Low Flow Study
of
Northern Ireland

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A. Gustard and F. Sutcliffe

Institute of Hydrology
Wallingford
Oxfordshire

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PREFACE

This report describes the results of a low flow study of Northern Ireland. The work was commissioned by the Department of the Environment (N.I.) and was carried out by the Institute of Hydrology. The main objective of the study was to improve techniques for low flow estimation at the ungauged site. The study was based on mean daily discharge for 21 flow records using data provided by the Water Data Unit, Water Services Department. The main conclusion of the study was that relationships between low flow statistics and drift geology can be used to estimate low flows at sites without flow records. It is recommended that the estimation equations are revised when the current revision of the water archive for Northern Ireland is complete.

CONTENTS

1. INTRODUCTION

Water resource investigations require information on low river flows for designing river abstraction schemes, assessing the dilution of domestic and industrial effluent and for estimating the yield of direct supply reservoirs. Where river flow records are available at the site of interest, then these can be analysed to provide estimates for the above design problems. However, this is not always possible because flow data may be absent or the records too short for accurate estimation of extreme low flows. An earlier study (Department of the Environment (NI) 1984) included the development of regional estimation techniques for determining the yield of a reservoir of given storage for a specific return period of failure. The objective of the current investigation is to develop methods for estimating low flows for effluent dilution and river abstraction design problems at locations without historical flow records.

A number of regional low flow studies (Institute of Hydrology 1980; Pirt and Douglas, 1982; Hanna and Wilcock, in press) have noted the importance of catchment geology in controlling low flow regimes. In Northern Ireland, rocks of low permeability are dominant, notably, the Silurian and Ordovician greywackes in the south east and crystalline basement rocks of Moinian and Dalradian age in the north east, north west and west. Productive solid rock aquifers are limited in extent to the Permian and Triassic sandstones of the Lagan valley and west of Lough Neagh. The outcrop of Cretaceous chalk is also of limited extent and although it is of lower permeability than its English counterpart, it can sustain low river flows from a number of springs which issue where the base of the chalk overlies impermeable strata.

With the exception of the upland areas, the solid geology of the Province is covered by a veneer of drift material of varying lithology. Extensive deposits of impermeable boulder clay restricts recharge to and discharge from, underlying permeable strata. The baseflow component of the stream hydrograph is thus very small despite the presence of saturated aquifers below the impermeable horizons. The only exception to this are where permeable fluvo glacial deposits of sands and gravel maintain the low flows at relatively high discharges. These outcrop most extensively to the west and north of Lough Neagh and in the Lagan Valley.

The approach used to develop estimation techniques at the ungauged site was to relate low flow statistics derived from the daily discharge data to a number of climate, physiographic, soil and geological characteristics. Section 2 of the report describes the analysis of the discharge data, section 3 the catchment characteristics and section 4 the derivation of the estimation equations.

2. LOW FLOW ANALYSIS

A data set of 21 mean daily flow records from the Water Data Unit (NI) were used throughout the study. These stations were selected on the basis of good accuracy of low flow measurement and a relatively low degree of artificial control. Table 1 lists the period of record for each of the 21 stations and a number of flow measures. These flow statistics were derived using methods described in the Low Flow Studies Report (Institute of Hydrology 1980). They include the mean discharge (ADF), the base flow index (BFI), the mean annual minimum (MAM) and the 95 percentile discharge (Q95) from the flow duration curve. Values of MAM(1) and MAM(10) the one and ten day mean annual minima were calculated and similarly Q95(1) and Q95(10) from the one and ten day flow duration curve. These discharge values were expressed as a percentage of the mean flow. This standardization procedure permits comparison between different rivers by reducing the effect on the slope and location of the flow duration curve of differences in catchment area and higher or lower than average flows during the period of record.

In comparison with low flows in other regions of the United Kingdom, discharges are relatively low in Northern Ireland. For example there is only one catchment with a value of Q95(10) in excess of 18% ADF - the average for 456 U.K. flow records. With the exception of three catchments all values of the 10 day mean annual minima are below 15% ADF reflecting the generally low base flows and flashy nature of catchments in Northern Ireland

3. CATCHMENT CHARACTERISTICS

The low flow indices described in section 2 were correlated with catchment characteristics to develop prediction formulae for use on ungauged sites. The selection of catchment characteristics was decided by their availability in map form for the entire province and the factors considered to control low flows. The following paragraphs summarize the definition and calculation of the characteristics listed in Table 2.

Gauging station	Period of record	(1) MAM1	(10) MAM10	(1) Q951	(10) Q9510	BFI	ADF
201002 FAIRY WATER AT DUDGEON BR	72.80	5.17	6.07	6.63	7.41	0.27	4.78
201005 CAMOWEN AT CAMOWEN TERRACE	72.80	14.12	16.65	15.44	16.96	0.42	6.37
201006 DRUMRAGH AT CAMPSIE BRIDGE	72.80	4.63	5.53	5.63	6.15	0.36	7.57
201007 BURNDENNET AT BURNDENNET BR	76.80	19.10	20.75	19.89	21.48	0.47	3.69
201008 DERG AT CASTLEDERG	79.80	3.64	5.82	5.55	6.35	0.26	16.39
203010 BLACKWATER AT MAYDOWN BR	70.81	2.89	6.06	6.73	7.81	0.40	16.13
203011 MAIN AT DROMONA	70.80	9.94	11.61	12.80	14.57	0.45	5.81
203012 BALLINDERRY AT BALLINDERRY	70.80	15.89	17.47	16.93	18.37	0.46	8.87
203013 MAIN AT ANDRAID	70.80	11.05	11.94	11.86	13.35	0.36	15.66
203018 SIX MILE WATER AT ANTRIM	70.80	10.59	12.16	11.30	13.11	0.49	5.25
203020 MOYOLA AT MOYOLA NEW BR	71.80	11.12	14.23	14.52	17.13	0.41	7.24
203021 KELLS WATER AT CURRYS BR	71.80	5.11	6.00	7.05	7.91	0.30	3.15
203025 CALLAN AT CALLAN NEW BR	71.81	11.59	12.97	11.99	13.12	0.40	2.74
203027 BRAIDE AT BALLEE	72.80	11.06	13.30	12.70	14.60	0.49	3.85
203028 AGIVEY AT WHITE HILL	73.80	5.30	7.59	8.39	9.97	0.31	2.40
203029 SIX MILE WATER AT BALLYCLARE	73.80	12.84	13.45	11.43	12.10	0.47	1.63
203033 UPPER BANN AT BANNFIELD	75.80	7.16	9.96	8.60	9.70	0.34	2.72
204001 BUSH AT SENEIRL	72.76	12.67	14.22	14.98	16.37	0.45	5.27
205004 LAGAN AT NEWFORGE	72.80	9.92	11.40	9.84	10.76	0.46	8.69
205005 RAVERNET AT RAVERNET	72.80	1.44	2.00	1.92	2.56	0.40	1.25
205008 LAGAN AT DRUMILLER	74.80	2.34	2.81	2.40	2.58	0.36	1.71

MAM Mean annual minimum for 1 and 10 days, % ADF
Q95 95 percentile for 1 and 10 days, % ADF
BFI Base Flow Index
ADF Average flow cumecs

TABLE 1 Flow variables

Gauging Station	Drift Geology Percentage cover					SOIL	SAAR	AREA	STMFRQ	
	TL	RK	PT	GL	AL				63,360	50,000
201002 FAIRY WATER AT DUDGEON BR	25	44	18	0	13	.461	1218	161.2	.16	.63
201005 CAMOWEN AT CAMOWEN TERRACE	35	16	28	12	9	.420	1166	274.6	.24	.48
201006 DRUMRAGH AT CAMPSIE BRIDGE	58	14	15	2	11	.422	1155	324.6	.19	.47
201007 BURNDENNET AT BURNDENNET B	40	18	18	19	5	.390	1175	145.3	.25	.55
201008 DERG AT CASTLEDERG	10	40	45	0	5	.406	1500	337.3	.58	.59
203010 BLACKWATER AT MAYDOWN BR	80	3	4	7	6	.437	1043	951.4	.84	
203011 MAIN AT DROMONA	53	18	17	7	5	.445	1234	288.8	.12	.48
203012 BALLINDERRY AT BALLINDERRY B	57	6	6	23	8	.303	1087	419.5	.58	.34
203013 MAIN AT ANDRAID	57	25	8	6	4	.422	1175	646.8	.20	.50
203018 SIX MILE WATER AT ANTRIM	69	17	4	5	5	.412	1070	277.3	.15	.27
203020 MOYOLA AT MOYOLA NEW BR	44	11	11	24	10	.339	1167	306.5	.43	.76
203021 KELLS WATER AT CURRYS BR	48	32	12	3	5	.470	1309	127.0	.18	.58
203025 CALLAN AT CALLAN NEW BR	81	7	4	2	6	.375	975	164.1	.08	.49
203027 BRAID AT BALLEE	45	34	11	5	5	.385	1201	177.2	.29	.64
203028 AGIVEY AT WHITE HILL	59	10	24	4	3	.417	1177	98.9	.19	.70
203029 SIX MILE WATER AT BALLYCLARE	67	27	2	2	2	.426	1175	58.4	.02	.46
203033 UPPER BANN AT BANNFIELD	74	19	4	0	3	.301	1400	100.8	.72	.34
204001 BUSH AT SENEIRL	50	7	27	13	3	.410	1138	306.1	.15	.53
205004 LAGAN AT NEWFORGE	69	16	2	7	6	.382	950	490.4	.39	.27
205005 RAVERNET AT RAVERNET	55	41	1	0	3	.450	922	69.5	.47	.36
205008 LAGAN AT DRUMILLER	68	21	2	0	9	.447	975	85.2	.85	.35

TL = till RK = rock PT = peat GL = sand and gravel AL = alluvium
SOIL Flood Studies Soil Index
SAAR Annual Average Rainfall mm
AREA Catchment Area km^2
STMFRQ Number of stream junctions per square kilometre from 1:63 360 and 1:50 000 sheets

TABLE 2 Catchment Characteristics

Geology: The influence of solid geology on low flows is restricted owing to the substantial deposits of drift material throughout the area. Attention was thus focussed on the drift deposits of each catchment and these were estimated by overlaying catchment boundaries on the 1:250,000 drift geology map produced by the Geological Survey of Northern Ireland. The proportion of till (boulder clay), peat, sand and gravel, alluvium and rock dominant areas were calculated for each catchment. The solid geology map was also examined to determine the nature of the solid rock in catchments with a significant percentage of rock dominant areas.

Soil: The Flood Studies (NERC 1975) Winter Rainfall Acceptance Potential map was used to calculate the proportions of each of the five soil classes from which the FSR Soil Index (SOIL) was derived.

Precipitation: Values of annual average catchment precipitation (SAAR) were provided by the Water Data Unit (NI).

Catchment Area: The topographic catchment area was used. However because the low flow variables have been standardized by mean runoff it was unlikely that high correlations between low flows and catchment size would be observed.

Stream frequency: Previous studies of both floods and low flows have indicated that the number of stream junctions per square kilometre (STMFRQ) is a useful predictive variable in regional hydrology. It is known for example that a high stream frequency will increase the rate of quick response runoff and this might be expected to reduce low flow discharges. Values were initially derived for the 1:63 360 and these showed significant correlations with low flows. However, when stream frequency was calculated from the more recent 1:50 000 series there was little predictive value in the catchment characteristics.

4. RELATIONSHIPS BETWEEN LOW FLOWS AND CATCHMENT CHARACTERISTICS

4.1 Estimation Equations

The design method recommended in the Low Flow Studies Report is based on regional regression equations between the Base Flow Index and low flow statistics and local relationships between BFI and catchment geology. The correlation between Q95(10) and BFI in Northern Ireland was 0.61 compared to 0.74 for the 456 catchments used in the Low Flow Studies project. The ability to predict BFI from catchment characteristics was also limited with the best two variable equations using GVL and TILL explaining only 35% of the variance of BFI. The relationship between BFI and SOIL was also explored in order to provide a method for estimating BFI at the ungauged site. The results of this were disappointing with very poor correlations between BFI and both the SOIL index and the proportions of different soil classes. It was thus decided to omit the Base Flow Index from the procedure and relate low flow statistics directly to catchment characteristics.

The flow variables Q95(10) and MAM(10) were related to the catchment characteristics shown in Table 2 using data for the 21 catchments. Logarithmic and square root transformations were used but these showed no improvements over untransformed variables. The most useful correlations were with the proportions of drift deposits particularly sands and gravel (GL) where the correlation coefficient was 0.80 with Q95(10) and 0.73 with MAM(10). (These were significantly higher than the correlation of 0.49 bestween GL and BFI). The recommended equations for Northern Ireland are thus:-

$$Q95(10) = 0.55\ GL + 7.8 \qquad R^2 = .64 \qquad Se = 3.2$$

$$MAM(10) = 0.50\ GL + 7.2 \qquad R^2 = .55 \qquad Se = 3.4$$

These permit estimation of low flow indices from the 1:250 000 drift map of Northern Ireland with an error of just over 3 percent of the average flow.

It has not been possible to derive new duration and frequency relationships within the scope of this current project. However, the performance of the Low Flow Studies duration relationship was tested on the Northern Ireland data set. This was done by comparing the observed ratios of Q95(1) and Q95(10) with the predicted ratios and this confirmed that the national duration relationship could be used in N. Ireland. Until further Low Flow Studies are carried out the duration and frequency relationships in the Low Flow Studies Report should be used.

The final stage in the estimation procedure is to calculate the mean flow at the site of interest using the methods outlined in LFSR number 3. (The applicability of this method for catchments with rainfall in excess of

1000 mm was confirmed in the Study of Water Demand and Supply in Northern Ireland.)

4.2 Winter Rainfall Acceptance Potential Map

It is interesting to compare the correlation between BFI and the proportions of drift geology with that between BFI and the Flood Studies SOIL index. The best three variables were GVL, TILL and ROCK and these explained 40% of the variance of BFI. In contrast the SOIL index was not correlated with BFI explaining only 2% of the variance. Although BFI was developed for low flow estimation purposes, (1-BFI) is an index of the rapid response runoff and this has been found useful in flood estimation (Boorman, 1985), explaining nearly 60% of the variance of standard percentage runoff. Furthermore, the correlation between BFI and SOIL in mainland Britain of the order of -0.70 have been observed from 426 catchments. There is also evidence (Gustard 1986) that the value of BFI observed from WRAP classes in Northern Ireland are significantly lower than their counterparts elsewhere in the United Kingdom. The poor predictive ability of the Northern Ireland WRAP map and the inconsistency of classification suggests that a revision of the Flood Studies soil map is required.

5. CONCLUSIONS

Methods have been developed for estimating the 95 percentile 10 day discharge and 10 day mean annual minimum discharge at ungauged sites from the drift map of Northern Ireland. The Water Data Unit (NI) are currently validating the mean daily flow archive. When this work is complete it is proposed that this study should be updated using the improved data and the longer time series which will then be available. Until this task is completed the recommended equations are provisional. This study has also indicated a need for a revision of the Flood Studies soil map of Northern Ireland.

6. REFERENCES

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