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USE OF MICRO LOW FLOWS WITHIN QUASAR

LOIS Working Note No. 2

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1 Introduction

The river flow and water quality model QUASAR is currently being applied to the Ouse catchment as part of the LOIS core modelling project. A necessary first step in this work is to examine the monitored flow conditions in the Ouse system with regard to the annual water balance throughout the catchment. Basic quality assurance on the river flows at NRA gauging stations within this catchment has been carried out, the results of which are given in Lewis (1994). The conclusion of this report of interest here is that a river model such as QUASAR using only the gauged flows at the starting points of the main rivers and the reliably gauged tributaries as inputs, would underestimate the actual flows downstream at Skelton (near York) by 35%.

As the flow regime in the Ouse catchment is not sufficiently monitored, it is necessary to consider means of estimating flows for the ungauged sub-catchments which feed into the main river systems and contribute to the flow at Skelton. The aim of this report is to identify methods for estimating the ungauged flows, to calculate annual flows and to use them to carry out a new annual water balance analysis of the Ouse river network. In this catchment, the total abstractions and effluent discharges are both small (< 2 cumecs) and also approximately equal. This study is an important independent cross-check on the gauged flows of the catchment and also provides a background for catchment modelling.

2 Method of estimating ungauged flows

The Micro Low Flow (MLF) system developed at IH estimates flow statistics from catchment characteristics at gauged and ungauged sites. It enables the naturalised mean annual flow (MF) and the 95 percentile from the 1 day flow duration curve (Q95) at ungauged sites to be estimated. The standard annual average rainfall (SAAR) and an estimate of the area (A) covered by a sub-catchment can also be obtained.

Mean catchment flow is estimated using the water balance approach developed for the Low Flow Studies Report (1980). This approach assumes that the annual catchment yield (AY) over the long term, is equal to the difference between SAAR and the actual evaporation (AE). A catchment value of SAAR is estimated from the standard period (1941-1970) Meteorological Office rainfall map. The actual evaporation is calculated using $AE = r * PE$ where PE is the potential evaporation derived from the Meteorological Office map of average annual potential evaporation based on the Penman equation (originally 1 x 1 km grid size). Sub-catchment values are determined from the weighted area covered on each map. The adjustment factor r is a function of catchment rainfall, increasing with SAAR until a limit of 1100 mm is reached when it is assumed that actual evaporation is equal to potential. This factor, therefore represents the effect of soil moisture deficit in limiting evaporation.

Mean flow MF (cumecs) is calculated from the expression MF = (SAAR - r PE)* A /31525, where AY is in mm and A is in km^2 and 31525 is the units conversion factor.

In calculating the Q95 value for an ungauged site the MLF system uses a provisional classification scheme of 29 hydrological response HOST classes and in addition URBAN and LAKE classes (Boorman and Hollis, 1990). The 31 classifications are replaced in the MLF system by 12 different Low Flow HOST groups. Using multiple regressional analysis, expressions relating the percentage of Low Flow HOST classes and Q95 values for 865 gauged catchments were obtained (Institute of Hydrology Report No. 108). The 95 percentile exceedance flow at ungauged sites can then be estimated from the fraction of Low Flow HOST classes present within the ungauged sub-catchment. There are no topographical influences included in the determination of the Q95 value.

These expressions can be calculated taking into account the bias exerted by artificial influences such as abstractions and effluent returns. Both the MF and Q95 values are then naturalised by the addition of the resultant of these artificial flows, assigning abstractions with a positive sign (export from the catchment) and effluent returns with a negative sign (import into the catchment). In these simulations no such artificial influences were input. The MLF simulations of MF and Q95 are thus representative of natural catchments.

It is useful to express the Q95 values as a percentage of the mean flow (Q95%), since two sub-catchments are assumed to have similar hydrological responses if their 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 ground water dominated. Correspondingly, 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.

3 Annual flow statistics

3.1 CALCULATION OF ANNUAL FLOW STATISTICS

The MLF system consists of a river network database (with an associated on-screen display) from which synthetic catchment boundaries can be generated. These boundaries are estimated by overlaying a computer generated grid of cell size 0.5 x 0.5 km onto the digitised river network. Each cell within this grid is assigned to a stretch subject to the constraints of digitised: coastlines, Hydrometric area boundaries and sub-catchment boundaries. Walking down the river networks, from the sources to the mouths, the array of cells above each stretch can be stored. To calculate catchment characteristics each grid is assigned numerical values from the Q95, SAAR, and PE databases. As the array of grid squares above any stretch is known, so averaging of all the individual grid square values allows the calculation of catchment average values above each stretch. Easy access to the flow estimates for any river stretch in the network is gained through use of the mouse-driven interactive-roam capability of the package. Using this facility the flow statistics and characteristics of all the sub-catchments of area greater than 5 km^2 have been determined for the main rivers in the Ouse catchment.

FIGURE 1 DIGITISED RIVER NETWORK WITHIN THE OUSE CATCHMENT INCLUDING SHADING ACCORDING TO SUB-CATCHMENT SIZES

Area cutoff = 20 Km^2

Area cutoff = 10 Km^2

Area cutoff = 5 Km^2

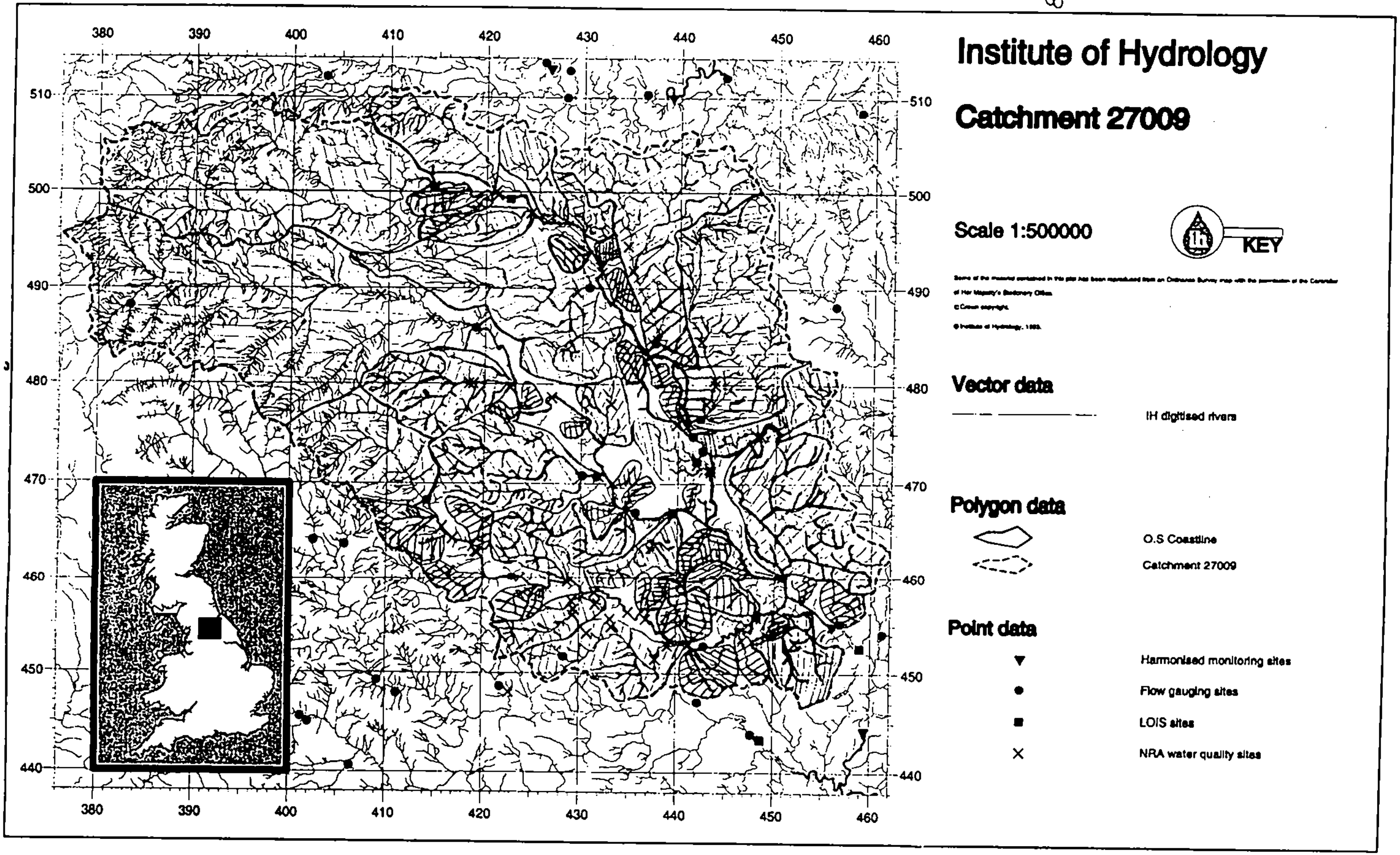
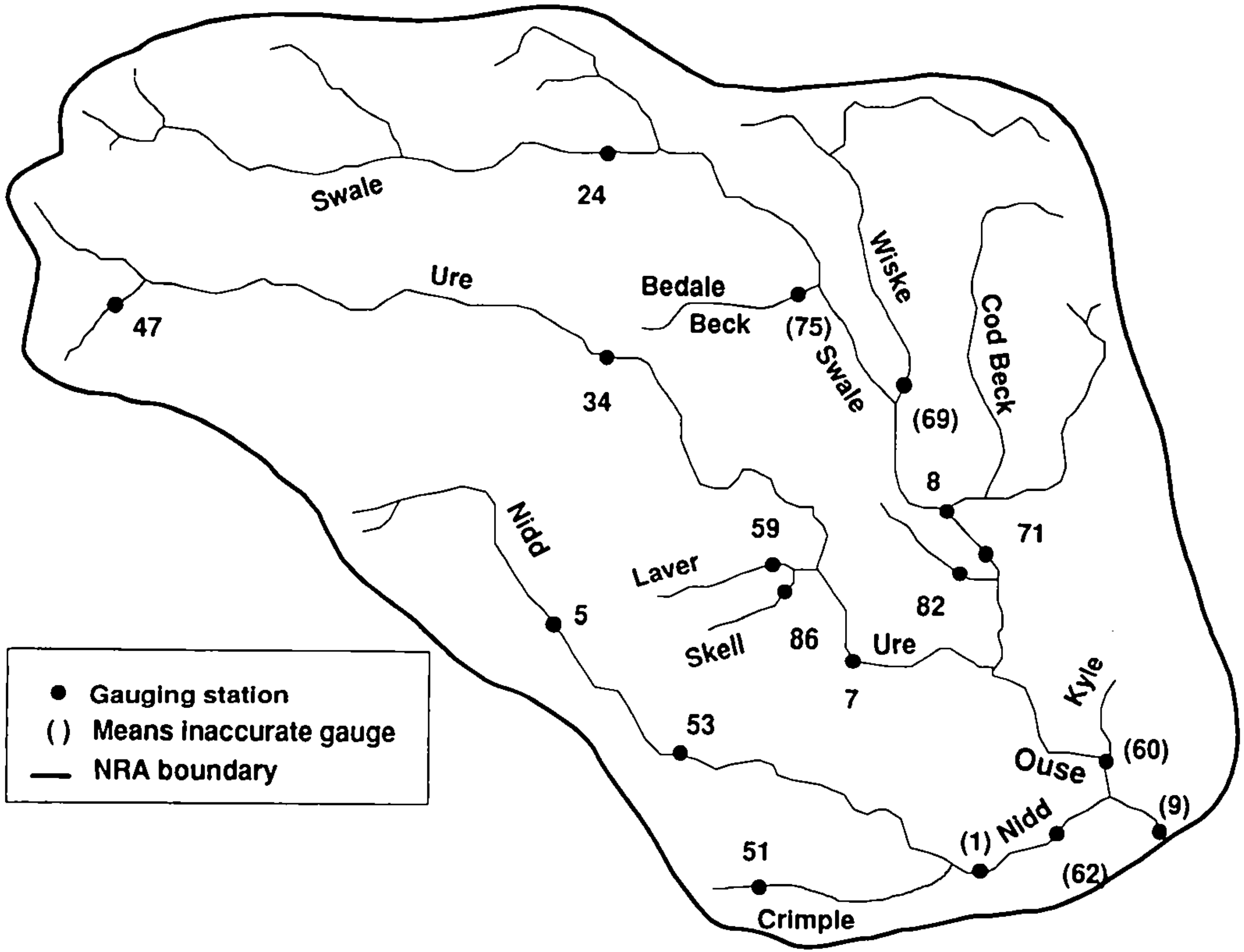


Figure 2. Gauging stations within the Ouse catchment.



3.2 ANNUAL FLOW STATISTICS

Figure 1 shows the river network used in the MLF analysis of the Ouse catchment, with the main rivers investigated shown in thick outline. Also included in this figure is an indication of the relative sizes of the sub-catchments, with shading according to three categories of size: > 20 km^2, 10 to 20 km^2 and 5 to 10 km^2. The areas below 5 km^2 are not shaded. This figure also shows the NRA flow gauging sites used in the study. These are shown in more detail in Figure 2 which is a more schematic map of the main gauged rivers and tributaries in the catchment. The numbers attached to the gauging stations in Figure 2 are the last two digits of the station number, and the available stations with poor quality flow records (Lewis, 1994) are shown in brackets.

Values of the naturalised annual mean flow MF, cumulative flow down a main river, area, SAAR and Q95% for the sub-catchments indicated in Figure 1 are given in Tables 1 to 4 for the River Swale, the River Nidd, the River Ure and the River Ure - River Ouse stretch from the Swale-Ure confluence, respectively.

3.2.1 River Swale

In Table 1 the MLF predictions for all sub-catchments of area greater than 5 km^2 moving downstream from the NRA station at Richmond are given. Two values bracketed together in the tables represent a paired MF estimation and gauging station observation (flows indicated by an absence of SAAR and cumulative flow values). Three values bracketed together represent a paired MF estimation and station observation and a MF value for the stretch entering the main river. Comparisons made between the MLF MF and the observed MF at the gauged stations show that the Bedale Beck and the Wiske tributaries, are both outside the error bands of the MLF predictions, by an excess of 10 and 30% respectively. Both of these overestimates can be explained by backing up from the Swale as noted in the NRA station summary (Lewis, 1994). Those MF estimates for gauging stations along the main River Swale (indicated by an †) give good agreement with the corresponding gauging station values.

Cumulative flows are the result of adding the estimated MF at the bottom of every tributary joining the Swale, moving downstream from Richmond. The total cumulative flow at the last input from a tributary is 19.49 cumecs which is to be compared with the MF estimation at the last stretch of the Swale of 19.94. Hence an underestimate of only 2.3% is evident when neglecting contributions from areas less than 5 km^2. Table 5 shows the underestimation for the sub-catchment cutoff areas mentioned above as a percentage of MF. These figures show that with a 20 km^2 cutoff in the case of the Swale, only 5.8% of the flow is underestimated. Hence, it is reasonable to consider only those sub-catchments in excess of this cutoff area when modelling flow.

3.2.2 River Nidd

The MLF statistics for the River Nidd moving downstream from Gouthwaite reservoir are given in Table 2. All the gauging stations considered in this work are on the main river reach and only those at Birstwith Bridge and Hunsingore Weir agree well with the MF predictions. The other stations, namely Gouthwaite and Skip Bridge, have discharge values outside of the MF error ranges. In the case of Gouthwaite the gauged site has a flow lower than the estimated MF because of the controlled abstractions from the reservoirs in the upper catchment (see Lewis (1994), for details of these abstractions). The station at Skip Bridge is known to give an overestimate in the measurement of high flows and for this reason gives a

40% larger flow than the MF value. The MF estimation is consistent with the station at Hunsingore Weir.

Table 5 shows that even with a cutoff sub-catchment area of 5 km^2 the MF is underestimated by 14.2%. However the errors associated with the MF are large enough to accommodate this underestimate. It is evident that the smaller sub-catchments feeding into the Nidd have a significant effect on the flow conditions and should all be included in modelling the flow conditions.

3.2.3 River Ure

The River Ure moving downstream from Kilgram Bridge is well represented by the MLF analysis. Gauging station values compare favourably with the MF predictions. A 3.6% underestimate of the MF value at the confluence of the Ure with the River Swale is evident with a 20 km^2 cutoff area. It is therefore reasonable to consider only those sub-catchments in excess of this cutoff area.

3.2.4 River Ure - River Ouse

This stretch of river is also well represented with only one problematical area, namely that of the River Kyle which has gauging station values far in excess of the MF predictions. This is considered due to substantial errors in measurement caused by backing up from the River Ouse and the MLF value should be used as a substitute to the gauged flow in any modelling exercise. A 0.5% underestimate results from a 20 km^2 cutoff area.

Table 1 *Micro Low flows - Naturalised Mean flows, annual rainfall, 95 percentiles and catchment areas for particular river reaches and tributaries*

River SWALE - Moving downstream from Richmond (Catchment area ≥5 km^2)

Gauging Station		Grid Ref.	Area (km^2)	SAAR (mm)	MF (cumecs)	Cumulative Flows (cumecs)	Q95 (%MF)
Richmond 27024	{	NZ146007†	384.50	1316	10.89±1.04	10.89	13.23
		NZ147006†	381.00	-	10.35	-	11.17
		NZ180003	11.75	887	0.16±0.003	11.05	12.87
		SE205997	12.50	846	0.16±0.03	11.21	16.44
		NZ212000	83.00	859	1.07±0.23	12.28	32.43
		SE249973	25.00	777	0.27±0.07	12.55	22.50
		SE289966	45.50	708	0.37±0.12	12.92	14.77
		SE302958	21.25	648	0.14±0.06	13.06	10.50
		SE306937	9.75	665	0.07±0.03	13.13	51.01
		SE319923	8.50	640	0.06±0.02	13.19	29.84
Bedale Beck 27075	{	SE305904	143.50	741	1.40±0.39	-	32.49
		SE306902	160.30	-	2.01	-	14.83
		SE317900	147.75	738	1.43±0.40	14.62	32.79
		SE331886	10.75	631	0.07±0.03	14.69	19.86
		SE340860	61.50	677	0.49±0.17	15.18	27.37
River Wiske 27069	{	SE375844	215.25	650	1.53±0.59	-	14.03
		SE375844	215.50	-	3.32	-	5.60
		SE367834	216.25	650	1.54±0.59	16.72	14.14
		SE369828	6.75	624	0.05±0.02	16.77	31.85
		SE359804	10.00	627	0.07±0.03	16.84	38.25
		SE399763	8.00	625	0.06±0.02	16.90	30.97
		SE413750	218.75	692	1.91±0.59	18.81	14.01
Leckby Grange 27008	{	SE415749†	1357.80	878	19.13±3.69	-	19.29
		SE415749†	1345.60	-	20.14	-	18.97
Crakehill 27071	{	SE424735†	1360.00	878	19.15±3.69	-	19.28
		SE425734†	1363.00	-	19.45	-	17.53
		SE432733	51.25	689	0.43±0.14	19.24	13.51
Bat Bridge 27082	{	SE419719	25.25	634	0.17±0.07	-	38.75
		SE419725	N.A.	-	0.15	-	18.92
		SE431716	36.75	633	0.25±0.10	19.49	37.40
		SE431660†	1467.00	862	19.94±3.98	-	19.50

† - means values taken for main river reach

{ - means these values are to be compared for a particular reach/tributary

Table 2 *Micro Low flows - Naturalised Mean flows, annual rainfall, 95 percentiles and catchment areas for particular river reaches and tributaries*

River NIDD - Moving downstream from Gouthwaite reservoir (Catchment area ≥5 km^2)

Gauging Station		Grid Ref.	Area (km^2)	SAAR (mm)	MF (cumecs)	Cumulative Flows (cumecs)	Q95 (%MF)
Gouthwaite Res. 27005	{	SE140683†	116.50	1382	3.44±0.32	3.44	11.30
		SE141683†	113.70	-	2.61	-	24.77
		SE151664	20.00	1214	0.48±0.05	3.92	13.76
		SE162648	10.50	1131	0.23±0.03	4.15	10.34
		SE189639	16.25	995	0.29±0.04	4.44	11.92
		SE201601	16.50	1026	0.30±0.05	4.74	10.62
Birstwith Bridge 27053	{	SE229603†	220.50	1225	5.41±0.60	-	12.29
		SE230603†	217.60	-	5.10	-	15.71
		SE253589	11.00	907	0.16±0.03	4.90	10.24
		SE269590	7.25	892	0.10±0.02	5.00	10.50
		SE286597	24.00	908	0.36±0.07	5.36	15.15
		SE304583	36.00	861	0.49±0.10	5.85	12.47
		SE363571	5.00	669	0.04±0.01	5.89	23.24
		SE372569	8.00	682	0.06±0.02	5.95	11.31
		SE387544	11.75	679	0.09±0.03	6.04	20.31
		SE405531	83.75	775	0.90±0.23	6.94	17.31
		SE413534	14.00	666	0.11±0.04	7.05	21.07
		SE418524	13.75	680	0.11±0.04	7.16	16.17
		SE420522	13.00	666	0.10±0.04	7.26	23.31
Hunsingore Weir 27001	{	SE431531†	499.00	978	8.40±1.36	-	14.43
		SE427529†	484.00	-	8.13	-	12.37
		SE466543	9.75	658	0.07±0.03	7.33	29.47
		SE473551	6.50	649	0.05±0.02	7.38	37.48
Skipp Bridge 27062	{	SE482563†	525.75	961	8.59±1.43	-	14.94
		SE483561†	516.00	-	14.30	-	10.73
		SE484564	13.75	645	0.10±0.04	7.48	32.03
		SE499563	6.50	646	0.04±0.02	7.52	10.45
		SE512576†	550.50	947	8.76±1.50	-	15.28

† - means values taken for main river reach

{ - means these values are to be compared for a particular reach/tributary

Table 3 *Micro Low flows - Naturalised Mean flows, annual rainfall, 95 percentiles and catchment areas for particular river reaches and tributaries*

River URE - Moving downstream from Kilgram Bridge (Catchment area ≥5 km²)

Gauging Station		Grid Ref.	Area (km²)	SAAR (mm)	MF (cumecs)	Cumulative Flows (cumecs)	Q95 (%MF)
Kilgram Bridge 27034	{	SE190860†	506.25	1372	15.10±1.38	15.10	19.55
		SE190860†	510.20	-	15.32	-	6.91
		SE230798	97.00	1045	1.82±0.26	16.92	18.92
		SE239777	5.75	750	0.05±0.02	16.97	31.41
		SE307758	5.75	706	0.05±0.02	17.02	10.38
		SE322736	30.00	652	0.22±0.08	17.24	49.52
River Laver 27059	{	SE304708	79.25	904	1.13±0.22	-	17.25
		SE301710	87.50	-	1.06	-	9.68
		SE325709	120.25	895	1.68±0.33	18.92	18.30
		SE335699	6.75	645	0.05±0.02	18.97	21.41
		SE334673	5.25	714	0.05±0.01	19.02	10.50
		SE344675	8.50	642	0.06±0.02	19.08	29.12
		SE347672	52.25	786	0.57±0.14	19.65	17.66
Westwick Lock 27007	{	SE355669†	913.25	1140	20.04±2.48	-	21.26
		SE355672†	914.60	-	20.68	-	13.04
		SE403674	43.75	681	0.35±0.12	20.00	20.15
		SE411676	5.00	632	0.03±0.01	20.03	13.03
		SE430660	982.00	1107	20.47±2.67	-	21.24

† - means values taken for main river reach

{ - means these values are to be compared for a particular reach/tributary

Table 4 *Micro Low flows - Naturalised Mean flows, annual rainfall, 95 percentiles and catchment areas for particular river reaches and tributaries*

River URE - River OUSE -Moving downstream from URE-SWALE confluence (Catchment area ≥5 km^2)

Gauging Station		Grid Ref.	Area (km^2)	SAAR (mm)	MF (cumecs)	Cumulative Flows (cumecs)	Q95 (%MF)
		SE430660†	982.00	1107	20.47±2.67	20.47	21.24
		SE431660	1467.00	862	19.94±3.98	40.41	19.50
		SE431654	8.25	653	0.06±0.02	40.47	10.50
		SE456641	9.50	648	0.07±0.03	40.54	10.46
		SE471604	11.50	652	0.08±0.03	40.62	32.22
		SE506601†	2503.50	953	40.76±6.80	-	20.08
River Kyle	{	SE508602†	168.25	635	1.11±0.46	41.73	15.60
27060	{	SE509602†	167.60	-	10.95	-	1.19
		SE512576	550.50	947	8.76±1.50	50.49	15.28
		SE526576†	3230.00	935	50.67±8.77	-	19.01
		SE527578	5.25	625	0.03±0.01	50.52	10.50
		SE539562	52.50	639	0.34±0.14	50.86	14.40
		SE566555	15.50	623	0.09±0.04	50.95	10.18
Skelton	{	SE570553†	3314.80	927	51.20±9.00	-	18.86
27009	{	SE568554†	3315.00	-	48.82	-	15.19

† - means values taken for main river reach

{ - means these values are to be compared for a particular reach/tributary

Table 5 *Number of ungauged tributaries for each main river and percentage of MF underestimated against cutoff area*

River	Cutoff Area (km^2)							
	5	%MF	10	%MF	15	%MF	20	%MF
Nidd	19	14.2	13	18.3	6	29.0	4	35.3
Swale	15	2.3	11	3.5	7	5.8	7	5.8
Ure	10	2.1	4	3.6	4	3.6	4	3.6
Ure-Ouse	6	-3.2	3	-2.8	2	-2.7	1	-2.5

4 Conclusions and Discussion

Using the MLF system alone, the water balance dynamics moving down the main rivers in the (naturalised) Ouse catchment can be well described. This is due to the fact that the system was designed to be capable of linking the flow conditions from small sub-catchments to larger river networks in a comprehensive and uncontroversial way. As shown here, the system does seem to be intrinsically consistent and reliable in describing a naturalised catchment.

The test of any model is in the comparison of its predictions with observation. From this work it is apparent that there is good agreement between the predicted MF and the reliably gauged flows along the main river reaches. There is however disagreement for some tributaries and gauging stations on the main rivers e.g. Bedale Beck and the Wiske tributaries on the River Swale, Gouthwaite Reservoir and Skipp Bridge on the River Nidd and the River Kyle station. These discrepancies can be explained in the main by poor observations, usually associated with high flow and backing up from the main river. In the case of Gouthwaite Reservoir, this is due to abstractions taking place in the upper catchment.

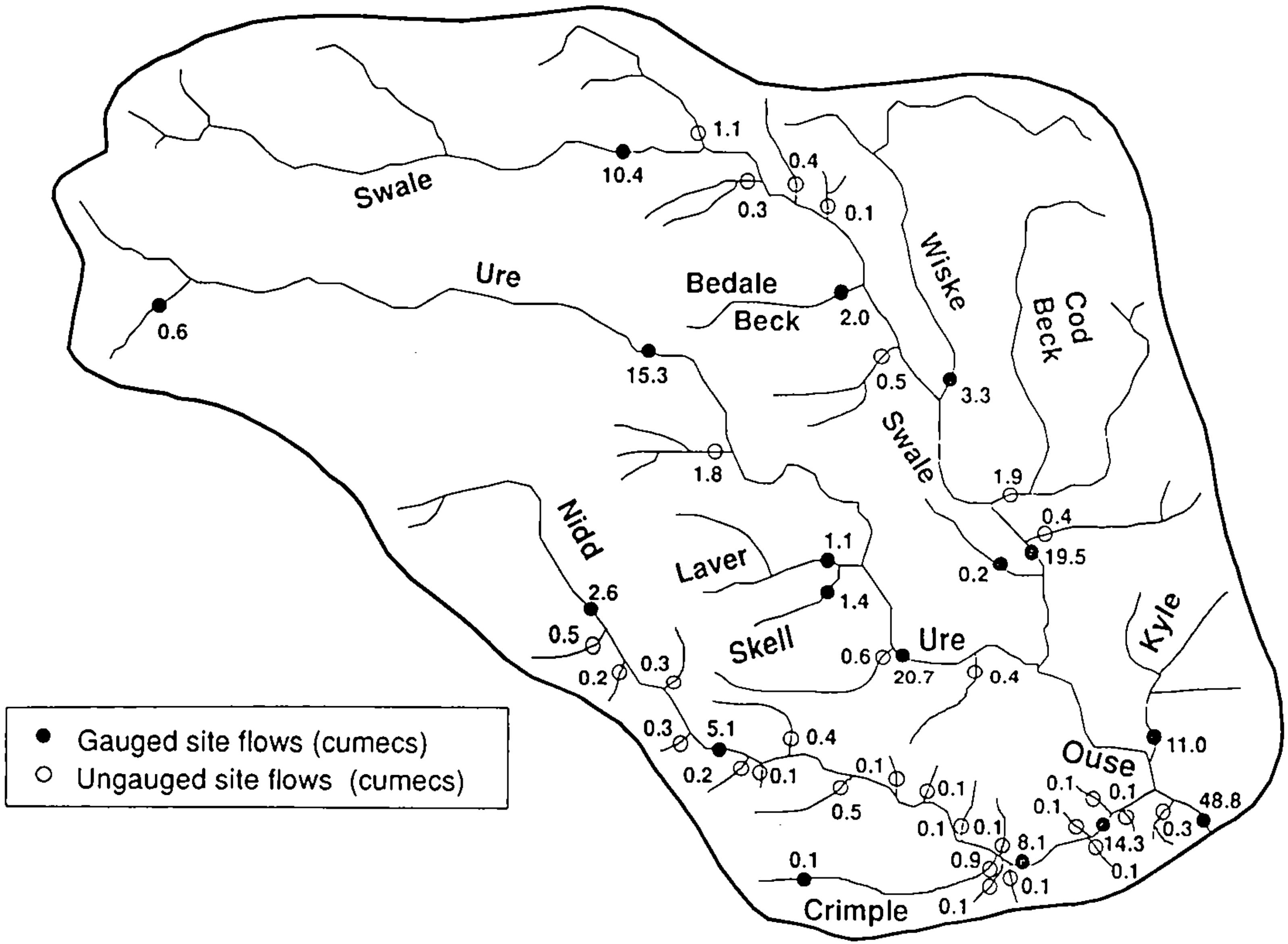
A good degree of confidence can therefore be given to the MLF results as used to describe the flow conditions throughout the Ouse catchment on an annual basis. It is also evident that the Ouse catchment is close to a natural flow system since the actual flows correspond well with the MLF predictions. The combined abstractions and effluent discharges in the Ouse system approximately cancel each other out. Using the MLF system the significant ungauged sub-catchments may be determined, and combining these with the gauged flows, an annual water balance can be attained throughout the Ouse catchment.

Figure 3 shows the tributaries which have been identified by this work to significantly contribute to the mean annual flows in the main rivers. A cutoff area of 20 km^2 was used to determine the tributaries for the Swale, Ure and Ure-Ouse, with a 5 km^2 cutoff required for the Nidd. As shown this implies that ungauged flows are required for 7, 4, 1 and 19 sub-catchments on the Swale, Ure, Ure-Ouse and Nidd respectively. Also indicated on the diagram are the annual mean flows for the gauged stations according to the Hydrometric Register (Marsh and Lees, 1993) and the MLF MF for all ungauged tributaries.

Adding up the contributions from the MLF MF identified above and the reliable gauged flows required as inputs for QUASAR leads to a total of 48.28 cumecs predicted at Skelton, which is to be compared with the measured value of 48.82 cumecs. Hence an underestimate of 1.1% would result from this combination of flows.

The next step for progress in applying QUASAR to the River Ouse, is to attain daily time series for the ungauged sub-catchments. Using the daily flows of gauged sub-catchments and the catchment characteristics of the gauged and ungauged sub-catchments a transformation factor between gauged and ungauged sites can be determined. This provides a rough but quick estimate of inflows for immediate use. These flows will ultimately be superseded by runoff generated by catchment models.

Figure 3. Main tributaries and mean annual flows within the Ouse catchment.



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