Institute of Hydrology

Natural Environment Research Council

Hydrological Impacts of Proposed Water Resources Schemes in Northern Ireland (Eastern Area)

A. Gustard, A.J. Wesselink, G. Roberts, I.W. Johnson

Report to
Department of the Environment (NI)
Water Service
Belfast

Institute of Hydrology
Wallingford
Oxfordshire
OX10 8BB

June 1991

Contents

List of Tables

List of Figures

Executive Summary

It is proposed that the augmentation of water source capacity in the Eastern Area of the Department of Environment (NI)'s Water Service is achieved by either the development of an upland source or by increasing the abstraction from Lough Neagh. The Water Service anticipate a requirement for an additional 65 to 130 $Ml.day^{-1}$, dependent on the growth in demand. The proposals are:-

1. 65 $Ml.day^{-1}$ reservoir scheme at Kinnahalla/Lough Island Reavy.
2. 130 $Ml.day^{-1}$ reservoir scheme at Glenwhirry, constructed in two stages.
3. Various 130 $Ml.day^{-1}$ direct abstraction options from Lough Neagh, constructed in two stages.

This study estimates the hydrological impact of the possible schemes on the downstream river flows and on Lough Neagh water levels. Daily mean flow data (from the Water Data Unit of the Water Service) and daily Lough Neagh water levels (from the Department of Agriculture, Northern Ireland) have been used to define the current hydrological regime. The data was also used to calibrate hydrological models in order to estimate the hydrological regime at sites without hydrometric data. A simulation model of each scheme was developed and used to predict the impact, at different stages of development, on downstream river flows and Lough Neagh water levels.

The report identifies the locations where there are changes in three river flow statistics - namely the mean, the 95 and the 5 percentile exceedance flow. The 95% exceedance, a low flow parameter, is that flow, in cubic metres per second ($m^3.s^{-1}$), which is equalled or exceeded for 95% of the time. The 5% exceedance, a high flow parameter, is the flow, in $m^3.s^{-1}$, which is equalled or exceeded for 5% of the time. Sites where these parameters change by more than 10, 5 and 2 percent are identified. We consider changes in the parameters of the order of 10% to be significant hydrologically, in that such changes are greater than the current natural variability of the flow regimes and greater than the measurement error of the flow statistics. In contrast, changes of the order of 2% are less than the natural variability, are within the measurement errors, and may be construed to locate the limit of the effect of the proposed scheme.

The impacts of the reservoir schemes, or direct abstraction, on Lough Neagh levels and flows in the Lower Bann is dependent upon the future operating procedures for the sluice gates at Toome. There is a statutory requirement to maintain the Lough" .... so far as conditions .... permit" within the range 50'0" to 50'6" (Poolbeg Datum) - these are the control levels/limits. The Department of Agriculture (NI) endeavours to maintain the Lough at a precise operational level which varies between 50'1" and 50'5" dependent on the time of the year.

The flows and levels of the Lough were computer-modelled with various abstraction rates over the period 1981-89. 1984 was an exceptional year in that the early part of the year was so wet that the Lough experienced its maximum level for the decade: the Lough experienced it s minimum level for the decade later in that year as 1984 proved to contain a drought event

approaching a 1 in 50 year return period. The impact of the scheme on Lower Bann flows is as in the case of the current regime, strongly influenced by the operating policy for the Toome Sluice gates. For the purpose of the computer modelling exercise, when possible, historic Lough levels were maintained and the historic flows to the Lower Bann were replicated for the greatest possible time, i.e. when the modelled level was above the operational level, or when the modelled level was below the operational level and historic flows below the minimum required flow. The modelled flow was less than the actual flow only when the modelled Lough level was less than the operational level and historic outflows were above the minimum required flow.

The percentage of time that the level is either above the upper or below the lower control limit was used as a variable to define the change in level regime. When modelled at the proposed additional abstraction rates of 65 and 130 $Ml.day^{-1}$, the upper limit was exceeded an additional 1.3% and 0.4% of the time; the time when levels were less than the lower limit increased by 0.4% and decreased by 0.3% respectively. 1.3%, 0.4% and 0.3% of the time are equivalent to 4.7, 1.5 and 1.1 historic days per year on average. The Lough fell to a minimum level of 49'2" in 1984; with the additional abstractions, the minimum levels would have been 49'1" and 49'0" respectively. The mean flow in the Lower Bann at Toome is presently 79.94 $m^3.s^{-1}$; this is reduced by 0.75 and 1.52 $m^3.s^{-1}$ for abstraction rates of 65 and 130 Ml/d. Using the modelling procedure outlined above, these reductions in flows are concentrated into short periods of time, on average 14 and 35 days per year respectively.

Glenwhirry stages 1 and 2 and Lough Island Reavy/Kinnahalla reduce the Lower Bann mean flow by 0.79, 1.26 and 0.49 $m^3.s^{-1}$ respectively. For the reasons described above, these reductions are concentrated into, on average, 9, 14 and 5 days per year respectively. The upper limit to the control level was exceeded an additional 0.9, 0.5 and 1.6% of the time respectively, whereas the time when levels were less than the lower limit decreased by 2.7, 1.9 and 2.4%. The minimum levels in 1984 would have been unchanged from the actual 49'2".

Recognising the strategic role of Lough Neagh as a water source which may be used for even larger abstractions, at some time beyond the foreseeable future, the hydrological impacts of various further abstraction rates were also tested. Rates of abstraction (above current) of 175, 220 and 350 $Ml.day^{-1}$ were used. As one would expect the greatest abstraction had the greatest effect; the time when the Lough was less than its lower control level (50'0") increased by, on average, 13.5 days per year and the minimum level in 1984 would have been 48'8". The mean flow in the Lower Bann decreased by 4.08 $m^3.s^{-1}$ and it was reduced on 82 days per year on average.

1. Introduction

It is proposed that the augmentation of water source capacity in the Eastern Area of the Department of the Environment for Northern Ireland, Water Service is achieved by increased abstractions from Lough Neagh or by the development of an upland reservoir source. This study estimates the hydrological impact of these proposed schemes on the downstream river flows, and Lough Neagh water levels. Daily mean flow data (from the Water Data Unit, the Water Service) and daily Lough Neagh water levels (from the Department of Agriculture, Northern Ireland) have been used to define the current hydrological regime. These data were also used for calibrating hydrological models in order to estimate the hydrological regime at sites without hydrometric data. A simulation model of each scheme was developed and used to predict the impact of each scheme at different stages of development on downstream river flows and Lough Neagh water levels. The scheme development and details of impact assessment are shown in Table 1.

Table 1 Summary of hydrological impact assessment

	Hydrological impact assessment		
	Downstream of Impounding Reservoir	L. Neagh	Lower Bann
Glenwhirry Reservoir Scheme			
Current regime	6 sites	✓	✓
Stage 1 (yield 65 $Ml.day^{-1}$)	6 sites	✓	✓
Stage 2 (yield 130 $Ml.day^{-1}$)	6 sites	✓	✓
Lough Island Reavy/Kinnahalla Reservoir Scheme			
Current regime (yield 18 $Ml.day^{-1}$)	8 sites	✓	✓
Yield 83 $Ml.day^{-1}$	8 sites	✓	✓
Lough Neagh Abstraction			
Current regime (nett abstraction average 124 $Ml.day^{-1}$)		✓	✓
Stage 1 (nett additional abstraction 65 $Ml.day^{-1}$)		✓	✓
Stage 2 (nett additional abstraction 130 $Ml.day^{-1}$)		✓	✓
Sensitivity to greater abstractions:			
a. (nett additional abstraction 175 $Ml.day^{-1}$)		✓	✓
b. (nett additional abstraction 220 $Ml.day^{-1}$)		✓	✓
c. (nett additional abstraction 350 $Ml.day^{-1}$)		✓	✓

Details of the resource development for each stage and the location for impact assessment were provided by the Water Service. Operating rules for each reservoir (section 2.1 and 2.2) consisted of constant compensation flows and constant abstraction rates without reductions in drought periods. A simple daily accounting model based on inflow, abstraction, compensation flow, change in reservoir storage and reservoir spill was used to estimate the change in downstream flow regime. Rules for Lough Neagh (section 2.3) were based on constant abstraction rates whilst target levels were maintained by reducing releases to the current minimum flows.

The following sections of the report describe the analysis and interpretation of the observed and simulated data for each of the three schemes as follows:

Section 2.1	River flows below Glenwhirry
Section 2.2	River flows below Lough Island Reavy/Kinnahalla
Section 2.3	Lough Neagh levels and Lower Bann flows for Lough Neagh abstraction and reservoir schemes

Chapter 3 of the report summarises the impact of water resource development, the hydrological significance of the changes and comments on the flow series used in relation to the longer term runoff series.

2. Hydrological impact analysis

2.1. RIVER FLOWS DOWNSTREAM OF THE PROPOSED GLENWHIRRY RESERVOIR

2.1.1 Introduction

The proposed Glenwhirry reservoir scheme (Figure 1) would be implemented in two stages:

Stage 1. Building a reservoir immediately upstream of Battery Bridge and abstracting 65 $Ml.day^{-1}$ all of which is exported from the catchment.

Stage 2. Increasing the flows into the reservoir by diverting water from four indirect catchments enabling an increase in the abstraction rate to 130 $Ml.day^{-1}$ all of which is exported from the catchment.

The existing and proposed schemes have been modelled, using the available flow records for Kells Water at Curry's Bridge (gauging station 203021) and daily and monthly records of rainfall within the Curry's Bridge catchment (section 2.1.2). The results have been used to estimate the hydrologic impact of the proposed schemes (section 2.1.3) on downstream river flows and Lough Neagh water levels.

2.1.2 Modelling the existing situation and the proposed schemes

Appendix A1 describes the generation of three daily flow records at the proposed site of the dam and at Curry's Bridge for the period 1972 to 1989 (inclusive). They represent:

1. undisturbed conditions
2. stage 1 - reservoir with direct catchment - yield 65 $Ml.day^{-1}$
3. stage 2 - reservoir with direct and indirect catchments - yield 130 $Ml.day^{-1}$

The generation of the daily mean flow series for the three stages was carried out in two steps. First the estimation of inflows into the reservoir, allowing for diversions from catchwaters where appropriate. Second, a simulation of reservoir behaviour using these daily inflows, together with precipitation on the reservoir surface, evaporation losses and abstraction in order to estimate the spill and compensation water.

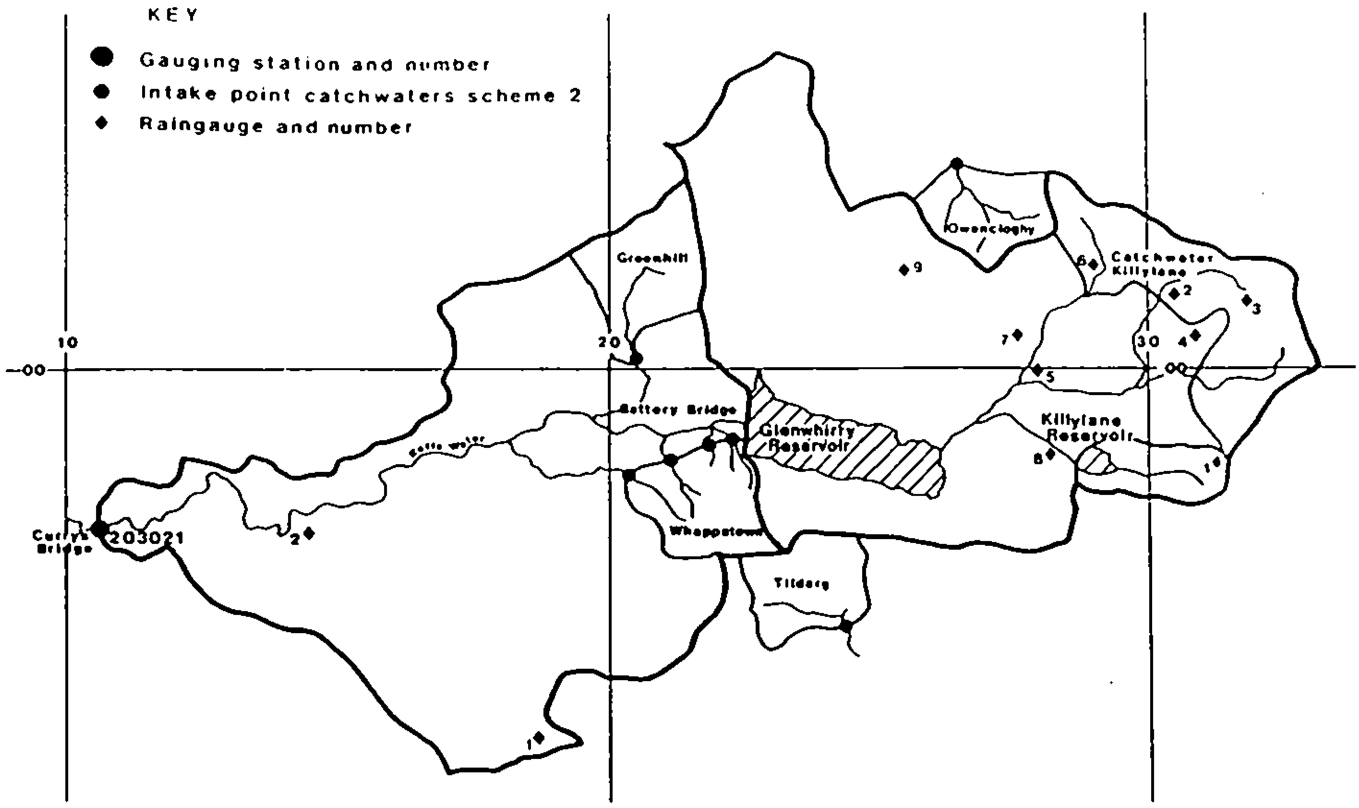


Figure 1 Proposed Glenwhirry reservoir schemes

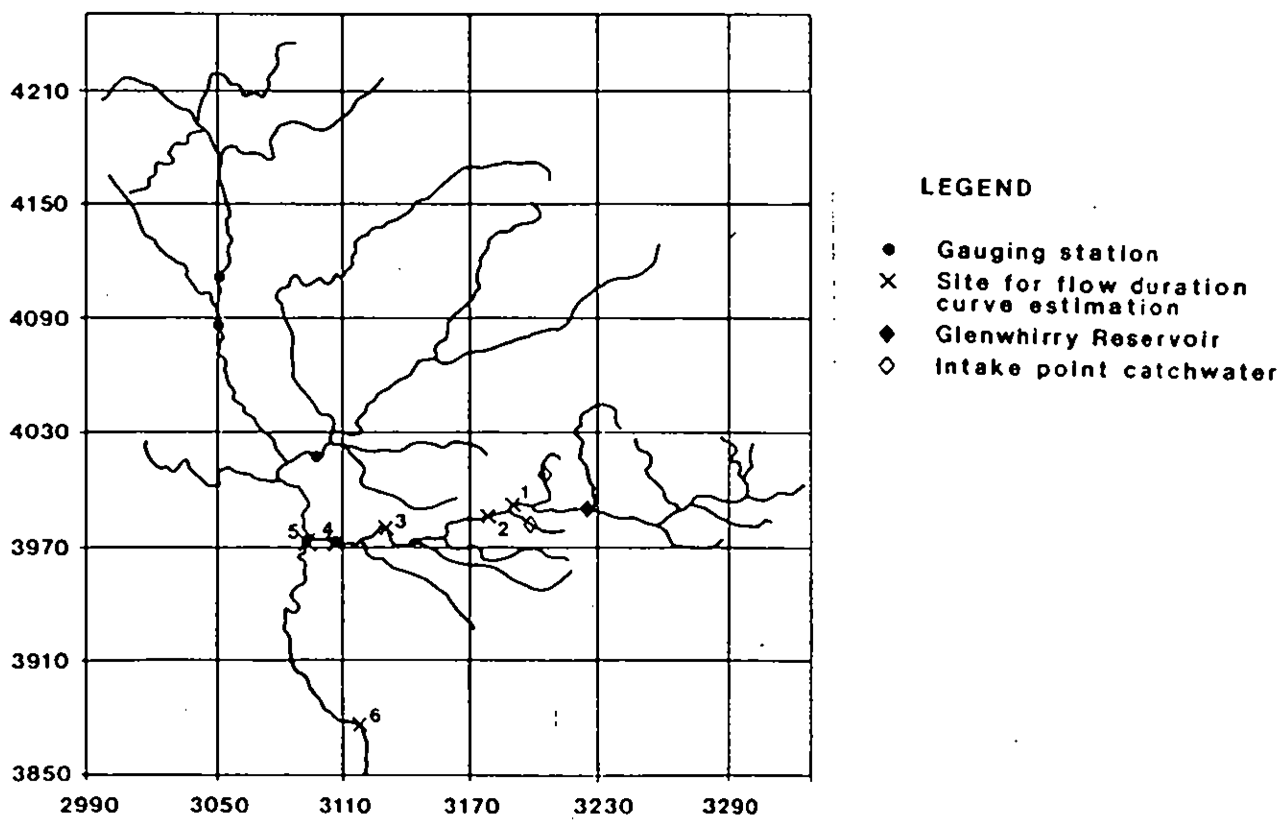


Figure 2 Sites for estimation of FDCs in Glenwhirry scheme

Reservoir inflows were calculated from measured flows at Curry's Bridge which were used for calibrating the model. These flows are not entirely natural because of the presence of the Killylane reservoir. This was allowed for by calculation of a naturalized flow record at Curry's Bridge. Conversion of these naturalized flows to flows in catchments upstream was achieved by multiplication by both area and average catchment rainfall factors (Appendix A1). The reservoir simulations were based on a daily reservoir water balance. The outflows (compensation flow plus spill) from the reservoirs, and where appropriate the undiverted water from the indirect catchments, were input into the lower, "natural" part of the catchment to give modified flow records at Curry's Bridge. The system was modelled to include a daily abstraction of 14.0 $Ml.day^{-1}$ from the existing Killylane reservoir.

2.1.3 Hydrologic effect of the proposed schemes

The effect of the proposed schemes has been estimated by two means: the change in mean flow, and the change in flow duration curves. A flow duration curve (FDC) is a plot of discharge (optionally expressed as percentage of the mean flow) against the percentage of time when the flow is exceeded. For example, the 95 percentile flow is exceeded on average 347 days of the year, that is the flow is less than the 95 percentile flow on average 18 days of the year.

Mean flows and flow duration curves (FDCs) were determined for the Kells Water at Curry's Bridge and at Battery Bridge (Figure 1) for each of the three flow series generated (section 2.1.2). These were then used to estimate the flow duration curve for the period 1972-1989 at each of the six downstream sites specified by the Water Service (Table 2 and Figure 2). Estimates were based on a pro-rata adjustment based on the mean flow calculated from the Institute of Hydrology's Micro Low Flow system. The difference between the current FDC at Battery Bridge and the simulated FDC was then used to estimate FDC for the six downstream sites under the stage 1 and stage 2 resource development.

Table 2 Sites for estimation of FDCs in Glenwhirry scheme

Site name	Grid reference
1. Moorfield STW	3187 3992
2. Fish Farm, Kells	3173 3984
3. Kildrum, Kells	3130 3978
4. Curry's Bridge (Stn 203021)	3106 3971
5. Andraid (Stn 203013)	3092 3973
6. Shane's Viaduct	3086 3896

The procedure for estimating the artificially influenced FDC at a site downstream of the reservoir or intake point (e.g. at point A in Figure 3) is as follows. Downstream of the dam site, e.g. at B in Figure 3 the FDCs resulting after the dam construction are determined by adding up the FDCs, expressed in $m^3.s^{-1}$, at A and the FDCs for the area above B excluding the area draining to A, which can be considered the "natural" part of the catchment B. The shape of predicted FDCs for the "natural" area B-A is based on the FDC of the records at the gauging station downstream of the site of interest. The mean flow for area B-A is determined by subtracting the estimated natural mean flow at A from the estimated mean flow at B. An example is given in Table 3.

The estimated current FDCs (Stage 0) and the FDCs for two stages of reservoir development are shown in Figures 4a to 4f, with discharge standardised by the mean of the natural flow at the site. Table 4 presents the FDCs expressed in $m^3.s^{-1}$, and Table 5 summarizes the predicted changes in mean flow.

From the analyses the following conclusions can be drawn:

1. The mean flow decreases at all sites due to the schemes, and more so with implementation of scheme 2.

2. The FDCs (in $m^3.s^{-1}$) shift downwards due to the schemes, most notably in the 20-80 percentile range. However, the compensation flow would markedly increase the 85 percentile and below.

3. The influence of the schemes is negligible after the confluence of Kell's Water and the Main. However, the exact impact on Lough Neagh levels and outflows depends on the procedure adapted for operating Lough Neagh. This will be discussed in Section 2.3.

Table 3 Adding up artificial and natural FDCs

Percentage of time flow exceeded	FDC at A (% of MF)	FDC at A ($m^3.s^{-1}$)	FDC from B-A (% of MF)	FDC from B-A ($m^3.s^{-1}$)	FDC at B ($m^3.s^{-1}$)	FDC at B (% of MF)
5	680	68	400	80	148	493
10	350	35	250	50	85	283
20	85	8.5	125	25	33.5	112
50	15	1.5	60	12	13.5	45
80	14	1.4	20	4	5.4	18
90	13	1.3	15	3	4.3	14
95	12	1.2	12	2.4	3.7	12

NB: In this example it has been assumed that the mean flow at A = 10 cumecs and the mean flow at B = 30 cumecs
MF = mean flow

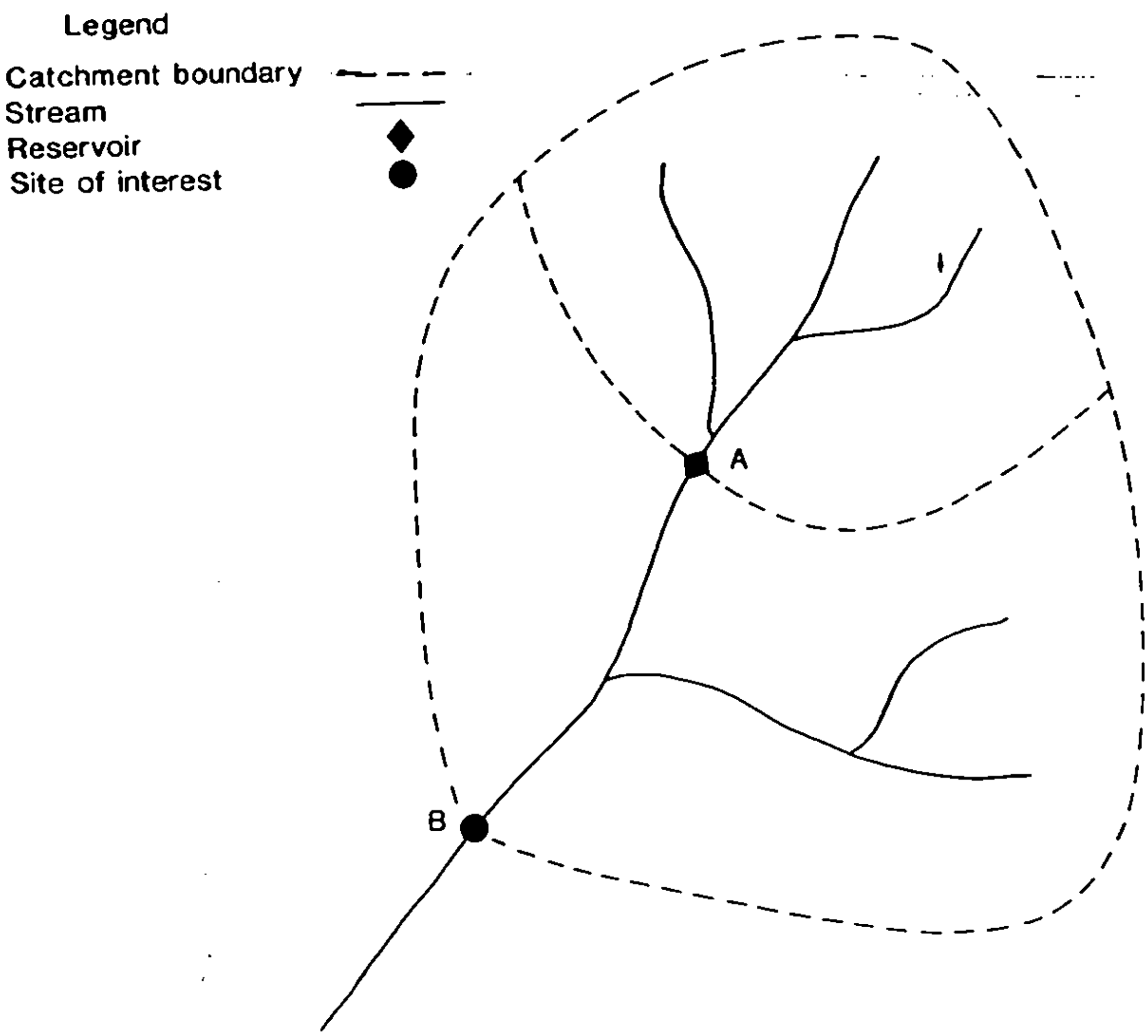


Figure 3 Adding up artifical and natural FDCs - illustrative catchment

Table 4 Current and post-scheme FDCs (in $m^3.s^{-1}$) for 6 sites downstream of proposed Glenwhirry water resource schemes

Percentage of time flow exceeded	Site 1 Moorfield STW			Site 2 Fish Farm, Kells		
	Pre	Scheme 1	Scheme 2	Pre	Scheme 1	Scheme 2
1	16.6	12.7	11.3	17.0	13.1	11.6
5	8.60	5.93	4.26	8.82	6.15	4.33
10	5.56	3.35	1.86	5.71	3.50	1.90
20	3.35	1.42	0.66	3.44	1.51	0.69
50	1.16	0.41	0.38	1.19	0.44	0.39
80	0.37	0.28	0.27	0.37	0.29	0.28
90	0.21	0.25	0.25	0.22	0.26	0.26
95	0.15	0.24	0.25	0.15	0.25	0.25
99	0.087	0.23	0.24	0.089	0.24	0.24

	Site 3 Kildrum, Kells			Site 4 Curry's Bridge		
	Pre	Scheme 1	Scheme 2	Pre	Scheme 1	Scheme 2
1	22.3	18.5	17.0	23.7	19.8	18.3
5	11.6	8.94	7.12	12.3	9.64	7.83
10	7.52	8.30	3.70	7.97	5.75	4.16
20	4.53	2.59	1.77	4.80	2.87	2.05
50	1.57	0.81	0.77	1.66	0.91	0.86
80	0.49	0.41	0.40	0.52	0.44	0.43
90	0.29	0.33	0.33	0.31	0.35	0.85
95	0.20	0.30	0.30	0.21	0.31	0.31
99	0.12	0.26	0.27	0.12	0.27	0.28

	Site 5 Andraid			Site 6 Shane's Viaduct		
	Pre	Scheme 1	Scheme 2	Pre	Scheme 1	Scheme 2
1	95.7	93.8	92.4	101.0	102.0	100.0
5	51.9	49.5	48.6	54.8	53.7	52.8
10	35.6	33.4	32.0	37.5	36.2	34.9
20	22.3	20.2	19.5	23.5	22.0	21.3
50	8.41	7.59	7.52	8.88	8.26	8.19
80	3.41	3.20	3.18	3.60	3.47	3.46
90	2.32	2.25	2.24	2.45	2.44	2.43
95	1.88	1.86	1.86	1.99	2.01	2.01
99	1.31	1.37	1.36	1.38	1.47	1.47

Table 5 Current and post-scheme mean flows for 6 sites downstream of proposed Glenwhirry water resource schemes (in $m^3.s^{-1}$)

		pre-scheme	scheme 1	scheme 2
1.	Moorfield STW	2.28	1.30	0.99
2.	Fish Farm, Kells	2.34	1.36	1.01
3.	Kildrum, Kells	3.08	2.10	1.75
4.	Curry's Bridge	3.27	2.29	1.94
5.	Andraid	15.27	14.29	13.94
6.	Shane's Viaduct	16.11	15.52	15.17

FIGURE 4a

GLENWHIRRY SCHEME - ESTIMATES FOR SITE 1 (MOORFIELD STW)

FLOW DURATION CURVES MF = 2.28 $m^3.s^{-1}$

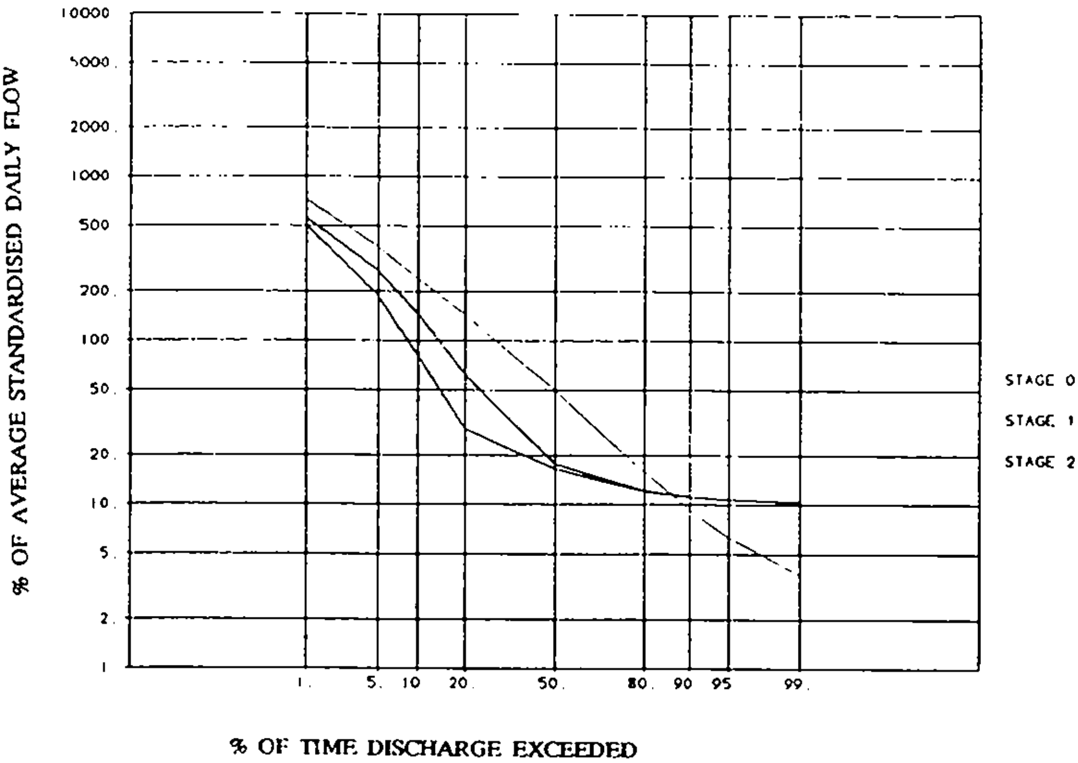


FIGURE 4b

GLENWHIRRY SCHEME - ESTIMATES FOR SITE 2 (FISH FARM, KELLS)

FLOW DURATION CURVES MF = 2.34 $m^3.s^{-1}$

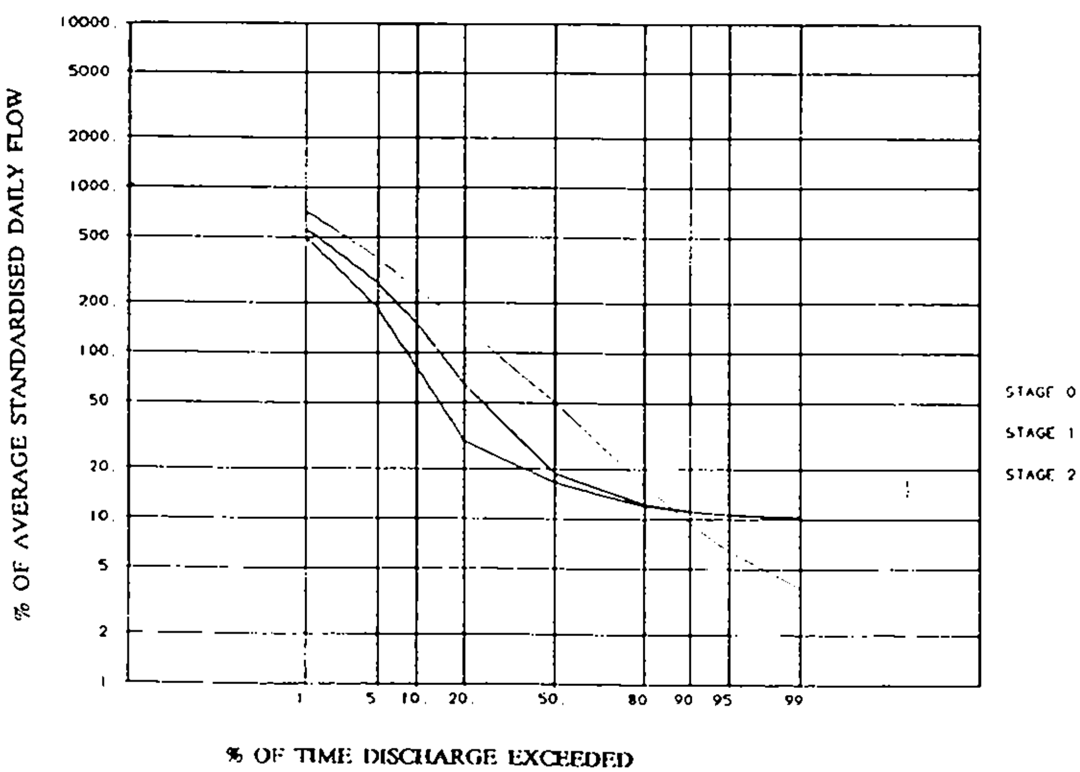


FIGURE 4c

GLENWHIRRY SCHEME - ESTIMATES FOR SITE 3 (KILDRUM, KELLS)

FLOW DURATION CURVES MF = 3.08 m³. s⁻¹

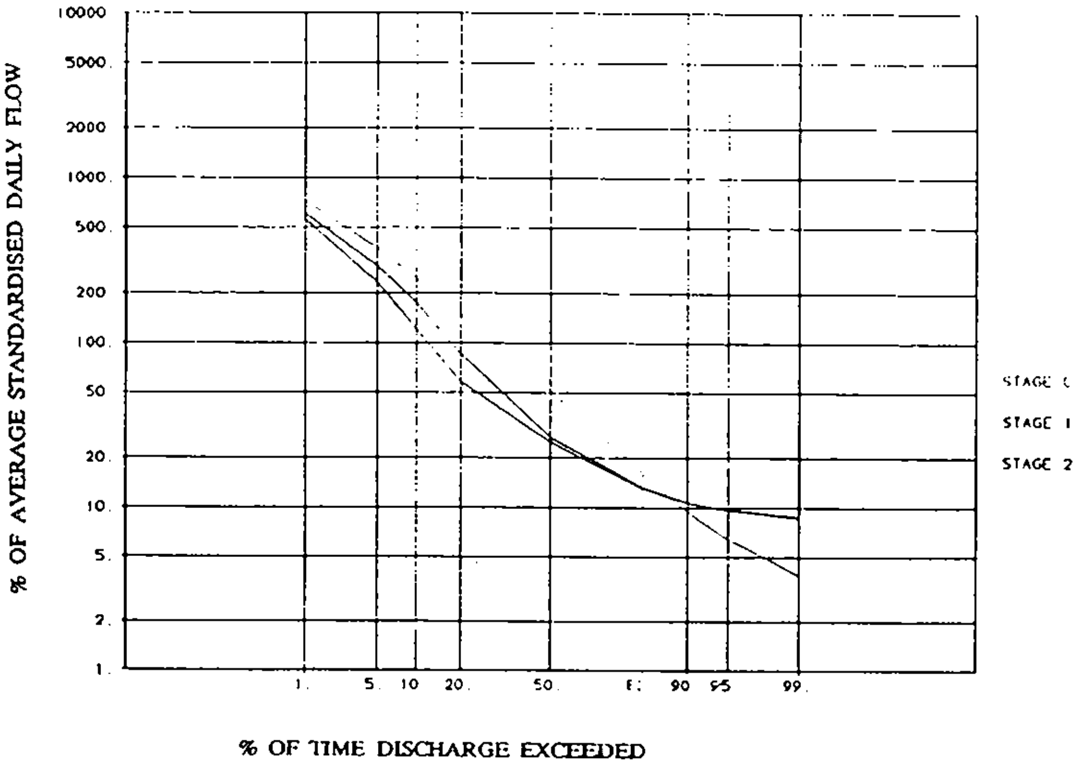


FIGURE 4d

GLENWHIRRY SCHEME - ESTIMATES FOR SITE 4 (CURRY'S BRIDGE)

FLOW DURATION CURVES MF = 3.27 m³. s⁻¹

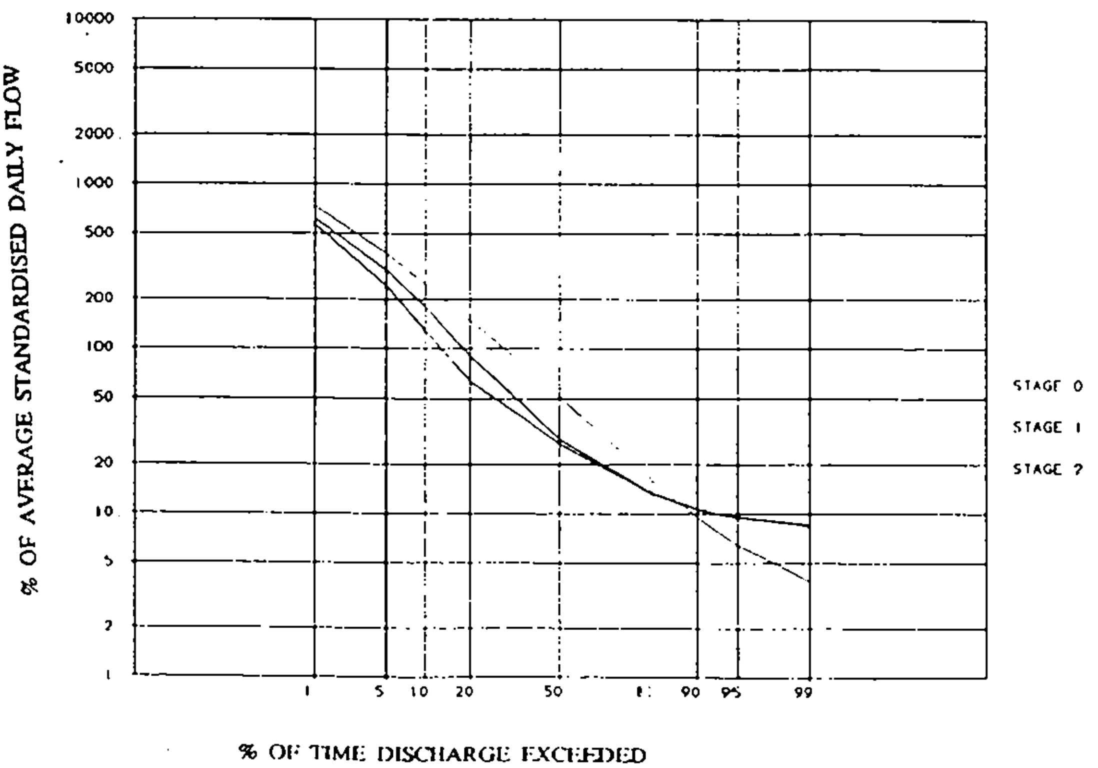


FIGURE 4e

GLENWHIRRY SCHEME - ESTIMATES FOR SITE 5 (ANDRAID)

FLOW DURATION CURVES MF = 15.27 $m^3.s^{-1}$

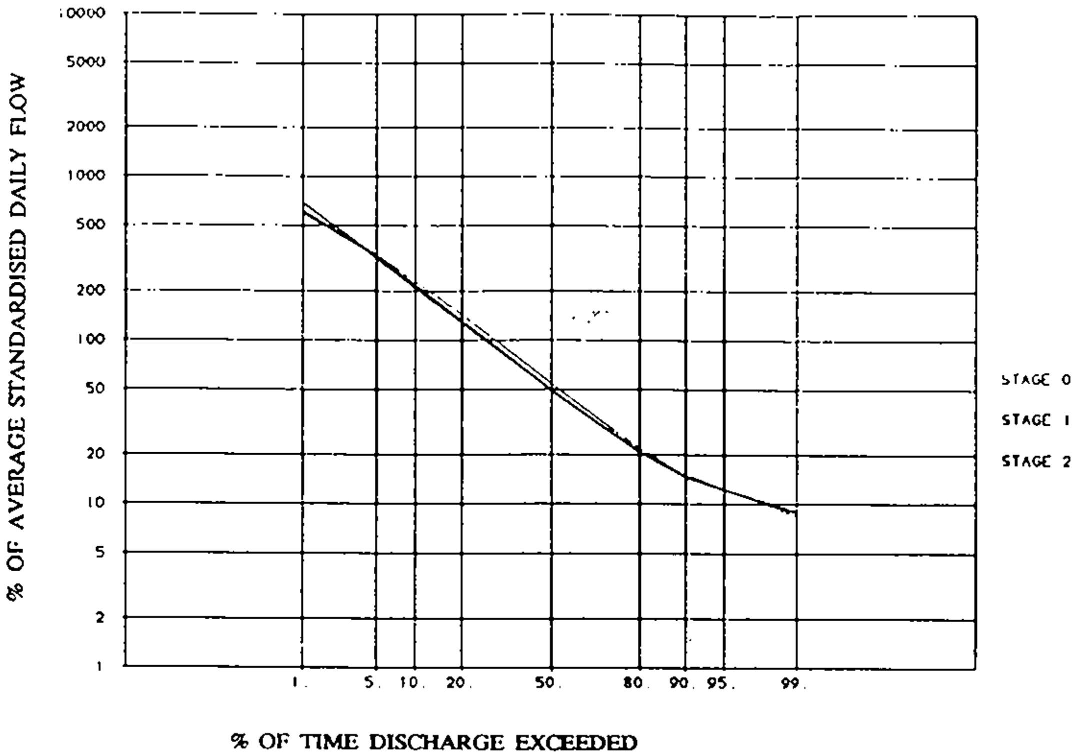
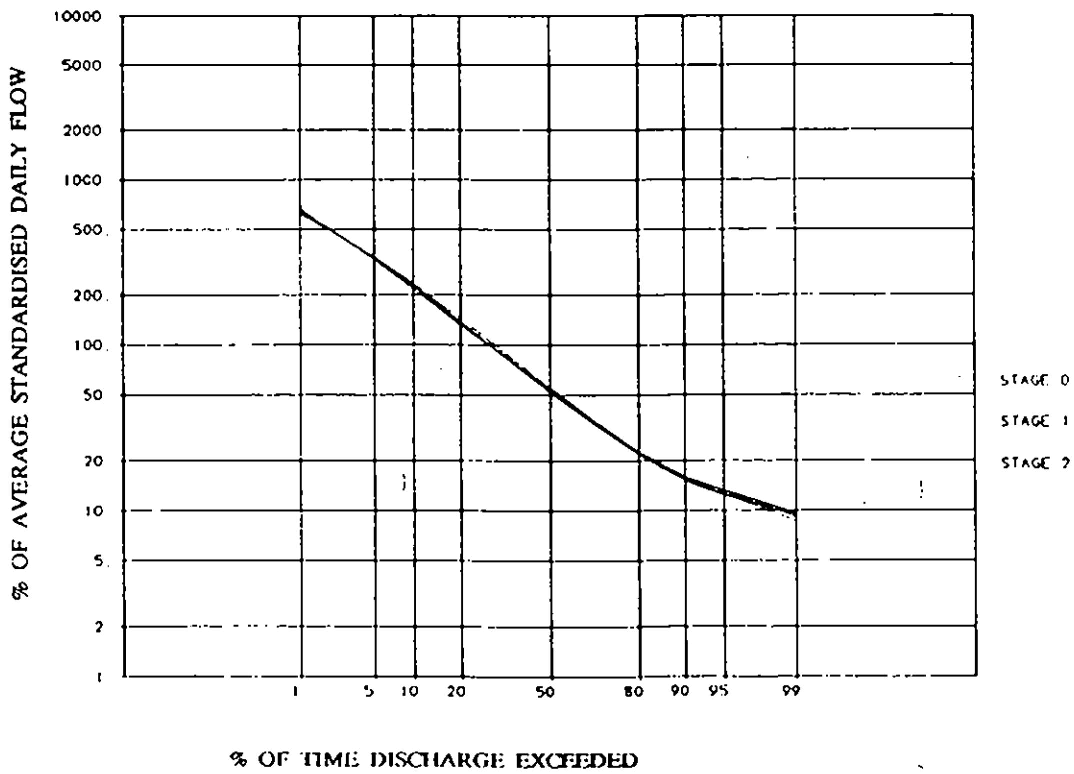


FIGURE 4f

GLENWHIRRY SCHEME - ESTIMATES FOR SITE 6 (SHANE'S VIADUCT)

FLOW DURATION CURVES MF = 16.11 $m^3.s^{-1}$



2.2 RIVER FLOWS DOWNSTREAM OF THE PROPOSED LOUGH ISLAND REAVY/KINNAHALLA ABSTRACTION SCHEME

2.2.1 Introduction

The proposed scheme (Figure 5) involves augmenting the yield of the present Lough Island Reavy reservoir scheme by:

1. Addition of two more indirect catchments

2. Construction of a new reservoir, Kinnahalla, downstream of the Spelga Dam, its yield augmented by flows from three indirect catchments.

Water would be conducted into the Lough Island Reavy water treatment plant and the total abstraction would be increased from the present 18 $Ml.day^{-1}$ to 83 $Ml.day^{-1}$, all of which would be exported from the basin.

The existing and proposed schemes have been modelled, using the available flow records for the Rocky River (gauging station 203038) and the river Bann at Bannfield Bridge (gauging station 203033) and daily and monthly records of rainfall within the Bannfield Bridge catchment (section 2.2.2). A reservoir simulation was then carried out using these inflows in order to estimate the hydrologic effect of the proposed schemes (section 2.2.3).

2.2.2 Modelling the existing situation and the proposed scheme

Appendix A2 presents the generation of two daily flow records at all relevant sites (Table 6) for the period 1972 to 1989 inclusive for:

1. current conditions, including existing Lough Island Reavy scheme

2. proposed Kinnahalla reservoir and extended Lough Island Reavy scheme.

The measured flows in the Rocky River have been used as a basis for modelling the upland catchments, i.e. the direct and indirect catchments draining into the reservoirs. Conversion of the Rocky River flows to flows in other upstream catchments has been achieved by multiplication by area factors (Appendix A2). For the months July and August 1983, December 1984, April to July (inclusive) 1985 and April and May 1986 flow data for the Rocky River were missing and they were infilled based on the following regression equation between the Rocky River flows (203028) and the flows at Bannfield Bridge (203033).

$$\text{Rocky River} = 0.1315 * \text{Bannfield Bridge}^{0.800}$$

The equation was also used to estimate flows before the start of the record (1 December 1983). The correlation between the log of the daily flows at Bannfield Bridge and Rocky River is 0.87. The flows at Bannfield Bridge were used to model the flows from the lower part of the catchment, unaffected by the schemes.

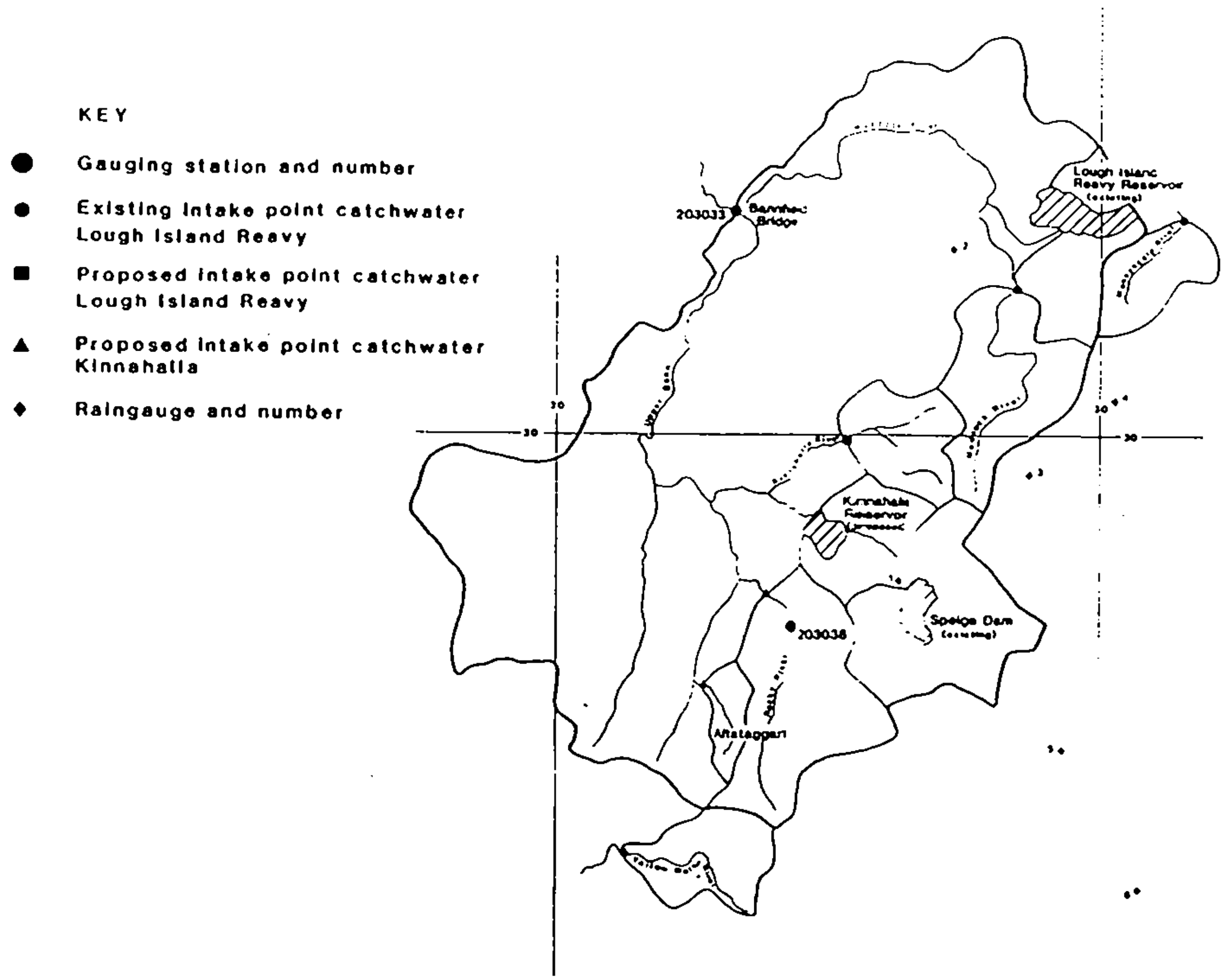


Figure 5 Proposed Lough Island Reavy/Kinnahalla reservoir scheme

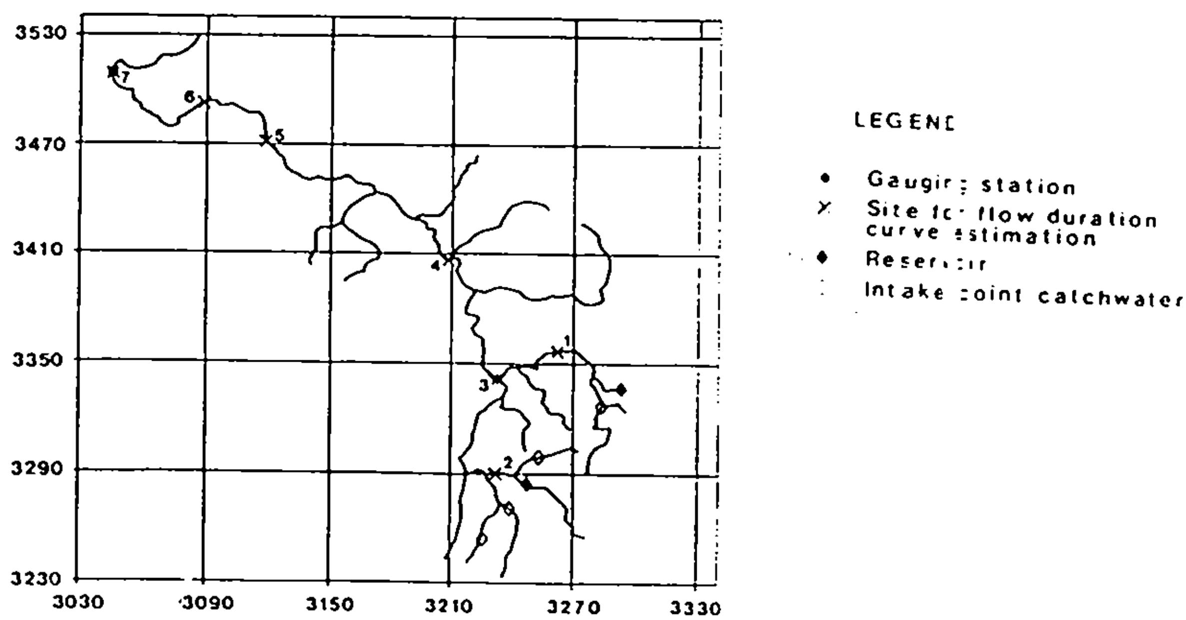


Figure 6 Sites of estimation of FDCs in Lough Island Reavy/Kinnahalla scheme

The simulations of the reservoirs are based on a daily reservoir water balance. The outflows from the reservoirs, and the excess water from the indirect catchments were input into the lower, "natural" part of the catchment to give modified flow records at Bannfield Bridge.

Table 6 Sites where FDCs were derived from modelled data (Lough Island Reavy/Kinnahalla scheme)

Site name	Grid reference
1. Lough Island Reavy reservoir outlet	3293 3337
2. Muddock River intake point	3284 3326
3. Kinnahalla River intake point	3253 3298
4. Kinnahalla reservoir outlet	3247 3285
5. Rocky River intake point	3238 3271
6. Altataggart catchment intake point	3227 3254
7. Upper Bann at Bannfield Bridge	3233 3341

2.2.3 Hydrologic effect of the proposed scheme

Flow duration curves for the period 1972-1989 were determined from the modelled flow records downstream of Lough Island Reavy reservoir and Kinnahalla reservoir, and downstream of the intake points of indirect catchments within the Bannfield Bridge catchment (Table 6). Flow duration curves under current conditions were estimated at the eight downstream sites (Table 7 and Figure 6) using a pro-rata adjustment based on the mean flow at each site calculated from the Institute of Hydrology Micro Low Flow system. The difference in any FDC between the current condition and the proposed development was calculated from the modelled data series (Table 6) and used to estimate the modified flow duration curves at each of the eight sites. This procedure has been described in section 2.1.3 above.

Table 7 Sites for estimation of FDCs in Lough Reavy/Kinnahalla scheme

Site name	Grid reference
1. Muddock River	3258 3357
2. Hilltown	3218 3290
3. Bannfield Bridge	3233 3341
4. Katesbridge STW	3206 3408
5. Banbridge STW	3116 3468
6. Tullylish	3082 3488
7. Dyne's Bridge	3043 3509
8. Lough Neagh	2960 3628

The estimated current FDCs (Stage 0) as well as the FDCs for two stages of reservoir development are shown in Figures 7a to 7h, with discharge standardised by the mean of the natural flow at the site. Table 8 presents the FDCs expressed in $m^3.s^{-1}$, and in Table 9 pre- and post-scheme mean flows are given.

Table 8 Current and post-scheme FDCs (in $m^3.s^{-1}$) for 8 sites downstream of proposed Lough Island Reavy/Kinnahalla water resource scheme

Percentage of time flow exceeded	Site 1 Muddock River		Site 2 Milltown		Site 3 Bannfield Bridge	
	Pre	Post	Pre	Post	Pre	Post
1	4.48	6.00	8.69	3.34	23.9	19.7
5	2.05	2.25	2.60	1.72	10.9	7.32
10	1.32	1.40	1.67	0.93	7.01	4.64
20	0.76	0.78	0.95	0.34	4.07	2.72
50	0.26	0.24	0.33	0.082	1.40	0.99
80	0.11	0.10	0.11	0.044	0.47	0.38
90	0.082	0.070	0.071	0.037	0.30	0.26
95	0.071	0.07	0.058	0.035	0.25	0.23
99	0.062	0.061	0.045	0.032	0.19	0.19
	Site 4 Katesbridge STW		Site 5 Banbridge STW		Site 6 Tullyish	
	Pre	Post	Pre	Post	Pre	Post
1	29.3	25.7	37.7	34.1	39.0	35.5
5	13.8	10.4	17.8	14.4	18.4	15.0
10	8.67	6.46	11.2	0.95	11.6	9.35
20	4.90	3.68	6.31	5.09	6.54	5.31
50	1.65	1.29	2.12	1.76	2.20	1.83
80	0.68	1.57	0.88	0.77	0.91	0.80
90	0.43	0.39	0.55	0.51	0.57	0.53
95	0.33	0.32	0.38	0.41	0.44	0.43
99	0.21	0.22	0.24	0.26	0.28	0.29
	Site 7 Dyne's Bridge		Site 8 Lough Neagh			
	Pre	Post	Pre	Post		
1	40.9	37.3	75.3	72.3		
5	19.3	15.9	35.8	32.4		
10	12.1	9.90	22.5	20.3		
20	6.84	5.62	12.7	11.5		
50	2.30	1.94	4.27	3.91		
80	0.96	0.85	1.77	1.67		
90	0.60	0.56	1.11	1.07		
95	0.46	0.45	0.86	0.84		
99	0.29	0.30	0.54	0.55		

From the analysis the following conclusions can be drawn:

1. The mean flow decreases at all sites except site 1 where there is a small increase in mean flow due to the increased abstraction being less than the increase in flow from additional indirect catchments.

2. The FDCs (in $m^3.s^{-1}$) shift downwards due to the scheme, except at site 1 where the pre- and post scheme situation is influenced by Lough Island Reavy reservoir and Muddock River compensation flow situation. Higher peak flows arise from the addition of an indirect catchment, as in 1. above.

3. In comparison with the existing regime the hydrological change is a reduction by 9% for the mean and 25% for Q95 at the inflow to Lough Neagh (site 8).

Table 9 Current and post-scheme mean flows in Lough Island Reavy/Kinnahalla water resource scheme ($m^3.s^{-1}$)

Site	pre-scheme	post-scheme
A. Intake points and reservoirs		
1. Lough Island Reavy reservoir	0.076	0.083
2. Muddock	0.037	0.036
3. Kinnahalla River	0.130	0.012
4. Kinnahalla reservoir	0.320	0.185
5. Rocky River	0.288	0.058
6. Altataggart River	0.054	0.010
7. Yellow River	0.905	0.384
B. 8 sites downstream of schemes		
1. Muddock River	0.52	0.53
2. Hilltown	0.66	0.31
3. Bannfield Bridge	2.77	1.92
4. Katesbridge STW	3.66	2.81
5. Banbridge STW	4.71	3.86
6. Tullylish	4.88	4.03
7. Dyne's Bridge	5.11	4.26
8. Lough Neagh	9.49	8.64

FIGURE 7a

LOUGH ISLAND REAVY SCHEME - ESTIMATES FOR SITE 1 (MUDDOCK RIVER)

FLOW DURATION CURVES MF = 0.52 $m^3.s^{-1}$

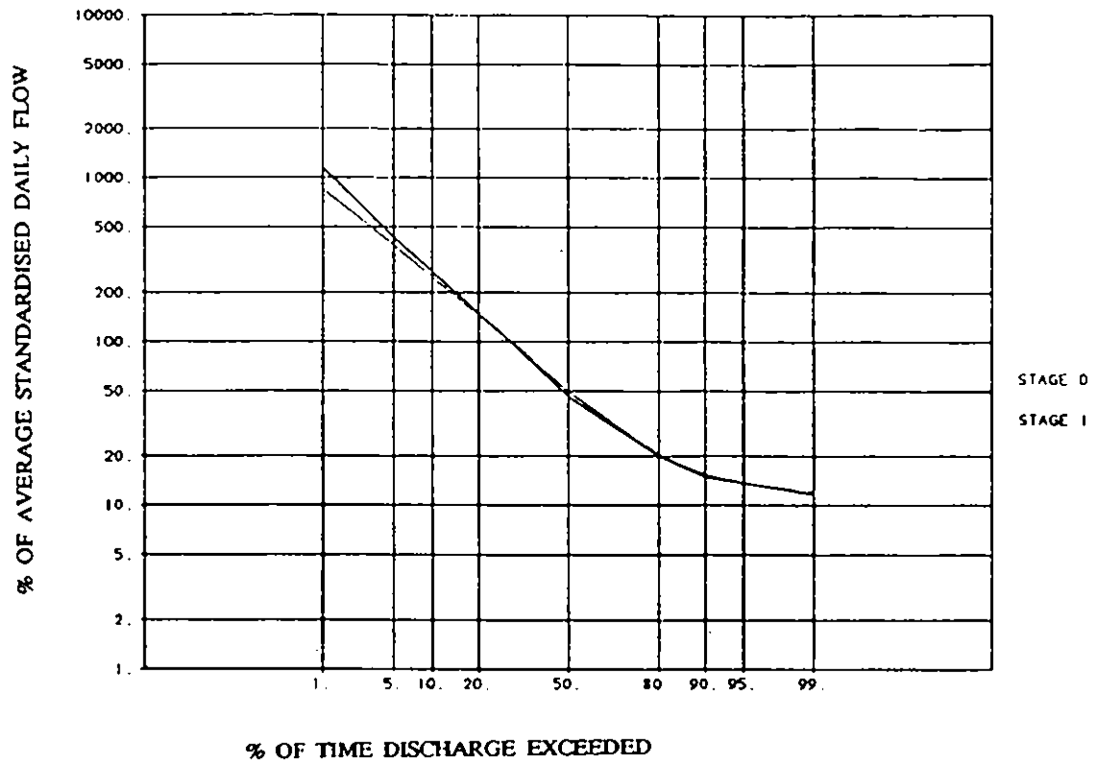


FIGURE 7b

LOUGH ISLAND REAVY SCHEME - ESTIMATES FOR SITE 2 (HILLTOWN)

FLOW DURATION CURVES MF = 0.66 $m^3.s^{-1}$

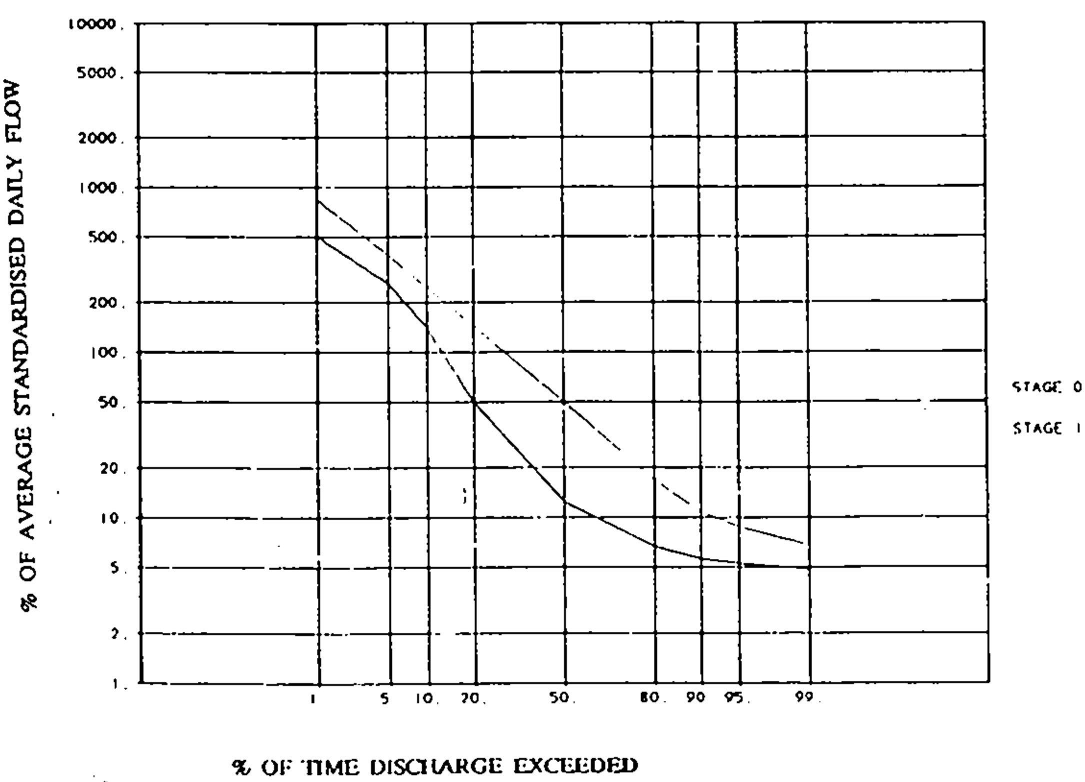


FIGURE 7c

LOUGH ISLAND REAVY SCHEME - ESTIMATES FOR SITE 3 (BANNFIELD BRIDGE)

FLOW DURATION CURVES MF = 2.77 $m^3.s^{-1}$

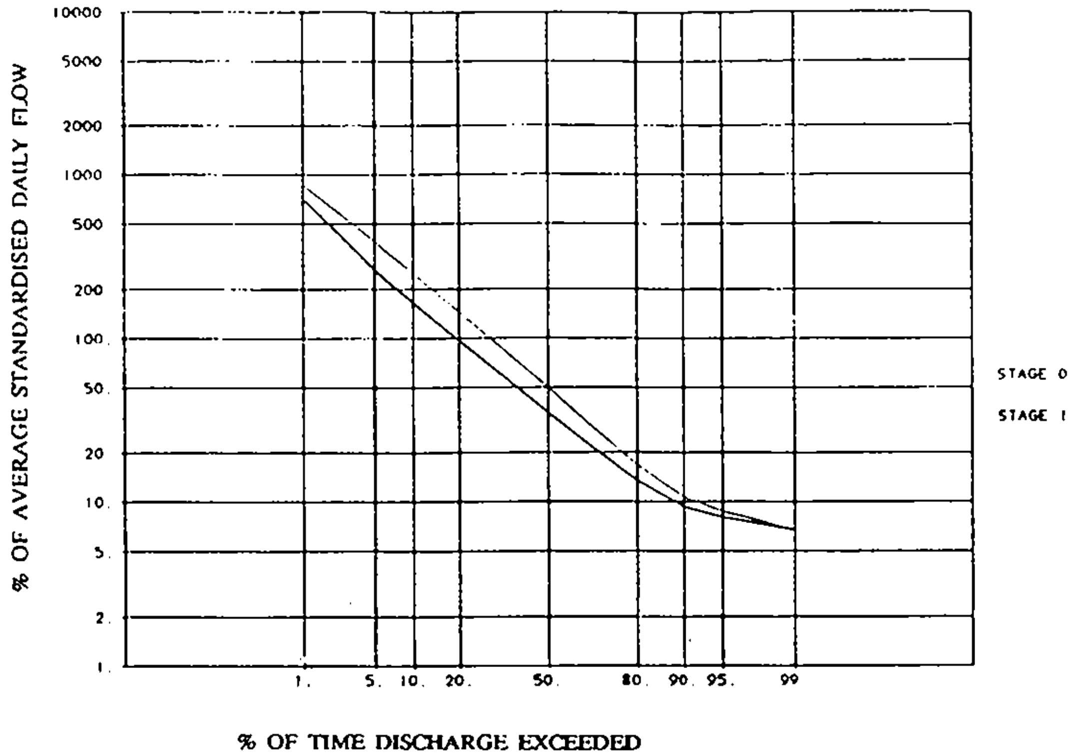


FIGURE 7d

LOUGH ISLAND REAVY SCHEME - ESTIMATES FOR SITE 4 (KATESBRIDGE STW)

FLOW DURATION CURVES MF = 3.66 $m^3.s^{-1}$

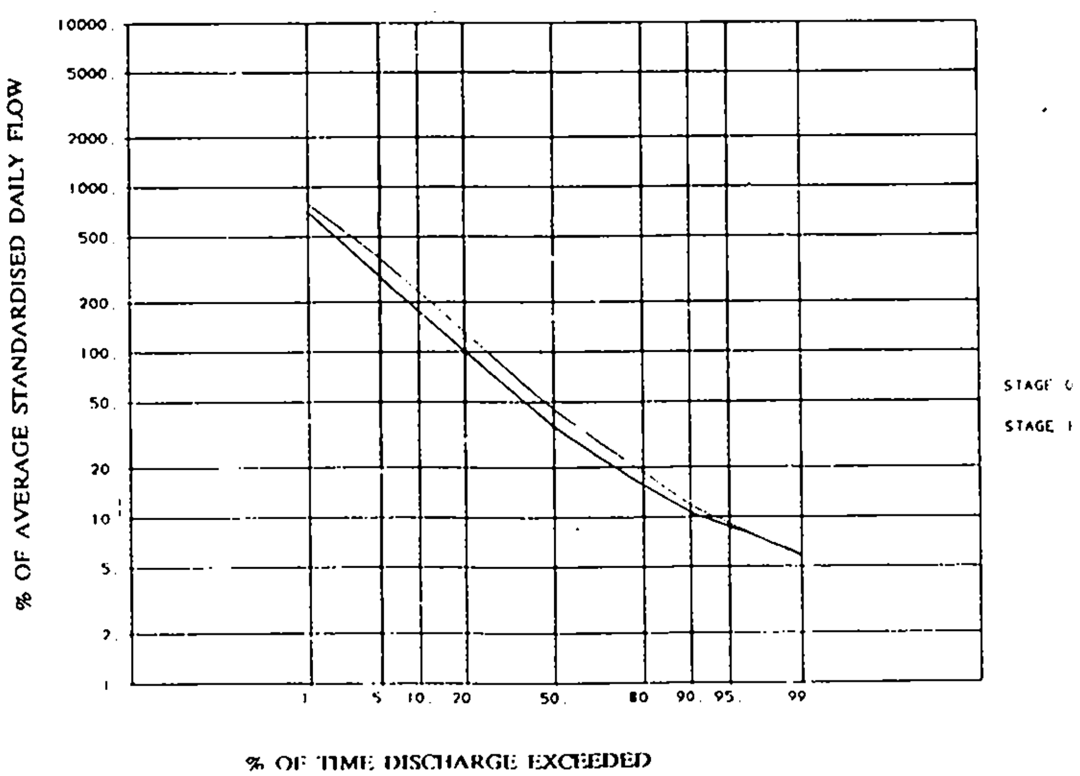


FIGURE 7e

LOUGH ISLAND REAVY SCHEME - ESTIMATES FOR SITE 5 (BANBRIDGE STW)

FLOW DURATION CURVES MF = 4.71 m^3. s^{-1}

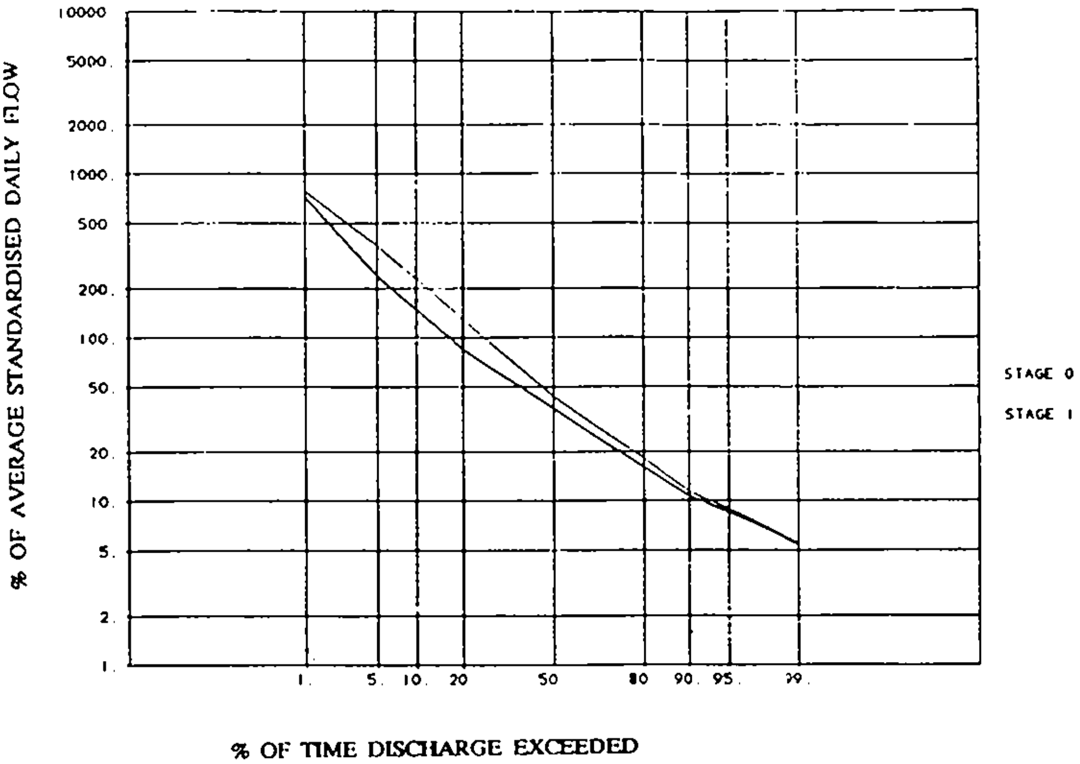


FIGURE 7f

LOUGH ISLAND REAVY SCHEME - ESTIMATES FOR SITE 6 (TULLYLISH)

FLOW DURATION CURVES MF = 4.88 m^3. s^{-1}

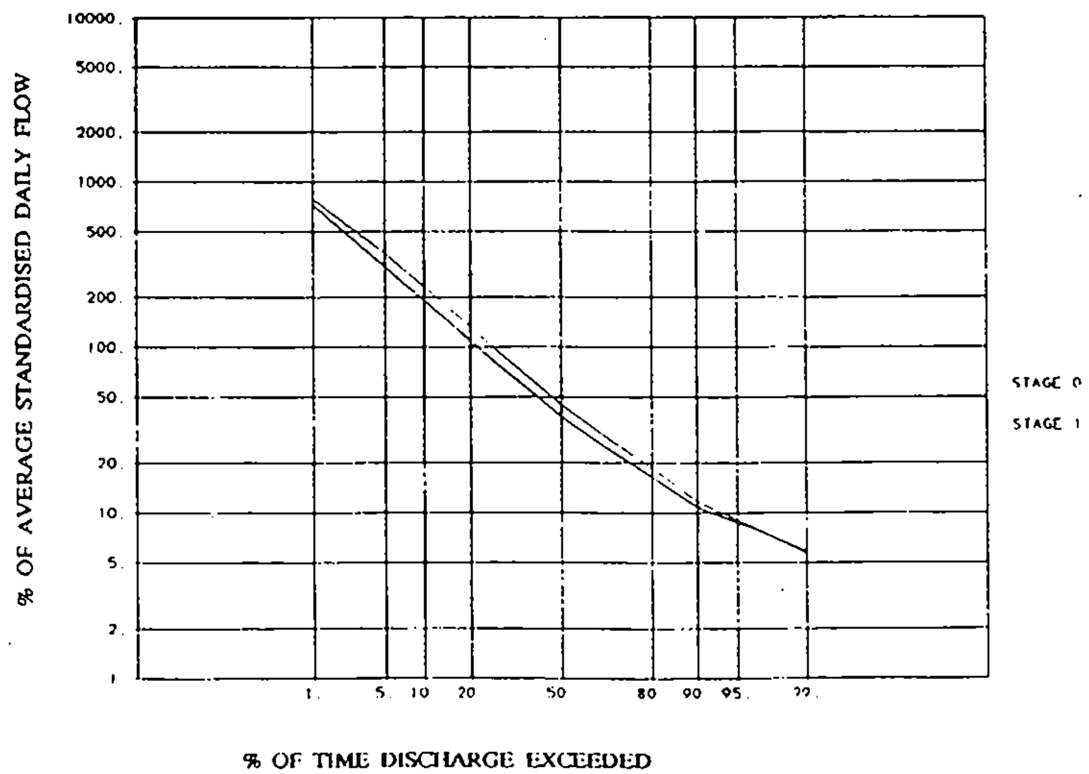


FIGURE 7g

LOUGH ISLAND REAVY SCHEME - ESTIMATES FOR SITE 7 (DYNE'S BRIDGE)

FLOW DURATION CURVES

MF = 5.11 $m^3 . s^{-1}$

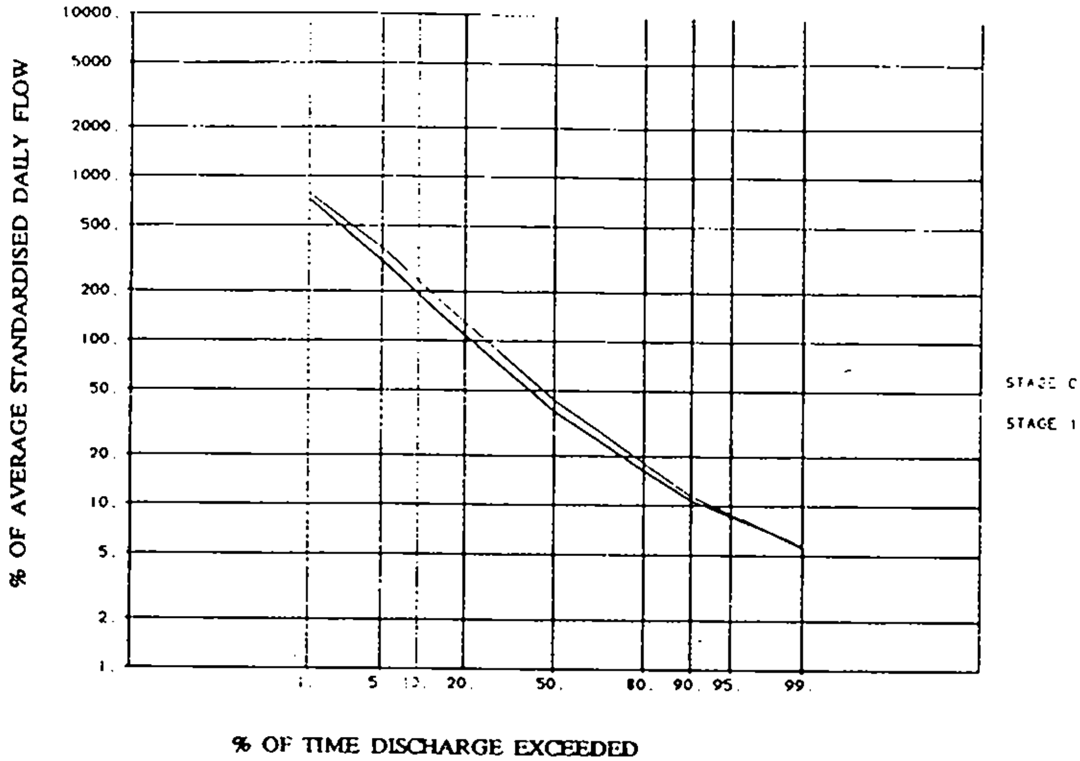
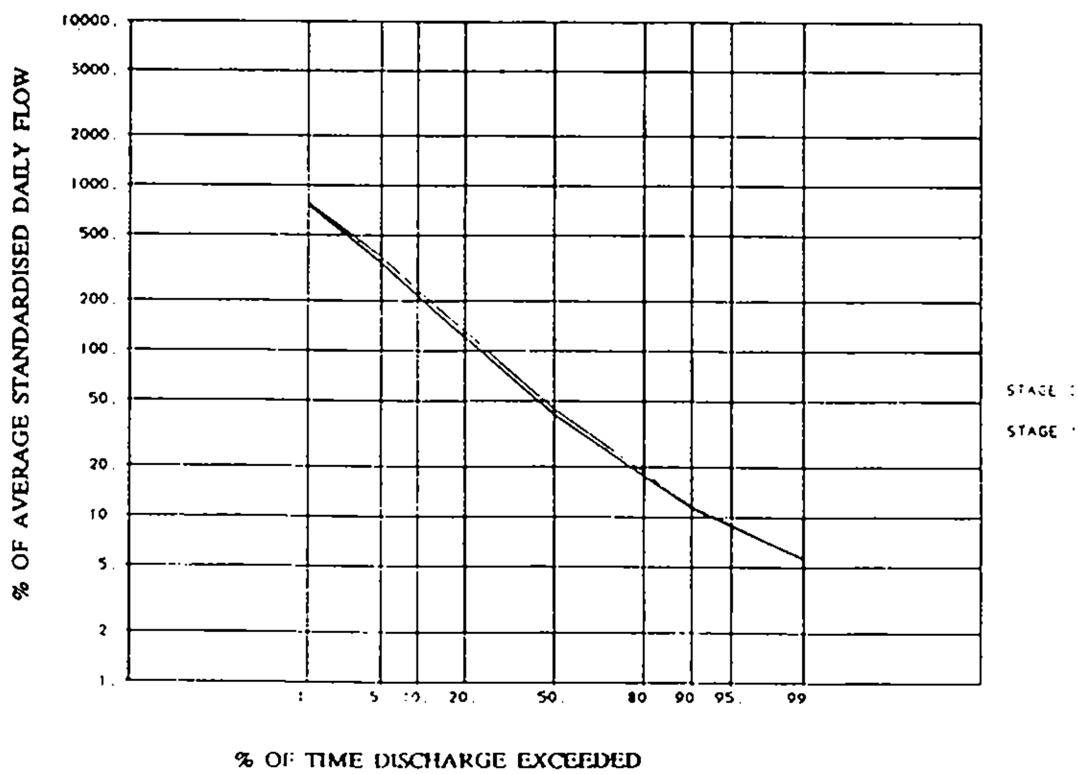


FIGURE 7h

LOUGH ISLAND REAVY SCHEME - ESTIMATES FOR SITE 8 (LOUGH NEAGH)

FLOW DURATION CURVES

MF = 9.79 $m^3 . s^{-1}$



2.3 LOUGH NEAGH LEVELS AND LOWER BANN FLOWS

2.3.1 Control of Lough Neagh levels

Water levels in Lough Neagh and outflow from the Lough into the Lower Bann are controlled by operation of 5 sluice gates at Toome Bridge to conform as closely as possible to the stipulations laid down in the 1955 Lough Neagh Drainage Act which applies to this day. These stipulations require that 'so far as conditions of rainfall wind and other natural causes appear to the Ministry to permit':

1. the water level in the Lough should be maintained within the control range 50ft 6" to 50ft 0" above Poolbeg Dublin Datum

2. a minimum sluice gate opening of one gate at 6" be maintained at all times to preserve a minimum flow in the Lower Bann.

In order to maintain the Lough level within the control range for the maximum time possible a system of sluice operation was developed which aims to maintain the level as close as possible to an operational level which is as follows:

1 October	-	31 March	:	50ft 1"
1 April	-	30 April	:	steady rise to 50ft 5"
1 May	-	30 June	:	50ft 5"
1 July	-	30 September	:	steady fall to 50ft 1"

The aims of this study are to assess any impact of additional abstraction from Lough Neagh on the Lough level and outflow in the Lower Bann in the context of the existing control policy and operational levels.

The impacts of proposed additional direct abstractions from Lough Neagh of 65 and 130 $Ml.day^{-1}$, nett exports from the Lough Neagh basin, have been studied using flow data from the period 1981-1989. In addition the sensitivity of the system to further abstractions has been tested by increasing the abstraction to 175, 220 and 350 $Ml.day^{-1}$. The study was limited to this period because of availability of computerised flow data in the Lower Bann at Movanagher (station 203040) for the period 1981 to 1989 only. Likewise the impact of reduced inflow to the Lough resulting from the proposed Glenwhirry and Lough Island Reavy reservoir schemes has been studied. The current flow regime at Toome has been estimated by appropriate adjustment of data from gauging stations 203040 (Lower Bann at Movanagher) and 203019 (Clady at Glenone Bridge). Lough levels are taken as an average of the records at Toome Bridge and Daryadd Bay.

2.3.2 Simulation of Lough Neagh levels with historic outflow and increased abstraction

For illustrative pruposes only the following "worst case" scenario has been modelled for one year only. If in the choice of sluice gate settings at Toome no allowance was made for an additional abstraction, and historic flows were maintained the Lough level would continue to fall steadily in proportion to the rate of abstraction. Figure 9 shows the effect of an additional abstraction of 130 Ml/day^{-1} over the year 1981 which results in a reduction in Lough level of 4.9 inches by the end of the year. This illustrates the relative scale of the impact of the maximum abstraction on Lough levels when no impact on Lower Bann flows is tolerated. In practice a reduced Lough level would reduce the head difference across the sluice gates at Toome and therefore the outflow. The impact of increased abstraction is exaggerated in this simulation, since outflow is assumed to have remained unaltered and hence Lough levels fall more than they would in reality when outflows are restricted with falling Lough levels. For this reason Figure 9 may be viewed as a 'worst case'. In order to maintain Lough levels with the increased abstraction the outflow must of course be reduced and this is considered in the following section.

2.3.3 Simulation of Lough levels with reduced outflow and increased abstraction or reservoir scheme

Although target flows and levels have been set by the 1955 Lough Neagh Drainage Act, an explicit operating policy in terms of gate setting for given Lough levels and time of year is not stipulated. The simulation has therefore been based on changed flows and levels and for the purpose of this study no explicit assessment of revised gate settings has been undertaken.

The control policy used in this simulation may be summarised as follows.

1. Replicate historic outflow at Toome if <u>either</u>

   a) Lough level is above the operational level

<u>or</u>

   b) historic outflow at Toome is less than or equal to the required minimum flow.

2. Reduce outflow at Toome to the minimum required flow if

   a) Lough level is below operational level

<u>and</u>

   b) historic outflow is greater than prescribed minimum.

In order to prevent overcompensation an extra criterion was enforced before any flow reduction was made, which is that the simulated level be below the historic level. However, the time step was one day, with the consequence that on some occasions the simulated level did exceed the historic level.

The 'minimum flow' has been interpreted as the flow through a single gate opening of 6" at Toome which is given as 1360 $Ml.day^{-1}$ ($15.74\ m^3.s^{-1}$) (Department of Agriculture, Drainage Division, June 1989). The control policy is illustrated in the following flow chart:

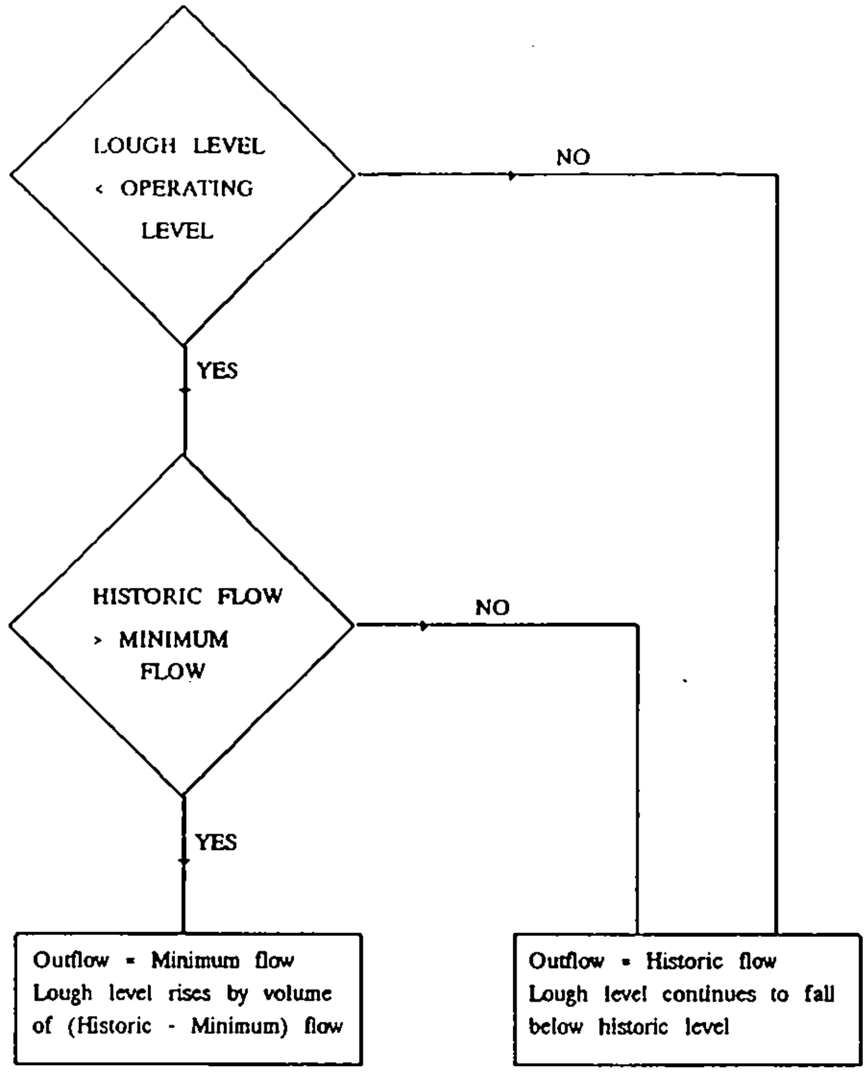


Figure 8 Schematic representation of Lough Neagh model operations

Results of this simulation are summarised in Table 10 for each of the constant abstraction rates over the period 1981-1989.

For the proposed reservoir schemes the difference between historic inflow and predicted inflow has been treated as effective abstraction from the Lough, which gives a different abstraction value every day. Results for each of the proposed schemes are summarised in Table 11 using the same measures as were used to describe the effect of increased abstraction from Lough Neagh . The equivalent continuous average abstraction rate of the three schemes has been calculated. The impact of the Glenwhirry Stage 1 scheme is estimated to be slightly greater than the proposed additional daily abstraction from the upland reservoirs. This is a result of comparing modelled flow series with actual gauged flow, the difference of 2.5 $Ml.d^{-1}$ reflecting the errors in the modelling procedure.

For Glenwhirry Stage 2 and Lough Island Reavy the impact is less than the actual abstraction 130 $Ml.d^{-1}$ and 65 $Ml.d^{-1}$ respectively. In addition to small modelling errors this arises primarily from:

1. abstracted water derived from indirect catchwaters that do not drain into Lough Neagh and thus do not reduce the outflows from the Lough;

2. there is some reduction in reservoir storage over the modelled period;

3. the upland reservoirs are unable to meet the required abstraction rates for a limited period of time and thus the modelled abstractions are less than the design figures.

Frequency duration curves for both Lough level and outflow at Toome for all simulations are presented in Figures 10a to 10f and in Table 12 they are summarized. Table 13 gives the mean flow and mean Lough Neagh level for the simulated records. 1984 was the year in which the Lough level took both its maximum and minimum value, (see Table 10) hence any alteration in levels would have had maximum impact in this year. Figures 11a to 11f give hydrographs of Lough levels and outflows according to the simulations over 1984 for three different cases: abstraction rates of 65 $Ml.day^{-1}$ and 130 $Ml.day^{-1}$, and the Glenwhirry scheme 2 development. The impact of Glenwhirry scheme 1 and the Lough Island Reavy/Kinnahalla scheme is less than that of Glenwhirry scheme 2.

According to the simulations, the Lough Neagh level would experience both increases and reductions in level compared to historic levels. Increased levels are predicted as a result of the daily timescale used for modelling: reduction of the outlfow from historic to minimum allowed rate for a whole day sometimes over compensates the fall in level in the preceding dry period. Refinement of the model would result in no predicted increase in levels. Evidence that increased levels result only from modelling on a daily time-sclae and have no physical significance is given by the fact that predicted increases in levels are largely independent of abstraction rate. Likewise the percentage of time that the level rises above the upper control level is predicted to be independent of abstraction rate and should not be seen as being physically significant.

On the contrary, reductions in the Lough level are augmented with higher abstraction rates. The daily timescale of the model has little effect on predicted reduced levels which occur as a result of abstraction and are physically significant. Likewise the percentage of time that the level fails to attain the lower control level is predicted to increase with increased abstraction.

It is therefore likely that with more precise regulation of outflow than has been assumed in these simulations, it should be possible to maintain the historic regime of the levels that were above the minimum control level. However the average of levels below minimum control levels, and the minimum experienced levels, are predicted to decrease with increasing abstraction. The percentage of time that level is below the minimum control level is predicted to increase with increasing abstraction.

Outflows at Toome

Flow through the sluices at Toome are predicted to be reduced for 3.3 and 8.6% of the time for additional direct abstractions of 65 abd 130 Ml/day respectively (Table 10). Sensitivity tests predict that this reduction would be 21.3% for an additional abstraction of 350 Ml/day. For the reservoir schemes the corresponding figures are 0.8 and 1.3%, for Glenwhirry stages 1 and 2 respectively, and 0.5% for the Lough Island Reavy/Kinnahalla scheme (Table 11).

Predicted reductions in the mean outlfow at Toome are 0.75 m^3s^{-1} (0.9%) and 1.52 m^3s^{-1} (1.9%) for additional direct abstractions of 65 and 130 Ml/day respectively. An additional direct abstraction of 350 ml/day would give a reduction of 4.08 m^3s^{-1} (5.1%). For the reservoir schemes the corresponding reductions predicted are 0.79 m^3s^{-1} (1.0%), 1.26 m^3s^{-1} (1.6%) and 0.49 m^3s^{-1} (0.6%) for Glenwhirry stages 1 and 2, and the Lough Island Reavy/Kinnahall scheme respectively.

The FDCs (Table 12a) show the maximum reduction in flows to be at the 50 percentile flow (Q50) with this reduction being augmented by increased abstraction. For additional direct abstractions of 65 and 130 Ml/day predicted reductions in the Q50 are 5.7% and 13% respectively. Sensitivity tests predict a reduction in the Q50 of 32% for additional abstraction of 350 ml/day. For the reservoir schemes the corresponding reductions predicted are 3.5 and 6.6% for Glenwhirry stages 1 and 2 respectively and 3.3% for the Lough Island Reavy/Kinnahalla scheme.

Flows in the Lower Bann

In the case of an unregulated Lower Bann River, the regime at sites downstream of the Toome sluices could be calculated from the predicted changes in flow regime at Toome in much the same way as was described in sections 2.1.3 and 2.2.3. In the present situation, where the Lower Bann is regulated to a high extent, the way in which a changed flow regime would be transmitted would depend on the operation of sluices and locks, and thus no detailed analysis has been made. However, with increased abstraction the mean flow would become lower, with the decrease in flows concentrated on days where minimum allowable flow would be released instead of the historic flow.

Table 10 Simulation of Lough Neagh levels with reduced outflow - different abstraction rates

	Additional abstraction rate ($Ml.day^{-1}$) (a)					
	0 (current)	65 (Stage 1)	130 (Stage 2)	175 a.	220 b.	350 c.
				(sensitivity analysis)		
1. Lough level changes (compared with historic levels)						
Maximum increase level (inches)		1.20	1.20	1.10	1.10	1.40
Maximum decrease level (inches)		0.90	2.40	2.90	3.90	6.20
Average increase in level (inches) (b)		0.44	0.42	0.39	0.38	0.43
Average decrease in level (inches) (c)		0.30	0.41	0.54	0.70	1.08
% of time for which level is reduced		60.8	67.5	73.8	79.8	79.4
Average of (level-upper control level) for levels above upper control level (inches)	5.89	5.73	5.72	5.55	5.73	5.73
Average of (lower control level-level) for levels below lower control level (inches)	2.69	2.97	3.38	3.45	3.57	4.16
% of time level above upper control limit (50.6')	19.7	21.0	20.1	19.8	18.9	17.6
% of time level below lower control limit (50.0')	21.0	21.4	20.7	21.4	23.1	23.3
Maximum Lough level (inches)	633.3	633.7	632.9	632.4	632.5	630.8
(Poolbeg Dublin Datum)	52'8"	52'8"	52'7"	52'7"	52'7"	52'6"
date	(10.2.84)	(10.2.84)	(10.2.84)	(10.2.84)	(10.2.84)	(10.2.84)
Minimum Lough level (inches)	590.1	589.3	588.0	587.7	586.9	584.9
(Poolbeg Dublin Datum)	49'2"	49'1"	49'0"	49'0"	48'9"	48'3"
date	(31.8.84)	(31.9.84)	(31.9.84)	(31.9.84)	(31.9.84)	(31.9.84)
2. Outflow changes at Toome (compared with historic outflow)						
Mean flow ($m^3.s^{-1}$)	79.94	79.18	78.42	77.87	77.35	75.86
Reduction in mean flow over total simulation period ($m^3.s^{-1}$)		0.75	1.52	2.06	2.58	4.08
Number and percentage of days on which outflow is reduced (3190 days total)		106 (3.3%)	275 (8.6%)	363 (11.3%)	477 (14.9%)	680 (21.3%)
Average reduction in outflow over number of days ($m^3.s^{-1}$)		22.69	17.59	18.12	17.28	19.13

Notes: (a) the current abstraction rate is 28 $Ml.day^{-1}$. The quoted abstraction rates are in addition to this -

(b) calculated from all levels above operating levels

(c) calculated from all levels below operating levels

Table 11 Simulation of Lough Neagh levels with reduced outflow - effect of reservoir schemes

	Scheme		
	Glenwhirry Stage 1	Glenwhirry Stage 2	Lough Island Reavy/Kinnahalla
1. Equivalent average abstraction (Ml.day^{-1})	67.5	108.8	40.2
2. Lough level changes (compared with historic levels)			
Maximum increase in level (inches)	1.30	1.20	1.30
Maximum decrease in level (inches)	1.00	2.60	0.80
Average increase in level (inches) (a)	0.46	0.44	0.47
Average decrease in level (inches)(b)	0.20	0.38	0.17
% of time for which level is reduced	47.7	59.5	48.60
Average of (level-upper control level) for levels above upper control level (inches)	5.61	5.25	5.60
Average of (lower control level-level) for levels below lower control level (inches)	2.77	2.81	2.95
% of time level above upper control limit (50'6")	20.6	20.2	21.3
% of time level below lower control limit (50'0")	18.3	19.1	18.6
Maximum Lough level (inches)	632.2	630.9	632.4
(Poolbeg Dublin Datum)	52'7"	52'6"	52'7"
date	(10.2.84)	(10.2.84)	(10.2.84)
Minimum lough level (inches)	590.9	590.7	589.9
(Poolbeg Dublin Datum)	49'2"	49'2"	49'2"
date	(31.8.84)	(31.8.84)	(31.9.84)
2. Outflow changes at Toome (compared with historic outflow)			
Mean flow (m^3.s^{-1})	79.15	78.67	79.45
Average reduction in flow over total simulation period (m^3.s^{-1})	0.79	1.26	0.49
Number and pecentage of days on which outflow is reduced (3190 days total)	76 (2.4%)	125 (3.9%)	46 (1.4%)
Average reduction in outflow (cumecs) when flow is reduced	33.02	32.27	33.88

Notes: (a) calculated from all levels above operating levels
(b) calculated from all levels below operating levels

Table 12a Current and simulated FDCs for the outflow at Toome

Percentage of time flow exceeded	Current (124)	Abstraction rate ($Ml.day^{-1}$) 65	130	175	220	350	Glenwhirry Scheme 1	Glenwhirry Scheme 2	Lough Island Reavy/Kinnahalla
1	211	211	211	211	211	211	210	211	210
5	188	188	188	188	188	188	187	187	187
10	177	177	177	177	177	177	177	177	178
20	162	162	162	162	162	162	162	162	162
50	45.2	42.6	39.3	36.8	35.7	30.7	43.2	42.2	43.7
80	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4
90	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
95	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69	9.69
99	6.81	6.81	6.81	6.81	6.81	6.81	6.81	6.81	6.81

Table 12b Current and simulated level duration curves for Lough Neagh levels (in metres above Mean Sea Level Belfast Datum)

Percentage of time exceeded	Current (124)	Abstraction rate ($Ml.day^{-1}$) 65	130	175	220	350	Glenwhirry Scheme 1	Glenwhirry Scheme 2	Lough Island Reavy/Kinnahalla
1	13.06	13.04	13.05	13.05	13.05	13.02	13.03	130.3	13.06
5	12.83	12.82	12.82	12.81	12.82	12.81	12.82	12.81	12.83
10	12.73	12.72	12.71	12.70	12.70	12.69	12.71	12.70	12.72
20	12.64	12.62	12.61	12.61	12.60	12.60	12.62	12.62	12.62
50	12.54	12.53	12.52	12.52	12.52	12.51	12.53	12.52	12.53
80	12.47	12.46	12.46	12.46	12.45	12.45	12.46	12.46	12.46
90	12.44	12.41	12.40	12.39	12.39	12.37	12.42	12.41	12.42
95	12.38	12.35	12.33	12.32	12.31	12.28	12.36	12.35	12.35
99	12.37	12.22	12.18	12.18	12.16	12.12	12.26	12.23	12.23

Table 13a Current and simulated mean flows at Toome

Scheme	Mean flow ($m^3.s^{-1}$)
current (124 Ml.day^{-1})	79.94
65 Ml.day^{-1}	79.18
130 Ml.day^{-1}	78.42
175 Ml.day^{-1}	77.87
220 Ml.day^{-1}	77.35
350 Ml.day^{-1}	75.86
Glenwhirry Scheme 1	79.15
Glenwhirry Scheme 2	78.67
Lough Island Reavy/Kinnahalla	79.45

Table 13b Current and simulated mean Lough Neagh levels

Scheme	Mean Lough level (metres above Mean Sea level Belfast Datum)	Mean Lough level (inches above Poolbeg Dublin Datum)
current (124 Ml.day^{-1})	12.55	50 ft 3.5"
65 Ml.day^{-1}	12.53	50 ft 3.0"
130 Ml.day^{-1}	12.52	50 ft 2.5"
175 Ml.day^{-1}	12.52	50 ft 2"
220 Ml.day^{-1}	12.52	50 ft 2"
350 Ml.day^{-1}	12.52	50 ft 2"
Glenwhirry Scheme 1	12.52	50 ft 3"
Glenwhirry Scheme 2	12.52	50 ft 3"
Lough Island Reavy/Kinnahalla	12.52	50 ft 3"

FIGURE 9

LOUGH NEAGH : DIRECT ABSTRACTIONS 130 Ml.day^{-1}

LEVEL HYDROGRAPH

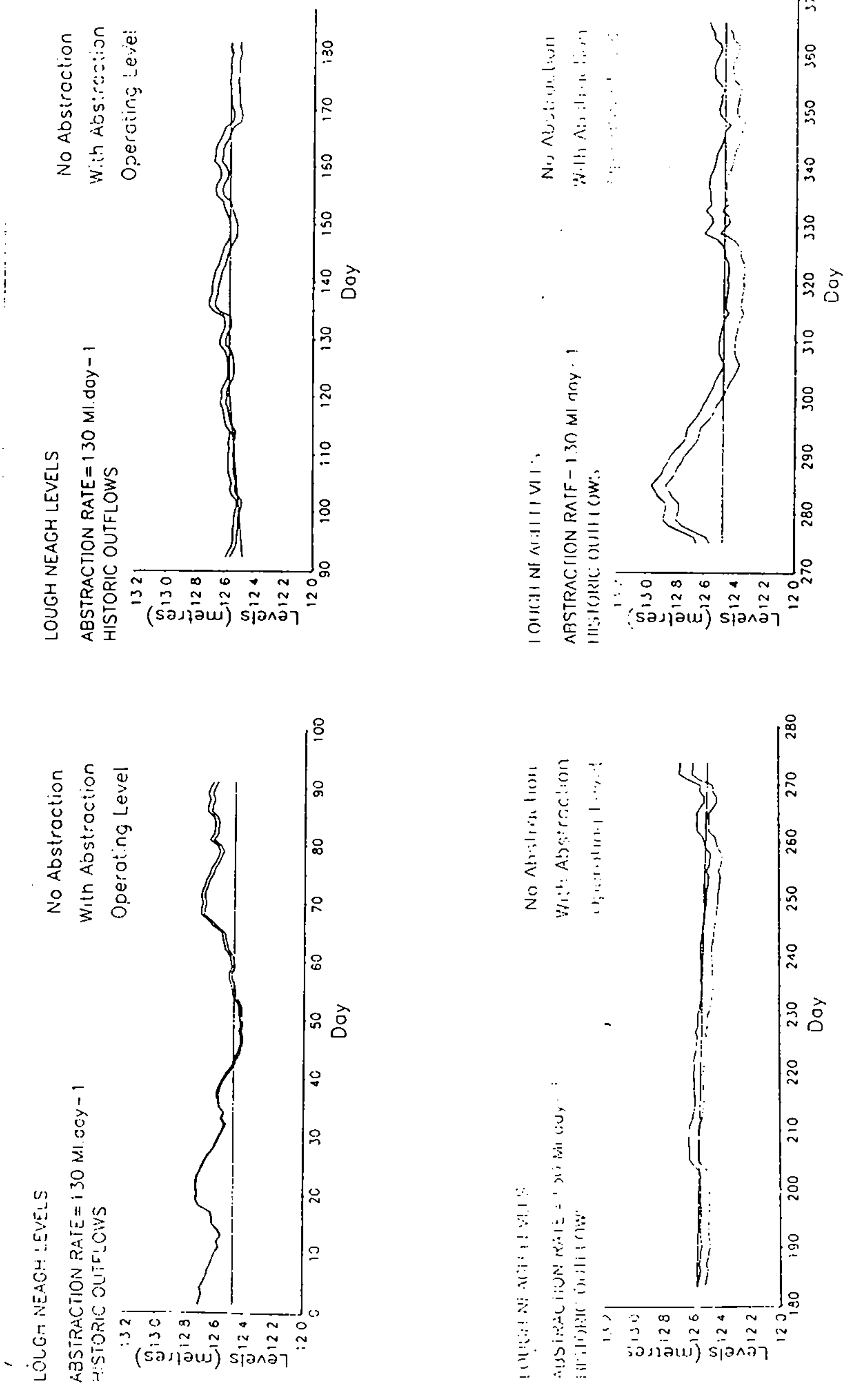


FIGURE 10a

TOOME FLOWS: DIRECT ABSTRACTIONS

FLOW DURATION CURVES MF = 79.9 $m^3.s^{-1}$

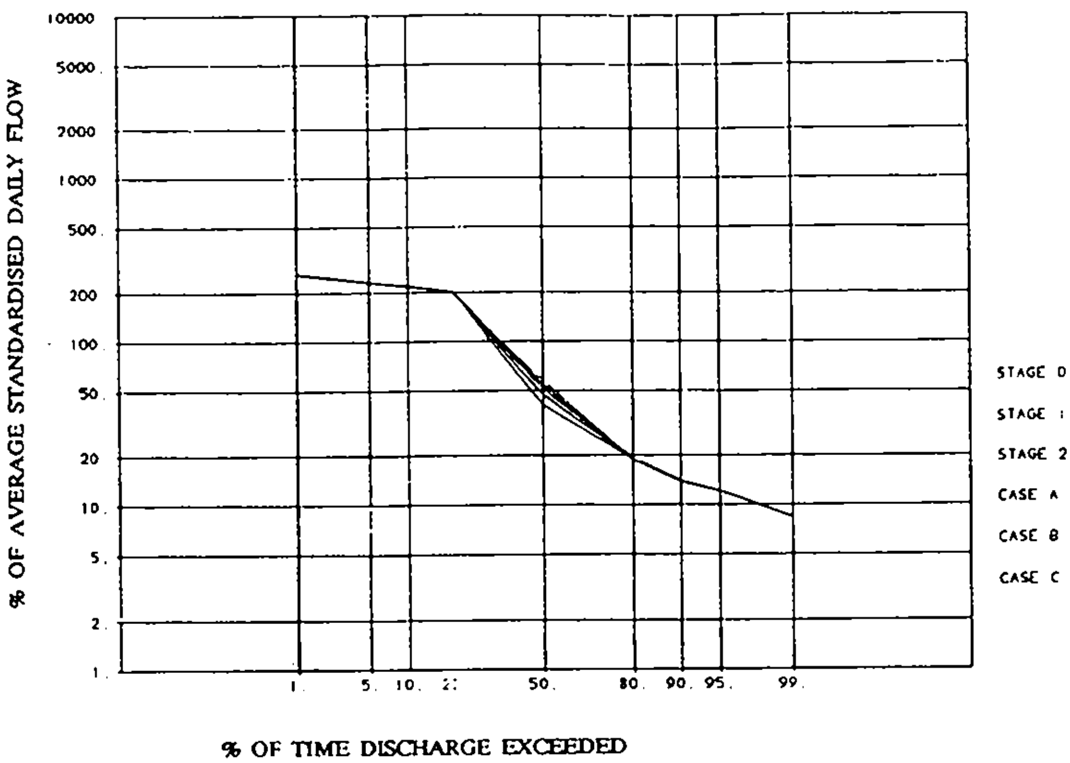


FIGURE 10b

LOUGH NEAGH: DIRECT ABSTRACTIONS

LEVEL EXCEEDANCE CURVES

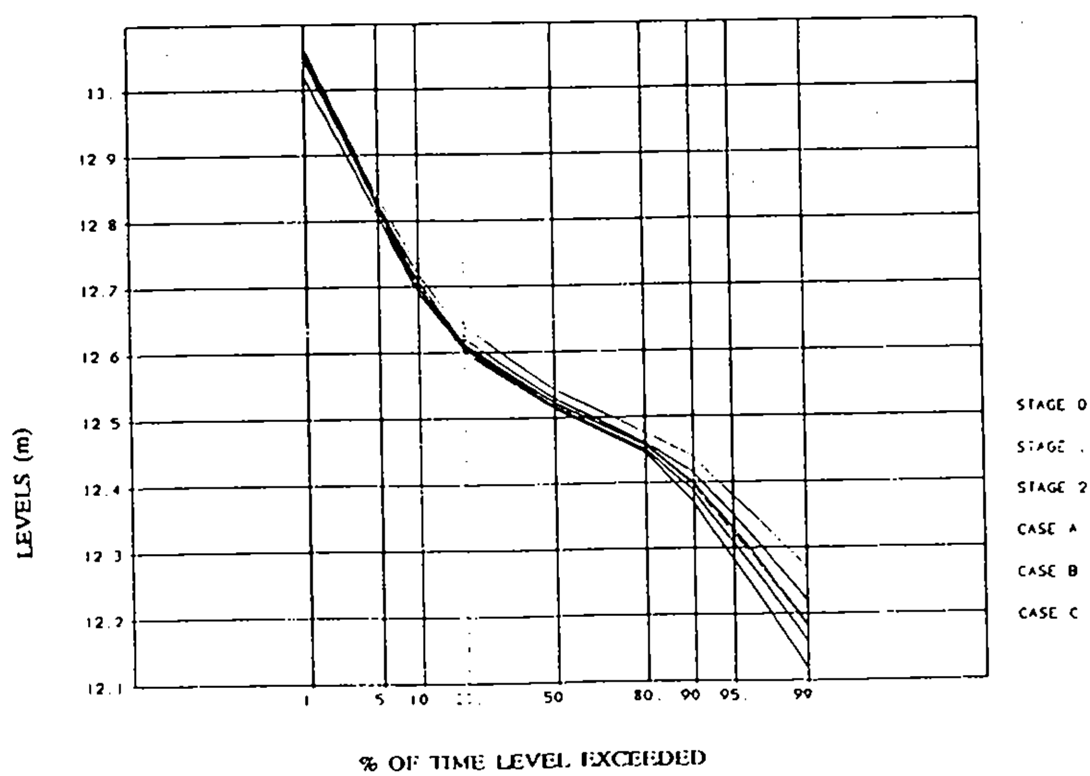


FIGURE 10c

TOOME FLOWS: GLENWHIRRY SCHEME

FLOW DURATION CURVES   MF = 79.9 $m^3.s^{-1}$

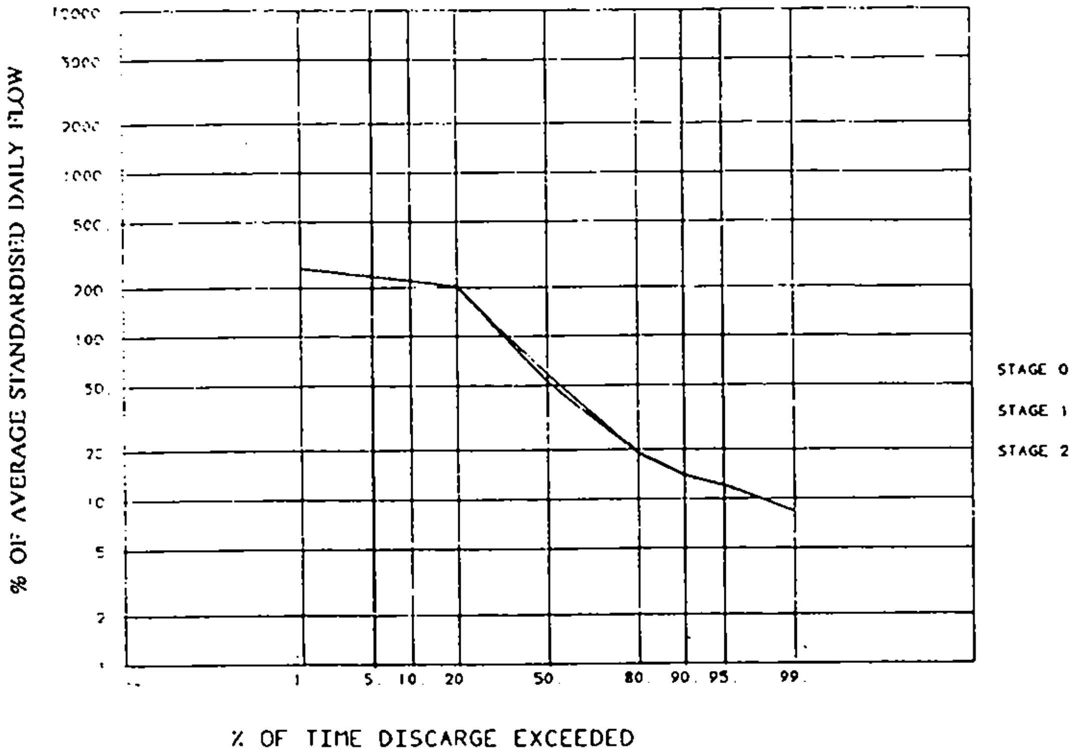


FIGURE 10d

LOUGH NEAGH : GLENWHIRRY SCHEME

LEVEL EXCEEDANCE CURVES

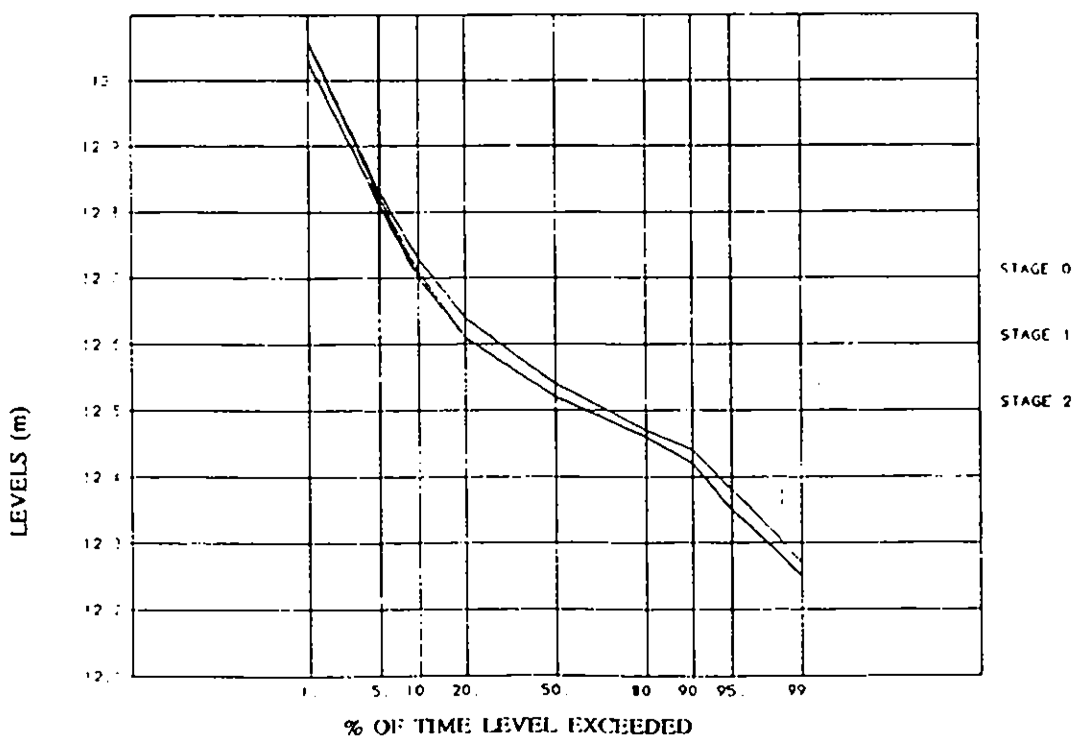


FIGURE 10c

TOOME FLOWS: LOUGH ISLAND REAVY/KINNAHALLA SCHEME

FLOW DURATION CURVES MF = 79.9 $m^3 . s^{-1}$

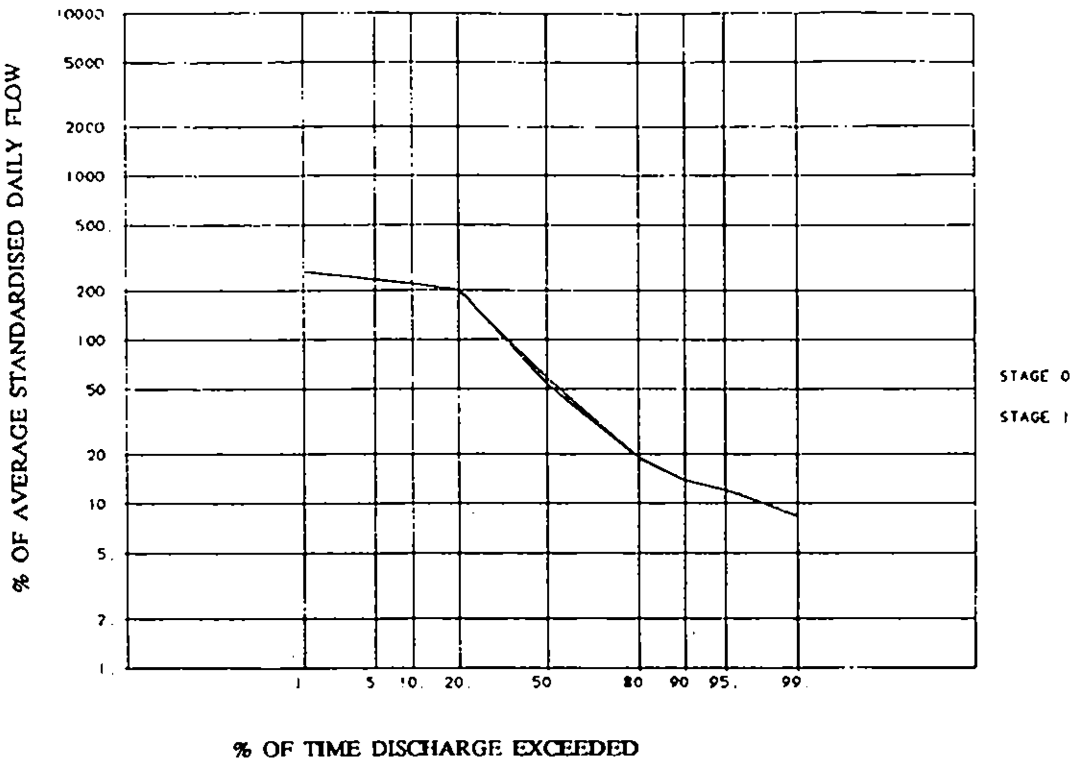


FIGURE 10f

LOUGH NEAGH : LOUGH ISLAND REAVY/KINNAHALLA SCHEME

LEVEL EXCEEDANCE CURVES

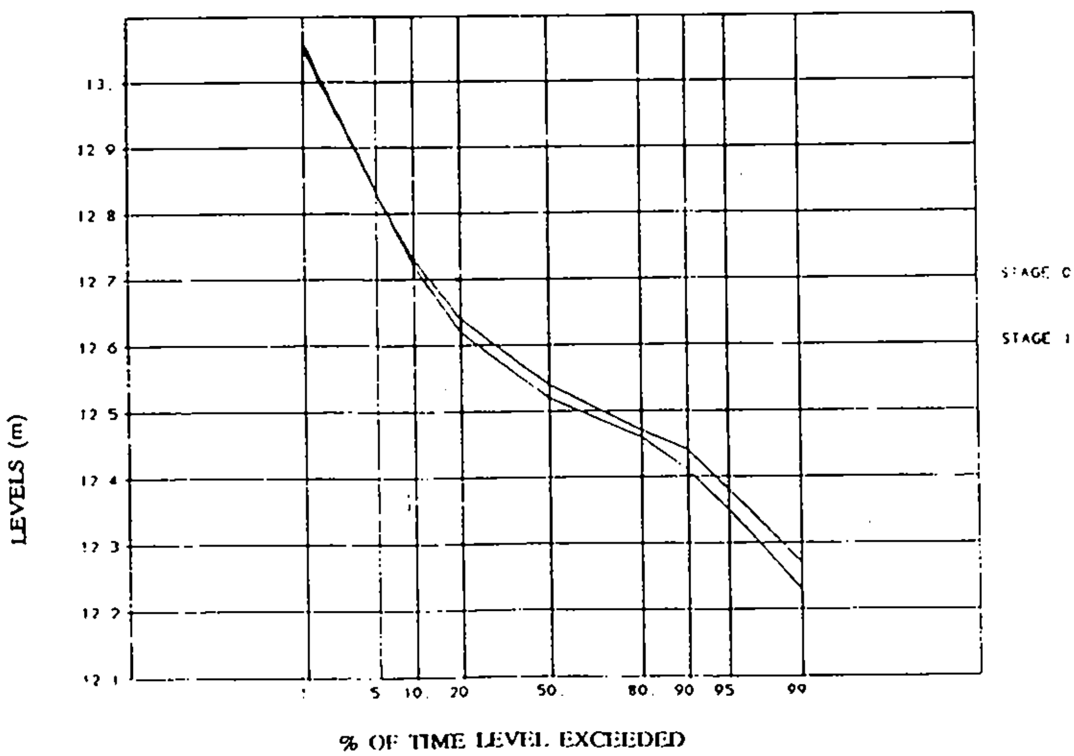


FIGURE 11a

LOUGH NEAGH LEVELS HYDROGRAPH - ABSTRACTION RATE 65 $Ml.day^{-1}$

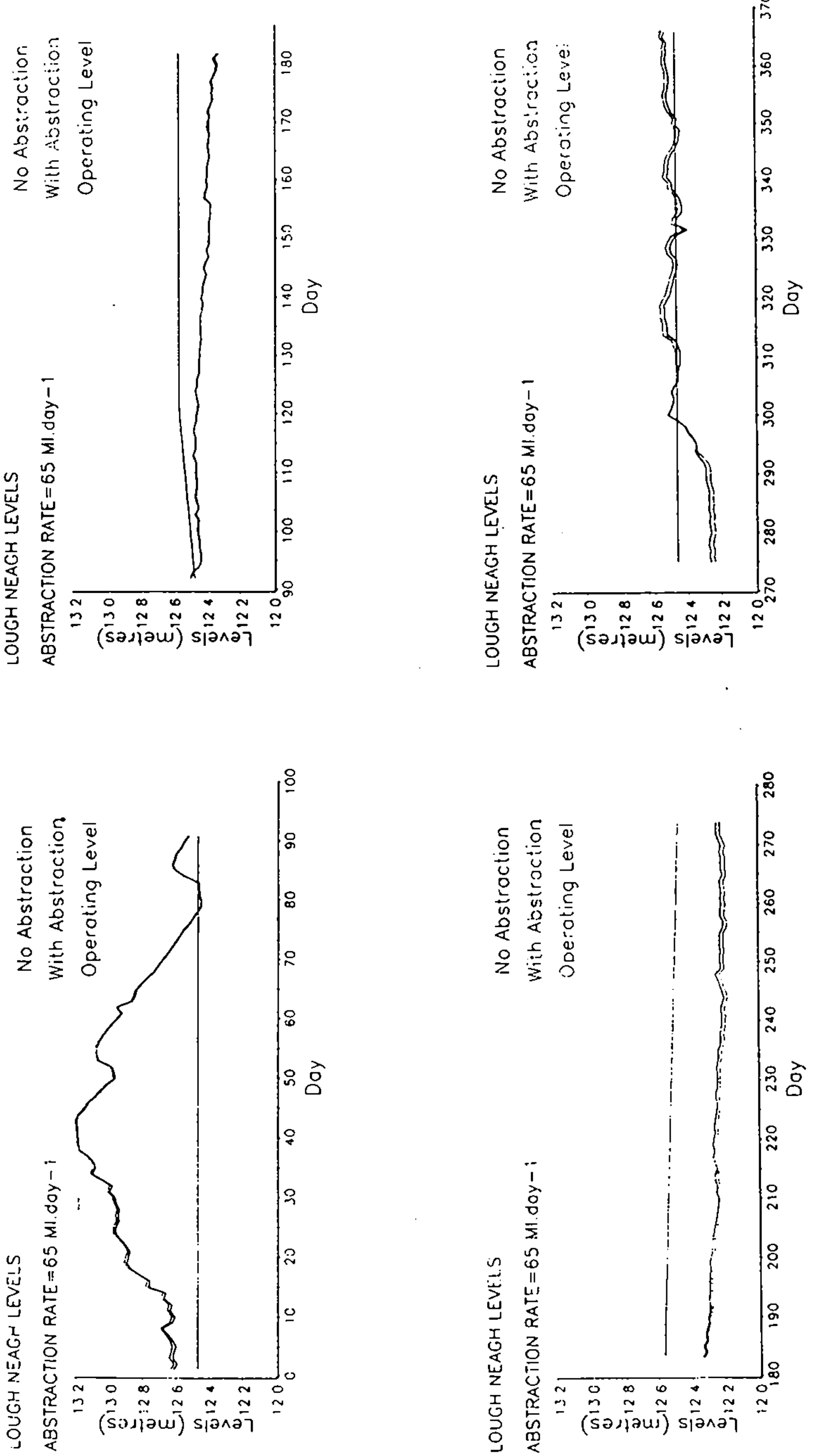
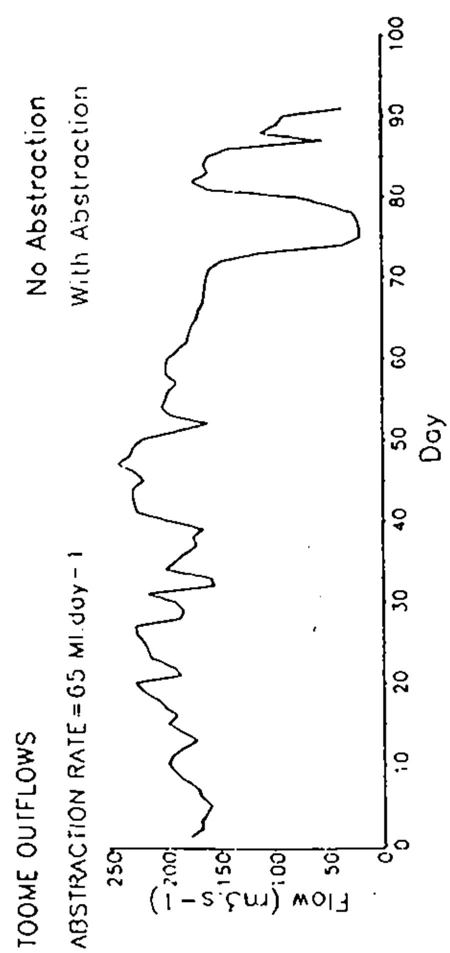
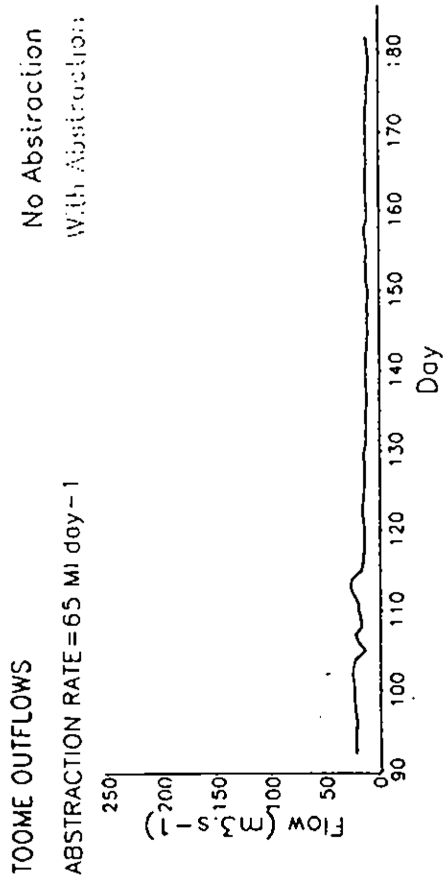
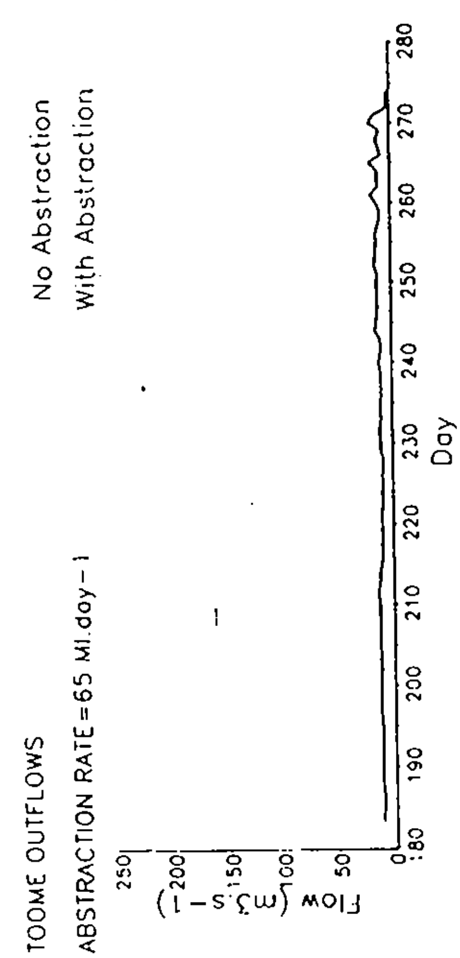


FIGURE 11b

TOOME OUTFLOWS HYDROGRAPH - ABSTRACTION RATE 65 Ml.day[-1]







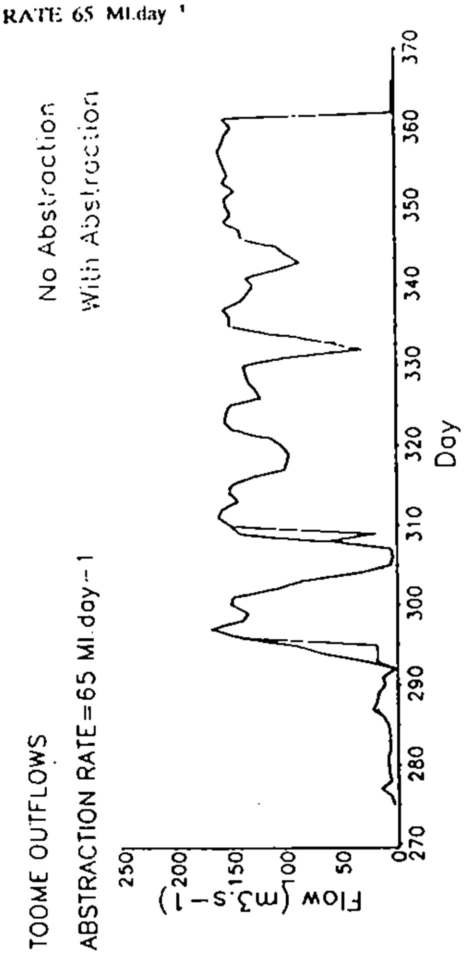


FIGURE 11c

LOUGH NEAGH LEVELS HYDROGRAPH - ABSTRACTION RATE 130 Ml.day^{-1}

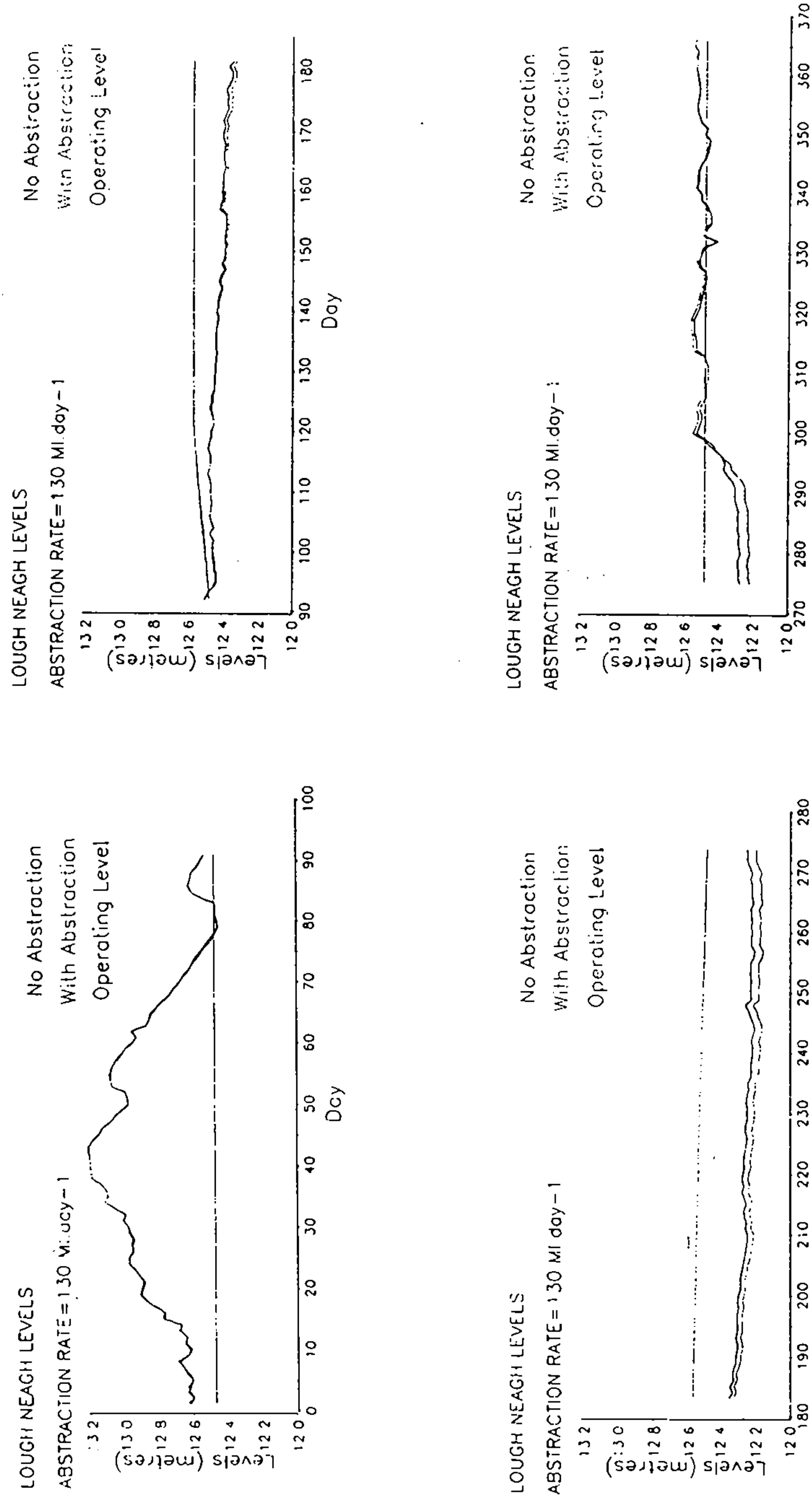


FIGURE 11d

TOOME OUTFLOWS HYDROGRAPH - ABSTRACTION RATE 130 Ml.day^{-1}

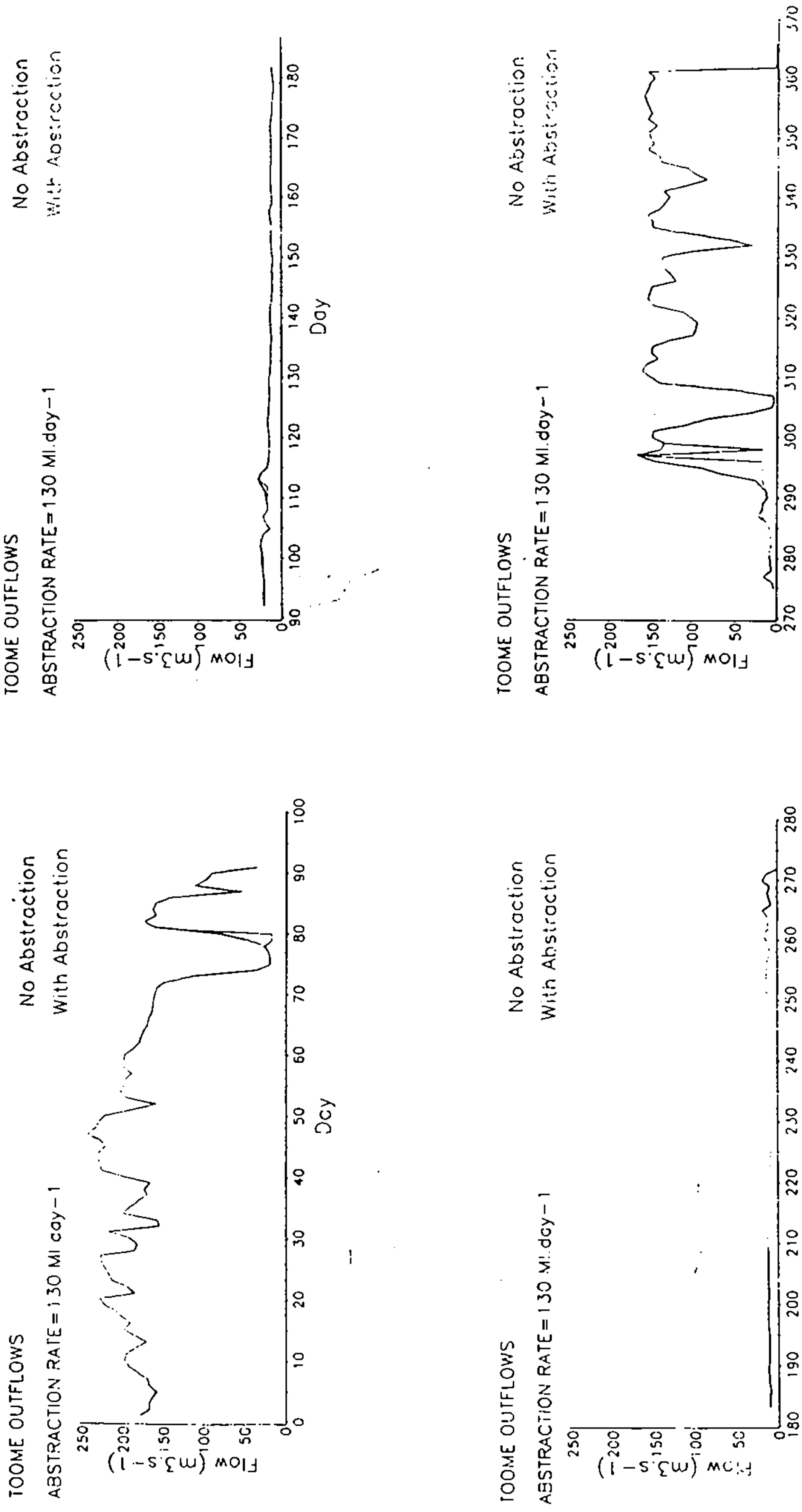


FIGURE 11c

LOUGH NEAGH LEVELS HYDROGRAPH - GLENWHIRRY SCHEME 2

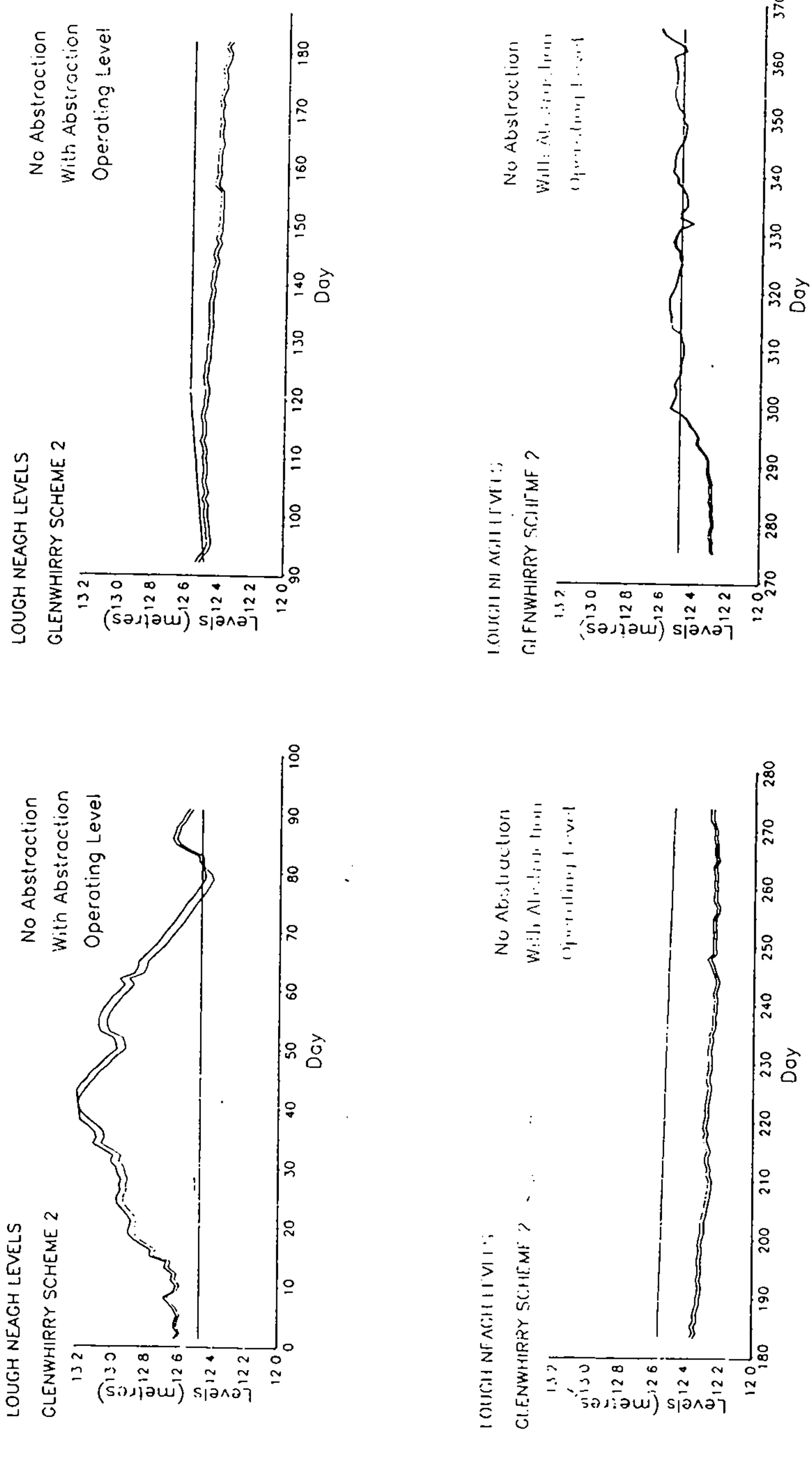
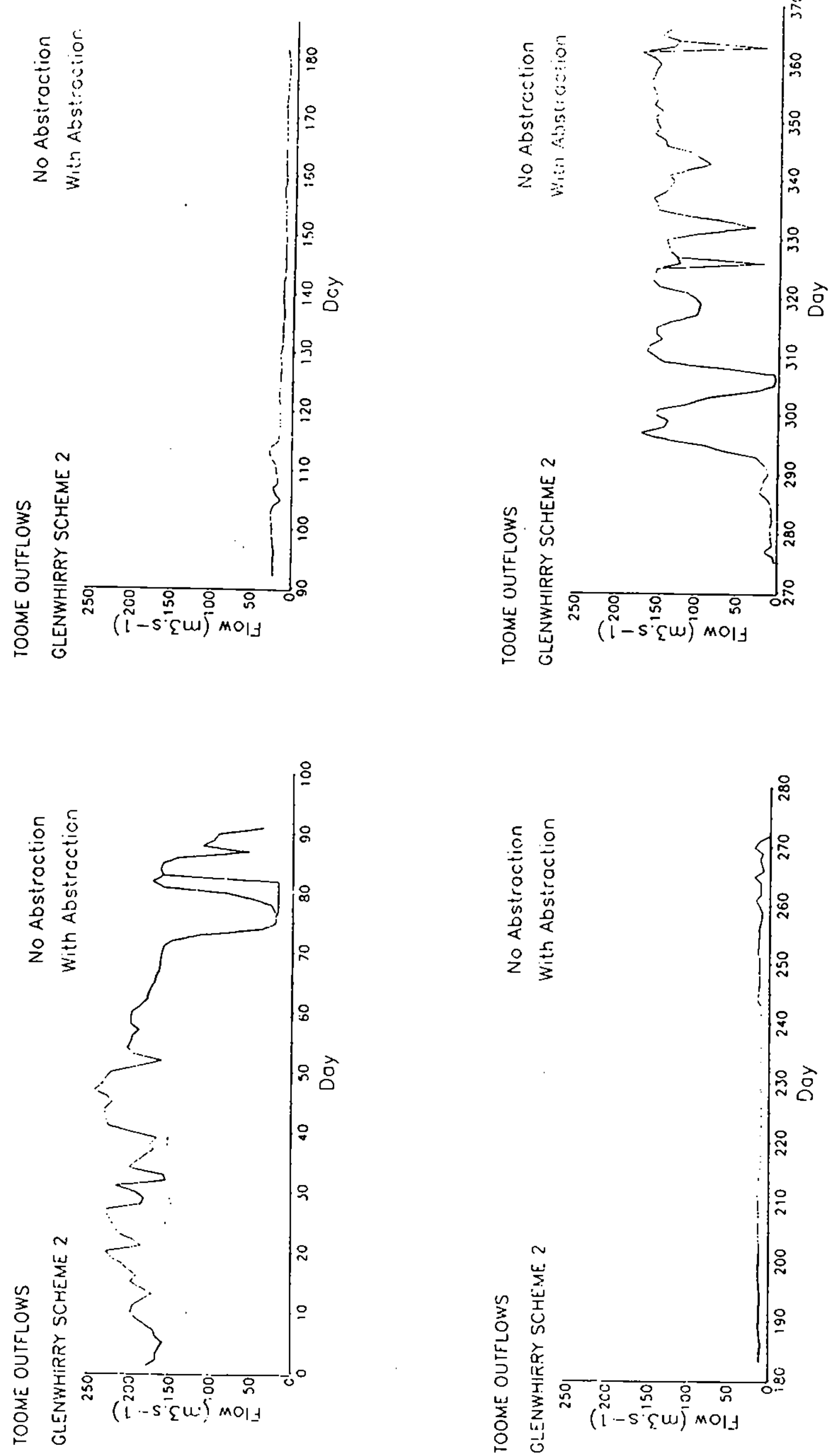


FIGURE 11C

TOOME OUTFLOWS HYDROGRAPH - GLENWHIRRY SCHEME 2



3. Conclusions

The hydrological effect of the implementation of two proposed upland reservoirs was estimated using riverflow and rainfall data from the period 1972-1989. Table 14 summarises this work, giving the downstream limits of significant changes (positive or negative) in flow regime due to the proposed schemes, with thresholds of 10%, 5% and 2% change from historic flows. The parameters that were used to describe the flow regimes are mean flow, Q95 (for low flows) and Q5 (for peak flows). In all cases the changes reflect increases of Q95 and reduction of Q5 and mean flow.

Table 14 Limits of change in flow regimes downstream of upland reservoirs

Scheme	Mean flow	Q95	Q5
Threshold 10% change			
Glenwhirry 1	Andraid (site 5)	Andraid (site 5)	Andraid (site 5)
Glenwhirry 2	Andraid (site 5)	Andraid (site 5)	Andraid (site 5)
LIR/Kinnahalla	Lough Neagh (site 8)	Bannfield Bridge (site 3)	Lough Neagh (site 8)
Threshold 5% change			
Glenwhirry 1	Shane's Viaduct (site 6)	Andraid (site 5)	Andraid (site 5)
Glenwhirry 2	All sites greater than 5%	Andraid (site 5)	Shane's (site 6) Viaduct
LIR/Kinnahalla	All sites greater than 5%	Kates Bridge STW	All sites greater than 5%
Threshold 2% change			
Glenwhirry 1	All sites greater than 2%	Andraid (site 5)	Shane's Viaduct (site 6)
Glenwhirry 2	All sites greater than 2%	Andraid (site 5)	All sites greater than 2%
LIR/Kinnahalla	All sites greater than 2%	Dyne's Bridge (site 7)	All sites greater than 2%

In the United Kingdom, two droughts with significant return periods have occurred in the modelled period: 1975-1976 and 1984. However, in Northern Ireland the 1975-1976 drought was much less severe than in southern England, and also much less severe than the 1984 drought (Marsh and Lees, 1984). For the latter, return periods of 20 to 50 years have been estimated for runoff minima of 10 to 180 days duration in Western Scotland, where the April to August rainfall was a similar or slightly lower percentage of normal compared with in Northern Ireland. It can therefore be said with confidence that the modelled results cover a drought event with a return period of at least 20 years, and probably 50 years. A similar conclusion was reached in the Study of water demand and supply (Gibb & Partners, 1984, Vol. 2, p.439), where it is concluded that "the recent period has included some notable drought events of both long and short duration with return periods equal to or in excess of 100 years" (Note: this is for rainfall, not runoff).

With respect to the impact of the proposed abstraction schemes on Lough Neagh levels, the simulations for the period 1981-1989 indicate a maximum decrease in water level to 49ft 1" with an abstraction rate of 65 $Ml.day^{-1}$, and to 48ft 8" with an abstraction rate of 350 $Ml.day^{-1}$ compared with a gauged historic minimum of 49ft 2" (Table 10). Estimates for drawdowns for five return periods and with given abstraction rates were also published in the Lough Neagh Working Group report (Vol. 1, p. 59, 1971). The estimated minimum level with an abstraction rate of 90 $Ml.day^{-1}$and a return period of 20 years is 48ft 8½", and with a return period of 50 years it is 48ft 6" (assuming drawdown starts at 50ft 5" as on p.60 of the same report). These drawdowns are greater than the estimates in this report because of the following reasons:

1. in this present study the scheme has been simulated to minimize the impact of additional abstractions on Lough Neagh levels;

2. the Lough Neagh Working Group had less flow data available;

3. differences in the return period between the two studies.

The impact on Lower Bann flows would depend on the operating rules for maintaining Lough Neagh levels and Toome outflows. However, the simulation for the period 1981-1989 with the simple operating rules that were used indicates reduction in the mean outflow at Toome drom 79.94 m^3s^{-1} (historic outflow) to 79.18 m^3s^{-1} and 78.42 m^3s^{-1} for additional abstraction rates of 65 and 130 Ml/day respectively. Whilst maintaining historic outflows for flows in the 1-20 and 80-99 percentile ranges the model predicts a reduction in the Q50 flow from 45.2 m^3s^{-1} (historic outflow) to 42.6 m^3s^{-1} and 39.3 m^3s^{-1} for additional abstraction rates of 65 and 130 Ml/day respectively (Table 12a).

4. References

Department of Agriculture, Drainage Division, Northern Ireland 1970s. Control of the water level of Lough Neagh and flow in the Lower Bann river.

Department of the Environment, Water Service, Northern Ireland 1986. Northern Ireland Water Statistics.

Ferguson & McIlveen et al., 1977. Augmentation of Water Source Capacity in the Eastern Area. Report, Appendices, Drawings.

Gibb, Sir Alexander & Partners 1984. Study of water Demand and Supply in Northern Ireland. Volumes 1 & 2.

Institute of Hydrology 1980. Low Flow Studies, Institute of Hydrology, Wallingford.

Lough Neagh Working Group, 1971. Advisory Report, volume 1 + 2.

Marsh, T. J. & Lees, M.L. 1985. The 1984 Drought. Institute of Hydrology, Wallingford.

Ministry of Agriculture, Fisheries & Food 1967. Potential Transpiration (Technical Bulletin no. 16).

Appendix 1

Modelling the proposed Glenwhirry water abstraction schemes

Harry Bart

Appendix 1

MODELLING THE PROPOSED GLENWHIRRY WATER ABSTRACTION SCHEMES

1. INTRODUCTION

The proposed scheme would be implemented in two stages:

(i) Building a reservoir immediately upstream of Battery Bridge (Figure 1) and abstracting 65 $Ml.day^{-1}$.

(ii) Supplementing flows from the direct catchment into the reservoir by four indirect catchments (Figure 1), two in the lower Kells Water catchment (Whappstown and Greenhill), and the other two outside the catchment (Owencloghy and Tildarg). Abstraction rates would then be increased to 130 $Ml.day^{-1}$.

The purpose of the study was to determine the effects of the two schemes on flow regimes downstream of Battery Bridge and on water levels within Lough Neagh. Available hydrologic data included daily streamflows for Kells Water at Curry's Bridge (gauging station 203021) and a number of daily and monthly records of rainfall within the Kells Water catchment.

In order to assess the effects of the schemes, three records of daily flows at both Battery Bridge and Curry's Bridge have been produced for the period 1972 to 1989 (inc). These represent:

(i) undisturbed conditions;

(ii) Stage 1, reservoir only;

(iii) Stage 2, reservoir and indirect catchments.

For this purpose, the Kells Water catchment at Curry's Bridge has been divided into three parts:

(i) the area draining into Killylane Reservoir;

(ii) the area draining directly into the proposed Glenwhirry reservoir, but omitting the area in (i);

(iii) the area downstream of the proposed reservoir.

The areas involved have been digitised and are as follows:

(i)	Killylane reservoir catchment	11.77 km^2
(ii)	Glenwhirry direct catchment - Killylane reservoir catchment	49.98 km^2
(iii)	Kells Water catchment below reservoir	65.25 km^2
	Total catchment area above Curry's Bridge	127.00 km^2

The Killylane reservoir catchment area is composed of the area of the reservoir itself (0.3 km^2), the direct catchment area (2.43 km^2), and a catchwater or indirect catchment area (9.04 km^2).

For Scheme 2, areas (ii) and (iii) had to be adjusted slightly to allow for the four catchwater areas providing additional flow to the reservoir. These adjustments are described later.

The output of the upstream catchments was used as input to the downstream catchment. Each of the three areas outlined above have been modelled separately. As a first step in the analysis, mean areal monthly rainfall has been calculated for the areas of the Kells Water catchment below and above Battery Bridge in order to provide conversion factors for the river flow. The rain gauges used were as follows:

(i) Above Battery Bridge (see Fig. 1)

	Gauge No	Grid ref	Alt (m)	SAAR(mm)	Period	Type*
1	953554	3313 3983	347	1397	1960 →	M
2	953561	3305 4015	290	1400	1966 → 1967	M
3	953563	3318 4013	351	1404	1961 →	M
4	953574	3309 4006	317	1435	1962 →	M
5	953598	3279 3999	213	1400	1980 →	D
6	953606	3288 4018	306	1418	1962 →	M
7	953620	3276 4005	271	1432	1965 → 1980	D
8	953635	3286 3986	247	1355	1976 →	D
9	953649	3253 4019	299	1343	1965 →	M

* M = monthly D = Daily, SAAR = Standard Annual Average Rainfall 1941-1970

(ii) Below Battery Bridge (see Fig. 1)

	Gauge No	Grid ref	Alt(m)	SAAR(mm)	Period	Type*
1	953936	3188 3932	209	1165	1961 → 1984	M
2	953976	3144 3968	47	1037	1964 → 1983	D

* M = monthly D = Daily

All available data from these individual gauges have been used to calculate mean rainfall to the Kells Water catchment, and to areas above and below Battery Bridge. Annual values for 1972 → 1983 (inc) are given below. No data for the lower catchment are available after 1983.

	Catchment mean (mm)	Above reservoir (mm)	Below reservoir (mm)
1972	1071	115[illegible] (1.07)	985 (0.92)
1973	1011	11[illegible] (1.10)	904 (0.89)
1974	1225	139[illegible] (1.13)	1055 (0.86)
1975	901	96[illegible] (1.07)	833 (0.92)
1976	1143	12[illegible] (1.13)	990 (0.87)
1977	1200	13[illegible] (1.13)	1042 (0.87)
1978	1234	13[illegible] (1.07)	1141 (0.92)
1979	1242	1329 (1.07)	1148 (0.92)
1980	1304	1395 (1.07)	1201 (0.92)
1981	1386	1523 (1.10)	1244 (0.90)
1982	1262	139[illegible] (1.11)	1124 (0.89)
1983	978	10[illegible] (1.11)	867 (0.89)
	1163	1275 (1.10)	1045 (0.90)

The figures in brackets refer to ratios of rainfall for the upper and lower areas compared with the catchment average. These percentages are remarkably consistent and, on average, show a 10% greater rainfall in the upper area, compared with the whole catchment, with a 10% reduced rainfall in the lower catchment. These percentages have been used in modelling streamflow from the two parts of the catchment.

Catchment mean rainfall has been compared, on an annual basis, with streamflow losses, expressed in mm over the catchment, as measured by the gauging station at Curry's Bridge.

	RAINFALL P (mm)	STREAMFLOW, Q (mm)	P - Q
1972	1071	683.3 (64%)	387.7
1973	1011	623.6 (62%)	387.4
1974	1225	838.4 (68%)	386.6
1975	901	515.9 (57%)	385.1
1976	1143	713.6 (62%)	429.4
1977	1200	770.8 (64%)	429.2
1978	1234	837.5 (68%)	396.5
1979	1242	873.0 (70%)	369.0
1980	1304	920.9 (71%)	383.1
1981	1386	1132.0 (82%)	254.0
1982	1262	876.4 (69%)	385.6
1983	978	634.5 (65%)	343.5
1984	1168*	818.2 (70%)	349.8
1985	1221*	869.8 (71%)	351.5
1986	1376*	987.3 (72%)	388.8
1987	1159*	780.4 (67%)	378.8
1988	1523*	1023.0 (67%)	499.8
1989	1136*	702.5 (62%)	433.3

* Given by 0.90 x Rainfall on upper catchment

The figures in brackets are the percentage of rainfall inputs appearing as streamflow. Again, the results are remarkably consistent suggesting the suitability of the available data for modelling purposes.

The modelling was done in three stages:

(i) Stage 0 - or undisturbed conditions;
(ii) Stage 1 - direct catchment inflow to reservoir, abstraction 65 $Ml.day^{-1}$.
(iii) Stage 2 - additional from indirect catchments inflows to reservoir, abstraction 130 $Ml.day^{-1}$.

2.1 STAGE 0 - UNDISTURBED CONDITIONS

The measured flows in Kells Water at Curry's Bridge have been used as a basis for modelling. These flows are slightly unnatural because of the presence of Killylane reservoir. In (a) below, this reservoir has been modelled so that "natural" flows in Kells Water could be used in the simulations for stage 1 and 2.

(a) Killylane reservoir catchment

Estimates have been made of the areal extent of the Killylane reservoir and the catchments draining into it. The areas are as follows:

Killylane Reservoir	0.30 km^2
Direct catchment	2.43 km^2 (to reservoir perimeter)
Indirect catchment	9.04 km^2

The following inputs to and outputs from the reservoir are considered:

(i) Direct rainfall inputs to the water surface.
(ii) Streamflow inputs from the direct catchment.
(iii) Abstractions from the indirect catchment.
(iv) Open water evaporation losses from the reservoir.
(v) Abstractions from the reservoir for water supply.

The above are considered on a daily basis, and the daily reservoir 'balance' used to estimate streamflow inputs to Killylane Burn below the reservoir, either as compensation flow or as overflow from the reservoir.

(i) Direct rainfall inputs to the water surface

These were calculated using rainfall data from the three daily-read gauges (gauges 5, 7 and 8 in Fig. 1) within the upper Kells Water catchment. Daily rainfall was calculated as the mean of the available daily totals from the individual gauges. For part of the study period, 1972 → 1976, no data were available for any of the three gauges. For this period, reliance had to be made on the records from eight daily-read rain gauges surrounding Lough Neagh. Mean annual totals from the Lough Neagh and the Glenwhirry daily gauges are shown below.

	LOUGH NEAGH	GLENWHIRRY
1977	789.2	1294.9 (1.64)
1979	919.2	1282.5 (1.40)
1980	959.6	1380.1 (1.44)
1981	937.2	1572.0 (1.68)
1982	927.4	1439.8 (1.55)
1983	743.6	1115.8 (1.50)
1984	824.5	1212.9 (1.47)
1985	873.9	1298.4 (1.49)
1986	865.0	1483.1 (1.71)
1987	795.9	1232.1 (1.55)
1988	946.7	1536.7 (1.62)

The figures in brackets refer to the ratio of rainfall at Glenwhirry compared to that at Lough Neagh. The average value of 1.55 was used as the multiplication factor for infilling Glenwhirry daily rainfall data using the Lough Neagh daily rainfall averages. Daily rainfall totals (mm) were multiplied by the area of the reservoir (0.3 km^2) to give an input in million litres per day.

(ii) Streamflow inputs from the direct catchment

These are obtained using daily mean flows, in $m^3.s^{-1}$, from the flow record for Curry's Bridge (station no. 203021). These flows were 'naturalised' by adding the daily abstraction from Killylane reservoir although allowances were not made for changes in reservoir storage. Finally, the flows are multiplied by two factors:

(I) The ratio of the catchment areas, in this case 2.43/127.0.

(II) The ratio of the rainfall inputs to the upper Kells catchment compared to that of the whole catchment, as estimated earlier, 1.10.

Finally, these streamflow inputs to the reservoir were converted to $Ml.day^{-1}$.

(iii) Abstractions from the Indirect Catchment

The first step for estimating these is similar to the estimates of streamflow inputs from the direct catchment i.e., using the naturalised Curry's Bridge flow record and multiplying by the area ratio, 9.04/127.0, and the areal rainfall factor, 1.10.

A correction was made to account for the limited capacity of the intakes which exclude the high flows. This correction is based on the fact that only 80% of the flow is transferred. Flow Duration curves for typical Northern Ireland upland catchments show that 80% of the runoff takes place at flows not exceeding 300% of the mean flow (Ferguson & McIlveen, 1977). The mean flow, in $m^3.s^{-1}$, has been calculated, and all individual daily flows below this value, while allowing for the compensation flow, routed to the reservoir. For days when the flow was greater than three times the mean flow, the excess was added to the above compensation flows. The abstracted flows, ABS in $Ml.day^{-1}$, are added to the inputs to the reservoir.

Therefore, an upper limit of 36.5 $Ml.day^{-1}$ was abstracted from the indirect catchments, the rest by-passing the inlets, and added to the compensation flow. Compensation flow from the two indirect catchments was calculated as suggested by Ferguson and McIlveen (1977) by multiplication of the catchment area by 0.31, giving 0.3 $Ml.day^{-1}.km^{-2}$.

This may be expressed as follows:

If DFLOW < TABS then ABS = DFLOW - COMP and
STREAM = COMP
If DFLOW > TABS then ABS = TABS - COMP and
STREAM = (DFLOW - TABS) + COMP

where DFLOW = daily flow ($m^3.s^{-1}$)
TABS = total capacity of intakes, 36.5 $Ml.day^{-1}$ (300% of mean flow)
ABS = flow abstracted to reservoir
STREAM = flow retained in stream (to be added later to the modelled upper catchment not affected by Killylane Reservoir)
COMP = compensation flow = 0.31* catchment area

Finally, the abstracted daily flows were converted to $Ml.day^{-1}$.

(iv) Open water evaporation from the reservoir

The long term Penman potential evaporation, for the area of 403 mm per year, was derived by overlaying the area on a 1x1 km grid of Penman potential evapotranspiration and used as the basis of this estimate. This annual total was distributed on a monthly basis according to figures for Northern Ireland in the Ministry of Agriculture, Fisheries and Food, Technical Bulletin No. 16, Potential Transpiration. Actual daily values (mm) used for each month were:

January	0.04	July	2.15
February	0.32	August	1.76
March	0.82	September	1.14
April	1.55	October	0.53
May	2.30	November	0.10
June	2.49	December	0.02

These daily values were multiplied by the reservoir area, 0.3 km^2, to give evaporation losses in $Ml.day^{-1}$.

Reservoir water balance

It was assumed that at the start of the modelling period, 1st January 1972, the reservoir is full i.e. it is at its maximum capacity of 1327 Ml. Each day the water in the reservoir is augmented by the above inputs and outputs, i.e.

RES = RES (start) + RAIN+DIR. STREAM+INDIR. STREAM-EVAP
(all values in Ml).

where RES = reservoir volume at the end of the day
RES (start) = reservoir volume at the start of the day
RAIN = direct rainfall inputs to water surface, calculated in (i)
DIR.STREAM = streamflow inputs from the direct catchments, as calculated in (ii)
INDIR.STREAM = inflow from indirect catchments, as calculated in (iii)
EVAP = open water evaporation from reservoir

Losses from the reservoir were calculated as the sum of compensation flow + abstractions for water supply:

ALOSS = COMP + ABS

where COMP = compensation flow 0.31 x catchment area = 0.31 x 2.73 = 0.86 $Ml.day^{-1}$.
ABS = daily abstraction values in $Ml.day^{-1}$. Three sets of values for these were used; the effects of these on the volume of water in the reservoir will be described later.
ALOSS = losses

A test is made to determine whether the reservoir will be full as a result of the inputs and losses.

(i) If the reservoir is full at the end of the day i.e.
RES > 1330 + ALOSS, then:

COMP = (RES - 1330 - ABS)

i.e. it is assumed that the reservoir 'overtops' and the compensation flow will be equal to the overtopped volume. The reservoir will be full at the end of the day.

(ii) If the reservoir is not full at the end of the day i.e.
RES - ALOSS < 1330 then

COMP = 0.86 $Ml.day^{-1}$
RES = RES - COMP - ABS

i.e. the level in the reservoir will drop to an extent equal to the sum of the abstracted water and compensation flow.

If there is insufficient water in the reservoir to satisfy the amount of abstraction and compensation flow, it is assumed that no water is abstracted from the reservoir, and its volume drops only by the amount of compensation to the stream.

The compensation flows from Killylane reservoir have been added to those from the indirect catchments to give total flows from the Killylane scheme. These have been subtracted from the gauged flows at Curry's Bridge to give flows from the 'natural' part of the catchment, i.e. below Killylane reservoir.

(b) The 'natural' part of the catchment above Battery Bridge

These have been obtained by multiplying the flows from the total 'natural' catchment, obtained as outlined above, by the area ratio, 49.98/115.23, and the areal rainfall factor, 1.10.

(c) The 'natural' part of the catchment below Battery Bridge

The flows from this part of the catchment are obtained as above, multiplying by the area ratio, in this case 65.25/115.23, and the rainfall factor, 0.90.

Finally, the flows at Battery Bridge were given as (a) + (b), whilst those at Curry's Bridge, used for comparison with the observed, given by (a) + (b) + (c).

2.2 STAGE 1 - GLENWHIRRY RESERVOIR - DIRECT CATCHMENT ONLY

Three areas have been considered:

(i) The reservoir itself, 3.87 km^2,
(ii) The catchment upstream of the reservoir unaffected by the Killylane reservoir scheme, 46.11 km^2,
(iii) The Killylane reservoir scheme, 11.77 km^2.

The proposed reservoir is modelled in much the same way as the existing Killylane reservoir by considering inputs and outputs on a daily basis, the 'balance' being fed into Kells Water below Battery Bridge either as compensation flow or as overflow from the reservoir.
The following inputs and outputs were estimated:

(i) Direct rainfall inputs to the water surface

These were calculated using the daily rainfall record for the upper Kells Water catchment, described previously. Each mean daily rainfall value, in mm, was multiplied by the reservoir area, 3.87 km^2, to give an input volume in $Ml.day^{-1}$.

(ii) Stream flow inputs from the direct catchment

These were obtained using daily mean flows, in $m^3.s^{-1}$, from the previously modelled flow record for the 'natural' part of the catchment above Battery Bridge. Each daily flow value was multiplied by the ratio of areas, in this case 46.11/(46.11 + 3.87).

(iii) Inputs from Killylane reservoir scheme

These were modelled flows (compensation and overflow) from the reservoir and its indirect catchments.

(iv) Open water evaporation

These were estimated using the long-term Penman potential evaporation, distributed on a monthly basis as described previously.

<u>Reservoir Water Balance</u>

As for Killylane, it was assumed that at the start of the modelling period, 1st January 1972, the reservoir is full i.e., it is at its maximum capacity of ~~17390~~ Ml. (Ferguson and McIlveen, 1977). Each day the water in the reservoir is augmented by the above inputs and outputs, converted into Ml.day^{-1}, i.e., 40,000 Ml

RES = RES (start) + RAIN + DIR STREAM + KILLRES - EVAP

where KILLRES = output from Killylane reservoir, calculated in Stage 0

For other symbols, see section 2.1.

Total losses, ALOSS, from the reservoir were calculated as the sum of compensation flow + abstractions for water supply:

ALOSS = COMP + ABS

where COMP = 0.31 x catchment area = 0.31 x (3.87 + 46.11 + 11.77)
= 19.14 Ml.day^{-1}

ABS = 65.00 Ml.day^{-1}

The reservoir was modelled taking into account the following constraints:

(i) The amount of water in the reservoir is not allowed to fall below 1800 Ml (Ferguson and McIlveen, 1977), i.e., if:

RES - ABS - COMP < 1800

then no abstraction or compensation is taken out of the reservoir.

(ii) If the reservoir is full at the end of the day, i.e.

RES - ALOSS > 17390
COMP = (RES - 17390 - ABS)

i.e., it is assumed that the reservoir 'overtops' and the compensation flow will be equal to the overtopped volume. The reservoir will be full at the end of the day.

(iii) If the reservoir is not full at the end of the day i.e.

RES - ALOSS < 17390

COMP = 19.14 $Ml.day^{-1}$
RES = RES - COMP - ABS

i.e., the level in the reservoir will drop to an extent equal to the sum of the abstracted water and compensation flow.

The total flow from the reservoir, ie. compensation flow plus overtopped volume, are the modelled flows at Battery Bridge under Scheme 1. These have been added to the flows from the 'natural' part of the catchment below Battery Bridge, estimated previously, to give modelled flows at Curry's Bridge.

2.3 STAGE 2 - GLENWHIRRY RESERVOIR - DIRECT AND INDIRECT CATCHMENTS

The modelling of this stage of the scheme is similar to that of Stage 1, with the following modifications:

(i) Water has been diverted from four indirect catchments, two outside and two inside the Kells Water catchment, into the proposed Glenwhirry reservoir. Details of these indirect catchments are as follows:

Outside Kells Water			
Owencloughy	5.08 km^2	Compensation	= 1.12 $Ml.day^{-1}$
Tildarg	4.92 km^2	"	= 1.08 $Ml.day^{-1}$
Inside Kells Water			
Whappstown	3.19 km^2	Compensation	= 0.92 $Ml.day^{-1}$
Greenhill	6.02 km^2	"	= 1.75 $Ml.day^{-1}$

Inputs to the reservoir from each indirect catchment is obtained using the modelled flows for the 'natural' part of the catchment above Battery Bridge multiplied by an area factor and by 86.4 to convert into $Ml.day^{-1}$. A correction was made to account for the limited capacity of other intakes, which exclude high flows, in the same way as above (see section 2.1.).

(ii) The reservoir storage capacity is increased to accommodate the extra inputs to 21620 Ml and the abstraction rate increased to 130 $Ml.day^{-1}$.

(iii) When calculating the flows at Curry's Bridge, flow from the reservoir, ie. compensation and overtopping, are added to the compensation and excess flows from the Whappstown and Greenhill indirect catchments. These summed flows are then added to the modelled flows from the 'natural' flows from Greenhill and Whappstown by multiplying by (65.25 - 3.19 - 6.02)/65.25, i.e. the unaffected area/total area.

Appendix 2

Modelling the proposed Lough Island Reavy/Kinnahalla water abstraction scheme

Appendix 2

MODELLING THE PROPOSED LOUGH ISLAND REAVY/KINNAHALLA WATER ABSTRACTION SCHEME

1. INTRODUCTION

The proposed scheme involves augmenting the yield of the present Lough Island Reavy reservoir scheme, with direct catchment and two indirect catchments, in two ways:-

(i) By the addition of one further indirect catchment. As from the second proposed indirect catchment (Fofanny) only reservoir spills were going to be conducted into Lough Island Reavy reservoir, DoE NI directed us to discard this element of the analysis.

(ii) By constructing a new reservoir, Kinnahalla, downstream of the present Spelga Dam Reservoir (see Fig.1), its yield being augmented by flows abstracted from three indirect catchments.

Water would be pumped from the Kinnahalla Reservoir into the Lough Island Reavy water treatment plant and the abstraction rate of both reservoirs together would be increased from the current 18 $Ml.day^{-1}$ to 83 $Ml.day^{-1}$.

Estimates were required of the effects of the scheme on flows downstream of the reservoirs, in the Upper Bann and on water levels in Lough Neagh.

In order to assess the effects of the schemes, records of daily flows have been produced for the period 1972 to 1989, representing modelled flows at two stages:

(i) present conditions, including existing Lough Island Reavy reservoir;

(ii) proposed Kinnahalla reservoir and extended Lough Ilsand Reavy scheme.

Flow records were required for both stages at the following sites:

(i) Lough Island Reavy reservoir outlet
(ii) Muddoch River intake point
(iii) Kinnahalla River intake point
(iv) Kinnahalla reservoir outlet
(v) Rocky River intake point
(vi) Altataggart catchment intake point
(vii) Upper Bann at Bannfield Bridge

In order to model case (i), Lough Island Reavy reservoir has been modelled similarly to Killylane reservoir, while taking into account that the flows at

Bannfield Bridge were not allowed to fall below the required minimum flow. In this case the Bannfield Bridge catchment was divided into three parts, namely (i) and (ii) above plus the remaining area downstream. The "natural" flows from the areas (iii) to (vi) were estimated separately.

In order to model case (ii), the Bannfield Bridge catchment was divided into parts (i) to (vi) above plus the remaining area downstream.

In the following, the same principles will be applied that have been used to model the Glenwhirry reservoir scheme.

2.1 PRESENT LOUGH ISLAND REAVY SCHEME

Estimates have been made of the areal extent of the Lough Island Reavy Reservoir and the catchments draining into it. The areas are as follows:-

Lough Island Reavy reservoir		1.04 km^2
Direct catchments		4.51 km^2
Indirect catchments	- Muddock river	5.26 km^2
	- Moneyscalp river	3.04 km^2

Of the indirect catchments, the Muddoch is within the Upper Bann catchment, whilst the Moneyscalp is outside.

The following inputs to and outputs from the reservoir have been considered:

- (i) Direct rainfall inputs to the water surface.
- (ii) Streamflow inputs from the direct catchment.
- (iii) Abstractions from the indirect catchments.
- (iv) Open water evaporation losses from the reservoir.
- (v) Abstractions from the reservoir for water supply.
- (vi) Compensation to the Muddoch river below the reservoir.

(i) Direct rainfall inputs to the water surface.

Rainfall inputs to the high altitude areas of the Upper Bann were calculated as the mean of data from six daily-read gauges. The position of these gauges are shown in Fig.2 and details given below.

	Gauge No	Grid ref.	Alt (m)	SAAR(mm)	Period	Type
1	940628	3263 3273	317	1659	1955 →	D
2	940648	3275 3304	263	1585	1976 →	D
3	975115	3285 3292	283	1585	1907 →1966	D
4	975130	3301 3304	215	1590	1985 →	D
5	975666	3293 3242	311	1500	1977 →1982	D
6	975691	3305 3216	129	1402	1958 →	D

Mean daily values from these gauges were multiplied by the area of the reservoir, 1.04 km^2 to give inputs in $Ml.day^{-1}$.

(ii) Streamflow inputs from the direct catchment.

These were calculated using daily mean flows, in $m^3.s^{-1}$, from the flow record for the Rocky River (203038). This flow record is restricted to 1984 onwards, and it was necessary to correlate the natural logarithms of daily flows from this station with those from the Battery Bridge station (203033) and to use the coefficients of the subsequent linear regression analysis for infilling the flow record pre-1984.

The estimated and measured flows were multiplied by the area ratio (4.51/6.8) and converted to $Ml.day^{-1}$.

(iii) Abstractions from the indirect catchments.

Natural daily flow records were calculated using the same input data as used for the direct catchment, using the appropriate area ratio. These were transferred to the reservoir after allowing for compensation flows of 0.24 $Ml.day^{-1}$ from the two catchments. An allowance was also made to account for the limited capacity of the connecting aqueducts which exclude the higher flows. The average daily flow, in $m^3.s^{-1}$, has been calculated, and all individual daily flows below three times this value transferred to the reservoir. For days when the flow was greater than three times the average daily flow, the excess flow remained in the stream,in addition to the compensation flow.

In the case of the Muddock catchment, the sum of compensation flow plus any non-abstracted flows were retained within the Upper Bann catchment; for the Moneyscalp catchment, they were lost from the Upper Bann catchment.

(iv) Open water evaporation from the reservoir.

This was calculated using the long term Penman potential evaporation, 398 mm per year, distributed on a monthly basis according to the figures given in MAFF Bulletin no.16 (see also Appendix section 2.1).

Daily values were multiplied by the reservoir area, 1.04 km^2, to give evaporation losses in $Ml.day^{-1}$.

<u>Reservoir Water Balance</u>

It was assumed that at the start of the modelling period, 1st January 1972, the reservoir was full, i.e. at its maximum capacity of 9170 Ml. Each day the water in the reservoir is augmented by the above inputs and outputs i.e.

RES = RES (start) + RAIN + DIR. STREAM + INDIR. STREAM - EVAP

No compensation flows are allowed for in agreement with DoE NI, but the flows at Bannfield Bridge are not allowed to drop below 18 $Ml.day^{-1}$ or 0.208

cumecs. This compensation flow of maximum 18 $Ml.day^{-1}$ was taken from the reservoir.

ie. RES = RES - ABS when FLOW > 18 $Ml.day^{-1}$
RES = RES - ABS - (18.0 - FLOW) when FLOW < 18 $Ml.day^{-1}$

where RES = reservoir volume
ABS = abstraction rate
FLOW = flow at Bannfield Bridge

A test was made to determine whether the reservoir is full as a result of these inputs and outputs. If so, it was assumed that, according to information given by DoE NI, no abstractions from the indirect catchments have taken place. Under these circumstances, flow from the indirect catchments is equal to the "natural" modelled flow.

For the Muddoch catchment, this flow remains in the Upper Bann catchment; for the Moneyscalp catchment, it is lost to the system.

If the reservoir is still full at the end of the day, it was assumed that it overtops by a quantity OVERTOP where:-

OVERTOP = RES - 7190 - OUTPUTS

where OUTPUTS = ABS + (if necessary, 18.0 - FLOW)

The reservoir will be full at the end of the day.

If the reservoir is not full at the end of the day, the volume of water will drop by an extent equal to the total outputs.

ie. RES = RES - OUTPUTS

Any water overtopping from the reservoir was added to compensation plus excess water from the Muddoch to give total 'returned' water to the Bannfield Bridge catchment. The existing Spelga reservoir area is considered separately. A simple water balance is applied. This consists of rainfall inputs as described above, and outputs in the form of abstracted water, 16.77 $Ml.day^{-1}$ compensation flow below the reservoir, and evaporation as described above. The water balance is applied daily. If, at the end of the day, the reservoir is full, then it is assumed that it overtops and the compensation flow will be augumented by this overtopped volume. If the reservoir is not full at the end of the day, its volume will drop by an amount equal to the abstracted yield and compensation flow. The totals from the Lough Island Reavy scheme plus Spelga reservoir were subtracted from the measured flows at Bannfield Bridge, modified as described above to ensure that flows never dropped below 0.208 cumecs, to give total flows from the area of the Bannfield Bridge catchment not influenced by the present Lough Island Reavy reservoir scheme.

2.2 PROPOSED KINNAHALLA RESERVOIR AND EXTENDED LOUGH ISLAND REAVY RESERVOIR SCHEME

The existing and proposed scheme are as follows:-

Lough Island Reavy

Reservoir area	Existing	1.04 km^2
Direct catchment	Existing	4.51 km^2
Indirect catchments:		
Kinnahalla River	Proposed	3.24 km^2
Moneyscalp River	Existing	3.04 km^2
Muddock River	Existing	5.26 km^2

Kinnahalla

Reservoir area	Proposed	0.43 km^2
Direct catchment below		
Spelga reservoir	Proposed	3.11 km^2
Spelga reservoir area	Existing	0.54 km^2
Spelga direct catchment	Existing	6.83 km^2
Indirect catchments:		
Rocky River	Proposed	7.20 km^2
Altataggart	Proposed	1.36 km^2
Yellow River	Proposed	5.46 km^2

In order to estimate the effects of the new proposal it was necessary to estimate flows from those areas of the Bannfield Bridge catchment, unaffected by the present Lough Island Reavy scheme, but which would be affected by the new proposals. These areas were the Kinnahalla River catchment, the Kinnahalla reservoir area and its direct catchment below Spelga reservoir, the Spelga reservoir area and its direct catchment, and the Rocky River and Altataggart catchments.

Flows from the Bannfield Bridge catchment area unaffected by the existing and proposed scheme, are calculated as the measured flows at Bannfield Bridge, adjusted to maintain minimum flows, minus flows from the existing Lough Island Reavy Scheme (see Appendix Section 2.1) multiplied by an area factor (post-scheme unaffected area/pre-scheme unaffected area).

(a) Extended Lough Island Reavy Scheme

The flows of the proposed extension for the Lough Island Reavy Scheme have been modelled in the same way as the effects of the existing scheme with the following exceptions:-

(i) Flows from the indirect catchments were increased to take into account abstractions from the Kinnahalla River catchment. Allowance has been made to account for the limited capacity of the connecting aqueducts which exclude the higher flows. Compensation flows have been set at 0.25 $Ml.day^{-1}$ km^{-2}. For the Kinnahalla river catchment, all excess high flows and compensation are retained within the Lower Bann catchment.

(ii) Abstraction rates from the reservoir are increased to 45.7 $Ml.day^{-1}$, which is the proportion of the total yield of 83 $Ml.day^{-1}$ for Lough Island Reavy reservoir.

(b) The Kinnahalla scheme

The following inputs to and outputs from the reservoir have been estimated:

(i) Direct rainfall inputs to the water surface.
(ii) Streamflow inputs from the direct catchment.
(iii) Abstractions from the indirect catchment.
(iv) Open water evaporation losses from the reservoir.
(v) Abstractions from the reservoir for water supply.

The above are considered on a daily basis, and the daily reservoir 'balance' used to estimate streamflow inputs to Kinnahalla River below the reservoir, either as compensation flow or as overflow from the reservoir.

(i) Direct rainfall inputs to the water surface

These have been calculated using the rainfall data record for the Upper Bann catchment, described previously. Daily values, in mm, have been multiplied by the reservoir area, 0.43 km^2, to give inputs in $Ml.day^{-1}$.

(ii) Streamflow inputs from the direct catchment

This includes the effect of the Spelga reservoir. Following the procedure outlined above, it was assumed that if the reservoir is over-full at the end of the day, it overtops and the excess water is added to the compensation flow. If the reservoir is not full at the end of the day, its volume drops by an amount equal to the compensation plus abstraction.

Streamflow inputs from the rest of the direct catchment have been estimated using the flow record for the Rocky River, multiplied by an area factor (9.94/6.8) and converted to $Ml.day^{-1}$.

(iii) Abstractions from the indirect catchments.

These were calculated using the flow record for the Rocky River using the appropriate area ratios. The allowance for the limited capacity of the aqueducts was applied, and compensation flow allowed as follows:-

Rocky River	0.27 $Ml.day^{-1}$ km^{-2}
Altataggart	0.23 $Ml.day^{-1}$ km^{-2}
Yellow River	NIL

Compensation and excess flows for the Rocky River and Altataggart River catchments were retained within the Upper Bann catchment, those from the Yellow River were lost from the catchment.

(iv) Open water evaporation from the reservoir.

This was calculated using the monthly distributed Penman potential evaporation for the area, 398mm per year, multiplied by the reservoir area, 0.43 km^2, to give outputs in $Ml.day^{-1}$.

Reservoir Water Balance

The reservoir water balance was calculated on a daily basis using estimates of all inputs and outputs, assuming that the reservoir was full, at its maximum storage volume of 6800 Ml, at the start of the modelling period.

Compensation at 0.16 $Ml.day^{-1}$ km^{-2} was allowed for, and the rate of abstraction set at 37.3 $Ml.day^{-1}$, which is the proportion of the combined yield of 83 $Ml.day^{-1}$ for Kinnahalla reservoir, given the relative design yields for Lough Island Reavy and Kinnahalla reservoir.

TERRESTRIAL AND FRESHWATER SCIENCES DIRECTORATE

Natural Environment Research Council
Polaris House
North Star Avenue
Swindon SN2 1EU
Tel: 0793 411500 Fax: 411502
Telex: 444293 ENVRE G

INSTITUTE OF FRESHWATER ECOLOGY

Windermere Laboratory
Far Sawrey, Ambleside
Cumbria LA22 0LP
Tel: 09662 2468 Fax: 6914
Telex: 94070416 WIND G

River Laboratory
East Stoke, Wareham
Dorset BH20 6BB
Tel: 0929 462314 Fax: 462180
Telex: 94070672 WARE G

Edinburgh Laboratory
Bush Estate, Penicuik
Midlothian, EH26 0QB
Tel: 031 445 4343 Fax: 3943
Telex: 72579 BUSITE G

Eastern Rivers Laboratory
Monks Wood Experimental Station
Abbots Ripton, Huntingdon
Cambs PE17 2LS
Tel: 04873 381 Fax: 467
Telex: 32416 MONITE G

Teesdale Laboratory
c/o Northumbrian Water
Lartington Treatment Works
Lartington, Barnard Castle
Co Durham DL12 9DW
Tel: 0833 50600 Fax: 50827

INSTITUTE OF HYDROLOGY

Maclean Building
Crowmarsh Gifford
Wallingford
Oxon OX10 8BB
Tel: 0491 38800 Fax: 32256
Telex: 849365 HYDROL G

Plynlimon Office
Staylittle, Llanbrynmair
Powys SY19 7DB
Tel: 05516 652 Fax: 441

Balquhidder Office
Tulloch Lodge
Balquhidder, Lochearnhead
Perthshire FK19 8PQ
Tel: 08774 257

INSTITUTE OF TERRESTRIAL ECOLOGY (NORTH)

Edinburgh Research Station
Bush Estate, Penicuik
Midlothian EH26 0QB
Tel: 031 445 4343 Fax: 3943
Telex: 72579 BUSITE G

Banchory Research Station
Hill of Brathens, Glassel
Banchory, Kincardineshire, AB31 4BY
Tel: 03302 3434 Fax: 3303

Merlewood Research Station
Grange-over-Sands, Cumbria LA11 6JU
Tel: 05395 32264 Fax: 34705
Telex: 65102 MERITE G

INSTITUTE OF TERRESTRIAL ECOLOGY (SOUTH)

Monks Wood Experimental Station
Abbots Ripton, Huntingdon
Cambs PE17 2LS
Tel: 04873 381 Fax: 467
Telex: 32416 MONITE G

Bangor Research Unit
University College of North Wales
Deinol Road, Bangor LL57 2UW
Tel: 0248 370045 Fax: 355365
Telex: 61224 BANITE G

Furzebrook Research Station
Wareham, Dorset BH20 5AS
Tel: 0929 551518/9 Fax: 551087

INSTITUTE OF VIROLOGY AND ENVIRONMENTAL MICROBIOLOGY

Mansfield Road, Oxford OX1 3SR
Tel: 0865 512361 Fax: 59962

UNIT OF COMPARATIVE PLANT ECOLOGY

Department of Animal and Plant Sciences
University of Sheffield, Sheffield S10 2TN
Tel: 0742 768555 Fax: 760159
Telex: 547216 UGSHEF G

CENTRE FOR POPULATION BIOLOGY

Imperial College, Silwood Park
Ascot, Berks SL5 7PY
Tel: 0344 23911 Fax: 294339

WATER RESOURCE SYSTEMS RESEARCH UNIT

Department of Civil Engineering, Newcastle University
Newcastle-upon-Tyne NE1 7RU
Tel: 091 232 8511 Fax: 091 261 1182
Telex: 53654 UNINEW G

UNIT OF BEHAVIOURAL ECOLOGY

Department of Zoology, University of Oxford
South Parks Road, Oxford OX1 3PS
Tel: 0865 271165 Fax: 310447

Natural
Environment
Research
Council

Terrestrial and Freshwater
Sciences