APPORTIONMENT OF IDB COSTS FOR THROUGH-DRAINAGE OF HIGHLAND WATER

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Report to Grantham, Brundell and Farran

Institute of Hydrology
October 1988

1. Context

Alan Gardner rang 20 September 1988 to discuss dispute between an IDB and Anglian Water regarding the above. Grantham, Brundell and Farran are acting for Ancholme IDB but believe that the problem will concern all IDBs in Anglian WA's region.

2 IDB Method

The IDB method of apportioning costs is a simple one based on nominal runoff rates from highland and lowland areas: 2.1 and 1.4 l/s/ha respectively. Their origin is probably Imperial values of 30 and 20 cusecs per 1000 acres. A typical pumping station capacity in the Anglian region is indeed about 1.4 l/s/ha (see Table 6.1 of IWEM manual on river engineering). Presumably the higher nominal runoff rate for highland areas is based on accumulated experience of IDB engineers. However, a rationale for the 50% "mark-up" for runoff from highland areas is not obvious and it is perhaps no surprise that the RWA should challenge this.

3. Anglian Water Method

Anglian Water propose that apportionment of costs be based on nominal annual runoff rates of 0.0635 l/s/ha for highland and 0.0628 l/s/hâ for lowland. These values derive from mapped values of 1941-1970 Standard Average Annual Rainfall (SAAR) after allowance for evaporation and percolation:

		Highland	Lowland
SAAR	mm	638	624
Evaporation/percolation	mm	437	426
Hence: AARO	mm	201	198
	l/s/ha	0.0637	0.0628

Thus the "mark-up" for runoff from highland areas is a mere 1.4% in the Anglian Water method. Understandably, the IDB reject the Anglian Water method both because it is much less favourable to IDBs and because it refers only to long-term average runoff rates.

4. Discussion

The IDB rightly argue that the design and maintenance of the drains and pumping stations relate to their ability to discharge flood events, (eg. a sustained runoff rate of about 1.4 l/s/ha) rather than an average daily runoff rate of only 0.06 l/s/ha. The Anglian water method is therefore not considered further. However, the IDB contention that flood runoff rates from highland areas are systematically 50% higher than from lowland areas remains to be proven.

As an aside it might be said that a perfect method of cost allocation would relate directly to the costs incurred: with the apportionment made at the level of job time sheets and purchase orders. Presumably this is deemed too bureaucratic. Moreover it would still require a method of apportionment in the majority of cases where a given job or equipment purchase does not relate solely to one or other of the highland and lowland drainage functions.

5. Critique of the IDB Method

Apportionment based on purely nominal runoff rates has the merit of simple accounting but inevitably many weaknesses. Some that spring to mind are as follows.

There is scope in some catchments to segregate highland and lowland water, and for some gravity discharge. The special costs and benefits of such practice are not represented in the apportionment based on nominal runoff rates.

There is no explicit treatment of the design standards of different drainage systems nor of the benefits that they provide.

Some of the drainage systems are dominated by highland water (eg. Scawby Beck); others are dominated by lowland water (eg. Waddingham Sth etc.). If the flood runoff characteristics of highland catchments differ so much from those of lowland catchments (as the IDB method imputes), one might expect their design and maintenance characteristics to differ also.

The IDB method does not identify those cases where extreme land use changes beyond their remit (eg. urbanization) have led to increased costs and/or reduced standards of flood protection.

However, the chief criticism of the IDB method remains the unsupported assumption of 50% higher flood runoff rates from highland areas. Some form of hydrological assessment may therefore be helpful.

6. A Method of Design Flood Estimation

The Flood Studies Report (FSR) rainfall-runoff method synthesises the flood frequency relationship using a unit hydrograph/losses model coupled to standard "design inputs". These inputs ensure that, on average, design hydrographs synthesised by the unit hydrograph model have a peak flow of the required return period.

A feature of the approach is its generality: parameter estimates can be obtained from mapped characteristics of the catchment, such as stream length and soil type. However, where gauged flow data are available locally, it is recommended that these be analysed to derive improved estimates of the key parameters of the model (the unit hydrograph time-to-peak, Tp, and standard percentage runoff, SPR).

The calculations are relatively complex and time-consuming. Thus, in the trial analysis that follows, full use has been made of the microFSR computer package.

Present recommendations for flood synthesis on lowland pumped catchments are given in Chapter 6 of the IWEM manual on River Engineering practice. These are based on earlier analysis of the Newborough Fen catchment near Peterborough. The one change to the standard FSR methodology is to replace *the customary triangular unit hydrograph by a flat-topped unit hydrograph*, representing the slow but sustained response of a flat, well-drained fenland area.

7. Example - Boygrift Pumped Catchment

Boygrift catchment in East Lincolnshire is one of three pumped catchments that have been instrumented by the Institute of Hydrology in strategic research funded by MAFF. Boygrift is a 21.13 km^2 catchment, chosen for research because of its marked highland component (7.41 km^2). When complete, the analysis will provide a further check on use of the FSR rainfall-runoff method for flood estimation on pumped catchments, and insight into the significance of highland and lowland components of flood runoff.

Synthesis of the 10-year flood was chosen for trial purposes. Four sets of calculations were carried out as follows:

LO-25: Lowland subcatchment, 25-hour storm
HI-13: Highland subcatchment, 13-hour storm
HI-25: Highland subcatchment, 25-hour storm
LO-13: Lowland sucatchment, 13-hour storm.

Except where explicitly stated, all cases use the standard FSR rainfall-runoff method, as updated in Flood Studies Supplementary Report No. 16.

Case LO-25 applies a 25-hour design storm to the lowland subcatchment. The flat-topped unit hydrograph shape recommended in the IWEM manual was adopted, but with an equivalent time-to-peak of 15 hours rather than 24 hours. [The characteristic response of the Boygrift catchment is known to be swifter than at Newborough. This is, of course, partly due to the highland element, but partly also to the typically shorter drainage paths to the main drain.] *For a Tp value of 15 hours, application of the standard FSR equation* for design storm duration yields D=25 hours. The resultant flood peak is 3.00 cumecs or 2.19 l/s/ha. A summary of the calculations is given in Appendix 1.

Case HI-13 applies a 13-hour design storm to the highland subcatchment. The standard triangular unit hydrograph shape is used, but with an estimate of Tp derived from observed runoff response times (LAG=8.5 hours) rather than from catchment characteristics. Application of the standard FSR equation for design storm duration gives D=13 hours. The resultant flood peak is 2.78 cumecs or 3.75 l/s/ha. The calculations are summarized in Appendix 2.

It is unreasonable simply to compare these design runoff rates. This is because the combined drainage system (as it exists) has to accommodate runoff from both lowland and highland sources. The above design runoff rates stem from significantly different design storms that could not coexist in a real flood event. Two further flood estimates were therefore made (Appendices 3 and 4): one applying a 13-hour design storm to the lowland subcatchment, the other applying a 25-hour design storm to the highland subcatchment. The latter condition is the appropriate choice, giving a higher combined hydrograph. The four sets of flood estimates are summarized in Table 1.

TABLE 1 10-year peak flows and runoff rates

	Highland (cumecs)	Lowland (cumecs)	Highland (l/s/ha)	Lowland (l/s/ha)
13-hour storm	2.78	2.59	3.75	1.89
25-hour storm	2.61	3.00	3.52	2.19

When the peak flows are expressed in units of l/s/ha, it is seen that, for the 25-hour design storm, the 10-year flood runoff rate from the highland subcatchment is 61% higher than that from the lowland subcatchment.

Because of the storage characteristics of the main drain, the maximum 6-hour runoff rate may be a more relevant statistic (than the instantaneous peak value) in determining the engineering design. Such values are shown in Table 2.

TABLE 2 10-year maximum 6-hour mean flows and runoff rates

	Highland (cumecs)	Lowland (cumecs)	Highland (l/s/ha)	Lowland (l/s/ha)
13-hour storm	2.59	2.58	3.50	1.88
25-hour storm	2.50	2.98	3.37	2.17

The 10-year 6-hour maximum runoff rates from the highland and lowland subcatchments are seen to be 3.37 and 2.17 l/s/ha respectively. These are appreciably higher than the nominal runoff rates of 2.1 and 1.4 l/s/ha cited in Section 2. However, the ratio of highland to lowland runoff rates (3.37/2.17 = 1.55) is in close agreement with the ratio assumed in the IDB method (2.1/1.4 = 1.5).

The highland response (to the 25-year design storm) peaks some eight hours before the lowland response peaks. Some of this difference will be negated by the time taken for the highland contribution to travel the length of the main drain. Delaying the highland response hydrograph by a nominal 3 hours before adding the lowland response hydrograph yields a 10-year peak flow of:

2.59 + 2.89 = 5.48 cumecs

and a 10-year maximum 6-hour mean flow of 5.36 cumecs. This estimate can be compared with the nominal installed capacity of 3.5 cumecs.

The above flood estimates appear to be rather high when compared to the regional experience that design values of 1.4 and 2.1 l/s/ha can comfortably accommodate at least the 10-year event. This discrepancy is disappointing but not altogether surprising: flood estimates based on rainfall statistics coupled to generalized (but relatively simple) models of catchment response can be expected to be relatively inaccurate.

However, the above assessment provides no evidence that the IDB method's "50% mark-up" for highland areas is unreasonable; indeed, the ratio of 1.55 derived is embarrassingly close to 1.50.

8. Summary

A hydrological assessment of highland and lowland flood runoff rates has been carried out for the Boygrift pumped catchment. The assessment is based largely on published recommendations, namely: the FSR rainfall-runoff method, as updated by Flood Studies Supplementary Report No. 16, and the modified unit hydrograph shape recommended for lowland catchments in the IWEM River Engineering manual. Some account has been taken of the characteristic response times noted in experimental monitoring of the Boygrift catchment.

There is no evidence from the hydrological assessment that the IDB method's "50% mark-up" for flood runoff from highland areas is unreasonable.

9. Qualifications

The above hydrological assessment is not beyond criticism. It is possible that the Boygrift catchment is atypical of pumped catchments, either in the

Ancholme IDB or in the AWA region in general. Also, it is possible that slightly different definitions have been used for highland and lowland areas.

The assessment could be strengthened by the analysis of flow data for gauged catchments in the region: either by a comprehensive analysis of flood event data or through the simpler mechanism of analysing daily mean flows (to refine estimates of SPR using the baseflow index, BFI).

The derivation of flow duration curves (indicating the proportion of days on which a given daily mean flow rate is exceeded) might also be useful in characterizing the difference between highland and lowland catchments in Eastern England, if suitable gauged records are available or can be derived from pump-run data.

10. Recommendation for Further Research

A more direct approach would be to examine long-term records of maximum 1-day pumped quantities for land drainage pumping stations in the region, some of which are already held by the Institute of Hydrology. The IWEM manual of river engineering design practice reports results for pumped catchments in the South Holland Board's area. Additional research would seek to quantify the extent to which actual flood runoff rates from largely lowland pumped catchments differ from those of largely highland pumped catchments.

One technique would be to correlate the observed annual maximum 1-day runoff depth, ROBAR, with a highland/lowland index, HIGHLAND, defined as the fraction of the catchment from which through-drainage of highland water is received. This would seek to establish a regression model such as:

$$\text{ROBAR} = a + b \text{ HIGHLAND}$$

or

$$\text{ROBAR} = c\,(1 + \text{HIGHLAND})^d .$$

While the percentage variance explained by such a regression might be relatively modest, it might nevertheless provide a useful and easily implemented refinement of the IDB method. Note that, with ROBAR in l/s/ha, the IDB method corresponds to:

$$\begin{aligned}\text{ROBAR} &= 1.4\,(1 - \text{HIGHLAND}) + 2.1 \text{ HIGHLAND}\\ &= 1.4 + 0.7 \text{ HIGHLAND}\\ &= 1.4\,(1 + 0.5 \text{ HIGHLAND}) .\end{aligned}$$

The factor $(1 + \text{HIGHLAND})^d$ would replace the (1 + 0.5*HIGHLAND) implicit in the current method. The scaling factor for highland areas would then be 2^d rather than the present 1.5 .

The approach is not without difficulty. The analysis would have to exclude those catchments where gravity discharge of highland water is possible but is ungauged. Also, pumps and drains are subject to deterioration, maintenance and renovation; the changing performance of the drainage system will be reflected in non-stationarity in the time series of annual maximum 1-day pumped volumes.

However, runoff estimates based on actual pumped quantities are to be preferred to generalized methods that rely on catchment characteristics and rainfall-runoff modelling. It is therefore strongly recommended that a detailed study of flood runoff rates be made by reference to pumping records in the region.

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APPENDIX 1

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UK DESIGN FLOOD ESTIMATION                           MICRO-FSR DEMONSTRATION

Summary of estimate using Flood Studies Report rainfall-runoff method
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Description : 'Lowland' component of Boygrift pumped catchment
Printed on 29- 9-1988 at 11.10                          Run Reference - BOYLC
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Estimation of T-year flood
==========================
                                                        (UH option        :  0)
Includes Tp scaling factor      :   1.00

Design storm duration           :   25.0   hours        (Dur option       :  1)

Using rainfall statistics for England and Wales

Return period for design flood :   10.0   years
 requires rain return period    :   17.0   years
M5-25.0 hour/M5-2day            :    0.906 mm.
M5-25.0 hour                    :   42.6   mm.
MT/M5                           :    1.32
M  17.0-25.0 hour               :   56.4   mm.  (point)
ARF                             :    0.97
M  17.0-25.0 hour               :   54.8   mm.  (area)

Design storm depth              :   54.77  mm.          (P  option        :  1
                                                        (Profile  option  :  4
Design CWI                      :   91.61               (CWI option       :  1
Percentage runoff               :   37.31  %            (PR option        :  1

Response hydrograph peak        :    2.89  cumecs
Baseflow                        :    0.11  cumecs       (Baseflow option :  1
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Design hydrograph peak          :    3.00  cumecs
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UK DESIGN FLOOD ESTIMATION   MICRO-FSR DEMONSTRATION

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

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Description : Lowland component of Boygrift pumped catchment

Printed on 29- 9-1988 at 11.10   Run Reference - BOYLC

	Time (hours)	(-- Rainfall Total (mm)	Profile % --)	Net (mm)	Unit Hydrograph cumecs/cm per 100sq km	%	(---- Flow Baseflow (cumecs)	Response (cumecs)	Total (cumecs) ----)
1	1.00	0.7	1.2	0.2	1.40	0.50	0.11	0.00	0.11
2	2.00	0.7	1.2	0.2	2.80	1.01	0.11	0.01	0.12
3	3.00	0.8	1.5	0.3	4.30	1.55	0.11	0.03	0.14
4	4.00	1.0	1.8	0.4	5.70	2.05	0.11	0.05	0.16
5	5.00	1.0	1.8	0.4	7.10	2.56	0.11	0.08	0.19
6	6.00	1.1	2.0	0.4	8.50	3.06	0.11	0.12	0.23
7	7.00	1.6	2.9	0.6	9.90	3.56	0.11	0.17	0.28
8	8.00	2.0	3.6	0.7	10.60	3.82	0.11	0.23	0.34
9	9.00	2.6	4.7	1.0	10.70	3.85	0.11	0.31	0.42
10	10.00	3.7	6.8	1.4	10.60	3.82	0.11	0.40	0.51
11	11.00	4.6	8.4	1.7	10.70	3.85	0.11	0.53	0.64
12	12.00	5.0	9.1	1.9	10.60	3.82	0.11	0.68	0.79
13	13.00	5.5	10.0	2.0	10.70	3.85	0.11	0.86	0.97
14	14.00	5.0	9.1	1.9	10.60	3.82	0.11	1.08	1.19
15	15.00	4.6	8.4	1.7	10.70	3.85	0.11	1.31	1.42
16	16.00	3.7	6.8	1.4	10.60	3.82	0.11	1.55	1.66
17	17.00	2.6	4.7	1.0	10.70	3.85	0.11	1.79	1.90
18	18.00	2.0	3.6	0.7	10.60	3.82	0.11	2.01	2.12
19	19.00	1.6	2.9	0.6	10.70	3.85	0.11	2.21	2.32
20	20.00	1.1	2.0	0.4	10.60	3.82	0.11	2.38	2.49
21	21.00	1.0	1.8	0.4	10.70	3.85	0.11	2.52	2.63
22	22.00	1.0	1.8	0.4	10.60	3.82	0.11	2.63	2.74
23	23.00	0.8	1.5	0.3	10.30	3.71	0.11	2.71	2.82
24	24.00	0.7	1.2	0.2	9.60	3.46	0.11	2.78	2.89
25	25.00	0.7	1.2	0.2	8.90	3.20	0.11	2.83	2.94
26	26.00				8.20	2.95	0.11	2.86	2.97
27	27.00				7.40	2.66	0.11	2.88	2.99
28	28.00				6.70	2.41	0.11	2.89	3.00
29	29.00				6.00	2.16	0.11	2.89	3.00
30	30.00				5.30	1.91	0.11	2.87	2.98
31	31.00				4.60	1.66	0.11	2.85	2.96
32	32.00				3.90	1.40	0.11	2.80	2.91
33	33.00				3.20	1.15	0.11	2.74	2.85
34	34.00				2.50	0.90	0.11	2.66	2.77
35	35.00				1.80	0.65	0.11	2.56	2.67
36	36.00				1.10	0.40	0.11	2.44	2.55
37	37.00				0.40	0.14	0.11	2.30	2.41
38	38.00						0.11	2.15	2.26
39	39.00						0.11	1.99	2.10
40	40.00						0.11	1.83	1.94
41	41.00						0.11	1.66	1.77
42	42.00						0.11	1.49	1.60
43	43.00						0.11	1.32	1.43
44	44.00						0.11	1.16	1.27

APPENDIX 2

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UK DESIGN FLOOD ESTIMATION                              MICRO-FSR DEMONSTRATION

Summary of estimate using Flood Studies Report rainfall-runoff method
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Description : Highland component of Boygrift pumped catchment
Printed on 29- 9-1988 at   5.55                         Run Reference - BOYHI
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Estimation of T-year flood
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                                                        (UH option    :  1)
Unit hydrograph time to peak   :    7.5   hours         (TP option    :  3)
Data interval                  :   1.00   hours
Includes Tp scaling factor     :   1.00

Design storm duration          :   13.0   hours         (Dur option   :  1)

Using rainfall statistics for England and Wales

Return period for design flood :   10.0   years
 requires rain return period   :   17.0   years
M5-13.0 hour/M5-2day           :   0.773  mm.
M5-13.0 hour                   :   38.7   mm.
MT/M5                          :   1.34
M  17.0-13.0 hour              :   51.6   mm. (point)
ARF                            :   0.97
M  17.0-13.0 hour              :   50.1   mm. (area)

Design storm depth             :   50.05  mm.           (P  option    :  1
                                                        (Profile  option :  4
Design CWI                     :  104.69                (CWI option   :  1
Percentage runoff              :   31.24  %             (PR option    :  1

Response hydrograph peak       :    2.67  cumecs
Baseflow                       :    0.11  cumecs        (Baseflow option :  1
                                  -------
Design hydrograph peak         :    2.78  cumecs
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~~Estimated~~ 13 hour storm

LAG = 8·5 hrs (from gauged data)

Triangular u.h.

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UK DESIGN FLOOD ESTIMATION MICRO-FSR DEMONSTRATION

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

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Description : Highland component of Boygrift pumped catchment

Printed on 29- 9-1988 at 5.55 Run Reference - BOYHI

	Time (hours)	(-- Rainfall Total (mm)	Profile %	--) Net (mm)	Unit Hydrograph cumecs/cm per 100sq km	%	(---- Flow Baseflow (cumecs)	Response (cumecs)	----) Total (cumecs)
1	1.00	1.2	2.3	0.4	3.90	1.40	0.11	0.01	0.12
2	2.00	1.6	3.1	0.5	7.80	2.81	0.11	0.03	0.14
3	3.00	1.8	3.6	0.6	11.70	4.21	0.11	0.08	0.18
4	4.00	2.9	5.7	0.9	15.60	5.62	0.11	0.14	0.25
5	5.00	5.1	10.1	1.6	19.50	7.02	0.11	0.25	0.36
6	6.00	7.9	15.8	2.5	23.40	8.42	0.11	0.44	0.55
7	7.00	9.3	18.6	2.9	27.30	9.83	0.11	0.71	0.82
8	8.00	7.9	15.8	2.5	28.04	10.09	0.11	1.04	1.15
9	9.00	5.1	10.1	1.6	25.47	9.17	0.11	1.39	1.50
10	10.00	2.9	5.7	0.9	22.90	8.24	0.11	1.75	1.86
11	11.00	1.8	3.6	0.6	20.34	7.32	0.11	2.09	2.20
12	12.00	1.6	3.1	0.5	17.77	6.40	0.11	2.38	2.49
13	13.00	1.2	2.3	0.4	15.21	5.47	0.11	2.59	2.70
14	14.00				12.64	4.55	0.11	2.67	2.78
15	15.00				10.07	3.63	0.11	2.62	2.73
16	16.00				7.51	2.70	0.11	2.47	2.58
17	17.00				4.94	1.78	0.11	2.26	2.37
18	18.00				2.38	0.86	0.11	2.02	2.13
19	19.00						0.11	1.75	1.86
20	20.00						0.11	1.47	1.58
21	21.00						0.11	1.19	1.30
22	22.00						0.11	0.92	1.03
23	23.00						0.11	0.67	0.78
24	24.00						0.11	0.45	0.56
25	25.00						0.11	0.28	0.39
26	26.00						0.11	0.16	0.27
27	27.00						0.11	0.09	0.20
28	28.00						0.11	0.05	0.16
29	29.00						0.11	0.02	0.13
30	30.00						0.11	0.01	0.11

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APPENDIX 3

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UK DESIGN FLOOD ESTIMATION   MICRO-FSR DEMONSTRATION

Summary of estimate using Flood Studies Report rainfall-runoff method

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Description : Highland? component of Boygrift pumped catchment

Printed on 29- 9-1988 at 11.20   Run Reference - BOYHI

Estimation of T-year flood

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				(UH option	:	1)
Unit hydrograph time to peak	:	7.5	hours	(TP option	:	3)
Data interval	:	1.00	hours			
Includes Tp scaling factor	:	1.00				
Design storm duration	:	25.0	hours	(Dur option	:	1)

Using rainfall statistics for England and Wales

Return period for design flood	:	10.0	years			
requires rain return period	:	17.0	years			
M5-25.0 hour/M5-2day	:	0.906	mm.			
M5-25.0 hour	:	45.3	mm.			
MT/M5	:	1.32				
M 17.0-25.0 hour	:	59.7	mm. (point)			
ARF	:	0.98				
M 17.0-25.0 hour	:	58.3	mm. (area)			
Design storm depth	:	58.26	mm.	(P option	:	1
				(Profile option	:	4
Design CWI	:	104.69		(CWI option	:	1
Percentage runoff	:	32.41	%	(PR option	:	1
Response hydrograph peak	:	2.50	cumecs			
Baseflow	:	0.11	cumecs	(Baseflow option	:	1

Design hydrograph peak	:	2.61	cumecs			
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UK DESIGN FLOOD ESTIMATION MICRO-FSR DEMONSTRATION

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

Description : Highland component of Boygrift pumped catchment
Printed on 29- 9-1988 at 11.20 Run Reference - BOYHI

	Time (hours)	Rainfall Total (mm)	Rainfall Profile %	Rainfall Net (mm)	Unit Hydrograph cumecs/cm per 100sq km	Unit Hydrograph %	Flow Baseflow (cumecs)	Flow Response (cumecs)	Flow Total (cumecs)
1	1.00	0.7	1.2	0.2	3.90	1.40	0.11	0.01	0.12
2	2.00	0.7	1.2	0.2	7.80	2.81	0.11	0.02	0.13
3	3.00	0.9	1.5	0.3	11.70	4.21	0.11	0.04	0.15
4	4.00	1.0	1.8	0.3	15.60	5.62	0.11	0.07	0.18
5	5.00	1.0	1.8	0.3	19.50	7.02	0.11	0.11	0.22
6	6.00	1.2	2.0	0.4	23.40	8.42	0.11	0.16	0.27
7	7.00	1.7	2.9	0.5	27.30	9.83	0.11	0.23	0.34
8	8.00	2.1	3.6	0.7	28.04	10.09	0.11	0.31	0.42
9	9.00	2.7	4.7	0.9	25.47	9.17	0.11	0.41	0.52
10	10.00	4.0	6.8	1.3	22.90	8.24	0.11	0.53	0.64
11	11.00	4.9	8.4	1.6	20.34	7.32	0.11	0.69	0.79
12	12.00	5.3	9.1	1.7	17.77	6.40	0.11	0.87	0.98
13	13.00	5.8	10.0	1.9	15.21	5.47	0.11	1.10	1.20
14	14.00	5.3	9.1	1.7	12.64	4.55	0.11	1.35	1.45
15	15.00	4.9	8.4	1.6	10.07	3.63	0.11	1.61	1.72
16	16.00	4.0	6.8	1.3	7.51	2.70	0.11	1.88	1.99
17	17.00	2.7	4.7	0.9	4.94	1.78	0.11	2.12	2.23
18	18.00	2.1	3.6	0.7	2.38	0.85	0.11	2.31	2.42
19	19.00	1.7	2.9	0.5			0.11	2.44	2.55
20	20.00	1.2	2.0	0.4			0.11	2.50	2.61
21	21.00	1.0	1.8	0.3			0.11	2.49	2.59
22	22.00	1.0	1.8	0.3			0.11	2.41	2.52
23	23.00	0.9	1.5	0.3			0.11	2.28	2.38
24	24.00	0.7	1.2	0.2			0.11	2.10	2.21
25	25.00	0.7	1.2	0.2			0.11	1.91	2.02
26	26.00						0.11	1.69	1.80
27	27.00						0.11	1.47	1.58
28	28.00						0.11	1.25	1.36
29	29.00						0.11	1.03	1.14
30	30.00						0.11	0.83	0.94
31	31.00						0.11	0.66	0.76
32	32.00						0.11	0.50	0.61
33	33.00						0.11	0.38	0.48
34	34.00						0.11	0.28	0.39
35	35.00						0.11	0.21	0.31
36	36.00						0.11	0.15	0.26
37	37.00						0.11	0.11	0.21
38	38.00						0.11	0.07	0.18
39	39.00						0.11	0.05	0.15
40	40.00						0.11	0.03	0.13
41	41.00						0.11	0.01	0.12
42	42.00						0.11	0.00	0.11

APPENDIX 4

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**************************************************************************************
UK DESIGN FLOOD ESTIMATION                                 MICRO-FSR DEMONSTRATION

Summary of estimate using Flood Studies Report rainfall-runoff method
**************************************************************************************

Description : Lowland component of Boygrift pumped catchment
Printed on 29- 9-1988 at 11.15                               Run Reference - BOYLC
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Estimation of T-year flood
=========================
                                                             (UH option        :  0)
Includes Tp scaling factor      :    1.00

Design storm duration           :    13.0   hours           (Dur option       :  1)

Using rainfall statistics for England and Wales

Return period for design flood  :    10.0   years
 requires rain return period    :    17.0   years
M5-13.0 hour/M5-2day            :     0.773 mm.
M5-13.0 hour                    :    36.3   mm.
MT/M5                           :     1.34
M   17.0-13.0 hour              :    48.8   mm.  (point)
ARF                             :     0.96
M   17.0-13.0 hour              :    46.9   mm.  (area)

Design storm depth              :    46.95  mm.             (P  option        :  1)
                                                             (Profile  option :  4)
Design CWI                      :    91.61                  (CWI option       :  1)
Percentage runoff               :    36.10  %               (PR option        :  1)


Response hydrograph peak        :     2.48  cumecs
Baseflow                        :     0.11  cumecs          (Baseflow option :  1)
                                  -------
Design hydrograph peak          :     2.59  cumecs
                                  =======
**************************************************************************************
micro-FSR  -  Institute of Hydrology
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UK DESIGN FLOOD ESTIMATION MICRO-FSR DEMONSTRATION

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

Description : Lowland component of Boygrift pumped catchment
Printed on 29- 9-1988 at 11.15 Run Reference - BOYLO

	Time (hours)	(-- Rainfall --) Total (mm)	Profile %	Net (mm)	Unit Hydrograph cumecs/cm per 100sq km	%	(---- Flow ----) Baseflow (cumecs)	Response (cumecs)	Total (cumecs)
1	1.00	1.1	2.3	0.4	1.40	0.50	0.11	0.01	0.12
2	2.00	1.5	3.1	0.5	2.80	1.01	0.11	0.03	0.14
3	3.00	1.7	3.6	0.6	4.30	1.55	0.11	0.06	0.17
4	4.00	2.7	5.7	1.0	5.70	2.05	0.11	0.10	0.21
5	5.00	4.7	10.1	1.7	7.10	2.56	0.11	0.19	0.30
6	6.00	7.4	15.8	2.7	8.50	3.06	0.11	0.32	0.43
7	7.00	8.7	18.6	3.2	9.90	3.56	0.11	0.52	0.63
8	8.00	7.4	15.8	2.7	10.60	3.82	0.11	0.76	0.87
9	9.00	4.7	10.1	1.7	10.70	3.85	0.11	1.03	1.14
10	10.00	2.7	5.7	1.0	10.60	3.82	0.11	1.31	1.42
11	11.00	1.7	3.6	0.6	10.70	3.85	0.11	1.58	1.69
12	12.00	1.5	3.1	0.5	10.60	3.82	0.11	1.83	1.94
13	13.00	1.1	2.3	0.4	10.70	3.85	0.11	2.05	2.16
14	14.00				10.60	3.82	0.11	2.22	2.33
15	15.00				10.70	3.85	0.11	2.33	2.44
16	16.00				10.60	3.82	0.11	2.40	2.51
17	17.00				10.70	3.85	0.11	2.44	2.55
18	18.00				10.60	3.82	0.11	2.46	2.57
19	19.00				10.70	3.85	0.11	2.47	2.58
20	20.00				10.60	3.82	0.11	2.48	2.59
21	21.00				10.70	3.85	0.11	2.48	2.59
22	22.00				10.60	3.82	0.11	2.48	2.59
23	23.00				10.30	3.71	0.11	2.47	2.58
24	24.00				9.60	3.46	0.11	2.47	2.58
25	25.00				8.90	3.20	0.11	2.46	2.57
26	26.00				8.20	2.95	0.11	2.44	2.55
27	27.00				7.40	2.66	0.11	2.40	2.51
28	28.00				6.70	2.41	0.11	2.35	2.46
29	29.00				6.00	2.16	0.11	2.27	2.38
30	30.00				5.30	1.91	0.11	2.16	2.27
31	31.00				4.60	1.66	0.11	2.02	2.13
32	32.00				3.90	1.40	0.11	1.88	1.99
33	33.00				3.20	1.15	0.11	1.72	1.83
34	34.00				2.50	0.90	0.11	1.56	1.67
35	35.00				1.80	0.65	0.11	1.40	1.51
36	36.00				1.10	0.40	0.11	1.23	1.34
37	37.00				0.40	0.14	0.11	1.07	1.18
38	38.00						0.11	0.91	1.02
39	39.00						0.11	0.75	0.86
40	40.00						0.11	0.60	0.71
41	41.00						0.11	0.46	0.57
42	42.00						0.11	0.32	0.43
43	43.00						0.11	0.21	0.32
44	44.00						0.11	0.13	0.24

****
UK DESIGN FLOOD ESTIMATION MICRO-FSR DEMONSTRATION
****

Description : Lowland component of Boygrift pumped catchment
Printed on 29- 9-1988 at 5.25 Run Reference - BOYLO

Catchment Characteristics

Area	:	13.72 sq.km.	Soil 1	:	0.000
Length	:	-1.00 km.	Soil 2	:	0.000
Slope	:	-1.00 m./km.	Soil 3	:	0.430
SAAR	:	633 mm.	Soil 4	:	0.570
M5-2D	:	47.0 mm.	Soil 5	:	0.000
Jenkinson's r	:	0.40			
Urban	:	0.00			
Smdbar	:	-1.0 mm.	RSMD	:	-1.000 mm.
Stmfrq	:	-1.00 junctions/sq.km.			
Lake	:	-1.00			
EMP 2 hour	:	-1.00 mm.	BFI	:	-1.00
EMP 24 hour	:	-1.00 mm.	LAG	:	hr.

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UK DESIGN FLOOD ESTIMATION — MICRO-FSR DEMONSTRATION

Description : **Highland** component of Boygrift pumped catchment
Printed on 29- 9-1988 at 5.50 Run Reference - BOYH

Catchment Characteristics

Area	:	7.41 sq.km.	Soil 1	:	0.350
Length	:	-1.00 km.	Soil 2	:	0.000
Slope	:	-1.00 m./km.	Soil 3	:	0.000
SAAR	:	710 mm.	Soil 4	:	0.650
MS-2D	:	50.0 mm.	Soil 5	:	0.000
Jenkinson's r	:	0.40			
Urban	:	0.00			
Smdbar	:	-1.0 mm.	RSMD	:	-1.000 mm
Stmfrq	:	-1.00 junctions/sq.km.			
Lake	:	-1.00			
EMP 2 hour	:	-1.00 mm.	BFI	:	-1.00
EMP 24 hour	:	-1.00 mm.	LAG	:	8.50 hr

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Reference ....

11 Oct 88

FML/

This is a second small job for Grantham, Brundell & Farran. It is closely related to our research on pumped drainage systems (proj T5/9/A) and I had intended to show the receipt there. However, given the possibility that it may lead to further work, perhaps it is more appropriate to register the job separately.

The topic of IDB financing is in MAFF's mind also at the moment. Nigel has been to a preliminary meeting (1 July 88) to discuss a possible framework for fixing urban v lowland contributions (based on a benefits approach). Highland is a third factor.

DWR/

CODE 18-78

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