THE RIVER FANE FLOW REGULATION SCHEME
A CASE STUDY IN RIVER ENVIRONMENT MANAGEMENT

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1. INTRODUCTION

1.1 DESIGN CONCEPT

The River Fane Scheme is a Low Flow Augmentation Scheme which depends on the development of Lough Muckno as a Storage Reservoir in order to supply the water demand of Dundalk. Water from Lough Muckno will supplement flow deficiency in the River Fane so as to provide the required flows at various points downstream and particularly at the Dundalk U.D.C. Intake at Stephenstown County Louth. The Scheme therefore has two centres of activity, the Headworks at Lough Muckno and the Intake-Treatment Works at Stephenstown and Cavan Hill, more than 20 km downstream.

The Scheme has been designed not only to meet the demand of Dundalk and its hinterland, but also to provide for projected requirements of a second Local Authority (County Monaghan) abstracting directly from Lough Muckno; of Newry and Mourne District Council in Northern Ireland who already abstract from Lough Ross (3km downstream) as well as Riparian Users and Compensation Water below the Stephenstown Intake. See Fig 1 below.

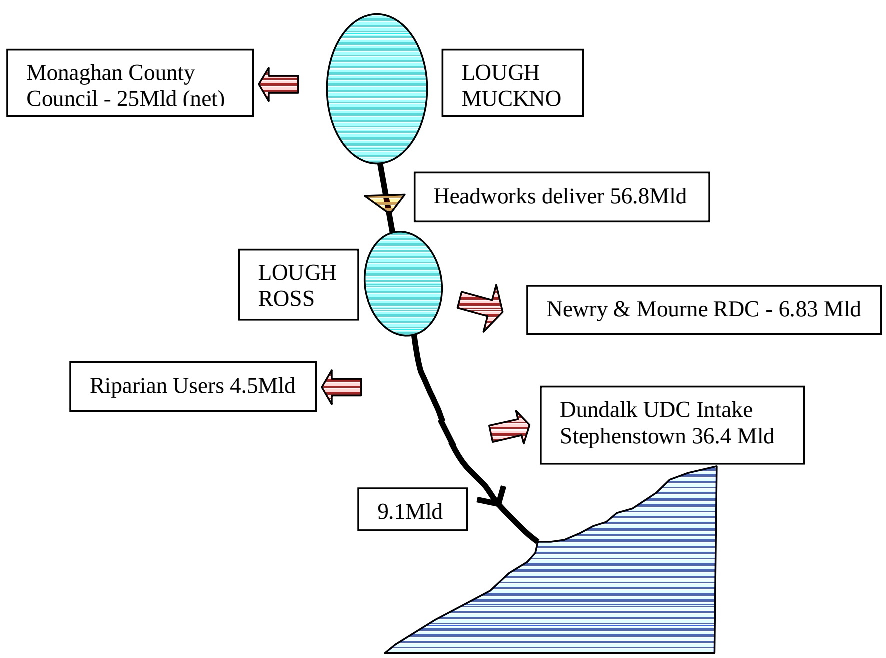

Figure 1 – Schematic Diagram of Headworks and Abstraction

The compensation water is intended to facilitate movement of migratory salmon, sea-trout and eels along the Fane River System. The Fane though relatively small in catchment area (350 sq.km) is one of Irelands primary late run salmon rivers, with adult fish moving upstream in September-November to spawning grounds in the Clarebane River, a short reach between Loughs Muckno and Ross, as well as to tributary streams in the upper catchment.

While Dundalk U.D.C. have a Water Order for a 36.4 Mld. abstraction at Stephenstown, the total Regulation Flow downstream of Lough Muckno includes all downstream water demand and river management requirements and will ultimately reach 56.8 Mld. The natural unregulated river has gone dry in 1975 and has a record - averaged 90 Percentile Flow of 17.3 Mld. at a Gauging Station in the lower half of the catchment.

1.2 THE INFLUENCE OF THE RIVER ENVIRONMENT ON HEADWORKS DESIGN

The Scheme is unusual in that, in order to avoid irreparable damage to salmon spawning grounds by excavation in the gravel redds in the Clarebane River, a decision was made to design a Headworks that would regulate outflow from Lough Muckno in two ways; by gravitational spillage for as long in the year as possible, but then by pumping from a reduced water level in the upstream Lough Muckno to a higher water level in the undisturbed Clarebane River downstream. The overspill gates in Spring therefore function as backstop gates for the pumped flow in late Summer and Autumn, and the entire installation is designed to operated unmanned, by PLC control, except for telemetric supervision from the Main Treatment Works. The dual flow aspect of the Head Station design has meant a consequent need for a conventional two stage gravitational fish pass as well as a pumped flow Fish Chute for upstream migration and a Fish Lift for downstream migration during pumping periods.

A secondary feature of the Scheme, arising from the under reservoired nature of Lough Muckno, is the impoundment of storage at as late a stage in Springtime, as is possible, so as to reduce the risk of additional flooding of lands in the upper catchment. This is achieved by monitoring the recession hydrograph of winter flows using the PLC which operates the control gates, and using knowledge of the shape of this hydrograph to manage the storage so that it is just full when it is first required to supplement river flow.

Thirdly, the flow attenuation effects of the intermediate catchment and particularly the intermediate Lough Ross, have been studied and incorporated into a storage management policy, which adjusts releases at the Headworks in good time to match receding or rising flow hydrograph at the Intake, so as to reduce Environmental Impact by over abstraction at Lough Muckno.

The Scheme is also notable in that Simulated Gate Control Polices (1) were applied to historically wet and dry years to assist in explaining the environmental impact of the Scheme to the public at the Public Inquiry held under the Water Supplies Act and these policies were subsequently used to evolve simple, Fail-Safe control software particular to the requirements of the site.

2. HYDROLOGY OF THE LOUGH MUCKNO - FANE RIVER SYSTEM

The design of the Headworks at Lough Muckno followed a detailed Hydrographic Survey of the Lake bed as well as hydrological study of the Lake-River System.

As has been mentioned, there are two lakes of significant size on the Fane River System, Lough Muckno being the upstream and major lake, connected with the downstream Lough Ross by a 3 km short reach of river known as the Clarebane River. There are two principal Flow Gauging Stations on the catchment, one at the Clarebane Bridge approximately midway between the two lakes, the second on the River Fane downstream of Lough Ross at Moyles Mill near Inniskeen, County Monaghan.

The principal characteristics of Lough Muckno and the flow recording stations are as follows:

A.	**STORAGE/AREA**	**Lough Muckno**
1.	Lake area at Maxium Recorded Flood Level	568 ha
2.	Lake area at Lowest Recorded Summer Level	338 ha
3	Impounded Storage (92.1m OD to 91.3m OD)	2.6 million cu.m
4	Available Storage for Pumping (91.3m OD - 88.6m OD)	8.4 million cu.m
B.	**LEVELS (metres AOD)**	
1.	Highest Recorded Flood Level	92.87
2.	Upper Impoundment Level	92.1
3.	Level at which Pumping must Commence at full demand	91.3
4.	Lowest Recorded Summer Level	90.97
5.	Control Structure Apron Level	90.7
6.	Projected Drawdown Level at Full Demand in 1975 type Drought Conditions	88.6

TABLE 1 : LOUGH MUCKNO HYDROGRAPHIC CHARACTERISTICS

Flow Gauging Station	**Clarebane Bridge**	**Moyles Mill**
Catchment Area to Station	163 km²	230 km²
Mean Annual Flow	2.75 m³/s	3.76 m³/s
Peak Flood	17. m³/s	34.6 m³/s
Lowest Recorded Flow	0.02 m³/s	0.00 m³/s

TABLE 2 : RIVER FANE FLOW GAUGING SYSTEMS

Lough Ross is a relatively small lake, 88 ha in area, and will operate without controls, rising and falling in response to releases at Lough Muckno. Referring to the flow records, it might appear anomalous that a flow of zero could be recorded at a downstream station during a period when the flow at an upstream point was 0.02 m³/s (1.7 Mld), approximately, but the circumstances may be explained by the fact that a water supply from Lough Ross is at present abstracted to serve the adjacent area in Northern Ireland.

It is a characteristic of the flows on the Fane System that although the Mean Annual Flow is respectably high, flows at or above this level do not persist over anything like half the year, and much lower flows are experienced over long periods in drier summers. The geology of the catchment is mostly Ordovician-Silurian Shales with some Sandstone Drifts and the Fane Catchment shares with the nearby Glyde and Dee Catchments a particularly low baseflow contribution from groundwater in prolonged dry weather (Fig 2).

Since the headworks are some distance upstream of the abstraction point, our initial assumption was that intermediate catchment flow could be counted upon to permit fractional releases at Lough Muckno. This assumption was tested by comparison of the flows at Clarebane Bridge and downstream at Moyles Mill over different periods of the year. When adjustment was made for the existing water supply abstraction from Lough Ross it was found that the overall correspondence between Catchment Area and Mean Annual Flow did not persist into the drier periods of the year. In 1975 for example 97% of the flow at Moyles Mill in May was already in the river at Clarebane Bridge and in the following month the flows at both stations were equal (when allowance for Newry is made).

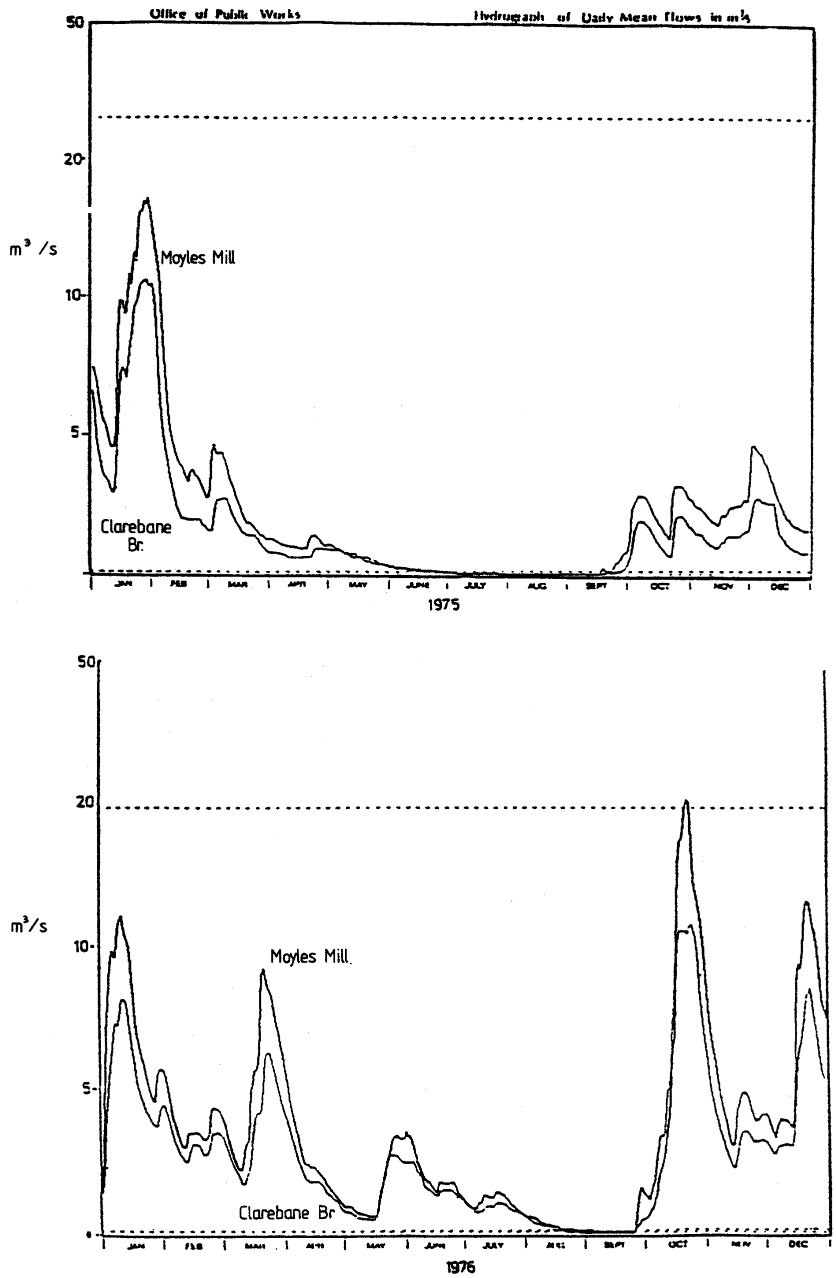

FIG. 2 HYDROGRAPHS AT CLAREBANE BRIDGE AND MOYLES MILL SHOWING LOW INTERMEDIATE BASEFLOW

In June 1976 the figure was 87% and in May 1977 it was 91%. In designing releases from Lough Muckno for abstraction at Stephenstown during severe drought periods it was therefore assumed that the intermediate catchment would contribute negligible amounts to the overall flow arriving at the Intake.

3. HEADWORKS DESIGN

3.1 PUMPING STATION DESIGN

Based on a Hydrographic Survey of Lough Muckno, a Storage/Elevation curve for the Lake was prepared prior to the Water Order Enquiry of 1982. The flow records for 1975 & '76 suggested that in particularly dry years, with all Water Supply Authorities drawing at full demand, water level on Lough Muckno could drop to 88.6m above OD compared to normal summer levels of 91.0m OD. Since the Pumping Station is located approximately 450m from the lake outlet, and allowing for water from the 88m OD contour in the lake to the Pumping Station would be required and that the Wet Wells in the Station itself would have to anticipate a maximum drawdown water level of 88.0m OD at the Station. The construction of a lined and normally submerged concrete Revetment Channel in the Pumping Station therefore formed part of the Civil Works Contract.

The Pumping Rate depends on the flow deficit between water demand and the naturally available flow in the Fane at Stephenstown, so that the Pumps are variable speed pumps capable of pumping over a flow range from 11.4 Mld. to 56.8 Mld.

3.2 GATE CONTROL

Activation of the Gates from the passive Winter position takes place on reaching a predetermined point on a falling recession hydrograph, or on reaching a predetermined date. The PLC controls the raising of the Gates so as to pass the Regulation Flow while impounding into storage, aiming to just achieve a full storage when drafts from storage are first required. Water Level upstream and downstream is logged at 15 minute intervals and the Gates pause at each movement (for a period which is related to the response time of the Clarebane River) during which the effect of the adjustment is monitored.

The PLC is programmed to drop the gate at a rate related to the known rate of rise of the worst recorded flood hydrograph on Lough Muckno, and when the spilling of excess floodwater has stabilised water level on the lake the programme will recognise when to resume impoundment of water. The Gate Control Panel has a backup battery power supply, as does the PLC and hydraulic accumulators are designed to permit one full manual cycle of adjustment of all the gates following power failure. The Gates will either remain in the vertical back stop position or will drop to the passive position whichever is fail-safe (at that time of the year) on power failure.

The hydraulic control of outflow from Lough Muckno will be balanced between free discharge over the gates on the one hand and backwatering of the Control Structure because of the throttling effect of the Clarebane River at higher flows on the other. Upstream water level determines the controlling head for free flow over the gates, downstream water level is then monitored together with the Rating Curve as a check on outflow. Once the flow over the gates is no longer free, control is passed to the downstream level alone.

4. RECESSION CURVE ANALYSIS

Since Lough Ross lies between the headworks and the intake, and since these are in any case separated by more than 20km of the river length, it is clear that any variation in release from Lough Muckno, particularly at low flows, would be extensively attenuated in Lough Ross and in the river reach downstream. If water is not to be needlessly pumped at Lough Muckno, or if a deficit is not to arise at Stephenstown then releases at Lough Muckno will have to be anticipatory in nature both as to timing and magnitude. Long term prospects for river bank storage at Stephenstown will permit regulation of bank-side storage to compensate to some degree for over or under releases but a careful analysis of river recession rates permits a substantial degree of control in the early years of the Scheme as demand grows towards its long term values.
Recession analysis depends upon the isolation of good recession hydrographs, uncontaminated by rainfall if possible, from which to derive the natural decay factor defined by the equation:

$$\frac{dQ}{dt} = -kQ \qquad (1)$$

Where k is a constant (the recession rate). The solution to this equation is given by

$$Q_t = Q_0 e^{-kt} \qquad (2)$$

So that the ratio of flows one time unit apart can be expressed

$$\frac{Q_t}{Q_{t+1}} = R_q \text{ where } R_q = e^{-kt} \qquad (3)$$

The assumption that the ratio of flows in successive time periods remains constant throughout the range of flow is often not justified in practice.
The difficulties of estimating the decay factor from the ratio of flows one day apart are many including errors of measurement, "contamination" of the recession by small amounts of rainfall, and in the case of Lough Muckno poor rating curve definition at very flow flows. It was recognised moreover that the time required for equilibrium to be established between inflows to Lough Ross and outflows to Lough Ross and outflows to the River Fane below would vary between 3 and5 days approximately, with the longer period applying at low flows. Accordingly it was decided to estimate recession factor using the expression.

$$\frac{Q_t}{Q_{t+5}} = R_Q \qquad (4)$$

and these have been plotted for Clarebane Bridge in Fig 3. These show that the Recession Factor (R_Q) at Clarebane Bridge is relatively constant at 0.9 but rises to 0.92 at low flows. Since Storage/Yield analyses suggest that winter inflow will always be adequate to replenish storage at the levels of demand which are projected, inactivation of outlet controls for the winter period will be possible thus minimising interference with winter floods.

A knowledge of the recession characteristics of Lough Muckno has permitted a point to be identified on the recession curve which will trigger the filling of storage to any selected target level while guaranteeing releases throughout the filling sequence. It remains to check that the recession factor has not been significantly altered by the outlet works which have been constructed, since other sources (3) have found this to be the case elsewhere.

The presence of substantial natural storage in Lough Muckno greatly influences the recession rates on the hydrograph at gauging stations downstream. From the Storage/Elevation curve on Lough Muckno, and the rating curve for outflow from the lake into the Clarebane River, it is possible to calculate an approximate decay curve for the lake alone assuming no inflow from the minor lakes and catchment upstream, and this has also been plotted on Fig 3. In future it is the behaviour of Lough Ross at low flow that will dominate the response of the lower catchment during regulation periods since all inflows to Lough Muckno will be completely absorbed in replenishing storage depletion. While an accurate Storage/Elevation curve for Lough Ross has not been produced, there are indications that its "nonflow" recession factor is of the order of 0.66 for flows in the region of 20 Mld, and that it is somewhat larger (0.74) for flows in the region of 7.5 Mld.

Recession Analysis of the hydrograph at Moyles Mill, in the Lower Fane Catchment, suggests that the recession at this point is still dominated by Lough Muckno particularly at medium and high flows. We would hope to research the extent to which the recession factor of 0.88 to 0.92 recorded at Moyles Mill changes as Lough Muckno becomes a more regulated reservoir. We have prudently assumed that it will approach the "no-inflow" calculated recession for Lough Ross but this can not be practically tested until the system is exposed to a few drought years which require pumping on Lough Muckno.

We attach importance to the Recession Analysis at Lough Muckno, Moyles Mill and Stephenstown in order

(a) to minimise the extent of pumping from Lough Muckno and
(b) to ensure that pumping is commenced in good time and then discontinued when refilling has taken place to an extent that resumed pumping shortly afterwards is not required

(c) to determine the consequences of power failure on the Clarebane River during pumping periods.

The Station at Lough Muckno will be unmanned and the intention is to carry out a major maintenance cleaning of screens, pumps etc. at the end of the pumping season. The sequence of operation required to set the pumping regimen in train, while not particularly complex, would be such that a well defined, reliable end pint to the pumping season should be established

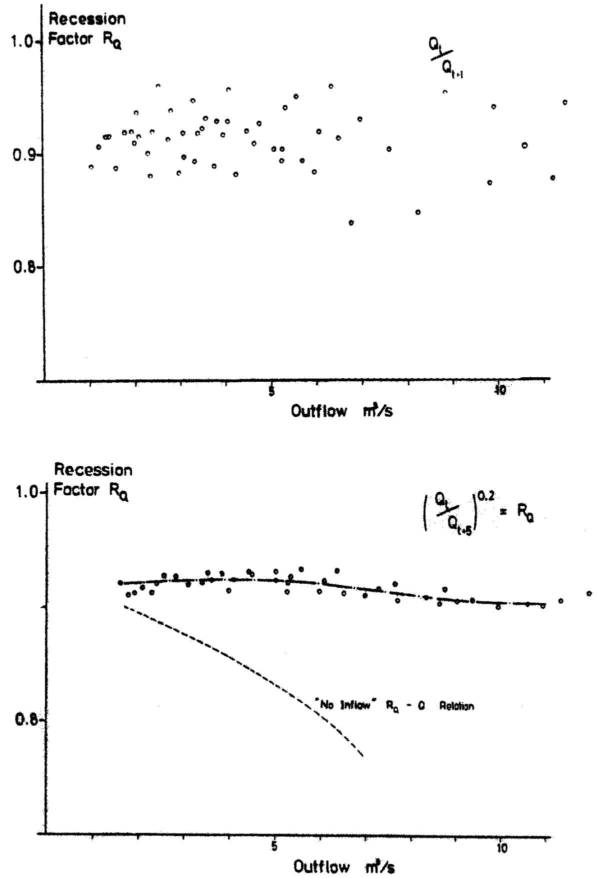

Figure 3 – Recession factor & decay curve for Lough Muckno

5. MIGRATORY FISH MOVEMENT

The Control Structure includes two Fish Pass Gates which will in the initial stages of a drought simply act to divide the level difference between lake and river into two steps whilst flow to the Clarebane River spills over the gates. The PLC will control gate lip level so that a minimum depth of flow of 200mm over the Fish Pass Gates always exists, irrespective of minimum Regulation Flow.

Once pumping commences, a fraction of the pumped flow will be delivered to a Fish Chamber which discharges over the downstream Fish Pass Gate. Fish migrating upstream will be attracted into the Fish Chamber and counted as they enter. On reaching a pre-determined number of fish, or overridden by a timer, a penstock will open allowing the fish to be flushed down a chute which terminates upstream of the Intake.

Fish migrating downstream during the pumping phase of operation must pass from a low level Lough Muckno to a higher level Clarebane River. On entering the Station via the operating Intake Channel, they can pass through the coarse screens but are confined in the sump outside the Bandscreens. The Intake, Bandscreens and entry to the Wet Well are designed on a Twin Stream basis symmetrical abut the axis X-X so that any one half of the Intake-Bandscreen arrangement can accommodate the entire flow. It is then possible to isolate one side by closing Penstocks A, B & C and pump its contents into the other, in the process drawing fish into the base of the Fish Lift. Closure of the penstock at the base of the Lift (D) and reversal of the flow from the Fish Lift Pump together with the closure of Sl. Valve E will flood the shaft of the Fish Lift. A stainless steel mesh basket on vertical guides in the Fish Lift is then drawn up from below, forcing the fish to rise above it. At the top of the Fish Lift Shaft an outlet pipe will take the Fish to the downstream side of the Control Structure.

6. CONCLUSIONS

The River Fane Flow Regulation Scheme makes use of developments in Telemetry and transfer of information to give a high degree of flow control to the overall advantage of the river environment. Indeed the design concept of the Scheme makes such control essential if abstractions from Lough Muckno are to be optimised so as to protect the amenity of the lake itself in the first instance and of the River Fane System as a whole. We were fortunate in the design stage in that a 16 year record included two severe droughts in 1975 and 1976 and two particularly wet summers in 1985 and 1986 so that the data bank was available to test our Operations Policy against documented extreme historical conditions. A considerable amount of work on recession analysis has already been carried out, projections have been made of how the recession rate would change in the lower catchment following substantial regulation of Lough Muckno as demand grows. The particular needs of migratory fish to move upstream and downstream, sometimes simultaneously depending on species, during both the gravitational flow and pumping periods has resulted in a novel approach to Pumping Station Design.

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