Institute of Hydrology

Natural Environment Research Council

A REVIEW
OF THE NORTHERN IRELAND
HYDROMETRIC NETWORK

Report to
Department of the Environment
for Northern Ireland
Environment Service

by

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EXECUTIVE SUMMARY

The Department of the Environment for Northern Ireland (DoENI) Environment Service (ES) and Water Executive (WE), and the Department of Agriculture for Northern Ireland (DANI), have, between them, responsibilities relating to the prevention of pollution, supply of potable water and the promotion of conservation and cleanliness of the water resources and waterways in the Province. A network of river flow gauges, initiated in 1970, has been installed, developed and expanded until it now comprises 84 stations, 50 of which are owned by the DoENI and the remainder by DANI. For this project, the ES have commissioned the Institute of Hydrology (IH) to provide a baseline assessment of the current network.

The IH approach has been to assess the network through each of five complementary studies which together investigate facets of the network's scope and utility. The studies comprise: a theoretical approach, considering identifiable physical characteristics and climatic variables; a Data Use Survey which canvassed Departmental users on their perception of the present and anticipated value of the station for a range of uses; an evaluation of the use of the Micro LOW FLOWS package and the Flood Studies regression method in surrogate Welsh catchments to estimate low flow and flood characteristics from time series and spatial data; a comparison between the network densities in the UK and other EC countries with respect to population and area; a review of the quality of the hydrometric data, from assessing the gauges' potential to produce good results to the effectiveness of the ensuing archive data in meeting conventional archive standards. Subsequently, a synthesis of the results was carried out and recommendations made to respond to the individual requirements within the terms of reference.

The general results and recommendations were:

- The focus of hydrometric activity must be put firmly on achieving data quality appropriate to data uses.

- More small, upland catchments are required to give the network the representativeness required of it.

- Index stations at major catchment outfalls play a strategic role in the network and should continue to be operated and maintained accordingly.

- Many perceived data uses do not justify continuing operation of stations; spatial transfer of information using models should always be considered, and records need not be extended indefinitely.

- Spatial data can and should be used for flow estimation, but need to be underpinned by a comprehensive time series database.

- Gauging densities in Northern Ireland are broadly similar to expectations in a UK context, but a little low in relation to European standards.

- In mountain areas lacking adequate rainfall estimation, favourable benefit / cost ratios for gauging to improve catchment yield may be demonstrated.

From the network, 5 stations are recommended for closure, 3 for relocation and 5 others for further review; at least 3 provide data of insufficient quality for their purpose.

Acknowledgements

This report is the final product of a considerable amount of consultation with both ES and DANI staff in Belfast. The authors wish to record their thanks in particular to John Waterworth of the DoE(NI) Environment Service and John Hanna, Richard Cole and Derrick Pinkerton of DANI for help given on a wide range of aspects of this study.

The wide range of Institute of Hydrology resources drawn upon in the course of this study, both in terms of staff and databases, is readily apparent in this report. Thanks therefore go to, Alan Gustard and Ann Sekulin for their input to the Micro LOW FLOWS work, David Boorman and Beate Gannon for assistance with the HOST data set, Rob Flavin for developing software for the hypsometric comparisons and producing the maps, and also to Samantha Green, Felicity Sanderson and Shirley Black for assistance with many of the tables and maps in the report.

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1 Introduction

1.1 BACKGROUND AND APPROACH TO COMMISSION

This report is prepared for the Department of the Environment for Northern Ireland Environment Service as fulfilment of a contract to review the hydrometric network of the Province. Adhering to the requirements of the consultant's brief, the review considers and reports upon seven specific aspects of the network, namely its efficacy in:

- obtaining flows from all major rivers, their tributaries and a variety of catchment types and sizes
- providing flow data for catchment management plans being developed for the control of water quality
- the provision of accurate data for water resources management studies
- the monitoring of land use, climate, acid rain and other changes
- data provision for PARCOM returns
- supporting the derivation of low flow parameters for setting discharge standards, and
- providing data to assist the analysis of reservoir yield for capacity planning and operational purposes.

The review takes a broad approach to addressing these issues, through five complementary studies which together produce a comprehensive picture of the present network. These are as follows:

- Theoretical assessment of network - characteristics of the present network of gauged catchments are compared with those of Northern Ireland as a whole, and conclusions are drawn regarding the representativeness of the network (Chapter 2).
- *Data use survey* - the results of a survey of all present gauging station data uses are presented, with an assessment of the present and anticipated value of each station. The benefit of data collection is discussed in relation to individual gauging stations (Chapter 3).
- *Use of spatial data* - an evaluation of a Micro LOW FLOWS application to Q_{95} estimation in Wales is made, with suggestions for optimising the balance between use of time series and spatial data in Northern Ireland. Further conclusions are drawn in relation to the existing deployment of gauging stations (Chapter 4).
- *Comparison with other UK regions and EC countries* - results are presented for a comparison of gauging densities both with respect to population and area (Chapter 5).
- *Hydrometric data quality review* - gauging station data quality and utility is assessed in relation to present and anticipated uses, and suggestions made for individual stations (Chapter 6).

The remaining chapters contain:

- A detailed consideration of the flow gauging requirements of supply reservoirs and presents a scenario of the benefit / cost of river gauging for yield studies (Chapter 7).

- Conclusions from each of the studies are synthesised into desirable network changes; the seven key considerations of the consultants' brief are then addressed and specific recommendations for implementation made (Chapter 8).

- The report concludes with a forward look for gauging strategy through into the 21^{st} century (Chapter 9).

1.2 CURRENT NETWORK SITES AND OPERATION

The current network of gauging stations in Northern Ireland is a young one in a UK context (there are no current stations pre-dating 1970), having its origins in the work of the Lough Neagh Working Party. Also, unlike the rest of the UK, its growth has followed a somewhat evolutionary path rather than having been directed by any official development plan. It appears that stations have been constructed - and indeed many have subsequently been closed - on the basis of changing needs within the two sponsoring Government departments. This has led to ample data provision for specific requirements but water resources and climate change concerns, for example, may demand information in the future which could best be served by instituting gauging activities today.

The network presently comprises 84 stations (not including urban stream stations). Fifty are owned by the Department of the Environment for Northern Ireland (DoE(NI)) with the remainder owned by the Department of Agriculture for Northern Ireland (DANI). While stations may be operated specifically for the purposes of either or both of these bodies, they are all operated and maintained, and mostly constructed, by DANI. DoE(NI) is responsible for the analysis and publication of river flow data. In order to allow estimates of river flows for a wide range of applications, information on current meter gaugings and stage-discharge relations is passed within and between the two departments. Appendix A lists the basic station details and Figure 1.1 shows their distribution.

Within the DoE, the Environment Service (ES) is charged with preventing water pollution under the Water Act (NI) 1972, being primarily concerned with low to median river flows. Catchment Management Plans are seen as an important new method for ES to promote good practice in all areas of catchment water management, and to ensure compliance with environmental standards. ES therefore requires flow data from a wide range of catchments in all areas of Northern Ireland.

The DoE Water Executive (WE) is responsible for the supply of potable water and is therefore concerned with yield assessments, particularly in upland catchments contributing to existing or potential supply reservoir sites. The WE's interest in river flow data is, accordingly, rather more restricted than that of the ES, and with the siting of many gauging stations at the outfall of major catchments, its needs are often poorly served by the present network.

The DANI acts as the drainage authority in Northern Ireland and studies the full range of flows, but has particular interest in high flows. It too draws on data collected in all parts of the Province, and from time to time requires data as factual evidence in cases of litigation.

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Figure 1.1
Northern Ireland gauging station network

Scale 1:750000

Coastline

Elevation above 250 metres

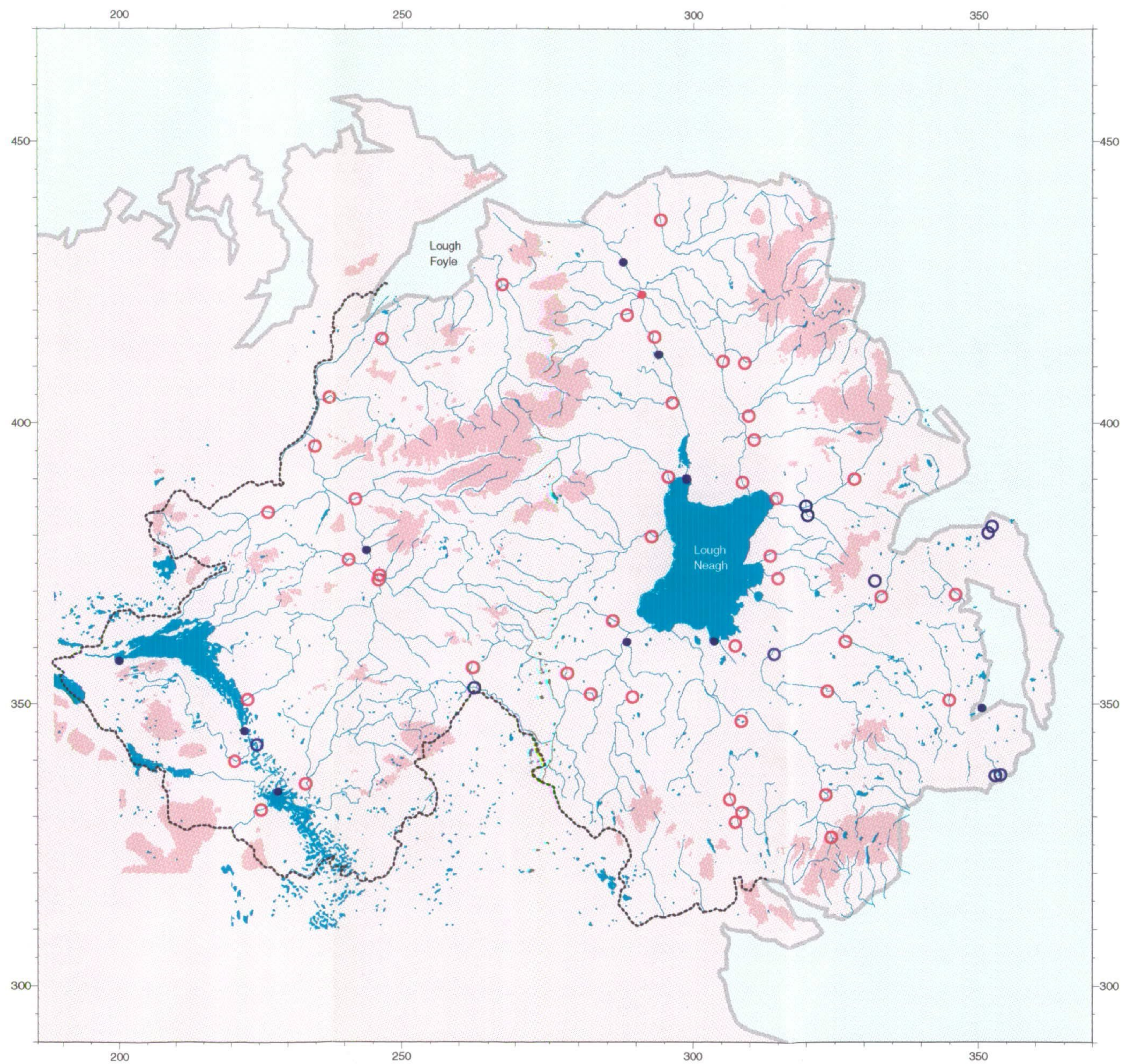
Rivers

DOE(NI) flow station

DANI flow station

DOE(NI) level-only station

DANI level-only station



Dgener8 map producing software

2 Theoretical assessment of network

A theoretical consideration of the Northern Ireland gauging station network is a logical first step in assessing its suitability for current and future needs, but is not to be seen as any more important than any of the other studies described in the following four chapters. Rather, each is complementary to the others. This theoretical assessment of the network considers how representative the current scatter of gauging stations is of Northern Ireland as a whole, in terms of catchment characteristics. Five physical characteristics are considered:

- area
- standard average annual rainfall (SAAR: 1941-70)
- annual evaporation
- hypsometry
- soils

and for each, the scatter of values for the gauged catchments is compared with the terrain of Northern Ireland as a whole. For the first three of these characteristics, data were derived from a Northern Ireland Micro LOW FLOWS application (Dixon and Bullock, 1990). Values for each of these variables were produced for approximately 16,000 stream reaches covering the whole river network of the Province digitised at a scale of 1:50,000. Data were collected by independent means for the other two variables (see below).

Knowledge of the representativeness of the gauging network is important when considering the value of flow data in their wider context. Time series data are, by definition, specific to individual sites, but are widely used as a means of servicing data needs at other locations, often on ungauged streams or rivers. Whether this transfer of information across space takes place by means of a formally-constituted model, or more informally in the context of less systematic small-scale studies, it is common for flow information from one catchment to be applied within another of different catchment and flow characteristics. It is therefore desirable to have, in any authority's area, a gauging network which covers the full spectrum of catchment types, so that flow data from appropriate analogue catchments can be applied to ungauged sites. A more pragmatic view might be to aim towards a network with most emphasis on those catchment types where data are most often required. However, it is impossible to foresee every data need of the future, and in contemplating changes to the Northern Ireland network, provision for the unexpected must be made by ensuring that a wide range of catchment types are included in the network.

In considering the catchment characteristics which are most important in determining streamflow characteristics, attention here is focused entirely on the 54 currently operating flow gauging stations: as will be shown in Chapter 3, the level-only stations are operated for very specific purposes and their consideration here seems inappropriate.

2.1 CATCHMENT AREA

Figure 2.1 shows catchment area cumulative percentage frequency curves for both the 16,000 digitally derived stream reaches and the 54 NI gauging stations. While the logarithmic x-axis scale magnifies differences at lower area values, it is immediately apparent that the two distributions, particularly at lower values, are considerably different. Such a difference is not surprising, as there is no gauging authority in the world which is known to gauge very small

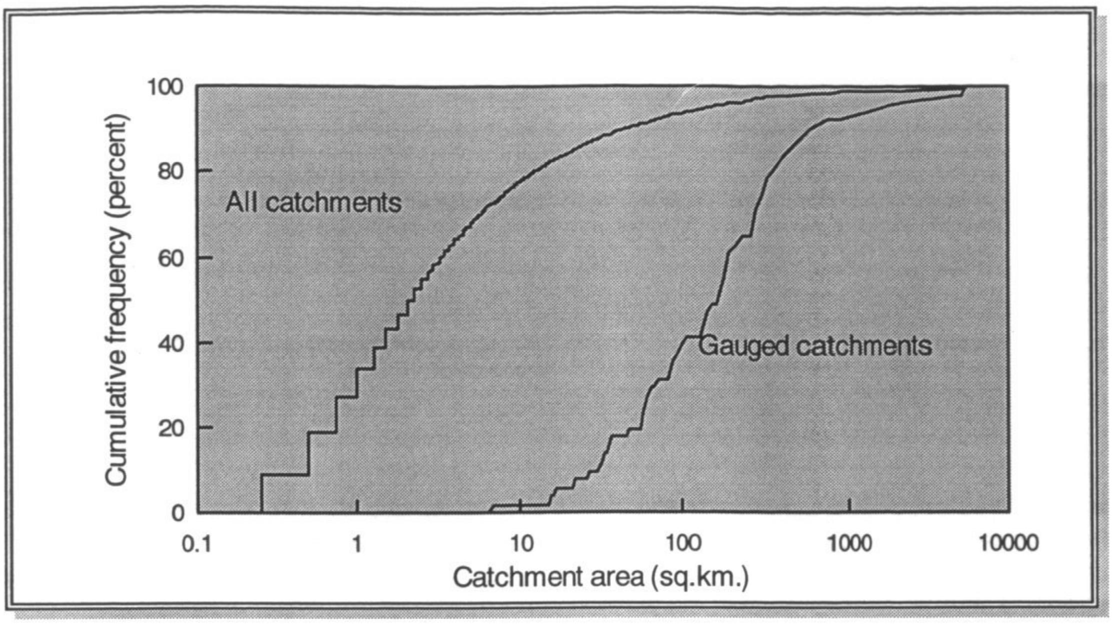


Figure 2.1 *AREA: cumulative frequency distribution for all and gauged catchments*

catchments in large numbers, yet it still raises a point of note. The analysis indicates that 50% of all river reaches shown on the 1:250,000 map drain areas no greater than 2.25 km^2, yet no gauging stations are sited on streams draining such small catchments. Indeed, using this (conservative) representation of the NI river network, 90% of its length is in reaches draining areas no greater than 43.25 km^2 in area, but only 18% of gauging stations are on such rivers. Conversely, the gauging network contains 10% of catchments with areas in excess of 608 km^2, while the corresponding river network figure is 43.25 km^2. Small catchments are therefore under-represented in the gauged network, and large catchments over-represented. Parameters of the two distributions are given in Table 2.1.

Table 2.1 *Area exceedance parameters for the NI river and gauging station networks*

Catchment area exceeded in % of cases	River network	Gauging network
10	43.25	608.0
25	8.25	307.0
50	2.25	157.0
75	0.75	56.25
90	0.5	29.5

The implications of this strong bias in the gauged network must be highlighted. Variability in the flow characteristics of small catchments goes very largely undetected; for catchments below, say, 2 km^2 it may be argued that there is no practical use for such data, but with only five stations on streams with catchments of less than 30 km^2 in area, there is limited scope for gaining a good

understanding of the characteristics of the wide range of small catchments which - at such scales - show hydrological behaviour very simply. Further, it must be accepted that with the present network, the results of modelling flow characteristics may be subject to relatively wide margins of uncertainty.

The positive aspect of this distribution of catchment areas is that, as confirmed by reference to Figure 1.1, all major catchments are gauged. This reflects the factors responsible for the establishment of the current network of stations and the continuing use of their data. A large part of the flow data usage in Northern Ireland relates to these larger catchments (this is likely to become increasingly true as catchment management plans come into wider use), in many cases in an operational context, and such a disposition of gauging stations is clearly therefore of benefit (see Chapter 3).

Nonetheless, a general deficiency of flow data from small catchments is seen as a weakness in the present network, and this finding is taken into consideration when discussing suitable changes to the network in Chapter 8.

2.2 AVERAGE ANNUAL RAINFALL

A similar analysis to the above was conducted for catchment standard average annual rainfall (SAAR: 1941-70 period) data, with Figure 2.2 and Table 2.2 showing the results. Catchment rainfall values for gauging station sites were obtained from the Micro LOW FLOWS database by

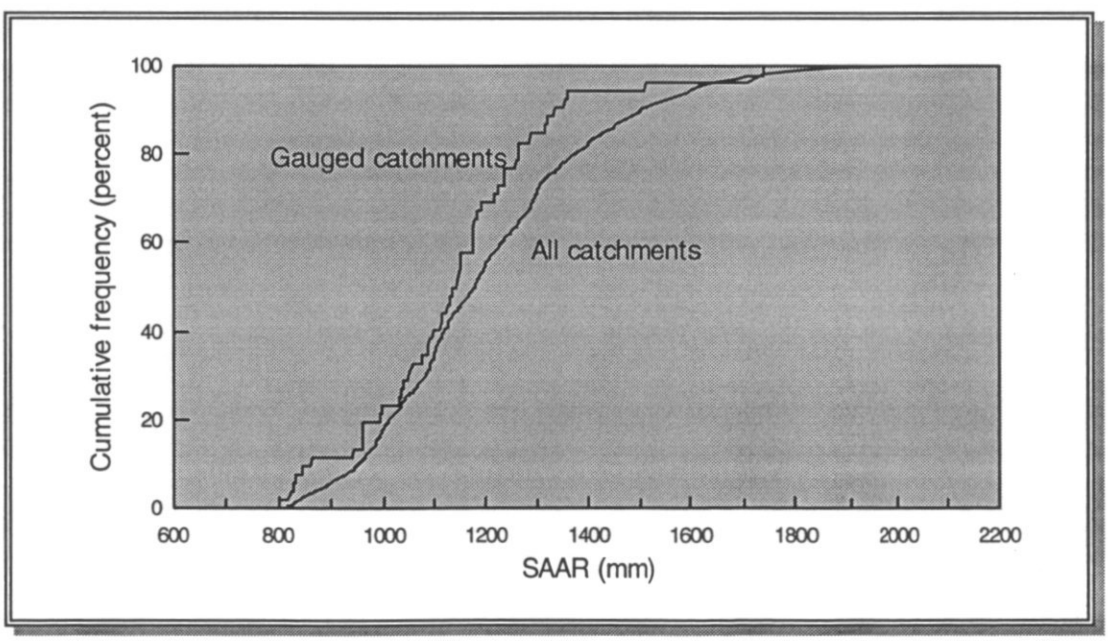


Figure 2.2 *SAAR: cumulative frequency distribution for all and gauged catchments*

Table 2.2 *SAAR exceedance parameters for the NI river and gauging station networks*

Annual Rainfall (mm) exceeded in % of cases	River network	Gauging network
10	1503	1335
25	1321	1235
50	1178	1136
75	1045	1031
90	953	845

using grid references, and allow direct comparison with the frequency distribution for all river reaches.

For much of the range of average annual catchment rainfall values, the two distributions are quite close to each other; typically within 50 mm for any percentage exceedance value (see Table 2.2). The two curves diverge at high rainfall values, with the all-catchments maximum rainfall of 2013 mm being considerably in excess of the wettest gauged catchments of the Clanrye at Mount Mill Bridge and Cambane at Bessbrook (both in hydrometric area 206) which share the maximum catchment rainfall of 1740 mm. Less than 6% of catchments are found with average rainfall values exceeding 1400 mm whereas the corresponding proportion of all catchments is 18%. This represents an important under-sampling by the network and, while many types of study have no particular need for data from such wet (upland) areas, there is a specific need in relation to reservoir yield studies (see Chapter 7) and also potentially for some benchmark monitoring.

The gauged catchment with the lowest average rainfall, Ravernet at Ravernet with 802 mm, lies below the 0.5 percentile catchment rainfall for Northern Ireland as a whole, and with four other catchments with rainfall values below 850 mm it is felt that this tail of the overall rainfall distribution is well represented. There is a fairly even spread of values in the median range of catchment rainfall totals. Therefore emphasis in future developments of the network should aim towards capturing more information from catchments with high rainfall values.

2.3 EVAPORATION

Actual evaporation (AE) data were also estimated by the Micro LOW FLOWS study referred to, by obtaining catchment potential evaporation (PE) values and applying an adjustment based on annual average rainfall (see Dixon and Bullock, 1990). Comparison of the distribution of values for all river reaches could be made with that for the gauging station sites as a means of assessing the current network's representativeness (Figure 2.3).

The first point worth noting from the figure is the restricted range of the values, between 395 mm and 460 mm in the all catchments data set. This compares with an approximate range of 350 mm to 600 mm for the UK as a whole. The NI range is almost fully covered by the gauged catchments, with minima and maxima of 397 and 451 mm respectively. There is some minor

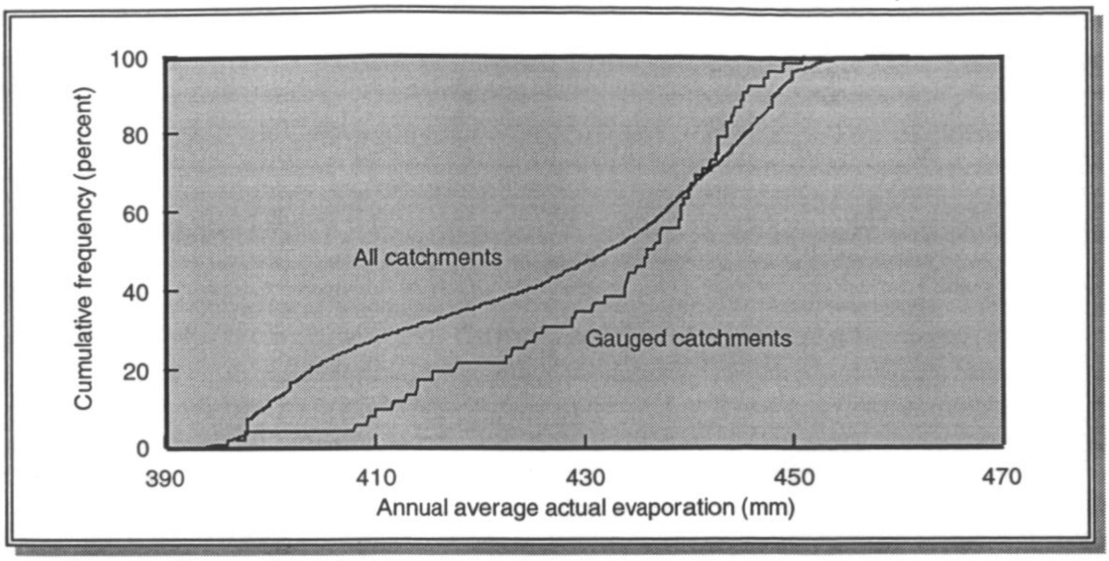


Figure 2.3 *Actual evaporation: cumulative frequency distribution for all and gauged catchments*

Table 2.3 *Annual average actual evaporation values for gauged catchments (mm)*

Station	AE	Station	AE	Station	AE
201002	417.9	203025	433.7	205004	434.9
201005	409.4	203026	439.5	205005	445.3
201006	408.2	203027	426.1	205008	447.7
201007	445.7	203028	440.1	205011	434.1
201008	410.0	203029	424.4	205017	440.0
201009	413.9	203932	435.9	205018	442.0
201010	415.3	203033	414.0	205020	439.4
202001	444.3	203938	445.0	206001	397.8
203010	429.3	203040	437.4	206003	443.5
203012	434.0	203041	436.8	206004	396.9
203018	437.3	203042	439.1	236905	428.9
203019	450.9	203043	441.2	236006	440.6
203020	439.4	203046	442.7	236007	431.9
203021	423.1	203049	443.9	236009	425.3
203922	412.8	203092	422.4	236051	436.1
203023	442.7	203093	430.8		
203024	449.1	204001	442.4		

under-representation of catchments with less than 410 mm average annual AE, and a balancing over-representation in the range of 420 mm - 440 mm. However, considering the small overall range of values involved, this is not considered to represent any significant deficiency of information. High values, above 440 mm, are found in all gauged hydrometric areas, i.e., in all parts of Northern Ireland; they are not geographically restricted. The two notably low values are both found in hydrometric area 206, but other low values are found in other areas, so these too are widely distributed (both coastal and upland catchments are represented), the actual patterns being determined by the PE, and to a lesser extent, SAAR maps. AE values for the gauged catchments are presented in Table 2.3

With such a limited overall range of AE values, and a good spread of gauged catchment values within this, the network is seen to represent conditions in Northern Ireland well, and no recommendations for change are justified in this respect.

2.4 HYPSOMETRY

A consideration of catchment hypsometry is useful in a review of this type, as the distribution of catchment altitude exerts an important control on the rate of runoff from a catchment. In assessing the representativeness of the gauged catchments in Northern Ireland, the NI Institute of Hydrology Digital Terrain Model (IHDTM) was identified as holding the most useful data for this purpose.

Digitised boundaries were available for the catchments of 34 river flow gauging stations and, in conjunction with the elevations held in the IHDTM, enabled the construction of a hypsometric curve for each. These are presented in Appendix B, grouped according to region. Whilst not all presently gauged catchments are represented, the information provided by the curves is coupled with catchment minimum and maximum altitude values to provide the basis of some comments on the representativeness of the network and for making some recommendations. It is striking that only one gauged catchment has its outfall at an altitude greater than 100 m. Each hydrometric area contains gauged catchments with maximum altitudes above 300 m (most areas have land rising to above 600 m), so scope exists across Northern Ireland to have small gauged catchments sited at high altitudes.

Referring to Appendix B, it can be seen that in only three of the catchments shown does the median (50 percentile) altitude lie above 200 m so, in the majority of catchments - even when relatively high maximum altitudes are attained - the majority of the catchment area lies at low altitudes. This finding may not be surprising, but it does reinforce the findings elsewhere in this chapter that there are few small, upland catchments in the Northern Ireland network; overall catchment slopes are therefore modest.

Considering catchment maximum altitude values, nine are found with maxima below 300 m, with seven of these rising to no more than 200 m and occurring exclusively in the south-east of the Province. If it is accepted that those catchments encompassing a large range of altitudes are generally the larger river basins, and those with either low maximum altitudes or high outfalls are the smaller ones, then in absolute terms (accepting the arbitrary definitions used here) small, lowland catchments are better represented in the network than are small upland ones.

There are particular implications of this distribution in terms of catchment rainfall and soils, and these are discussed in the relevant sections of this chapter. In terms of catchment slope, the under-representation of upland catchments also leads to an under-representation of steep catchments; steep catchments are also known to occur along the Antrim coast at relatively low altitudes and

Table 2.4 *Hydrology of Soil Type (HOST) classification scheme. Published with permission of the HOST project group.*

The HOST classification

SUBSTRATE HYDROGEOLOGY	MINERAL SOILS						PEAT SOILS	
	Groundwater or aquifer	No impermeable or gleyed layer within 100cm	Impermeable layer within 100cm	OR gleyed layer within 40cm	Gleyed layer within 40cm			
Weakly consolidated, microporous, by-pass flow uncommon (Chalk)	Normally present and at >2m	**1**	**13**		**14**		**15**	
Weakly consolidated, microporous by-pass flow uncommon (Limestone)		**2**						
Weakly consolidated, macroporous, by-pass flow uncommon		**3**						
Strongly consolidated non or slightly porous. By-pass flow common		**4**						
Unconsolidated, macroporous, by-pass flow very uncommon		**5**						
Unconsolidated, microporous, by-pass flow common		**6**						
					IAC* <12.5 [<1m/day]	IAC* >12.5 [>1m/day]	*Drained*	*Undrained*
Unconsolidated, macroporous, by-pass flow very uncommon	Normally present and at <2m	**7**			**9**	**10**	**11**	**12**
Unconsolidated, microporous, by-pass flow common		**8**						
			IAC# >7.5	IAC# <7.5				
Slowly permeable	No significant groundwater or aquifer	**16**	**18**	**21**	**24**		**26**	
Impermeable (hard)		**17**	**19**	**22**			**27**	
Impermeable (soft)			**20**	**23**	**25**			
Eroded peat							**28**	
Raw peat							**29**	

Emboldened numbers are HOST class numbers. No extensive UK soil types exist outside the table or within the shaded portions of the diagram.

* Integrated Air Capacity (IAC) used to index lateral saturated hydraulic conductivity

\# IAC used to index soil water storage capacity

Table 2.5a *Areas of major NI hydrometric areas by dominant HOST class (sq.km.)*

Stn No	HOST class 5	8	9	10	12	13	15	16	17	18	21	24	25	26	29	91	98	99	TOTAL
201000	103	26	61	12	0	0	75	0	0	1070	223	128	0	584	596	38	10	11	2940
202000	154	90	3	0	0	0	1	8	0	22	217	36	0	172	188	0	1	0	891
203000	336	20	157	8	5	0	26	276	0	1368	959	1273	143	559	268	4	13	389	5800
204000	11	0	3	0	0	0	0	255	0	132	9	17	0	238	224	0	1	0	889
205000	217	21	20	16	0	0	72	63	26	197	852	340	0	117	26	0	18	0	1980
206000	29	0	6	0	0	0	79	2	0	239	205	0	0	110	20	42	0	0	731
236000	35	0	8	0	0	1	18	6	0	130	1209	595	0	176	199	21	0	121	2520
TOTAL	884	157	258	36.1	4.64	1.26	271	610	25.6	3160	3670	2390	143	1960	1520	105	42.5	522	15760

Note: columns shown as integer; totals to 3 significant figures Column 91 - Urban cover; Column 98 - Lake cover; Column 99 - Sea cover.

Table 2.5b *Areas of gauged catchments by dominant HOST class (sq.km.)*

Stn No	HOST class 5	8	9	10	12	13	15	16	17	18	21	24	25	26	29	91	98	99	TOTAL
201002	0	0	0	0	0	0	19	0	0	61	0	43	0	25	14	0	0	0	161
201005	0	0	4	6	0	0	0	0	0	161	0	16	0	64	22	0	1	0	275
201006	0	0	3	6	0	0	0	0	0	104	117	52	0	26	17	0	0	0	325
201007	35	0	0	0	0	0	0	0	0	0	59	0	0	21	30	0	0	0	145
201008	0	6	0	0	0	0	6	0	0	103	0	0	0	113	94	6	0	9	337
201009	35	3	0	0	0	0	0	0	0	78	0	10	0	191	127	0	0	0	442
201010	41	25	6	12	0	0	25	0	0	708	117	127	0	462	299	6	7	9	1840
202001	60	28	0	0	0	0	0	1	0	18	67	33	0	67	92	0	0	0	366
202002	49	0	0	0	0	0	1	0	0	0	81	0	0	69	73	0	0	0	272
203010	13	0	28	7	0	0	0	0	0	461	271	67	0	67	34	0	0	0	948
203011	9	0	0	0	0	0	0	0	0	79	0	59	0	49	33	0	0	0	229
203012	40	0	9	0	0	0	0	29	0	214	32	15	0	58	22	0	0	0	419
203013	15	0	17	0	0	0	0	0	0	93	35	259	0	144	73	0	10	0	647
203017	0	0	6	0	0	0	25	3	0	140	127	8	0	25	1	0	0	0	336
203018	32	0	4	0	0	0	0	20	0	0	0	167	0	50	2	0	2	0	277
203019	0	1	0	0	0	0	0	7	0	23	0	59	0	27	14	0	0	0	130
203020	72	16	8	0	0	0	0	57	0	62	2	4	0	40	46	0	0	0	306
203021	0	0	1	0	0	0	0	0	0	0	0	59	0	49	18	0	0	0	127
203023*	16	0	0	0	0	0	0	0	0	32	0	4	3	3	2	0	0	0	60
203024	0	0	1	0	0	0	1	0	0	1	141	11	0	17	5	0	0	0	177

* Surrogate catchment used

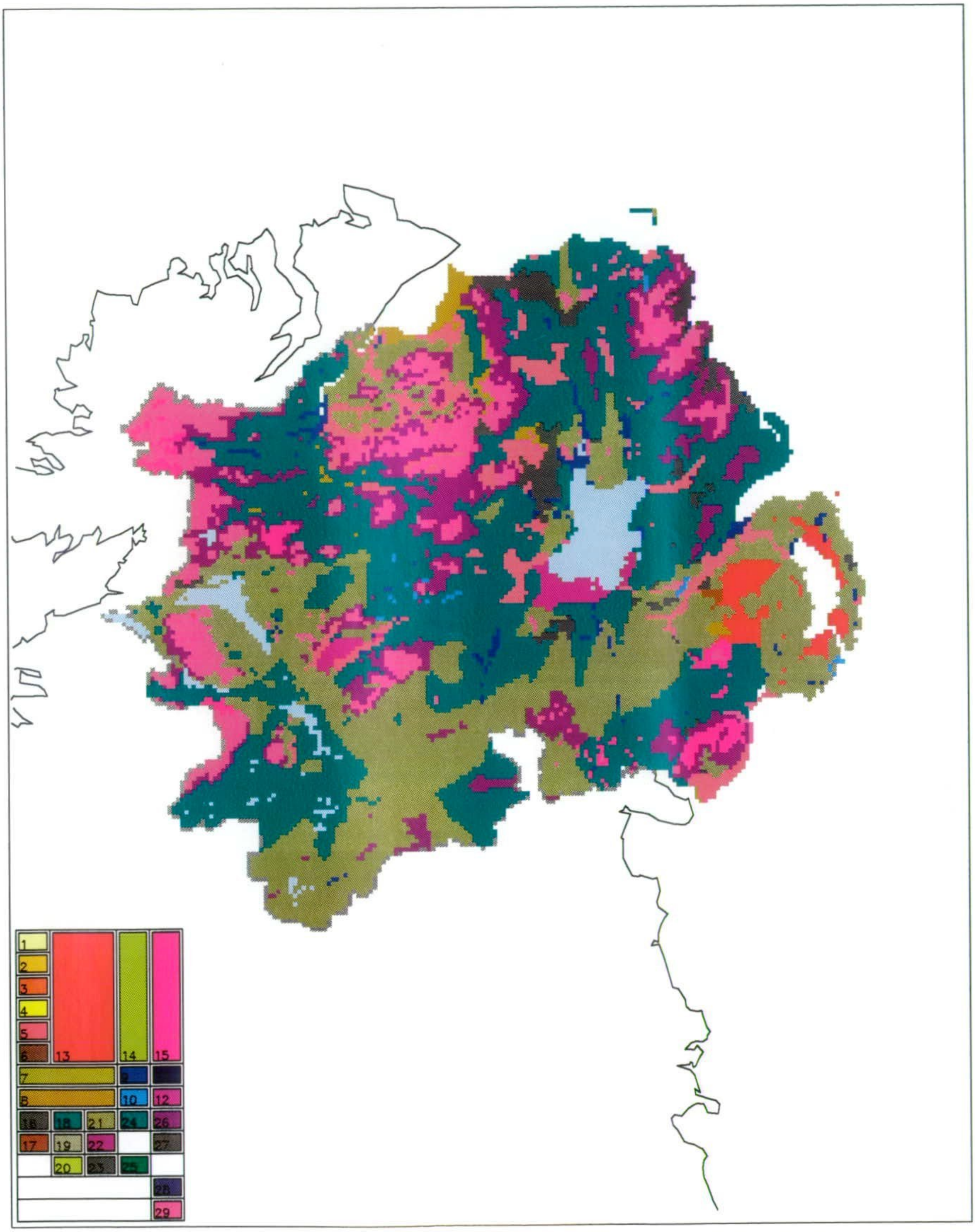
Table 2.5b (cont'd) *Areas of gauged catchments by dominant HOST class (sq.km.)*

Stn No	HOST class																	
	5	8	9	10	12	13	15	16	17	18	21	24	25	26	29	91	98	99	TOTAL
203025	0	0	0	0	0	0	0	8	0	42	86	0	0	23	6	0	0	0	164
203026	0	0	0	0	0	0	0	1	0	0	0	39	0	4	0	0	0	0	45
203027	5	0	5	0	0	0	0	0	0	12	0	89	0	40	18	0	7	0	177
203028	18	2	0	0	0	0	0	0	0	19	0	3	0	34	22	0	0	0	99
203029	0	0	1	0	0	0	0	0	0	0	0	40	0	15	1	0	2	0	58
203033	0	0	1	0	0	0	15	3	0	57	0	0	0	24	0	0	0	0	101
203038	0	0	0	0	0	0	6	0	0	0	0	0	0	1	0	0	0	0	7
203039*	0	0	0	0	0	0	0	0	0	12	0	33	0	21	17	0	0	0	84
203040	276	17	152	7	0	0	26	183	0	1200	948	1162	142	467	229	4	12	385	5210
203042	2	0	1	0	0	0	0	0	0	0	0	49	0	2	0	0	0	0	54
203093	15	0	22	0	0	0	0	0	0	94	58	278	0	147	80	0	10	0	704
204001	3	0	5	0	0	0	0	17	0	174	29	0	0	25	53	0	0	0	306
205003	68	5	0	8	0	0	16	27	10	8	261	25	0	12	5	0	0	0	445
205004	78	5	0	8	0	0	16	27	10	8	296	25	0	12	5	0	0	0	490
205005	1	0	0	0	0	0	0	3	9	0	57	0	0	0	0	0	0	0	70
205006	48	5	0	8	0	0	16	17	0	8	196	12	0	1	5	0	0	0	316
205008	0	5	0	0	0	0	16	1	0	8	50	0	0	0	4	0	0	0	85
205010	18	6	0	0	0	0	17	5	0	9	129	0	0	0	6	0	0	0	190
205011*	0	4	4	0	0	0	2	0	2	11	165	0	0	0	0	0	0	0	187
205020	12	0	0	0	0	0	0	0	0	0	43	0	0	0	0	0	0	0	55
206001	0	0	1	0	0	0	0	0	0	87	33	0	0	11	1	0	0	0	133
206002	0	0	1	0	0	0	0	0	0	0	31	0	0	0	0	0	0	0	32
236005	42	0	3	0	0	0	0	0	0	7	115	42	0	62	39	0	0	0	309
236007	0	0	0	0	0	2	1	0	0	0	90	13	0	3	59	0	0	0	168

* Surrogate catchment used

Note: columns shown as integer; totals to 3 significant figures *Column 91 - Urban cover; Column 98 - Lake cover; Column 99 - Sea cover.*

Figure 2.4 *Dominant HOST Class for Northern Ireland on 1km Grid*



again, owing to practical problems, do not occur in the gauged network.

In aiming towards a network providing data from a wide range of catchments to support flow parameter estimation in a range of situations, it is therefore felt that the inclusion of some steep, upland catchments would be of value in enhancing the comprehensiveness of the hydrometric database.

2.5 SOILS

Digital data held at the Institute of Hydrology enable the soils of Northern Ireland as a whole to be compared with those of gauged catchments. This allows an assessment to be made of the representativeness of the present gauging network from a soils perspective. The data used are provisional dominant HOST (Hydrology Of Soil Types, see Boorman *et al*, 1991) class data based on a 1 km grid. A key to the HOST classification, including recent revisions, is presented as Table 2.4. 17 of the 29 HOST classes are found in Northern Ireland, including urban, lake and unclassified Republic of Ireland areas.

Existing digitised boundaries were available for all hydrometric areas, many gauging station catchments and the boundaries of river basins identified in the 1986 Northern Ireland Water Statistics (DoE(NI), 1986). Where the catchment boundary of a recently installed gauging station was not available, river basin boundaries were used as substitutes where the outfall approximated well to the station location.

For each of the major hydrometric areas (201 - 206, 236) and each of the gauging station catchment or substitute catchment areas, the percentage of total area under each HOST class was found using dominant HOST class with the 1 km grid. Results of this analysis are presented in Tables 2.5 a and b. In assessing representativeness, the key objective was to determine whether each major HOST class was found to dominate at least one gauged catchment. The distribution of total area values for the HOST classes suggested a threshold of 100 km^2 should be used to define all major HOST classes, giving 11 in all. The maximum percentage cover of each HOST class for any catchment is shown in Table 2.6.

Table 2.6 *Maximum coverage for each major HOST soil class in all catchments used*

HOST Class	Area covered (km^2)	Maximum percentage
5	884	27.5
8	157	7.6
9	258	4.3
15	271	84.9
16	610	18.5
18	3158	65.7
21	3673	95.7
24	2390	90.7
25	143	5.2
26	1957	43.1
29	1522	35.5

It can be seen that in seven of the 11 HOST classes, the maximum class coverage is less than 50%, and attention therefore focuses on whether the inclusion of additional catchments with high coverage of these classes is desirable and realistic. They are considered in numerical order, with the geographical distribution of each class being shown in Figure 2.4.

Classes 5 and 9 These soils are generally found in valley bottoms and cannot therefore form a major part of any single catchment other than perhaps very small streams draining into major rivers. It does not seem sensible to try to find a site where the major part of a catchment is composed of soils of this type.

Class 8 These soils cover just 1% of Northern Ireland, and are dominant in only very small clusters of 1 km^2 squares except on the eastern margin of Lough Foyle. The limited coverage of this type gives its explicit representation in the gauging network limited value.

Classes 16 and 29 Peat soils do occur as dominant types as more contiguous areas, particularly in the uplands, and because of this merit specific attention in the gauging network. Opportunities for gauging areas covered by the former type can be seen in the Coleraine, Cookstown and Antrim coast areas, while for the latter the Antrim and Sperrin Mountains stand out clearly. As the present network includes no catchment with more than 35.5% covered by these two classes combined (catchment of Sillees at Drumrainy Bridge), while one hydrometric area (204) has as much as 53.9% peat cover, there is a clear need for increased representation in the gauging network.

Class 25 This class' dominance is centred exclusively around the southern shores of Lough Neagh. This is clearly a contiguous area, but its surface hydrology is dominated by the major rivers entering the lough and with so few other streams in this area, it is not felt that any streamflow gauging recommendations are warranted.

Class 26 These soils are generally found on slopes surrounding higher areas covered by class 28 peats. While there may be some merit in attempting to focus on the hydrology of this soil type alone, the nature of its occurrence on lower hill-slopes in association with peats suggests that a more representative sampling strategy would be to establish new stations on catchments with a combination of these soil types. Possibilities include those areas identified for class 29 above, the Mourne Mountains and other areas.

While some stations do measure flows in catchments containing large areas of peat, none has a high proportion of total catchment area as peat. 13.5% of the land area covered by this classification lies in classes 16 and 29 and this is felt to justify a high prioritisation of new flow measurement activity in peaty areas. Achieving this goal will be seen, in Chapter 8, to be realisable in parallel with some of the other priorities identified in this chapter, reflecting the strong links between elevation, slope and precipitation.

2.6 OTHER FACTORS

Further to the specific considerations covered in the preceding sections of this chapter, attention needs to be directed towards a number of more general considerations. It is seen as highly desirable that each major catchment should have at least one gauging station, as data demands such as water resource, assimilative capacity or design flood assessments are geographically widespread, and the availability of gauging station data will aid these studies. Figure 1.1 shows that all major rivers have at least one gauging station, so this consideration is well served.

The geographical distribution of gauging stations does contain gaps, however, notably along the Antrim coast and in the Sperrin Mountains. While rivers draining from the Sperrins are gauged in their lower courses, a modest number of smaller catchments higher up in the mountains would provide a greater level of detail which could complement the results of spatially derived flow parameter estimates for other sites in this type of steep, wet environment. Similarly, the establishment of a single gauging station on a river draining to the Antrim coast would be of value in supporting estimates made for other rivers in this area. With the high gradients characteristic of these rivers, it is important to have a reliable means of assessing the accuracy of estimation methods used for ungauged sites and a basis for the adjustment of such estimates. The catchments could also serve as useful benchmarks at a time of potential climatic instability.

It is also important to be mindful of the fact that catchments in Northern Ireland are more diverse than in other parts of the UK. The range of average annual catchment rainfall values is similar to some regions of Scotland, e.g. the Tweed basin, as also are the slopes, soils and land uses, but such ranges are much greater than are found in most parts of England. In order to represent this diversity well, it may be necessary to employ a higher density of gauging stations than would be expected for other regions of similar size. This point is taken up in Chapter 5.

2.7 SUMMARY

The results of this chapter can be summarised in a number of provisional recommendations for change in the river gauging network:

- Incorporation of more small catchments into the gauged network, particularly those of less than 30 km^2 in area. The high level of representation of large catchments is of strategic value and is reflected by high data use (see Chapter 3), and should be maintained.

- Inclusion of further catchments in areas of high annual rainfall, particularly where SAAR > 1400 mm.

- More steep, upland catchments should be included.

- The present under-representation of catchments with peaty or mid-slope gley soils should be rectified; the establishment of one or more gauges on streams draining a combination of these types would contribute some important typical Northern Ireland catchments to the network.

- The lack of gauging in the Antrim coast and Sperrin Mountain areas produces a geographical imbalance in the network and, considering the diverse nature of the land surface of Northern Ireland, it would be beneficial to instigate new flow measurement activity in these areas.

3 Data use survey

Beyond the theoretical consideration of the hydrometric network's characteristics outlined in the previous chapter, it was considered important to assess the current and anticipated uses of data being produced by the existing network. This practical activity sought to reveal many of the reasons for the form of the present network, and provide information on the constraints within which any changes would have to be formulated.

The focus of this activity was to identify those principal uses to which gauging station data were put, and to this end a questionnaire was produced. Data were collected on the basis of interviews at ES and DANI, thus covering the full range of data uses, both within these departments and in other organisations. A list of 13 data uses was agreed with both departments and is given, with an explanation of each item, below.

3.1 DATA USE CATEGORIES

1. *Residual/prescribed flows/levels*	A station may be used to record river levels or flows in order to monitor compliance with a specific requirement, e.g., passage of a minimum compensation flow from a storage reservoir.
2. *River regulation /transfer schemes*	Operational use of a gauging station to monitor flows as part of the management of a water resources scheme, e.g monitoring river flows on a river heavily used for water sup.,ply, in order to determine when additional supplies should be released from reservoirs.
3. *Abstraction point spillage protection*	Where an abstraction to a supply scheme is made, real-time flow data may be required in order to provide information on the time of travel from an upstream pollutant spillage to the abstraction point; protection of the water supply system is thus afforded.
4. *Catchment yield assessment*	Historic flow data are used to evaluate the yield of a catchment for a water resources project (typically public water supplies or hydro-electric power).
5. *Flood forecasting*	Gauging station data can be applied in real time (perhaps in conjunction with rainfall intensity information) to the assessment of flood risk in downstream areas, and can accordingly be a basis for mobilising flood emergency teams, building defences, etc.
6. *Flood design studies*	Gauging station time series may be valuable in assessing the future statistical risk of flooding at a site. When structures are to be built on or near a river, an assessment of the risk of exceedance of some flow or level threshold (or the stage expected in a flood of given return period) is required, and is greatly benefitted by the availability of gauging station data.

7. *PARCOM*	The UK is committed to the PARis COMmission on the discharge of materials to the sea, requiring a programme of water quality sampling in the lower reaches of specified rivers, accompanied by flow measurement in order to calculate fluxes of the various materials. Gauging station operation is thus necessitated.
8. *Assimilative capacity*	Any application for a licence to discharge effluent requires an assessment of the assimilative capacity of the watercourse in question. Attention centres on low flow periods when stress on the receiving waters is greatest; Q_{95} flow values are generally used to index such low flows and can best be directly quantified on the basis of long, accurate flow records.
9. *Consent standards*	A rated gauging station may be of use in the monitoring of an effluent discharge, either when assessing the rate of effluent inflow, or in supplying flows for use in conjunction with water quality data.
10. *Transmission to NRFA*	Transmission of daily mean flows and monthly highest instantaneous peaks for archiving and national access in the Institute of Hydrology's National River Flow Archive.
11. *Ecological studies/ recreational monitoring*	The use of gauging station data for ecological studies, e.g., effects of change of water utilisation on fish habitats, or monitoring to protect recreational interests, e.g., keeping lake levels between specified limits or flows for angling interests.
12. *Benchmark monitoring*	This category of data use was included to identify those stations with long, good quality records from which changes in flow regime due, say, to climate or land use change may be detected. It is envisaged that operation of these stations should continue in order to extend the existing time series and provide the facility to confidently detect future changes.
13. *Hydrological studies*	The final category was provided to flag stations used for other studies. This proved especially useful in relation to the water quality catchment management plans currently being prepared or planned; see below.

3.2 SCORING

The possibility exists for data uses to be given different ratings according to the type of activity to which they contribute. One possibility is that those data uses which are essential for either Departments' activities should receive a higher score in the questionnaire than those for which the data are simply useful or desirable. However, this distinction is a difficult one to sustain, and in the course of discussions with the client it was resolved that the only difference in data usage to be noted would be whether or not there was any statutory requirement for data. In essence, therefore, a three-fold classification was employed to describe the different levels of data usage:

0 Data not required for specified use
1 Data currently or anticipated to be of use in function
2 Data required in order to meet statutory requirement

The scores shown can then be added to produce a total data usage score for each station.

3.3 RESULTS AND DISCUSSION

Staff at both the ES and the DANI were asked to specify their use for gauging station data against each of the 13 data uses listed above, and the final results are tabulated in Appendix C.1. It is immediately apparent from the results of the questionnaire that no station in the network is redundant, and that points are scored against each of the 13 categories listed. Histograms showing the frequency distribution of data use scores for all stations are shown in Figure 3.1.

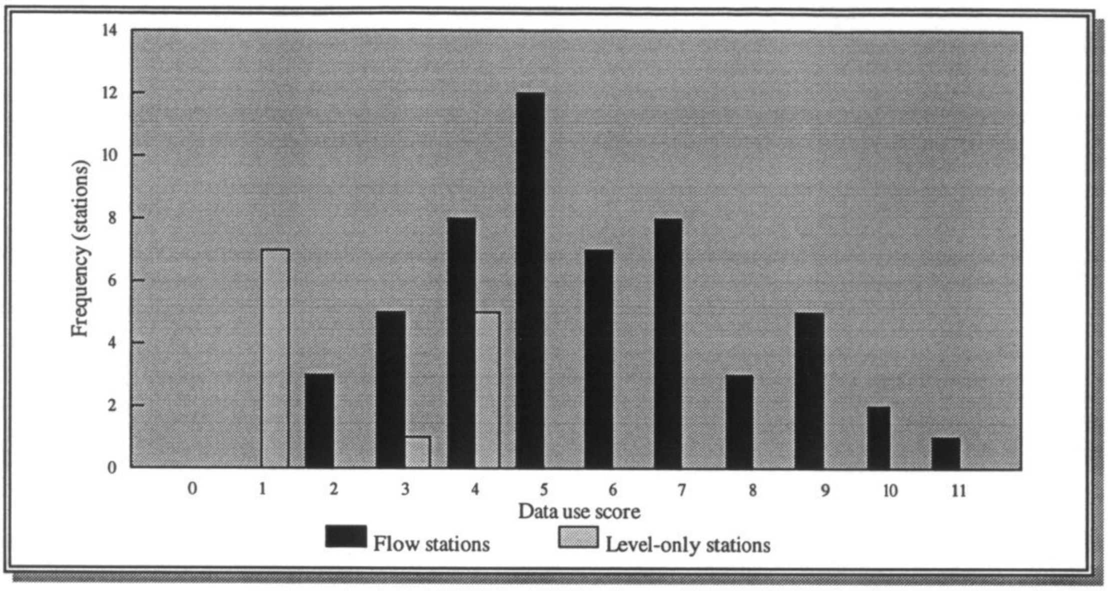


Figure 3.1 *Frequency distribution of data use scores*

Statistics describing the range of levels of data use are:

Data use scores:	mode	5
	median	5
	minimum	2 (flow stations) / 1 (level-only stations)
	maximum	11 (flow stations) / 4 (level-only stations)

The spatial distribution of high and low scores shows some basic spatial patterns. The eleven stations scoring eight or more points are, with only two exceptions, the lowest gauges on major catchments, namely the Mourne, Burn Dennet, Faughan, Roe, Lower Bann, Kells Water, Bush, and Lagan. One exception is the Upper Bann at Bannfield, with nine different data uses cited, and the other is the Blackwater at Derrymeen Bridge with eight. The station with the highest score is the Lagan at Newforge, the station nearest Belfast; the only station with two statutory requirements is the lowest station on the Bann at Movanagher, with a catchment area greater than one third of the whole of Northern Ireland. Finding the greatest use of data to be on major rivers conforms with expectations.There also seems to be a pattern amongst those stations with little data use. Seven of the ten stations scoring only one or two points are level-only stations, being sited on the rivers Lower Bann, Blackwater (immediately upstream of Lough Neagh) and Quoile (for use in conjunction with the Quoile Barrier). The three rated stations are close to lakes, being Killough Bridge, Strand Brickworks and Killyhevlin.

The level-only stations listed are used only for either operational purposes in regulating levels or for flood forecasting. The three flow stations are all associated with lakes and their value lies only in anticipated use for water quality catchment management plans: no other specific uses were identified.

To achieve a full understanding of the gauging station data requirements in each category, each is considered in turn in Appendix C.2.

The sum of each of these component scores gives a numerical evaluation of the usefulness of each of the gauging stations considered. The range of scores is discussed above, and it has already been shown that some stations stand out as having value in a wide range of applications. However, others have only very limited value and consideration is now given to whether continued operation of all of these stations is in the operating/measuring authorities' interests.

In discussing the various uses of gauging station data in the preceding section, a distinction was made between site-specific/operational requirements which demand the continuing generation of data from gauging stations (perhaps on a real-time basis) and data uses which utilise whatever flow data are available on a river (or another nearby), without being site-specific. The two types are hereafter referred to as Types A and B respectively. Included in the former group are those stations where data generation is required to serve statutory functions. Those categories which are deemed to justify continuing operation of a station irrespective of any other uses are:

- PARCOM
- Prescribed/residual flow/level monitoring
- River regulation/transfer schemes
- Flood forecasting (where warning times are adequate)
- Consent standard monitoring.

For those categories remaining, it is argued that while the data collected are of value they need not specifically be collected at those stations currently operating, though at the same time any changes to the network should not prejudice its ability to represent the full range of catchments found in Northern Ireland, as discussed in Chapter 2. Beyond this, it is recognised that some Type B stations are useful in a range of categories and that despite no single critical use demanding their continued operation, this is still desirable. Thirty-four flow gauging stations and eight level-only stations fall into Type A as a result of having at least one site-specific data use, and accordingly their continuing operation seems desirable subject to other factors being satisfactory (especially data quality).

Table 3.1 shows the frequency distribution of data use scores for flow and stage-only stations of Type B. The data suggest no obvious threshold below which consideration may be given to a cessation of operation, and it is ultimately a matter for the operating/measuring authorities to decide at what level of data use the continued operation of a station ceases to be justified. However, using an arbitrary threshold of two data use points, it is felt that the three flow stations scoring only two points and the three level-only stations achieving only one are of very limited worth. The three flow stations (Killough Bridge, Strand Brickworks and Killyhevlin) gain points only for (potential) use in hydrological studies and transmission to the NRFA; this is seen as a clear indication that the stations have no specific function, and by this analysis it therefore follows that consideration should be given to their closure, with other stations providing data for these catchments if required.

Table 3.1 *Frequency distribution of data use scores: Type B stations*

Score	Flow stations	Level-only stations
7	1	-
6	2	-
5	5	-
4	5	-
3	4	1
2	3	-
1	-	4

Similar consideration might also be given to the four lowest-scoring level-only stations (Loughan Island, Portna, Agivey Bann Bridge and Verners Bridge). Three of these stations lie on the middle-lower reaches of the Lower Bann, with a flow station (Movanagher) and a gauged tributary (Agivey at White Hill) between the highest and lowest of the three. Reinforcing the meaning derived from the low scores at these stations, this geographical perspective further calls the value of these stations into question. It is confidently anticipated that level information for these sites could be obtained indirectly, by the use of suitable models, from the flow stations operated. Similarly with Verners Bridge, the River Blackwater is gauged upstream at Maydown Bridge, with a tributary also gauged at Callan New Bridge; the necessity for the operation of this station is therefore also questioned.

Full consideration is given to these matters in Chapter 8 and Appendix F, along with the results of the other studies. The combined approach is used to arrive at an overall evaluation of the existing gauges in the network, from which specific recommendations are derived in Chapter 8. Reservations expressed regarding the future role of some individual stations are not therefore to be taken as final assessments of their value.

3.4 SUMMARY

A wide range of data use scores was recorded, with some gauging stations amassing scores for almost all the available categories of data use while others registered scores against only one or two items. Appendix C.1 gives details of all the scores awarded and Appendix C.2 discusses the results in individual categories.

- Stations providing data for PARCOM/Harmonised Monitoring, prescribed/residual flow/level monitoring, river regulation/transfer schemes, flood forecasting (subject to adequate warning times) and consent standard monitoring were identified as being absolutely necessary.

- Those scoring only one or two points were identified as being of particularly limited worth.

- Scope exists for closing some stations on the grounds that flow or level information can be derived for them from other sites, in many cases on the same river.

- Neither the staff of ES or DANI referred to any data need presently ill-served by the network. *(See footnote)*[1]

- No reasons for opening new stations arise out of this part of the study.

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1 The questionnaire presented the staff of ES and DANI with a list of sites. This list was not exhaustive and did not reflect sites which had been etablished by DANI to investgate small catchments through commissioning a study by the University of Ulster at Coleraine. These catchments were in both the urban and rural evironments. With hindsight, these catchments may have provided useful additional input to the study and awareness of their existence should have demonstrated that DANI were aware that the network, as presented, did not fully satisfy their requirements.

The catchments were not part of the formal network and no data are held by the NRFA; some station appraisal would thus be required before their status was changed to full network stations.

4 Use of spatial data

Within the last few years considerable advances have been made in the availability of spatial data for the UK as a whole. These include ground surface features (elevation, soils and vegetative covers, land use, river networks), climatological variables (rainfall and evaporation measures) and point features (measuring and sampling sites, outfall and abstraction points). They may be held in vector, raster or point location form and modern Geographical Information Systems (GIS) and similar technologies allow for their collaborative use. Most recently attention has been focused on enhancing the accessibility and utility of these data sets. The growth in spatial data volume and usage is necessary for, and enhances the potential of, the modelling of various aspects of the hydrological cycle. The *Flood Studies Report* (FSR - NERC, 1975) represents an important landmark in harnessing both spatial and time series data for hydrological problem-solving, and since that time there has been a steady growth in the number and range of projects where such modelling techniques have found successful application. The IH has implemented these models in widely marketed micro-computer software packages, so that practitioners in hydrology may utilise them along with relevant data sets which are available on computer media.

Hydrological models are developed on the strength of both time series and spatial data in order that river (typically flow) characteristics can be understood, and subsequently predicted, on the basis of identified catchment characteristics. This enables hydrological parameters to be estimated for ungauged sites, thus extending greatly the value of existing time series which, of necessity, can only be collected at a number of discrete points. Hydrological information is often required at locations distant from any gauging station; this is equally true of high flow, low flow and total runoff data needs.

In this chapter, investigations have appraised modelling techniques for a range of catchments. This was a means of identifying those situations where modelling appears to be generally successful in producing reliable estimates, and those where the use of spatial data produces results which differ substantially from measured flow values. Two specific assessments were selected:

- Estimation of Q_{95} values with the IH package Micro LOW FLOWS (an implementation of IH Report 108 *Low flow estimation in the United Kingdom* (Gustard *et al.*, 1992));

- Estimation of mean annual flood values using the *Flood Studies Report* statistical method.

These two methods allow an assessment of the accuracy of flow estimation from spatial data at opposite ends of the flow range. Unfortunately, it was not possible in the context of this study to apply either method in Northern Ireland because of the shortcomings of existing data sets. Micro LOW FLOWS for Northern Ireland was not available with the necessary 1:50,000 rivers network and, owing to the relative paucity of flow data in the early 1970s when the *Flood Studies Report* work was carried out, catchment characteristics were not derived for these catchments. The assessment of modelling methods therefore used an analogue region. Wales was selected for this purpose, notwithstanding known differences in low flow characteristics between NI and Wales identified in previous studies. In terms of catchment size, slope and permeability, a broadly similar range of gauged catchment types exists, and usefully, there is also a comparable range of mean annual rainfall values. Wales was considered to be the best analogue available for this purpose. The two following sections therefore concentrate on evaluating these modelling approaches with reference to recorded values of Q_{95} and mean annual flood in Welsh catchments. Conclusions are drawn for the Northern Ireland gauging station network in terms of the importance of collecting flow data from the range of catchment types.

Full discussion of the methods and presentation of the results is given in Appendices D1 and D2; some material may be duplicated in the précis below.

4.1 COMPARISON OF MICRO LOW FLOWS Q_{95} ESTIMATES WITH RECORDED VALUES

4.1.1 Introduction

Implementation of Micro LOW FLOWS for a complete area would require the provision of a large volume of data and the expenditure of considerable amounts of time in loading these data into the computer software system. This work has been done for most regions of the National Rivers Authority (England & Wales), including the Welsh Region. For a given ungauged site, a number of catchment characteristics are required:

- catchment area
- standard annual average rainfall
- potential evaporation
- soils information, from which a HOST (Hydrology Of Soil Types) hydrological response class can be derived (Boorman and Hollis, 1990; Boorman *et al.*, 1991).

Low flow parameters such as Q_{95} and mean annual minima (of various durations) can then be derived and related to synthetic flow duration curves (see Gustard *et al.*, 1992 for full details). In this study only Q_{95} values have been used to index the low flow behaviour of a river.

Of 131 gauging stations in Wales available for study, only those which could be designated as natural (i.e., the gauged flow is estimated as within 10% of the natural flow at or above the 95 percentile flow) were considered for use. Twenty-three natural catchments were identified from Factors Affecting Runoff codes in the National River Flow Archive. As these stations have been used in an illustrative capacity, a full description of the model application and the evaluation of results is featured in Appendix D.1. Selected elements and conclusions are featured below.

4.1.2 Discussion

It was the purpose of this investigation to identify those catchment types in which the model has been successful, and those where problems have occurred. The required accuracy of flow parameters varies from one application to another but, as an arbitrary definition, it was assumed that Q_{95} values were required to within 25% of the measured value. The characteristics of those catchments meeting this specification were therefore compared with those which did not.

The stations at which Q_{95} the estimated /measured ratio were closest to unity were generally the smaller (<100 km^2) and lower rainfall ones (<1750 mm), while at higher annual rainfalls or larger catchment areas, the chance of an estimate falling outside the ±25% range were somewhat higher. Over-estimation in steep catchments, for example, may be explained in physical terms by suggesting that steep slopes cause faster drainage of runoff and therefore lower Q_{95} runoff values; smaller catchments are likely to be more simple hydrologically and therefore more easily modelled. It should also be noted, however, that flow measurement problems such as gauge insensitivity and algal growth may also contribute to some of the larger discrepancies between estimated and measured values.

The results of this simple study seem most helpful when considering the potential role of hydrological models for low flow estimation in Northern Ireland. In discussing data usage with ES staff as part of the survey reported in Chapter 3, it became apparent that much of the focus of model-based low flow estimation work (as in other regions) is concentrated in more developed areas at lower altitudes (lower rainfall) and in relatively small catchments. Where estimates of low flow parameters are required on larger rivers, the current network of gauging stations located on all major rivers provides measured data which may be translated up or downstream to the point of interest. In small, steep and wet catchments there is generally little demand to utilise water resources, and the lower level of success of the method is not of particularly great consequence. However, the need for reservoir inflow data and flow regime characterisation for hydro-electric power generation present obvious exceptions to this.

In all cases, it is important to use information on abstractions and/or discharges to temper the results of the type of modelling work discussed here. This facility is built into Micro LOW FLOWS version 2.

The Micro LOW FLOWS Q_{95} estimation method is seen as having applicability to a large number of the low flow estimates currently undertaken by the Water Quality Unit of the ES. However, it is recommended that comparisons should be made, wherever possible, between statistically derived low flow estimates and flows measured at gauging stations in analogous catchments, and to compare measured and estimated values for gauging station sites. While Micro LOW FLOWS has been seen to achieve a fair degree of success in some types of catchment, comparison will allow confidence to be justified in catchment types where the method works well and adjustments made where other catchment characteristics appear to affect estimated values.

The estimation method was not particularly successful in small, upland catchments, and while this may be of little consequence for assessing the impact of any (typically minor) discharges in such areas, for example, it is rather more important in relation to assessing low flows in conjunction with water supply schemes in general and supply reservoirs in particular. No evidence has been found to call the general applicability of the Micro LOW FLOWS methodology into question in this type of catchment; rather, it is suspected, there are local factors (such as steep slopes) which cause estimates to be significantly at odds with measured values. In such cases, it is felt that the collection of flow data at gauging stations (perhaps complemented by spot gaugings) would allow corrections to be applied to low flow estimates for ungauged sites. The choice of catchments to be gauged is considered to be very important.

4.2 COMPARISON OF FLOOD STUDIES REPORT STATISTICAL MEAN ANNUAL FLOOD ESTIMATES WITH RECORDED VALUES

4.2.1 Introduction

The mean annual flood (MAF) is a widely used index of flood magnitude both at gauged and ungauged sites. With gauging station records, either annual maximum or peaks-over-threshold (POT) series can be used for derivation; without such data the *Flood Studies Report* suggested the use of either a statistical method (based on catchment characteristics) or a rainfall-runoff method to estimate the MAF and outlined methods for both. Regional growth curves were then provided for the estimation of floods of higher return periods.

The statistical approach relating MAF to catchment characteristics uses the equation:

$$MAF = C\ AREA^{0.94}\ STMFRQ^{0.27}\ S1085^{0.16}\ SOIL^{1.23}\ RSMD^{1.03}\ (1+LAKE)^{-0.85}$$

where	C	denotes a regional multiplier (here 0.0213 for all catchments in Wales),
	AREA	catchment area (km^2)
	STMFRQ	stream frequency (junctions.km^{-2})
	S1085	stream slope (m.km^{-1})
	SOIL	soil index based on Winter Rain Acceptance Potential
	RSMD	net 1-day rainfall of 5-year return period (mm)
	LAKE	Fraction of a catchment draining through a lake or reservoir

Definitions for each of these parameters are available in the FSR (NERC, 1975). This section of the work reports on application of this equation to assess the usefulness of spatial data in estimating a high flow quantile for a range of catchments.

4.2.2 Method

For this section, not all of the necessary catchment characteristics data were available, so the physical analogue of Wales was again used. The study was based exclusively on the data available for the 45 Welsh stations in Volume IV of the FSR; this offered the advantage of a ready-to-use data set, although the flood series were not as long as would have been possible using more recent data.

Ratios of the estimates of MAF from the regression equation to measured values from obtaining annual maximum series were computed and formed the basis of the analysis.

4.2.4 Discussion

With six independent variables used in the equation to predict MAF, an assessment of the performance of the method was unlikely to be straightforward. It is worth noting in the first instance, however, that using the same ±25% tolerance as in the Q_{95} section, a greater degree of success has been achieved in the estimation of MAF values, although this takes no account of any inaccuracies or bias in the measured flow data. It can be noted that estimates at 71% of stations in the sample lay within ±25% of BESMAF (best estimate of the mean annual flood) values. The most common reason for estimates being less accurate was the coincidence of very high or very low independent variable values, resulting in MAF over-estimation or under-estimation respectively. This appears to be an inevitable consequence of the regression approach to the FSR statistical method and must be accepted as the price to be paid for the benefits which accrue from its application. The Welsh catchments in which estimation was seen to be less successful cover a range of types.

Many of those with high estimates are neither especially small or large but drain wet catchments with soils of low permeability and high drainage densities, and may be characterised by flood attenuation by lakes. Relating this to Northern Ireland, this focuses the need for gauging stations not so much towards the headwaters, but to moderately sized catchments of say 100 km^2 draining upland areas. Analysis in Chapter 2 has indicated the NI network to be well provided for in this respect.

Of those catchments with low estimates, those which are due to reservoir effects should not be counted as failures of the method, as in any study this type of effect could be specifically catered for. The remainder seem to follow no clear pattern and are relatively few in number: it therefore seems wise to make no specific gauging recommendation in this respect.

4.3 SUMMARY

- The Micro LOW FLOWS Q_{95} study found estimation to be quite reliable in small (area <100 km^2), less wet (AAR <1750mm) catchments.
- Reliability was less, particularly in small, upland catchments.
- The FSR statistical approach application to Wales found less reliable performance in a number of *c.* 100 km^2 upland catchments, as a result of the coincidence of high values in several of the predictor variables. These results, and some of the more severe under-estimations, appear to be the inevitable consequences of the use of a regression equation, but should not lead to serious design problems if records from analogue catchments can be used.
- A full range of catchment types in the network is highly desirable in order to enable the use of spatial data to transfer hydrological characteristics.
- The need for gauges in small, upland catchments is seen to be quite acute.

5 Comparison with other UK regions and EC countries

International and regional comparisons of the density of river flow gauges in Northern Ireland enables an understanding to be gained of where local gauging practice lies relative to expectations from other countries and regions. Each country and UK region has its own physical character, pattern and level of water utilisation, and history of flow measurement. By studying other areas, useful input can be obtained for the present assessment of future directions for the NI network.

Comparisons were made between the density of gauges per 1000 km^2 and per million of population in Northern Ireland, Great Britain and those countries in Europe which were studied in the Flow Regimes from International Experimental and Network Data (FRIEND) project (Gustard, 1993).

5.1 EUROPE

Data for this section were taken from the INFOHYDRO manual, compiled in 1987 using data mostly from 1983 (WMO, 1987). Discharge recording stations and level-only stations were listed separately and are presented here in Table 5.1. Discharge stations are defined as water level stations with a rating to enable the calculation of discharge.

Table 5.1 *Gauging station densities for countries in Europe*

Country	Area km^2	Data for year	Pop.$ x10^6	Number of stns flow	Number of stns stage	Total	Density /1000 km^2	Density /10^6 pop
Austria	83,849	83	7.666	363	297	660	7.9	86
Belgium	30,513	83	9.922	192	5	197	6.5	20
Czech/Slovak*	127,869	83	15.283	1327	79	1406	11.0	92
Denmark	43,069	83	5.133	199	53	252	5.9	49
Finland	337,009	83	4.991	224	425	649	1.9	130
France	551,695	84	56.596	2000	605	2605	4.7	46
Germany**	248,577	84	61.420$$	2909	1355	4264	17.2	69
Netherlands	40,844	86	15.022	7	154	161	3.9	11
Norway	324,219	83	4.273	829	332	1161	3.6	272
Rep. of Ireland	70,283	73	3.489	275	54	329	4.7	94
Sweden	449,964	83	8.564	359	300	659	1.5	77
Switzerland	41,288	83	6.784	389	78	467	11.3	69
UK	244,046	81	57.236	906	20	926	3.8	16
Average							6.5	79

* Czech & Slovak Republics: data for former Czechoslovakia
** Data for former Federal Republic of Germany
$ Population from Oxford Hammond Atlas of the World, 1993
$$ Population from Times Atlas of the World, 1985

5.2 UNITED KINGDOM

Data for this section is compiled from the Hydrometric Register and Statistics 1986-90 (IH/BGS, 1993), comprising all stations with data on the National River Flow Archive. Table 5.2 shows the data divided into NRA and Scottish RPB regions, together with those for Northern Ireland.

Table 5.2 *Gauging station densities for UK regions*

Region	Area* km^2	Pop.** $x10^6$	Number of stations	Number per 1000 km^2	Number per 10^6 pop.
Highland	23,110		34	1.5	
North East	10,420		33	3.2	
Tay	8,710		40	4.6	
Forth	4,520		45	10.0	
Tweed	4,580		31	6.8	
Solway	6,970		27	3.9	
Clyde	13,555		49	3.6	
Northumbria	9,274	2.606	54	5.8	21
Yorkshire	13,503	4.500	86	6.4	19
Severn-Trent	21,666	8.300	143	6.6	17
Anglian	26,795	5.600	168	6.3	30
Thames	12,917	11.700	113	8.7	10
Southern	10,604	4.070	82	7.7	20
Wessex	9,918	2.500	65	6.6	26
South West	10,884	1.500	53	4.9	35
Welsh	21,262	2.800	123	5.8	44
North West	14,445	6.845	99	6.9	14
N. Ireland	14,133	1.589$	43	3.0	27
Average	(England & Wales only)			**5.7**	**24**

* From Hydrometric Register and Statistics 1986-90

** From *Who's Who in the water industry, 1992,* Water Services Association (England and Wales)

$ Population from Times Atlas of the World, 1992

5.3 DISCUSSION

5.3.1 Comparison of density of stations per 1000 km^2

Comparisons of this type can be very sensitive to the interpretation, in individual countries, of what constitutes a gauging station. An example of the kind of problem encountered is provided by the inordinately low, and unrealistic, entry here for the Netherlands. Such inconsistencies dictate that only provisional conclusions may be drawn from Table 5.1. Fortunately a sensibly consistent definition of a gauging station has been applied throughout the United Kingdom allowing meaningful regional comparisons to be made.

Figure 5.1 *Density of gauging stations per 1000 sq.km*

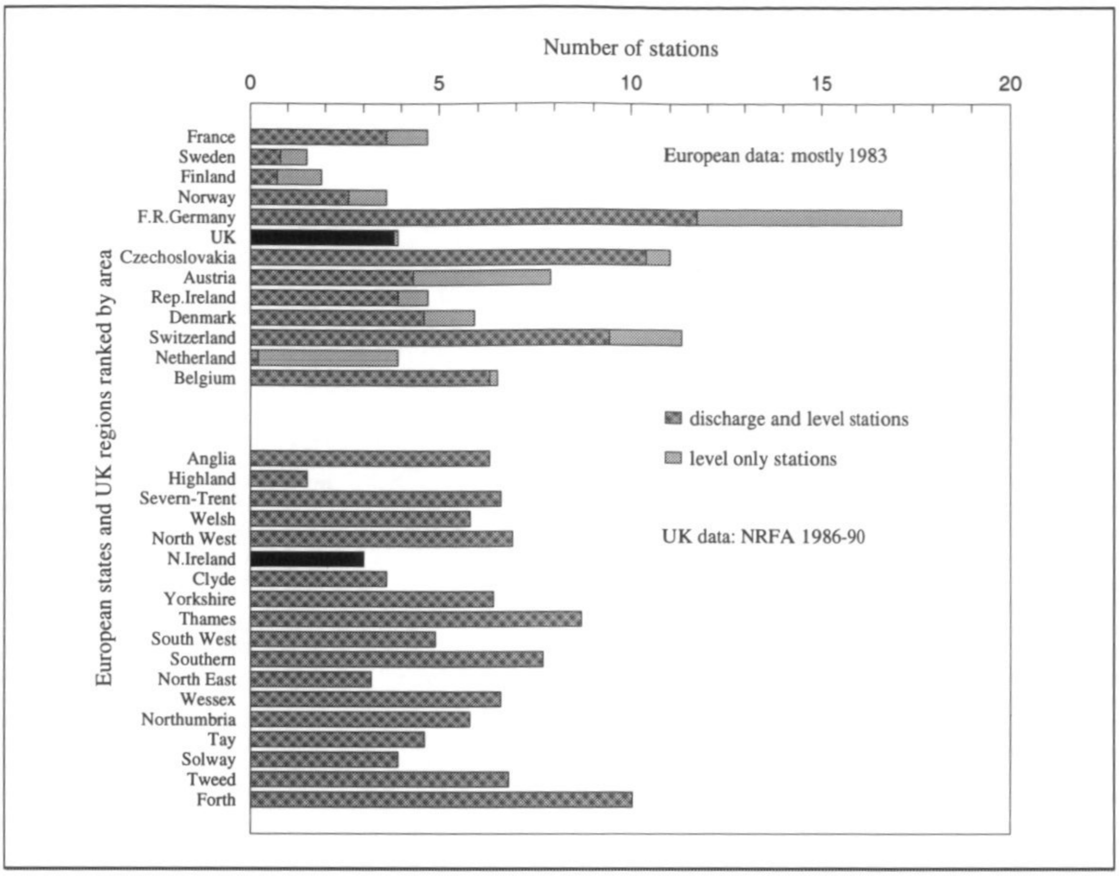
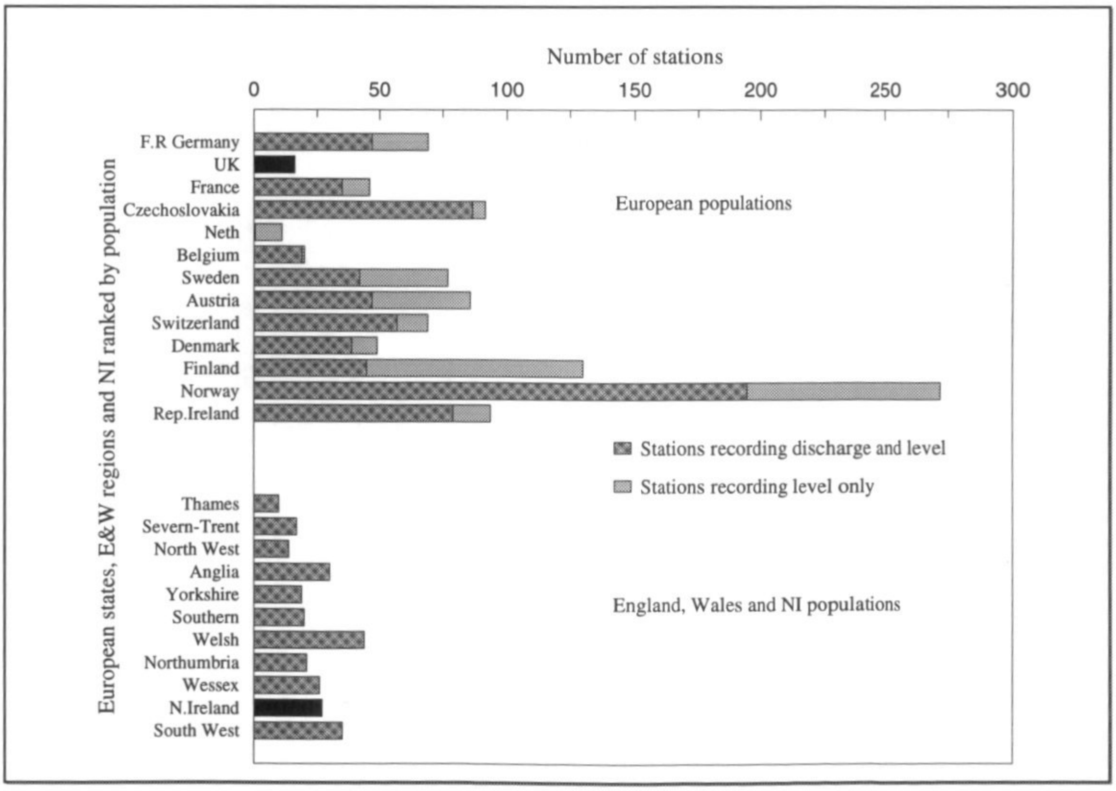


Figure 5.2 *Density of gauging stations per million population*



Referring to Table 5.1 and Figure 5.1it can be seen that in the European countries studied in the FRIEND project (Gustard, 1993), the largest countries by area (France, Sweden, Finland and Norway) have a low density of stations. However, F.R. Germany (the 5th largest by area) has a density of 17.2 per 1000 km^2, approximately 50% higher than either of the two countries with the next two highest densities (Czechoslovakia with 11.0 and Switzerland with 11.3). The UK can be seen to have a roughly median gauging density with respect to area, if anything slightly lower than other countries of similar size. France has undertaken an active programme of station expansion over the last ten years and the figures are likely to be an underestimate.

Within the United Kingdom, (Table 5.2 and Fig. 5.2), the density of stations in Northern Ireland is the second smallest at 3.0 per 1000 km^2, only Highland RPB having fewer (1.5 per 1000 km^2). Forth RPB has the greatest density (10 stations per 1000 km^2) and is also the smallest area. The relationship between region size and density per unit area is not a meaningful one, being much more dependent on administrative boundaries than patterns of water utilisation, so the low NI density should be taken at face value in this respect. However, the number of gauges quoted (43), based on NRFA data holdings, is much lower than indicated by ES sources (84 including level only stations), so after making this adjustment it would seem that the density per unit area is roughly typical of the UK as a whole. This may be surprising when considering the relatively low level of water utilisation in Northern Ireland, but is justifiable on account of the diverse physiography of NI catchments.

5.3.2 *Comparison of density of stations per million population*

Figure 5.2 shows that all the European countries considered, with the exception of the Netherlands, have a greater density of stations per million population that the UK as a whole. The countries of lowest population (Finland, Norway and the Republic of Ireland) have a high density of stations (130, 272 and 94 stations per million population respectively) and, to a certain extent, *vice versa*.

In Europe the average density of stations per million population is 79 if the total number of stations is considered, and 54 if only discharge stations are considered, compared to the average in England, Wales and Northern Ireland of 24 stations per million population. The UK therefore records a rather low gauging density in relation to population.

Within the UK (excepting Scotland for which no data were available), Northern Ireland achieves a relatively high density (rank 4th of 11), but there does appear to be an inverse relationship between population and density.

5.4 SUMMARY

- The position of Northern Ireland is about average for the UK in comparison with other European countries, having fewer stations per 1000 km^2 than all except Sweden, Finland and Norway, these countries being the three largest in area except for France.

- With a low population density and therefore relatively low pressure on water resources, a low density per unit area might have been expected; that this is not the case is encouraging in terms of monitoring flows in the wide diversity of environments present in Northern Ireland.

- The low density per unit population suggests an increase in density may be warranted. The physically similar Republic of Ireland, for example, has a density per unit population between 1.5 and 2 times that of Northern Ireland, and again the diverse nature of NI catchments suggests that this should be the case.

- The findings of this investigation give rise to no conflict with the recommendations arising from other parts of the study.

6 Hydrometric data quality review

6.1 DATA UTILITY

In the past many network reviews have focused, understandably, on the perceived data needs of the sponsoring organisation and major data users. In this study a baseline review of individual gauging stations via a simple indexing system, reflecting a spectrum of existing and potential applications for the river flow data, has been carried out in section 3.2. Clearly such an approach is an essential pre-requisite for a network appraisal. However, in order to establish a rational strategy for an overall network review it is also necessary to direct attention to the quality of the basic hydrometric data and the utility of the derived information. Too often data from a nominally primary gauging station at a critical location is found, at the analysis stage, to be of inadequate accuracy for the application considered, or too incomplete to apply the types of statistical treatments envisaged. Shortcomings in the data set may reflect a variety of factors, for example a very unstable stage-discharge relation in the low flow range or the pattern of upstream water usage disturbing the flow regime to such an extent as to render the gauged flows unrepresentative.

In order to index more effectively the performance and data quality of stations in the Northern Ireland network a broadly-based Data Utility Score (DUS) was developed to help establish the relative value of the time series of gauged flows associated with each individual monitoring site. One objective is to allow comparisons to be made between the user-perceived value of a station (section 3.2) and the actual quality of hydrometric data it may be expected to provide. Significant mismatches will help to highlight areas of the network where a critical review of station disposition and network evolution should be concentrated. A low 'utility' score at a strategically important site may indicate the need for improved flow measurement facilities whilst the opposite may suggest that de-commissioning should be considered.

The mix of the components incorporated in the Data Utility Score has, in part, been determined by the availability of the necessary information within the time constraints set for the project. The composition of the DUS is outlined below, with some key characteristics of the stations being shown in Table 6.1.

6.1.1 Low flow score

The accuracy and stability of the stage-discharge relation is, after the precision of stage monitoring, the most important determinand of the accuracy of daily mean flows. As part of the Institute of Hydrology's Low Flow Study, the scatter of check gaugings about the storage-discharge curve in the low flow range was assessed, mostly graphically but in a few cases the factorial standard error was available from a regression analysis (i.e. antilog the positive element of the standard error of estimate). These were not generally available for NI stations and an alternative appraisal was carried out with the staff from DANI who are engaged in maintaining the NI gauging programme. It was thus possible to evaluate the general hydraulic characteristics of the gauging section, its stability over time, susceptibility to weed growth, scour and accretion effects. A simple scoring system was selected, with four divisions. For some gauging stations DANI personnel preferred to discriminate to a finer level of detail by appending a plus or a minus; these refinements were pragmatically incorporated into the individual station scores (see Table 6.2).

Table 6.1 *Hydrometric data utility: basic information*

Station Number	River Name	Station Name	Station Type	Sensitivity (%)	Assoc. Acc. (mm)	Factors Affecting Runoff	Mean Annual Flood (cumec)	Highest Gauging (cumec)
201002	Fairy Water	Dudgeon Bridge	VA	15.0	3.0	N	70.4	21.9
201005	Camowen	Camowen Terrace	VA	29.0	2.0	N	90.0	110.4
201006	Drumragh	Campsie Bridge	VA	11.0	5.0	N	109.6	164.3
201007	Burn Dennet	Burndennet Bridge	VA	12.0	4.0	E	76.5	46.8
201008	Derg	Castlederg	VA	18.0	3.0	NE	197.9	187.1
201009	Owenkillew	Crosh	VA	7.0	7.0	N	306.9	297.4
201010	Mourne	Drumnabuoy House	VA	6.0	8.0	N	655.4	534.3
202001	Roe	Ardnargle	VA	15.0	3.0	NS	150.5	102.9
202002	Faughan	Drumahoe	VA	10.0	5.0	N	152.3	114.0
203010	Blackwater	Maydown Bridge	VA	16.0	3.0	N	103.0	130.5
203011	Main	Dromorna	VA	17.0	3.0	NS		
203012	Ballinderry	Ballinderry Bridge	VA	13.0	4.0	N	148.7	76.3
203013	Main	Andraid	VA	4.0	13.0	N		
203017	Upper Bann	Dynes Bridge	VA	12.0	4.0	S	75.9	82.9
203018	Six Mile Wr	Antrim	VA	11.0	5.0	NREI	84.9	94.3
203019	Claudy	Glenone Bridge	VA	38.0	1.0	N	45.7	51.7
203020	Moyola	Moyola New Bridge	VA	20.0	3.0	N	104.8	63.4
203021	Kells Water	Currys Bridge	VA	19.0	3.0	N	84.5	46.1
203022	Blackwater	Derrymeen Bridge	VA	14.0	3.6	N	38.5	27.7
203023	Torrent	The Moor Bridge	VA	10.0	5.0	I		
203024	Cusher	Gambles Bridge	VA	20.0	3.0	N	57.5	97.1
203025	Callan	Callan New Bridge	VA	9.0	6.0	N	34.8	35.9
203026	Glenavy	Glenavy	TPVA	17.0	3.0	P	24.2	24.3
203027	Braid	Ballee	VA	5.3	9.4	E	84.9	44.6
203028	Agivey	White Hill	VA	17.0	3.0	N	94.0	54.1
203029	Six Mile Wr	Ballyclare	VA	18.0	3.0	N		
203033	Upper Bann	Bannfield	VA	16.0	3.0	R	65.7	49.9
203038	Rocky	Rocky Mountain	FV	90.0	0.6	N		
203039	Clogh	Tullynewy Bridge	VA	19.0	2.6	P	36.1	21.1
203040	Lower Bann	Movanagher	VA			R		
203041	Ballygawley Wr	Tullybryan	VA	21.0	2.4	N	23.1	8.0
203042	Crumlin	Cidercourt Bridge	VA	25.0	2.0	N	42.1	34.2
203043	Oona Wr	Shanmoy	VA	22.0	2.3	N		
203046	Rathmore Bm	Rathmore Bridge	VA	23.0	2.2	N	10.9	12.8
203049	Clady Wr	Clady Bridge	VA	16.0	3.1	N	24.7	14.2
203093	Main	Shane's Viaduct	VA	11.0	5.0	N	220.2	230.5
204001	Bush	Seneirl	VA	9.0	6.0	N	64.0	77.7
205004	Lagan	Newforge	VA	14.0	3.6	GP	88.3	156.4
205005	Ravernet	Ravernet	FV	47.0	1.0	N	14.4	9.0
205008	Lagan	Drummiller	VA	26.0	2.0	N	27.0	32.8
205010	Lagan	Banoge	VA	17.0	3.0	N		
205011	Annacloy	Kilmore	VA			N	34.4	51.2
205015	Cotton	Grandmere Park	VA			N	4.3	
205020	Enler	Comber	FV	20.0	2.5	N	28.3	
205029	Lagan	Feney	VA					
206001	Clanrye	Mount Mill Bridge	VA	16.0	3.0	N	18.2	12.6
206002	Jerretspass	Jerretspass (River)	VA	50.0	1.0	N	9.8	15.5
206004	Cambane	Bessbrook	VA	13.0	3.8	N	11.9	13.9
236005	Colebrooke	Ballindarragh Bridge	VA	7.0	7.0	N	219.7	209.6
236006	Upper Erne	Killyhevlin	VA			R		
236007	Sillees	Drumrainy Bridge	VA	23.0	2.0	N	25.0	21.5
236009	Swanlinbar	Thompsons Bridge	VA					
236051	Ballycassidy	Ballycassidy Bridge	VA			N		

Table 6.2 *Data utility scores*

Station Number	Low Flow Score	Sensitivity Score	Total Low Flow Score	High Flow Score	QBAR /HG Score	Total High Flow Score	Record Length Score	Completeness Score	'Natural' Increment	Adjacency Score	Data Utility Score
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
201002	2.00	4	8.0	3.00	1	7.0	5	3	2	1	**26.0**
201005	3.75	2	9.5	2.75	5	10.5	5	5	2	2	**34.0**
201006	2.00	4	8.0	4.00	5	13.0	5	3	2	4	**35.0**
201007	2.00	4	8.0	3.00	2	8.0	4	5		3	**28.0**
201008	3.25	3	9.5	4.00	3	11.0	4	5	2	1	**32.5**
201009	3.00	5	11.0	2.00	3	7.0	3	3	2	1	**27.0**
201010	3.00	5	11.0	3.25	3	9.5	3	4	2	2	**31.5**
202001	2.00	4	8.0	3.00	2	8.0	4	2	2	2	**26.0**
202002	3.00	4	10.0	4.00	3	11.0	4	3	2	1	**31.0**
203010	3.00	4	10.0	3.00	5	11.0	5	5	2	3	**36.0**
203011	3.00	3	9.0	3.00			5		2	1	**17.0**
203012	3.25	4	10.5	3.25	1	7.5	5	5	2	2	**32.0**
203013	0.75	5	6.5	0.75			5	5	2	1	**19.5**
203017	2.00	4	8.0	2.00	4	8.0	5	3		2	**26.0**
203018	2.75	4	9.5	3.25	4	10.5	5	2	2	3	**32.0**
203019	2.75	1	6.5	3.00	4	10.0	4	3	2	4	**29.5**
203020	4.00	3	11.0	3.00	2	8.0	5	3	2	3	**32.0**
203021	3.25	3	9.5	3.00	1	7.0	5	3	2	4	**30.5**
203022	3.00	4	10.0	3.25	3	9.5			2	4	**25.5**
203023	0.75	4	5.5	0.75			5	1		1	**12.5**
203024	3.00	3	9.0	3.00	5	11.0	5	3	2	1	**31.0**
203025	1.75	4	7.5	2.00	4	8.0	5	3	2	1	**26.5**
203026	1.00	3	5.0	2.00	4	8.0	5	3		3	**24.0**
203027	1.25	5	7.5	2.25	1	5.5	5	3		2	**23.0**
203028	3.00	3	9.0	3.00	2	8.0	5	5	2	1	**30.0**
203029	1.00	3	5.0	0.00			5	3	2	4	**19.0**
203033	4.00	4	12.0	3.25	3	9.5	4	1		2	**28.5**
203038	3.75	1	8.5	1.00			3	1	2	1	**15.5**
203039	3.00	3	9.0	3.00	2	8.0	3			1	**21.0**
203040	3.25	4	10.5	3.00			3	3		1	**17.5**
203041	1.75	3	6.5	1.75	1	4.5	3		2	1	**17.0**
203042	3.00	2	8.0	3.00	3	9.0		3	2	3	**25.0**
203043	4.00	3	11.0	3.00			3		2	1	**17.0**
203046	3.00	3	9.0	3.00	4	10.0	3		2	3	**27.0**
203049	3.25	4	10.5	3.25	2	8.5			2	4	**25.0**
203093	3.25	4	10.5	4.00	4	12.0	2	5	2	2	**33.5**
204001	3.25	4	10.5	3.00	5	11.0	5	5	2	3	**36.5**
205004	2.00	4	8.0	3.25	5	11.5	5	1		3	**28.5**
205005	4.00	1	9.0	1.25	2	4.5	5	1	2	2	**23.5**
205008	4.00	2	10.0	3.25	5	11.5	4	5	2	1	**33.5**
205010	1.00	3	5.0	1.00			4	5	2	2	**18.0**
205011	3.25			4.00	5	13.0	3		2	2	**20.0**
205015	3.00			3.00			3		2	4	**9.0**
205020	4.00	3	11.0	3.00			3	1	2	3	**20.0**
205029										1	**1.0**
206001	1.75	4	7.5	3.00	2	8.0	5		2	2	**24.5**
206002	1.00	1	3.0	1.00	5	7.0	5	5	2	2	**24.0**
206004	3.00	4	10.0	3.00	4	10.0			2	3	**25.0**
236005	2.00	5	9.0	2.00	3	7.0	4	2		2	**24.0**
236006							3			2	**5.0**
236007	2.00	3	7.0	3.00	3	9.0	3	5	2	1	**27.0**
236009										4	**4.0**
236051	3.00			3.00					2	3	**5.0**

Note: The Total Low Flow Score is calculated by doubling the Low Flow Score and adding the Sensitivity Score.
Th Total High Flow Score is double the High Flow Score plus the QBAR/HG Score (QBAR = $\overline{Q}$)
The Data Utility Score is calculated by adding columns 3, 6, 7, 8, 9, and 10

Understandably, over a period of up to or exceeding ten years, the gaugings showed a significant degree of scatter with natural controls, illustrated by wide standard error of estimates for discharge. Within the DoE(NI), the philosophy was to be more responsive to possible changes in the low flow rating with time and to use subsets of gaugings in time slices, similar to mainland and international practice. A rating harmonisation exercise was under way which could provide the best way forward to discuss and reconcile these different approaches. However, in the context of the scoring procedure utilised here, the approaches are not considered to have materially affected the results.

6.1.2 Sensitivity

The sensitivity index, here defined as the percentage change in flow associated with a 10 mm increase of stage at the 95% exceedence flow, provides a measure of the vulnerability of computed low flows to systematic errors in the measurement of stage. Modern sensing and recording instrumentation is capable of limiting random errors in depth measurement to less than 5 mm and the impact on computed daily mean flows is normally negligible. However, the nature of rivers in Northern Ireland, as elsewhere in the UK, is such that small systematic errors, arising perhaps from operator error or algae/weed growth on a station control or weir crest can result in substantial errors in computed discharges; the factors contributing to such errors imply that there is a substantially greater chance that computed flows will be over estimated. Table 6.1 presents sensitivity percentages for stations in the NI network; the figures confirm that the distribution of sensitivities is similar to that for much of Great Britain. Table 6.1 usefully highlights the distinction between the major rivers, like the Mourne and Main, where the accuracy of stage measurement is less critical, and the small upland catchments where, despite the installation of Flat Vee weirs, computed flows remain very vulnerable to small systematic errors in recorded stage (see the Ravernet and the extreme example of the Rocky stream). Broadly, the largest sensitivity errors tend to correspond with the smaller catchments that, generally, are among the most hydrologically valuable; in unreservoired catchments the flow regimes are usually subject to relatively little artificial disturbance.

For some stations the sensitivity percentages were necessarily derived using provisional estimates of the 95% exceedence flow and, of course, some variation will occur as stage-discharge relations are revised. Nonetheless, the percentages are considered perfectly adequate for partitioning into the five divisions which constitute the Sensitivity Score featured in Table 6.2.

6.1.3 'Associated accuracy'

This is a corollary of the sensitivity; it indicates the precision (in millimetres) with which the stage needs to be measured at the 95% exceedence flow to restrict errors (from this source) to less than 5%. The entries in Table 6.1 demonstrate how the nature of the rivers in Northern Ireland set a practical limit to the achievable accuracy and serve to emphasise the importance of rigorous hydrological standards to maintain the quality and consistency of stage data. When considered alongside the perceived strategic and operational importance of individual gauging stations the sensitivity characteristics provide a useful means of establishing priorities for hydrometric expenditure both in relation to maintenance and instrumentation requirements and the need for major upgrading of stations (for example, installation of a low flow control).

6.1.4 Total low flow score

The Low Flow and Sensitivity Scores were combined to derive a Total Low Flow Score (TLFS); this is featured in Table 6.2 and on Figure 6.1.

6.1.5 High flow index

The index of high flow data utility was based on the grading procedure adopted for the Flood Studies Report and focused on the existence of confirmatory gaugings in the high flow range and the degree of containment in the flood range. A similar four category assessment to that for low flows was carried out with the same DANI personnel; the resulting High Flow Scores (HFS) appear in Table 6.2. A second component was incorporated following the provision of a schedule of mean annual floods ($\bar{Q}$) and highest gauging (HG) for each gauging station (compiled by DANI). An index score (in the range 1-5) was awarded on the basis of the ratio of $\bar{Q}$ to the highest gauging. The number of sites for which this ratio is less than unity testifies to a commitment to flood gauging that is unique within the UK. DANI personnel are to be commended for the thoroughness with which the high flow calibration has been monitored at the great majority of gauging stations. The consequent increased precision in the assessment of design will be of direct benefit in relation to river engineering and catchment management.

6.1.6 Total high flow score

Following the procedure adopted for the TLFS, the Total High Flow Score (THFS) was derived by doubling the HFS and adding the $\bar{Q}$/HG ratio score. The THFS is featured in Table 6.2 and on Figure 6.2.

6.1.7 Length of record

As with most time series, the value of a river flow record increases with its length, providing a more representative data set upon which to base water management decisions and a more robust input to the improvement in engineering design procedures. The average record length for Northern Ireland gauging stations - less than 15 years - is only about two-thirds of that for Great Britain and the lack of any series exceeding 25 years means that the historical context in which contemporary runoff variability can be directly examined is very restricted (see Chapter 1). In Table 6.2, scores have been ascribed in proportion to the number of years of data held on the National River Flow Archive.

6.1.8 Completeness of record

The apparent value of a river flow time series as indexed by the period since the commissioning of the gauging station may, in practice, be substantially diminished by even a moderate amount of missing data. For example, an overall loss of a few percent of daily mean flow values may obscure a large information loss under circumstances where the missing data are predominantly in the low flow range and the derivation of index statistics (e.g. annual 10-day minima, long term 95%ile flows) becomes impractical without considerable analytical effort. To provide a measure of the extent of missing data for Northern Ireland stations, a simple 'completeness' score has been incorporated in Table 6.2. The difficulties associated with the commissioning of a new archiving

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Figure 6.1
Total low flow score

Scale 1:750000

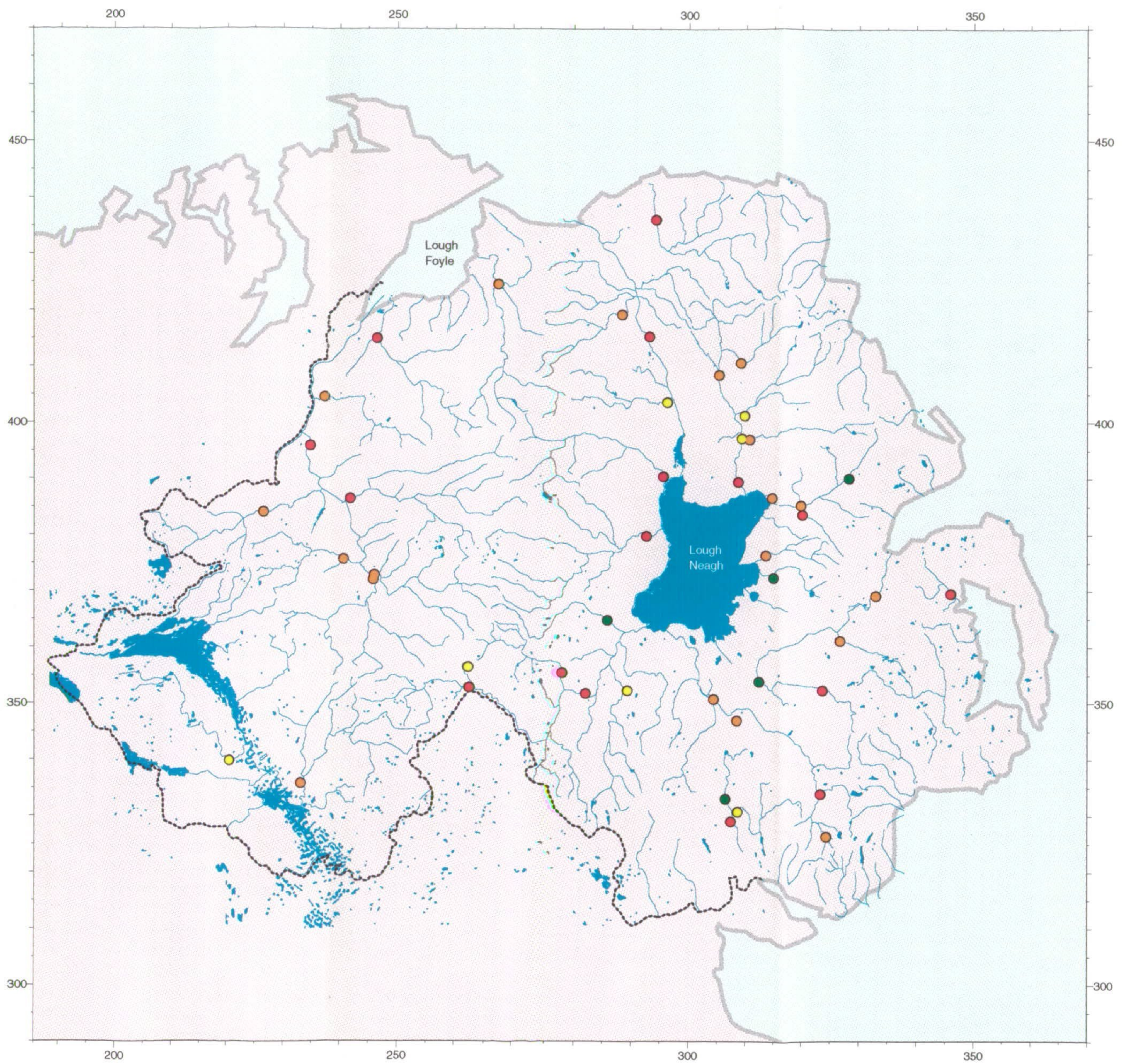
KEY

Coastline

Rivers

SCORE

- >= 10.0
- 8.0 - 9.5
- 6.0 - 7.5
- < 6.0



Dgener8 map producing software

Institute of Hydrology

Figure 6.2
Total high flow score

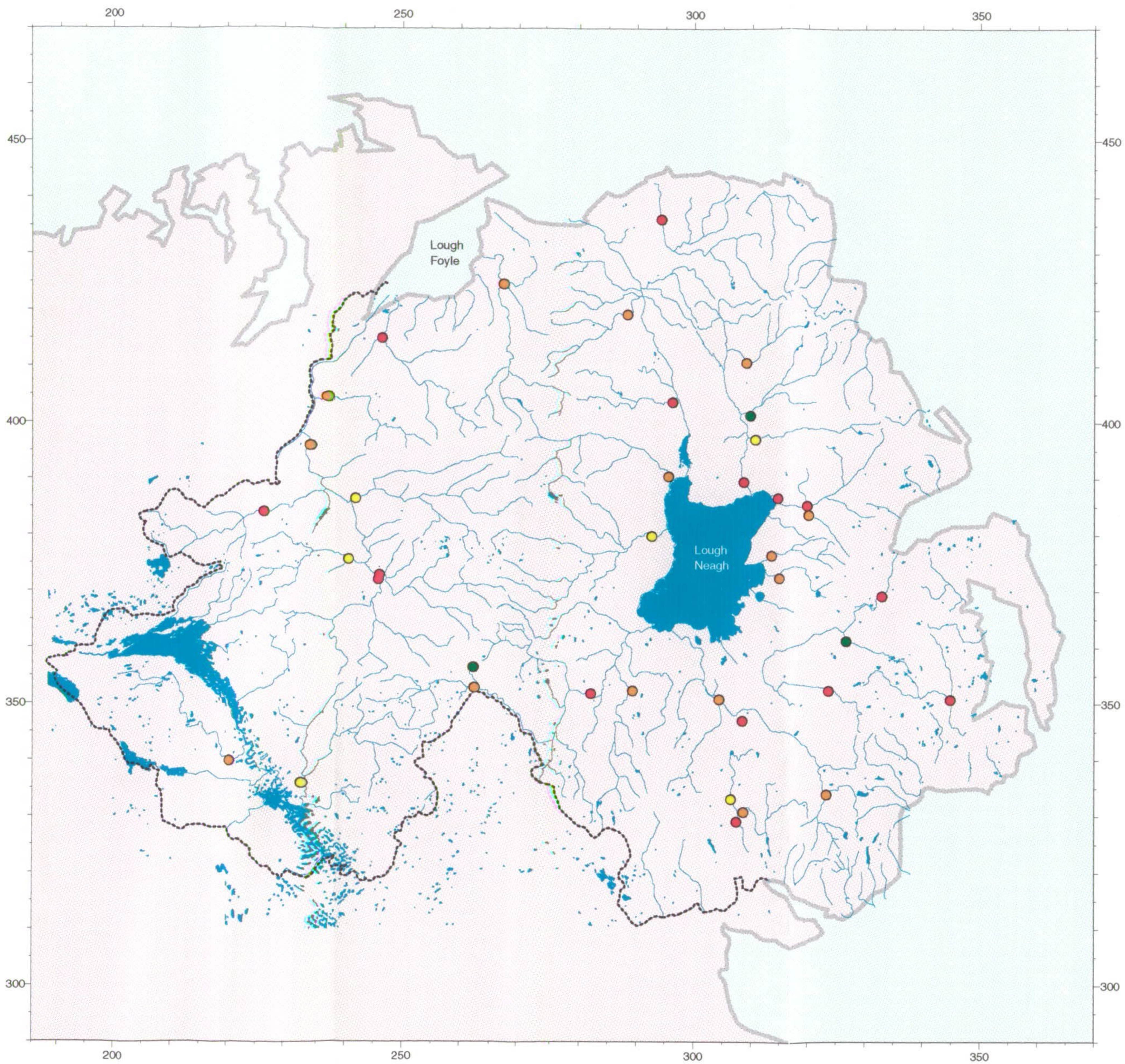
Scale 1:750000

Coastline

Rivers

SCORE

- >= 10.0
- 8.0 - 9.5
- 6.0 - 7.5
- < 6.0



system and the comprehensive review of NI rating equations currently in train has resulted in the omission of a significant number of stations from the data sets transferred to the National River Flow Archive in the recent past. Consequently, the period 1983-90 was adopted as a standard for assessing data completeness in this study. A score of 5 implies that more than 98% of the monthly records are complete; a 1 indicates that at least 12% of the months are incomplete. Adjustments to the score were made where the first or last year of record fell within the 1983-90 period and, in isolated cases, where the pattern of missing monthly peak flows differed appreciably from that displayed by the corresponding daily flow series.

6.1.9 Station type

For much of the UK, flow measurement structures - of various types - constitute well over half the hydrometric network and the station type can have a significant influence on the value of individual sites to the overall network. Gauging stations in Northern Ireland are predominantly of the velocity-area type so there is little potential for differentiation under this heading. However, the station type is significant in relation to the accuracy requirement associated with a number of important uses for hydrometric data - and may be a determining factor in the designation of benchmark stations. It is included in Table 6.1 for reference purposes; code meanings are listed in Appendix A.

6.1.10 Factors affecting runoff[2]

The continuing development of water-supply and sewerage systems, land drainage practices and land-use change all combine to disturb the pristine relation between rainfall and river flow in Northern Ireland. The net effect on low flow patterns especially can be significant and (unadjusted) gauged flows can be unrepresentative. For some applications which depend essentially on the actual flow in the river, this may present few problems but for others, including the development of catchment management plans, artificial influences can substantially reduce the value of a gauged flow series. Careful allowance for, say, the net impact of upstream abstractions and discharges can help restore the full utility of the data set but such flow naturalisation is not routinely practised in Northern Ireland. This is understandable given the very modest net disturbance to most flow patterns and - where abstractions and discharges are important - the availability of data from nearby analogous catchments with natural regimes. Natural catchments comprise about 80% of the NI network; the corresponding figure for England and Wales is around 15%. Nonetheless, in data utility terms clear benefits accrue from the monitoring of natural catchments - this is recognised in Table 6.2 by the 'natural flow increment'.

6.1.11 Co-location with primary water quality monitoring sites

A feature of hydrometric data usage over the last 15 years has been the increasing need to analyse both flow and quality data for the same catchment; often to investigate the complex interactions between the two but also to satisfy a growing demand for mass flow assessments. Such analyses

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2 The philosophy behind "Factors affecting runoff" is explanied in the IH publication "Hydrometric Register and Statisitics 1986-90" (ed. Marsh and Lees). The range of categories of adjustments and their codes are described; in the data section individual stations' codes are listed, together with a brief commentary regarding the extent of their impact on the flow regime.

are greatly facilitated by the co-location of monitoring stations. Experience with the management of the Harmonised Monitoring Scheme in Great Britain has underlined the difficulties resulting from even relatively small differences in the catchment size monitored at a gauging station and that of nominally paired water quality station. This reflects both the volume and properties of the inflows between the monitoring sites and the difficulties associated with attempts to routinely adjust the flows for the catchment area differences. On average, paired quantity and quality monitoring stations are closer in NI than on the mainland but where operational data requirements allow, there would still be considerable merit in maximising co-location as the joint networks evolve. In a few instances it is expected that existing or potential water quality applications will justify continued flow monitoring at NI gauging stations even in the absence of water resources or land drainage justifications.

The 'adjacency' column in Table 6.2 provides a simple index of the degree to which primary river flow and water quality monitoring sites are co-located. A score of 4 indicates that the sites are sensibly co-incident, whereas a 1 signals a mapped departure of more than two kilometres between the sites.

6.1.12 Data utility score

The overall station utility score includes low and high flow elements and contributions from the other components featured in Table 6.2. Arithmetically the DUS is derived as follows:

2 x Low Flow Score + Sensitivity + 2 x Flood Score +$\bar{Q}$/HG ratio score + Record Length + Completeness + Natural Increments + Adjacency.

Given the broad scope of this network review, it was determined that equal weighting should be attached to the low and high flow scores. It will be appreciated, however, that when particular applications are being considered there would be merit in varying the relative contribution of each component in the overall assessment. For example, if drought monitoring was of principal concern, the low flow items should feature strongly and length of record would assume an enhanced significance. The collation of the individual component scores in spreadsheet form allows the compilation of revised overall scores targeted on the aims of particular projects or programmes.

The overall utility scores are mapped on Figure 6.3 and underpin many of the network refinements detailed in Chapter 8. They also allow the relative value of individual station records to the information output from the network to be examined. Table 6.3 ranks the DUS scores; care is needed in interpreting the relative position of individual stations where information for some score components is not available. Nonetheless, the spread of scores usefully distinguishes between those which may be considered fully primary and those where such status is inappropriate. Consideration of the station performance and the quality of hydrological information required for the uses identified in Chapter 3 merits a critical review. Generally, stations scoring over about 25 may be expected to form the backbone of the NI network. It will be evident, however, for several gauging stations the *ranking* of the high or low flow score is markedly poorer than that for the DUS - examples include 201007 and 201009. A review of the hydrometric performance of the stations - and especially the derivation of stage-discharge relations - is recommended in these cases (see Chapter 8). Equally, severe inconsistencies between the range of uses identified in Appendix C1 and the corresponding Data Utility Score require further investigation with an emphasis on how stringent the data requirements actually are (examples include 201007 and 205004). Encouragingly, there is a strong general correlation

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Figure 6.3
Data utility score

Scale 1:750000

Coastline

Rivers

SCORE

>= 30.0

25.0 - 29.5

20.0 - 24.5

< 20.0

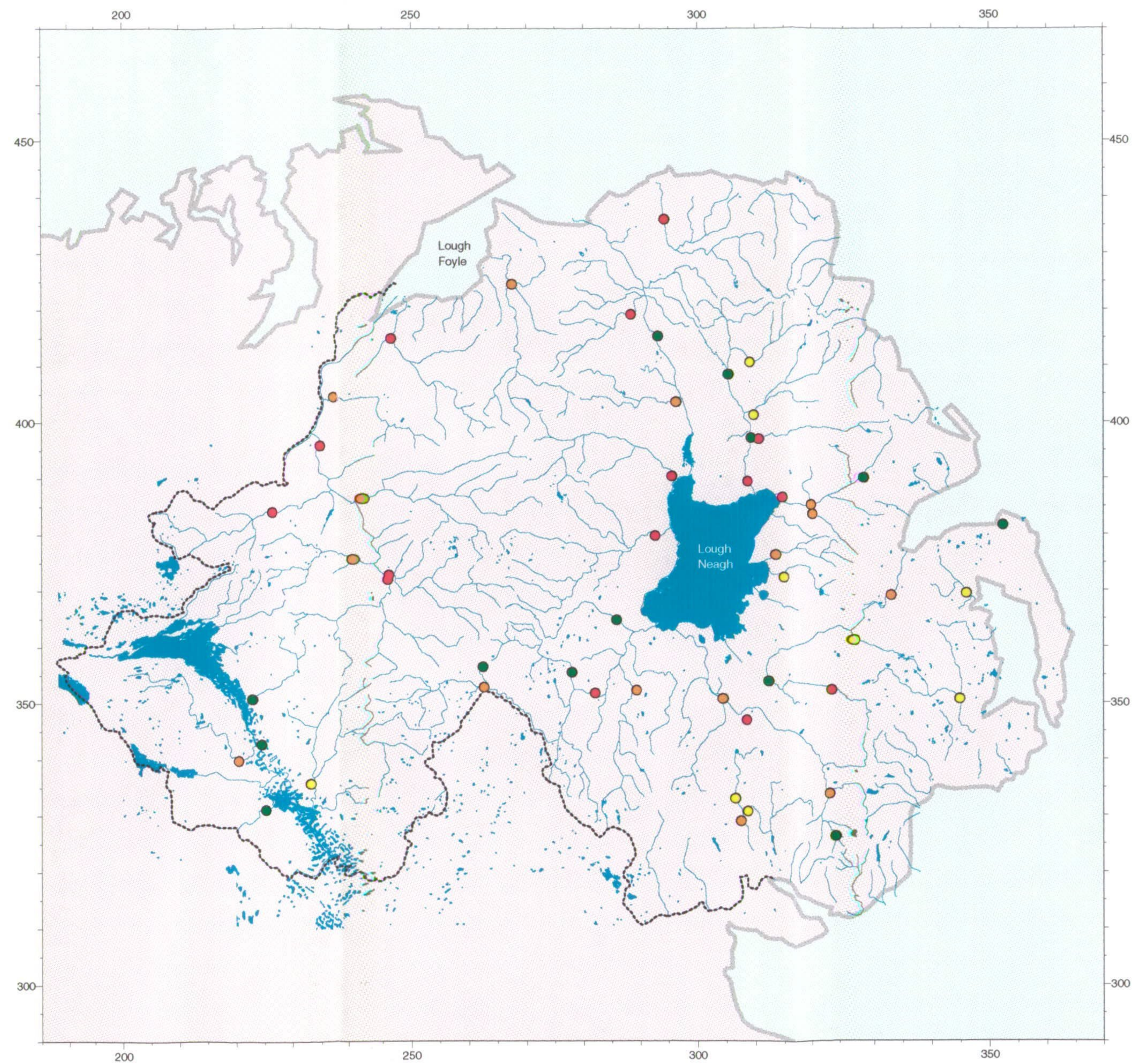


Table 6.3 *Ranked data utility scores*

Station Number	Data Utility Score	Total Low Flow Score	Total High Flow Score	'Uses' Score
204001	36.5	10.5	11.0	9
203010	36.0	10.0	11.0	7
201006	35.0	8.0	13.0	5
201005	34.0	9.5	10.5	5
203093	33.5	10.5	12.0	5
205008	33.5	10.0	11.5	7
201008	32.5	9.5	11.0	7
203020	32.0	11.0	8.0	5
203012	32.0	10.5	7.5	8
203018	32.0	9.5	10.5	6
201010	31.5	11.0	9.5	10
203024	31.0	9.0	11.0	5
202002	31.0	10.0	11.0	10
203021	30.5	9.5	7.0	9
203028	30.0	9.0	8.0	7
203019	29.5	6.5	10.0	5
203033	28.5	12.0	9.5	9
205004	28.5	8.0	11.5	11
201007	28.0	8.0	8.0	9
201009	27.0	11.0	7.0	7
236007	27.0	7.0	9.0	4
203046	27.0	9.0	10.0	4
203025	26.5	7.5	8.0	4
201002	26.0	8.0	7.0	7
203017	26.0	8.0	8.0	0
202001	26.0	8.0	8.0	8
203922	25.5	10.0	9.5	8
203042	25.0	8.0	9.0	5
206004	25.0	10.0	10.0	6
203049	25.0	10.5	8.5	3
206001	24.5	7.5	8.0	7
206002	24.0	3.0	7.0	5
203026	24.0	5.0	8.0	5
236005	24.0	9.0	7.0	6
205005	23.5	9.0	4.5	6
203027	23.0	7.5	5.5	6
203039	21.0	9.0	8.0	3
205020	20.0	11.0		6
205011	20.0		13.0	7
203013	19.5	6.5		0
203029	19.0	5.0		4
205010	18.0	5.0		0
203040	17.5	10.5		9
203041	17.0	6.5	4.5	4
203911	17.0	9.0		0
203043	17.0	11.0		4
203938	15.5	8.5		3
203023	12.5	5.5		3
205915	9.0			3
236051	5.0			5
236006	5.0			2
236009	4.0			6
205029	1.0			4

between high DUS and high 'uses' scores which provides an endorsement of the network's capability in relation to the priority user needs.

Recommendations regarding the improvement in the hydrometric performance and maximising the information recovery from the network appear in Chapters 8 and 9.

6.2 SUMMARY

- A methodology has been developed to allow comparison of gauging station utility and performance between sites using a Data Utility Score.
- The method is valuable in identifying mismatches between gauge performance and required accuracy.
- The method may be tuned to vary the importance ascribed to the component elements - increasing the weighting of the low flow component, for example.
- There is generally a high correlation between the DUS and the "uses" score (see Chapter 3 and Appendix C1).
- The hydrometric performance of some sites requires investigation, given the anticipated use for the data.

7 Gauging requirements for reservoir yield studies

7.1 REVIEW OF EXISTING STREAMFLOW GAUGING AND SPECIFIC RECOMMENDATIONS FOR GAUGING REQUIREMENTS

The current Northern Ireland network is biased around the gauging of rivers in their lower reaches, or upstream of a confluence for tributaries. No gauge is sited within a reservoir gathering ground and only one gauge exists at an elevation appropriate for such runoff estimation. The site, the River Rocky at Rocky Mountain, has a catchment area of 6.68 km^2 and its elevation is about 200 m. Other sites, gauged at elevations above 80 m, have been closed, with the exceptions of the Clogh at Tullynewy Bridge and the Lagan at Drummiller, both of which are over 80 km^2 in area. The Clogh has Dungonnell Water in its headwaters which impounds nearly 15% of the Tullynewy Bridge catchment. The formal flow gauging network thus provides little direct information on the yield of reservoired catchments.

The W. S. Atkins report (1993) echoed the Gibb report (1984) in highlighting the importance of maintaining a time series record for flow data on major intakes and reservoired catchments.

With little benefit deriving from the existing flow network, other choices for evaluating inflows are necessarily indirect, being:

- the sum of storage change, outflows, spill and supply draw-off
- the application of a rainfall-evaporation loss model.

Storage change is a notoriously difficult and insensitive measure but it is possible with reservoir level recorders augmented by wave recorders. Outflows may be gauged effectively by weirs in the stilling basin or at wider range sites further down the channel - invariably less challenging environments than gauging reservoir inflow conditions - with the benefit that spill would also be accommodated. Gauging directly from spillweirs is possible but again subject to insensitivity. Draw-off to direct supply is invariably by pipe meter. Such approaches, while possible, normally yield data reliable over timescales of not less than one week but which are probably good enough for yield assessment purposes.

An understanding of the pattern of rainfall variability in headwaters is likely to be limited and assumptions regarding the conservative nature of evaporative loss may be incorrect (as implied, for instance, by the unexpectedly high interception losses deduced at the Balquhidder sites in Perthshire, Central Scotland from heather moorland). Although the Province in general is well served for rain recorders and climate stations, the higher elevation sites tend, along with the long record daily sites, to be sited at reservoirs or at the abstraction treatment works (e.g. Quoile Res., Altnahinch filters, Spelga Dam), that is, below the elevations where uncertainties are most pertinent to yield assessments. Raingauges in the reservoir gathering grounds mostly capture monthly accumulations. Rainfall records at sub-daily resolution to assist in the analysis of extreme flood events are scarce. Improving the information provision from this sector of hydrometry is an option which would involve relatively modest cost; modern logging devices would not require the daily visits that autographic instruments required in the past, for example.

We have interpreted the recommendations for gauging sites and would suggest the following candidate areas should be considered:

- Sperrin Mountains - headwaters of the Roe catchment. Glenshane or Banagher Forests would capture data from forested areas and benefit from the long rainfall records at Altnaheglish. Alternatively or in addition, southern draining tributaries to the Glenally River would also be candidates, with the prospect of good access from the B47.

- Antrim Mountains - either a catchment draining from Orra Head, perhaps the Glendun or Glenshesk rivers or from Collin Top, the headwaters of the Braid.

- Mourne Mountains - a formal flow gauge on the Annalong river, upstream of the tunnel to capitalise on the long Annalong record. Such a site would have attractions for the monitoring of climate change.

Following on from an observation in the review, it is recommended that steps are taken to ensure the capture of data from the established sites in the Annalong river system.

7.2 ECONOMIC VALUE OF GAUGING RESERVOIR-RELATED FLOWS

A conventional approach would be to justify gauging where:

$$\frac{\text{Value of extra yield}}{\text{Cost of gauging}} > 1$$

In mountain areas lacking adequate rainfall estimation, resources are often under-estimated on small headwater streams. Proving an extra 100 mm per year average runoff through good gauging procedures would not be uncommon; once reservoired, 75% of that stream resource which had been identified might become extra gross yield. The corresponding gain to supply could be two thirds of that figure i.e. 50 mm per year. Hence, for a reservoir with a 10 km^2 catchment, the supply gain would be 1.4 Mld. It would not be reasonable to assign a higher value to that yield than its selling price. At a typical OFWAT calculation of close to 60 pence / m^3, 1.4 Mld would bring an income of £306,000 per year. On recent figures, even if all costs of creating that yield were deducted, the average income to shareholders would be almost 25% of that figure, say £76,000 per year.

The cost of gauging reflects the size of stream to be spanned by a weir and the subsequent maintenance and data processing costs. Constructing a concrete weir is not likely to exceed £5000 per metre stream width, even with difficult access, unless planning requirements for the recorder and logger housing are expensive to implement. Allowing for a 5m wide stream gives a capital cost of £25,000, to which should be added running costs of £2000 per year, assuming there is no siltation problem and all processing is computerised as part of a bigger hydrometric operation. Thus all-in loan repayment and ruuning costs can be put at about £5000 per year. Consequently a reasoned benefit cost ratio is the income from the previous paragraph against the running cost, i.e., 76,000 / 5000 = 15.2 (it would be higher if gauging ceased as soon as the enhanced yield was verified). Such a figure can be improved in its accuracy by local re-estimation of the components. However, it is only reached after many years. Allowance can be made by Present Worth methods for the way in which the gauging expenditure may run 10 years ahead of the income stream from the any water sales, and possibly 25 years ahead of when the extra (and hence final) increment of scheme yield will be first sold. At 5% test discount rate the value of £1 in 25 years time is 29.5p now and in 50 years time 8.7p; so the true long term benefit / cost ratio is likely to remain well above unity so long as the reservoir is built and used in timely fashion after gauging begins.

Gauging will always be most valuable where most uncertainty exists about the hydrological regime. Many scenarios are possible where the flow variablity is less well known. On the most pessimistic approach the gauging results at a particular NI dam site might prove a drop of yield of, say, 1.4 Mld. In such a case, the corollary is a firm argument for a lower compensation flow. As such a flow is conventionally one half of nett yield, the value of gauging could then be put at 0.7 Mld or £38,000 per year, leading to a benefit / cost ratio of 7.6 in the long term and possibly below unity once gradual uptake of scheme yield is accounted for. This points to the value of low cost interim gauging at the dam site to narrow the scope for change at the earliest possible date.

To put it another way, by inverting the reasoning above, provided the mean streamflow cannot be estimated from generalised techniques to within 1.8 Mld per year, then fomal gauging is likely to be justified. No value has been put here on the higher precision of reservoir operation that is possible with good gauging. Control rules can be defined with more confidence and so it may be realistic to suggest that up to 10% less storage need be held in reserve for contingencies. The value of that storage for yield (plus some incidental flood control) will vary from location to location but might well double the benefit / cost figures above.

In practical terms, if there is already a good naturalised flow record for an earlier reservoir in an adjacent valley, it is unlikely that the additional knowledge by a further measurement of the one hydrological regime will be justified. (Hence, it is very rare to find extra gauging prior to a second or third reservoir being built in cascade down the valley).

It can occur that the case for full gauging is poor in terms of yield assessment but that the cost of spillway works (and freeboard) warrants local continuous measurement of rainfall, time to peak and percentage runoff. In such cases, a temporary level recorder upstream of a rateable natural control is usually fully justified - particularly when the form of construction requires a tunnel or culvert diversion with a coffer dam.

Saving money by not gauging before dam construction could lead eventually to a lower supply reliability than is normal. However, recent research, yet to be substantiated outside of the USA (Howe and Smith, 1994), suggests consumers are unwilling to pay for the marginal costs of the extra security that water engineers feel is proper. This may be the result of contingent valuation surveying in a normal period rather than after a critical drought. Nevertheless, it does seem possible that in water supply systems not prone to a sole dam emptying, lower reliability could be countenanced, providing the community accepted the increased frequency of minor restrictions (e.g., hose pipe bans).

Applying similar thinking after reservoir construction will determine whether permanent instrumentation should be added in order to compute outflow totals, storage change and inferred inflow (preferably on an hourly time scale to permit unit hydrograph and loss function derivation). For modern UK dams, frequently designed to contain the probable maximum flood (PMF), there is a high chance that modern instrumentation will permit a later rise in the spillweir crest level. This is particularly so if the instrumentation is enhanced by a reservoir wave recorder in the dam approach. The costs of permanent instrumentation can be kept down by careful planning of the method of data processing and the use of standard profiles on spillweirs and stilling basin outlet weirs.

7.3 REVIEW OF GAUGING STRUCTURES TO BE INSTALLED

The difficulties associated with gauging in upland areas may be summarised as follows:

- gauge site selection - favourable straight reaches for at least 10 times the channel surface width, of uniform cross section - these are hard to locate;

- steep slopes - too steep a slope raises problems of critical or supercritical flow conditions and standing waves in the channel; ideally approach channel slopes and channel roughness should be such that Froude numbers are in the range 0.1 to 0.5;

- coarse sediment transport - the high energy associated with steep streams results in the transport of material of coarse gravel, cobble and, occasionally, boulder size;

- rapid fluctuations in river stage - may lead to problems with stilling well lag and the "hunting", of instruments, particularly mechanical followers;

- instability of gauging section, laterally and longitudinally - scour and redeposition following high flow events;

- wide variation in discharge - with impermeable catchments in particular, low flow sensitivity and acceptable high flow capacity may be difficult to reconcile;

- remoteness of location and access - ongoing considerations when a station is operational. This has an impact on the frequency of visits and the provision of maintenance;

- possibility of ice formation affecting flow patterns and instrumentation.

Some other aspects are more favourable:

- limited artificial disturbances;

- a greater likelihood that the full flow range would be contained.

7.3.1 Upland catchment gauging - UK practice

Within the UK, the methods employed to gauge upland rivers are covered by the following:

i. Velocity-area method (Stage-discharge method)
ii. Flow measurement structure
iii. Dilution gauging

A feature of gauges on small upland catchments is the prevalence of structures as the measuring method. Of the gauges above 200 m elevation and at or below 25 km^2 in area whose details are held in the National River Flow Archive (about 60 in number), only four sites utilise the velocity-area method exclusively. The most favoured structure has been a thin-plate weir of some description. However, many sites so measured are at reservoir outfalls and although a thin-plate weir maybe appropriate in this situation because of modest cost and potential precision, the sites are atypical of natural conditions, where a more aggressive flow regime will obtain. Of the 28 stations currently in operation on natural channels, the number installed with the variety of measuring method are as follows:

8 Flumes, 6 of which are steep stream structures at the IH's Plynlimon experimental catchments
5 Compound, Crump profile (1:2 upstream, 1:5 downstream) level crest weirs
4 Shallow Vee Crump profile weirs, cross slopes normally 1:10
4 Velocity-area sites, rating established by gauging (but includes 3 sites with informal shallow vee controls)
3 Single, Crump profile, level crest weirs
3 Thin-plate low flow controls with sections calibrated by gauging when the capacity of thin plate is exceeded
1 Miscellaneous structure rated by model or gauging

The reasons for structures being favoured for continuous monitoring over a wide flow range are compelling:

- If correctly installed, the accuracy of measurement is high;

- if the measurement of stage can be effected without significant lags occurring between the channel and the stage recorder, then the rapid response of upland rivers can be captured;

- the maintenance demands should be modest; check gaugings would be performed at intervals but a current metered relationship is unlikely to improve upon the theoretical calibration where the field conditions conform to the limits established for the laboratory-derived calibration. On the basis of limited evidence it is apparent that many structures, the Crump profile weir particularly, are capable of effective operation outside of the limits established by laboratory confirmation and International Standards (but see Appendix F on IH gauging experience). Accretion on the upstream apron of weirs may require periodical remedial action. Long-throated flumes if well designed are self cleansing. As structures rely upon establishing critical flow conditions to function, which *generally* implies an accelerated velocity over the approach, they have the attribute of being able to pass coarse material of considerable size without significant damage;

- the stabilisation of the channel at the structure (if sympathetically designed to accord with the natural channel dimensions) lessens the task of reviewing calibration following significant flow events as would be standard practice with velocity-area stations;

- there is the opportunity, in theory at least, of operating the Crump profile weirs in the non-modular range, although it is unlikely that the conventional design of crest tapping, via an orifice plate just downstream of the crest within the separation pocket and thence to a separate stilling chamber, would be reliable enough in upland conditions (no measuring authority uses them). The potential of using modem, robust and sensitive pressure transducers in such a position has encouraging possibilities. However, with suitable siting, these weirs in upland sites may remain modular for the full range of flow.

7.3.2 Ultrasonic (US) and Electromagnetic (EM) gauging methods

Other gauging methods in use in England and Wales are those utilising ultrasonic or electromagnetic instruments. These are primarily velocity-area stations with the new technologies being used to estimate velocity within a channel of known - and generally formalised - configuration and dimensions. They have proved popular in circumstances where conventional methods may not be successful; typically deep sections with low velocities, sites where there was no unique relationship between stage and discharge, heavily weeded sections, sites affected by flow reversals and, for the US method, rivers of substantial width and depth. As electronic devices have become cheaper, the early high capital cost of the new technology sites has moderated and made them much more competitive in cost terms with the conventional civil engineering works associated with structures and/or cableway suspension systems and stilling wells (civil works associated with EM gauges may still be considerable). As they are installed in open channel sections, albeit formalised, their aesthetic appearance is favourable and effect on river afflux is minimised. Potentially, the EM method is a particularly attractive option for monitoring small upland rivers but currently a significant requirement for both EM and US gauges is access to a mains power source, which would probably render them impractical for remote sites.

7.3.3 Recommendations for gauging method

The upland sites which would be chosen for the refinements of yield assessment may not be associated with the potential for developing reservoir storage in that catchment - although that remains an option. The gauge(s) would permit the transfer of flow characteristics to analogous sites and to the inflow regimes of existing reservoirs. This would allow some flexibility in establishing sites which were not too challenging to gauge. At such sites, the combination of low flow sensitivity, predictable stage-discharge relationship and good capacity favours the installation of shallow vee, Crump profile structures. Depending upon the natural degree of containment and breadth of the section, the site may need to be augmented by flood banks and have a subsidiary cableway for high flow measurement. Where appraisal of gauge results indicate that field calibration is unavoidable, the IH's experience suggests that current metering in difficult environments, whilst challenging, is still practical. It would seem advisable to provide some mechanism for allowing check gauging and monitoring of upstream apron accretion and velocity distribution, perhaps with sturdy bridges as are present at Balquhidder.

7.4 REVIEW OF DATA COLLECTION AND ANALYSIS METHODS

In anticipation that any upland gauging would be integrated into the wider hydrometric network, the general recommendations regarding data capture and processing are to be found in Chapter 6. Some observations regarding the recording instrumentation are appropriate. Float driven instruments in a stilling well should have as little inertia and backlash as possible to allow a prompt and accurate following of rapid stage changes. In this regard, the optical shaft encoder scores very highly with its low inertia and minimal backlash, with the additional benefit that its digital output is in a format compatible with solid state data logging and/or telemetry transmission or interrogation. Backup instrumentation could include a horizontal drum reversing chart recorder; typical British practice is now to use chart recorders with two weekly or monthly traverses. We believe that in a small catchment, the monthly chart is inappropriate. Indeed, were the chart to be used to infill records where a shaft encoder had failed, say, we would still recommend the weekly chart option. Stilling wells in remote upland locations can be susceptible to freezing which renders float driven recorders unreliable. Another option includes depth gauges in the river channel close to the tapping point. Potential candidates would be upward or downward facing ultrasonic gauges or pressure transducers.

Our recommendation would be to consider an optical shaft encoder as the primary means of data capture, recording onto a solid state logger, linked by telephone for telemetric data transmission. Back-up instrumentation would be a within channel pressure transducer recording onto a separate channel in the logger at sites where freezing could be a problem. Otherwise, a chart recorder providing a visual display of the stream's behaviour on site would be an alternative. The ability to display a stage hydrograph from the logger on-site (with a portable microcomputer) would allow more latitude with the above combinations. Such a viewing may also be provided in the office, following transmission of stage levels by telemetry on a daily basis, say.

7.5 REVIEW OF PROCEDURES FOR MAINTENANCE AND THE SKILL AND NUMBER OF OPERATIVES

Once a station has been installed then the evaluation and maintenance of its performance is ensured by monitoring elements which are subject to change and ensuring stability in others which should remain within identifiable tolerances. Some of these functions may be carried out to a regular schedule, others are responses to recognised changes. There has been considerable attention paid to the recognition, description and implementation of gauging station operating procedures on the mainland in recent years, with the desire on the part of some measuring authorities to submit these procedures for accreditation in accordance with the criteria of BS5750 or ISO9000. Many of these are not yet in the public domain. However, a set of functions to be included within operational procedures to secure the hydrometric quality of the station should be:

i. Surveying of station datum levels against Ordnance Bench Marks (two if possible);
ii. surveying and measurement of structural dimensions;
iii. maintaining correspondence between the river level and the level captured by the recording device(s), including back-up instruments and their correct registration against the station datum levels;
iv. monitoring the condition of the control(s) which affect(s) the site and effecting remedial action if necessary;
v. maintain a gauging regime to check and, if appropriate, eventually revise the station calibration;
vi. maintenance of a station log of visits, levels taken, flow estimates from the rating equation, status of instrumentation, batteries, remedial works effected or required, revised levels following maintenance, replacement of instruments, observer's name - the log preferably in duplicate to allow a history always to be present at the site. If a chart recorder is present, annotate the chart with levels and date/times, plus commentary if necessary for clarity.

In order to realise these functions, other maintenance aspects relating to the physical nature of the site, its instrumentation and communications have to be included:

a. diagnostic testing of electrical components, if appropriate, following codes of practice to ensure electrical safety, and displaying data stored by logging devices;
b. ensuring free operation of float driven couplings;
c. follow manufacturer's schedules for the lubrication and maintenance of winches and cableway systems;
d. removal of obstructions, including excessive material accreted onto weir aprons and clearance of stilling well intake pipes by rodding or back flushing;
e. ensuring weir crests are free from algal or vegetative build up (could easily equate to 10-15 mm of head and significantly distort low flow estimates);
f. excessive wear or damage to weir crests to be remedied by replacement crest sections or refinishing, followed by resurveying and measurement;
g. repair or replace items damaged by vandalism, lightning strikes, storms;
h. ensure that the access routes, fences, gates, locks are in good repair, ditto for ancillary equipment - pumps, valves, ladders, generators, survival kits;
j. ensure that leases, wayleaves, payments and ownerships are routinely checked;
k. check and recalibrate if appropriate, portable measuring equipment such as current meters and dipflash/diptone devices.

The third major set of considerations relate to Health and Safety. A British Standard Code of Practice, 'Safe Practice in Stream Gauging' is available which covers safety precautions and procedures that should be observed in the operation and maintenance of river gauging stations in the tasks associated with the measurement of level and flow in open channels. Examples would include access to stilling wells, buildings and gas detection; reporting procedures for lone workers and safe working conditions related to depth of water.

General qualities to be sought in hydrometric operatives should be enthusiasm and commitment, a practical and methodical approach and an enquiring nature. Academic or vocational qualifications of the level provided by BTEC courses would be appropriate. Specific training about hydrometric principles should be provided, whether in-house or by training agencies, with particular emphasis on how the good practice in the field is transmitted through the data processing route to yield data of significant utility. Within the hydrometric hierarchy, graduate engineers and hydrologists are likely to play a role in the specification of operational schedules, the quality control of the flow data produced and, crucially, the derivation of stage-discharge relations. Notwithstanding the necessary partitioning of responsibilities between professional and field staff, the latter should be encouraged to take a proprietorial attitude to both the gauging stations and hydrometric data under their aegis. This in turn can be encouraged by ensuring that jobs are structured so that field staff do not become isolated from the end product of their work - the archived data and their applications.

Numbers of operatives relate to the numbers of sites to be attended to, geographical location of sites and bases and the nature of gauging carried out at the sites. To repeat, in anticipation that the upland gauging sites would be members of a wider network, and together with some rationalisation of the network, it is not anticipated that significant changes to the numbers of gauging staff would be necessary.

7.6 SUMMARY

- The formal flow gauging network provides little direct information on the yield of catchments which contain or may be appropriate for reservoir operations.
- The hydrometry to assess inflows to existing reservoirs is not developed.
- The following candidate areas should be considered for gauging:
  - Sperrin Mountains; Roe and Glenally Rivers
  - Antrim Mountains; Glendun or Glenshesk Rivers
  - Mourne Mountains: Annalong River.
- In mountain areas lacking adequate rainfall estimation, favourable benefit / cost ratios for gauging to prove catchment yield may be demonstrated.
- Provided the site conditions permit of it, the shallow vee, Crump profile weir would be the preferred gauging instrument.
- An optical shaft encoder would be considered the preferred primary data capture instrument; recording should be to a solid state logger with a telemetered data transmission link.
- Guides to practice for gauging station operation and maintenance are current among mainland and international gauging agencies (although these may not be published). The forthcoming British Standard on Hydrometric Data Mangement would be an appropriate reference.
- It is not anticipated that significant changes to the numbers of gauging staff would be necessary.

8 Recommendations for network change

8.1 INTRODUCTION

In this chapter, attention is focused on the specific objectives identified in the consultant's brief for this study. Details are given, in summary form, of how the recommendations may benefit each of these objectives. It is stressed that a synthesising approach to improving the network is, in the authors' opinion, the only realistic one as the great majority of station changes can benefit more than one function of the hydrometric network. As the exploitation of the data from individual stations and recommendations for future action may serve a number of elements of the client's requirements, the presentation of general network observations follows.

8.1.1 Evaluation of existing stations

In Chapter 3, 34 flow stations and 8 level-only stations were identified for continuing operation because of specific data requirements. This list is used as the starting point for the present evaluation; recommendations for the future of sites not on the list being determined by:

- data utility assessments
- consideration of the contribution which each can make towards realising the objectives arising from the theoretical assessment of the network
- the requirements of modelling studies
- the overall shift in gauging density suggested by comparison with other areas.

Where the data utility assessment indicates that a site is clearly incapable of serving the needs identified in Chapter 3, upgrading or relocation is recommended irrespective of whether the initial recommendation was for automatic continued operation or not. At many other stations, however, data quality is lower than the requirement for some of the data uses identified, and therefore remedial action is required in such cases. Stations identified for closure, relocation or review are shown in Figure 8.1.

Stations justified by continuing specific data requirements

Stations automatically identified for retention in Chapter 3, and not associated with major conflicts between data quality and the requirements of the specified data uses:

Flow stations

201002	Fairy Water at Dudgeon Bridge
201007	Burn Dennet at Burndennet Bridge
201008	Derg at Castlederg
201009	Owenkillew at Crosh
201010	Mourne at Drumnabuoy House
202001	Roe at Ardnargle
202002	Faughan at Drumahoe
203010	Blackwater at Maydown Bridge
203012	Ballinderry at Ballinderry Bridge
203018	Six Mile Water at Antrim
203019	Clady at Glenone Bridge

203021	Kells Water at Currys Bridge
203922	Blackwater at Derrymeen Bridge
203033	Upper Bann at Bannfield
203040	Lower Bann at Movanagher
203042	Crumlin at Cidercourt Bridge
203092	Main at Dunminning Lower
204001	Bush at Seneirl
205004	Lagan at Newforge
205005	Ravernet at Ravernet
205008	Lagan at Drummiller
205011	Annacloy at Kilmore
205029	Lagan at Feney
206001	Clanrye at Mount Mill Bridge
206002	Jerretspass at Jerretspass (River)
206003	Newry Canal at Jerretspass (Canal)
206004	Cambane at Bessbrook
236905	Colebrooke at Ballindarragh Bridge

Level-only stations

203614	Lough Neagh at Derryadd Bay
203315	Lower Bann at Toome (Lower Bann)
203616	Lough Neagh at Toome (Lough Neagh)
205301	Quoile at Quoile Barrier Lower
205302	Quoile at Quoile Barrier Upper
236601	Lower Erne at Rosscor
236602	Upper Erne at Portora
236603	Upper Erne at Belle Isle

Following a review of stations not justified by any continuing specific data requirement 5 stations are recommended for closure, 2 for relocation and 5 others for further review; 3 are seen as requiring particular attention to improve data quality:

Closure:	201006	Drumragh at Campsie Bridge
	203024	Cusher at Gambles Bridge
	203025	Callan at Callan New Bridge
	203026	Glenavy at Glenavy
	203027	Braid at Ballee
Relocation:	203029	Six Mile Water at Ballyclare
	203041	Ballygawley Water at Tullybryan
Review:	203301	Lower Bann at Loughan Island (level-only)
	203902	Lower Bann at Agivey Bann Bridge (level-only)
	203308	Lower Bann at Portna (level-only)
	203009	Blackwater at Verners Bridge (level-only)
	203023	Torrent at The Moor Bridge

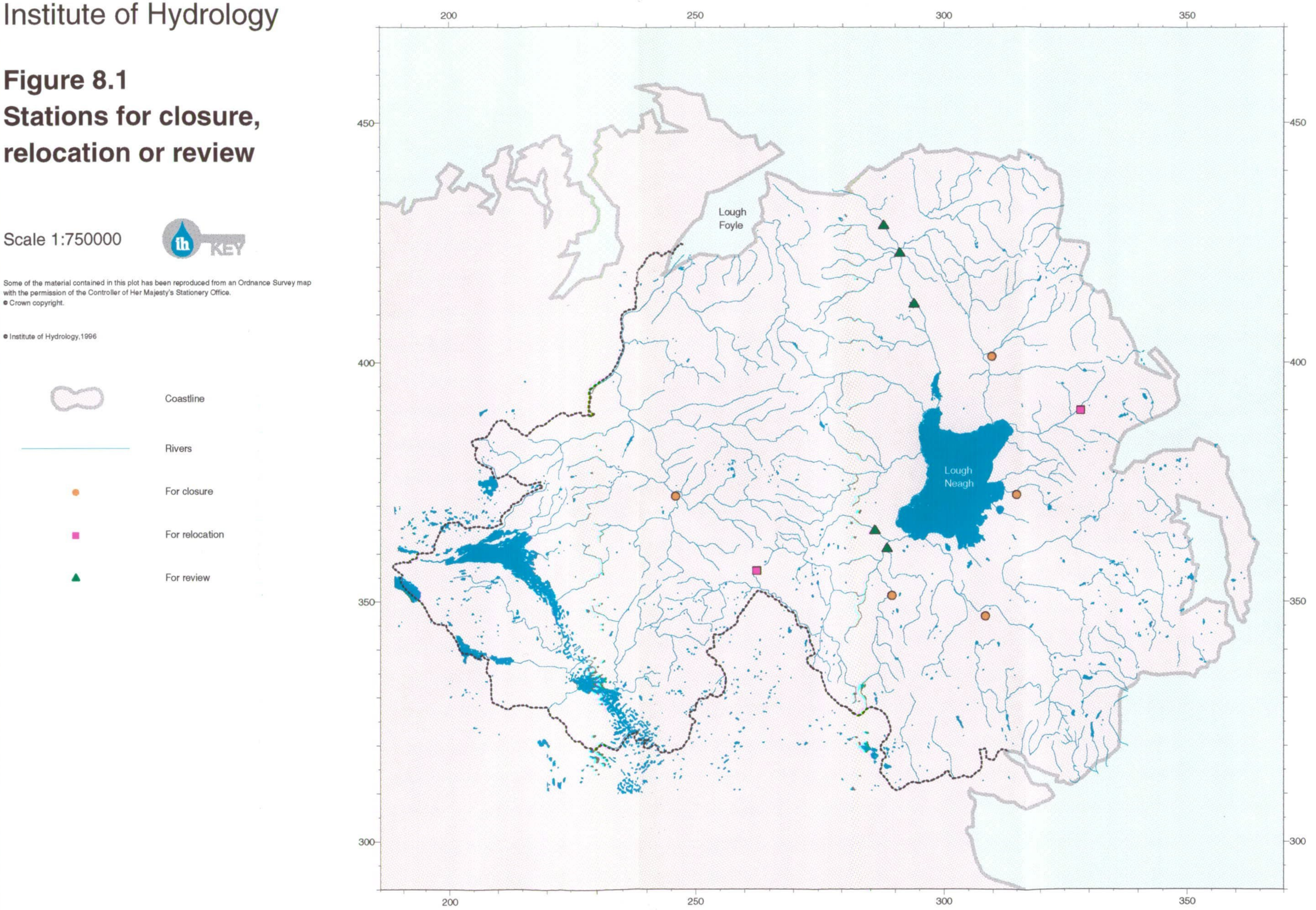
Major quality improvements required:

203039	Clogh at Tullynewy Bridge
236006	Upper Erne at Killyhevlin
236007	Sillees at Drumrainy Bridge

Institute of Hydrology

Figure 8.1
Stations for closure, relocation or review

Scale 1:750000



Dgener8 map producing software

The client is referred to Table 6.2 and it is recommended that in order to promote a greater responsiveness of stations to their perceived data uses, consideration is given to the suitability of each station, in terms of the various component scores achieved, to present and anticipated functions.

The individual station reviews are collected in Appendix F.

8.1.2 New station proposals

Reflecting a high level of satisfaction in relation to the gauging of major rivers, all the new station recommendations are for small, headwater catchments. Specific sites are not suggested as it is felt that this should be done on the basis of detailed ground survey. However, individual regions are identified, either on the basis of suggestions stemming from closures recommended above, or in response to some of the more general shifts in emphasis suggested in the preceding chapters. These are presented in approximate hydrometric area order, with locations identified on Figure 8.2.

Drumragh headwaters
This would realise the opportunity for a benchmark station in the west of the Province which could also serve a useful flood forecasting role.

Sperrin Mountains
This is the area of highest altitude in Northern Ireland and also one of the wettest areas. One or two small catchments are suggested, with gauges located close to the A6 Glenshane Pass road. This offers efficiency and reliability in terms of travel, and the opportunity to gauge flows in an area of forestry which may have value for land use studies.

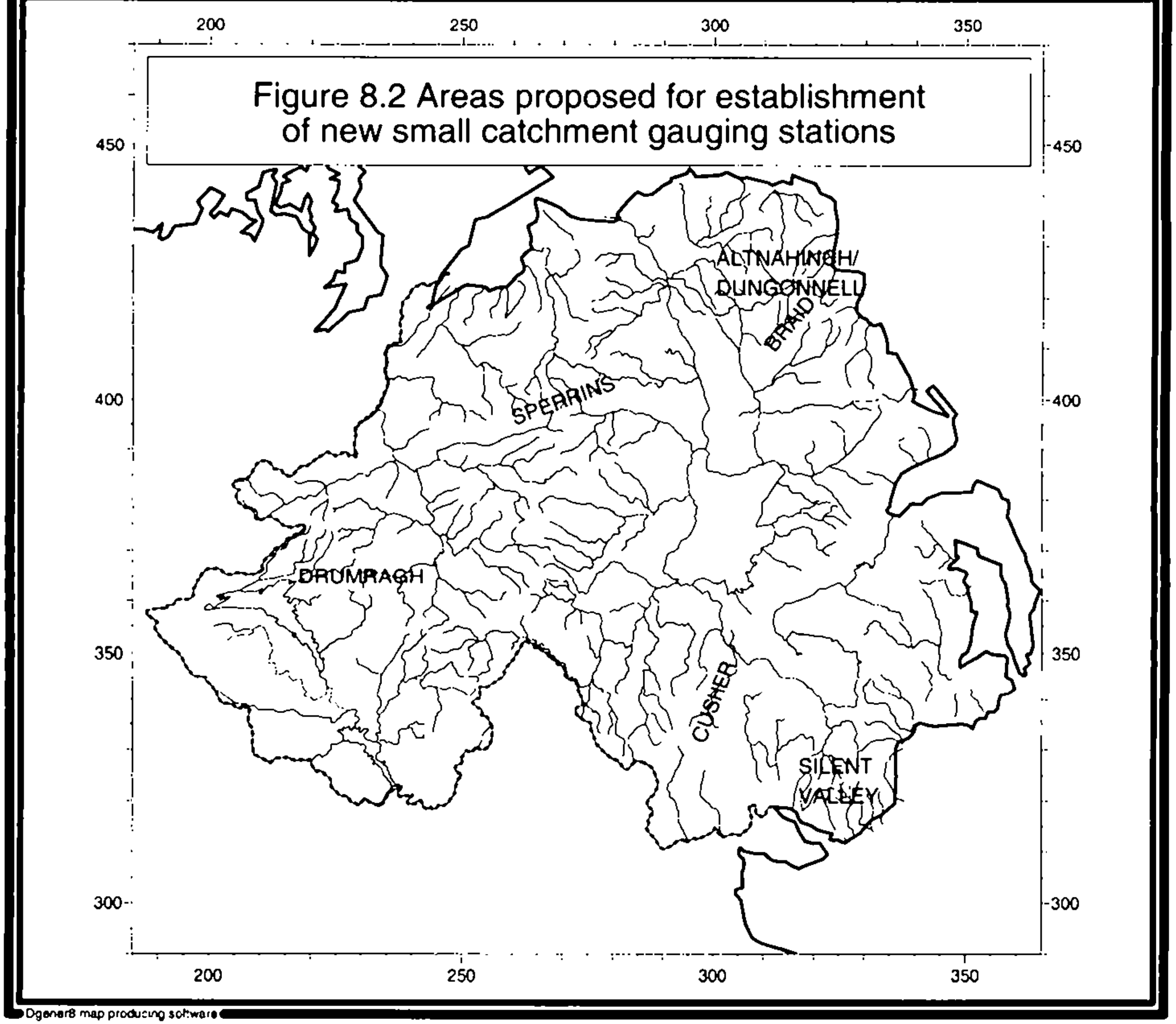
Braid headwaters
Data from such a site would supersede that from Ballee, recommended for closure, and be representative of many streams draining peat and gley soil areas in the Antrim Mountains. A stream including in its catchment either Carncormick or Knockramer might prove suitable.

Altnahinch Dam/Dungonnell Dam area
The advantage to be gained from siting a new gauge in this area is attractive: two reservoirs exist in relatively close proximity, long climatological and raingauge records have been accumulated, and the catchment size, soil, rainfall, altitude and slope characteristics of the area are under-sampled. Furthermore, plantation forestry is present and the inclusion of a forested catchment would benefit the network, giving particular potential for a range of environment change studies, including the effects of acid deposition which are often exacerbated by forestry. It may be considered advantageous to install two gauges in this area, one draining east and the other west thus reflecting rain-shadow effects, and/or one monitoring flows in an afforested catchment and the other an area of rough grazing.

Cusher headwaters
Such a site could be used as a representative of the Armagh Hills, which are less extreme in altitude and precipitation terms than the Sperrin or Mourne Mountains.

Silent Valley
This area contains the longest flow records in Northern Ireland, dating from the late 19th century. While there is presently no representation in the network, its inclusion would allow important historical perspectives to be realised in climate change assessments, and would be of general benefit to long-term considerations within reservoir yield studies.

Figure 8.2 Areas proposed for establishment of new small catchment gauging stations



8.2 DATA PROVISION IN RELATION TO MAJOR RIVERS AND CATCHMENT TYPES

The results of Chapter 2, and direct consultation of Figure 1.1, show that the present network achieves a high standard of attainment in gauging all major rivers. Indeed, it has been an important element in the evolution of the NI network that gauges have been constructed at the outfall of all major catchments, and there are no grounds for recommending that this policy need be extended. However, the strategic value of these stations is such that data quality throughout the range of flows is particularly important and while no change is recommended in the number of these stations, the results of Chapter 6 indicate that data quality should be improved at some major catchment outfalls.

Five such outfall sites were identified as requiring improvements in low flow data quality, namely stations 202001 - Ardnargle, 203018 - Antrim, 205004 - Newforge, 206001 - Mount Mill Bridge and 236007 - Drumrainy Bridge. None of the major catchment outfall stations was identified as having particular problems with high flow data quality. The network is therefore seen to have strength in its representation of major rivers and, owing to the value of inclusion of these stations, no reduction in their number should be contemplated.

It is recommended that as part of the shift towards a more representative network, and one which collects more data (rather than essentially the same information at different monitoring sites), those stations identified in Chapter 3 as having limited worth should eventually be closed.

- The most satisfactory way of doing this, while continuing to provide those interested parties with data appropriate to their needs, is to establish methods of estimating flows or levels at these sites from other gauging stations. The derivation of reliable relationships will serve as proof that the low value stations do not provide significant new information.

It is recommended that some are designated as permanent index stations, and appropriate measures taken to ensure that data quality is high enough to support all anticipated applications. These would be a subset of the network to provide summary estimates of runoff for the regional or national picture. Typically, these sites would have long records to provide a good historical perspective, preferably in excess of 20 years. They should have accompanying or corresponding climatic records. They would allow:

- Valuable overlap with shorter records, or even spot gauging records, at other sites would thus be possible. These stations would also allow detection of shifts in flow regimes, such as heightened seasonality or frequency of extreme events, including any increases in stress due to changing patterns of resource utilisation.

The tributary catchments of Northern Ireland's rivers are, of course, many and varied. No network can ever expect to gauge a large proportion of all watercourses, but what is important is that the full diversity of stream and catchment types is captured within it. The range of types represented is lacking in:

- Small, upland catchments and it is strongly recommended that this deficiency is addressed. Doing so would enable several objectives to be achieved:

    - the representativeness of network would be enhanced,
    - the data collected would support spatially-based flow estimation procedures,

- siting of new stations in pristine environments (as more frequently found in the uplands) would allow benchmark monitoring and the future detection of climate and/or land use changes, and
- siting of such stations in reservoir headwaters would service yield assessment data requirements.

• Further small catchment gauging outside of the uplands.

  - The Antrim coast, while bordering an upland area, is presently neglected by the gauging network and could provide a suitable location for additional flow measurement. The hydrological database could benefit from data collection in a pair of nested catchments, say one of 10 km^2 within another of 50 km^2 : variations in rainfall, evaporation, slope and soils would make flow characteristics of the two sufficiently different to make this type of strategy worthwhile.

8.3 DATA PROVISION FOR CATCHMENT MANAGEMENT PLANS

Discussions with ES staff indicated that almost all flow, and some level-only, stations would be of value in establishing catchment management plans (CMPs). There is therefore a large volume of data from which these plans can be formulated. It is important for this objective that data should be available from all geographical areas, and the network readily meets this requirement. Strategic sites on loughs and at the outfalls of major catchments are likely to be required for CMPs and the recommendations of Chapter 2, incorporated into the synthesis, are that this requirement is, and should continue to be, met.

Beyond this, it is proposed that modelling techniques should be employed to obtain flow estimates for sites where gauging is not justified on other grounds, except under circumstances where there might be real-time requirements for data of high precision which could not be obtained from models (see also 8.4, 8.6 and 8.7). Otherwise, the introduction of CMPs may lead to unreasonable demands being placed on the gauging network.

With gauges already in operation at the outfall of all major catchments, the basis for providing inflow and throughflow data for major catchments is already in place; modelling will allow considerable elaboration of the knowledge of fluxes through these river basins.

8.4 DATA PROVISION FOR WATER RESOURCE MANAGEMENT STUDIES

The major supply rivers have gauging facilities which can be considered at worst adequate and, at best, very good, particularly in the flow ranges which are critical for water resource studies. The relative locations of the gauges and the river abstractions (i.e., upstream or downstream) vary, but flow characteristics should be able to be transferred to the abstraction sites with confidence, particularly if regionalising models are employed. These comments apply to rivers or major tributaries which employ river abstractions in their lower reaches.

There are one or two exceptions, typically those in Fermanagh; the outfall from Lower Lough Erne and the Roogagh river. Although there is a gauge between the Lower and Upper Loughs (Killyhevlin), it is unlikely to yield a record for continuous assessment of flows but is capable of improvement; along with other gauged inflows to the Lower Lough, estimates of flow patterns downstream of the Lough should be capable of meeting resource study requirements. The

Roogagh river has a modest abstraction and would likely attract a low score in a data use survey (cf. Chapter 3). The best option here is an estimation approach based upon transferring information from other catchments; a resited gauge on the Drumragh river would be attractive for this purpose.

The other main class of rivers used for direct abstractions are those situated in headwater catchments. The multiplicity of these sources renders local measurement of flows impractical. The network is ill-served to provide data from analogous catchments in the general geographical region, principally the Mourne Mountains. Use of flow estimation models such as Micro LOW FLOWS should provide a practical method to use regionalised data in these situations but the lack of suitable upland sites for calibration purposes is a drawback. The under-representation of small upland catchments has been recognised elsewhere in the report and Chapter 7 has recommendations where new sites should be considered.

The historic data present in the database has come under some criticism (W S Atkins, 1993) and the completeness of some records has given rise to concern. The current exercise of reviewing the stage-discharge relations over the period of record is encouraged and any record reprocessing necessary should be carried out. Harmonisation of such data sets which are held by organisations other than DoE(NI) should be ensured by whole station record transfers for the affected gauges.

8.5 DATA PROVISION IN RELATION TO ENVIRONMENTAL CHANGE

The key requirements of a network for monitoring environmental change are to feature:

- long records
- high quality data
- monitoring of a wide range of environmental parameters
- small catchments to minimise 'noise' effects in trends
- stations in key locations.

Stations to be used for such monitoring should be identified as *benchmark* stations and maintained accordingly. The NI network is presently inadequate in this regard and if the ability to monitor future changes with the benefit of an historical perspective is sought, then the installation of some new stations, or improvements in data quality at others, should be undertaken. Of the new station recommendations made in section 8.1.2, three locations commend themselves particularly in this respect, namely those proposed for the Drumragh headwaters, the Silent Valley and the Altnahinch Dam/Dungonnell Dam areas. These three are widely separated and can therefore be used to represent different regions within Northern Ireland, and the latter two offer the added advantages of long historical records and current rainfall monitoring in small upland catchments. Stations 203020 - Moyola New Bridge, 203028 - White Hill and a relocated 203041 - Tullybryan are also noted for potential benchmark status; while none of these catchments is as small as those recommended for network extension into the headwaters, they do offer the advantage of existing flow records and, being able to reflect changes in larger areas, could complement the smaller catchment benchmark stations.

Land use is an important component of environmental change, with the effects of afforestation particularly prominent in the literature on the subject. Of all the forms of land use in Northern Ireland, it is the most pertinent in relation to runoff quantity and quality impact (excluding urban effects which, it is felt, are catered for by the DANI urban stream gauges). Work in the IH experimental catchments at Plynlimon, Balquhidder and Coalburn has done much to advance the understanding of the effects of forestry in the UK although many new questions have emerged in the process and demand further research. Work in the Woodburn catchments north of Belfast has addressed the forestry question in Northern Ireland, so by drawing on the results of all these studies, a good knowledge of forestry impacts is available in the Province. Addressing new questions would require the operation of experimental catchments, involving large sums for capital and recurrent expenditure. While it may be desirable to include one or two afforested catchments in the recommended programme of instrumenting small, upland catchments, no higher prioritisation would be possible without serious damage to existing flow measurement commitments if financial resources remain essentially constant. Major representation of afforested areas is not therefore recommended.

Use of headwater sites is considered to be advantageous for water quality monitoring as well as in the context of the flow gauging network, so it is recommended that these interests are considered together. The ability of the present flow gauging network to provide background information while evaluating trends in, say, acid deposition could thus be enhanced by the construction of headwater gauging sites. Again, it should be noted that network changes justified on this basis would be complementary to the realisation of other objectives.

8.6 DATA PROVISION FOR PARCOM RETURNS

8.6.1 General

Since over 60% of the total runoff from NI is channelled through to the Bann and Foyle estuaries, the drainage pattern lends itself to broad assessments of contaminant loads. Clearly this directs particular attention to the effectiveness of water quality and quantity monitoring on the Lower Bann and the Mourne. Generally, errors in flow measurement make only a minor contribution to the uncertainty in load estimates. The impact of limited water quality sampling frequencies is normally far more significant.

Load estimation can normally only be undertaken within wide confidence bands and the precision of computed mass flows will vary greatly from river to river, and from determinand to determinand. The recommended PARCOM algorithms also vary in their suitability for application in particular circumstances. In order to interpret the load estimates realistically, it is essential to appreciate what factors contribute to the uncertainty in mass flow estimates. A comprehensive review of the relevant factors is given in IH Report No. 117 (Littlewood, 1992).

The diversity of catchment types in NI implies that loads information computed for an index catchment may be very unrepresentative of other unmonitored catchments. The scope for regionalisation is restricted although for some determinands - for example, nitrates in areas where the principal source is land runoff - careful extrapolation may be justified. In addition, many contaminants enter rivers and estuaries below the lowest gauging station, this is particularly important in coastal districts around Belfast where industrial discharges may be the major source of many individual contaminants. In such circumstances, the loadings computed for monitoring sites upstream of the tidal limits would need to be complemented by more intense monitoring, or an audit programme, to address the totality of inputs to the estuary.

Substantial improvements in the quality of mass flow estimates are likely to be needed to guide water management decisions in the future. These improvements may be expected to exploit an increasing use of the continuous monitoring of selected determinands and a fuller understanding of the relation between changes in river flows and associated changes in water quality. This understanding will depend in part on the analysis of short interval (or 'continuous') water quality data sets associated with gauging stations capable of monitoring the full range of flow.

8.6.2 The NI PARCOM Network

Of the ten rivers in the PARCOM network, seven have gauging stations which monitor more than 90% of the runoff to the associated water quality station. The exceptions are the River Finn which has no flow measurement facility within the Province, the Newry (see below) and the Quoile where the Kilmore gauging station (on the Annacloy) measures around 70% of the average flow to the Quoile Bridge water quality station. In the latter case, the characteristics of the ungauged area are similar to those of the Annacloy catchment and a straightforward adjustment factor is recommended for application to the Kilmore flows to provide a suitable basis for load estimation at Quoile Bridge. The adjustment factor should be based on the respective catchment areas to Kilmore and Quoile Bridge corrected to account for the difference in the average effective rainfall in the gauged and ungauged areas. Although the great majority of the runoff to the Cutts on the Lower Bann is routed through Movanagher, the regime of the Agivey, and other smaller tributaries between the two sites, is significantly different. Therefore a modelled approach to the assessment of the ungauged component in the Bann runoff is proposed - based upon the measured flows at White Hill. It is essential that these simple adjustment procedures, if implemented, be documented and applied consistently. For the remaining PARCOM stations it is recommended that no areal adjustment be applied.

Evidence in Table 6.2 indicates that an improvement in low flow measurement - with consequential improvement in load assessment and a better understanding of water quality and quality interactions - should be considered for the rivers Roe, Lagan and Burn Dennet. This could take the form of closer monitoring of low flow rating changes or, where economically justifiable, the installation of low flow controls. Both the low and high flow scores for the River Newry (Table 6.2) confirm the inadequacy of this site as a primary gauging station; it is clearly incapable of furnishing runoff figures from which reliable mass flows could be computed. The presence of the Newry Canal restricts the options for alternative sites but consideration should be given to establishing a full range station upstream of Jerretspass - and then use the flows in conjunction with those on the Clanrye to model runoff at Newry. Alternatively, if knowledge of the mass flows into Carlingford Lough are considered a high priority, the practicality of installing an ultrasonic gauging station in the Newry river should be explored.

8.7 DATA PROVISION FOR DISCHARGE STANDARD DETERMINATIONS

The findings of Chapters 2 and 4 are of direct relevance to the question of providing low flow estimates for effluent discharge standard determinations and other similar uses. It is impossible for all small streams to be monitored, so estimation methods must be employed. This is most effective if the best available estimation techniques are employed, and supported by the most useful database possible.

The use of the Institute's Micro LOW FLOWS software system is recommended to satisfy the former requirement, encompassing as it does the latest available spatial data types and an appropriate model approach. With respect to the latter, the general principle that the gauging network should be as representative of the terrain as possible again applies. It is therefore recommended once more that network extension is pursued in the direction of small, upland catchments. Attention should be directed towards capturing catchments which are typical of many others, e.g. with respect to the make-up of soil types, rainfall range, slopes, etc.

It has been seen that some lowland streams from very small catchments (<5 km^2) have been gauged in the past in Northern Ireland (e.g. stations 205012, 205013, 205014); the client is encouraged to continue this type of activity in new areas. Pre-fabricated fibre-glass flumes set in concrete have been used to good effect in many small, Scottish catchments, producing good quality data without either high capital or running costs, and this type of approach could be used to extend the current database. Measured flow quantiles could then be compared with those produced by models, each complementing the other, and allowing estimates for ungauged sites to be produced on a more informed basis.

The establishment of a few more upland catchments in the network, along with a programme of spot gauging in small streams in a range of catchment types, would greatly benefit the estimation of low flow parameters at ungauged sites.

8.8 DATA PROVISION FOR RESERVOIR YIELD STUDIES AND OPERATIONAL NEEDS

There is a scarcity of appropriate data in Northern Ireland for thorough review of existing reservoir yields and as design input for future impoundments or dam modifications. Sites which have produced long records are not formal hydrometric network gauging stations (e.g. the Annalong River record) and are not currently maintained to a standard which demonstrates that such records have been treasured (W S Atkins, 1993). Indirect measurement methods to infer reservoir inflows, based upon summing the inflows and outflows and changes in storage of the reservoirs themselves or of rainfall / evaporative loss calculations, are not supported by recording methods of sufficient quality to have full confidence in the estimates.

An economic approach to the establishment of gauging for the purpose of enhancing quality in yield estimates is favourable if the uncertainty in rainfall and loss estimation is great, particularly if new upland sources are to be sought. There is not an overwhelming case for gauging headwater catchments solely to refine the yield estimates from the current suite of reservoirs with such a major potential source as Lough Neagh available. Improvements to intrumentation at reservoirs themselves may be the preferred and cheaper option.

Taken in conjunction with other cases for the establishment of headwater gauges, a coincidence of interest is apparent and it is recommended that new gauging sites should be considered in the Mourne, Sperrin and Antrim Mountains. These installations should be formal gauging structures with known hydraulic characteristics. Guides to practice and potential pitfalls are elaborated in Chapter 7 and Appendix E. A concurrent improvement in rainfall estimation via logger-recording tipping bucket raingauges in the uplands is also recommended.

The suggested reduction in monitoring at some sites should result in a substantially unchanged manpower effort in the installation and maintenance of these proposed sites.

8.9 KEY CONCEPTS ARISING FROM THE STUDY

- The focus of hydrometric activity must be put firmly on achieving data quality appropriate to data uses.

- More small, upland catchments are required to give the network the representativeness required of it.

- Index stations at major catchment outfalls play a strategic role in the network and should continue to be operated and maintained accordingly.

- The continued operation of some stations is not merited by the extent of data usage and/or by the inadequacy of the data produced.

- Spatial transfer of information using models should always be considered; records need not be extended indefinitely.

- Spatial data can and should be used for flow estimation but need to be underpinned by a comprehensive time series database.

- Gauging densities in Northern Ireland are broadly similar to expectations in a UK context, but a little low in relation to European standards.

- In mountain areas lacking adequate rainfall estimation, favourable benefit / cost ratios for gauging to prove catchment yield may be demonstrated.

9 Summary: a blueprint for flow gauging into the 21st century

In the preceding chapters, observations have been made regarding the efficacy of the present gauging network in various respects and recommendations made for the establishment of new sites, along with closure, relocation or further review of others. The intention in this final chapter is not to reiterate any of these specific recommendations, but to summarise and provide a clear sense of direction for the future development of the Northern Ireland gauging station network.

9.1 GAUGING STATIONS

Notwithstanding the absence of a hydrometric scheme blueprint, the NI network has evolved to form a firm basis for the wide spectrum of present and anticipated data needs. In numerical terms, relatively modest changes are proposed. With the implementation of these, and other recommendations relating to data processing and utility, the information output of the network will be enhanced without any increase in the overall resources devoted to hydrometric activities.

Five station closures have been recommended, with a further two to be relocated, the status of five to be subject to further review and at least three more requiring major improvements to data quality. A general move into small, upland catchments is advocated, allowing some present under-representation and lack of catchment diversity to be rectified. Possible sites for new stations are discussed in six broad geographical areas, such that the total number of stations may remain broadly constant.

On account of their strategic value, and the generally high demand for data relating to the full range of flow conditions, index stations at catchment outfalls are to be afforded long-term security and steps taken to ensure good data throughout the range of flows observed. The provision of new stations should be on the basis of infilling gaps in existing knowledge, with accuracy assured for the range of flows of interest at a site, and may involve the operation of stations for strictly finite periods of time. Spatial resolution in the flow database would also be enhanced by spot gaugings which could be related to flows at gauging stations in analogous catchments.

9.2 NEW TECHNOLOGIES

The rapid growth of spatial data sets and advances in modelling expertise make it inevitable that hydrological time series characteristics and spatial data will become ever closer to each other in the future: this is of great benefit to the hydrologist, enhancing the understanding of hydrological processes and behaviour and thus improving the ability to predict flow (and other) characteristics at ungauged river sites. The shifts in gauging emphasis recommended in the present review are designed to underpin the development of spatially based models and should be regarded as a strategic investment for the future.

Owing to Northern Ireland's political boundary not always coinciding with watersheds, it is clear than Northern Ireland and the Republic share common interests in spatial and time series data for common river systems. While some data are available for NI catchments with headwaters in the Republic of Ireland, some technical differences do exist between one side of the border and the other, such as those related to mapping resolution. Mutual benefits would accrue from achieving complete uniform coverage with spatial data sets such as the rivers network, elevation, HOST soils information, etc. It is hoped that constructive efforts will be made, within known constraints, towards achieving this goal.

Other technologies well-established in Britain would also give rewards if applied in Northern Ireland. Telemetry systems are now standard in most mainland authorities and when coupled with polling software for automatic data transmission, can lead to important gains in efficiency. Problems with level recording can be detected by daily inspection of hydrographs at a computer terminal and the deployment of gauging staff can be guided by knowledge of levels at gauging stations during the course of a working day. Alarm switches, prompting a gauge to call and transmit to its base station when high or low threshold levels are crossed, further add to the value of the network and are available at affordable prices.

Dissimilar computer systems, databases and software are employed to process, archive, retrieve and analyse data within the two Departments. Modern practice tends towards use of microcomputer-based data processing and archive packages. There are two main products of this type on the UK market (more internationally) and between them they are widely utilised within the NRA, RPBs and DoE(NI). These packages have been developed by software developers who also have a hydrometric/hydrological background and are in sympathy with the sorts of input and output formats, analyses, displays and quality control procedures which users require. Harmonising the processing platforms and software would yield an obvious improvement in the consistency of data treatment, capacity for data exchange between Departments and externally, and in the confidence with which the data may be exploited.

9.3 DATA QUALITY FOR NETWORK FUNCTIONS

Focus on the hydrometric network as the base of an integrated data provision system should never be lost. Field staff should be as fully aware of this as senior management at all times. Attention has been drawn at various points in this report towards ensuring that gauging stations are capable of measuring flows with the accuracy necessary to enable fulfilment of the functions demanded of them. Site maintenance, the derivation and monitoring of stage-discharge relations, the mechanics of data capture, transmission, processing and quality control all impinge on the quality of data available to the end user, so emphasis must always be maintained in all these activities on the final requirements of the data. Furthermore, it is never possible to foresee all future uses of data so, wherever possible, high quality should be achieved throughout a wide range of flows. This might, for example, involve the installation of low-cost informal low flow controls at stations where low flow accuracy is not a present priority, yet where such utility is clearly realisable.

9.4 ORGANISATIONAL STRUCTURE

Much of the discussion of this report has centred on the linkages which exist between the establishment, operation, data processing and data archiving of gauging stations on the one hand, and the uses of such data on the other. The philosophy of treating the network and all other activities associated with it as a continuum of data provision has been stressed as having relevance for all applications to which hydrological data are put. The importance of ensuring that information, in all its various forms, is transferred as freely as possible cannot be stressed too highly.

Staff who were dealt with in our fact finding visits were all committed and helpful in their attitude and it is recognised that substantial efforts have been made to harmonise the activities of the two groups involved in hydrometry. A key exercise in this process is the on-going audit of stage-discharge relations in use by DoE(NI) and DANI The unrestricted sharing of all types of information, relating in any way to the hydrology and hydrometry of Northern Ireland should be identified as the principal target for future effort.

9.5 AN ANNUAL HYDROMETRIC AUDIT FOR NORTHERN IRELAND

The potential information recovery - and with it water management benefits - resulting from the maintenance of the NI gauging station network are not currently being fully realised. In part, this is a consequence of a number of data processing and archiving difficulties exacerbated by the division of responsibilities between DoE(NI) and DANI. In order to capitalise more effectively on the resources devoted to hydrometric data acquisition in the Province it is recommended that an Annual Hydrometric Audit be introduced to form a focus for cooperative activities between the two organisations and to build on existing liaison arrangements. The issues and procedures to be addressed during the Hydrometric Audit should include :

i. Review network changes over the year and discuss development proposals.
ii. Agree the status of all gauging stations (a 'primary' classification implying an ability of the station to measure the full flow range and a commitment by DoE(NI)/DANI to maintain a sensibly continuous flow record).
iii. Critically review existing stage-discharge relations (guided by current-metering results over the preceding year) and determine which ratings should apply for contemporary and, where appropriate, historical data processing.
iv. Harmonise the data quality control procedures used by DoE(NI) and DANI and agree vigorous arrangements for the identification and rectification of erroneous or missing flow sequences.
v. Introduce periodic reviews of the full time series at selected gauging stations (five or six could be tackled each year).
vi. Update basic locational and other reference information and agree suitable station and catchment descriptions to increase the utility of the basic flow data.

Having established the relative merits of using spatial data in a range of catchment types, it remains to conclude this section with a summary of the wider benefits of using the type of methodology implemented in Micro LOW FLOWS. The software package offers fast, reproducible calculation of a wide range of low flow parameters and gives results based on the consistent application of a specific method. The automatic handling of abstraction and discharge data further adds to the utility of this system. Its use is therefore strongly recommended as the basis of a low flow estimation strategy. It should be noted, however, that the confidence which can be placed in the results will be much greater if model use is underpinned by data from a network of river flow gauging stations covering a full range of catchment types; without this, the ability to assess the success of the method in various types of catchment, and make alterations to estimates where appropriate, will be compromised.

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APPENDICES

A - F

Appendix A: Gauging station list

Flow stations

Station Number	River	Station name	Type	Irish Grid Reference	Catchment Area (sq.km.)
201002	Fairy Water	Dudgeon Bridge	VA	H 406 758	161.2
201005	Camowen	Camowen Terrace	VA	H 460 730	274.6
201006	Drumragh	Campsie Bridge	VA	H 458 722	324.6
201007	Burn Dennet	Burndennet Bridge	VA	C 372 047	145.3
201008	Derg	Castlederg	VA	H 265 842	337.3
201009	Owenkillew	Crosh	VA	H 418 866	442.5
201010	Mourne	Drumnabuoy House	VA	H 347 960	1844.5
202001	Roe	Ardnargle	VA	C 674 247	365.6
202002	Faughan	Drumahoe	VA	C 464 151	272.3
203010	Blackwater	Maydown Bridge	VA	H 820 519	951.4
203011	Main	Drumoma	VA	D 052 086	228.8
203012	Ballinderry	Ballinderry Bridge	VA	H 926 799	419.5
203013	Main	Andraid	VA	J 092 973	646.8
203017	Upper Bann	Dynes Bridge	VA	J 043 509	
203018	Six Mile Water	Antrim	VA	J 146 867	277.3
203019	Clady	Glenone Bridge	VA	C 962 037	130.1
203020	Moyola	Moyola New Bridge	VA	H 955 905	306.5
203021	Kells Water	Currys Bridge	VA	J 106 971	127.0
203022	Blackwater	Derrymeen Bridge	VA	H 625 530	175.7
203023	Torrent	The Moor Bridge	VA	H 858 649	59.9
203024	Cusher	Gambles Bridge	VA	J 084 471	176.7
203025	Callan	Callan New Bridge	VA	H 893 514	164.1
203026	Glenavy	Glenavy	VA TP	J 149 725	44.6
203027	Braid	Ballee	VA	D 097 014	177.2
203028	Agivey	White Hill	VA	C 883 193	98.9
203029	Six Mile Water	Ballyclare	VA	J 282 902	58.4
203033	Upper Bann	Bannfield	VA	J 233 341	100.9
203038	Rocky	+ Rocky Mountain	FV	J 243 265	6.7
203039	Clogh	Tullynewy Bridge	VA	D 090 108	83.6
203040	Lower Bann	Movanagher	VA	C 931 154	5209.8
203041	Ballygawley Water	Tullybryan	VA	H 623 566	516.4
203042	Crumlin	Cidercourt Bridge	VA	J 135 765	54.1
203043	Oona Wtr (2 Nr)	+ Shanmoy	VA	H 779 556	92.0
203046	Rathmore Burn	Rathmore Bridge	VA	J 198 854	26.2
203049	Clady Water	Clady Bridge	VA	J 201 837	30.7
203092	Main	Dunminning Lower	VA	D 051 111	211.7
203093	Main	Shanes Viaduct	VA	J 086 896	704.2
203097	Upper Bann	Moyallan	VA		
204001	Bush	Seneirl	VA	C 942 362	306.1
205004	Lagan	Newforge	VA	J 329 693	490.4
205005	Ravernet	Ravernet	FV	J 267 613	69.5
205008	Lagan	Drummiller	VA	J 236 525	85.2
205010	Lagan	Banoge	VA	J 123 540	189.8
205011	Annacloy	Kilmore	VA	J 448 509	186.6
205015	Cotton	+ Grandmere Park	VA	J 523 818	15.9
205017	Strand Lough	Killough Bridge	VA	J 538 376	34.8
205018	Strand Lough	Strand Brickworks	VA	J 529 375	21.2
205020	Enler	Comber	FV	J 459 697	54.8
205022	Wood Park Stream	Gransha Road		J 516 807	9.2
205029	Lagan	Feney	VA		
205101	Blackstaff	Eason's		J 318 721	15.6

Station Types		
	VA	Velocity-area
	TP	Thin-plate weir
	FV	Flat Vee weir
	L	Level-only

+ Broken record

continued/

Station Number	River	Station name	Type	Irish Grid Reference			Catchment Area (sq.km.)
Flow stations							
206001	Clanrye	Mount Mill Bridge	VA	J	086	309	132.7
206002	Jerretspass	Jerretspass (River)	VA	J	064	332	32.4
206003	Newry Canal	Jerretspass (Canal)	VA TP	J	064	332	56.7
206004	Cambane	Bessbrook	VA	J	074	292	34.5
236005	Colebrooke	+ Ballindarragh Bridge	VA	H	331	359	309.1
236006	Upper Eme	Killyhevlin	VA	H	245	429	2891.0
236007	Sillees	Drumrainy Bidge	VA	H	205	400	167.6
236009	Swanlinbar	Thompson's Bridge	VA	H	253	313	
236051	Ballycassidy	Ballycassidy Bridge	VA	H	229	509	
Level-only stations							
201304	Strule	Stone Br	L	H	437	775	817.7
203301	Lower Bann	Loughan Island	L	C	876	287	5636.7
203902	Lower Bann	+ Agivey Bann Br	L	C	909	229	5452.6
203308	Lower Bann	Portna	L	C	938	123	5175.3
203309	Blackwater	Verners Br	L	H	883	612	1380.9
203614	Lough Neagh	Derryadd Bay	L	J	036	613	
203315	Lower Bann	Toome (Lower Bann)	L	H	987	903	4836.3
203616	Lough Neagh	Toome (Lough Neagh)	L	H	988	900	
205301	Quoile	Quoile Barrier Lower	L	J	505	495	275.4
205302	Quoile	Quoile Barrier Upper	L	J	505	495	275.4
236601	Lower Eme	Rosscor	L	G	999	578	4212.0
236602	Upper Eme	Portora	L	H	223	453	3514.5
236603	Upper Eme	Belle Isle	L	H	283	345	2793.9

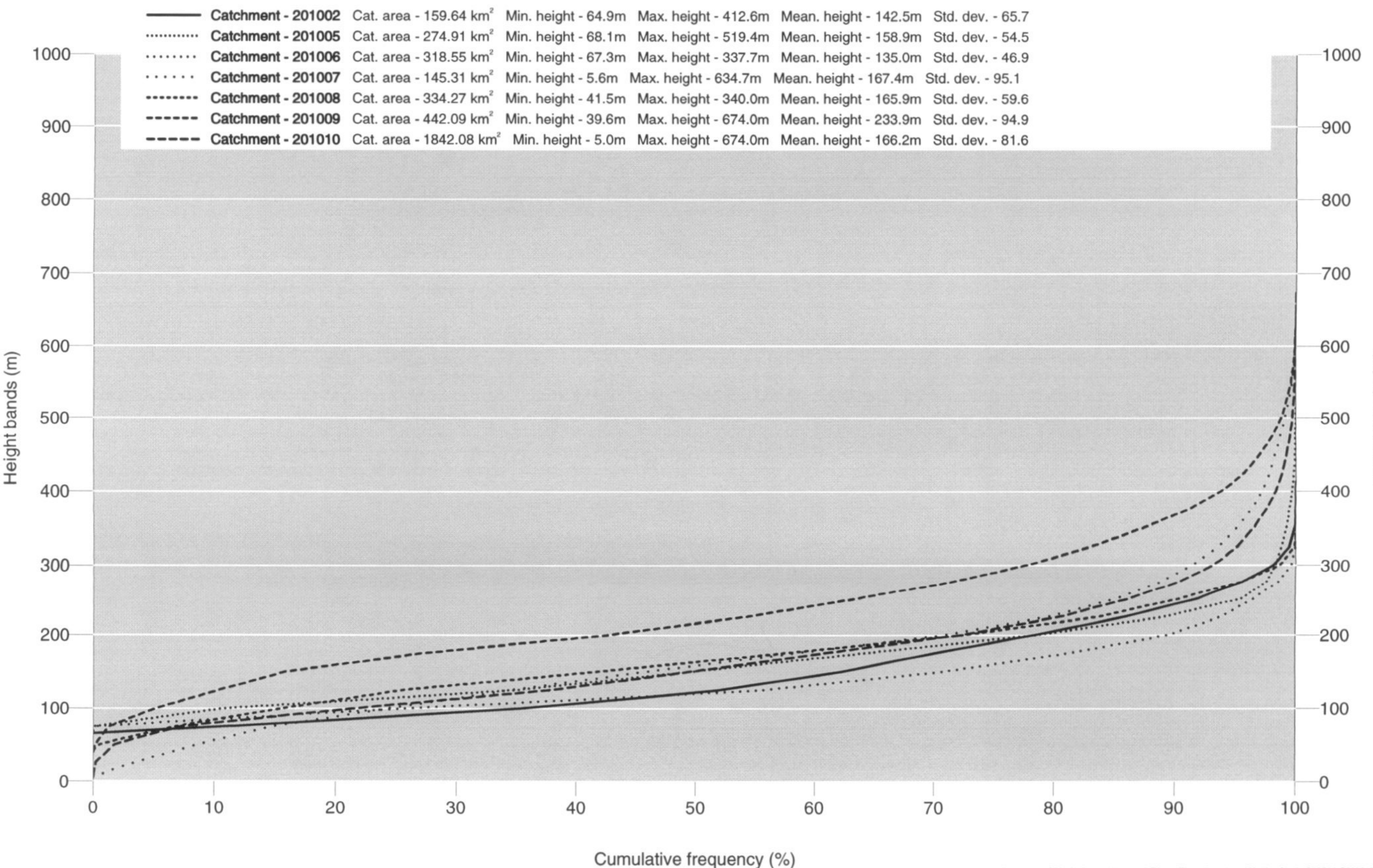
Station Types		
	VA	Velocity-area
	TP	Thin-plate weir
	FV	Flat Vee weir
	L	Level-only

+ Broken record

Appendix B

HYPSOMETRIC COMPARISONS

Hypsometric comparisons



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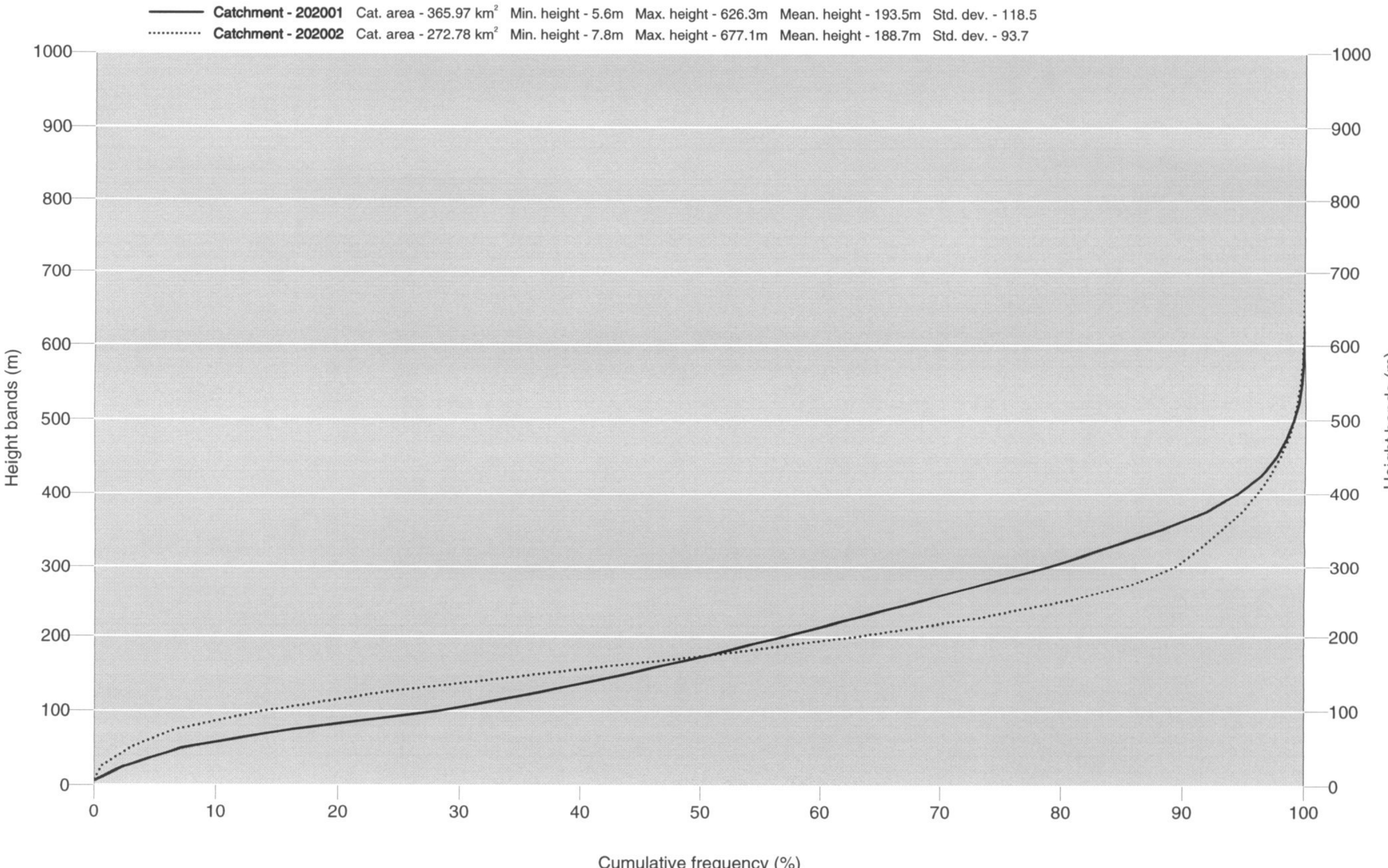

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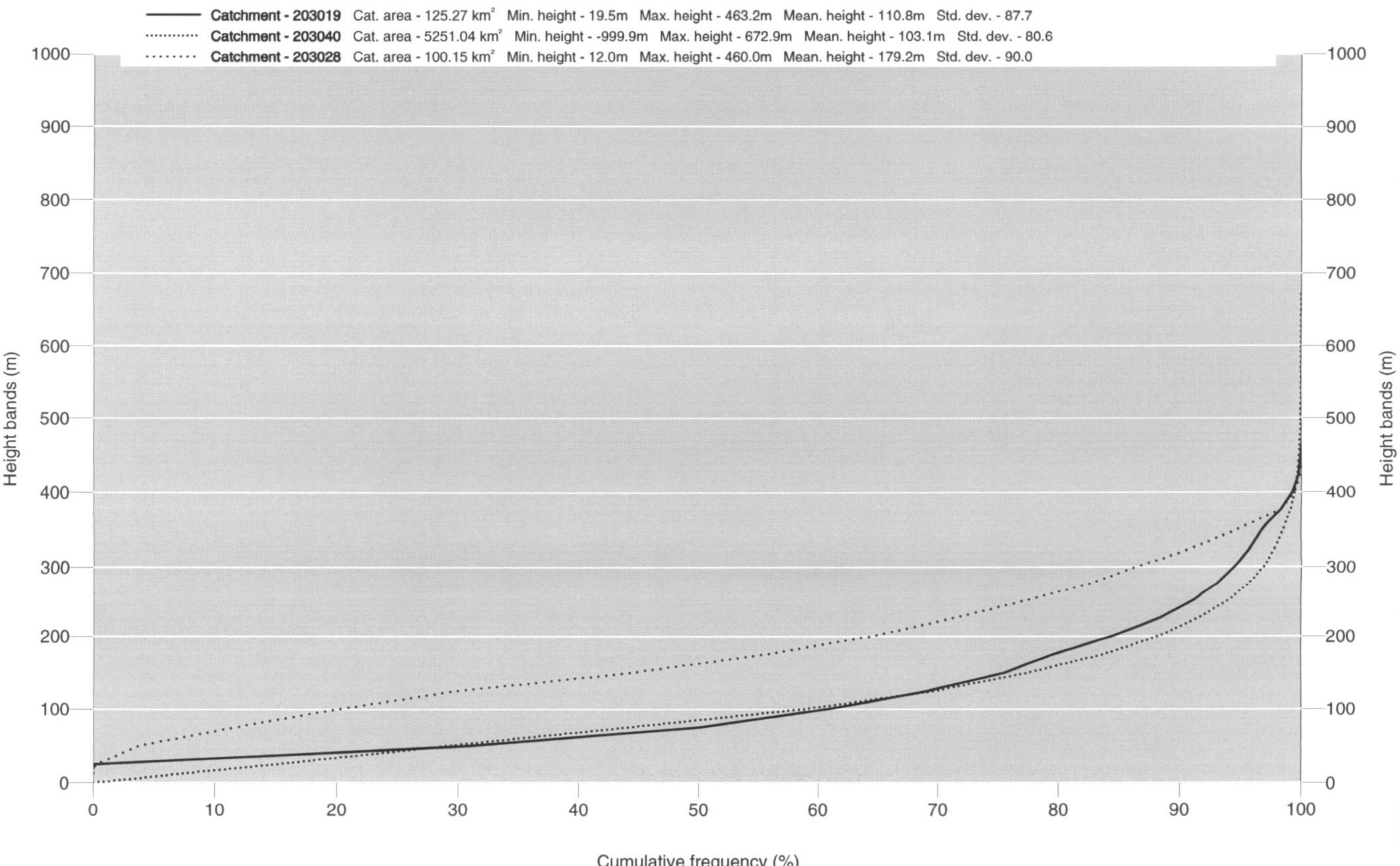
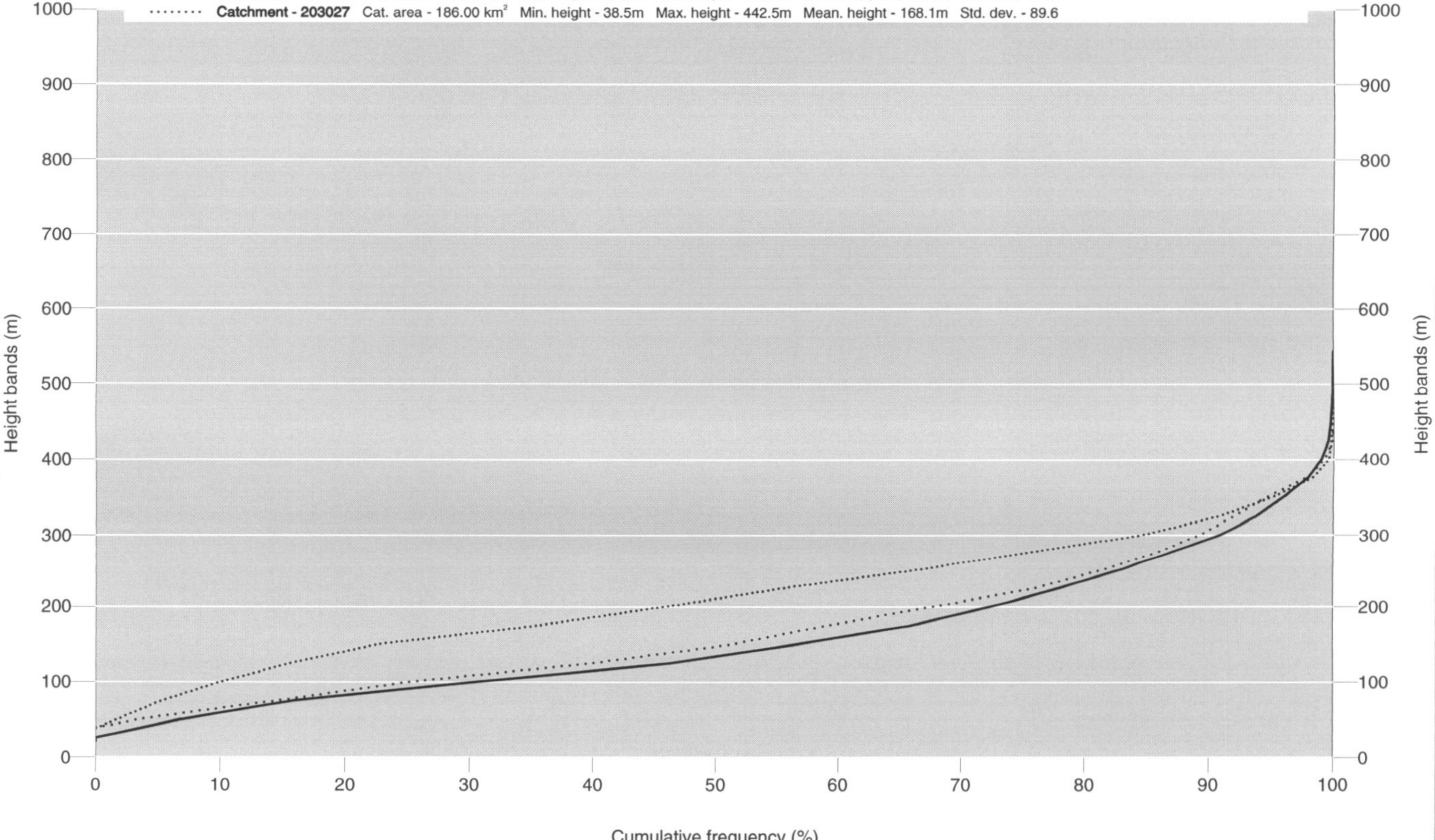


Hypsometric comparisons

Catchment - 203093	Cat. area - 703.54 km²	Min. height - 20.5m	Max. height - 542.4m	Mean. height - 157.7m	Std. dev. - 89.5
Catchment - 203021	Cat. area - 126.60 km²	Min. height - 37.9m	Max. height - 472.9m	Mean. height - 211.5m	Std. dev. - 82.1
Catchment - 203027	Cat. area - 186.00 km²	Min. height - 38.5m	Max. height - 442.5m	Mean. height - 168.1m	Std. dev. - 89.6



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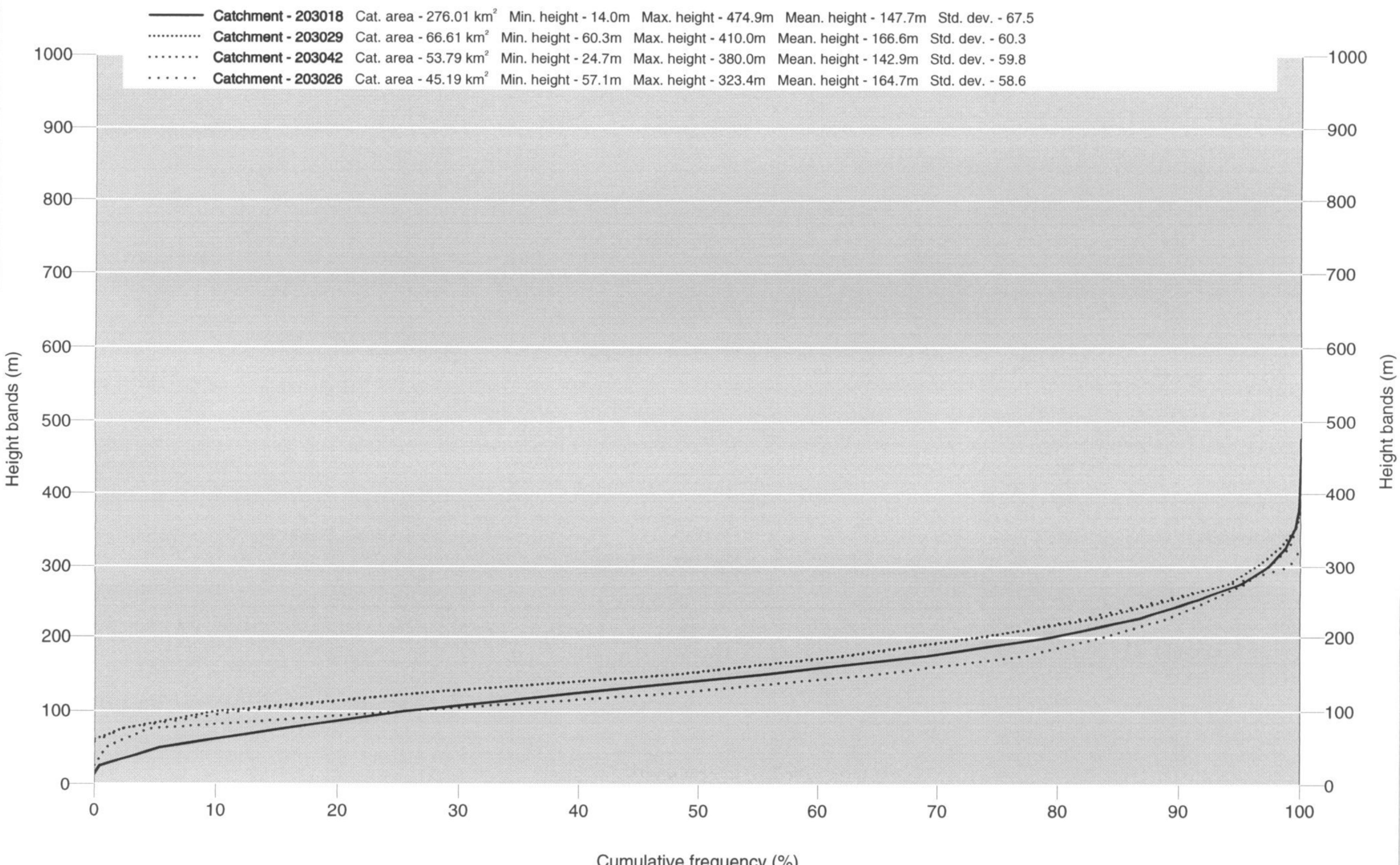

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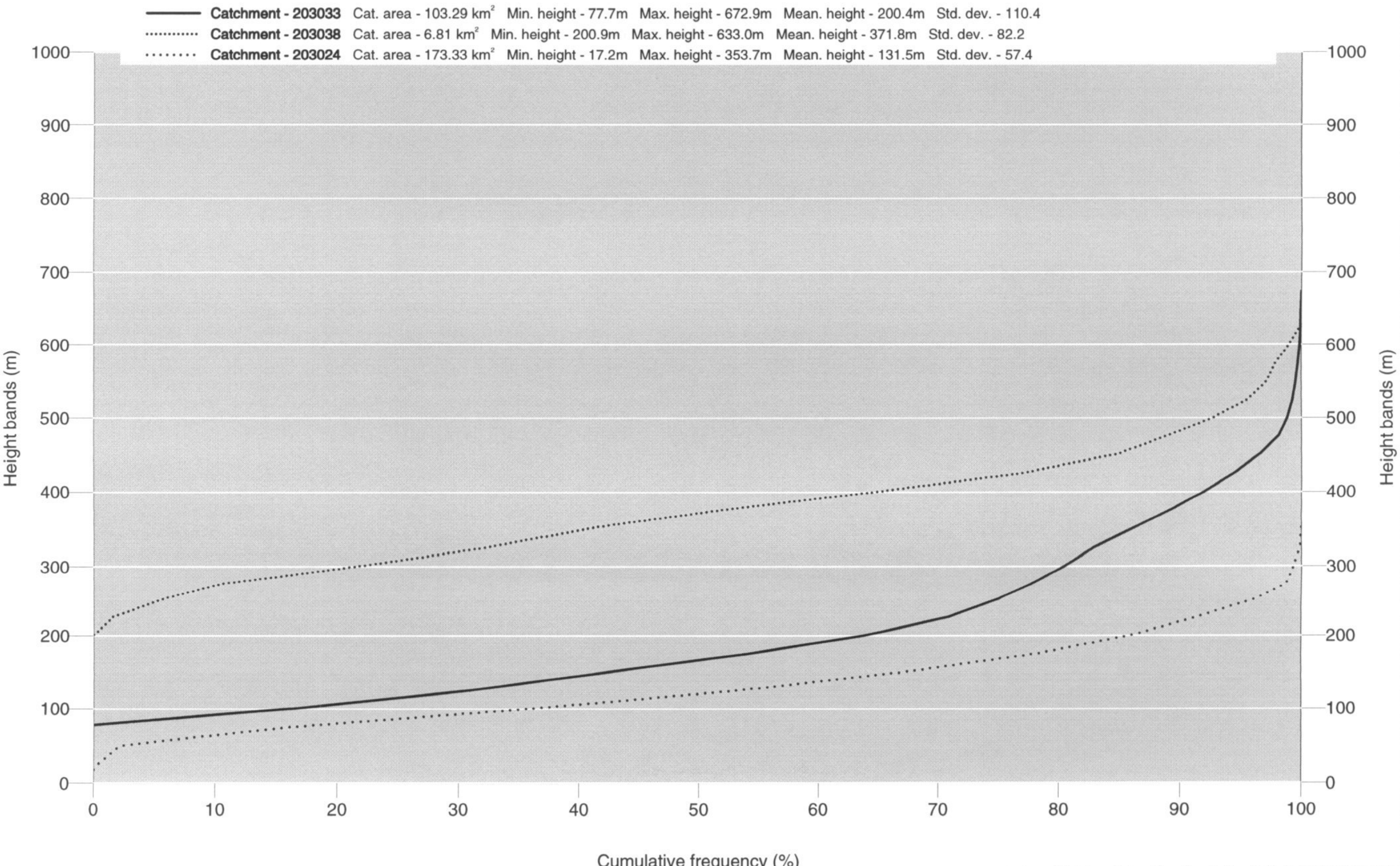

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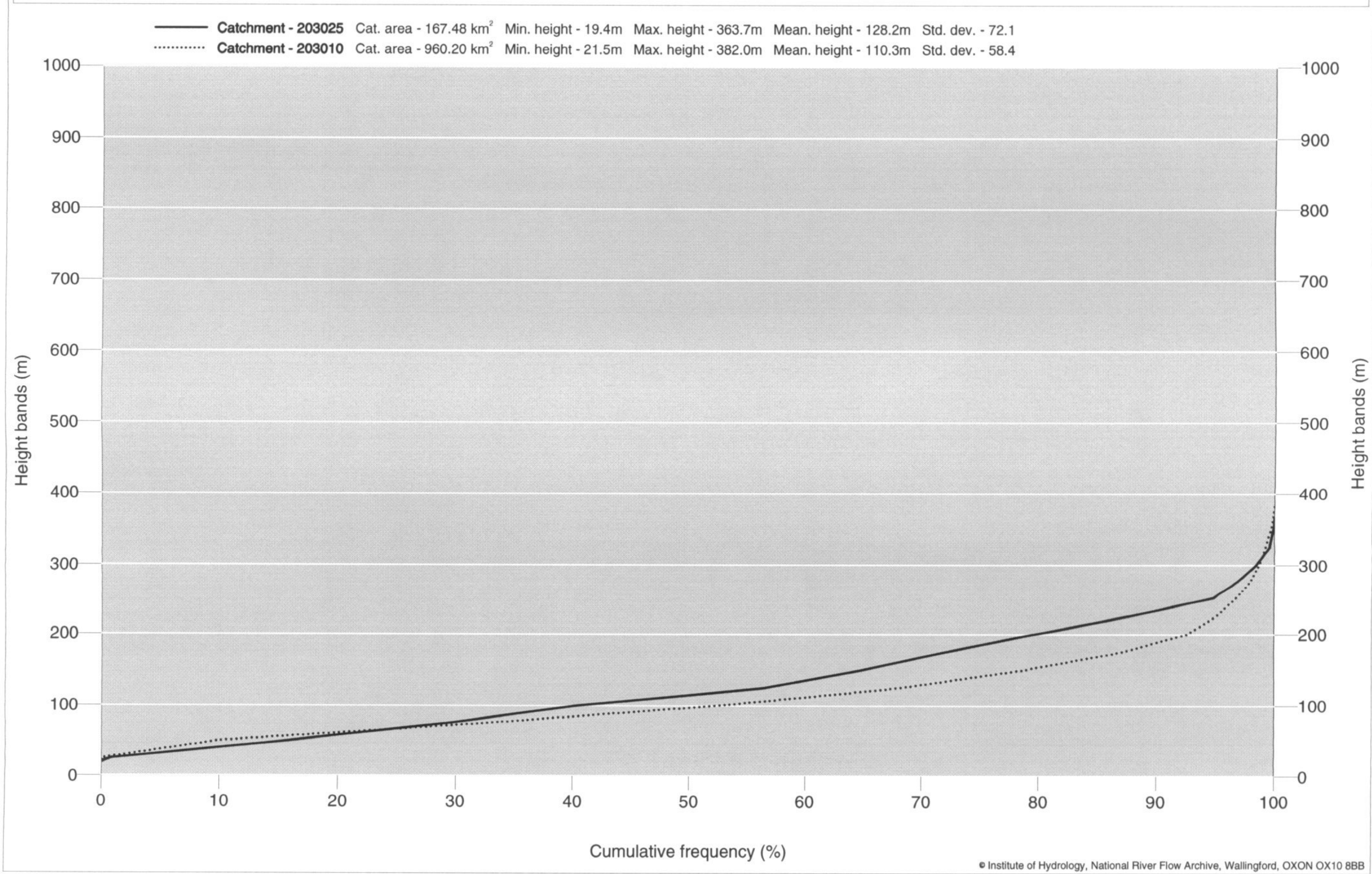

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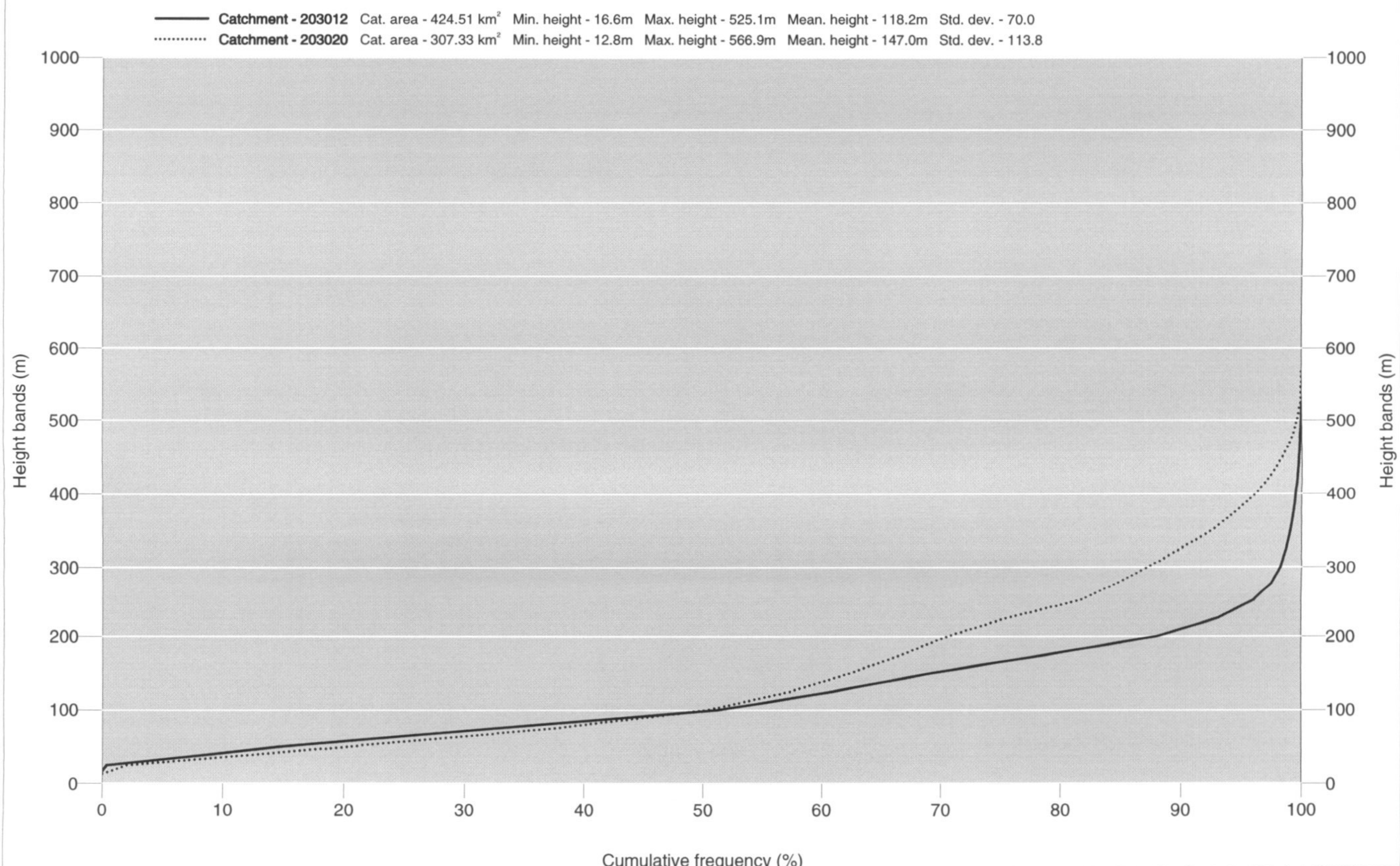

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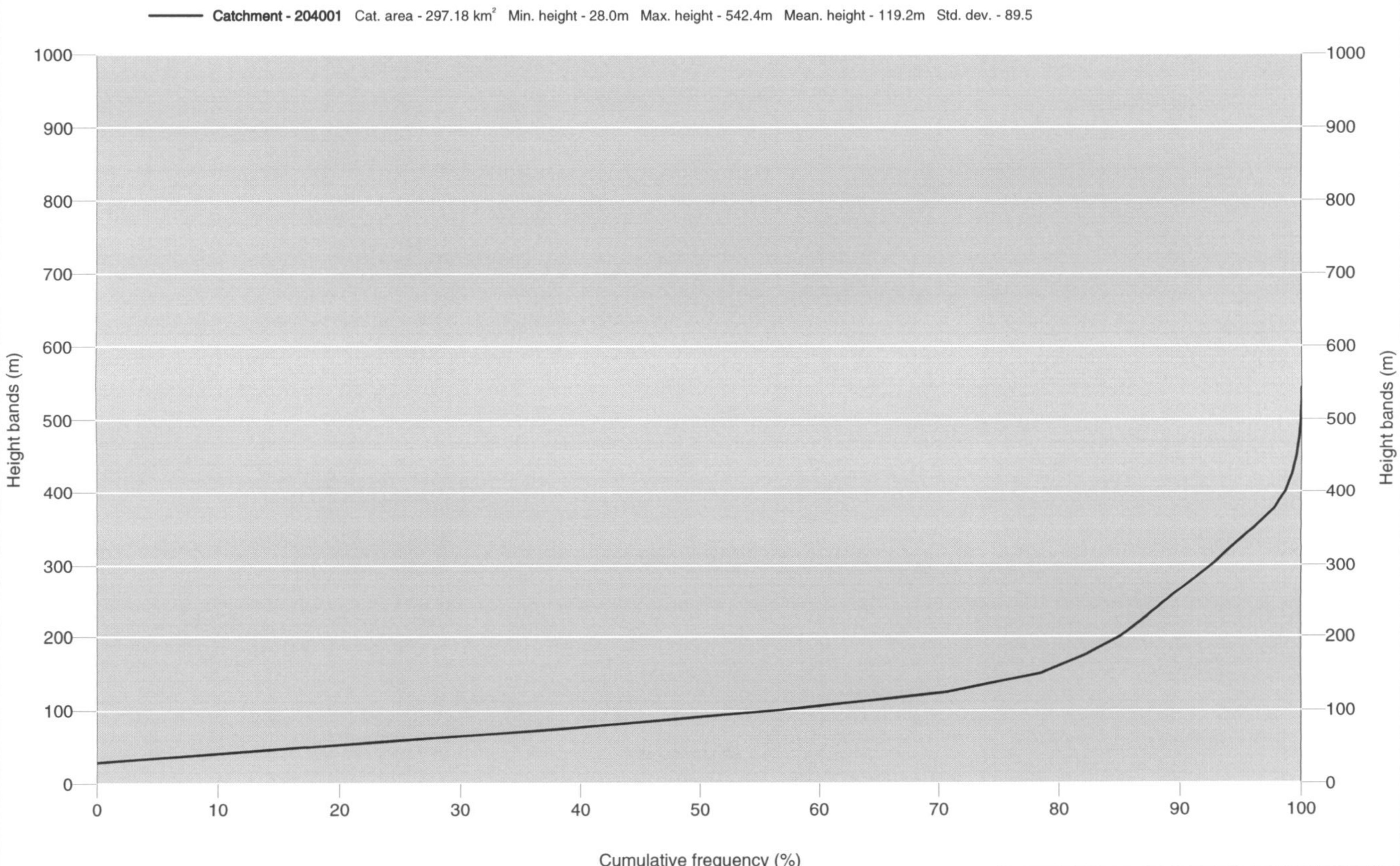
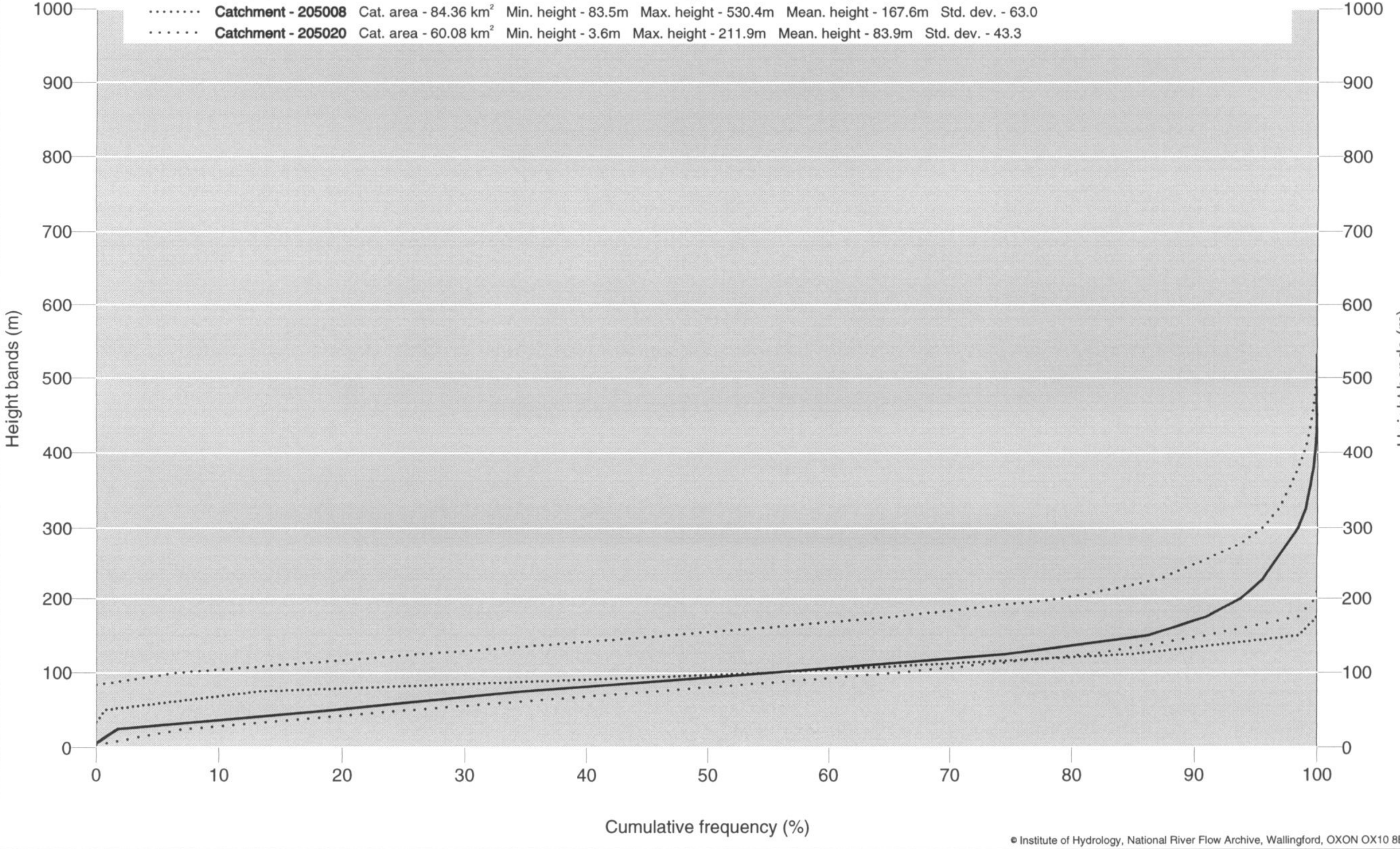


Hypsometric comparisons

Catchment - 205004 Cat. area - 493.20 km² Min. height - 5.4m Max. height - 530.4m Mean. height - 102.0m Std. dev. - 60.3
Catchment - 205005 Cat. area - 74.31 km² Min. height - 33.9m Max. height - 175.7m Mean. height - 99.1m Std. dev. - 22.6
Catchment - 205008 Cat. area - 84.36 km² Min. height - 83.5m Max. height - 530.4m Mean. height - 167.6m Std. dev. - 63.0
Catchment - 205020 Cat. area - 60.08 km² Min. height - 3.6m Max. height - 211.9m Mean. height - 83.9m Std. dev. - 43.3



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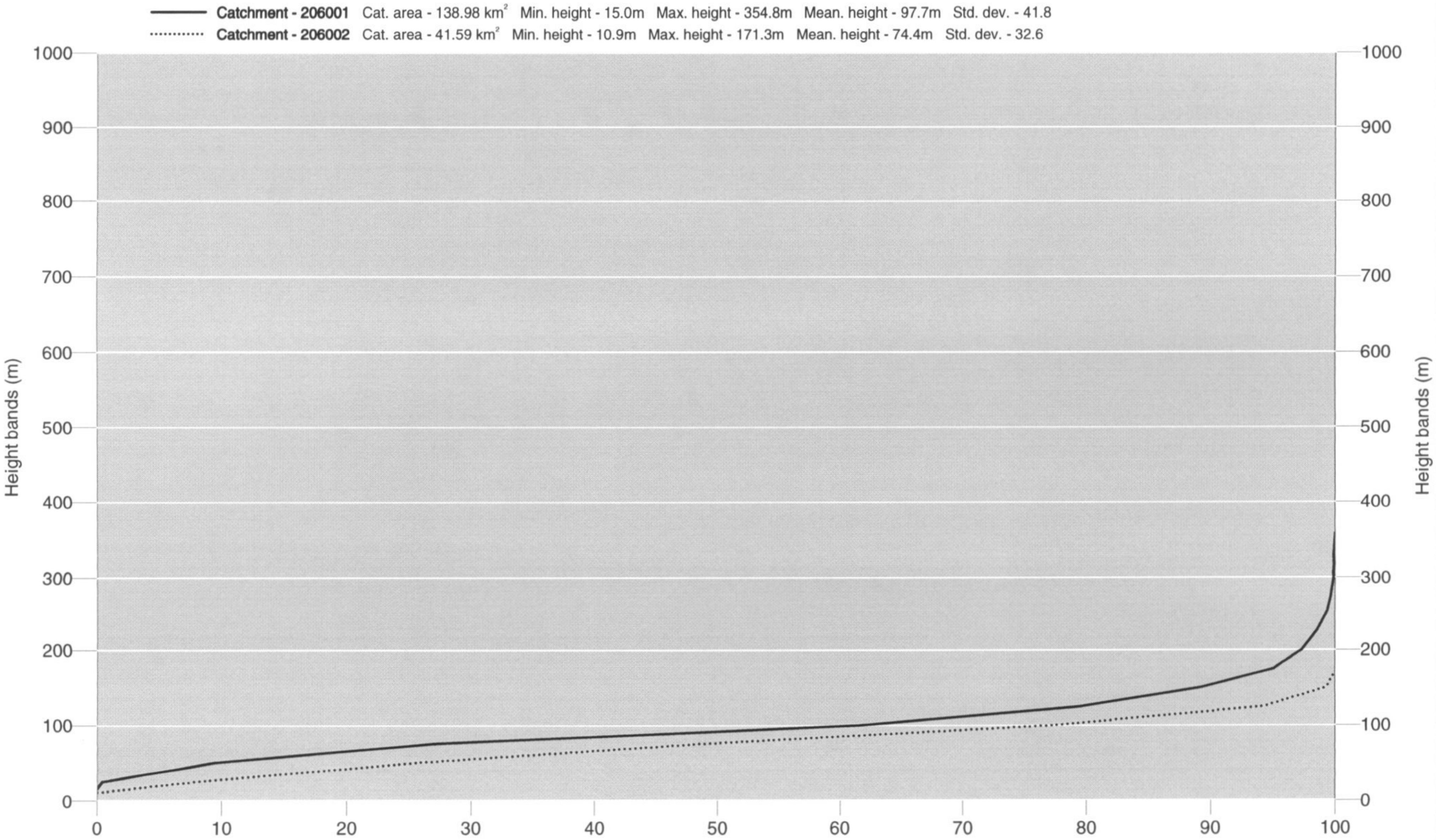

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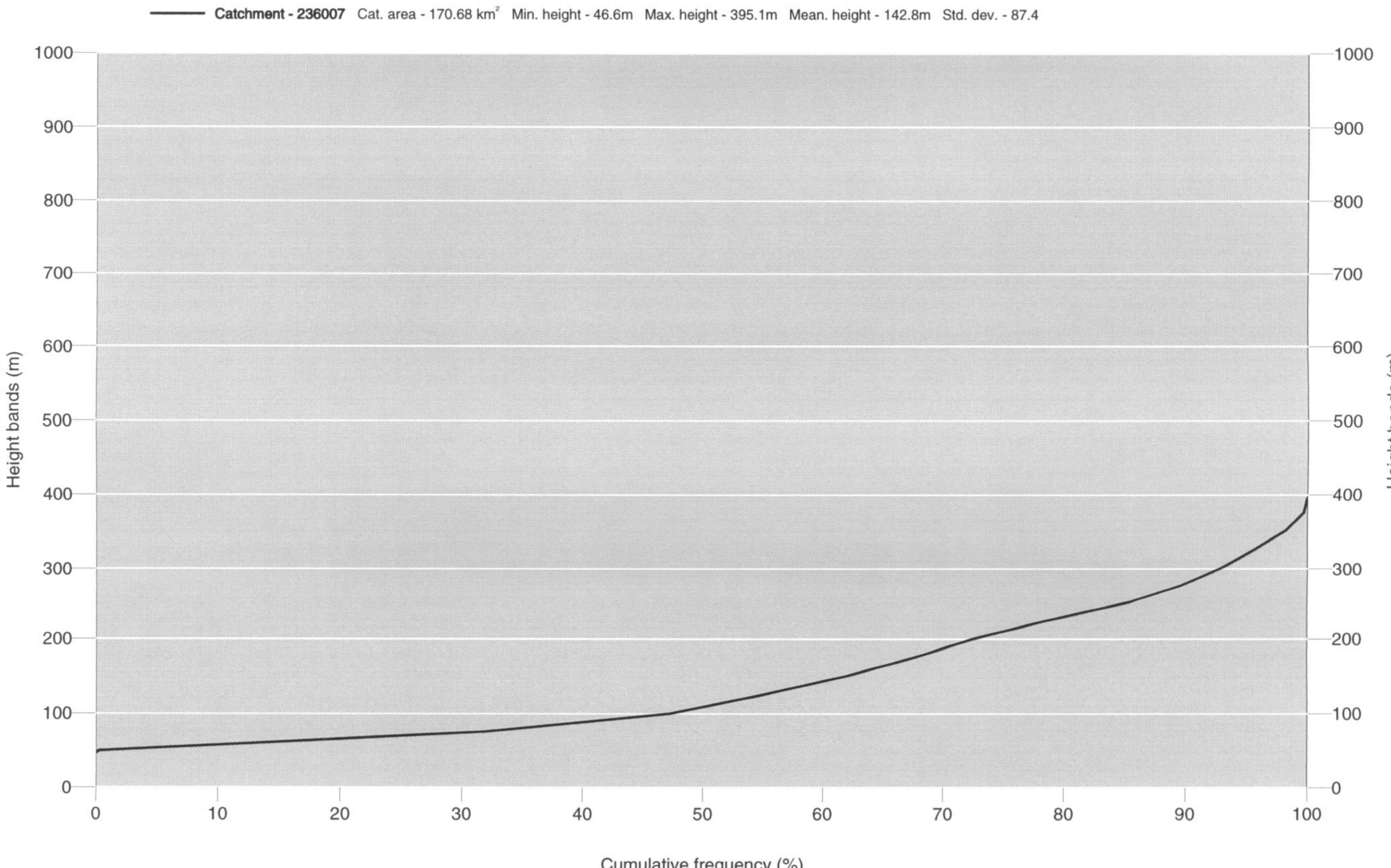

Appendix C1: Ranked data utility scores

Station		Data use (See section 3.1)	1	2	3	4	5	6	7	8	9	10	11	12	13	*SCORE*	
Flow stations																	
205004	Lagan	Newforge				1	1	1	2	1	1	1	1	1	1	11	*
201010	Mourne	Drumnabuoy House				1	1	1	2	1	1	1		1	1	10	*
202002	Faughan	Drumahoe			1	1	1	1	2	1	1	1			1	10	*
201007	Burn Dennet	Burndennet Bridge				1		1	2	1	1	1		1	1	9	*
203021	Kells Water	Currys Bridge	1			1		1		1	1	1	1	1	1	9	
203033	Upper Bann	Bannfield	1	1		1	1	1		1		1	1		1	9	
203040	Lower Bann	Movanagher	2	1		1			2	1		1			1	9	**
204001	Bush	Seneirl				1	1	1	2	1	1	1			1	9	*
202001	Roe	Ardnargle						1	2	1	1	1	1		1	8	*
203012	Ballinderry	Ballinderry Bridge				1	1	1		1	1	1	1		1	8	
203922	Blackwater	+ Derrymeen Bridge				1	1	1		1	1	1		1	1	8	
201002	Fairy Water	Dudgeon Bridge				1	1	1		1	1	1			1	7	
201008	Derg	Castlederg				1	1	1		1	1	1			1	7	
201009	Owenkillew	Crosh				1	1	1		1	1	1			1	7	
203010	Blackwater	Maydown Bridge				1	1	1		1	1	1			1	7	
203028	Agivey	White Hill				1	1	1		1		1	1		1	7	
205008	Lagan	Drummiller				1	1	1		1	1	1			1	7	
205011	Annacloy	Kilmore				1		1	2	1		1			1	7	*
206001	Clanrye	Mount Mill Bridge				1	1	1		1	1	1			1	7	
203018	Six Mile Water	Antrim				1		1		1	1	1			1	6	
203027	Braid	Ballee						1		1	1	1	1		1	6	
205005	Ravernet	Ravernet				1		1		1	1	1			1	6	
205020	Enler	Comber				1		1		1		1	1		1	6	
206004	Cambane	Bessbrook				1		1	2			1			1	6	*
236009	Swanlinbar	Thompsons Bridge		1		1				1		1	1		1	6	
236905	Colebrooke	+ Ballindarragh Bridge				1		1		1	1	1			1	6	
201005	Camowen	Camowen Terrace				1	1	1				1			1	5	
201006	Drumragh	Campsie Bridge				1	1	1				1			1	5	
203019	Clady	Glenone Bridge						1		1	1	1			1	5	
203020	Moyola	Moyola New Bridge						1		1	1	1			1	5	
203024	Cusher	Gambles Bridge				1		1		1		1			1	5	
203026	Glenavy	Glenavy						1		1	1	1			1	5	
203042	Crumlin	Cidercourt Bridge				1				1	1	1			1	5	
203092	Main	Dunminning Lower					1	1		1		1			1	5	
203093	Main	Shanes Viaduct				1		1		1		1			1	5	
206002	Jerretspass	Jerretspass (River)				1			2			1			1	5	*
206003	Jerretspass	Jerretspass (Canal)				1			2			1			1	5	*
236051	Ballycassidy	Ballycassidy Bridge				1		1		1		1			1	5	
203025	Callan	Callan New Bridge						1		1		1			1	4	
203029	Six Mile Water	Ballyclare					1			1	1	1				4	
203041	Ballygawley Water	Tullybryan								1	1	1			1	4	
203043	Oona Water (2 Nr)	+ Shanmoy						1		1		1			1	4	
203046	Rathmore Burn	Rathmore Bridge						1		1		1			1	4	
203932	Woodville (Flush)	+ Annesborough								1	1	1	1			4	
205029	Lagan	Feney					1	1				1			1	4	
236007	Sillees	Drumrainy Bridge				1		1				1			1	4	
203023	Torrent	The Moor Bridge								1	1	1				3	
203039	Clogh	Tullynewy Bridge						1				1			1	3	
203049	Clady Water	Clady Bridge						1				1			1	3	
203938	Rocky	+ Rocky Mountain				1						1			1	3	
205915	Cotton	+ Grandmere Park						1				1			1	3	
205017	Strand Lough	Killough Bridge										1			1	2	
205018	Strand Lough	Strand Brickworks										1			1	2	
236006	Upper Erne	Killyhevlin										1			1	2	

* 2 points included for one statutory data use
** 2 points each included for two statutory data uses
+ Broken record

Station		Data use (see sction 3.1)	1	2	3	4	5	6	7	8	9	10	11	12	13	*SCORE*	
Level-only stations																	
203614	Lough Neagh	Derryadd Bay	2	1											1	4	*
203616	Lough Neagh	Toome (Lough Neagh)	2	1											1	4	*
236601	Lower Erne	Rosscor	2	1											1	4	*
236602	Upper Erne	Portora	2	1											1	4	*
236603	Upper Erne	Belle Isle	2	1											1	4	*
201304	Strule	Stone Bridge				1				1					1	3	
203301	Lower Bann	Loughan Island					1									1	
203308	Lower Bann	Portna		1												1	
203309	Blackwater	Verners Bridge		1												1	
203315	Lower Bann	Toome (Lower Bann)		1												1	
203902	Lower Bann	+ Agivey Bann Bridge					1									1	
205301	Quoile	Quoile Barrier Lower		1												1	
205302	Quoile	Quoile Barrier Upper		1												1	

* 2 points included for one statutory data use
** 2 points each included for two statutory data uses
+ Broken record

APPENDIX C.2

DISCUSSION OF THE GAUGING STATION DATA REQUIREMENT IN EACH DATA USE CATEGORY

1 Prescribed/residual flows/levels

Data were required for statutory functions at five level-only stations on Loughs Neagh and Erne and also on the Lower Bann at Movanagher. Data were also required from Bannfield and Currys Bridge to service non-statutory commitments. Levels/flows at these sites generally require regulation to protect fisheries and other conservation interests.

2 River regulation/transfer schemes

Further to the first category, a few other sites were noted as requiring data for river regulation, notably the two River Quoile stations, to service operation of the Quoile Barrier at the inflow to Strangford Lough, and others on the Lower Bann, Blackwater and Swanlinbar. However, it became apparent that there was considerable overlap in these first two categories; the general finding being that there is an important gauging station data requirement for maintenance of lake levels and, to a lesser extent, of rivers where fisheries are important and control is possible by use of reservoir storages.

3 Abstraction point spillage protection

An anticipated data use was identified only for the River Faughan at Drumahoe.

4 Catchment yield assessment

Data use was identified at 34 of the 54 flow stations for this category, and also at one level-only station, Strule at Stone Bridge where there is the intention to upgrade the station to flow measurement status. These stations are widely distributed and include those at the outfalls of most major catchments. Unlike data use for monitoring purposes, however, such data use is not specific to the exact locations of the gauging stations. Rather, they are used to indicate flow characteristics for their respective catchments in general. Coupled with the possibilities offered by modelling for estimating flow quantiles from spatial data, there appears to be scope for revising the deployment of gauging stations in this respect. This is discussed further below.

5 Flood forecasting

Four clusters of stations were identified for this use, on the Rivers Mourne, Blackwater, Lagan and Lower Bann and their tributaries. Isolated data uses were also identified in other areas. It is noticeable that on some rivers, the only gauging stations used for flood forecasting are located at the catchment outfalls (Ballinderry Bridge, Seneirl, Mount Mill Bridge), or immediately upstream of settlements with particular flood risk (e.g., two stations upstream of Omagh) thus affording little warning time in either case. It is argued that flood forecasting should not therefore be used as a justification for these stations and that consideration should be given to upstream sites which would offer a clear advantage in these situations, notwithstanding the use of rainfall data in the real-time assessment of flood risk.

6 *Flood design studies*

Forty-one flow stations were considered useful for this purpose. The remainder are stations without cableways, thus being unable to provide accurate high flow data. The widespread coverage of stations identified with this data use is indicative of a capability to provide data when required for flood design work, but not that the stations identified are necessarily those points best suited to providing data for this purpose. Again, therefore, there seems to be scope for change; this too will be discussed below. It should be questioned whether it is desirable to continue operation of these stations *ad infinitum* for the extension of flood series.

7 *PARCOM*

Stations used for this purpose are those at the outfalls of all major catchments draining from Northern Ireland into the sea and, subject to adequate hydrometric data quality and co-location with quality monitoring sites (see Chapter 6), must be retained to continue the measuring authority's statutory commitment to providing information on the discharge of materials to the sea.

8 *Assimilative capacity*

Thirty-eight flow stations across the Province were identified against this item and included those at the outfalls of all major catchments. Many of those not cited lie in areas of low population density where there is little pressure on rivers to assimilate effluents. As with yield assessment and flood design studies, the information requirement here is not highly site specific; the over-riding need is for flow parameters to support effluent assimilation assessments in all catchments and consideration could therefore be given to resiting some of these stations if other data uses are also not site-specific.

9 *Consent standards*

Monitoring of discharge consents was found to involve use of data from 27 flow stations. All of these sites were also cited as being useful for assimilative capacity studies. Information provided in this category allows identification of those sites where there is a specific requirement for flow data, in contrast with those where only assimilative capacity assessments need to be made. In discussing possible changes to the network at the end of this section, attention will therefore be directed towards those catchments where data are required for assimilative capacity studies but not in relation to any specific discharge.

10 *Transmission to NRFA*

While there have been some problems recently in transmitting data to the National River Flow Archive, ES are now well towards resolving these difficulties and data will be supplied for all flow stations. A score is thus given to each flow station in recognition of the value of these data on the national archive.

11 Ecological studies/recreational monitoring

This category registered mainly those gauging stations which provided data useful for monitoring flows/levels in relation to fisheries interests. Only ten were found in all and most were located on rivers draining catchments of less than 200 km^2. The largest was the Lagan at Newforge, but data here were required not so much for supporting fisheries interests as for the new city centre recreational development of the Lagan in Belfast. From discussions it was felt that this type of data use does not rate highly in the justification of any individual gauging site but again, in the rivers identified, there is a requirement for some flow data.

12 Benchmark monitoring

Only five stations were recognised in this category of data use and some doubt exists as to whether there is any clear perception of a benchmark monitoring role within the network operating/measuring authorities. None of the stations identified is the oldest in its hydrometric area and it is not apparent from the hydrometric data quality review that they are selected on the basis of outstanding accuracy of flow measurement. Recommendations for the explicit designation of benchmark sites are made in Chapters 7 and 8.

13 Hydrological studies

Almost all of the stations in the Northern Ireland network recorded a score against this data use. Only three of the 54 flow stations were not cited as being useful, and, in addition, six of the level-only stations were also identified (including all those on Lough Neagh and Loughs Erne). The reason for the popularity of this item is the current thrust towards establishing water quality catchment management plans in Northern Ireland. Gauging station data will be valuable both in the preparation of the plans (by consultants) and in their subsequent operation. As with some other categories of data use, it is felt that the use of gauging station data in this way rarely depends on the availability of a station at a specific point on a river, but more often requires some data which are representative of all the major catchments involved. This is therefore taken into consideration in working towards recommendations in Chapter 3.

APPENDIX D.1

APPLICATION OF THE MICRO LOW FLOWS Q_{95} ESTIMATION METHOD AND PRESENTATION OF RESULTS

D1.1 Results

Of 131 gauging stations in Wales available for study, only those which could be designated as natural (i.e., the gauged flow is estimated as within 10% of the natural flow at or above the 95 percentile flow) were considered for use. Twenty-three natural catchments were identified from Factors Affecting Runoff codes in the National River Flow Archive; their basic characteristics are listed in Table D1.1.

Table D1.1 *Stations selected from NRA Welsh Region*

Station number	River/station name	Catchment area (km^2)
55008	Wye at Cefn Brewyn	10.6
55012	Irfon at Cilmery	244.2
55013	Arrow at Titley Mill	126.4
55025	Llynfi at Three Cocks	132.0
55028	Frome at Bishops Frome	77.7
55029	Monnow at Grosmont	354.0
55033	Wye at Gwy Flume	3.9
55034	Cyff at Cyff Flume	3.1
55035	Iago at Iago Flume	1.1
56007	Senni at Pont Hen Hafod	19.9
56013	Yscir at Pontaryscir	62.8
58008	Dulais at Cilfrew	43.0
58009	Ewenny at Keepers Lodge	62.5
60002	Cothi at Felin Mynachdy	297.8
60003	Taf at Clog-y-Fran	217.3
60006	Gwili at Glangwili	129.5
61003	Gwaun at Cilrhedyn Bridge	31.3
61004	Western Cleddau at Redhill	197.6
63001	Ystwyth at Pont Llolwyn	169.6
64001	Dyfi at Dyfi Bridge	471.3
64002	Dysynni at Pont-y-Garth	75.1
65005	Erch at Pencaenewydd	18.1
67018	Dee at New Inn	53.9

Measured and estimated Q_{95} values are presented in Table D1.2, along with ratios of the estimated to measured values. Figure D1.1 presents these ratios in the form of a histogram.

Table D1.2 *Measured and estimated Q_{95} values and ratios*

Station	Measured	Estimated	Ratio
55008	0.07	0.09	1.29
55012	0.75	1.09	1.45
55013	0.26	0.66	2.54
55025	0.16	0.25	1.56
55028	0.09	0.08	0.89
55029	0.68	1.05	1.54
55033	0.04	0.03	0.75
55034	0.02	0.03	1.50
55035	0.01	0.01	1.00
56007	0.10	0.21	2.10
56013	0.18	0.22	1.22
58008	0.25	0.21	0.84
58009	0.38	0.32	0.84
60002	0.91	1.30	1.43
60003	0.82	0.66	0.81
60006	0.41	0.49	1.20
61003	0.16	0.11	0.69
61004	0.72	0.63	0.88
63001	0.57	0.61	1.07
64001	2.09	2.28	1.09
64002	0.53	0.52	0.98
65005	0.09	0.10	1.11
67018	0.22	0.28	1.27

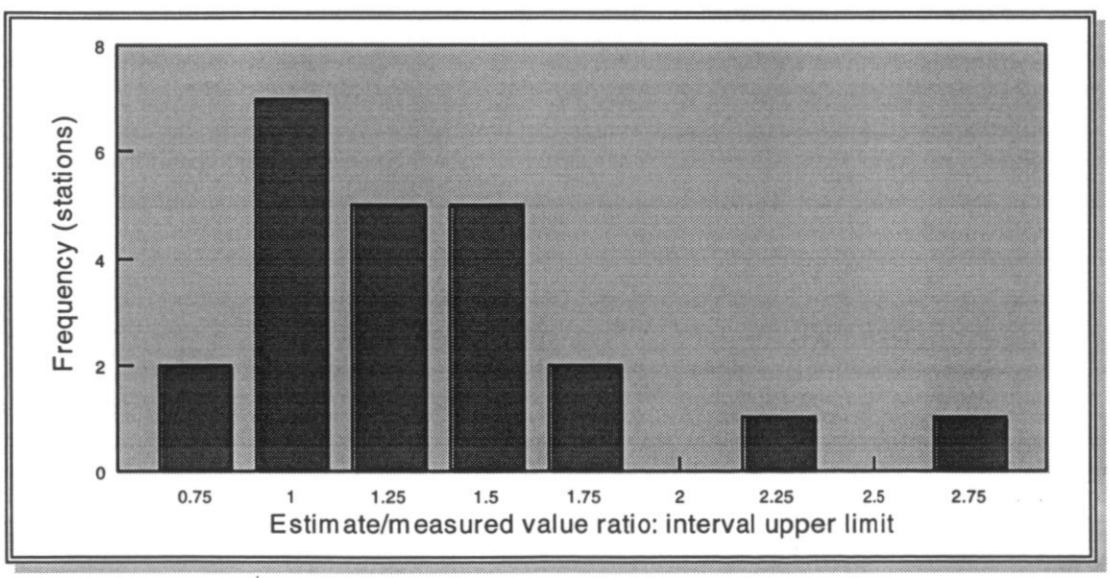

Figure D1.1 *Q_{95} estimated/measured value ratios: Welsh NRA Region natural catchments*

It can be seen that the ratio values range from 0.69 to 2.54, having a positively-skewed distribution and a median of 1.11. Only one station has a Q_{95} estimate of more than 25% less than the measured value, but nine have estimates more than 25% in excess of the measured values, including two with estimates more than 100% in excess of the actual. While some of these more serious mismatches may be the result of the periods of record used for the measured Q_{95} computations, it is clear that there are major variations in the success of the model for estimating Q_{95} values in this range of catchment types.

It was the purpose of this investigation to identify those catchment types in which the model has been successful and those where problems have occurred. The required accuracy of flow parameters varies from one application to another but, as an arbitrary definition, it was assumed that Q_{95} values were required to within 25% of the measured value. The characteristics of those catchments meeting this specification were therefore compared with those which did not.

As a first step in assessing the performance of the Micro LOW FLOWS estimation method, Q_{95} estimated/measured ratios were related to a number of basic catchment characteristics:

- catchment area
- long-term average annual rainfall
- 10-85 percentile slope
- station altitude
- FSR soil index.

No strong correlations were found between the ratio and any of these single variables. The highest correlation coefficient was $r = 0.463$ for altitude, suggesting that high altitude catchments were associated with high ratios and *vice-versa*. In reality, however, it was found that while some high altitude catchment Q_{95} values were seriously over-estimated, there was a great mix of over- and under-estimation in lower catchments. This moderately high statistic appears to be the result of just a few stations exercising undue influence in the correlation procedure. So, a second approach to elucidating the nature of the relationship between Q_{95} estimation and catchment characteristics was employed.

It was decided that rather than looking for linear relationships between single predictor variables and Micro LOW FLOWS performance, stations would be divided into groups on the basis of a number of catchment characteristics. Of the five characteristics noted above, it was decided to discard altitude from the analysis as it was highly correlated with slope ($r = 0.837$) and to a lesser extent rainfall ($r = 0.543$). Soil index values were available for only 11 of the 23 sites and appeared to be highly correlated with average rainfall and altitude (r = 0.873 and 0.686 respectively), so this too was omitted from analysis.

A table was constructed in which ratio values could be placed according to the physical characteristics of each catchment, thus allowing patterns to be identified. Values for each of the three remaining variables (area, rainfall and slope) were divided into three classes, with boundaries set in order to give approximately equal numbers of cases in each class, while taking into account the distribution of values for each variable. The class intervals chosen for each variable are shown in Table D1.3 (four are shown in order to represent better the range of values found).

The distribution of values in this three-dimensional classification is shown in Table D1.4. It can be seen in Table D1.4 that those stations at which Q_{95} estimation ratios are closest to unity are generally the smaller and lower rainfall ones, while at higher annual rainfalls or catchment areas, the chance of an estimate falling outside the ±25% range is somewhat higher. It can also be noted that in each catchment size class, there seems to be a weak inverse relationship between the

Table D1.3 *Class limits and (number of cases) for area, rainfall and slope variables*

	Low range	Number	Medium range	Number	High range	Number	Very high range	Number
Area (km^2)	<20	6	20-100	7	>100	10		
Ave ann rainfall (mm)	<1250	4	1250 -1749	10	1750 -2100	5	>2100	4
Slope (m km^{-1})	<6	7	6-16	10	>16	6		

success of the estimation method and catchment slope. Although the number of stations in this analysis is less than ideal, it is thought that these patterns may still have some value. That Q_{95} values should tend to be over-estimated in steep catchments, for example, may be explained in physical terms by suggesting that steep slopes cause faster drainage of runoff and therefore lower Q_{95} runoff values. Also, it should not be unexpected that estimation is more successful in smaller catchments as these will be hydrologically more simple and therefore more easily modelled. It should also be noted, however, that flow measurement problems such as gauge insensitivity and algal growth may also contribute to some of the larger discrepancies between estimated and measured values.

The results of this simple study seem most helpful when considering the potential role of hydrological models for low flow estimation in Northern Ireland. In discussing data usage with ES staff as part of the survey reported in Chapter 3, it became apparent that much of the focus of model-based low flow estimation work (as in other regions) is concentrated in more developed areas at lower altitudes (lower rainfall) and in relatively small catchments. Where estimates of low flow parameters are required on larger rivers, the current network of gauging stations located on all major rivers provides measured data which may be translated up or downstream to the point of interest. In small, steep and wet catchments there is generally little demand to utilise water resources and the lower level of success of the method is not of particularly great consequence. However, the need for reservoir inflow data and flow regime characterisation for hydro-electric power generation present obvious exceptions to this.

In all cases, it is important to use information on abstractions and/or discharges to temper the results of the type of modelling work discussed here. This facility is built into Micro LOW FLOWS version 2.

D1.2 Conclusions

From this brief study it can be seen that the Micro LOW FLOWS Q_{95} estimation method has been most successful in catchments smaller than 100 km^2 and with mean annual rainfall of less than 1750 mm. Taking the range of catchment types in Wales to be broadly analogous with those of Northern Ireland, this finding may be transferred as an endorsement of the applicability of using spatial data for estimating low flow parameters in such catchments. The method is seen as having applicability to a large number of the low flow estimates currently undertaken by the Water Quality Unit of the ES. However, it is recommended that comparisons should be made, wherever

Table D1.4 *Q95 estimate/measured ratio and station numbers for natural catchments in Wales*

	CATCHMENT AREA (sq.km)									
	>20			20-100			>100			
SLOPE (m/km)	<6	6-20	>20	<6	6-20	>20	<6	6-20	>20	**SAAR (mm)**
				0.89 (55028)			**1.56 (55025)**	***1.54 (55029)*** 2.538 (55013)		<1250
		1.11 (65005)			**0.84 (58009)** **1.22 (56013)**	0.69 (61003)	**0.88 (61004)** **0.81 (60003)** **1.43 (60002)** **1.20 (60006)**	***1.45 (55012)*** **1.07 (63001)**		1250 - 1749
		2.10 (56007)			**0.98 (64002)** **0.84 (58008)**	***1.27 (67018)***	**1.09 (64001)**			1750 - 2100
KEY *2.54 (55013)* ***1.45 (55012)*** **0.81 (60003)** 0.69 (61003)	**Ratio** >2.0 1.25-2.0 0.75-1.25 <0.75		**0.75 (55033)** ***1.5 (55034)*** ***1.29 (55008)*** **1.00 (55035)**							>2100

possible, between statistically derived low flow estimates and flows measured at gauging stations in analogous catchments, and to compare measured and estimated values for gauging station sites. While Micro LOW FLOWS has been seen to achieve a fair degree of success in some types of catchment, comparison will allow confidence to be justified in catchment types where the method works well and adjustments made where other catchment characteristics appear to affect estimated values.

For larger catchments, it is anticipated that measured flow data will be available at some point on each major watercourse. Estimation methods should be applied to these sites and comparisons with measured flow data used to condition estimates for ungauged sites. In all catchments, human modifications to flows should be taken into account when assessing the low flow values likely to be observed.

The estimation method was not particularly successful in small, upland catchments and while this may be of little consequence for assessing the impact of any (typically minor) discharges in such areas, for example, it is rather more important in relation to assessing low flows in conjunction with water supply schemes in general and supply reservoirs in particular. No evidence has been found to call the general applicability of the Micro LOW FLOWS methodology into question in this type of catchment; rather, it is suspected, there are local factors (such as steep slopes) which cause estimates to be significantly at odds with measured values. In such cases, it is felt that the collection of flow data at gauging stations (perhaps complemented by spot gaugings) would allow corrections to be applied to low flow estimates for ungauged sites; such questions are explored in detail in Chapter 7. The choice of catchments to be gauged is considered to be very important.

Having established the relative merits of using spatial data in a range of catchment types, it remains to conclude this section with a summary of the wider benefits of using the type of methodology implemented in Micro LOW FLOWS. The software package offers fast, reproducible calculation of a wide range of low flow parameters and gives results based on the consistent application of a specific method. The automatic handling of abstraction and discharge data further adds to the utility of this system. Its use is therefore strongly recommended as the basis of a low flow estimation strategy. It should be noted, however, that the confidence which can be placed in the results will be much greater if model use is underpinned by data from a network of river flow gauging stations covering a full range of catchment types; without this, the ability to assess the success of the method in various types of catchment, and make alterations to estimates where appropriate, will be compromised.

APPENDIX D.2

COMPARISON OF FLOOD STUDIES REPORT STATISTICAL MEAN ANNUAL FLOOD ESTIMATES WITH RECORDED VALUES

D.2.1 Introduction

The mean annual flood (MAF) is a widely used index of flood magnitude both at gauged and ungauged sites. With gauging station records, either annual maximum or peaks-over-threshold (POT) series can be used for derivation; without such data the *Flood Studies Report* suggested the use of either a statistical method (based on catchment characteristics) or a rainfall-runoff method to estimate the MAF and outlined methods for both. Regional growth curves were then provided for the estimation of floods of higher return periods.

The statistical approach relating MAF to catchment characteristics uses the equation:

$$MAF = C\ AREA^{0.94}\ STMFRQ^{0.27}\ S1085^{0.16}\ SOIL^{1.23}\ RSMD^{1.03}\ (1+LAKE)^{-0.85}$$

where C	denotes a regional multiplier (here 0.0213 for all catchments in Wales),
AREA	catchment area (km^2)
STMFRQ	stream frequency (junctions km^{-2})
S1085	stream slope ($m\ km^{-1}$)
SOIL	soil index based on Winter Rain Acceptance Potential
RSMD	net 1-day rainfall of 5-year return period (mm).
LAKE	Fraction of a catchment draining through a lake or reservoir

Definitions for each of these parameters are available in the FSR (NERC, 1975). This section of the work reports on application of this equation to assess the usefulness of spatial data in estimating a high flow quantile for a range of catchments.

D.2.2 Method

As mentioned above, problems of data availability dictated that this work could not be undertaken for Northern Ireland catchments. For this section, not all of the necessary catchment characteristics data were available, so the physical analogue of Wales was again used. It was found that many of the Welsh gauging sites for which catchment characteristics had been derived for the FSR are now no longer in operation and with the time constraints of this study, it was not considered possible to derive such data for stations opened since the time of that work. Therefore, the study was based exclusively on the data presented in Volume IV of the FSR; this offered the advantage of a ready-to-use data set, although the flood series were not as long as would have been possible using more recent data.

For each of the 45 stations for which all required information was presented in the FSR, MAF estimates, calculated using the above equation, were compared with BESMAF (best estimate of the mean annual flood) values derived from the annual maximum series (with the benefit of record extension where possible). Ratios of estimate to measured values were computed and form the basis of the analysis. A list of the gauging stations used and their catchment characteristics, is presented in Table D.2.1.

Table D.2.1 *Gauging stations used for FSR method and catchment characteristics*

No.	AREA	STMFRQ	S1085	RSMD	SOIL	LAKE
55001	4040	1.04	1.1	38.4	0.323	0.037
55002	1900	1.05	2	47.5	0.359	0.08
55003	886	0.6	2.32	49.9	0.287	0
55004	72.8	1.94	15.41	67.4	0.489	0
55005	167	1.13	5.8	69.5	0.41	0
55007	1280	1.16	3.7	60.1	0.381	0.118
55008	10.4	2.88	37.23	82.4	0.5	0
55009	357	2.06	7.58	39.6	0.314	0
55010	27.2	3.01	45.3	79.5	0.5	0
55015	24.6	3.5	38.07	58.3	0.433	0
55808	95.3	1.39	14.25	81.7	0.463	0
56001	912	1.18	2.84	55.6	0.37	0.052
56002	217	1.08	10.49	58.3	0.458	0
56003	62.2	1.01	9.02	52.5	0.344	0
56004	544	1.26	4.46	59.1	0.379	0.079
56006	184	1.67	7.87	62.9	0.322	0.11
57003	487	2.12	6.58	69.3	0.49	0.141
57004	109	2.33	7.3	79.5	0.495	0
58001	158	2.63	10.33	56.6	0.469	0
58002	191	2.59	13.5	80.2	0.499	0.041
58003	62.9	1.41	9.25	42.6	0.341	0
58004	85.7	2.87	17.22	47.7	0.5	0
59001	228	2.61	10.35	65	0.489	0
60001	1090	1.19	4.14	61.1	0.359	0
60002	298	0.82	4.82	58	0.375	0
60003	217	1.18	3.85	46.9	0.307	0
61001	198	0.89	2.74	45.5	0.329	0
61002	183	0.89	10.38	48.4	0.332	0
62001	894	0.72	1.82	48	0.321	0
63001	170	1.45	10.61	57.2	0.34	0
63002	182	1.8	9.89	66.5	0.39	0.249
64001	471	2.7	5.22	64	0.4	0
65001	68.6	5.93	33.37	109.1	0.5	0.046
66002	220	1.99	6.03	43.4	0.328	0.021
66003	69.9	1.85	17.38	37.2	0.367	0.034
66011	344	4.18	17.07	66.1	0.398	0.001
66801	10.4	2.68	16.27	117.5	0.5	0.15
67002	1040	1.62	1.42	48.3	0.391	0.212
67003	20.2	1.83	13.3	43.5	0.5	0
67005	114	1.01	10.72	44.1	0.4140	
67006	185	1.83	9.23	47.6	0.401	0.084
67007	728	1.92	1.42	52.8	0.393	0.303
67009	79.5	1.12	6.11	33.6	0.236	0
67801	105	1.78	11.88	81.9	0.472	0.548
67803	1830	1.22	1.51	28.2	0.387	0.122

Table D.2.2 *Estimated mean annual flood, BESMAF and estimate/BESMAF ratio*

No.	BESMAF	EST/MAF	EST/BESMAF
55001	519.28	555.12	1.07
55002	441.68	412.73	0.93
55003	50.04	151.29	3.02
55004	65.57	70.46	1.07
55005	137.01	94.45	0.69
55007	548.97	429.63	0.78
55008	16.74	18.32	1.09
55009	126.06	95.55	0.76
55010	53.21	45.52	0.86
55015	21.06	25.54	1.21
55808	89.22	93.37	1.05
56001	365.59	282.06	0.77
56002	87.09	125.47	1.44
56003	23.45	23.46	1.00
56004	341.15	203.82	0.60
56006	162.31	74.06	0.46
57003	285.16	346.66	1.22
57004	67.49	115.52	1.71
58001	103.99	117.96	1.13
58002	215.62	218.85	1.01
58003	19.34	20.78	1.07
58004	67.84	66.90	0.99
59001	196.35	201.79	1.03
60001	361.32	393.63	1.09
60002	139.03	107.79	0.78
60003	53.46	53.49	1.00
61001	44.44	45.45	1.02
61002	70.74	56.29	0.80
62001	177.59	169.99	0.96
63001	90.46	73.54	0.81
63002	70.59	94.07	1.33
64001	292.31	277.48	0.95
65001	62.31	165.61	2.66
66002	89.34	65.96	0.74
66003	31.38	25.27	0.81
66011	450.39	288.36	0.64
66801	18.33	20.14	1.10
67002	259.39	255.39	0.98
67003	13.38	13.29	0.99
67005	36.12	44.73	1.24
67006	80.23	78.50	0.98
67007	124.20	198.32	1.60
67009	8.88	11.34	1.28
67801	38.36	75.20	1.96
67803	203.94	246.15	1.21

D.2.3 Results

The results of the estimation work are presented in Table D.2.2 and a frequency distribution plot of the ratio values is presented in Figure D.2.1. Ratios range from 0.46 to 3.02, with a mean of 1.11 and a median of 1.01. Estimates were less than 75% of BESMAF values in five cases and greater than 125% in eight, leaving the remaining 32 (71% of the sample) within these limits.

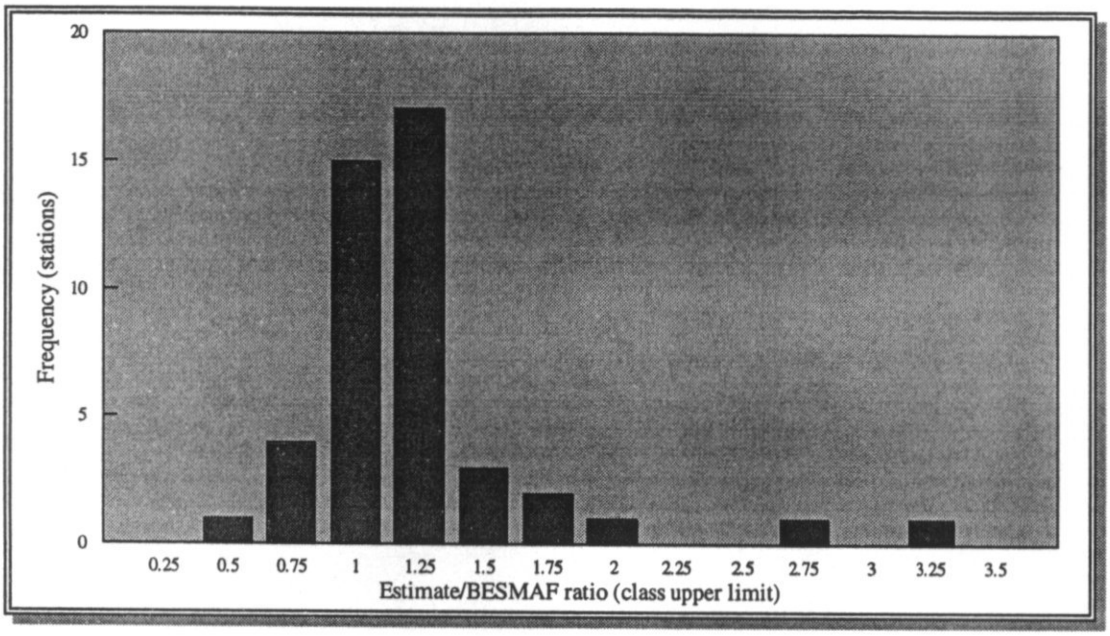

Figure D.2.1 *MAF estimate/BESMAF ratio frequency distribution*

With six independent variables used in the equation to predict MAF, an assessment of the performance of the method was unlikely to be straightforward. It is worth noting in the first instance, however, that using the same ±25% tolerance as in the Q_{95} section, a greater degree of success has been achieved in the estimation of MAF values, although this takes no account of any inaccuracies or bias in the measured flow data.

Five stations stand out as having conspicuously high EST/BESMAF ratios; in descending order of ratio they are: 55003, 65001, 67801, 57004 and 67007 (see Table D2.2). In the case of 55003, values of STMFRQ, SOIL and to a lesser extent S1085 are all very low, but BESMAF is exceptionally low in relation to AREA, so the estimate is greatly in excess of the measured value. With three very low values of predictor variables, this over-estimate is surprising; it is possible that data errors or other unidentified influences are responsible for the discrepancy in values. With the next three catchments, there is a coincidence of high RSMD, SOIL and STMFRQ values and it is not surprising that over-estimation occurs: the regression equation was developed with exponent values which minimised differences between observed and estimated values for all catchments in the FSR, and this type of error is difficult to avoid. At stations 67007 and 67801 extremely high LAKE values are recorded and it seems possible that the attenuating effect on flood values has not been fully represented in the MAF estimation for these catchments.

Considering the five stations for which MAF is most seriously under-estimated (56006, 56004, 66011, 55005 and 66002), some similarity can be found with the over-estimated values in the reasons for less successful MAF estimation. At stations 55005 and 66002 several of the independent variables are low or very low, with a compounding effect on the MAF estimate. With stations 56004 and 56006, reservoirs are sited in the catchment headwaters and it is felt that this must be at least partly responsible for the under-estimation of MAF. Finally at station 66011, under-estimation is not expected owing to very high STMFRQ and high S1085 values. As with the over-estimate at station 55003, it is possible that the effects of these factors have not been fully accounted for by the regression equation; these two stations appear to be somewhat anomalous in comparison with other stations for which there are large over- or under-estimates.

D.2.4 Discussion

Generalisation of the performance of the statistical MAF estimation method has been difficult, but it can be noted that estimates at 71% of stations in the sample lie within ±25% of BESMAF values. The most common reason for estimates being less accurate is the coincidence of very high or very low independent variable values, resulting in MAF over-estimation or under-estimation respectively. This appears to be an inevitable consequence of the regression approach to the FSR statistical method and must be accepted as the price to be paid for the benefits which accrue from its application. The Welsh catchments in which estimation was seen to be less successful cover a range of types.

Many of those with high estimates are neither especially small or large but drain wet catchments with soils of low permeability and high drainage densities, and may be characterised by flood attenuation by lakes. Relating this to Northern Ireland, this focuses the need for gauging stations not so much towards the headwaters, but to moderately sized catchments of say 100 km^2 draining upland areas. Analysis in Chapter 2 has indicated the NI network to be well provided for in this respect.

Of those catchments with low estimates, those which are due to reservoir effects should not be counted as failures of the method, as in any study this type of effect could be specifically catered for. The remainder seem to follow no clear pattern and are relatively few in number: it therefore seems wise to make no specific gauging recommendation in this respect.

D.2.5 Conclusions

With any regression equation, estimation of an unknown quantity will inevitably be more successful in some cases than in others. As found in Chapter 2, it is advantageous to collect data in extreme types of catchment as well as in the areas of more typical rainfall, slope and soil characteristics of a region. This study of mean annual flood estimation has found that where extreme high or low values of predictor variables coincide, estimation is less reliable than in more commonly occurring types of catchment. A good spread of catchment types in the Northern Ireland gauging network will guard against the dangers of such (rare) coincidences leading to serious errors in design studies.

A particular feature of this work has been to identify the occasional importance of lake attenuation on flood peaks and it therefore follows that the NI gauging station network should benefit from the inclusion of data from stations located below lakes. Although this has not been specifically addressed in Chapter 2, stations do exist below the major storages of Lough Neagh and Upper Lough Erne (but not Lower Lough Erne: its outfall is very close to the Republic of Ireland border), and with some other stations on rivers with reservoired headwaters, it is felt that the network addresses this need quite adequately.

Appendix E:

INSTITUTE OF HYDROLOGY EXPERIENCE WITH UPLAND GAUGING

As the foremost practitioner of upland gauging in the UK, the history of the operation of these flow gauges has some relevance to this review. This section is included to acquaint the Water Executive with the commitment which may be required to realise good results; it should be recognised that the IH investigations always push the measurement techniques to their limits in the pursuit of convincing results. All the IH gauges are structures; although some of the early gauges were inherited from other organisations, they have generally been revamped or rebuilt so that they now conform to the British Standard 3680, where such a standard exists for the structure.

E1.1 Plynlimon gauges

At Plynlimon the catchments are of three types. The main outfall gauges comprise a compound Crump profile weir with two crest levels and three sections (River Wye), and a trapezoidal long throated flume (River Severn). The subcatchment gauges are specialist, steep stream flumes where the shallow, wide natural channel is transformed into a narrow, deep flume. Froude numbers can be halved by increasing the depth and decreasing the width by four times, whilst maintaining velocity. Supercritical flow in the approach channel is reduced to critical flow in the throat. The following comments apply to the structures:

i. Compound weir - Wye at Cefn Brwyn. Found to be essential that accurate surveying of the weir dimensions, particularly the crest levels, is undertaken regularly. Any use of the theoretical calibration should utilise as-constructed dimensions. Incorrect recording of peaks was experienced after transitory deposition of sediment around the intake pipe sump during spates; these deposits were flushed out on the falling stage. This was remedied by the installation of a gabion sediment trap in the upper half of the stilling pool. A more fundamental problem was encountered with a departure of the low flow flume from the theoretical calibration. This was resolved by a combination of intensive current metering and quantitative (buckets!) flow measurements in drought conditions.

ii. Trapezoidal flume - Severn at Plynlimon. Costly to install to achieve a high quality, symmetrical structure. The disruptive effects of upstream accretion were solved by the excavation of a 160 m^3 sediment trap upstream. This was based on estimates of the annual sediment yield but proved oversized; the trap requires emptying about every five years.

iii. Steep stream structures. Costly to install as their deep throat and upstream energy dissipating section require complex shuttering and a lot of concrete. The flumes, with their steep entry ramp into the throat, were designed to operate best at bankfull discharge when the water levels in the natural channel and the approach section were level. In lower flow conditions, energy dissipating ripples were incorporated in the entry ramps to reduce the kinetic energy of the water accelerating down the slope. Only one flume has suffered from sediment accumulation within the throat but in all cases, there is a substantial reduction in velocity as the water leaves the structure downstream, with the result that after some spates shoals are deposited downstream. If these are large enough to drown the structure, then they must be removed by excavation.

E1.2 Balquhidder gauges

At the Balquhidder catchments, economy was of greater concern than at Plynlimon, which ruled out the steep stream structures. Level crested Crump profile weirs were chosen for the catchment outfalls; a shallow Vee, 1:10 cross slope weir was installed as a headwater gauge in one catchment. The following comments apply:

i. The level crested weirs were designed to contain the one in 50 year estimated flood and are insensitive at low flows for an experimental catchment. At one site, prefabricated fibreglass trapezoidal flumes were installed downstream to refine the low range but were not entirely successful. Both approaches to the weirs are rocky and steep and far from ideal, although the sitings were below high energy dissipating sections. Investigations using an array of current meters (up to 6 at 10-20 cm intervals on a rod) indicated that there were significant asymmetries in both the flow pattern and the velocity distributions on the approach aprons, such that the Coriolis coefficient (or energy flux correction) showed a wide departure from the value normally assumed (unity) and the maximum recommended (<1.25). Using estimates of the mean approach velocity and the flows obtained from both current metering and dilution gauging using sodium iodide, a new index of velocity asymmetry was derived (Hudson et al., 1990), which could be utilised in the theoretical equation. However, in all other respects, the structures have proved durable and the rating and the apron accretion have remained stable, modular conditions still obtaining when a flow of 27 m^3s^{-1} was recorded (design capacity, 30 m^3s^{-1}).

ii. The shallow vee weir was sited 2 km distant from the access track and was prefabricated in duralumin alloy with stainless steel crest sections and transported to the site by helicopter. This has proved a very successful installation. The channel conditions were less extreme as the site was around the break of slope from the plateau-like, peat covered interfluves. The high surface finish and accuracy permitted by working in metal has ensured a very accurate gauge, although the small catchment size renders the sensitivity poor at the 95 percentile flow.

Appendix F:

EVALUATION OF EXISTING STATIONS

The results of the preceding chapters can now be used to assess the worth of continuing to operate existing stations. These are dealt with in turn, followed by recommendations for new sites.

Review of stations not justified by any continuing specific data requirement

201004 Strule at Stone Bridge (level-only)
Plans exist to upgrade this station to rated status for specific data uses; retention is therefore desirable.

201005 Camowen at Camowen Terrace
Good data quality is achieved at low flows at this site, with over 20 years of data accumulated in a river draining west from the Sperrin Mountains. It is seen as being particularly valuable for drought monitoring and its retention in the network is recommended.

201006 Drumragh at Campsie Bridge
Like its neighbour 201005 this station has also accumulated a relatively long period of record but none of the data uses demanded of it, except flood forecasting, would benefit significantly from further extension. Closure is therefore recommended, with consideration to be given to establishing a new headwater tributary site. This would improve knowledge of headwater flow regimes, enhance network representativeness and provide greater flood warning time, particularly in westerly weather conditions.

203301 Lower Bann at Loughan Island (level-only)
203902 Lower Bann at Agivey Bann Bridge (level-only)
203308 Lower Bann at Portna (level-only)
While data uses have been noted for these stations, attention should be given to the possibility of using models to provide level data at these locations, since they lie in relatively close proximity and there are other flow gauges in the area with secure futures (see Chapter 3). Elimination of any of these stations would reduce annual maintenance costs. Further review is therefore recommended.

203009 Blackwater at Verners Bridge (level-only)
As the network stands at present, it ought to be possible to estimate flow at this point accurately on the basis of gauged flows at Maydown Bridge and Callan New Bridge. If station 203025 is closed (see below) and flow information is required at this site, it is felt that an ultrasonic installation would be appropriate here. With very limited use being made of the data generated at this station, it is recommended that its future be reviewed.

203020 Moyola at Moyola New Bridge
A high quality of data is achieved at this site, lying at the outfall to Lough Neagh of a moderately large and quite natural catchment. It is seen as making an important contribution to the network as a whole. It should be designated as a benchmark site and its operation continued into the future.

203024 Cusher at Gambles Bridge
The station has accumulated more than 20 years flow data and has similar physical characteristics to some neighbouring gauged catchments. None of the data uses associated with it justifies continued operation, so closure is recommended. The network would be enhanced, in terms of catchment diversity and representativeness, by establishment of a new station in the headwaters of this catchment.

203025 Callan at Callan New Bridge
Little demand exists for the data being produced from this station. Those which have been produced over the past 20 years are of limited quality and there seems to be little justification for extending this record; closure is recommended.

203026 Glenavy at Glenavy
This station is associated with an agricultural abstraction and is therefore poor in terms of naturalness; the quality of low flow data is also poor. Closure is recommended unless monitoring of this abstraction is a priority, in which case attention should be directed towards stabilising the low flow control.

203028 Agivey at White Hill
The station is noted as having a high level of data use and good data quality. It has a long record, a natural catchment and lies in a geographical area with only a modest density of gauged catchments. The combination of these factors indicates it is well suited to serving as a benchmark monitoring site and its retention in the network is recommended.

203038 Rocky at Rocky Mountain
In the context of the network as a whole, this station has a very valuable location on account of its high altitude, high rainfall, small size and steep slopes. From an operator's point of view, however, it is very problematic. It has not yet been possible to obtain high flow gaugings, and boulders can be deposited on the apron of the weir. Difficulties with the local landowner compound these problems. Nonetheless, the site is a very valuable one and it is recommended that the operating authority perseveres with it. A concerted effort to obtain high flow gaugings (intensive activity through a major event), perhaps using alternative flow measurement techniques such as dilution gauging, would enhance the value of data being obtained and should be considered. It may be found helpful to draw on experience gained in the IH experimental catchments at Plynlimon and Balquhidder (see Appendix E).

203039 Clogh at Tullynewy Bridge
There is little demand for flow data from this station, but it does lie in a useful location. Weed growth is known to be a problem, warranting attention in its maintenance. Continued operation is recommended, though not perhaps beyond another 5 years.

203042 Crumlin at Cidercourt Bridge
While the characteristics of the catchment draining to this station are somewhat similar to those of some of its neighbours, it achieves a good data quality and its 13 years of record accumulated to date would benefit from further extension; retention in the network is recommended.

203043 Oona Water at Shanmoy
With a Flat Vee weir installed and only about 10 years of data collected to date, this station is seen as having potential to add to the value of the Northern Ireland hydrometric database, although it need not necessarily be seen as having any long-term strategic value. Continued operation is recommended.

203046 Rathmore Burn at Rathmore Bridge
This small, relatively steep and natural catchment makes a useful contribution to achieving diversity in the network and should be retained.

203049 Clady Water at Clady Bridge
Another relatively small catchment with good data utility and only a short record: operation should be continued.

203093 Main at Shanes Viaduct
This station lies at the outfall of one of the major tributaries of Lough Neagh and achieves a high data utility score. It is seen as having strategic value and its continued operation is recommended.

205015 Cotton at Grandmere Park
The catchment draining to this station is the lowest in the NI network and, with its coastal location and part-urban land use, is a valuable member of the network. Retention is recommended.

205017 Strand Lough at Killough Bridge
205018 Strand Lough at Strand Brickworks
DANI data requirements, and the nature of the relationship between levels at these two sites, suggest that both these stations should remain in the network.

205020 Enler at Comber
A good quality of data is achieved at this site on a river draining a useful mixture of rural and urban areas. An existing DANI plan to gauge some of the tributaries of this river would enhance the value of the station, and retention is recommended.

236006 Upper Erne at Killyhevlin
Erne flow data from the Republic of Ireland, relating to its course upstream of Northern Ireland, is understood to be of limited value. With 2890 km^2 draining to this station, it is clearly of some strategic importance, although backing up effects mean that flow data cannot be reliably obtained from the stage record. Retention does seem to be justified, particularly considering the forthcoming catchment management plan for the Erne system, but data quality does need improvement; installation of an ultrasonic gauging station should be considered.

236007 Sillees at Drumrainy Bridge
Low flow data quality at this station is rather poor and is not appropriate to the uses made of data from this station. Gauging is of a generally low density in Fermanagh when compared to Northern Ireland as a whole, so existing sites are of significant value and the topography of this catchment in particular further merits its retention in the network. Attention should, however, be directed towards stabilising the low flow control.

236009 Swanlinbar at Thompsons Bridge
Little information was available regarding the quality of data being generated by this relatively new station, however the demand for data indicates that effort would be well justified. The catchment is likely to experience a rain-shadow effect, and the consideration of any future gauge sitings in this area should be done with regard to this.

236051 Ballycassidy at Ballycassidy Bridge
No single data use justifies retention of this station in the network, but its information from a relatively sparsely gauged area is of strategic value, justifying continued operation subject to adequate data quality.

Stations with major inconsistencies between data utility scores and required data uses

203023 Torrent at The Moor Bridge
This station is renowned for periodic problems of by-passing, irrespective of river flow. Rectification appears to be costly, but in the meantime operation of the station serves no useful purpose. A station on this reach of the Torrent is desirable owing to data requirements in relation to Coalisland consent standard monitoring. Options for resiting or solving the bypassing problem should be reviewed.

203027 Braid at Ballee
Data quality is very poor at this station, particularly at low flows, to an extent which invalidates its usefulness for the functions required of it. Some of the problems associated with this site, e.g., high flow gauging, are insoluble and closure is strongly recommended. Station 203021 may be used as a surrogate for some purposes and the siting of a new station in the headwaters of the Braid is recommended in order to provide data specific to this catchment and representative of an upland area with peat and gley soils.

203029 Six Mile Water at Ballyclare
Data quality is wholly inadequate for the assimilative capacity estimation and consent standard monitoring functions required of the station. Re-siting is recommended, preferably to a site with good containment for the benefit of the flood forecasting function also demanded of this station. If the new site selected is a significant distance from the points at which data are required, modelling techniques should be used.

203041 Ballygawley Water at Tullybryan
This station is very insensitive and unsuitable for present data needs. It lies in a useful position and relocation to a site with a good low flow control and full containment is therefore recommended; benchmark status may then be afforded.

205004 Lagan at Newforge
With the highest data use score of any NI station, this is clearly an important site, but the low flow score awarded indicates that the data being collected are not of adequate precision for some purposes. The site is already well contained but the installation of an informal shallow vee weir is recommended as a means of reducing the scatter amongst low flow gaugings. Such an improvement is only proper for a station of such strategic importance.

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