CALCULATION OF UNGAUGED DAILY FLOWS WITHIN THE OUSE CATCHMENT

LOIS Working Note No. 3

Douglas R. Lewis

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Institute of Hydrology
Crowmarsh Gifford
Wallingford
Oxon
OX10 8BB
UK

Tel: 0491 838800
Fax: 0491 832256
Telex: 849365 Hydrol G

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D. R. Lewis

1 Introduction

In LOIS Working Note No. 2 (Lewis, 1994b), emphasis was given to an analysis of the annual flows and the annual data available from the Micro Low Flow (MLF) system (Gustard et. al., 1992) for the Ouse catchment above York. As such, daily flows were not considered. Here, a transformation method (TM) will be described for transferring daily gauged flow data to ungauged sub-catchments. This procedure requires gauged and ungauged sites to be grouped together according to some classification scheme. Estimates of the 95 percentile exceedance flow expressed as a percentage of the mean flow, as calculated by the MLF system, is used for the purpose of this classification. Based on similar catchments nearby, estimates of daily flows for all the significant ungauged tributaries were made for the year 1990. The procedure adopted and results are given in Section 2.

The gauging station at Richmond on the Swale was discontinued in 1980. Since flows are required for more recent years, a method of modelling the River Swale to Richmond is also necessary. The rainfall-runoff model IHACRES (Jakeman et. al. 1990) has been applied to this catchment and calibrated for the years 1976 to 1980. Validation was carried out using data for the period 1974 to 1975. A comparison was also made with estimates derived using the transformation method applied to the ungauged catchments. Simulation runs using both methods were used to provide estimated flows for 1990. The methods and results are described in Section 3.

Section 4 considers the dynamic water balance throughout the Ouse system above York. The water quality model QUASAR is used to calculate the flows in the major rivers with the gauged tributary flows and the important ungauged tributary flows included as point inputs in the simulation. Comparisons with the NRA gauging station flows is made at the bottom of each of the major rivers and at the furthest downstream point considered in the system.

2 Transferring gauged flows to ungauged catchments on the basis of statistics derived from Micro Low Flows

2.1 TRANSFORMATION METHOD AND CLASSIFICATION SCHEME

It is assumed that similar catchments in the same area will produce a similar time series of daily flows. Consequently, if the daily flows and the relevant catchment characteristics are known for a gauged sub-catchment, then daily flows for an ungauged sub-catchment with similar catchment characteristics may be determined.

The time series transformation factor (TF) between sites is based simply on the catchment areas and average rainfalls, and is given by the equation

$$Q_u(t) = Q_g(t)\left(\frac{A_u}{A_g}\right)\left(\frac{SAAR_u}{SAAR_g}\right), \qquad (1)$$

where the subscripts g and u denote the gauged and ungauged sites, Q(t) is the daily flow time series (cumecs), A is the catchment area (km^2) and SAAR is the standard period average annual catchment rainfall (mm).

The method of classifying sites is based on the MLF 95 percentile exceedance flow (Q95). In calculating the Q95 value for an ungauged site the MLF system uses a provisional classification scheme of 29 hydrological response (HOST) classes (Boorman et. al. 1990) with the addition of URBAN and LAKE classifications. These 31 classes are replaced by 12 Low Flow HOST groups. Using linear least squares multiple regression analysis, expressions relating the percentage of Low Flow HOST classes and Q95 values for 865 gauged catchments were obtained (Gustard et. al., 1992). The 95 percentile exceedance flow at ungauged sites is then estimated by the MLF system from the fraction of Low Flow HOST classes present within the catchment.

It is useful to express the MLF Q95 values as a percentage of the mean flow (Q95%), since this adjusts for the scale of the catchment, and two catchments are assumed to have similar hydrological responses if their MLF Q95% values are of similar magnitude. A high Q95% value indicates that the catchment response is predominantly due to base flow, has permeable soil and is dominated by ground water. In contrast, a low Q95% value indicates that the catchment is flashy, has an impermeable layer and the response is mainly due to direct surface run-off.

In choosing the gauged stations from which transformations are calculated only gauged stations monitoring a tributary should be considered and not main river stations. The catchment must not be heavily controlled by reservoirs and is preferably nearby to the ungauged site. Based on these criteria, the gauged stations are grouped together into three classes of Q95% values. The estimated Q95% value of the ungauged catchment is then compared with those in each class and the gauged station with the closest value chosen.

The calculation of the ungauged daily flows are of course approximate since annual totals are used to transfer the gauged daily flows. A further approximation is introduced through the use of the hydrological response classification scheme since sizable differences can exist in the Q95% values for the two catchments.

2.2 RESULTS

Table 1 shows the gauged stations which can be used to provide the daily flows. These stations lie mainly within the Ouse catchment and the immediately surrounding catchments. This table also provides the catchment characteristics of area and SAAR, required to calculate the TF according to equation 1. The first row of each station entry gives the MLF values for the stretch which includes the gauging station. These include the Q95% value used to determine the hydrological classification of a catchment. The second row of each station entry gives the gauging site observations.

Table 1 *Micro Low Flows estimates of Naturalised Mean flows, annual rainfall, 95 percentiles and catchment areas for the gauged stations within and close to the Ouse catchment. Also shown in every second row are measured values.*

Gauging Station	Grid Ref.	Area (km^2)	SAAR (mm)	MF (cumecs)	MF/Area (mm)	Q95% (%MF)
Hunsingore Weir	SE431531	499.00	978	8.40±1.36	531	14.43
27001	SE427529	484.00	-	8.13	530	12.37
Gouthwaite Res.	SE140683	116.50	1382	3.44±0.32	931	11.30
27005	SE141683	113.70	-	2.61	724	24.77
Westwick Lock	SE355669	913.25	1140	20.04±2.48	692	21.26
27007	SE355672	914.60	-	20.68	713	13.04
Leckby Grange	SE415749	1357.80	878	19.13±3.69	444	19.29
27008	SE415749	1345.60	-	20.14	472	18.97
Skelton	SE570553	3314.80	927	51.20±9.00	487	18.86
27009	SE568554	3315.00	-	48.82	464	15.19
Washburn	SE225483	89.75	1025	1.65±0.24	580	12.49
27011	SE219488	87.30	-	0.58	210	26.38
Richmond	NZ146007	384.50	1316	10.89±1.04	893	13.23
27024	NZ147006	381.00	-	10.35	857	11.17
Kilgram Bridge	SE190860	506.25	1372	15.10±1.38	941	19.55
27034	SE190860	510.20	-	15.32	947	6.91
Wharfe at Addingham	SE092491	423.0	1391	12.70±1.15	947	13.11
27043	SE092494	427.0	-	14.59	1078	10.99
Snaizeholme Beck	SD834885	11.25	1789	0.49±0.03	1374	9.45
27047	SD833883	10.20	-	0.56	1731	4.26
Crimple Beck	SE295513	9.25	871	0.13±0.03	443	10.19
27051	SE295519	8.10	-	0.11	428	5.56
Birstwith Bridge	SE229603	220.50	1225	5.41±0.60	774	12.29
27053	SE230603	217.60	-	5.10	739	15.71
Rye at Broadway Foot	SE565877	135.25	931	2.13±0.37	497	12.06
27055	SE560882	131.70	-	2.21	529	23.03
River Laver	SE304708	79.25	904	1.13±0.22	450	17.25
27059	SE301710	87.50	-	1.06	382	9.68
River Kyle	SE508602	168.25	635	1.11±0.46	208	15.60
27060	SE509602	167.60	-	10.95	2060	1.19
Skipp Bridge	SE482563	525.75	961	8.59±1.43	515	14.94
27062	SE483561	516.00	-	14.30	874	10.73
River Wiske	SE375844	215.25	650	1.53±0.59	224	14.03
27069	SE375844	215.50	-	3.32	486	5.60
Crakehill	SE424735	1360.00	878	19.15±3.69	444	19.28
27071	SE425734	1363.00	-	19.45	450	17.53
Bedale Beck	SE305904	143.50	741	1.40± 0.39	308	32.49
27075	SE306902	160.30	-	2.01	395	14.83
Bat Bridge	SE419719	25.25	634	0.17±0.07	212	38.75
27082	SE419725	N.A.	-	0.15	-	18.92
River Skell	-	-	-	-	-	-
27086	SE316709	-	-	1.43	-	-

A comparison of the MLF Q95% value with the gauged 95 percentile value reveals the degree of agreement between estimated and observed values for the gauged case. However, it has to be realised that the measured values are based on a statistical analysis of the actual gauged flows. Whereas the MLF values are based on an analysis of a set of gauged flows and the relative proportions of the Low Flow HOST classifications in the catchment. The emphasis of the MLF system is also on natural flow conditions and naturalisation biases are introduced into the MLF calculations (Gustard et. al., 1992). The net result is that there is some disagreement among the two Q95% values.

It is now necessary to choose gauged stations which are suitable for transferring data to ungauged catchments. These need to cover as wide a range of Q95% as possible and to follow the criteria given in Section 2.1.

Based on these criteria, a total of only six gauging stations were deemed suitable for estimating the daily flows. These may, in turn, be grouped together into three classes of Q95% values, termed low, medium and high as shown in Table 2. Figures 1 to 6 show the gauged flows for these stations for 1990.

In matching ungauged sites to gauged sites, the Q95% class gives the first indication. Within a class, the matching is then based on the closest values of Q95%, followed by the SAAR and MF values and the nearness of the catchments.

Table 2 *Gauging stations considered to be suitable for transferring daily flows to ungauged sites within the Ouse catchment. The Micro Low Flows predictions are shown and the classification group for each station.*

Gauging Station	Classification/ Class name	Area (km^2)	SAAR (mm)	MF (cumecs)	Q95 (%MF)
Snaizeholme Beck 27047	Low SBL	11.25	1789	0.49±0.03	9.45
Crimple Beck 27051	Low CBL	9.25	871	0.13±0.03	10.19
River Wiske 27069	Medium RWM	215.25	650	1.53±0.59	14.03
River Laver 27059	Medium RLM	79.25	904	1.13±0.22	17.25
Bedale Beck 27075	High BBH	143.50	741	1.40± 0.39	32.49
Cundall Beck 27082	High CBH	25.25	634	0.17±0.07	38.75

Figure 1. Flows for Snaizeholme Beck on the River Ure (1990)

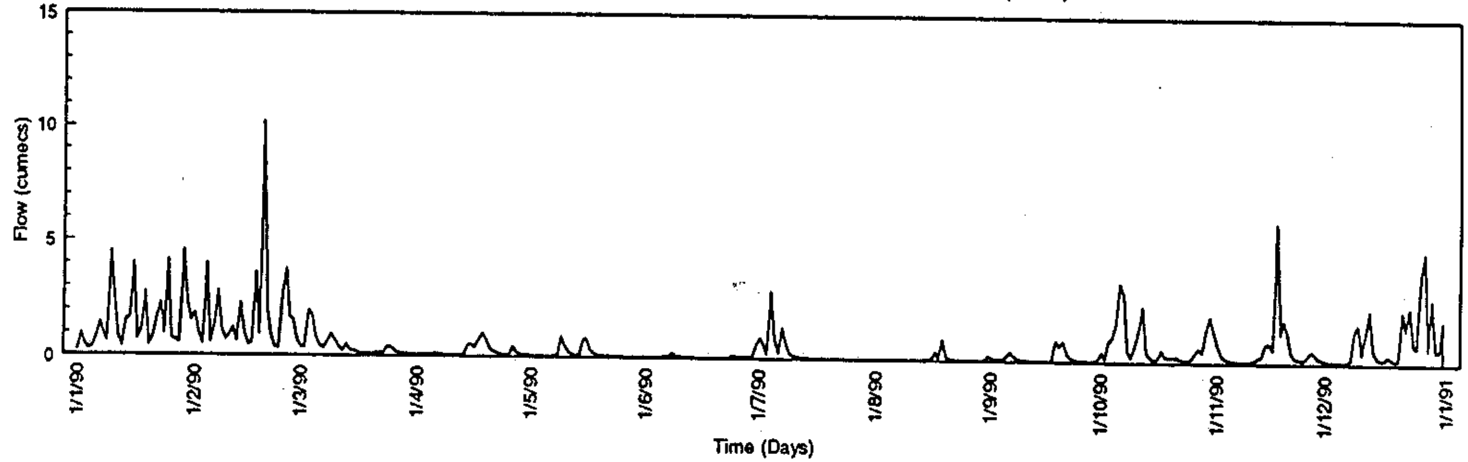


Figure 2. Flows for Crimple Beck on the River Nidd (1990)

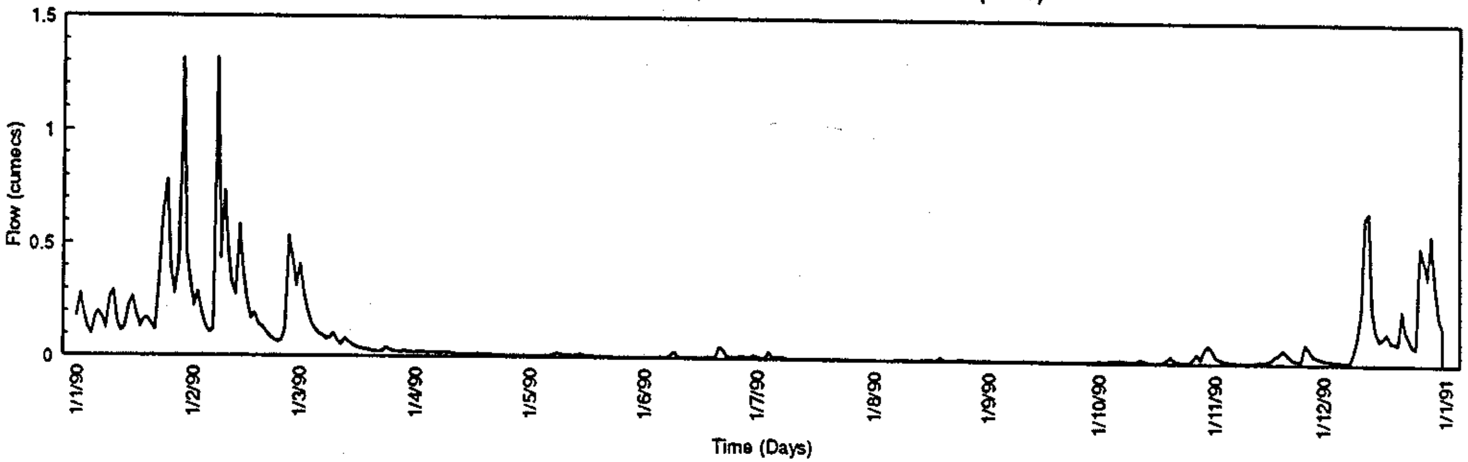


Figure 3. Flows for the River Wiske (1990)

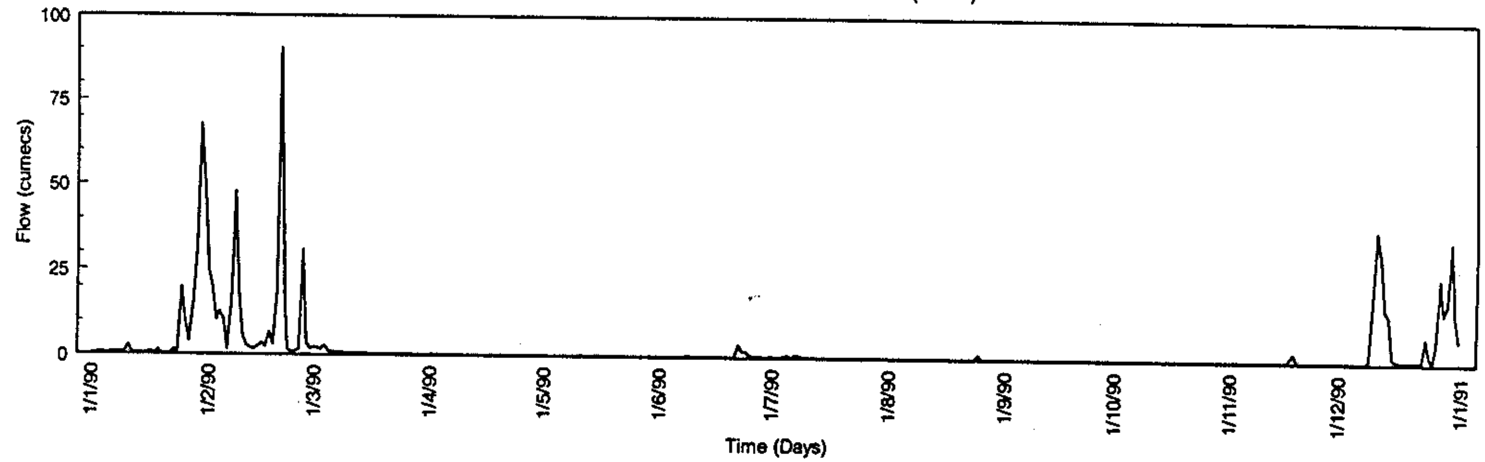


Figure 4. Flows for the River Laver on the River Swale (1990)

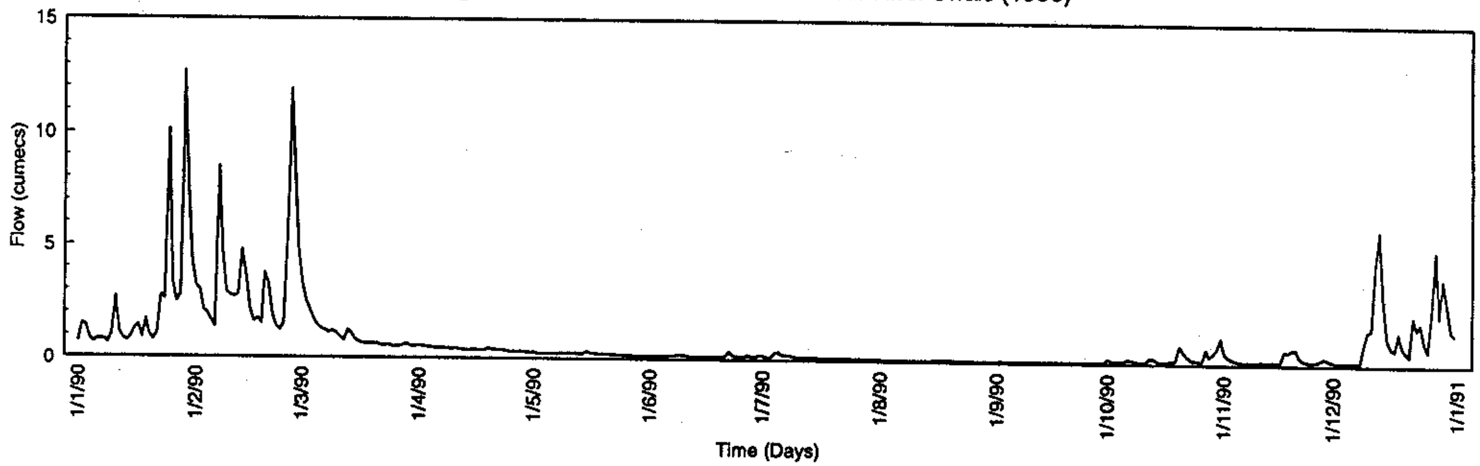


Figure 5. Flows for Bedale Beck on the River Swale (1990)

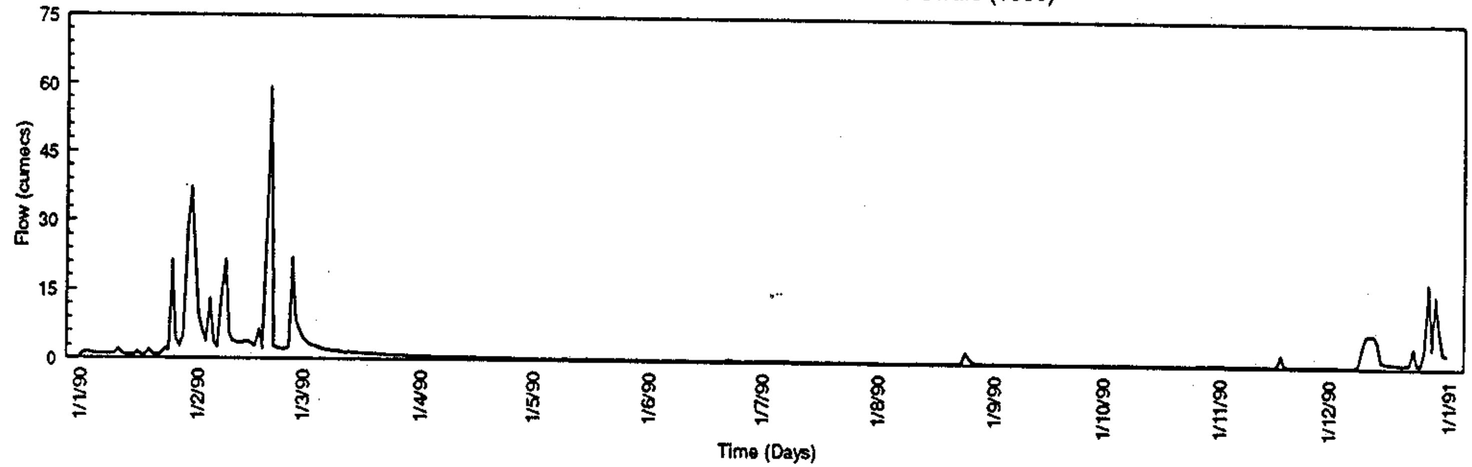
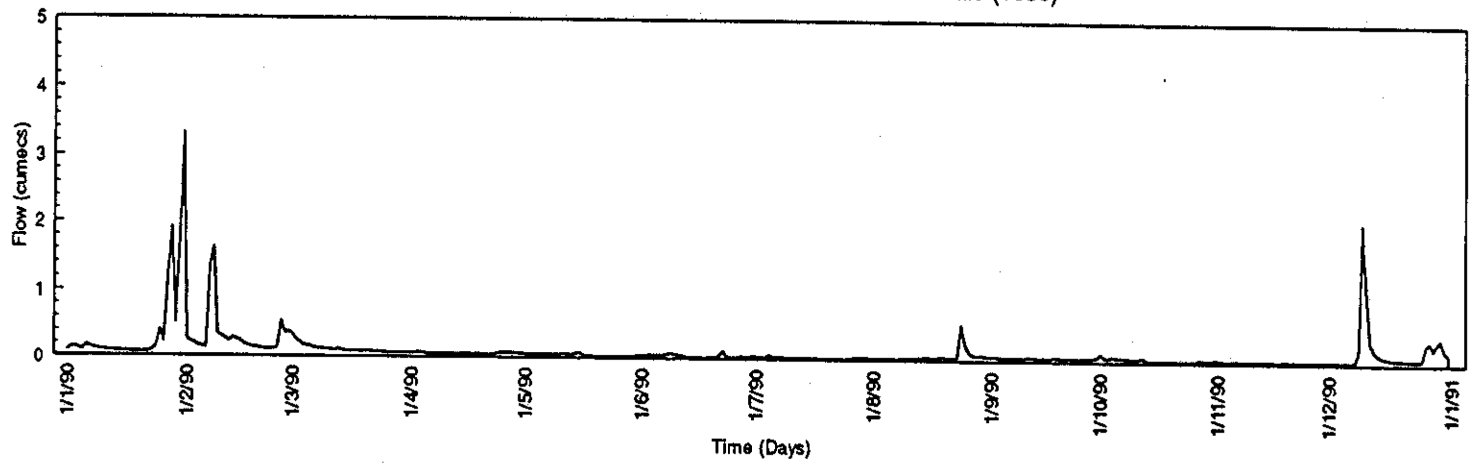


Figure 6. Flows for Cundall Beck on the River Swale (1990)



In Tables 3, 4, 5 and 6 the MLF estimates for the significant ungauged tributaries on the rivers Swale, Ure, Nidd, and Ure-Ouse are given. The tributaries are numbered in the tables according to the location of their inflow into the main river. Also indicated in these tables are the gauging stations to which the tributaries are matched and the required transformation factors. Figure 7 shows the tributaries which are thought to contribute significantly to the mean annual flows in the main rivers. Each tributary is identified by its MF value.

Also included in Table 3, are the MLF values for the main river stretch at Richmond. These values are included so that a comparison can be made between the flows calculated by the TM described here and those calculated by the rainfall-runoff model IHACRES as given in Section 3.

Table 3 *Micro Low Flow estimates for the relevant ungauged tributaries on the River Swale (catchment area ≥20 km²). Also included are the transferring stations and factors required for each tributary.*

Number	Grid Ref.	Area (km²)	SAAR (mm)	MF (cumecs)	Q95 (%MF)	Transferring Station	TF
Richmond	NZ146007	384.50	1316	10.89±1.04	13.23	RWM	3.6166
1	NZ212000	83.00	859	1.07±0.23	32.43	BBH	0.6705
2	SE249973	25.00	777	0.27±0.07	22.50	RLM	0.2711
3	SE289966	45.50	708	0.37±0.12	14.77	RWM	0.2302
4	SE302958	21.25	648	0.14±0.06	10.50	CBL	1.7091
5	SE340860	61.50	677	0.49±0.17	27.37	BBH	0.3916
6	SE413750	218.75	692	1.91±0.59	14.01	RWM	1.0819
7	SE432733	51.25	689	0.43±0.14	13.51	RWM	0.2524

Table 4 *Micro Low Flow predictions for the relevant ungauged tributaries on the River Ure (catchment area ≥20 km²). Also included are the transferring stations and factors required for each tributary.*

Number	Grid Ref.	Area (km²)	SAAR (mm)	MF (cumecs)	Q95 (%MF)	Transferring Station	TF
1	SE230798	97.00	1045	1.82±0.26	18.92	RLM	1.4149
2	SE322736	30.00	652	0.22±0.08	49.52	CBH	1.2219
3	SE347672	52.25	786	0.57±0.14	17.66	RLM	0.5732
4	SE403674	43.75	681	0.35±0.12	20.15	RLM	0.4159

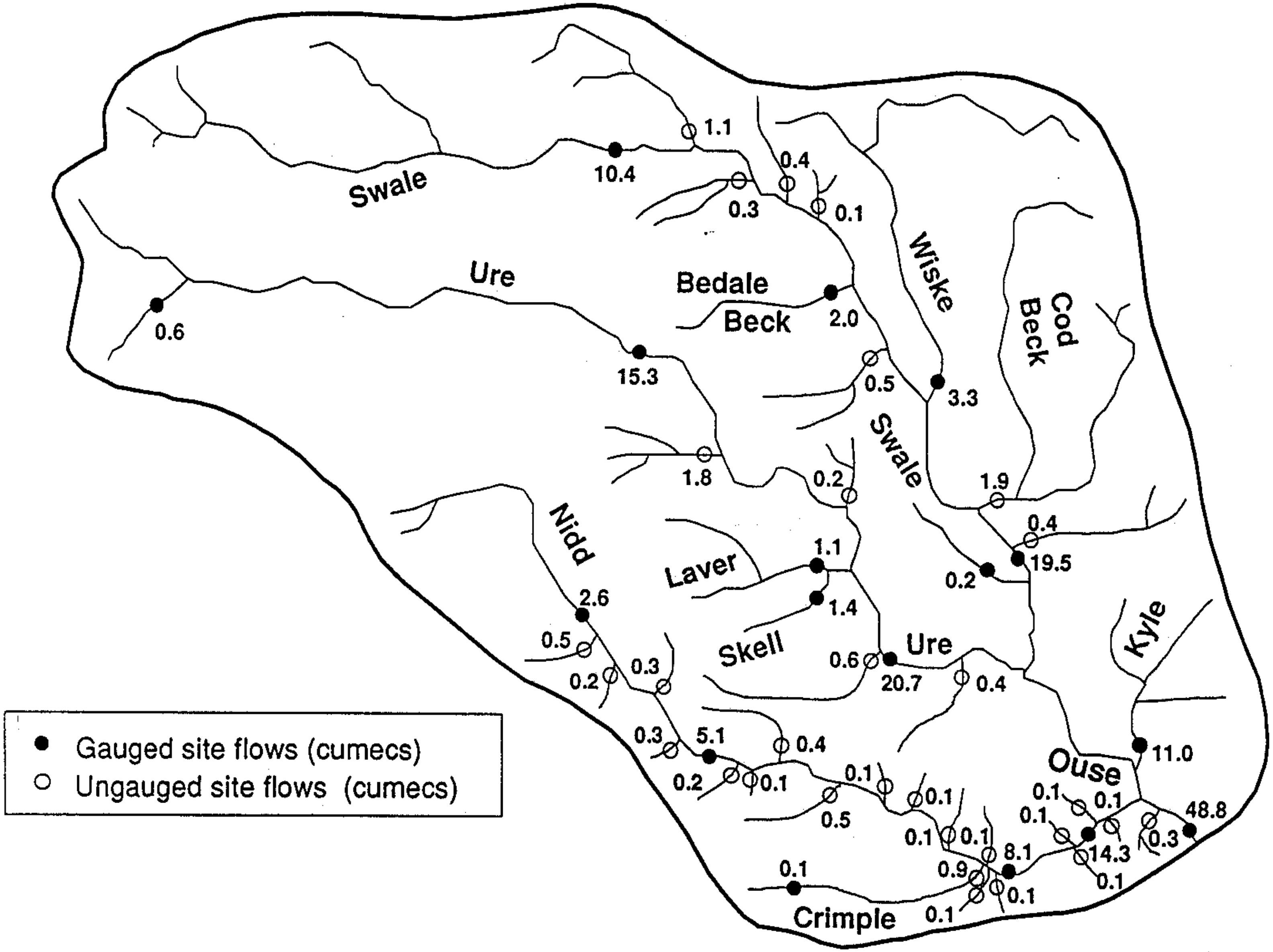
Table 5 *Micro Low Flow estimates for the relevant ungauged tributaries on the River Nidd (catchment area ≥5 km²). Also included are the transferring stations and factors required for each tributary.*

Number	Grid Ref.	Area (km²)	SAAR (mm)	MF (cumecs)	Q95 (%MF)	Transferring Station	TF
1	SE151664	20.00	1214	0.48±0.05	13.76	RWM	0.1735
2	SE162648	10.50	1131	0.23±0.03	10.34	CBL	1.4740
3	SE189639	16.25	995	0.29±0.04	11.92	CBL	2.0069
4	SE201601	16.50	1026	0.30±0.05	10.62	CBL	2.1012
5	SE253589	11.00	907	0.16±0.03	10.24	CBL	1.2383
6	SE269590	7.25	892	0.10±0.02	10.50	CBL	0.8027
7	SE286597	24.00	908	0.36±0.07	15.15	RLM	0.3042
8	SE304583	36.00	861	0.49±0.10	12.47	CBL	3.8472
9	SE363571	5.00	669	0.04±0.01	23.24	RLM	0.0467
10	SE372569	8.00	682	0.06±0.02	11.31	RLM	0.0762
11	SE387544	11.75	679	0.09±0.03	20.31	RLM	0.1114
12	SE405531	83.75	775	0.90±0.23	17.31	RLM	0.9060
13	SE413534	14.00	666	0.11±0.04	21.07	RLM	0.1301
14	SE418524	13.75	680	0.11±0.04	16.17	RLM	0.1305
15	SE420522	13.00	666	0.10±0.04	23.31	RLM	0.1209
16	SE466543	9.75	658	0.07±0.03	29.47	BBH	0.0603
17	SE473551	6.50	649	0.05±0.02	37.48	CBH	0.2635
18	SE484564	13.75	645	0.10±0.04	32.03	BBH	0.0834
19	SE499563	6.50	646	0.04±0.02	10.45	CBL	0.5212

Table 6 *Micro Low Flow predictions for the relevant ungauged tributaries on the River Ure - River Ouse (catchment area ≥20 km²). Also included are the transferring stations and factors required for each tributary.*

Number	Grid Ref.	Area (km²)	SAAR (mm)	MF (cumecs)	Q95 (%MF)	Transferring Station	TF
1	SE508602	168.25	635	1.11±0.46	15.60	RLM	1.4913
2	SE539562	52.50	639	0.34±0.14	14.40	RLM	0.4683

Figure 7. Main tributaries and mean annual flows within the Ouse catchment.



3 Modelling the River Swale to Richmond

3.1 THE IHACRES RAINFALL-RUNOFF MODEL

There are two basic components to the IHACRES model of the rainfall-streamflow process. One is a non-linear rainfall filter (RF) which is used to produce a rainfall excess or "effective rainfall" which takes into account the rainfall and soil moisture status, and effects such as evapotranspiration and storage. The second component is a linear conversion of rainfall excess to streamflow via the convolution integral:

$$y(t) = \int_0^t h(t-x)\, u(x)\, dx\,, \qquad (2)$$

where rainfall excess u(x) is operated on by the instantaneous unit hydrograph function h(t-x) and integrated over time t to yield streamflow y(t).

The rainfall-rainfall excess part of the model (the "loss" model) has just two parameters (τ_w and f) and requires only rainfall and temperature input data (r_k (mm) and t_k (°C)). The subscript k indicates the time variable (usually in days). This work used the following version of IHACRES (Littlewood, 1994), in which the basic loss module is defined by

$$u_k = \frac{r_k\,(s_{k-1} + s_k)}{2}\,, \qquad (3)$$

$$s_k = C r_k + \left(1 - \frac{1}{\tau_w(t_k)}\right) s_{k-1}\,, \qquad (4)$$

$$\tau_w(t_k) = \tau_w \exp(f\,(T - t_k))\,. \qquad (5)$$

A catchment wetness index s_k is employed to account for the fact that the soil moisture content of the catchment has a direct effect on the streamflow produced for a given rainfall; rainfall excess u_k is calculated as the product of r_k and the average of s_{k-1} and s_k. The parameter τ_w is the value of $\tau_w(t_k)$ at a reference temperature T=-10 °C, and $\tau_w(t_k)$ controls the rate at which s_k decays due to evaporative losses in the absence of rainfall. In periods of rainfall this decay still occurs but s_k is also incremented by a proportion (C) of r_k. The value of C is calculated internally within the model such that the volumes of rainfall excess and observed streamflow over the model calibration period are equal. Calibration periods are thus chosen to start at times of low flow so that the net change in the catchment storage of water over the period is close to zero. The parameter f controls the sensitivity of $\tau_w(t_k)$ to changes in temperature.

The rainfall excess-streamflow part of the model is based on the well known unit hydrograph theory but differs from traditional practical methods: rainfall excess is related to total stream flow rather than just to a direct runoff component of streamflow after base flow has been subtracted. Two linear storages in parallel have been found (Littlewood and Jakeman, 1994) to be the most appropriate structural configuration. These storages represent quick (flood) and slow (base) flows, with time constants denoted by τ_q and τ_s respectively. The relationship of these dynamic response parameters to physical catchment descriptors is speculative, but it is likely that low values of τ_q are associated with large surface flows, thin soils or significant changes in topography within the catchment. Large values of τ_s are possibly associated with deep soils and low soil permeability. V_q and V_s are the relative throughput volumes for the quick and slow components respectively, with $V_q + V_s = 1$. It is also reasonable to compare V_s with the Base Flow Index (BFI) (Littlewood, 1994) for the catchment.

Optimal values of τ_w and f are found by repeatedly searching the parameter space and fitting over the calibration period. Large $R^2 = 1 - \sigma_r^2/\sigma_o^2$ values, (where σ_r^2 and σ_o^2 are the variance of the residuals and the observed streamflow, respectively), and low Average Relative Parameter Error (ARPE) values are used as the criteria for a good fit.

3.2 SUMMARY OF IHACRES CALIBRATION RUNS FOR SWALE AT RICHMOND

The maximum altitude of the catchment is 713 m with the gauging station at an altitude of 107.6 m. The catchment is almost wholly on carboniferous limestone and is very steep, with flood waves reported to come down the river, on occasions, as a bore. Flow records at Richmond show that the catchment is very flashy, with large rises of up to 1.5 m in an hour recorded, however the high flows are considered to be measured with good accuracy. Consequently it has been given an A1 rating. Low flows are considered to be of poor quality due to an unstable gravel bed and abstractions upstream at Catterick army camp.

Calibration runs were carried out throughout the period Nov 1976 to May 1980 (a total of 1275 days). Daily rainfall was calculated using the IH program AREARAIN, as the average of all the raingauges in the immediate area. Daily discharge from the gauging station was available, along with the MORECS (Thompson et. al. 1981) monthly temperature (MORECS square 85). Simulation periods ranged from just under 1 year to the full 3.5 year period.

The best results of these simulations are given in Table 7. However it must be noted that several parameter combinations for any one of these calibration periods can produce similar R^2 and ARPE values, i.e. no distinctive minimum exists in the parameter space.

Generally poor R^2 values are produced in the calibration runs, with the result that several criteria must be employed in deciding which are the best set of parameters. The National River Flow Archive station file for the Swale at Richmond (see LOIS Working Note No. 1, Lewis, 1994a) gives a value of 0.35 for the BFI. This indicates that the simulation runs of rows six and seven in Table 7 are not appropriate. Since the aim of the exercise is to provide a simulation run for a complete year using the calibrated model, it is more appropriate to use calibration periods of several years thereby removing any dependence on a particular year. Using this argument, the parameters determined from the short term calibration period should not be used. This leaves a similar set of parameters used on three different calibration periods.

Table 7 Best fit parameters and R^2 values for various simulation periods.

Simulation period	R^2 (%)	ARPE (%)	f	τ_w	1/C	τ_q	τ_s	V_s
Nov 76-May 80	42.2	0.50	0.05	20	160.7	1.38	50.12	0.378
Aug 77-May 80	42.9	0.30	0.05	20	166.2	1.37	62.27	0.377
Jun 78-May 80	39.4	0.50	0.05	25	207.4	1.38	61.43	0.355
Jun 79-May 80	57.8	0.47	0.01	3	32.0	1.54	78.98	0.399
May78-Jun 79	32.5	4.83	0.03	5	54.6	0.67	77.23	0.667
Aug 77-Jun 78	61.3	0.53	0.03	3	32.3	1.14	71.03	0.572
Nov 76-Aug 77	43.3	1.93	0.15	10	105.3	1.84	15.84	0.386

To see why the R^2 values are low a calibration plot using the best fit parameters of τ_w=20 and f=0.05, is shown in Figures 8 and 9 (this produces an R^2 = 42.2%). Comparing the model predictions with the observed flows, shows that several large observed peaks are not predicted by IHACRES. Conversely there are several smaller peaks predicted (appearing before the large observed peaks) which are not observed. This pattern would arise with a model which cannot predict snowmelt effects. Unfortunately this is the case with the present version of IHACRES, which does not contain a storage module accounting for snowmelt. It is probable that snowmelt effects are causing the low R^2 values presented in Table 7. These effects are shown most clearly by the unobserved peaks, and a correspondence between the timing of the unobserved peaks and snow fall periods is identified more clearly in the next section.

3.3 SNOW SURVEY IN THE UPLAND SWALE CATCHMENT

3.3.1 Summary of snowfalls

A summary of snow falls in the upland Swale catchment, for the period October 1975 to May 1980 is presented. This summary was taken from the annual Meteorological Office Snow Survey reports 1975-80.

The only station of interest in the region is that at Osmotherly, near Northallerton (National Grid Reference SE 458 967). Since the altitude of the station is only 147 m it is to be expected that the measured snowfall rates and duration underestimates that at the upland swale catchment. Table 8 shows the snow observations made for this station and the surrounding area. Four values are given for each month, comprising:

Figure 8: IHACRES - Calibration plot for the River Swale at Richmond (1976-78)
$\tau_w = 20$ $f = 0.05$ $R^2 = 42.2\%$

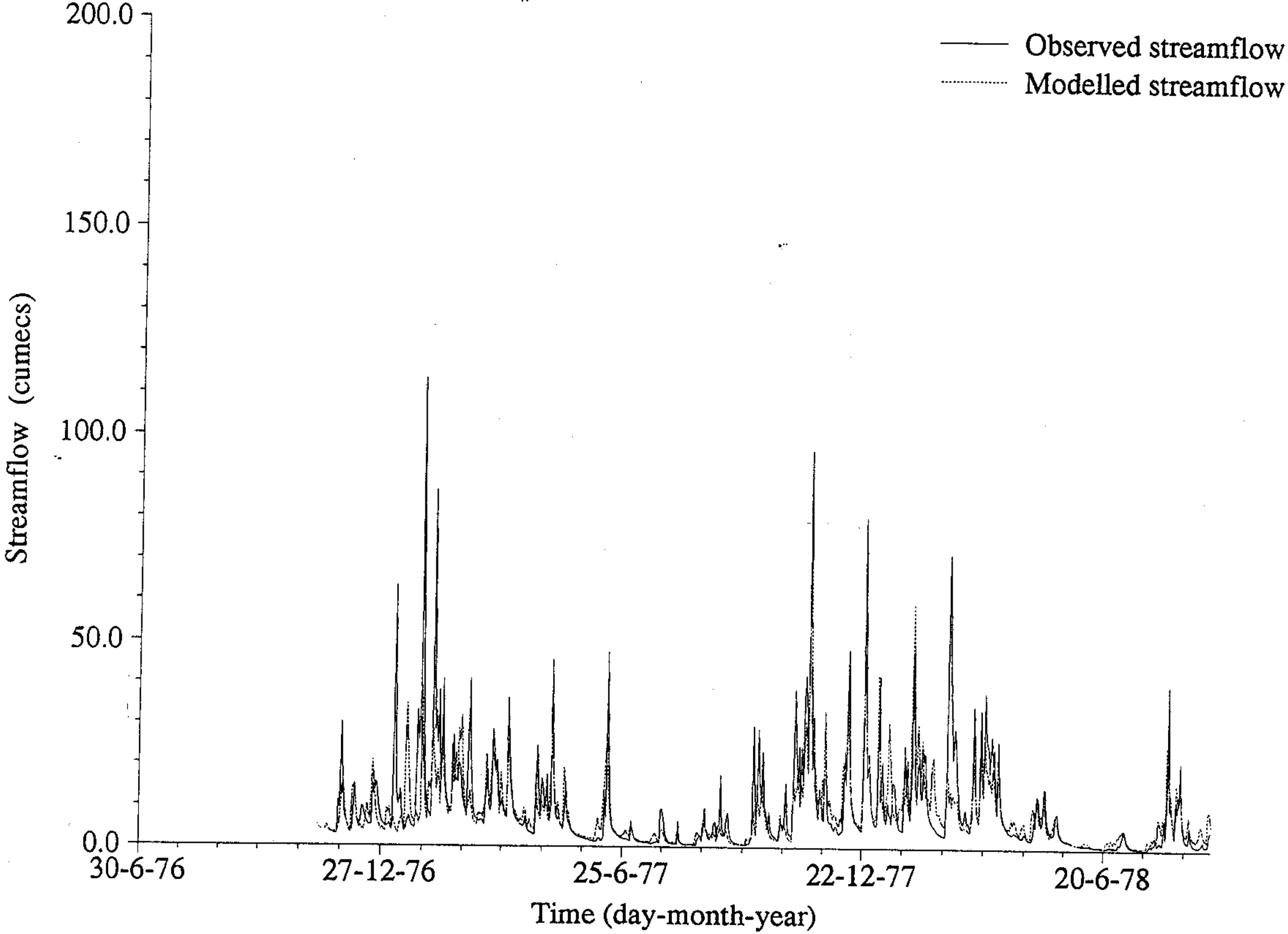
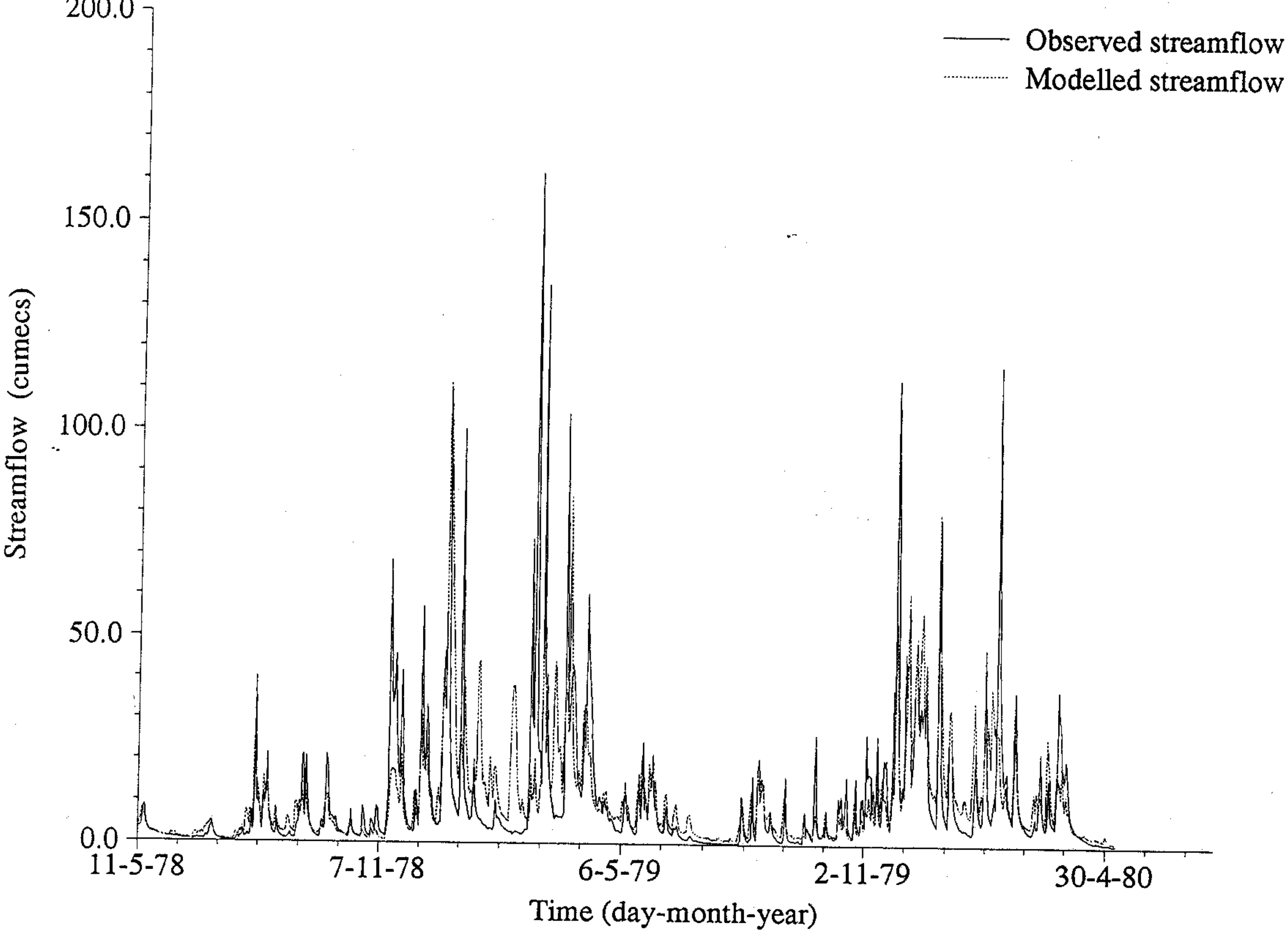


Figure 9: IHACRES - Calibration plot for the River Swale at Richmond (1978-80)
$\tau_w = 20$ $f = 0.05$ $R^2 = 42.2\%$



1. Number of days when snow occurred at the station.

2. Number of days when snow was lying at the station.

3. A measurement of the maximum depth of undrifted snow lying at the station.

4. The earliest date when this maximum depth of snow was attained.

The figures are arranged in the set pattern

1 2
3 4

with a D indicating that no snow depth was measured because of excessive drifting and T indicating that the depth of the snow was less than 0.5 cm.

Table 8 *Summary of snow fall at Osmotherly.*

Year	Nov		Dec		Year	Jan		Feb		March		April	
1975	1	0	5	1	1976	8	8	1	0	3	0	0	0
	-	-	3	13		14	25	-	-	-	-	-	-
1976	0	0	12	9	1977	8	15	1	0	3	2	2	1
	-	-	11	3		13	11	-	-	1	28	1	7
1977	3	0	1	0	1978	11	9	9	12	3	2	6	0
	-	-	-	-		5	11	30	13	1	15	-	-
1978	4	3	8	4	1979	17	28	14	20	13	13	2	2
	5	28	18	31		25	2	15	16	D	-	T	2
1979	0	0	3	11	1980	4	5	3	3	0	0	0	0
	-	-	8	20		4	21	10	4	-	-	-	-

3.3.2 Comparison with IHACRES

The snow summary shown in Table 8 can be compared with the results of running the rainfall-runoff model IHACRES for the upland Swale catchment to Richmond. Table 9 shows the dates of the large unobserved peaks which were simulated and which could indicate the importance of snowmelt effects.

Comparing the two tables shows that there is a good overlap in most of the periods of snowfall and the timing of the unmodelled peaks. This is determined by taking the earliest date at which the maximum depth was attained and then using the number of days when snow was lying at the station to provide the bounding dates. There is also likely to be a greater number of snow fall days in the higher altitude Richmond catchment. These comparisons strongly indicate that snowmelt is occurring at these times, since snowmelt effects cannot be modelled in the present versions of IHACRES.

Table 9 *Dates of unobserved peaks simulated by IHACRES.*

Year	Jan	Feb	March
1977	18*		
1978	19*	20*	
1979	21*	15*	20$
1980		6*	

* means that the peaks fall within the boundaries of the snowfall dates of Table 8.
$ indicates that there is no data on observed snowfall dates for that month.

3.4 VALIDATION RUNS - 1974 to 1975

Figure 10 shows the validation plot of the IHACRES model using the previously calibrated parameters for the Swale at Richmond. An R^2 = 65.1% was achieved for the two year (1974/75) validation period. This is a good fit overall with the base flow modelled well, but in general some of the observed flow peaks are underestimated by approximately 50%. The average observed discharge over the two year period was 8.34 cumecs while that estimated was 6.57 cumecs (neglecting the first 11 days run-in period).

It is not possible to compare the estimations of the TM with observation since the gauging station on the River Wiske began operating in 1980. In order to validate the TM, the gauging station at Crakehill (27071) is used as the matching station. The Q95% values for the catchments monitored at Crakehill (19.28) and Richmond (13.23) suggest that they are hydrologically similar. Figure 10 also shows the validation plot, produced using a TF of 0.4238. An R^2 = 57.8% was achieved, with an average observed discharge over the period of 8.61 cumecs and an estimation of 6.82 cumecs (neglecting October 1975 when only an average monthly value was available).

The similar R^2 values produced by the two methods do not allow any substantial distinction to be drawn between the methods. As a consequence of this it is reasonable to use either of the methods to estimate the flows for 1990.

3.5 SIMULATION OF 1990 FLOW

Figure 11 shows the IHACRES and TM estimations for the River Swale flow conditions at Richmond for 1990. The NRA station at Crakehill was used as the matching gauged station. In general, there is only a modest agreement between the estimations; positions and magnitudes of several of the peak flows for the two methods are different, whereas the base flows are comparable.

Figure 10. Validation plot for the River Swale at Richmond (1974-75) using IHACRES and the Transformation method (Crakehill station)

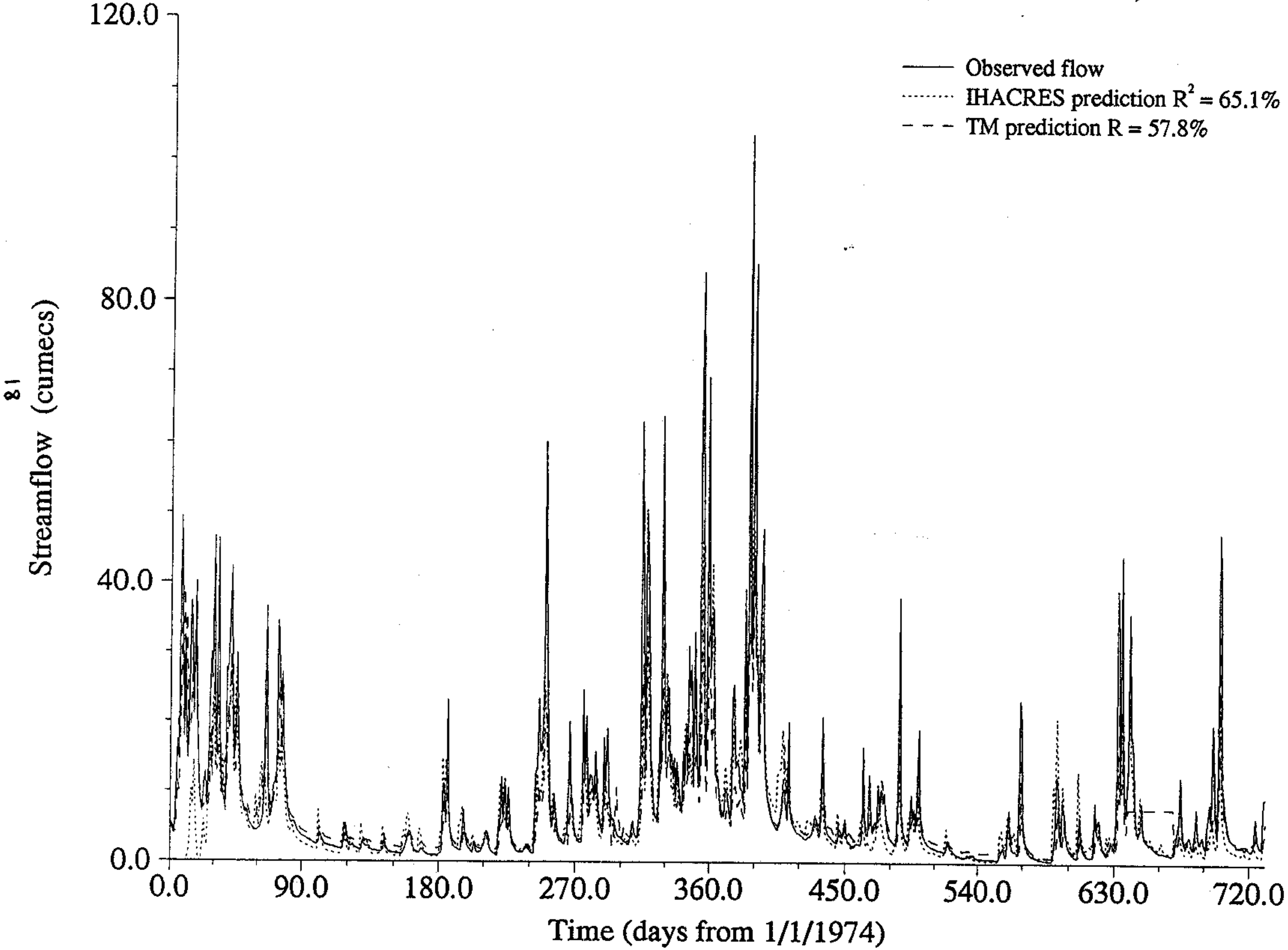
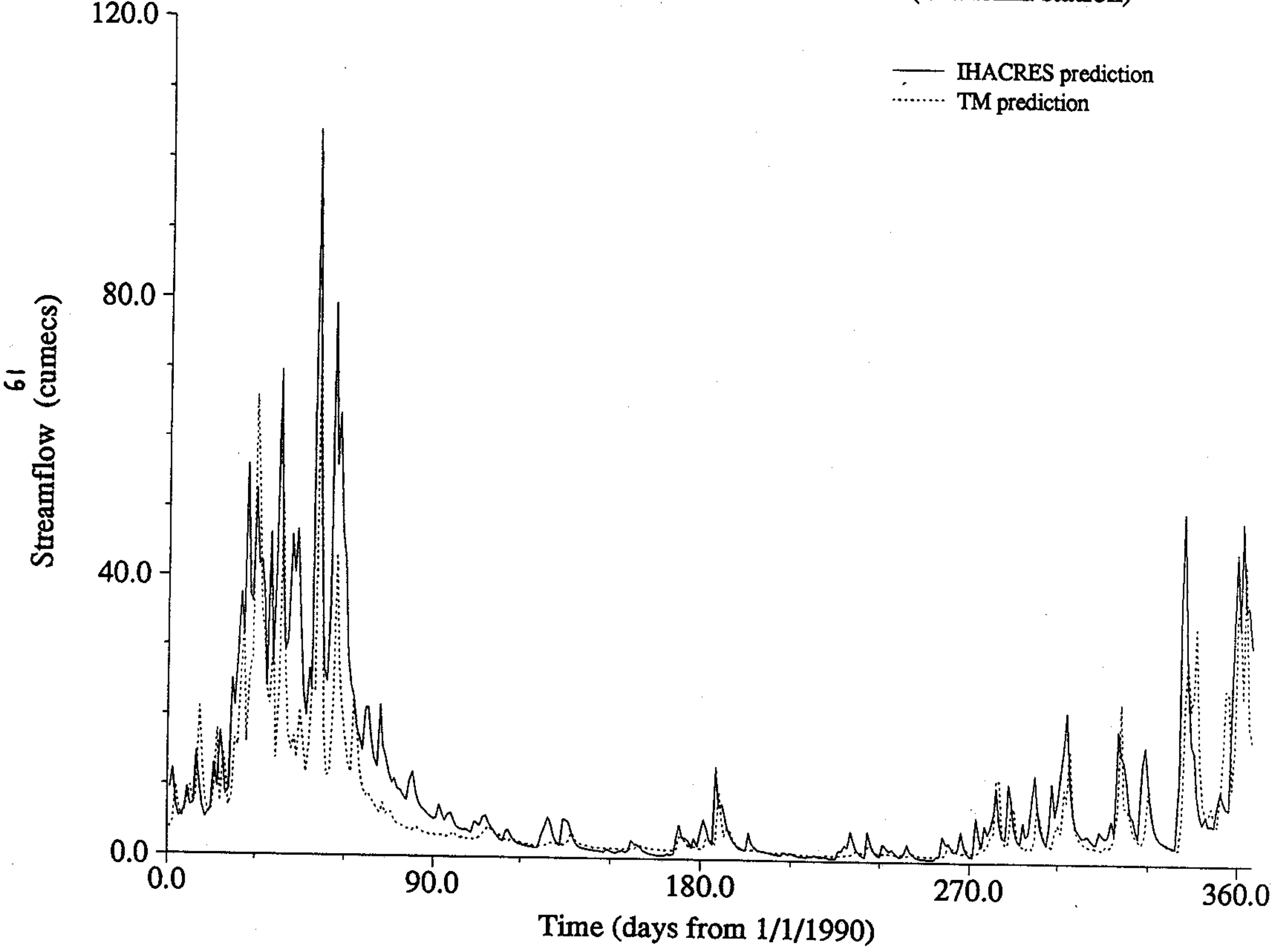


Figure 11. Simulation plot for the River Swale at Richmond (1990) using IHACRES and the Transformation method (Crakehill station)



4 Conclusions

The ungauged flows can be estimated using a straightforward matching classification and TM. Transformation factors and matching gauging sites are identified in this report. Using these estimated flows for the ungauged sites it is expected that a good approximation to the dynamic water balance throughout the Ouse catchment above York can be attained.

It has been demonstrated that the flows at Richmond can be estimated reasonably well using the rainfall-runoff model IHACRES, although snowmelt events are not well predicted. The TM using the station at Crakehill can also be used as a means of estimating these flows.

Using the ungauged flows mentioned in this report the water quality model QUASAR can be applied to the Ouse catchment with a good approximation to the inflows. R^2 values for the QUASAR flow estimations corresponding to major NRA gauging stations at the bottom of each river and at the furthest downstream point in the system are shown in Table 10. Two simulation runs were carried out using different inputs for the Swale at Richmond according to the IHACRES or TM estimates.

A larger R^2 value is achieved using the TM input when comparing the two QUASAR flow estimates with the observed flows at Crakehill on the Swale. Consequently the R^2 value at York (station no. 27009) is also higher with the TM input. On this basis and also for convenience of calculation the TM is preferred in estimating the flows at Richmond.

The QUASAR flow estimates agree very well with the gauging station on the River Nidd and the station on the River Ure. The agreement on the River Swale is good when the TM input is used and poor when the IHACRES input is employed. Flows at York are satisfactorily described using the IHACRES input, however they are better described using the TM input.

Good R^2 values are attained when the TM input is used and consequently the flows estimates in this simulation are expected to be reliable. Hence a good approximation to the dynamic water balance of the Ouse system above York can be achieved by the procedures documented in this report.

Table 10 *Comparison of the QUASAR estimates of flow at certain reaches in the Ouse system with gauging station flows. Two means of inputting the flow at Richmond are used, identified by the IHACRES method or the TM.*

River (Station)	IHACRES R^2 (%)	TM R^2(%)
Swale (27071)	50.0	70.7
Nidd (27001)	88.6	88.6
Ure (27007)	92.0	92.0
Ouse (27009)	60.5	68.8

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