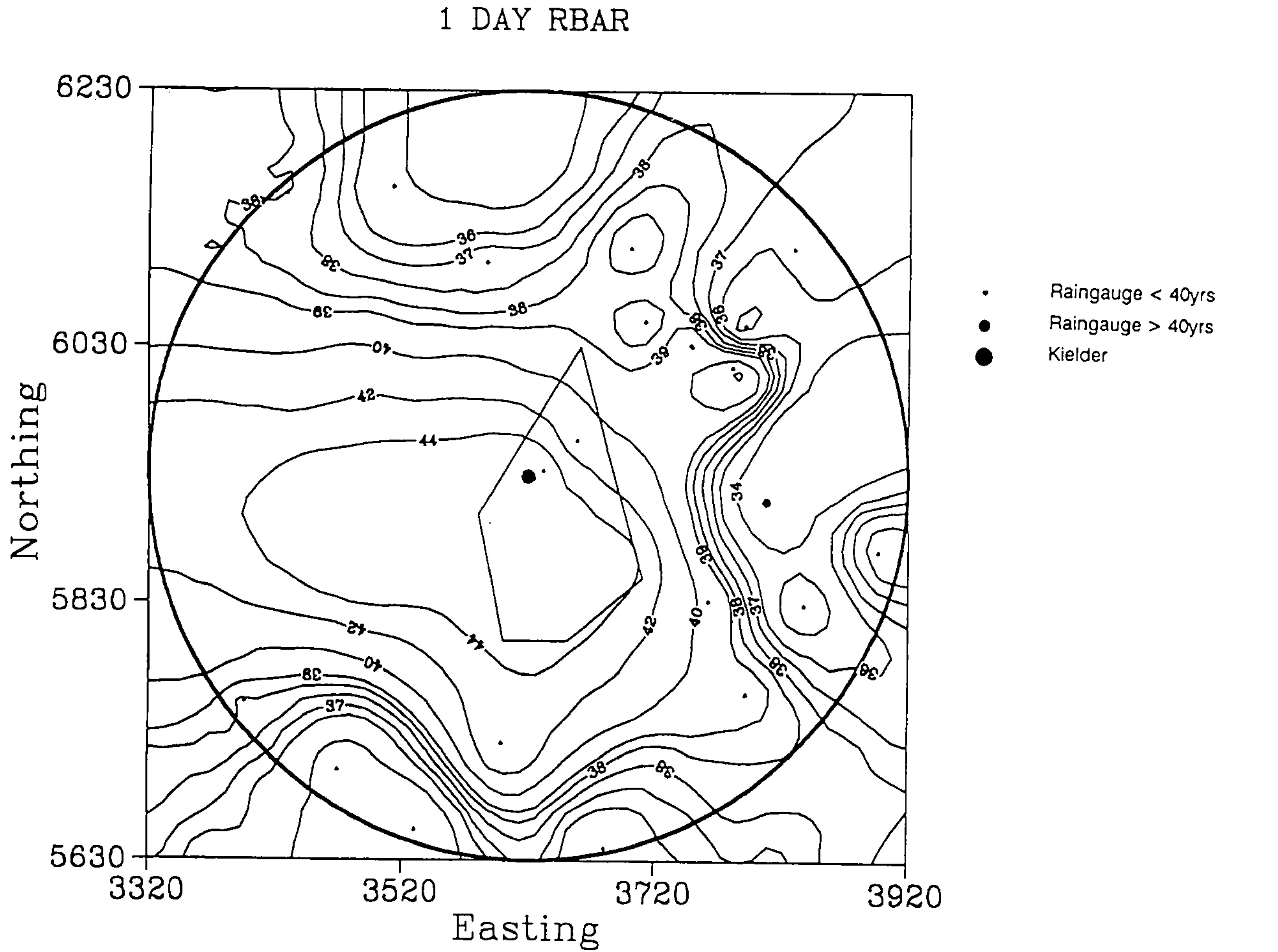

Figure 5.1 1-day RBAR map for Kielder

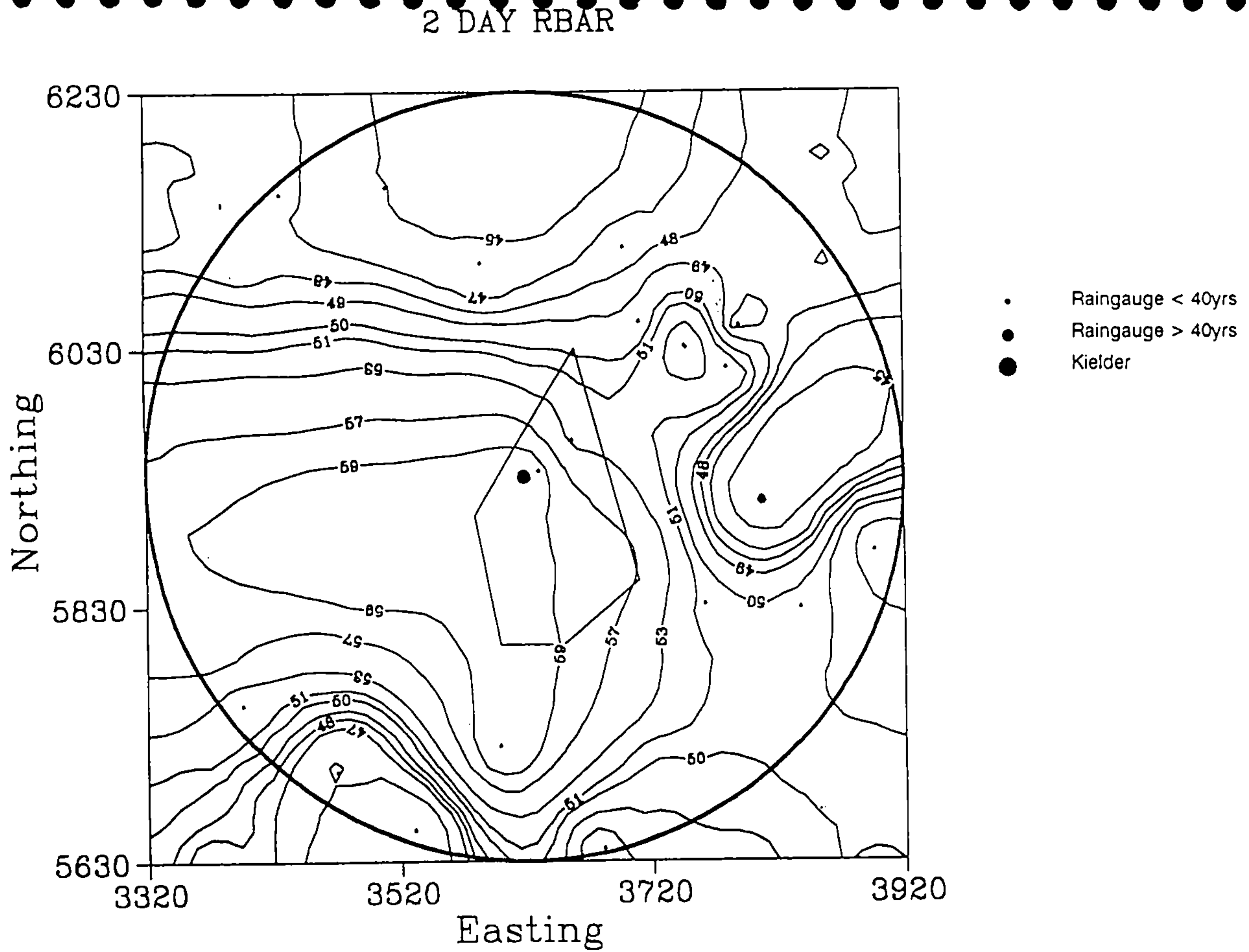

Figure 5.2 2-day RBAR map for Kielder

Table 5.1 RBAR values for Kielder reservoir (mm)

1 day RBAR	44.3
2 day RBAR	58.7

The second part of the analysis is to find the rainfall growth curve for Kielder. FORGE data has been collected for several local points close to Kielder; Newcastle upon Tyne, Darlington, Penrith, Dumfries and Kelso. The data are used to find the rainfall growth curves for Kielder, and from these curves the 10,000-year 1 and 2-day rainfalls for Kielder can be found. These results are found by multiplying the RBAR values, given in Table 5.1, by the values obtained from the rainfall growth curve corresponding to a 10,000 year event.

Table 5.2 10,000-year rainfalls for Kielder reservoir (mm)

	FORGE analysis	FSR
1 day duration	214	214
2 day duration	248	246

These results may be compared to those derived from FSR II which gives 1 and 2-day 10,000 year rainfalls of 214 and 246 mm respectively. These are virtually identical to the FORGE derived estimates presented in Table 5.2, and give additional confidence to the FSR derived PMP values for the Kielder catchment.

6. Spillway flood derivation

6.1 MICRO-FSR SOFTWARE

Flood estimates were obtained by application of IH's Micro-FSR software, which is a representation of the UK Flood Studies Report in PC format. The version of Micro-FSR used was a new, and as yet unreleased one, which incorporates a reservoir routing module.

The software enables flood estimates to be derived for sites having no data, using the FSR regression equations to estimate flood characteristics for the site of interest. However, local data may be applied at any stage of the estimation procedure to replace the no-data estimates. For the current study, the software was initially applied to the Kielder reservoir catchment using the no-data equations to estimate the PMF. The aim was to test the Micro-FSR estimate of the PMF with that obtained by Northumbrian NRA, using their in-house software.

As discussed in Section 4.3, the no-data estimates of Tp(0) and SPR derived from catchment characteristics were adjusted using the average ratios of observed to estimated Tp(0) and SPR for the area. The catchment characteristics used to derive the basic estimates of Tp(0) and SPR were given in Table 2.3. However, in the prediction equation for Tp(0), the slope (S1085) for the Kielder Burn at Kielder was used rather than the S1085 to the dam itself, as this was thought to be more typical of the steep tributaries feeding the reservoir. The aim was to determine the response time of the land phase of the catchment, hence the use of the Kielder Burn slope.

To check that this approach maximised the flood inflow, Micro-FSR was also run using an adjusted Tp(0) derived using the S1085 to the dam. The resulting storm duration, being a function of Tp(T), was greater than that derived using the Kielder Burn slope, but the unit hydrograph was less peaky. Consequently the peak inflow for a summer PMP was only 1347 in m^3sec^{-1} with this method compared with 1936 m^3sec^{-1} using the Kielder Burn estimates, leading to outflows of 914 m^3sec^{-1} and 959 m^3sec^{-1} respectively. The winter PMP with a snowmelt of 1.75 mm hr^{-1} similarly produced lower inflows and outflows; 1292 m^3sec^{-1} compared with 1685 m^3sec^{-1}, and 921 m^3sec^{-1} compared with 952 m^3sec^{-1}. Results of all runs are presented in Appendix I. Thus the most severe inflow conditions arise from short duration "flashy" inflows from the land phase of the catchment, and the unit hydrograph derived from Kielder Burn catchment characteristics is believed to provide the best representation of this runoff response.

6.2 RESULTS

The output from the Micro-FSR software is given in Appendix I and the key features of each run are summarised in Table 6.1.

A series of computer simulations were attempted to examine the effect of various inflow and outflow options on the behaviour of Kielder reservoir. In each case, three separate inflow options were studied, a summer PMP and a winter PMP with two rates of snowmelt, 1.75 mm hr^{-1} as suggested in the FSR, and 5.0 mm hr^{-1} as suggested by evidence collected by Northumbrian Water Authority. As can be seen from Table 6.1 and Appendix I, there is little difference in outflow peaks, and hence reservoir levels, resulting from the summer PMP and the winter PMP plus 1.75 mm hr^{-1} snowmelt. However, adoption of the much more severe snowmelt conditions leads to an increase in reservoir level of some 0.9 m where outflow is permitted only over the spillway. Because under normal circumstances, some water is released for hydropower production, and because the reservoir rises to fairly extreme levels during the PMF, the affect of releasing water through the various outflow facilities such as the scour pipe and drawoff pipe were examined as option 2. On average, reservoir level could be reduced by about 0.15 m by releasing 68.1 m^3s^{-1} through the various outlet facilities, and this could perhaps be increased to about 0.2 m if all possible outlet facilities were to be utilised.

Finally, for option 3, some outflow through the outlet facilities was permitted, but the initial reservoir level was selected as 183.5 m, rather than starting the PMF with reservoir spilling the long-term baseflow of 14.07 m^3s^{-1}. The resulting peak levels were significantly reduced over those achieved under option 2, with a 0.69 m reduction from 187.86 m to 187.17 m in the most extreme case of a winter PMP combined with 5.0 mm hr^{-1} snowmelt.

It appears therefore that there is some merit in utilising all available low-level outlet facilities during the PMF in order to reduce reservoir rise. In addition, in view of the extreme levels attained in options 1 and 2, there appears to be some grounds for attempting to maintain some degree of flood drawdown in the reservoir to reduce the reservoir rise. In the example tested, having the reservoir drawn down 1.7 m below spillway level at the start of the flood reduces the peak level reached during the flood by up to 0.69 m.

7. Recommendations

There must still be some doubts as to the validity of the spillway rating adopted for the present study. Because the rating suggests drowning for flows exceeding 900 m^3s^{-1} (equivalent to a head of 1.7 m over the spillway), the reservoir routing demonstrates an often masked increase in reservoir level during the PMF due to the apparent limitations of the spillway. In order to test the validity of the PMF routing, there may be benefit in re-examining the spillway rating using either more modern computer techniques, or detailed physical modelling, in order to check the upper rating. An organisation such as Hydraulics Research Ltd could undertake such a study.

There also appears to be merit in attempting to operate Kielder with effectively a flood drawdown rule curve. By starting reservoir routing with an initial reservoir level 1.7 m below the spillway crest, the peak level can, as explained above, be reduced by 0.69 m during the PMF.

No consideration has been give to wave action in the present study. However, it is clear that with an initial level of 185.2 m and without use of the low-level outlet facilities, a peak water level of 188.1 m is uncomfortably high and would appear to rely on the wave-wall. Given the expected wave run-up, there must be some concern as to the ability of the dam to pass the full winter PMP with 5.0 mm hr^{-1} snowmelt. Further work on this topic may be warranted.

Table 6.1 Summary of PMF estimates from various computer runs

OPTION 1: No releases through Scour valve and for HEP.
Initial level 185.2, Initial spill 14.1 $m^3 s^{-1}$ (average baseflow)

	SUMMER RAINFALL	WINTER RAINFALL Snowmelt rate 1.75 mm/hr	5 mm/hr
Peak Inflow ($m^3 s^{-1}$)	1936	1685	2213
Peak Outflow ($m^3 s^{-1}$)	959	952	1082
Max Reservoir Level (m)	187.24	187.19	188.1

OPTION 2: Release of 68.1 $m^3 s^{-1}$ through Scour Valve and for HEP.
Initial level 185.2, Initial spill 82.17 $m^3 s^{-1}$ (68.1 + baseflow)

	SUMMER RAINFALL	WINTER RAINFALL Snowmelt rate 1.75 mm/hr	5 mm/hr
Peak Inflow ($m^3 s^{-1}$)	1936	1674	2213
Peak Outflow ($m^3 s^{-1}$)	1012	993	1127
Max Reservoir Level (m)	187.12	187.01	187.86

OPTION 3: Release of 68.1 $m^3 s^{-1}$ through Scour Valve and for HEP.
Initial level 183.5 m

	SUMMER RAINFALL	WINTER RAINFALL Snowmelt rate 1.75 mm/hr	5 mm/hr
Peak Inflow ($m^3 s^{-1}$)	1934	1704	2190
Peak Outflow ($m^3 s^{-1}$)	602	625	1025
Max Reservoir Level (m)	186.44	186.47	187.17

References

Boorman D.B. (1985) "A review of the Flood Studies Report rainfall-runoff model parameter estimation equations", Institute of Hydrology Report No. 94.

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Natural Environment Research Council (1985) Flood Studies Supplementary Report No. 16.

Stewart E.J. (1989) "Regional Rainfall Frequency South West England", an Institute of Hydrology Report to South West Water.

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Appendix 1 Output from Micro-FSR

OPTION 1: INITIAL LEVEL 185.2 M

SPILLING LONG TERM BASEFLOW, 14.07 m^3s^{-1}

NO FLOW THROUGH SCOUR VALVES ETC.

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UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 15:26 Run Reference : KREPT

Reservoir characteristics

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Reservoir area set to : 10.860 sq. km
at : 1.700 metres
Area growth rate : 0.290 sq. km/metre

Device	HMIN	HMAX	B	C	D	E
1	0.000	0.253	185.000	1.481	0.000	1.126
1	0.253	1.000	185.000	2.032	0.000	1.356
1	1.000	1.200	185.000	2.032	0.000	1.541
1	1.200	1.700	185.000	1.975	0.000	1.699
1	1.700	9999.990	185.000	4.047	0.000	0.348
2	0.000	9999.000	0.000	0.000	0.000	0.100

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UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 11:15 Run Reference : KREPT

Summary of reservoir routing calculations

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Estimation of Probable Maximum Flood

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Summer season rainfall

Unit hydrograph time to peak		2.68	hours	
Data interval		0.50	hours	
Design storm duration	:	13.50	hours	
No snowmelt contribution to precipitation input				
Design storm depth	:	218.60	mm.	
Design CWI		151.37		
Standard Percentage Runoff		55.53		
Percentage runoff		79.09	%	
Baseflow	:	11.50	cumecs	
Inflow hydrograph peak	:	1926.81	cumecs	(Max ordinate)
	:	1935.49	cumecs	(Interpolated)
Outflow hydrograph peak	:	959.19	cumecs	(Max ordinate)
	:	959.44	cumecs	(Interpolated)
Attenuation rating	:	0.50	(From interpolated peaks)	
Reservoir LAG		2.82	hours	

Options

=======

Unit hydrograph option		1 - FSR-Triangle
Tp option		0 - Specified by user
Rainfall option		5 - Max precipitation
Duration option		2 - with reservoir lag
Percentage runoff option		1 - FSSR 16 equation
CWI option		1 - Design standard
PMF scaling factor		0 - Set to 1.0
Baseflow option		1 - FSSR 16 equation
SPR option		0 - Specified by user
Initial water level		2 - Outflow entered
Reservoir rainfall		1 - Explicit
Inflow to reservoir	:	1 - From micro-FSR

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UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 11:15 Run Reference : KREPT

Time series data from reservoir routing calculations

****

Time hours	Total Rain mm	Net Rain mm	Unit Hydrograph cumecs/cm /100sq km	Unit Hydrograph %	Inflow cumecs	Outflow cumecs	Water level metres
0.50	2.2	1.7	15.32	2.76	17.53	14.07	0.07
1.00	2.3	1.8	30.63	5.51	30.10	14.89	0.08
1.50	2.5	2.0	45.95	8.27	49.78	16.31	0.08
2.00	2.8	2.2	61.26	11.03	77.30	18.62	0.09
2.50	3.1	2.5	76.58	13.78	113.50	22.12	0.11
3.00	3.5	2.8	75.64	13.61	153.06	27.08	0.13
3.50	4.0	3.2	65.57	11.80	193.22	33.60	0.16
4.00	4.6	3.7	55.49	9.99	234.88	41.77	0.19
4.50	5.5	4.4	45.41	8.17	279.47	51.71	0.23
5.00	6.9	5.5	35.34	6.36	329.42	64.83	0.27
5.50	9.1	7.2	25.26	4.55	389.28	82.69	0.33
6.00	11.4	9.1	15.19	2.73	463.49	105.20	0.39
6.50	20.7	16.4	5.11	0.92	575.12	134.17	0.47
7.00	61.1	48.3			835.15	178.70	0.58
7.50	20.7	16.4			1127.46	260.00	0.76
8.00	11.4	9.1			1417.73	345.34	0.94
8.50	9.1	7.2			1689.25	457.97	1.14
9.00	6.9	5.5			1905.02	607.44	1.35
9.50	5.5	4.4			1926.81	770.34	1.55
10.00	4.6	3.7			1805.25	903.81	1.72
10.50	4.0	3.2			1634.30	927.29	1.85
11.00	3.5	2.8			1436.37	944.14	1.95
11.50	3.1	2.5			1222.91	954.67	2.01
12.00	2.8	2.2			1004.03	959.19	2.04
12.50	2.5	2.0			788.15	958.02	2.03
13.00	2.3	1.8			588.67	951.51	1.99
13.50	2.2	1.7			452.83	940.65	1.93
14.00					377.61	926.93	1.85
14.50					318.57	910.94	1.76
15.00					266.22	866.48	1.66
15.50					217.43	785.89	1.57
16.00					169.78	712.15	1.48
16.50					127.89	644.51	1.40
17.00					93.94	582.75	1.32
17.50					66.87	526.73	1.24
18.00					45.87	478.02	1.17
18.50					30.30	436.21	1.10
19.00					19.66	398.24	1.04
19.50					13.51	365.41	0.98

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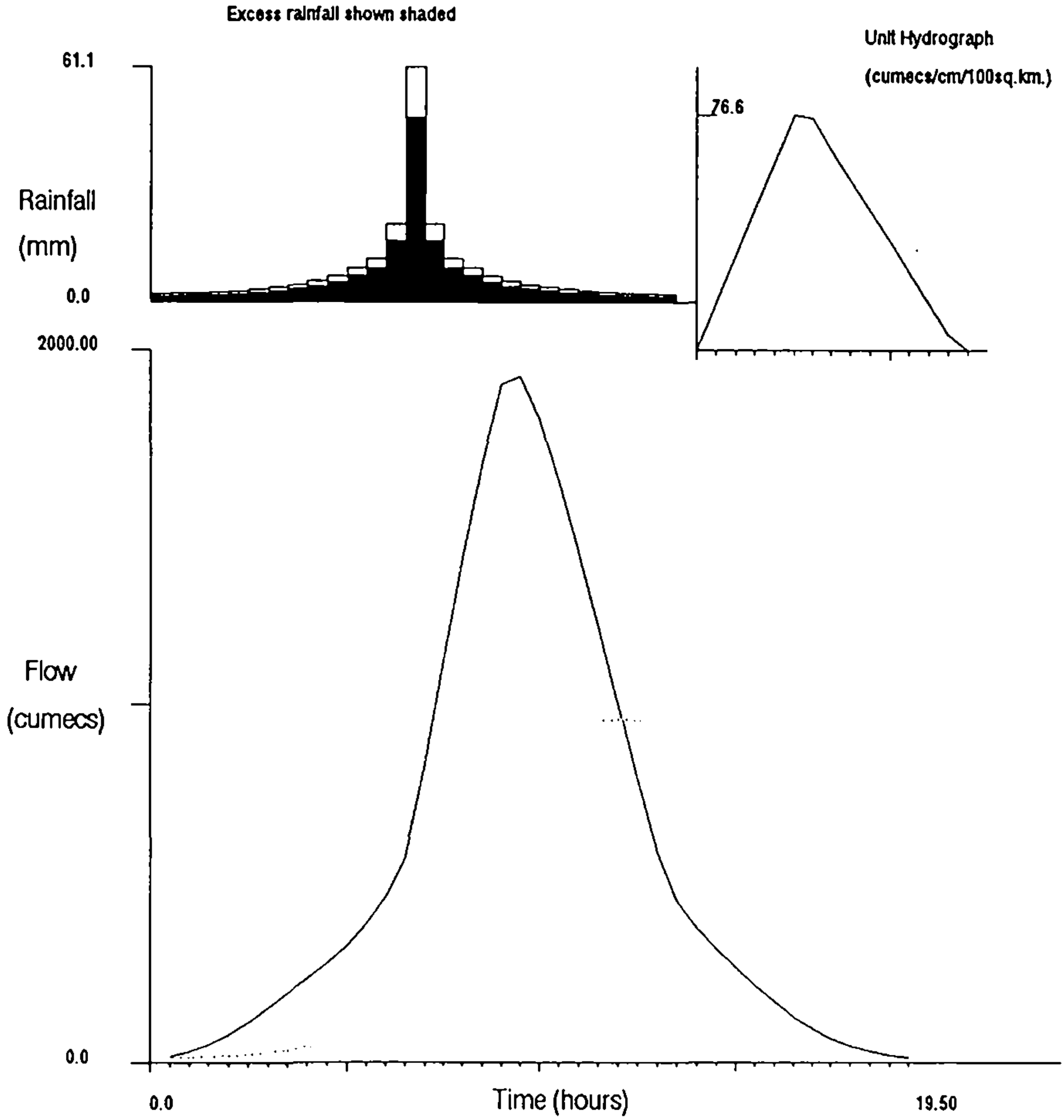
UK DESIGN FLOOD ESTIMATION
RAINFALL AND HYDROGRAPH

Institute of Hydrology

Description : Kielder PMF Final Estimates (CCs for Kielder Burn) **Run Reference:** KREPT
Printed on 18 6 1990 at 11:15



Data Interval(hours) : 0.50

Inflow
Outflow

****

UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 15:09 Run Reference : KREPT

Summary of reservoir routing calculations

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Estimation of Probable Maximum Flood

Winter season rainfall

Unit hydrograph time to peak	2.68	hours	
Data interval	0.50	hours	
Design storm duration	13.50	hours	
Pre-event snow depth	200.00	mm.	
Melt rate	1.75	mm/hr	
Design storm depth	204.71	mm.	
Design CWI	187.01		
Standard Percentage Runoff	55.53		
Percentage runoff	87.06	%	
Baseflow :	14.21	cumecs	
Inflow hydrograph peak :	1681.55	cumecs	(Max ordinate)
:	1684.71	cumecs	(Interpolated)
Outflow hydrograph peak :	951.02	cumecs	(Max ordinate)
:	951.56	cumecs	(Interpolated)
Attenuation rating :	0.56	(From interpolated peaks)	
Reservoir LAG	2.88	hours	

Options

Unit hydrograph option	1 - FSR-Triangle
Tp option	0 - Specified by user
Rainfall option	5 - Max precipitation
Duration option	2 - with reservoir lag
Percentage runoff option	1 - FSSR 16 equation
CWI option	1 - Design standard
PMF scaling factor	0 - Set to 1.0
Baseflow option	1 - FSSR 16 equation
SPR option	0 - Specified by user
Initial water level	2 - Outflow entered
Reservoir rainfall	1 - Explicit
Inflow to reservoir :	1 - From micro-FSR

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UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 15:09 Run Reference : KREPT

Time series data from reservoir routing calculations

****

Time hours	Total Rain mm	Net Rain mm	Unit Hydrograph cumecs/cm /100sq km	Unit Hydrograph %	Inflow cumecs	Outflow cumecs	Water level metres
0.50	3.0	2.6	15.32	2.76	23.49	14.07	0.07
1.00	3.2	2.8	30.63	5.51	42.60	15.48	0.08
1.50	3.4	3.0	45.95	8.27	72.16	17.82	0.09
2.00	3.6	3.2	61.26	11.03	112.94	21.53	0.10
2.50	3.9	3.4	76.58	13.78	165.85	27.11	0.13
3.00	4.3	3.8	75.64	13.61	222.20	34.92	0.16
3.50	4.8	4.2	65.56	11.80	277.34	45.05	0.20
4.00	5.4	4.7	55.49	9.99	332.20	57.51	0.25
4.50	6.3	5.5	45.41	8.17	388.30	75.54	0.31
5.00	7.6	6.6	35.34	6.36	448.14	97.56	0.37
5.50	9.7	8.4	25.26	4.55	516.43	124.03	0.44
6.00	11.5	10.0	15.19	2.73	596.55	156.01	0.52
6.50	17.8	15.5	5.11	0.92	704.84	194.83	0.62
7.00	35.5	30.9			894.77	246.63	0.73
7.50	17.8	15.5			1109.34	321.50	0.89
8.00	11.5	10.0			1320.48	407.27	1.05
8.50	9.7	8.4			1513.17	516.48	1.23
9.00	7.6	6.6			1657.71	649.95	1.40
9.50	6.3	5.5			1681.55	786.08	1.57
10.00	5.4	4.7			1608.13	901.91	1.71
10.50	4.8	4.2			1489.59	921.83	1.82
11.00	4.3	3.8			1343.45	936.61	1.90
11.50	3.9	3.4			1180.94	946.28	1.96
12.00	3.6	3.2			1012.62	951.00	1.99
12.50	3.4	3.0			846.90	951.02	1.99
13.00	3.2	2.8			694.95	946.70	1.96
13.50	3.0	2.6			583.00	938.79	1.92
14.00					504.39	928.25	1.86
14.50					436.37	915.11	1.78
15.00					372.02	898.38	1.70
15.50					308.52	822.22	1.61
16.00					243.36	750.05	1.53
16.50					184.54	681.60	1.44
17.00					136.06	617.35	1.36
17.50					96.82	557.83	1.28
18.00					65.94	503.31	1.21
18.50					42.75	457.48	1.14
19.00					26.69	416.13	1.07
19.50					17.31	378.72	1.00

****

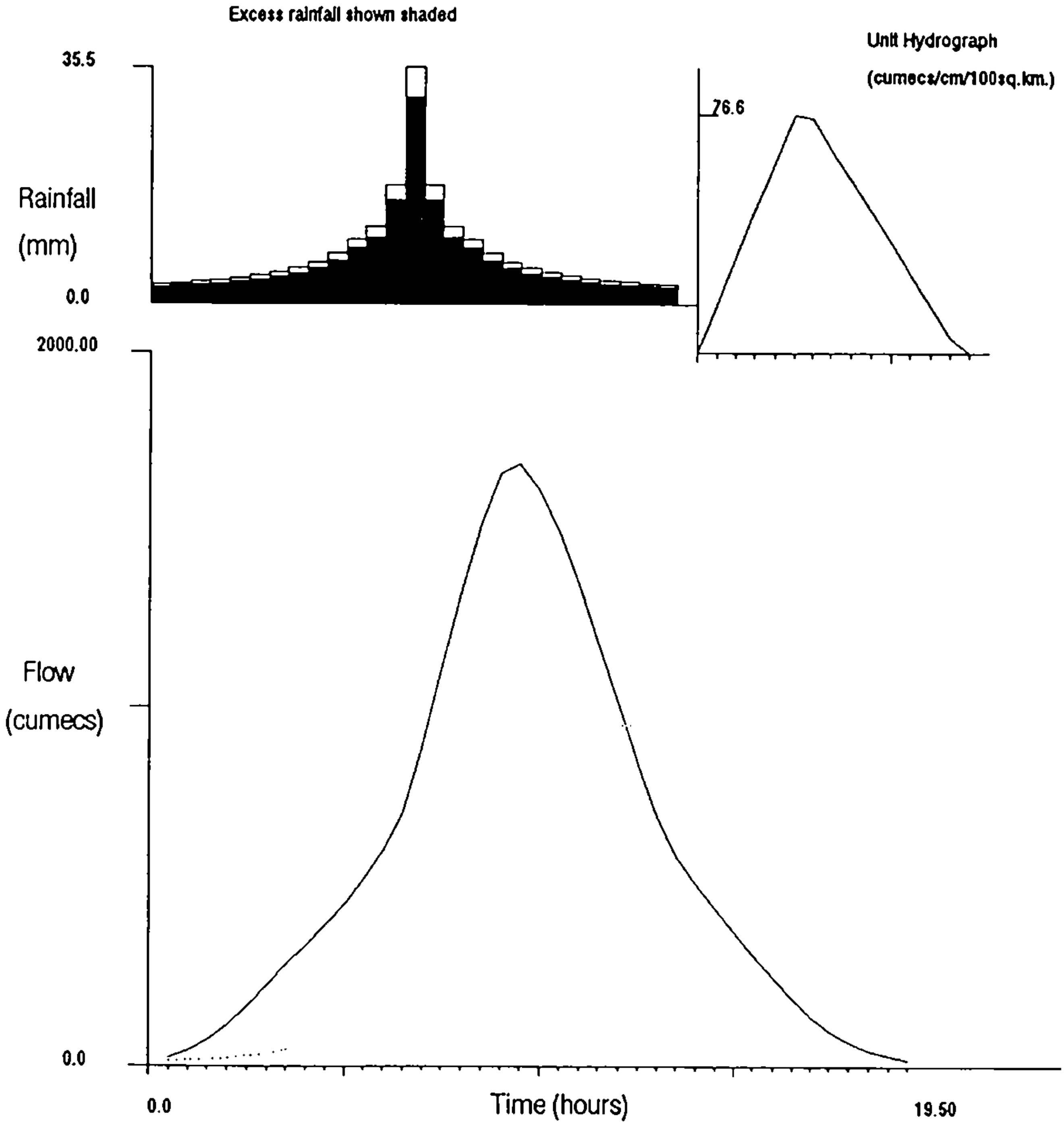
UK DESIGN FLOOD ESTIMATION
RAINFALL AND HYDROGRAPH

Institute of Hydrology

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)

Run Reference: KREPT

Printed on 18 6 1990 at 15:10



Data Interval(hours) : 0.50

Inflow

Outflow

****
Institute of Hydrology

UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 15:44 Run Reference : KREPT

Summary of reservoir routing calculations

****

Estimation of Probable Maximum Flood

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

Winter season rainfall

Unit hydrograph time to peak		2.68	hours
Data interval		0.50	hours
Design storm duration		14.50	hours
Pre-event snow depth		200.00	mm.
Melt rate		5.00	mm/hr
Design storm depth		257.57	mm.
Design CWI		237.93	
Standard Percentage Runoff		55.53	
Percentage runoff		103.24	%
Baseflow	:	18.09	cumecs
Inflow hydrograph peak	:	2209.12	cumecs (Max ordinate)
	:	2212.87	cumecs (Interpolated)
Outflow hydrograph peak	:	1081.74	cumecs (Max ordinate)
	:	1081.74	cumecs (Interpolated)
Attenuation rating	:	0.49	(From interpolated peaks)
Reservoir LAG	·	3.63	hours

Options

=======

Unit hydrograph option		1 - FSR-Triangle
Tp option		0 - Specified by user
Rainfall option		5 - Max precipitation
Duration option		2 - with reservoir lag
Percentage runoff option		1 - FSSR 16 equation
CWI option		1 - Design standard
PMF scaling factor		0 - Set to 1.0
Baseflow option		1 - FSSR 16 equation
SPR option		0 - Specified by user
Initial water level		2 - Outflow entered
Reservoir rainfall		1 - Explicit
Inflow to reservoir	:	1 - From micro-FSR

****

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Institute of Hydrology

UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 15:44 Run Reference : KREPT

Time series data from reservoir routing calculations

****

Time hours	Total Rain mm	Net Rain mm	Unit Hydrograph cumecs/cm /100sq km	Unit Hydrograph %	Inflow cumecs	Outflow cumecs	Water level metres
0.50	4.5	4.6	15.32	2.76	34.47	14.07	0.07
1.00	4.6	4.8	30.63	5.51	67.79	16.50	0.08
1.50	4.8	5.0	45.95	8.27	118.68	20.56	0.10
2.00	5.0	5.2	61.26	11.03	187.90	27.00	0.13
2.50	5.3	5.4	76.58	13.78	276.34	36.66	0.17
3.00	5.6	5.8	75.64	13.61	367.72	50.11	0.22
3.50	5.9	6.1	65.56	11.80	453.03	69.36	0.29
4.00	6.4	6.6	55.49	9.99	533.00	95.62	0.36
4.50	7.1	7.3	45.41	8.17	608.75	127.26	0.45
5.00	7.9	8.2	35.34	6.36	682.06	164.14	0.54
5.50	9.2	9.5	25.26	4.55	755.92	206.15	0.64
6.00	11.3	11.7	15.19	2.73	835.89	253.55	0.75
6.50	13.1	13.6	5.11	0.92	926.00	307.13	0.86
7.00	19.4	20.0			1050.92	368.33	0.99
7.50	37.1	38.3			1276.14	454.92	1.13
8.00	19.4	20.0			1530.59	584.24	1.32
8.50	13.1	13.6			1780.96	731.30	1.50
9.00	11.3	11.7			2009.46	897.56	1.70
9.50	9.2	9.5			2180.86	936.36	1.90
10.00	7.9	8.2			2209.12	971.56	2.12
10.50	7.1	7.3			2122.07	1002.61	2.32
11.00	6.4	6.6			1981.50	1028.39	2.49
11.50	5.9	6.1			1808.20	1048.80	2.64
12.00	5.6	5.8			1615.49	1064.03	2.75
12.50	5.3	5.4			1415.89	1074.34	2.83
13.00	5.0	5.2			1219.38	1080.09	2.87
13.50	4.8	5.0			1039.19	1081.74	2.88
14.00	4.6	4.8			906.44	1080.09	2.87
14.50	4.5	4.6			823.69	1076.18	2.84
15.00					747.55	1070.63	2.80
15.50					669.86	1062.90	2.74
16.00					587.23	1053.48	2.67
16.50					496.72	1042.15	2.59
17.00					396.70	1028.63	2.49
17.50					303.07	1012.77	2.38
18.00					224.28	994.66	2.26
18.50					159.32	974.48	2.13
19.00					107.36	952.39	2.00
19.50					67.77	928.56	1.86
20.00					39.98	903.14	1.72
20.50					23.55	793.94	1.58

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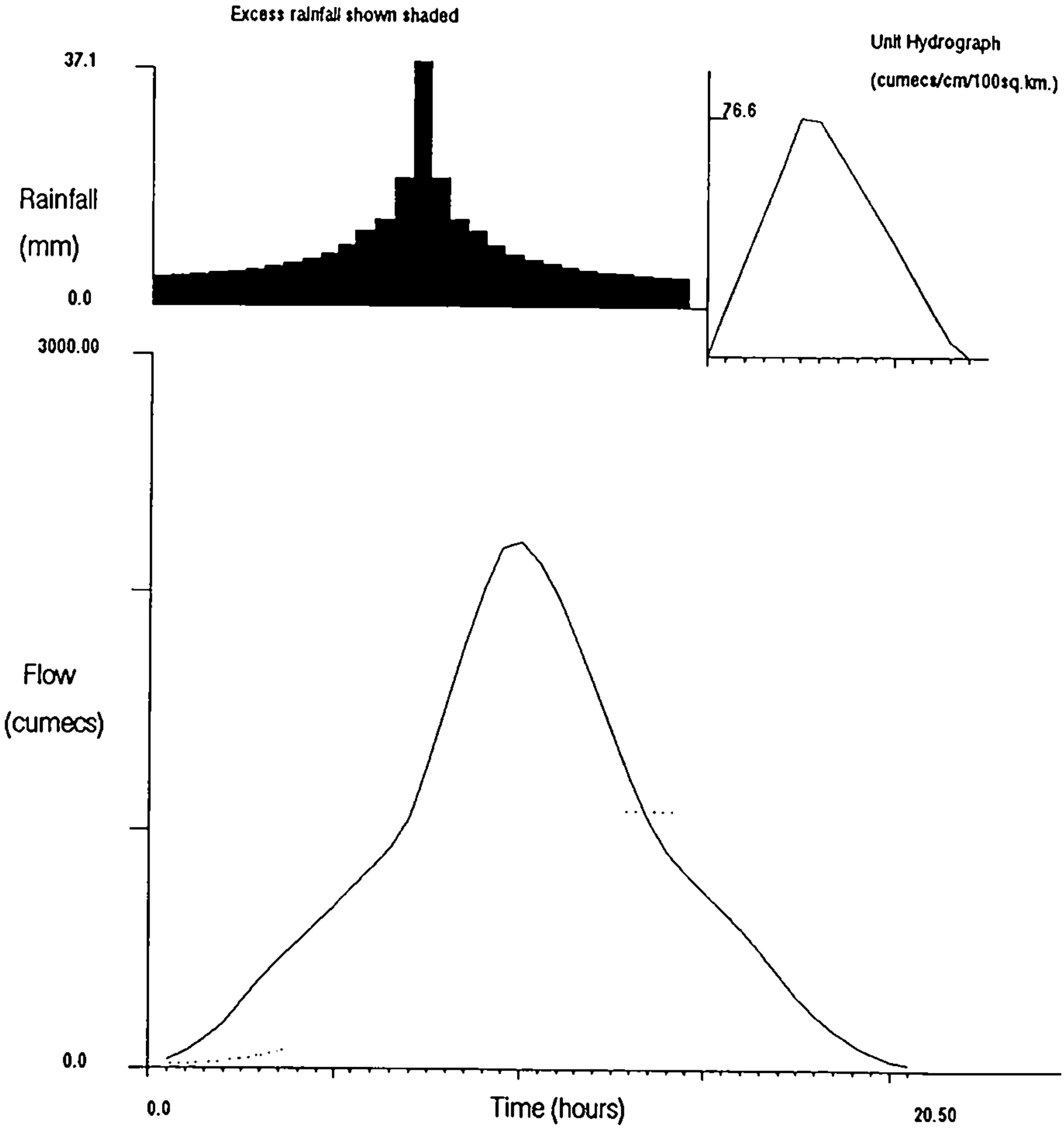
UK DESIGN FLOOD ESTIMATION
RAINFALL AND HYDROGRAPH

Institute of Hydrology

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)

Run Reference: KREPT

Printed on 18 6 1990 at 15:44



Data Interval(hours) : 0.50

Inflow

Outflow

OPTION 2: INITIAL LEVEL 185.2 M

SPILLING LONG TERM BASEFLOW, 14.07 m^3s^{-1}

68.1 m^3s^{-1} RELEASE THROUGH SCOUR VALVE AND FOR HEP

UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 11:27   Run Reference : KREPT

Reservoir characteristics

Reservoir area set to :   10.860 sq. km
at :   0.000 metres
Area growth rate :   0.290 sq. km/metre

Device	HMIN	HMAX	B	C	D	E
1	0.000	0.253	185.000	1.481	0.000	1.126
1	0.253	1.000	185.000	2.032	0.000	1.356
1	1.000	1.200	185.000	2.032	0.000	1.541
1	1.200	1.700	185.000	1.975	0.000	1.699
1	1.700	9999.990	185.000	4.047	0.000	0.348
2	0.000	9999.000	68.100	1.000	0.000	0.100

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                                                         Institute of Hydrology
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UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18  6 1990 at 11:30                         Run Reference : KREPT
----------------------------------------------------------------------------
Summary of reservoir routing calculations
****************************************************************************
Estimation of Probable Maximum Flood
====================================
Summer season rainfall

Unit hydrograph time to peak              2.68  hours
Data interval                             0.50  hours

Design storm duration           :        12.50  hours
No snowmelt contribution to precipitation input
Design storm depth              :       214.28  mm.

Design CWI                              152.64

Standard Percentage Runoff               55.53
Percentage runoff                        79.12  %

Baseflow                        :        11.60  cumecs
Inflow hydrograph peak          :      1927.61  cumecs   (Max ordinate)
                                :      1936.30  cumecs   (Interpolated)
Outflow hydrograph peak         :      1011.96  cumecs   (Max ordinate)
                                :      1011.97  cumecs   (Interpolated)
Attenuation rating              :         0.52  (From interpolated peaks)
Reservoir LAG                   .         2.70  hours

Options
=======
Unit hydrograph option                      1 - FSR-Triangle
Tp option                                   0 - Specified by user
Rainfall option                             5 - Max precipitation
Duration option                             2 - with reservoir lag
Percentage runoff option                    1 - FSSR 16 equation
CWI option                                  1 - Design standard
PMF scaling factor                          0 - Set to 1.0
Baseflow option                             1 - FSSR 16 equation
SPR option                                  0 - Specified by user
Initial water level                         2 - Outflow entered
Reservoir rainfall                          1 - Explicit
Inflow to reservoir             :           1 - From micro-FSR

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micro-FSR  -  Institute of Hydrology                       Version 2.1 c(ii)
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UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 11:30 Run Reference : KREPT

Time series data from reservoir routing calculations

****

Time hours	Total Rain mm	Net Rain mm	Unit Hydrograph cumecs/cm /100sq km	Unit Hydrograph %	Inflow cumecs	Outflow cumecs	Water level metres
0.50	2.3	1.8	15.32	2.76	18.13	82.17	0.13
1.00	2.5	2.0	30.63	5.51	31.79	80.21	0.12
1.50	2.8	2.2	45.95	8.27	53.28	79.19	0.12
2.00	3.1	2.5	61.26	11.03	83.46	79.47	0.12
2.50	3.5	2.8	76.58	13.78	123.40	81.42	0.12
3.00	4.0	3.2	75.64	13.61	167.55	85.28	0.14
3.50	4.6	3.7	65.57	11.80	213.19	91.12	0.16
4.00	5.5	4.4	55.49	9.99	261.77	99.00	0.19
4.50	6.9	5.5	45.41	8.17	315.71	109.11	0.22
5.00	9.1	7.2	35.34	6.36	379.57	122.68	0.27
5.50	11.4	9.1	25.26	4.55	457.77	142.35	0.32
6.00	20.7	16.4	15.19	2.73	573.41	168.50	0.39
6.50	61.1	48.3	5.11	0.92	835.55	210.07	0.50
7.00	20.7	16.4			1127.97	287.86	0.68
7.50	11.4	9.1			1418.34	369.82	0.85
8.00	9.1	7.2			1689.96	472.06	1.05
8.50	6.9	5.5			1905.81	609.76	1.26
9.00	5.5	4.4			1927.61	767.08	1.46
9.50	4.6	3.7			1806.01	910.08	1.63
10.00	4.0	3.2			1635.00	982.57	1.76
10.50	3.5	2.8			1436.99	998.90	1.85
11.00	3.1	2.5			1223.45	1008.59	1.90
11.50	2.8	2.2			1004.49	1011.96	1.92
12.00	2.5	2.0			788.53	1009.28	1.90
12.50	2.3	1.8			588.98	1000.92	1.86
13.00					447.05	987.76	1.78
13.50					365.78	966.00	1.69
14.00					300.68	883.03	1.60
14.50					242.27	805.62	1.51
15.00					187.42	733.50	1.42
15.50					140.13	666.52	1.33
16.00					102.20	604.85	1.25
16.50					72.20	550.12	1.17
17.00					49.09	503.15	1.10
17.50					32.05	460.14	1.03
18.00					20.45	423.66	0.96
18.50					13.78	391.83	0.90

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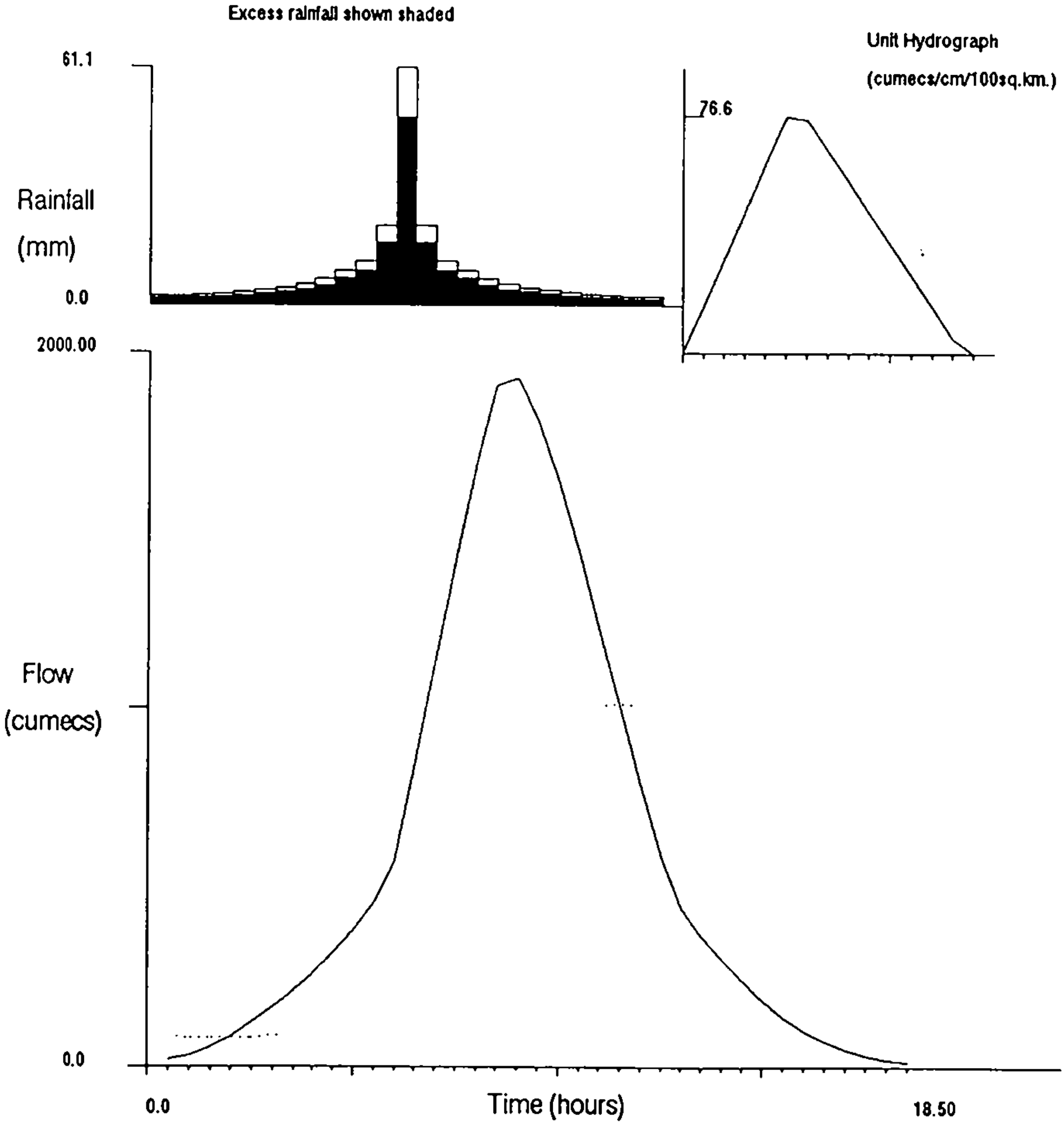
UK DESIGN FLOOD ESTIMATION

RAINFALL AND HYDROGRAPH

Institute of Hydrology

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 11:30

Run Reference: KREPT



Data Interval(hours) : 0.50

Inflow ———

Outflow

****

UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 11:34 Run Reference : KREPT

Summary of reservoir routing calculations

****

Estimation of Probable Maximum Flood
====================================

Winter season rainfall

Unit hydrograph time to peak		2.68	hours
Data interval		0.50	hours
Design storm duration		12.50	hours
Pre-event snow depth		200.00	mm.
Melt rate		1.75	mm/hr
Design storm depth		198.67	mm.
Design CWI		186.52	
Standard Percentage Runoff		55.53	
Percentage runoff		86.53	%
Baseflow	:	14.17	cumecs
Inflow hydrograph peak	:	1671.25	cumecs (Max ordinate)
	:	1674.39	cumecs (Interpolated)
Outflow hydrograph peak	:	992.61	cumecs (Max ordinate)
	:	992.73	cumecs (Interpolated)
Attenuation rating	:	0.59	(From interpolated peaks)
Reservoir LAG		2.74	hours

Options
=======

Unit hydrograph option		1 - FSR-Triangle
Tp option		0 - Specified by user
Rainfall option		5 - Max precipitation
Duration option		2 - with reservoir lag
Percentage runoff option		1 - FSSR 16 equation
CWI option		1 - Design standard
PMF scaling factor		0 - Set to 1.0
Baseflow option		1 - FSSR 16 equation
SPR option		0 - Specified by user
Initial water level		2 - Outflow entered
Reservoir rainfall		1 - Explicit
Inflow to reservoir	:	1 - From micro-FSR

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UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 11:34 Run Reference : KREPT

Time series data from reservoir routing calculations

****

Time hours	Total Rain mm	Net Rain mm	Unit Hydrograph cumecs/cm /100sq km	Unit Hydrograph %	Inflow cumecs	Outflow cumecs	Water level metres
0.50	3.2	2.8	15.32	2.76	23.94	82.17	0.13
1.00	3.4	2.9	30.63	5.51	44.09	80.86	0.12
1.50	3.6	3.2	45.95	8.27	75.39	80.83	0.12
2.00	3.9	3.4	61.26	11.03	118.75	82.57	0.13
2.50	4.3	3.7	76.58	13.78	175.32	86.57	0.14
3.00	4.8	4.1	75.64	13.61	236.19	93.14	0.17
3.50	5.4	4.7	65.57	11.80	296.78	102.29	0.20
4.00	6.3	5.4	55.49	9.99	358.60	113.99	0.24
4.50	7.6	6.6	45.41	8.17	424.15	130.56	0.29
5.00	9.7	8.4	35.34	6.36	498.08	152.12	0.35
5.50	11.5	10.0	25.26	4.55	583.78	179.11	0.42
6.00	17.8	15.4	15.19	2.73	697.47	212.89	0.51
6.50	35.5	30.7	5.11	0.92	889.31	259.14	0.61
7.00	17.8	15.4			1102.57	327.16	0.76
7.50	11.5	10.0			1312.40	402.17	0.92
8.00	9.7	8.4			1503.90	494.54	1.08
8.50	7.6	6.6			1647.56	609.74	1.26
9.00	6.3	5.4			1671.25	736.43	1.42
9.50	5.4	4.7			1598.29	852.13	1.56
10.00	4.8	4.1			1480.48	945.51	1.67
10.50	4.3	3.7			1335.23	980.49	1.74
11.00	3.9	3.4			1173.72	989.08	1.79
11.50	3.6	3.2			1006.44	992.61	1.81
12.00	3.4	2.9			841.74	991.30	1.80
12.50	3.2	2.8			690.72	985.48	1.77
13.00					570.24	975.79	1.72
13.50					482.89	928.10	1.65
14.00					406.05	865.43	1.58
14.50					332.88	802.94	1.51
15.00					260.54	741.06	1.43
15.50					196.35	680.43	1.35
16.00					143.96	622.15	1.28
16.50					101.85	567.03	1.20
17.00					68.92	520.29	1.13
17.50					44.30	476.65	1.05
18.00					27.32	437.33	0.99
18.50					17.43	404.57	0.92

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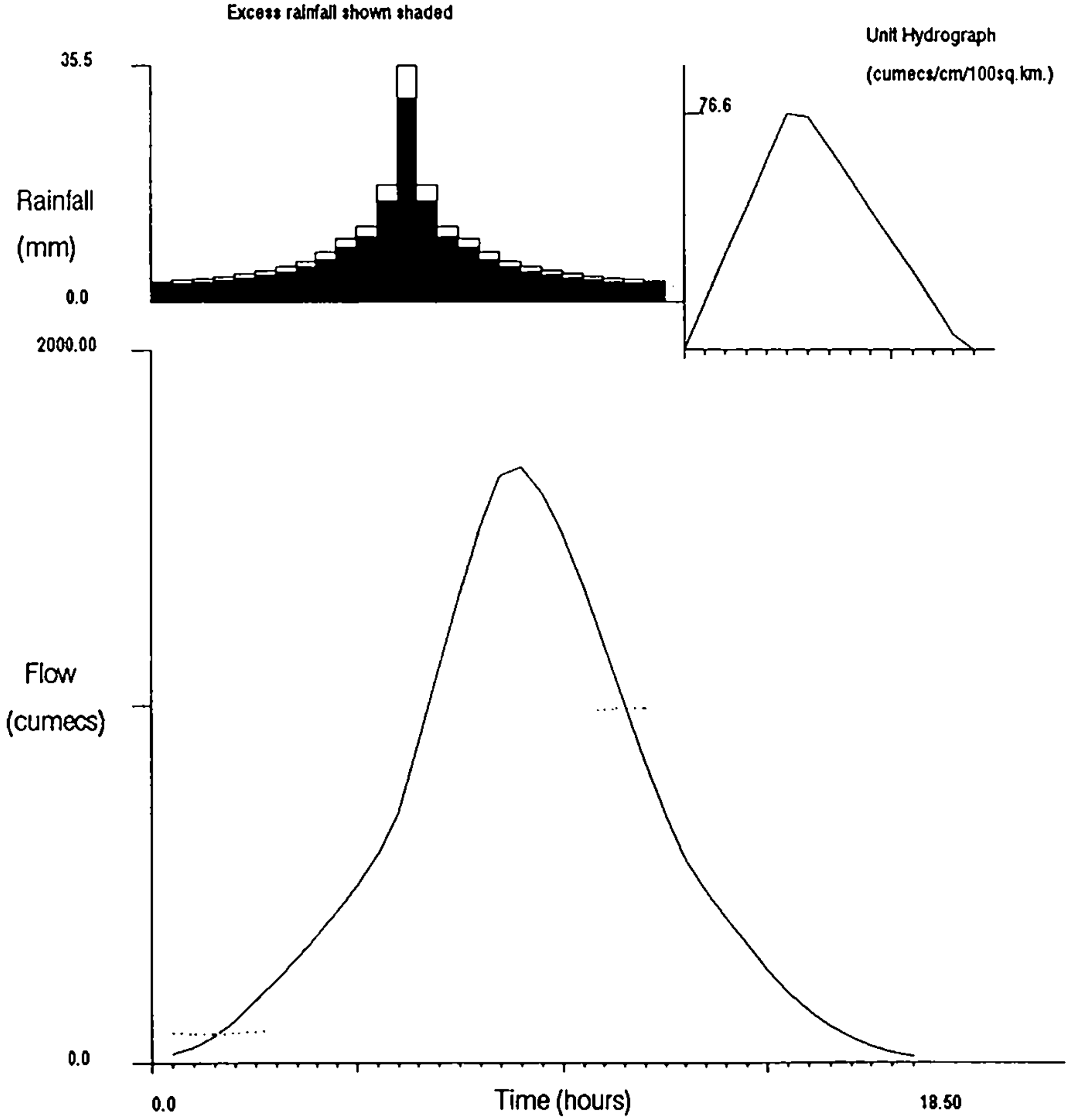
UK DESIGN FLOOD ESTIMATION
RAINFALL AND HYDROGRAPH

Institute of Hydrology

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)

Run Reference: KREPT

Printed on 18 6 1990 at 11:34



Data interval(hours) : 0.50

Inflow ———

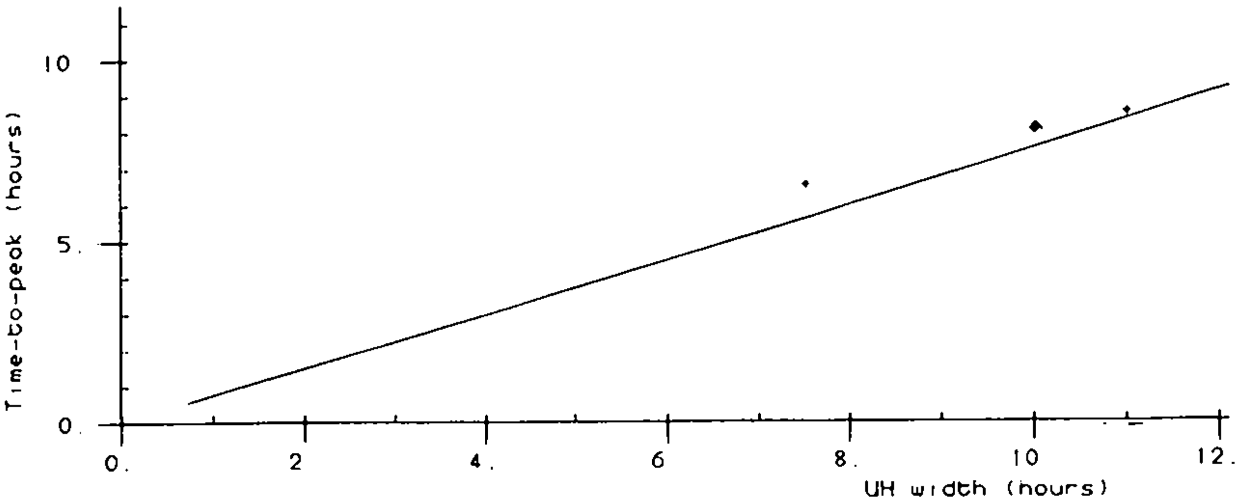
Outflow

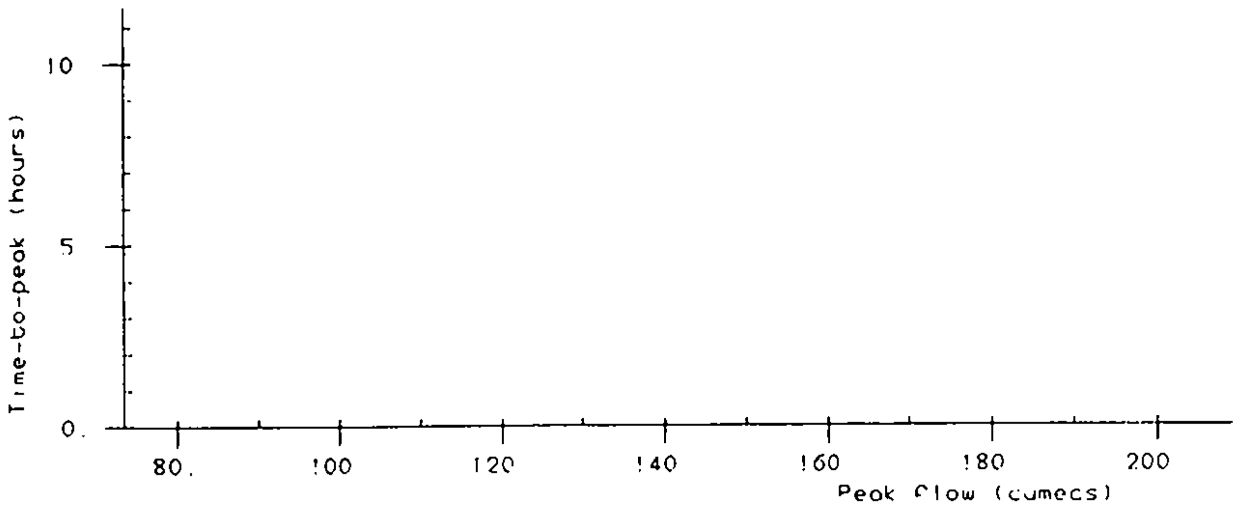
FLOOD EVENT
RESULTS ANALYSIS

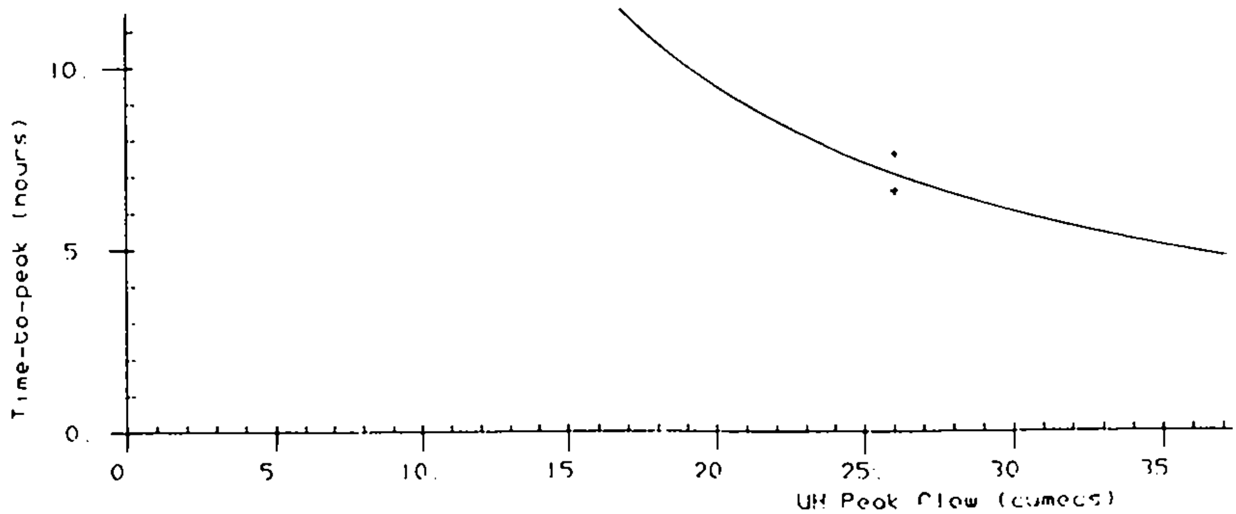
VARIATION IN TIME-TO-PEAK

23008

REDE AT REDE BRIDGE





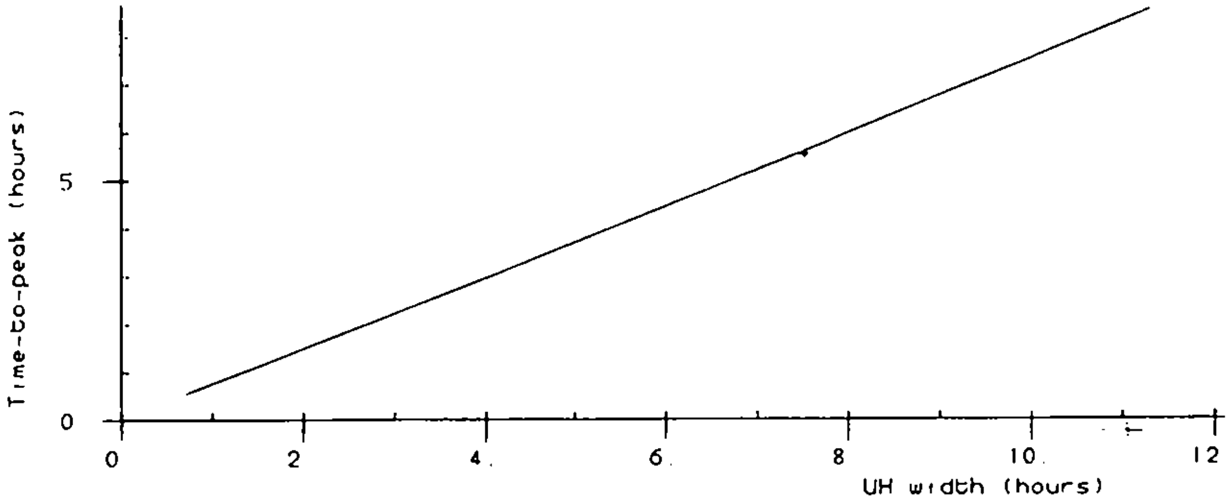


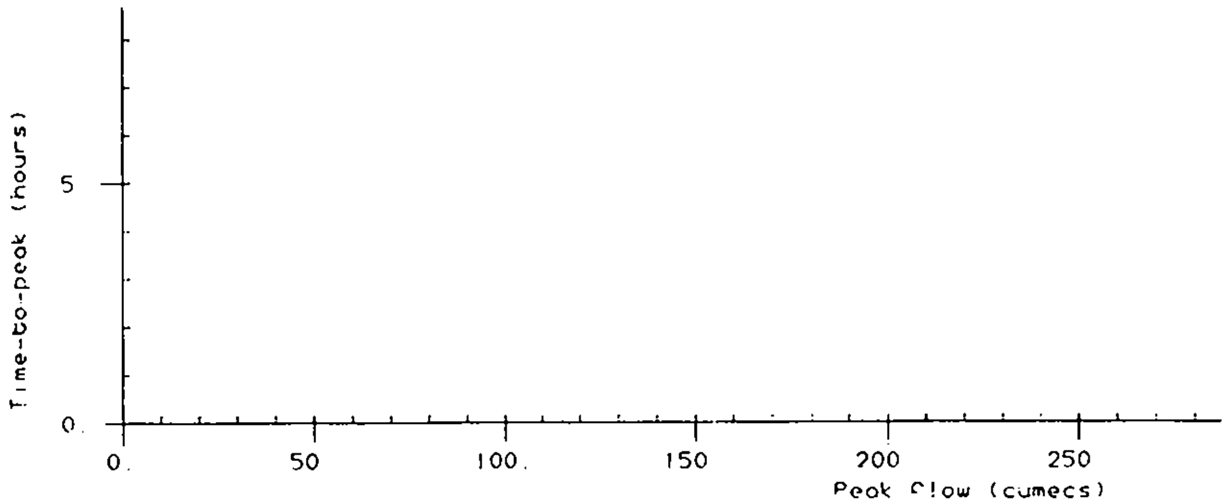
FLOOD EVENT
RESULTS ANALYSIS

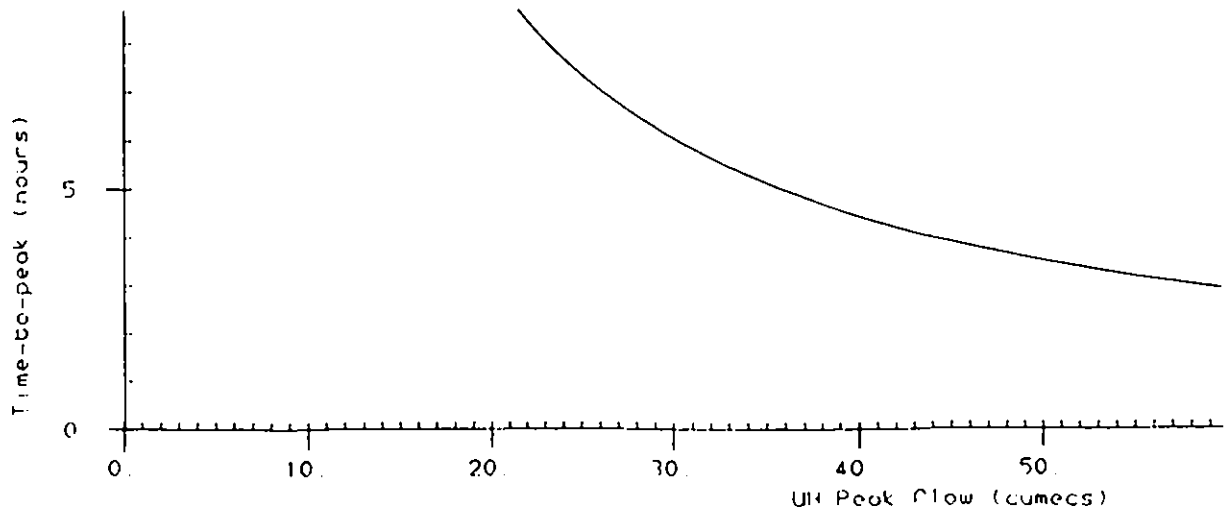
VARIATION IN TIME-TO-PEAK

23005

NORTH TYNE AT TARSET





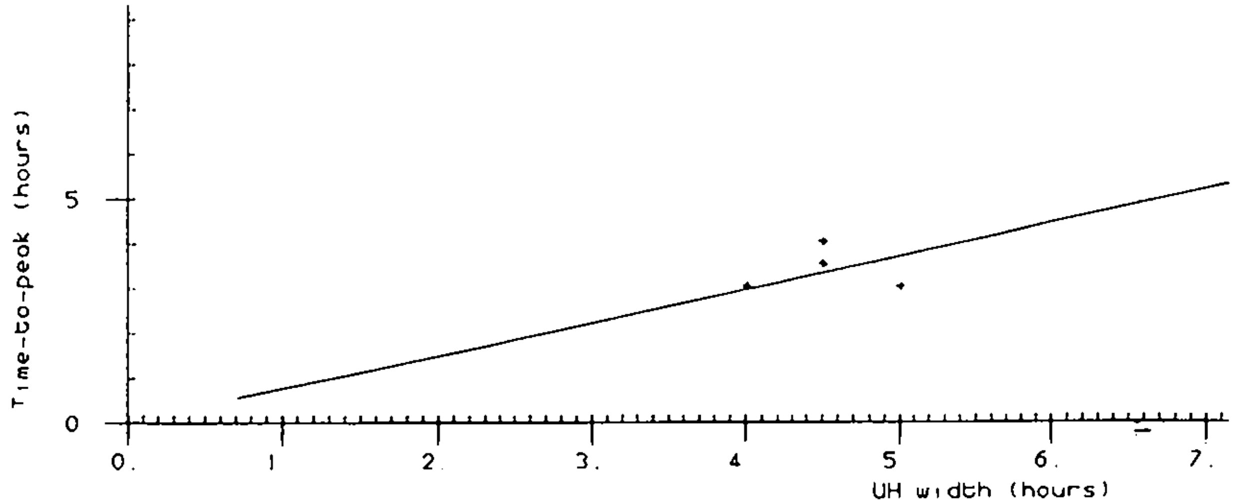


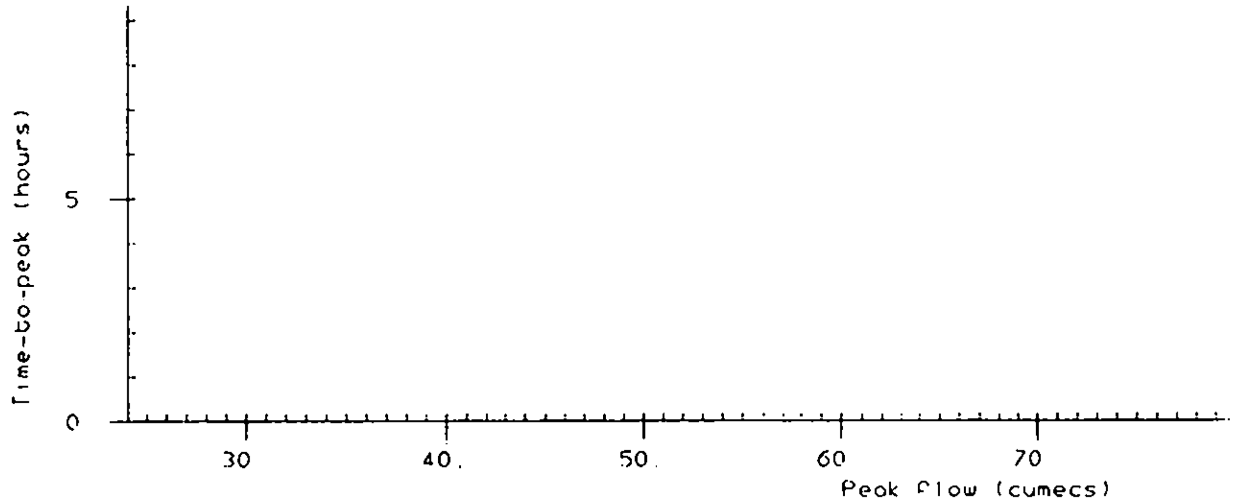
VARIATION IN TIME-TO-PEAK

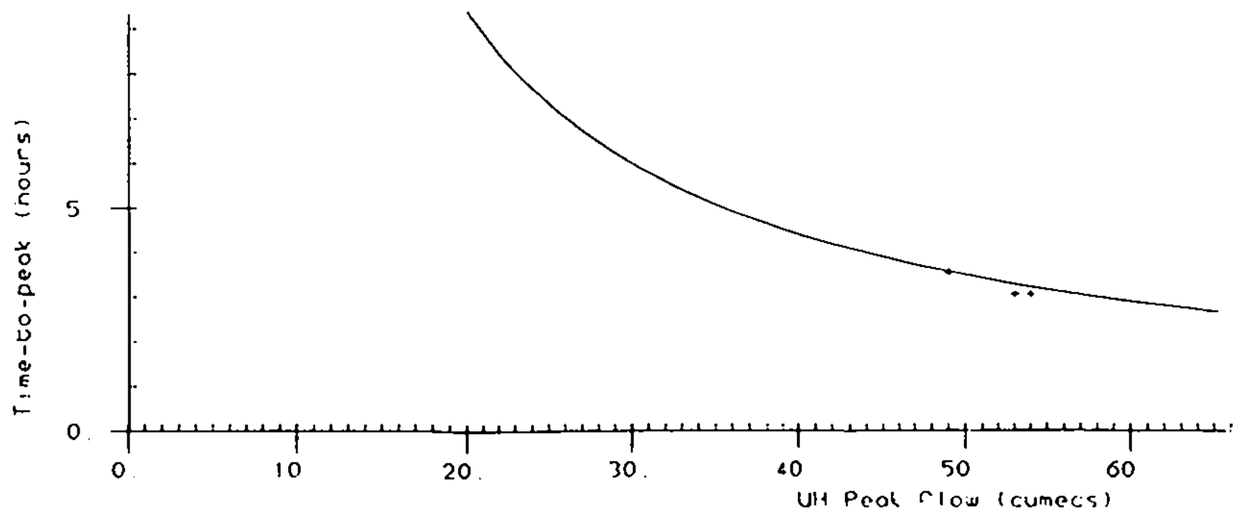
23011

KIELDER BURN AT KIELDER

FLOOD EVENT RESULTS ANALYSIS





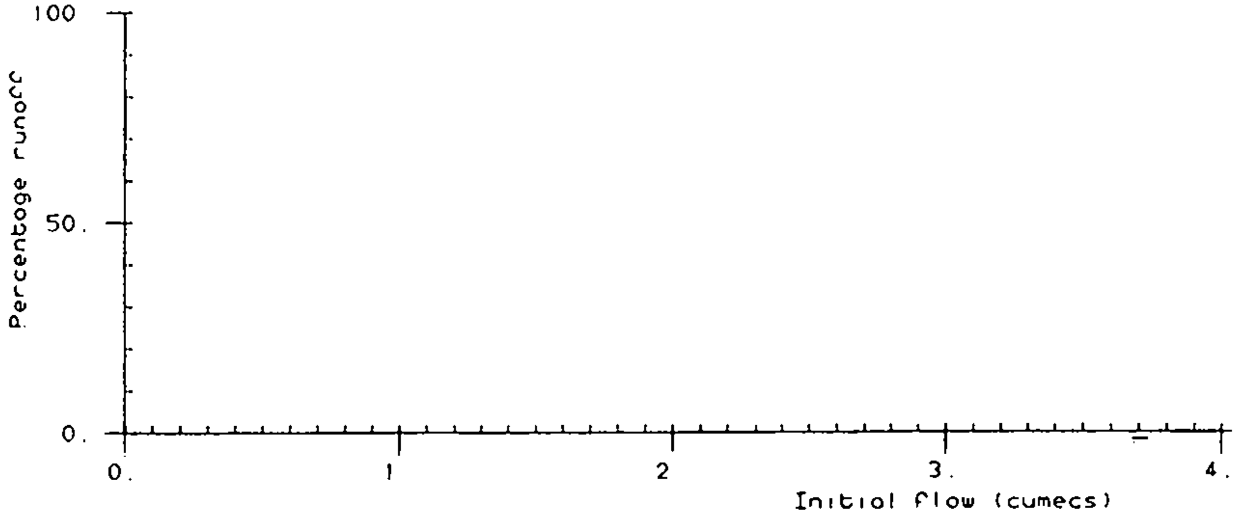


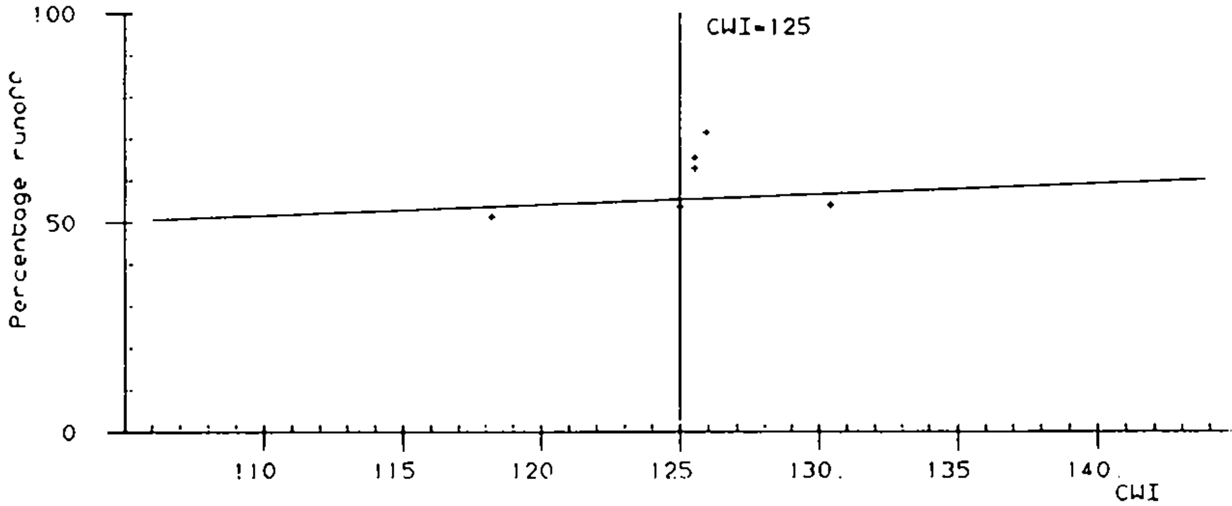
FLOOD EVENT
RESULTS ANALYSIS

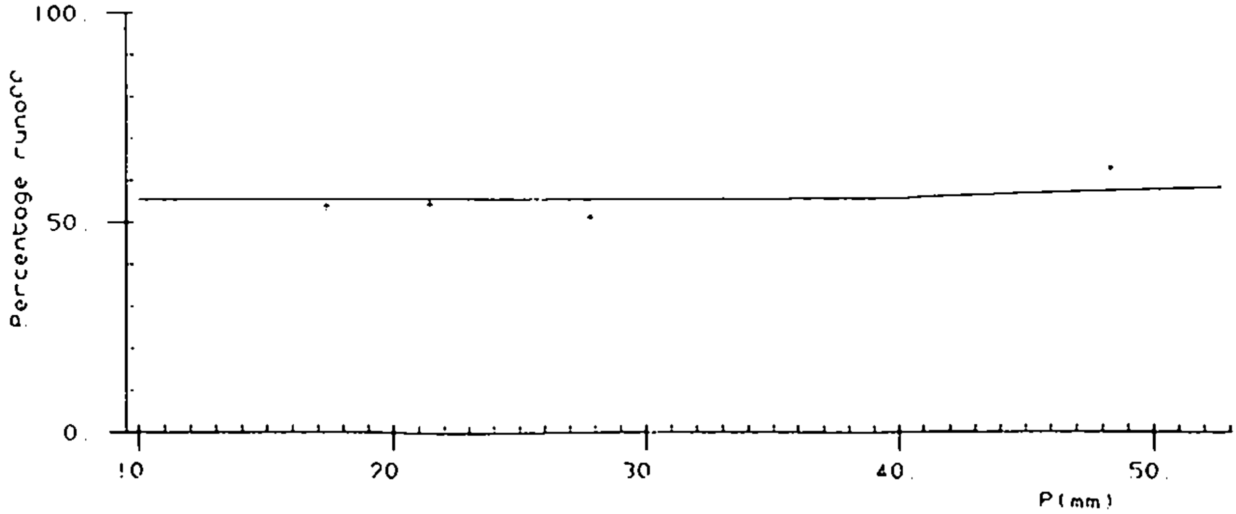
VARIATION IN PERCENTAGE RUNOFF

23010

TARSET BURN AT GREENHAUGH



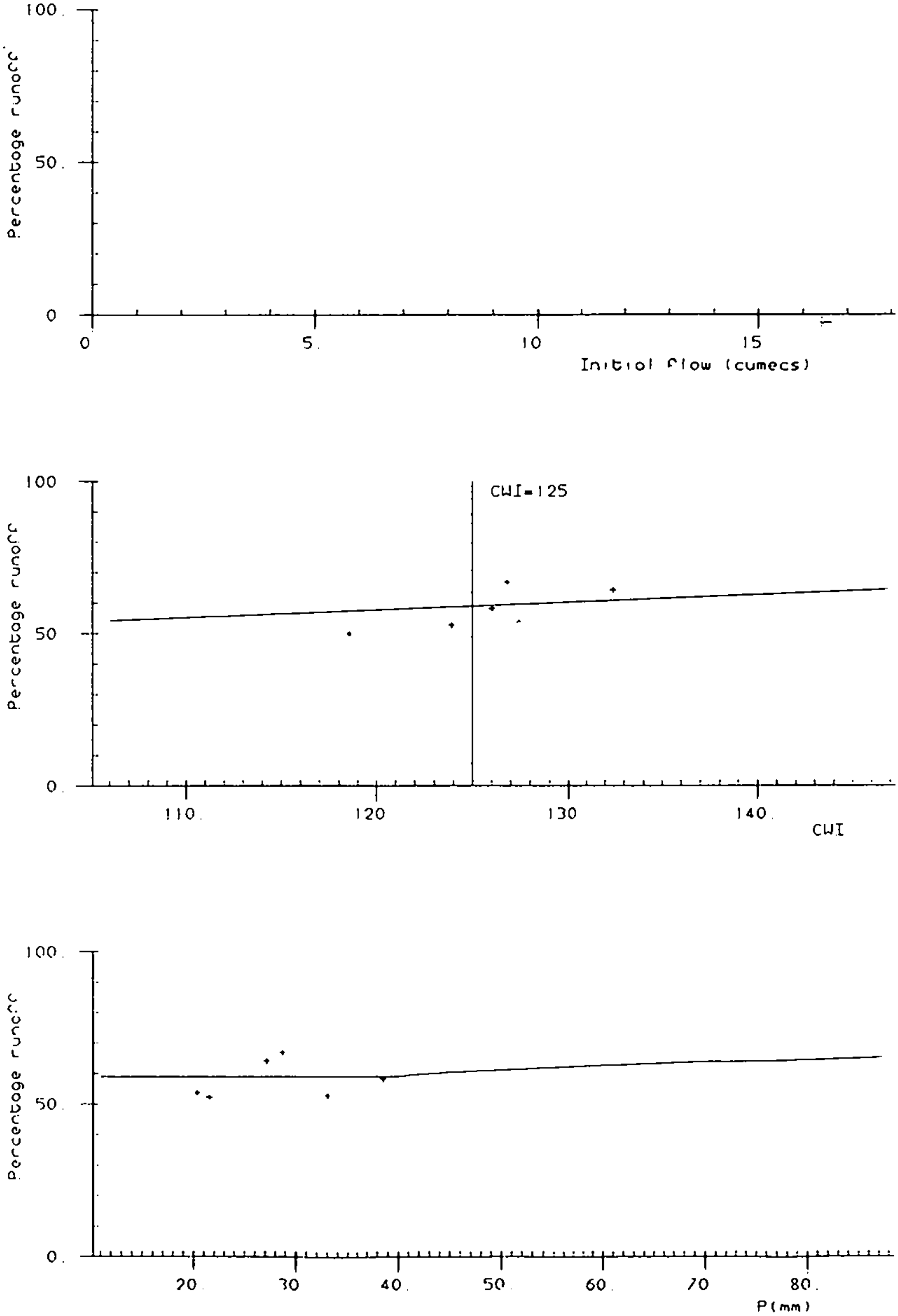




VARIATION IN PERCENTAGE RUNOFF

23008

REDE AT REDE BRIDGE

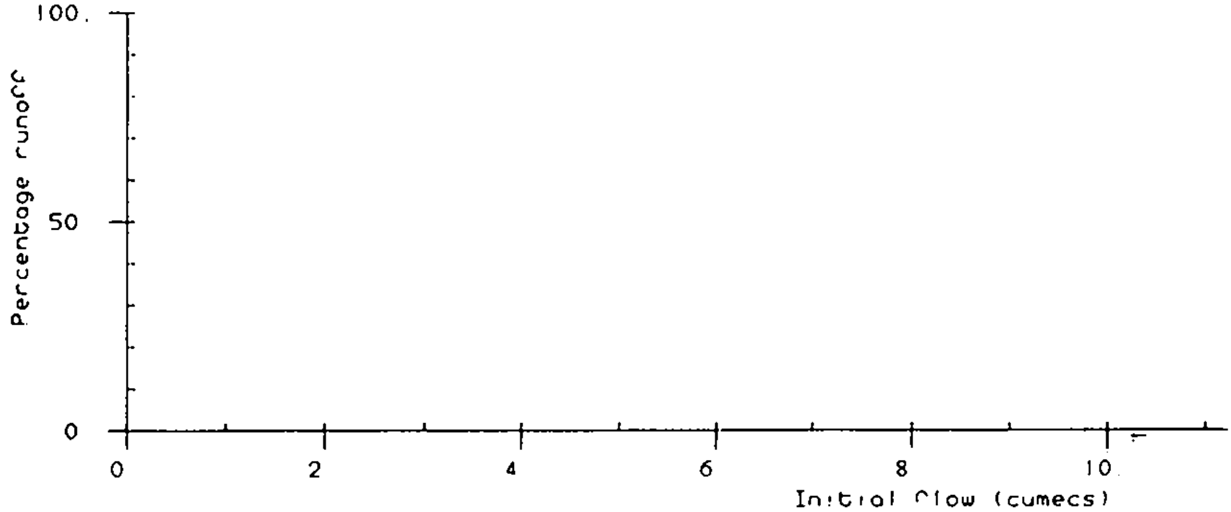


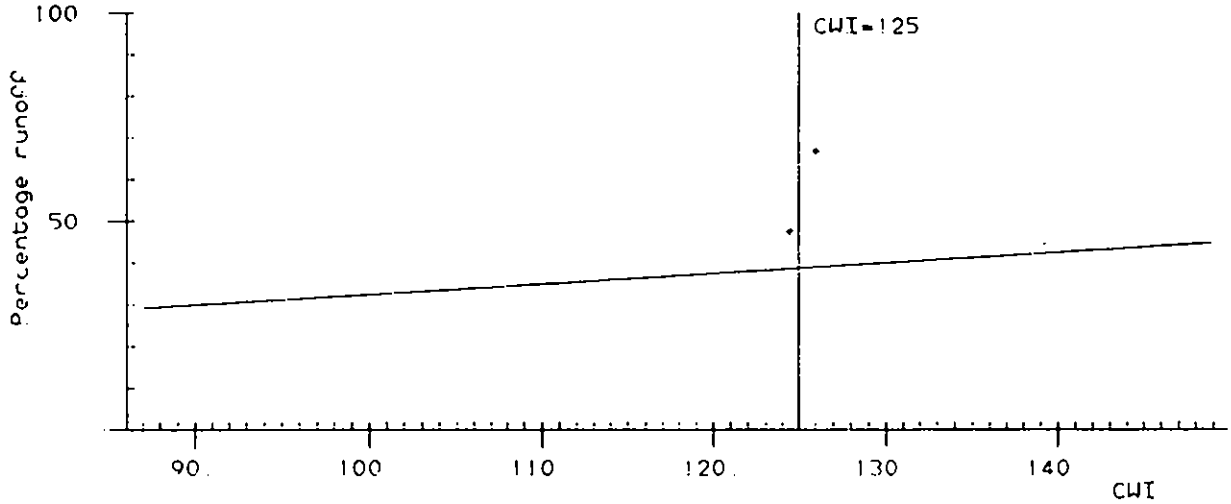
FLOOD EVENT
RESULTS ANALYSIS

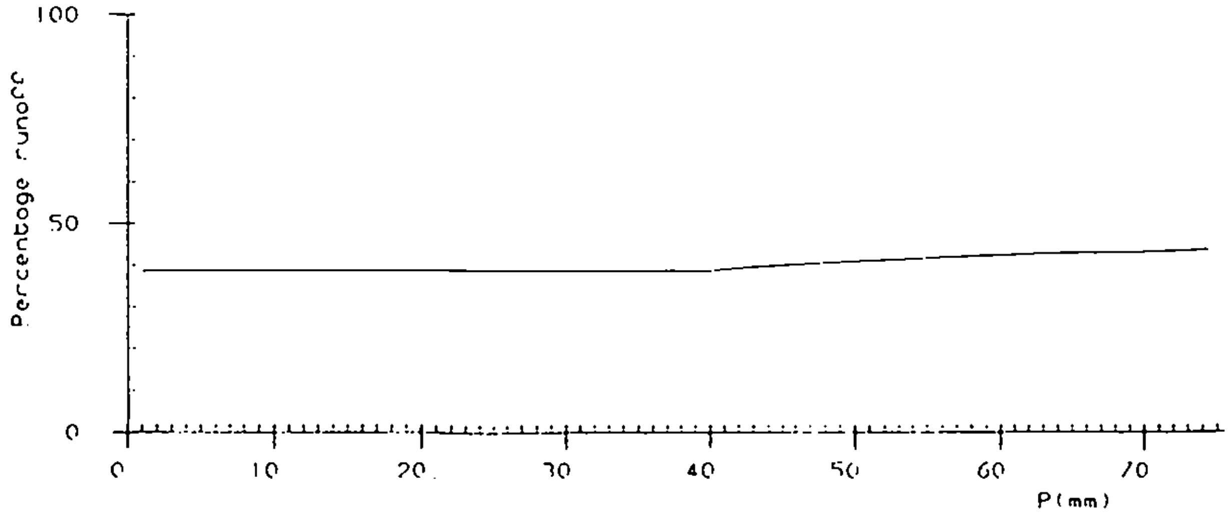
VARIATION IN PERCENTAGE RUNOFF

23005

NORTH TYNE AT TARSET





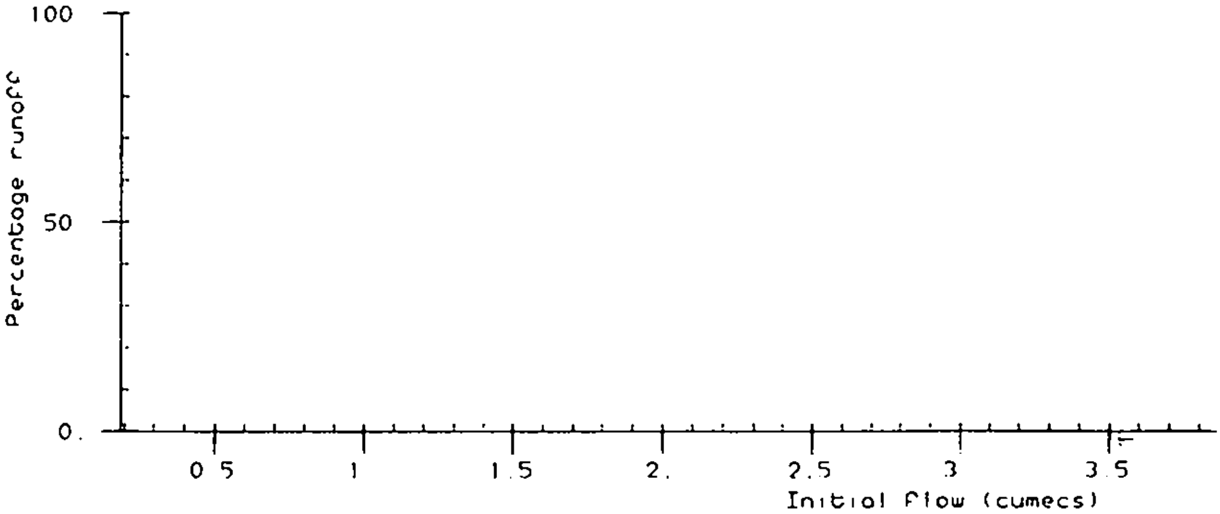


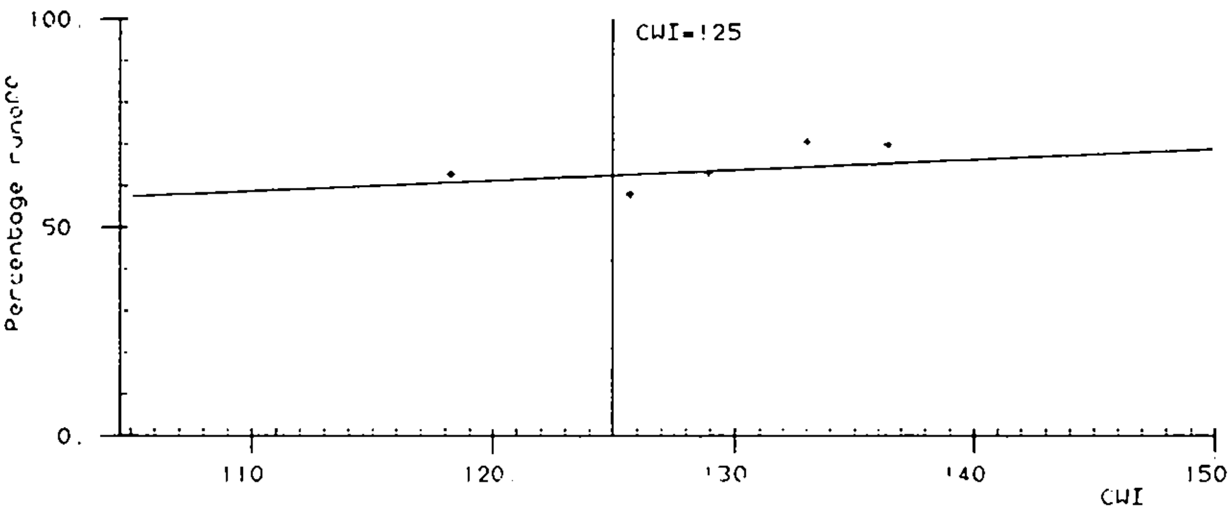
VARIATION IN PERCENTAGE RUNOFF

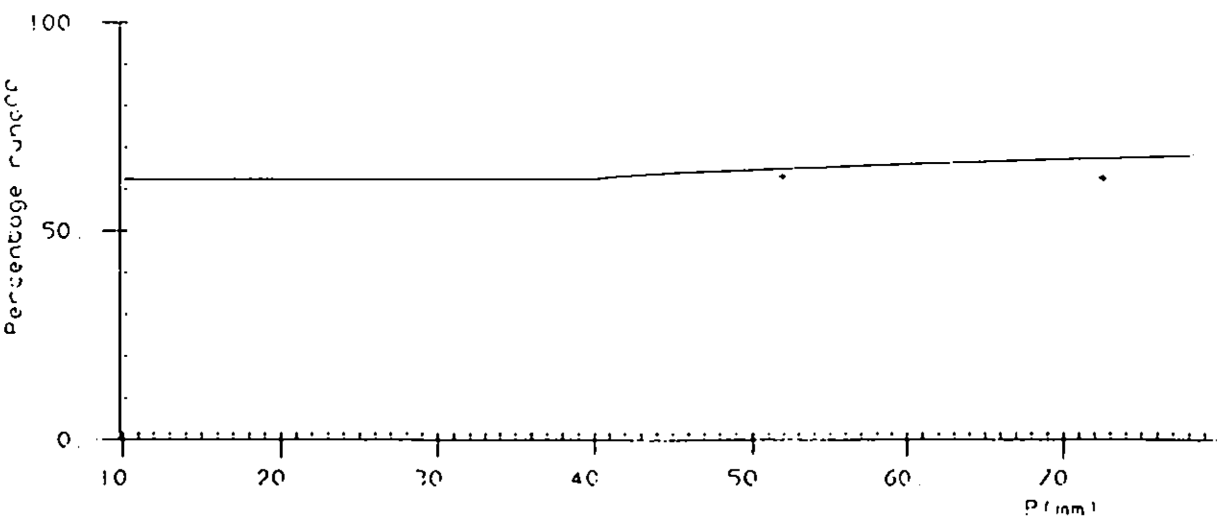
FLOOD EVENT
RESULTS ANALYSIS

23011

KIELDER BURN AT KIELDER







Appendix IV Graphical results of unit hydrograph - losses analysis

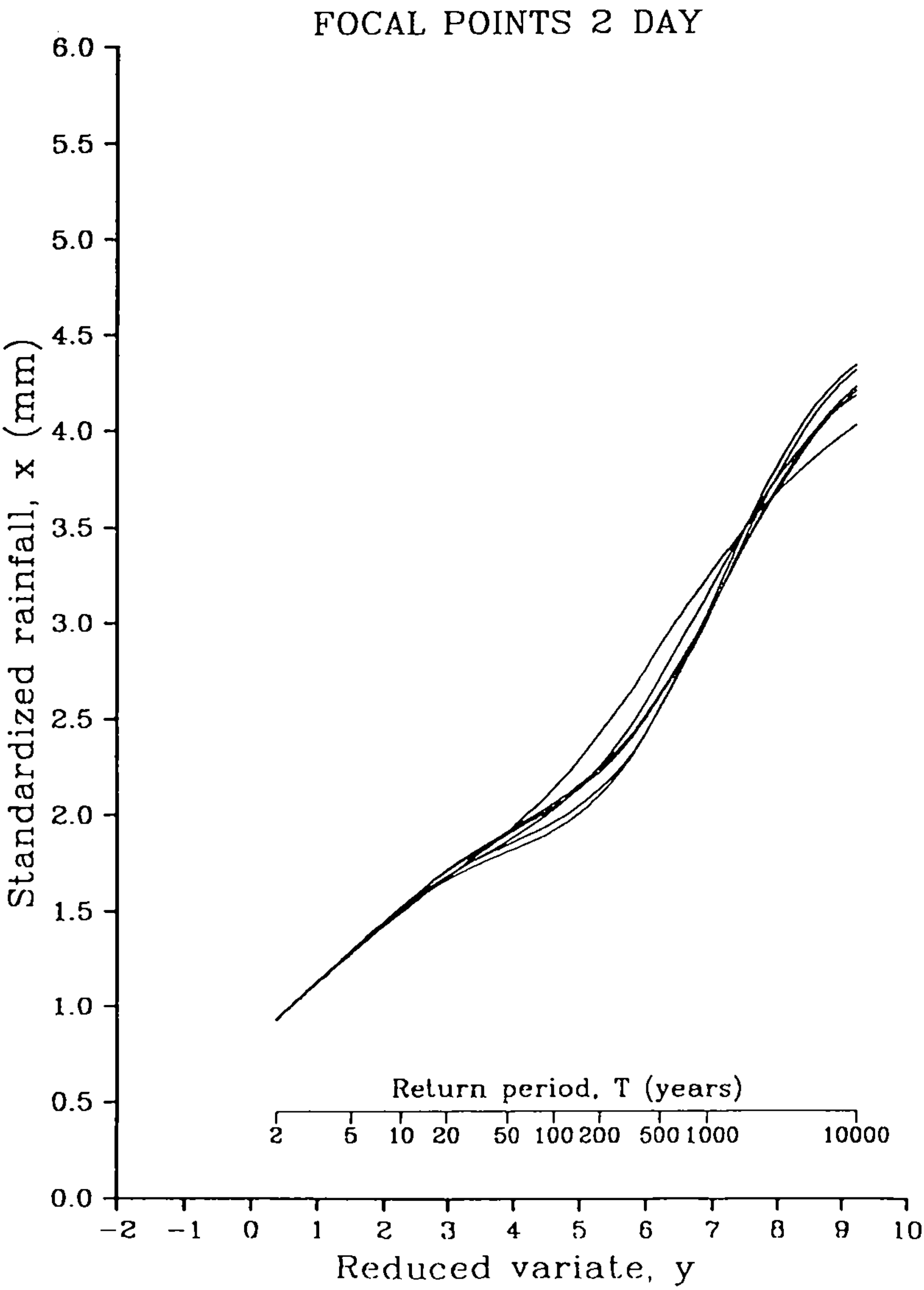


Figure III.5 2-day growth curve for all focal points

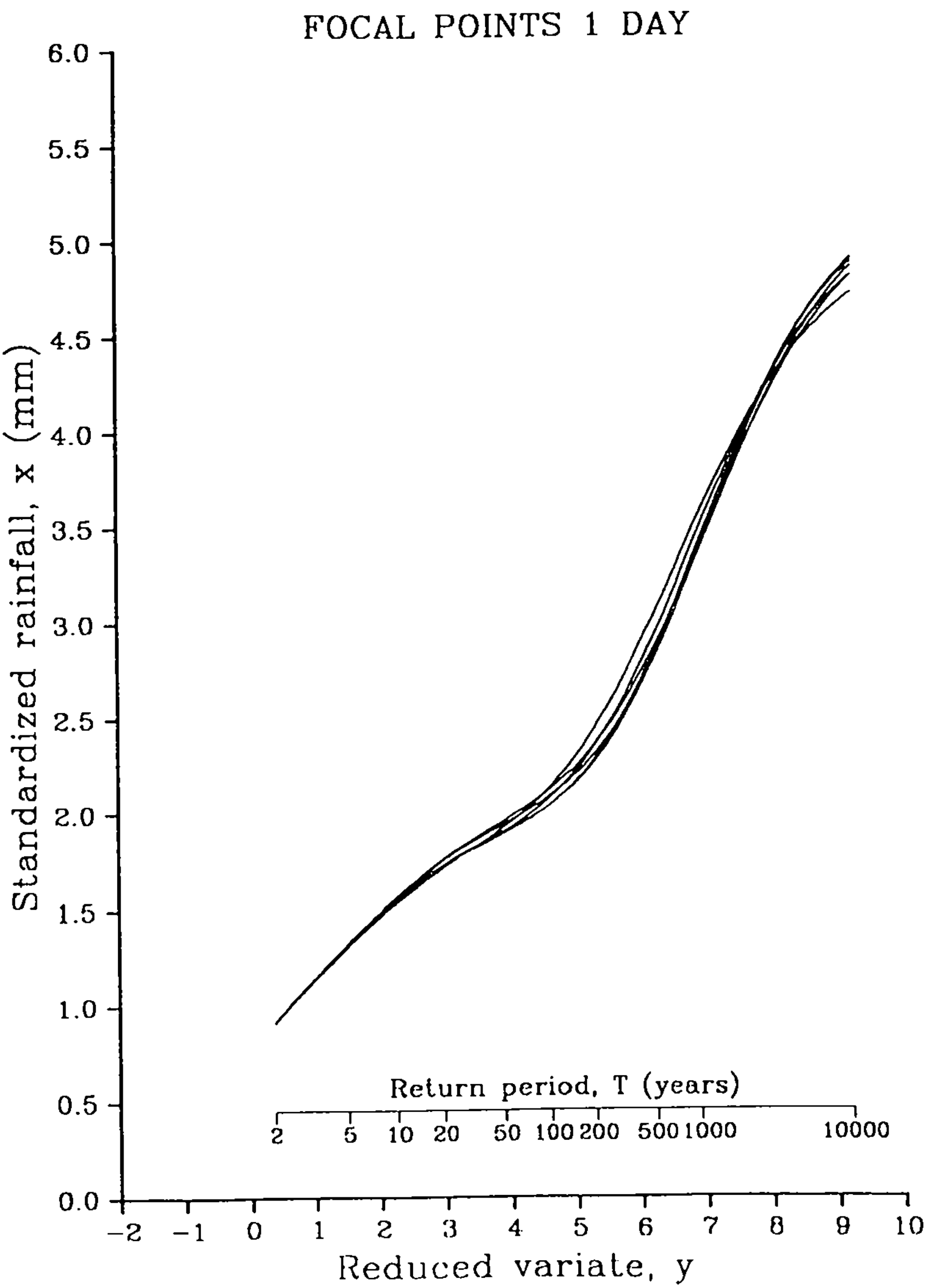


Figure III.4 1-day growth curve for all focal points

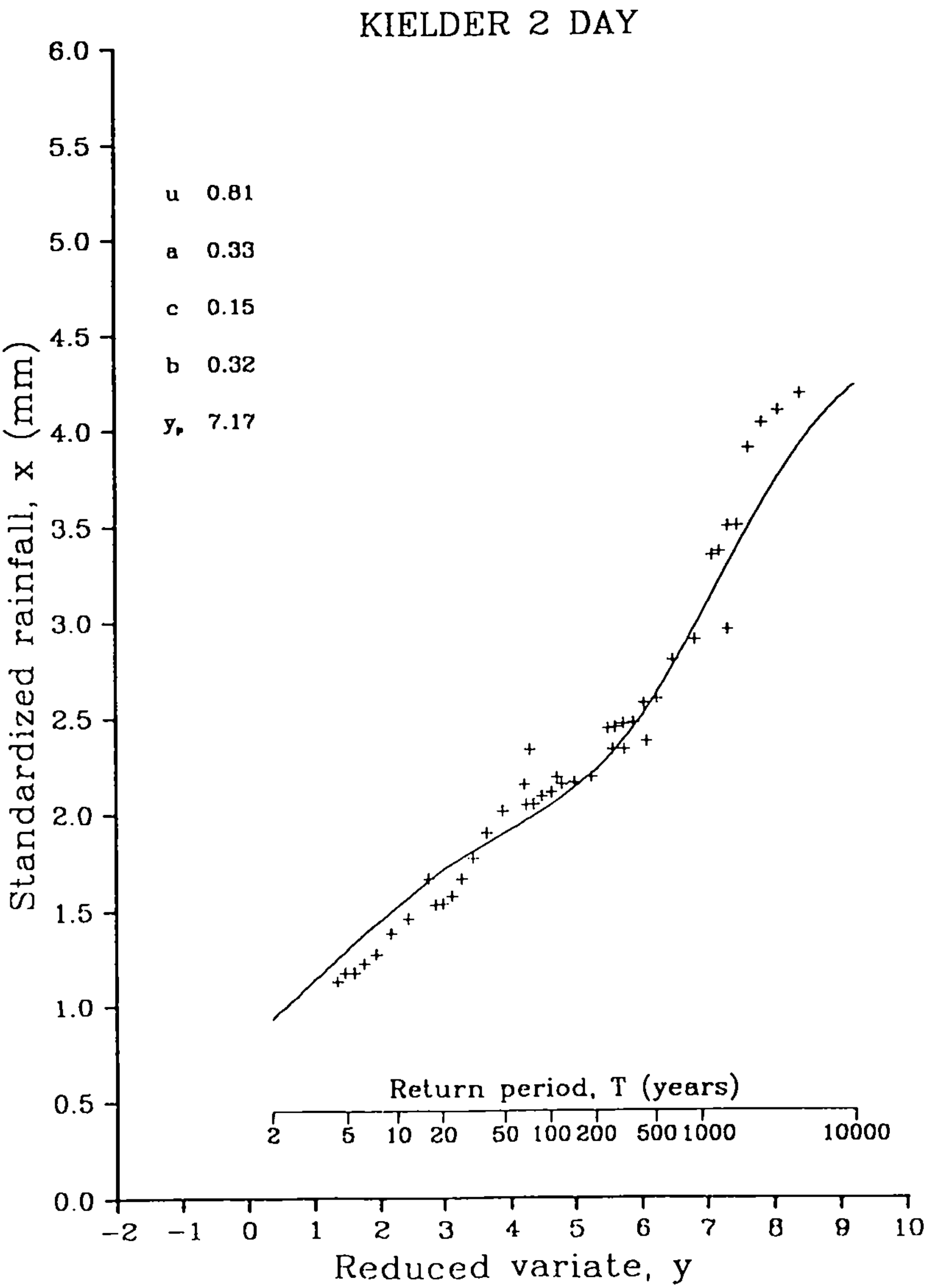


Figure III.3 2-day growth curve for Kielder

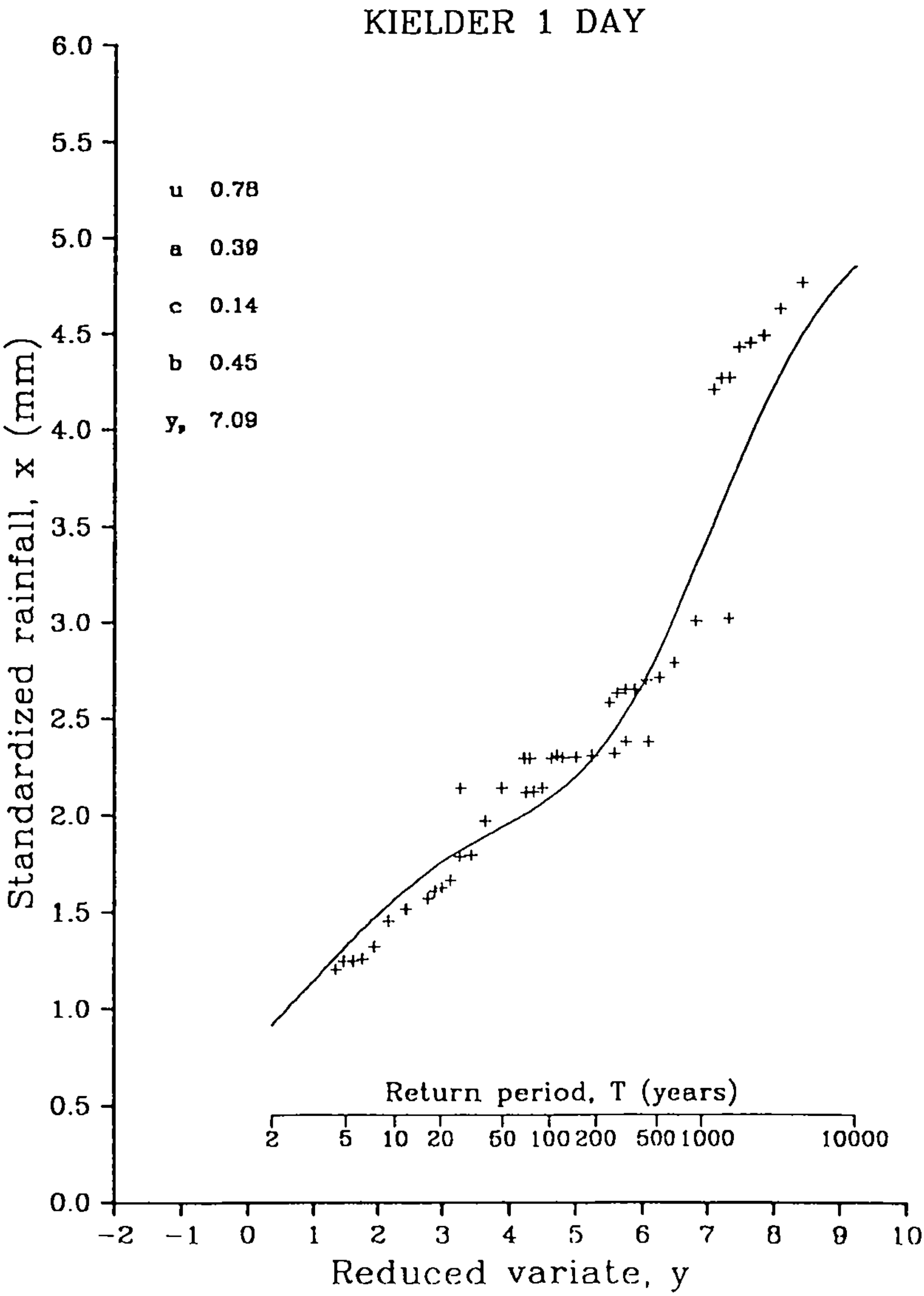


Figure III.2 1-day growth curve for Kielder

THE FOCAL POINTS FOR THE KIELDER ANALYSIS

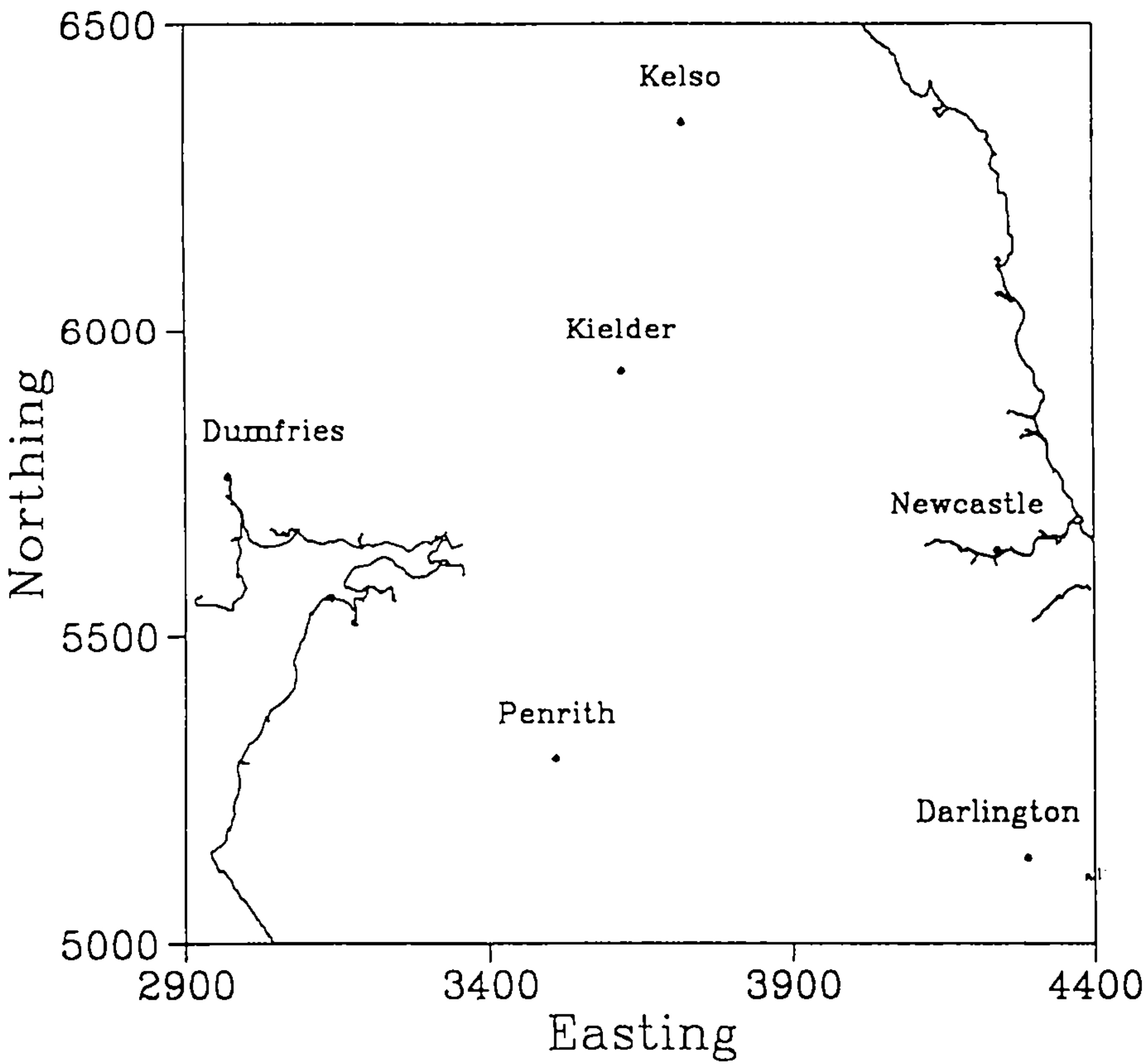


Figure III.1 Focal point locations

Table 1 The parameters of the 1-day Perturbed Gumbels

Focal points	a	u	Yp	b	c
Kielder	0.387	0.777	7.09	0.45	0.14
Newcastle	0.387	0.777	6.81	0.43	0.14
Darlington	0.387	0.777	6.59	0.37	0.14
Penrith	0.387	0.777	6.96	0.48	0.14
Dumfries	0.387	0.777	7.04	0.49	0.14
Kelso	0.387	0.777	7.03	0.41	0.14

Table 2 The parameters of the 2-day Perturbed Gumbels

Focal points	a	u	Yp	b	c
Kielder	0.333	0.808	7.17	0.32	0.15
Newcastle	0.333	0.808	6.81	0.30	0.15
Darlington	0.333	0.808	6.23	0.19	0.15
Penrith	0.333	0.808	7.06	0.43	0.15
Dumfries	0.333	0.808	7.16	0.40	0.15
Kelso	0.333	0.808	7.18	0.30	0.15

The analysis outlined here can only be as good as the data that are available. As more data are made available the accuracy of these results will increase; at this moment the Tweed rainfall data are being computerised and once this has been done the above analysis could be repeated and more confident results obtained.

The derived rainfall growth curves are attached as Figures III.1 onwards.

Appendix III Details of FORGE analysis

Full details of the FORGE analysis are given in Stewart (1989). However, the results of the frequency analysis are presented below for completeness.

The rainfall growth curves are assumed to follow a Perturbed Gumbel Distribution, defined by:

$$x = u + ay + b(y-Yp)\ \exp(-c(y-Yp)(y-Yp))$$

where u, a, Yp, b and c are the Perturbed Gumbel parameters, y is the reduced variate of the return period, which is a function of the equivalent station-years, and x is the standardized rainfall. The parameters u and a which make up the Regional Gumbel are found by fitting the Gumbel curve to the pooled set of data from all the focal points. Once the Regional Gumbel has been found, the Perturbed Gumbel for each of the focal points can be found by fitting the Perturbed Gumbel to each focal point FORGE data set.

In Tables 1 and 2 the parameters of the Perturbed Gumbel rainfall growth curves for all the focal points used in this analysis are presented. In practice, values of c are very similar, so for simplicity and to reduce variability, the value of c has been made the same at each focal point. Thus the value used is the mean of the six values calculated at the focal prints.

APPENDIX II - SUMMARY OF EVENTS STUDIED

CATCH NO.	STORM DATE	RAINFALL Total (mm)	RAINFALL Duratn (hr)	PEAK FLOW (cumecs)	LAG (hr)	ANSF (cumecs)	SMD (mm)	API5 (mm)	CWI (mm)	PR (mm)	PR %	SPR %	1-HR Unit Hydrograph Qp (cumecs)	1-HR Unit Hydrograph Tp(0) (hr)
23005	16 10 67	40.3	14	236.59	4.2	11.38	0.2	6	13	23.3	57.7	56.3		
	01 11 67	28.2	9	130.92	6.3	5	1	0.4	124	13.2	47	47.3		
	12 09 68	42	15	143.46	4.5	6.93	11.6	6.8	120	22.6	53.7	54.2	27.2	5.5
	17 09 69	26	10	140.25	5.6	4.42	26.1	0.8	99	11.8	45.3	51.8	42	7.5
	30 10 70	28.1	11	261.6	4.7	12.47	0	11.2	136	19.4	69.1	66.4	38	7.9
	08 11 72	31.7	14	140.33	3.5	10.24	6.2	1.7	120	14.7	46.3	47.6	54.5	5.5
	25 12 79	68.9	37	161.91	10	4.47	0	1	126	45.7	66.3	61.3	23.5	6.5
23008	25 12 79	43.4	44	121.5	11.6	4.44	0	0.4	125	27	62.3	61.1		
	22 11 81	28.7	19	136.64	13.1	5.95	1.8	3.6	127	19.1	66.5	66.1	24	10
	23 12 83	21.5	16	125.96	7.1	11.39	0	6.1	131	11.1	51.8	50.3	34	8
	12 01 84	20.3	10	100.54	8.5	9.06	0	2.4	127	10.8	53.3	52.7	32	10.5
	25 03 84	27.1	21	99.94	7.4	9.88	0	7.4	132	17.3	63.7	61.9	26	6.5
	06 05 86	24.8	14	96.71	6.4	7.32	4.3	1.9	123	10.6	42.8	43.4	26	7.5
	25 08 86	80.7	46	190.07	9	3.51	7.4	0.8	118	39.9	49.5	45.1		
	18 10 88	33	36	92.95	8.8	5.61	2.3	1.1	124	17.3	52.4	52.7	18.5	8.5
	29 11 88	38.5	40	92.65	7.6	6.43	0	1	126	22.3	57.8	57.6	15	8
23010	30 10 70	21.0	11	56.06	2.8	3.15	0	6.5	131	8.8	41.6	40.1		
	16 03 72	19.9	7	28.04	4.7	1.12	2.7	0.3	122	6.2	31.4	32.2		
	11 05 72	17.3	19	24.52	9.4	1.19	2.4	2.4	125	9.2	53.5	53.5		
	03 05 73	27.8	30	55.09	6.2	1.02	7.6	0.8	118	14.1	50.8	52.6		
	10 11 74	21.4	13	60.75	4.4	3.46	0	5.4	130	11.5	53.7	52.5		
	22 02 76	23.9	21	59.58	3.3	2.74	0	0.5	125	15.6	65.1	65.1		
	25 12 79	48.3	41	41.3	8.3	1.19	0	0.5	126	30.2	62.5	60.4		
23011	25 12 79	67.4	41	37.94	6.9	1.14	0	0.7	126	38.8	57.6	52.9	34	3.5
	13 12 80	17	9	41.82	2.9	3.66	0	11.4	136	11.8	69.4	66.6	53	3
	22 11 81	51.9	17	72.42	5.5	2.13	1.3	5.2	129	32.5	62.6	59.1	49	3.5
	23 12 83	29.3	16	42.12	7.9	3.61	0	8	133	20.5	70.1	68.1	43	8.5
	12 01 84	21	8	42.98	2.8	2.76	0	6.6	132	16	76.3	74.7	60	4
	06 05 86	23.3	12	41.1	2.1	2.9	3.7	1.9	123	12.2	52.3	52.8	54	3
	25 08 86	73.4	45	31.31	7.3	0.98	0	1	119	45.2	61.6	57.9		

Appendix II Summary of events studied

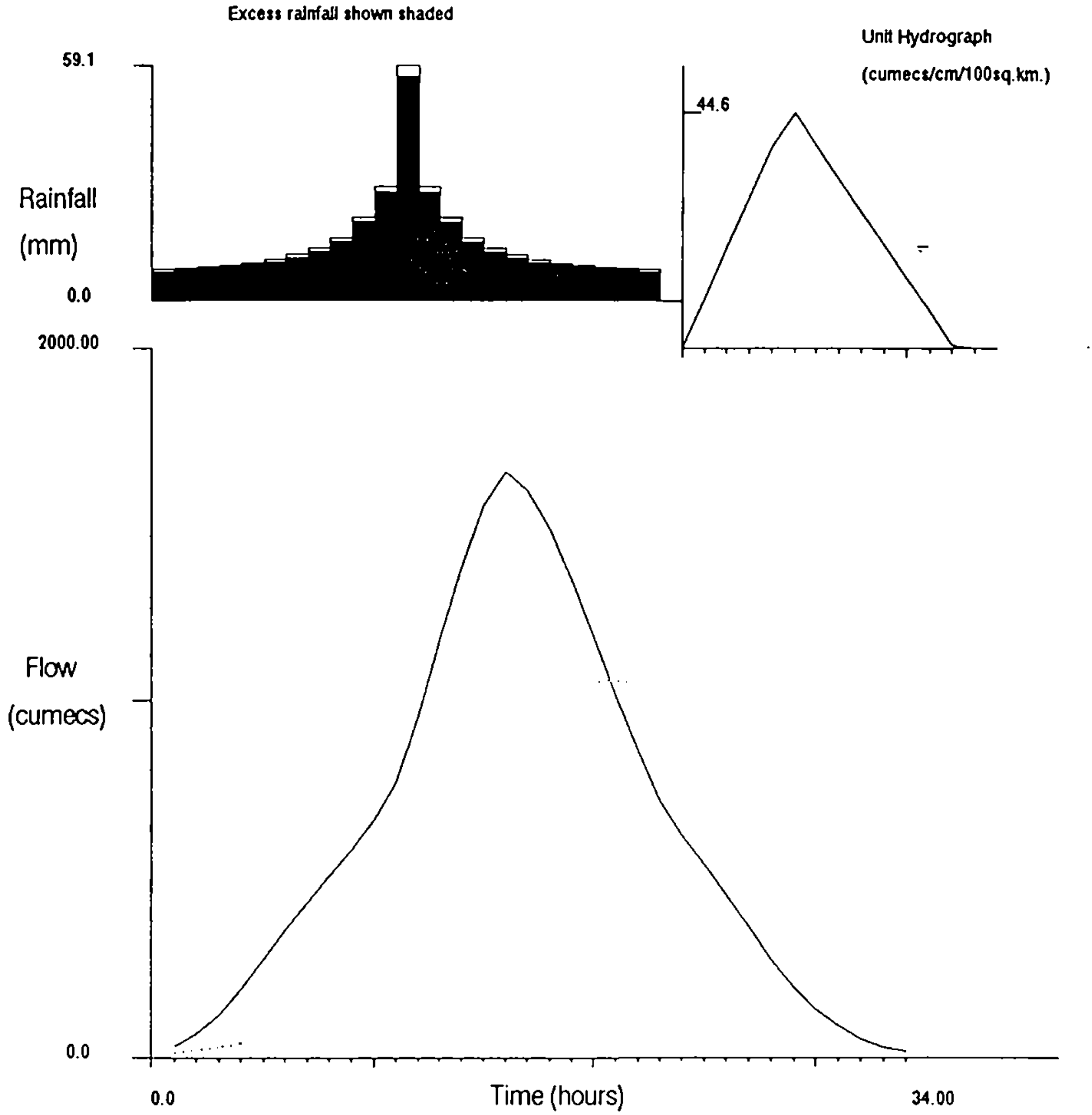
UK DESIGN FLOOD ESTIMATION
RAINFALL AND HYDROGRAPH

Institute of Hydrology

Description : Original Archer PMF estimate recreation

Run Reference: TRIAL

Printed on 5 4 1990 at 11:25



Data Interval(hours) 1.00

Inflow ———

Outflow

micro - FSR, Institute of Hydrology

Version: 2.1 c(ii)

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Institute of Hydrology

UK DESIGN FLOOD ESTIMATION

Description : Original Archer PMF estimate recreation
Printed on 5 4 1990 at 11:25 Run Reference : TRIAL

Time series data from reservoir routing calculations

****

Time hours	Total Rain mm	Net Rain mm	Unit Hydrograph cumecs/cm /100sq km	Unit Hydrograph %	Inflow cumecs	Outflow cumecs	Water level metres
1.00	8.0	7.7	9.53	3.43	31.65	14.83	0.08
2.00	8.3	7.9	19.07	6.86	65.92	19.22	0.09
3.00	8.7	8.3	28.60	10.30	118.39	26.84	0.13
4.00	9.1	8.7	38.14	13.73	190.03	39.22	0.18
5.00	9.7	9.3	44.57	16.04	276.57	57.81	0.25
6.00	10.5	10.0	38.29	13.78	357.01	88.76	0.34
7.00	11.6	11.0	32.02	11.53	432.52	128.75	0.45
8.00	13.2	12.5	25.75	9.27	505.11	176.92	0.57
9.00	15.8	15.1	19.48	7.01	578.63	232.61	0.70
10.00	21.0	20.0	13.21	4.75	661.82	296.18	0.84
11.00	28.7	27.4	6.93	2.50	768.03	370.42	0.99
12.00	59.1	56.4	0.66	0.24	956.94	476.55	1.17
13.00	28.7	27.4			1168.44	643.47	1.40
14.00	21.0	20.0			1376.95	816.09	1.60
15.00	15.8	15.1			1552.28	921.08	1.82
16.00	13.2	12.5			1647.16	960.35	2.05
17.00	11.6	11.0			1594.82	995.40	2.27
18.00	10.5	10.0			1484.28	1022.63	2.46
19.00	9.7	9.3			1340.54	1041.56	2.59
20.00	9.1	8.7			1180.81	1052.41	2.67
21.00	8.7	8.3			1016.04	1055.59	2.69
22.00	8.3	7.9			857.44	1051.61	2.66
23.00	8.0	7.7			718.21	1041.20	2.59
24.00					622.74	1025.70	2.48
25.00					539.84	1005.08	2.34
26.00					457.06	980.49	2.18
27.00					368.08	951.38	1.99
28.00					275.22	916.88	1.79
29.00					198.53	796.84	1.58
30.00					136.47	645.86	1.40
31.00					87.93	526.65	1.24
32.00					52.08	437.05	1.10
33.00					28.27	366.48	0.98
34.00					15.99	313.27	0.87

****

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UK DESIGN FLOOD ESTIMATION

Description : Original Archer PMF estimate recreation
Printed on 5 4 1990 at 11:24 Run Reference : TRIAL

Summary of reservoir routing calculations

****

Estimation of Probable Maximum Flood

Winter season rainfall

Unit hydrograph time to peak	4.80	hours
Data interval	1.00	hours
Includes Tp scaling factor	0.67	
Design storm duration	23.00	hours
Pre-event snow depth	200.00	mm.
Melt rate	5.00	mm/hr
Design storm depth	348.36	mm.
Design CWI	195.04	
Standard Percentage Runoff	53.00	
Percentage runoff	95.37	%

Baseflow	:	14.83	cumecs	
Inflow hydrograph peak	:	1647.16	cumecs	(Max ordinate)
	:	1648.69	cumecs	(Interpolated)
Outflow hydrograph peak	:	1055.59	cumecs	(Max ordinate)
	:	1055.60	cumecs	(Interpolated)
Attenuation rating	:	0.64	(From interpolated peaks)	
Reservoir LAG	:	4.80	hours	

Options

Unit hydrograph option	1 - FSR-Triangle
Tp option	1 - FSSR 16 Tp equation
Rainfall option	5 - Max precipitation
Duration option	2 - with reservoir lag
Percentage runoff option	1 - FSSR 16 equation
Tp scaling factor option	1 - Unscaled
CWI option	1 - Design standard
PMF scaling factor	0 - Set to 1.0
Baseflow option	1 - FSSR 16 equation
SPR option	2 - from SOIL
Initial water level	1 - Spilling baseflow
Reservoir rainfall	1 - Explicit
Inflow to reservoir	1 - From micro-FSR

****

UK DESIGN FLOOD ESTIMATION

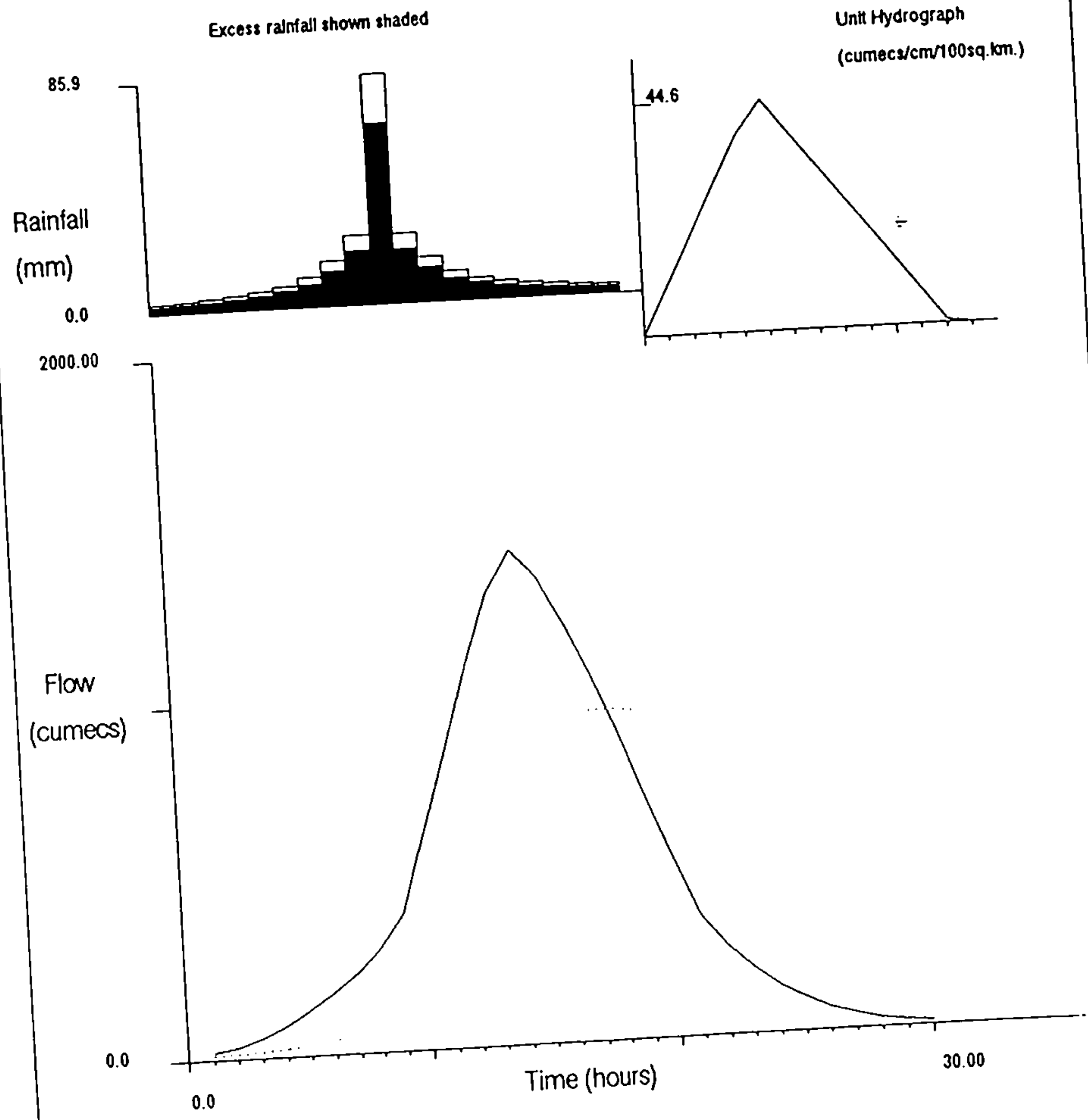
RAINFALL AND HYDROGRAPH

Institute of Hydrology

Run Reference: TRIAL

Description : Original Archer PMF estimate recreation

Printed on 5 4 1990 at 14:07



Data Interval(hours) : 1.00

Inflow ———

Outflow

Version: 2.1 c(ii)

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Institute of Hydrology

UK DESIGN FLOOD ESTIMATION

Description : Original Archer PMF estimate recreation
Run Reference : TRIAL
Printed on 5 4 1990 at 14:07

Time series data from reservoir routing calculations
****

Time hours	Total Rain mm	Net Rain mm	Unit Hydrograph cumecs/cm /100sq km	Unit Hydrograph %	Inflow cumecs	Outflow cumecs	Water level metres
1.00	3.8	3.0	9.53	3.43	17.88	11.30	0.06
2.00	4.3	3.4	19.07	6.86	31.87	13.12	0.07
3.00	4.9	3.8	28.60	10.30	54.30	16.30	0.08
4.00	5.7	4.5	38.14	13.73	86.57	21.55	0.10
5.00	6.8	5.4	44.57	16.04	128.48	29.65	0.14
6.00	8.5	6.7	38.29	13.78	173.89	41.19	0.19
7.00	11.3	8.9	32.02	11.53	226.17	56.67	0.25
8.00	16.8	13.2	25.75	9.27	293.05	81.56	0.32
9.00	25.9	20.4	19.48	7.01	387.76	117.48	0.42
10.00	85.9	67.6	13.21	4.75	610.57	175.99	0.57
11.00	25.9	20.4	6.93	2.50	852.26	291.67	0.83
12.00	16.8	13.2	0.66	0.24	1087.58	414.29	1.07
13.00	11.3	8.9			1292.99	582.14	1.32
14.00	8.5	6.7			1409.85	770.61	1.55
15.00	6.8	5.4			1331.46	906.00	1.73
16.00	5.7	4.5			1200.15	927.63	1.85
17.00	4.9	3.8			1039.86	939.13	1.92
18.00	4.3	3.4			865.69	940.68	1.93
19.00	3.8	3.0			687.19	932.44	1.88
20.00					508.23	914.33	1.78
21.00					341.79	834.19	1.63
22.00					252.24	702.49	1.47
23.00					187.33	590.91	1.33
24.00					133.86	497.13	1.20
25.00					93.87	424.71	1.08
26.00					63.87	364.04	0.98
27.00					41.82	315.97	0.88
28.00					26.38	273.81	0.79
29.00					16.60	237.28	0.71
30.00					11.76	206.02	0.64

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                                                    Institute of Hydrology
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UK DESIGN FLOOD ESTIMATION

Description : Original Archer PMF estimate recreation
Printed on  5  4 1990 at 14:07                      Run Reference : TRIAL
----------------------------------------------------------------------------
Summary of reservoir routing calculations
****************************************************************************
Estimation of Probable Maximum Flood
====================================
Summer season rainfall

Unit hydrograph time to peak          4.80  hours
Data interval                         1.00  hours
Includes Tp scaling factor            0.67

Design storm duration        :       19.00  hours
No snowmelt contribution to precipitation input
Design storm depth           :      261.86  mm.

Design CWI                          148.64

Standard Percentage Runoff           53.00
Percentage runoff                    78.66  %

Baseflow                     :       11.30  cumecs
Inflow hydrograph peak       :     1409.85  cumecs   (Max ordinate)
                             :     1410.80  cumecs   (Interpolated)
Outflow hydrograph peak      :      940.68  cumecs   (Max ordinate)
                             :      941.25  cumecs   (Interpolated)
Attenuation rating           :        0.67  (From interpolated peaks)
Reservoir LAG                         3.56  hours

Options
=======
Unit hydrograph option               1 - FSR-Triangle
Tp option                            1 - FSSR 16 Tp equation
Rainfall option                      5 - Max precipitation
Duration option                      2 - with reservoir lag
Percentage runoff option             1 - FSSR 16 equation
Tp scaling factor option             1 - Unscaled
CWI option                           1 - Design standard
PMF scaling factor                   0 - Set to 1.0
Baseflow option                      1 - FSSR 16 equation
SPR option                           2 - from SOIL
Initial water level                  1 - Spilling baseflow
Reservoir rainfall                   1 - Explicit
Inflow to reservoir                  1 - From micro-FSR

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micro-FSR  -  Institute of Hydrology                    Version 2.1 c(ii)
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Institute of Hydrology

UK DESIGN FLOOD ESTIMATION

Description : Original Archer PMF estimate recreation
Printed on 5 4 1990 at 11:21 Run Reference : TRIAL

Reservoir characteristics

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Reservoir area set to : 10.980 sq. km
at : 2.000 metres
Area growth rate : 0.290 sq. km/metre

Device	HMIN	HMAX	B	C	D	E
1	0.000	0.253	185.000	1.481	0.000	1.126
1	0.253	1.000	185.000	2.032	0.000	1.356
1	1.000	1.200	185.000	2.032	0.000	1.541
1	1.200	1.700	185.000	1.975	0.000	1.699
1	1.700	9999.000	185.000	4.047	0.000	0.347

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UK DESIGN FLOOD ESTIMATION

Description : Original Archer PMF estimate recreation
Printed on 5 4 1990 at 11:18 Run Reference : TRIAL

Catchment Characteristics

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Area	:	241.50 sq.km.	Soil 1	:	0.000
Length	:	26.70 km.	Soil 2	:	0.000
Slope	:	6.85 m./km.	Soil 3	:	0.000
SAAR	:	1372 mm.	Soil 4	:	0.000
M5-2D	:	-1.0 mm.	Soil 5	:	1.000
M5-25D	:	-1.0 % of SAAR			
Jenkinson's r	:	-1.00			
Urban	:	0.00			
Smdbar	:	-1.0 mm.	RSMD		-1.000 mm.
Stmfrq	:	-1.00 junctions/sq.km.			
Lake	:	0.00			
EMP 2 hour	:	138.00 mm.	BFI	:	0.26
EMP 24 hour	:	299.00 mm.	LAG	:	-1.00 hr.

****

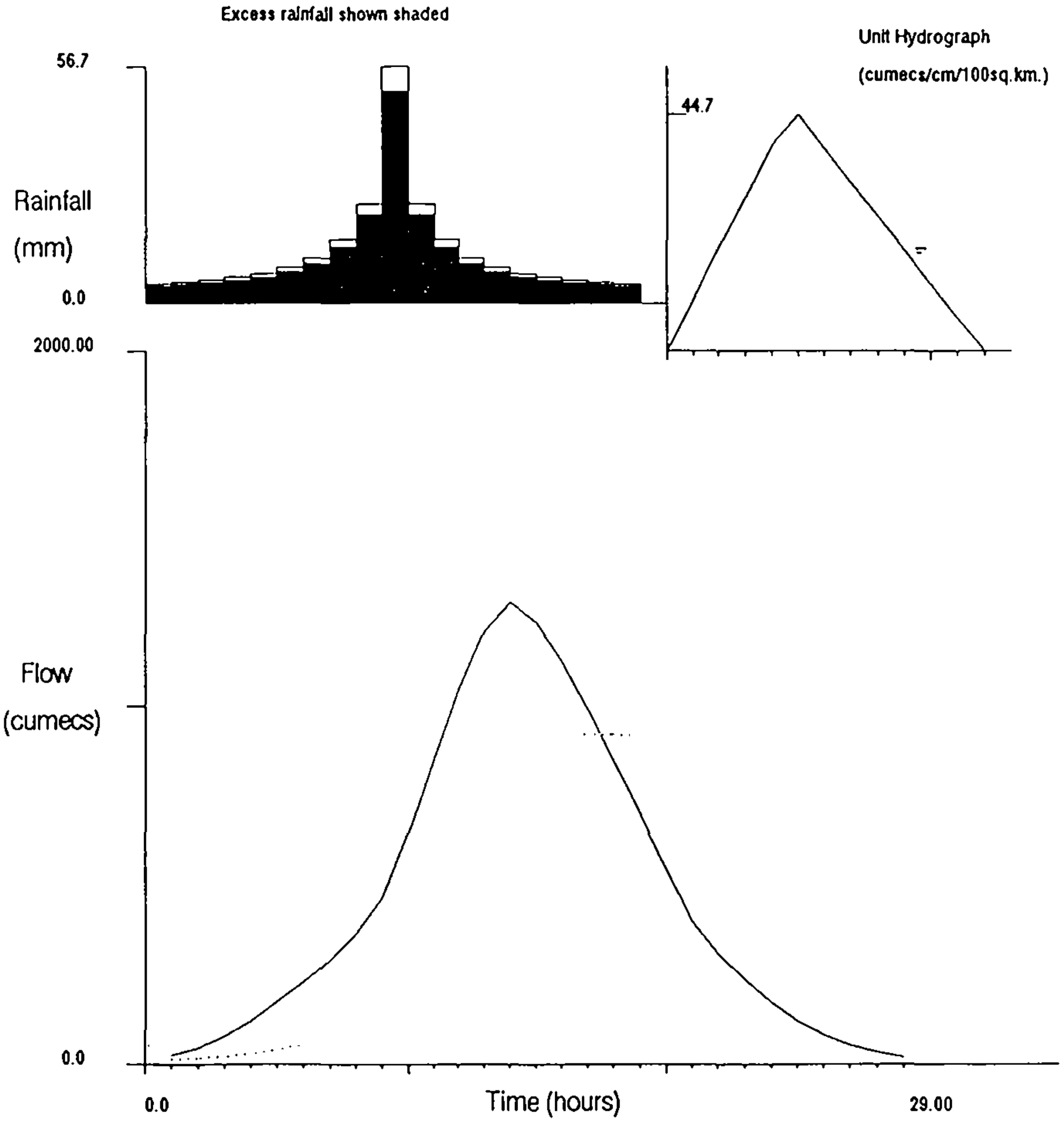
OPTION 5: COMPARISON OF MICRO-FSR OUTPUT WITH EARLIER RUNS USING D.ARCHER'S FLOOD ESTIMATION SOFTWARE

UK DESIGN FLOOD ESTIMATION
RAINFALL AND HYDROGRAPH

Institute of Hydrology

Description : Kielder PMF Final Results (CCs to Dam) **Run Reference:** KREP2

Printed on 18 6 1990 at 14:31



Data Interval(hours) : 1.00

Inflow

Outflow

****

Institute of Hydrology

UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Results (CCs to Dam)
Printed on 18 6 1990 at 14:31 Run Reference : KREP2

Time series data from reservoir routing calculations

****

Time hours	Total Rain mm	Net Rain mm	Unit Hydrograph cumecs/cm /100sq km	Unit Hydrograph %	Inflow cumecs	Outflow cumecs	Water level metres
1.00	4.9	4.4	9.75	3.51	24.14	14.07	0.07
2.00	5.2	4.7	19.50	7.02	44.48	16.55	0.08
3.00	5.7	5.1	29.25	10.53	76.37	20.90	0.10
4.00	6.4	5.7	39.00	14.04	121.12	28.02	0.13
5.00	7.3	6.5	44.71	16.10	176.52	38.86	0.18
6.00	8.7	7.8	38.30	13.79	232.80	53.88	0.24
7.00	10.9	9.8	31.88	11.48	293.13	76.72	0.31
8.00	15.4	13.7	25.47	9.17	364.66	107.87	0.40
9.00	23.9	21.4	19.05	6.86	462.16	149.52	0.51
10.00	56.7	50.7	12.64	4.55	648.16	210.74	0.65
11.00	23.9	21.4	6.22	2.24	851.43	309.86	0.87
12.00	15.4	13.7			1045.70	422.98	1.08
13.00	10.9	9.8			1210.03	569.36	1.30
14.00	8.7	7.8			1291.77	728.62	1.50
15.00	7.3	6.5			1234.15	862.71	1.66
16.00	6.4	5.7			1125.34	910.55	1.75
17.00	5.7	5.1			990.29	919.72	1.81
18.00	5.2	4.7			842.83	920.49	1.81
19.00	4.9	4.4			692.00	912.96	1.77
20.00					538.24	883.37	1.68
21.00					396.60	782.28	1.57
22.00					309.94	682.49	1.44
23.00					237.36	591.87	1.33
24.00					172.77	510.36	1.22
25.00					122.53	442.69	1.11
26.00					83.71	382.96	1.01
27.00					54.52	335.05	0.92
28.00					33.77	292.60	0.83
29.00					20.60	255.07	0.75

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UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Results (CCs to Dam)
Printed on 18 6 1990 at 14:31 Run Reference : KREP2

Summary of reservoir routing calculations

Estimation of Probable Maximum Flood

Winter season rainfall

Unit hydrograph time to peak		4.75	hours
Data interval		1.00	hours
Design storm duration		19.00	hours
Pre-event snow depth		200.00	mm.
Melt rate		1.75	mm/hr
Design storm depth		233.43	mm.
Design CWI		188.91	
Standard Percentage Runoff		55.53	
Percentage runoff		89.45	%
Baseflow	:	14.36	cumecs
Inflow hydrograph peak	:	1291.77	cumecs (Max ordinate)
	:	1292.29	cumecs (Interpolated)
Outflow hydrograph peak	:	920.49	cumecs (Max ordinate)
	:	921.18	cumecs (Interpolated)
Attenuation rating	.	0.71	(From interpolated peaks)
Reservoir LAG		3.51	hours

Options

Unit hydrograph option		1 - FSR-Triangle
Tp option		0 - Specified by user
Rainfall option		5 - Max precipitation
Duration option		2 - with reservoir lag
Percentage runoff option		1 - FSSR 16 equation
CWI option		1 - Design standard
PMF scaling factor		0 - Set to 1.0
Baseflow option		1 - FSSR 16 equation
SPR option		0 - Specified by user
Initial water level		2 - Outflow entered
Reservoir rainfall		1 - Explicit
Inflow to reservoir	:	1 - From micro-FSR

UK DESIGN FLOOD ESTIMATION
RAINFALL AND HYDROGRAPH

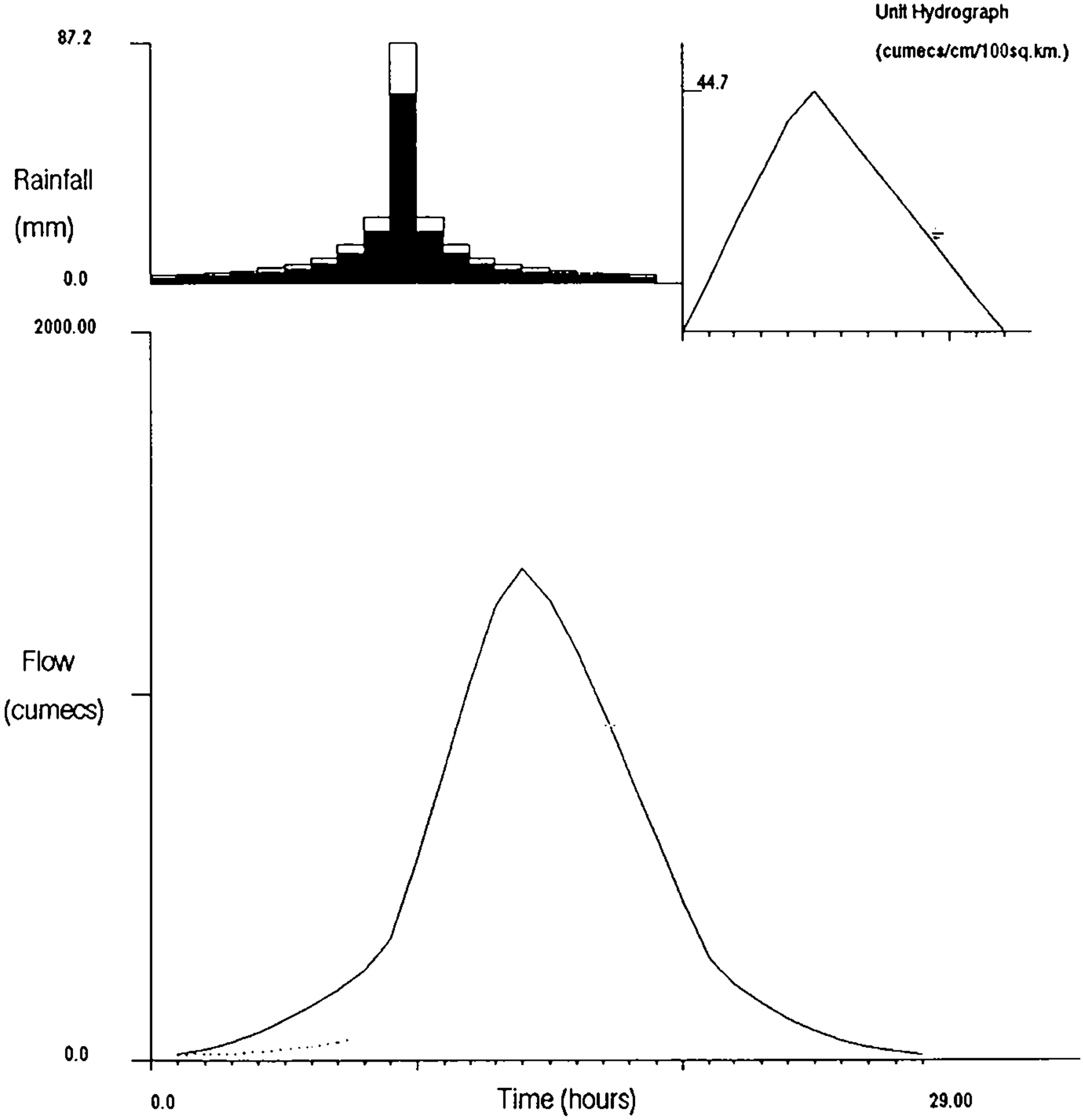
Institute of Hydrology

Description : Kielder PMF Final Results (CCs to Dam)

Run Reference: KREP2

Printed on 18 6 1990 at 14:34

Excess rainfall shown shaded



Data Interval(hours) : 1.00

Inflow ————

Outflow

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Institute of Hydrology

UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Results (CCs to Dam)
Printed on 18 6 1990 at 14:34 Run Reference : KREP2

Time series data from reservoir routing calculations

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Time hours	Total Rain mm	Net Rain mm	Unit Hydrograph cumecs/cm /100sq km	Unit Hydrograph %	Inflow cumecs	Outflow cumecs	Water level metres
1.00	3.1	2.5	9.75	3.51	16.64	14.07	0.07
2.00	3.5	2.8	19.50	7.02	28.44	15.34	0.08
3.00	4.0	3.2	29.25	10.53	47.37	17.72	0.09
4.00	4.7	3.7	39.00	14.04	74.62	21.77	0.11
5.00	5.6	4.4	44.71	16.10	109.56	28.11	0.13
6.00	7.0	5.5	38.30	13.79	147.46	37.16	0.17
7.00	9.3	7.4	31.88	11.48	191.22	49.34	0.22
8.00	14.0	11.1	25.47	9.17	247.52	67.14	0.28
9.00	24.0	19.0	19.05	6.86	331.97	95.18	0.36
10.00	87.2	68.9	12.64	4.55	553.73	144.00	0.49
11.00	24.0	19.0	6.22	2.24	795.76	247.53	0.73
12.00	14.0	11.1			1031.84	354.16	0.96
13.00	9.3	7.4			1239.58	497.85	1.20
14.00	7.0	5.5			1346.70	675.08	1.44
15.00	5.6	4.4			1258.27	827.18	1.62
16.00	4.7	3.7			1120.34	904.72	1.72
17.00	4.0	3.2			958.38	913.02	1.77
18.00	3.5	2.8			785.15	911.41	1.76
19.00	3.1	2.5			608.93	897.26	1.70
20.00					433.55	807.45	1.59
21.00					275.14	701.00	1.47
22.00					204.94	598.14	1.34
23.00					152.37	509.60	1.22
24.00					109.10	439.12	1.11
25.00					76.65	378.39	1.00
26.00					52.35	331.06	0.91
27.00					34.58	289.21	0.82
28.00					22.27	252.43	0.75
29.00					14.63	220.44	0.67

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                                                     Institute of Hydrology
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UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Results (CCs to Dam)
Printed on 18  6 1990 at 14:34                        Run Reference : KREP2
-----------------------------------------------------------------------------
Summary of reservoir routing calculations
*****************************************************************************
Estimation of Probable Maximum Flood
====================================
Summer season rainfall

Unit hydrograph time to peak            4.75  hours
Data interval                           1.00  hours

Design storm duration         :        19.00  hours
No snowmelt contribution to precipitation input
Design storm depth            :       237.80  mm.

Design CWI                            145.96

Standard Percentage Runoff             55.53
Percentage runoff                      78.99  %

Baseflow                      :        11.09  cumecs
Inflow hydrograph peak        :      1346.70  cumecs   (Max ordinate)
                              :      1346.92  cumecs   (Interpolated)
Outflow hydrograph peak       :       913.02  cumecs   (Max ordinate)
                              :       913.58  cumecs   (Interpolated)
Attenuation rating            :         0.68  (From interpolated peaks)
Reservoir LAG                           3.29  hours

Options
=======
Unit hydrograph option                  1 - FSR-Triangle
Tp option                               0 - Specified by user
Rainfall option                         5 - Max precipitation
Duration option                         2 - with reservoir lag
Percentage runoff option                1 - FSSR 16 equation
CWI option                              1 - Design standard
PMF scaling factor                      0 - Set to 1.0
Baseflow option                         1 - FSSR 16 equation
SPR option                              0 - Specified by user
Initial water level                     2 - Outflow entered
Reservoir rainfall                      1 - Explicit
Inflow to reservoir           :         1 - From micro-FSR

*****************************************************************************
micro-FSR  -  Institute of Hydrology                    Version 2.1 c(ii)
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****

Institute of Hydrology

UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Results (CCs to Dam)
Printed on 18 6 1990 at 14:19 Run Reference : KREP2

Catchment Characteristics

****

Area	:	241.50 sq.km.	Soil 1	:	0.000
Length	:	31.90 km.	Soil 2	:	0.000
Slope	:	4.36 m./km.	Soil 3	:	0.000
SAAR	:	1370 mm.	Soil 4	:	0.000
M5-2D	:	68.0 mm.	Soil 5	·	1.000
M5-25D	:	-1.0 % of SAAR			
Jenkinson's r	:	0.24			
Urban	:	0.00			
Smdbar	:	-1.0 mm.	RSMD		-1.000 mm.
Stmfrq	:	-1.00 junctions/sq.km.			
Lake	:	0.00			
EMP 2 hour	:	140.00 mm.	BFI	:	-1.00
EMP 24 hour	:	270.00 mm.	LAG	:	-1.00 hr.

****

micro-FSR - Institute of Hydrology Version 2.1 c(ii)

OPTION 4: USING UNIT HYDROGRAPH DERIVED FOR DAM

INITIAL LEVEL 185.2 m

SPILLING LONG TERM BASEFLOW, 14.07 m^3s^{-1}

NO FLOW THROUGH SCOUR VALVES ETC.

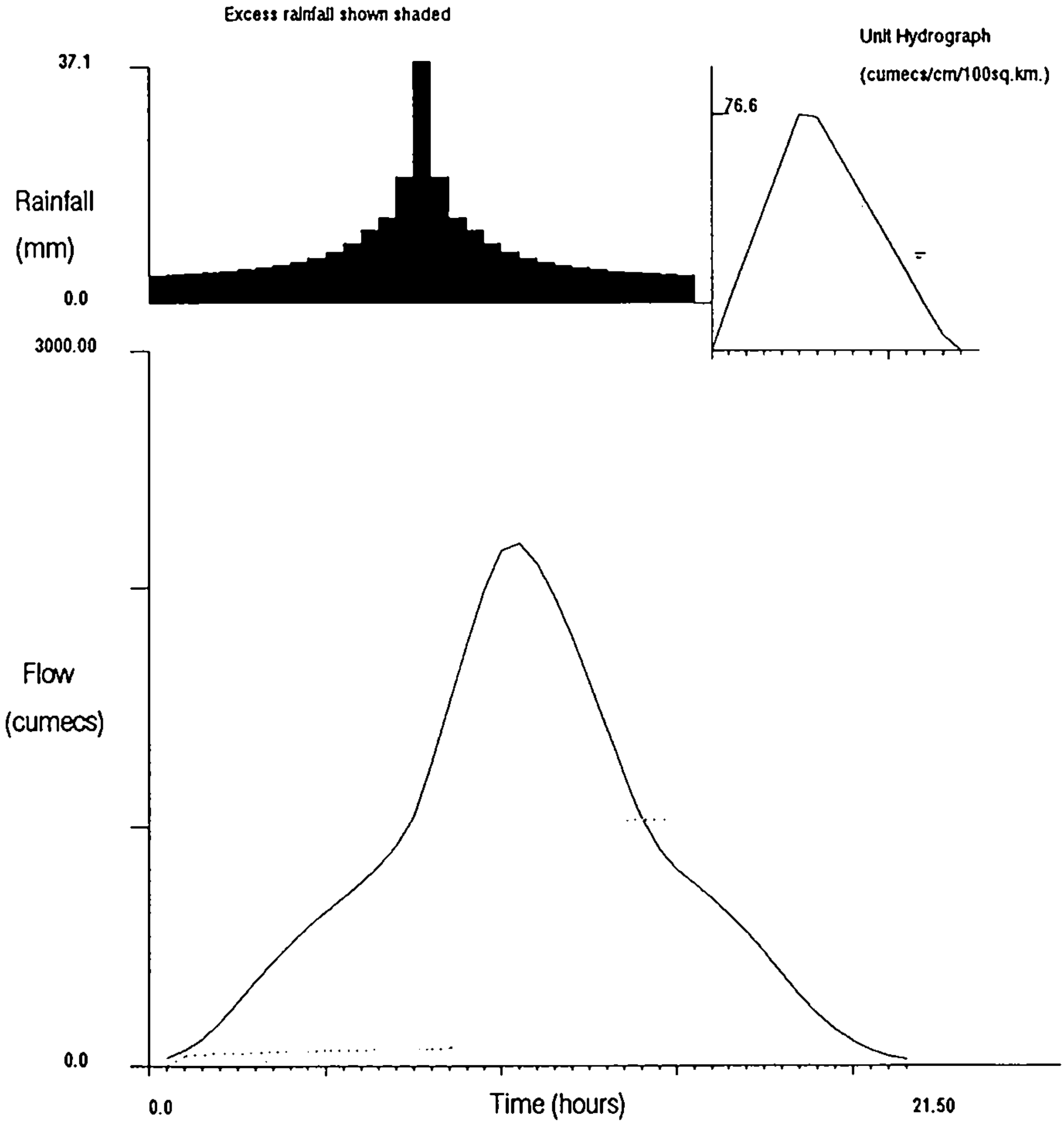
UK DESIGN FLOOD ESTIMATION
RAINFALL AND HYDROGRAPH

Institute of Hydrology

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)

Run Reference: KREPT

Printed on 18 6 1990 at 12:12



Data interval(hours) : 0.50

Inflow ——
Outflow

Institute of Hydrology

UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 12:12 Run Reference : KREPT

Time series data from reservoir routing calculations

Time hours	Total Rain mm	Net Rain mm	Unit Hydrograph cumecs/cm /100sq km	Unit Hydrograph %	Inflow cumecs	Outflow cumecs	Water level metres
0.50	4.4	4.5	15.32	2.76	33.34	0.00	0.00
1.00	4.5	4.6	30.63	5.51	65.30	42.71	0.01
1.50	4.6	4.7	45.95	8.27	114.02	46.48	0.02
2.00	4.8	4.9	61.26	11.03	180.14	49.83	0.04
2.50	5.0	5.1	76.58	13.78	264.39	52.81	0.08
3.00	5.3	5.4	75.64	13.61	350.96	55.44	0.13
3.50	5.6	5.7	65.57	11.80	431.04	57.71	0.19
4.00	5.9	6.1	55.49	9.99	505.12	59.69	0.27
4.50	6.4	6.6	45.41	8.17	573.91	61.42	0.36
5.00	7.1	7.2	35.34	6.36	638.53	62.96	0.46
5.50	7.9	8.1	25.26	4.55	700.73	64.35	0.57
6.00	9.2	9.4	15.19	2.73	763.47	65.61	0.69
6.50	11.3	11.6	5.11	0.92	832.27	66.79	0.82
7.00	13.1	13.4			916.19	67.90	0.97
7.50	19.4	19.8			1039.83	68.99	1.14
8.00	37.1	37.9			1262.74	70.12	1.34
8.50	19.4	19.8			1514.58	71.36	1.60
9.00	13.1	13.4			1762.38	110.56	1.87
9.50	11.3	11.6			1988.53	208.15	2.17
10.00	9.2	9.4			2158.18	339.82	2.47
10.50	7.9	8.1			2186.15	490.72	2.77
11.00	7.1	7.2			2099.99	666.25	3.03
11.50	6.4	6.6			1960.87	835.12	3.24
12.00	5.9	6.1			1789.34	974.71	3.40
12.50	5.6	5.7			1598.61	998.28	3.51
13.00	5.3	5.4			1401.06	1012.95	3.60
13.50	5.0	5.1			1206.57	1021.58	3.65
14.00	4.8	4.9			1028.23	1024.91	3.67
14.50	4.6	4.7			896.84	1024.03	3.66
15.00	4.5	4.6			814.93	1020.32	3.64
15.50	4.4	4.5			755.32	1014.76	3.61
16.00					694.17	1007.62	3.57
16.50					628.14	998.06	3.51
17.00					554.30	986.59	3.45
17.50					471.05	956.09	3.38
18.00					377.42	886.75	3.30
18.50					289.08	816.79	3.22
19.00					214.42	747.75	3.13
19.50					152.65	681.30	3.05
20.00					103.10	618.61	2.96
20.50					65.24	561.54	2.88
21.00					38.62	512.76	2.80
21.50					22.85	468.14	2.73

****

UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 12:12 Run Reference : KREPT

Summary of reservoir routing calculations

****

Estimation of Probable Maximum Flood
====================================

Winter season rainfall

Unit hydrograph time to peak		2.68	hours
Data interval		0.50	hours
Design storm duration		15.50	hours
Pre-event snow depth		200.00	mm.
Melt rate		5.00	mm/hr
Design storm depth		266.29	mm.
Design CWI		231.52	
Standard Percentage Runoff		55.53	
Percentage runoff		102.18	%
Baseflow	:	17.60	cumecs
Inflow hydrograph peak	:	2186.15	cumecs (Max ordinate)
	:	2189.86	cumecs (Interpolated)
Outflow hydrograph peak	:	1024.91	cumecs (Max ordinate)
	:	1025.09	cumecs (Interpolated)
Attenuation rating	:	0.47	(From interpolated peaks)
Reservoir LAG	.	3.77	hours

Options
=======

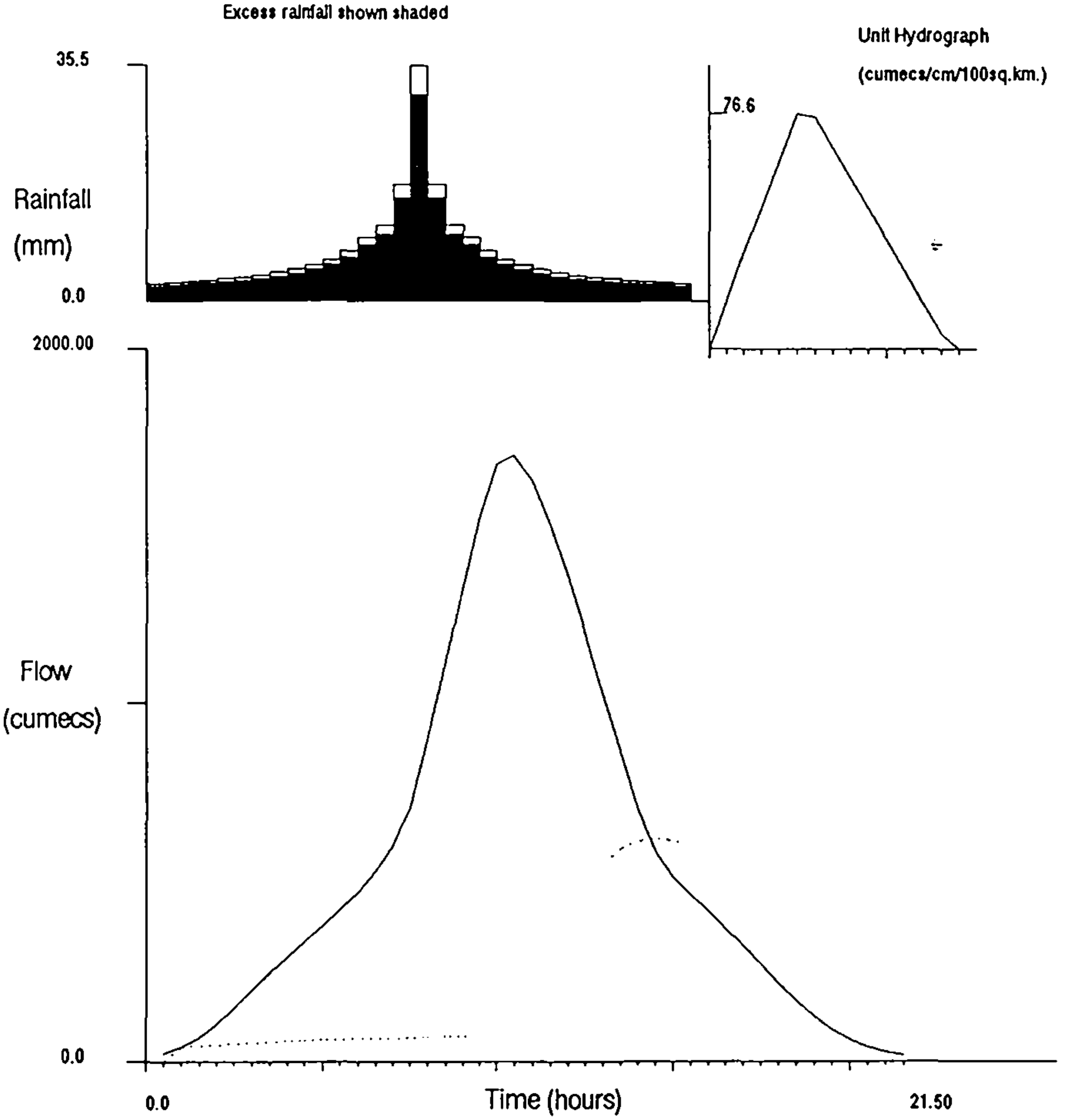
Unit hydrograph option	1 - FSR-Triangle
Tp option	0 - Specified by user
Rainfall option	5 - Max precipitation
Duration option	2 - with reservoir lag
Percentage runoff option	1 - FSSR 16 equation
CWI option	1 - Design standard
PMF scaling factor	0 - Set to 1.0
Baseflow option	1 - FSSR 16 equation
SPR option	0 - Specified by user
Initial water level	3 - Water level entered
Reservoir rainfall	1 - Explicit
Inflow to reservoir :	1 - From micro-FSR

****

UK DESIGN FLOOD ESTIMATION
RAINFALL AND HYDROGRAPH

Institute of Hydrology

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)   Run Reference: KREPT
Printed on 18 6 1990 at 12:16



Data interval(hours) : 0.50

Inflow ———
Outflow

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Institute of Hydrology

UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 12:16 Run Reference : KREPT

Time series data from reservoir routing calculations

****

Time hours	Total Rain mm	Net Rain mm	Unit Hydrograph cumecs/cm /100sq km	Unit Hydrograph %	Inflow cumecs	Outflow cumecs	Water level metres
0.50	2.7	2.4	15.32	2.76	22.79	0.00	0.00
1.00	2.9	2.5	30.63	5.51	40.22	39.98	0.00
1.50	3.0	2.7	45.95	8.27	67.04	42.95	0.01
2.00	3.2	2.8	61.26	11.03	103.79	46.10	0.02
2.50	3.4	3.0	76.58	13.78	151.11	49.03	0.04
3.00	3.6	3.2	75.64	13.61	200.75	51.63	0.06
3.50	3.9	3.5	65.57	11.80	248.11	53.89	0.10
4.00	4.3	3.8	55.49	9.99	293.63	55.86	0.14
4.50	4.8	4.2	45.41	8.17	337.92	57.59	0.19
5.00	5.4	4.8	35.34	6.36	381.93	59.14	0.24
5.50	6.3	5.5	25.26	4.55	427.19	60.56	0.31
6.00	7.6	6.7	15.19	2.73	476.24	61.87	0.38
6.50	9.7	8.5	5.11	0.92	533.82	63.10	0.47
7.00	11.5	10.1			606.14	64.30	0.56
7.50	17.8	15.7			712.67	65.49	0.68
8.00	35.5	31.2			904.73	66.77	0.82
8.50	17.8	15.7			1121.71	68.22	1.02
9.00	11.5	10.1			1335.22	69.53	1.23
9.50	9.7	8.5			1530.07	70.78	1.47
10.00	7.6	6.7			1676.24	78.13	1.73
10.50	6.3	5.5			1700.35	147.21	2.00
11.00	5.4	4.8			1626.11	240.67	2.25
11.50	4.8	4.2			1506.24	334.94	2.46
12.00	4.3	3.8			1358.45	419.95	2.64
12.50	3.9	3.5			1194.12	495.55	2.77
13.00	3.6	3.2			1023.90	556.07	2.87
13.50	3.4	3.0			856.33	598.23	2.93
14.00	3.2	2.8			702.66	620.49	2.96
14.50	3.0	2.7			589.46	625.47	2.97
15.00	2.9	2.5			518.89	619.58	2.96
15.50	2.7	2.4			467.53	607.51	2.95
16.00					419.89	591.38	2.92
16.50					373.10	570.45	2.90
17.00					324.65	548.92	2.86
17.50					273.13	524.98	2.82
18.00					217.72	498.69	2.78
18.50					166.57	470.44	2.73
19.00					123.88	442.30	2.68
19.50					88.96	415.98	2.63
20.00					61.25	389.75	2.58
20.50					40.30	364.15	2.52
21.00					25.70	339.65	2.47
21.50					17.12	316.59	2.42

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                                                      Institute of Hydrology
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UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18  6 1990 at 12:15                      Run Reference : KREPT
-----------------------------------------------------------------------------
Summary of reservoir routing calculations
*****************************************************************************
Estimation of Probable Maximum Flood
====================================
Winter season rainfall

Unit hydrograph time to peak            2.68   hours
Data interval                           0.50   hours

Design storm duration                  15.50   hours
Pre-event snow depth                  200.00   mm.
Melt rate                               1.75   mm/hr
Design storm depth                    215.92   mm.

Design CWI                            187.90

Standard Percentage Runoff             55.53
Percentage runoff                      88.04   %

Baseflow                               14.28   cumecs
Inflow hydrograph peak          :    1700.35   cumecs   (Max ordinate)
                                :    1703.54   cumecs   (Interpolated)
Outflow hydrograph peak         :     625.47   cumecs   (Max ordinate)
                                :     625.48   cumecs   (Interpolated)
Attenuation rating              :       0.37   (From interpolated peaks)
Reservoir LAG                           4.11   hours

Options
=======
Unit hydrograph option                 1 - FSR-Triangle
Tp option                              0 - Specified by user
Rainfall option                        5 - Max precipitation
Duration option                        2 - with reservoir lag
Percentage runoff option               1 - FSSR 16 equation
CWI option                             1 - Design standard
PMF scaling factor                     0 - Set to 1.0
Baseflow option                        1 - FSSR 16 equation
SPR option                             0 - Specified by user
Initial water level                    3 - Water level entered
Reservoir rainfall                     1 - Explicit
Inflow to reservoir             :      1 - From micro-FSR

*****************************************************************************
micro-FSR  -  Institute of Hydrology                      Version 2.1 c(ii)
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UK DESIGN FLOOD ESTIMATION

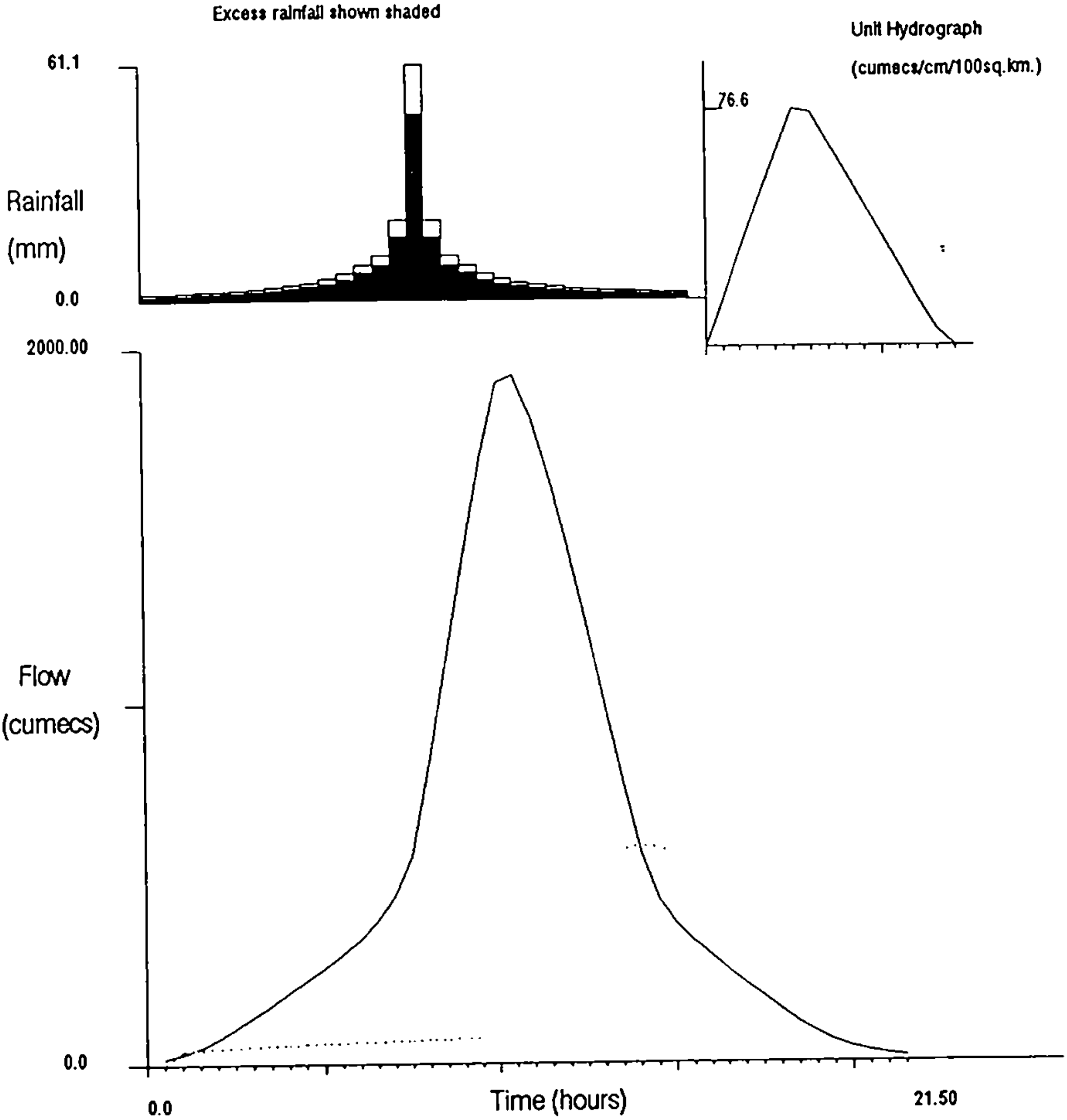
RAINFALL AND HYDROGRAPH

Institute of Hydrology

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)

Run Reference: KREPT

Printed on 18 6 1990 at 12:18



Data Interval(hours) : 0.50

Inflow

Outflow

micro – FSR, Institute of Hydrology

Version: 2.1 c(II)

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Institute of Hydrology

UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 12:18 Run Reference : KREPT

Time series data from reservoir routing calculations
****

Time hours	Total Rain mm	Net Rain mm	Unit Hydrograph cumecs/cm /100sq km	Unit Hydrograph %	Inflow cumecs	Outflow cumecs	Water level metres
0.50	1.9	1.5	15.32	2.76	16.56	0.00	0.00
1.00	2.0	1.6	30.63	5.51	27.39	37.45	0.00
1.50	2.2	1.7	45.95	8.27	44.25	39.36	0.00
2.00	2.3	1.8	61.26	11.03	67.64	42.51	0.01
2.50	2.5	2.0	76.58	13.78	98.15	45.61	0.02
3.00	2.8	2.2	75.64	13.61	130.93	48.35	0.03
3.50	3.1	2.5	65.57	11.80	163.33	50.71	0.05
4.00	3.5	2.8	55.49	9.99	195.74	52.75	0.08
4.50	4.0	3.1	45.41	8.17	228.76	54.56	0.11
5.00	4.6	3.7	35.34	6.36	263.27	56.18	0.15
5.50	5.5	4.4	25.26	4.55	300.71	57.67	0.19
6.00	6.9	5.4	15.19	2.73	343.51	59.07	0.24
6.50	9.1	7.2	5.11	0.92	396.22	60.41	0.30
7.00	11.4	9.0			464.96	61.73	0.37
7.50	20.7	16.4			574.67	63.08	0.47
8.00	61.1	48.3			834.57	64.67	0.60
8.50	20.7	16.4			1126.72	66.72	0.81
9.00	11.4	9.0			1416.85	68.36	1.04
9.50	9.1	7.2			1688.23	69.91	1.30
10.00	6.9	5.4			1903.89	71.37	1.60
10.50	5.5	4.4			1925.67	119.12	1.91
11.00	4.6	3.7			1804.17	217.05	2.19
11.50	4.0	3.1			1633.31	320.80	2.43
12.00	3.5	2.8			1435.48	413.43	2.63
12.50	3.1	2.5			1222.13	492.76	2.77
13.00	2.8	2.2			1003.36	553.30	2.87
13.50	2.5	2.0			787.59	589.94	2.92
14.00	2.3	1.8			588.21	602.33	2.94
14.50	2.2	1.7			452.44	594.89	2.93
15.00	2.0	1.6			382.86	577.08	2.90
15.50	1.9	1.5			334.68	556.50	2.87
16.00					293.19	534.24	2.84
16.50					255.25	509.61	2.80
17.00					218.45	484.23	2.76
17.50					181.47	458.30	2.71
18.00					143.54	434.07	2.67
18.50					109.35	410.08	2.62
19.00					81.24	385.93	2.57
19.50					58.56	362.12	2.52
20.00					40.79	339.03	2.47
20.50					27.52	316.94	2.42
21.00					18.38	296.08	2.38
21.50					13.08	276.60	2.33

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                                                 Institute of Hydrology
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UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18  6 1990 at 12:18                 Run Reference : KREPT
-----------------------------------------------------------------------
Summary of reservoir routing calculations
***********************************************************************
Estimation of Probable Maximum Flood
====================================
Summer season rainfall

Unit hydrograph time to peak          2.68  hours
Data interval                         0.50  hours

Design storm duration       :        15.50  hours
No snowmelt contribution to precipitation input
Design storm depth          :       226.36  mm.

Design CWI                          149.16

Standard Percentage Runoff           55.53
Percentage runoff                    79.05  %

Baseflow                    :        11.33  cumecs
Inflow hydrograph peak      :      1925.67  cumecs  (Max ordinate)
                            :      1934.34  cumecs  (Interpolated)
Outflow hydrograph peak     :       602.33  cumecs  (Max ordinate)
                            :       602.48  cumecs  (Interpolated)
Attenuation rating          :         0.31  (From interpolated peaks)
Reservoir LAG                         3.74  hours

Options
=======
Unit hydrograph option               1 - FSR-Triangle
Tp option                            0 - Specified by user
Rainfall option                      5 - Max precipitation
Duration option                      2 - with reservoir lag
Percentage runoff option             1 - FSSR 16 equation
CWI option                           1 - Design standard
PMF scaling factor                   0 - Set to 1.0
Baseflow option                      1 - FSSR 16 equation
SPR option                           0 - Specified by user
Initial water level                  3 - Water level entered
Reservoir rainfall                   1 - Explicit
Inflow to reservoir         :        1 - From micro-FSR

***********************************************************************
micro-FSR  -  Institute of Hydrology                 Version 2.1 c(ii)
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UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 11:45 Run Reference : KREPT

Reservoir characteristics

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Reservoir area set to : 10.860 sq. km
at : 1.700 metres
Area growth rate : 0.290 sq. km/metre

Device	HMIN	HMAX	B	C	D	E
1	1.700	1.953	185.000	1.481	1.700	1.126
1	1.953	2.700	185.000	2.032	1.700	1.356
1	2.700	2.900	185.000	2.032	1.700	1.541
1	2.900	3.400	185.000	1.975	1.700	1.699
1	3.400	9999.990	185.000	4.047	1.700	0.348
2	0.000	9999.000	68.100	1.000	0.000	0.100

****

OPTION 3: INITIAL LEVEL 183.5 M

$68.1\ m^3s^{-1}$ RELEASE THROUGH SCOUR VALVE AND FOR HEP

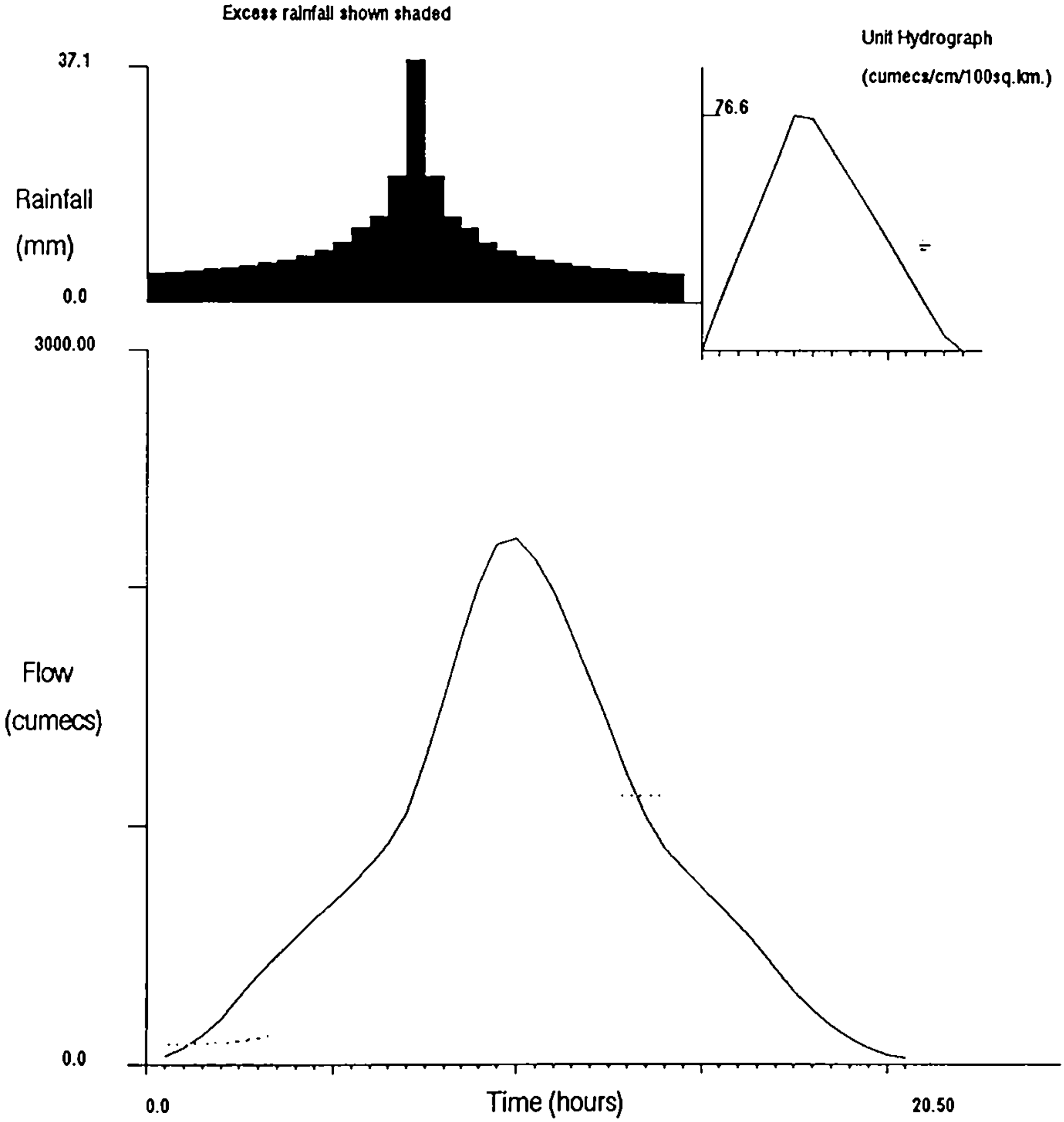
UK DESIGN FLOOD ESTIMATION

Institute of Hydrology

RAINFALL AND HYDROGRAPH

Description : Kielder PMF Final Estimates (CCs for Kielder Burn) Run Reference: KREPT

Printed on 18 6 1990 at 11:39



Data interval(hours) : 0.50

Inflow ———

Outflow

****

Institute of Hydrology

UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 11:38
Run Reference : KREPT

Time series data from reservoir routing calculations

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Time hours	Total Rain mm	Net Rain mm	Unit Hydrograph cumecs/cm /100sq km	Unit Hydrograph %	Inflow cumecs	Outflow cumecs	Water level metres
0.50	4.5	4.6	15.32	2.76	34.47	82.17	0.13
1.00	4.6	4.8	30.63	5.51	67.79	81.99	0.13
1.50	4.8	5.0	45.95	8.27	118.68	83.77	0.13
2.00	5.0	5.2	61.26	11.03	187.90	88.24	0.15
2.50	5.3	5.4	76.58	13.78	276.34	96.12	0.18
3.00	5.6	5.8	75.64	13.61	367.72	107.78	0.22
3.50	5.9	6.1	65.57	11.80	453.03	124.15	0.27
4.00	6.4	6.6	55.49	9.99	533.00	147.01	0.34
4.50	7.1	7.3	45.41	8.17	608.75	174.66	0.41
5.00	7.9	8.2	35.34	6.36	682.06	207.05	0.49
5.50	9.2	9.5	25.26	4.55	755.92	244.20	0.58
6.00	11.3	11.7	15.19	2.73	835.89	286.45	0.68
6.50	13.1	13.6	5.11	0.92	926.00	334.65	0.78
7.00	19.4	20.0			1050.92	390.26	0.89
7.50	37.1	38.3			1276.14	463.06	1.03
8.00	19.4	20.0			1530.59	575.01	1.21
8.50	13.1	13.6			1780.96	710.99	1.39
9.00	11.3	11.7			2009.46	866.64	1.58
9.50	9.2	9.5			2180.86	985.97	1.77
10.00	7.9	8.2			2209.13	1020.78	1.97
10.50	7.1	7.3			2122.07	1051.44	2.16
11.00	6.4	6.6			1981.51	1076.78	2.32
11.50	5.9	6.1			1808.20	1096.68	2.45
12.00	5.6	5.8			1615.50	1111.30	2.55
12.50	5.3	5.4			1415.89	1120.91	2.62
13.00	5.0	5.2			1219.39	1125.85	2.65
13.50	4.8	5.0			1039.19	1126.58	2.66
14.00	4.6	4.8			906.45	1123.89	2.64
14.50	4.5	4.6			823.69	1118.88	2.60
15.00					747.55	1112.16	2.56
15.50					669.86	1103.16	2.49
16.00					587.23	1092.38	2.42
16.50					496.72	1079.57	2.34
17.00					396.70	1064.44	2.24
17.50					303.07	1046.77	2.13
18.00					224.28	1026.66	2.01
18.50					159.32	1004.26	1.88
19.00					107.36	979.70	1.74
19.50					67.77	887.37	1.60
20.00					39.98	782.35	1.48
20.50					23.55	692.28	1.37

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Institute of Hydrology

UK DESIGN FLOOD ESTIMATION

Description : Kielder PMF Final Estimates (CCs for Kielder Burn)
Printed on 18 6 1990 at 11:38 Run Reference : KREPT

Summary of reservoir routing calculations

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Estimation of Probable Maximum Flood
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Winter season rainfall

Unit hydrograph time to peak		2.68	hours
Data interval		0.50	hours
Design storm duration		14.50	hours
Pre-event snow depth		200.00	mm.
Melt rate		5.00	mm/hr
Design storm depth		257.57	mm.
Design CWI		237.93	
Standard Percentage Runoff		55.53	
Percentage runoff		103.24	%
Baseflow	:	18.09	cumecs
Inflow hydrograph peak	:	2209.13	cumecs (Max ordinate)
	:	2212.87	cumecs (Interpolated)
Outflow hydrograph peak	:	1126.58	cumecs (Max ordinate)
	:	1126.72	cumecs (Interpolated)
Attenuation rating	:	0.51	(From interpolated peaks)
Reservoir LAG	:	3.48	hours

Options
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Unit hydrograph option		1 - FSR-Triangle
Tp option		0 - Specified by user
Rainfall option		5 - Max precipitation
Duration option		2 - with reservoir lag
Percentage runoff option		1 - FSSR 16 equation
CWI option		1 - Design standard
PMF scaling factor		0 - Set to 1.0
Baseflow option		1 - FSSR 16 equation
SPR option		0 - Specified by user
Initial water level		2 - Outflow entered
Reservoir rainfall		1 - Explicit
Inflow to reservoir	:	1 - From micro-FSR

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