FRESHWATER BIOLOGICAL ASSOCIATION

TEESDALE UNIT

Report to: Northumbrian Water Authority,
Department of the Environment,
Natural Environment Research Council.

Date: 11 September, 1981.

The Grassholme Channels.

P.A. Carling

c/o Northumbrian Water Authority
Lartington
BARNARD CASTLE
Co. Durham DL12 9DW
England

FRESHWATER BIOLOGICAL ASSOCIATION

TEESDALE UNIT

PROJECT 73

Report to: Northumbrian Water Authority,
Department of the Environment,
Natural Environment Research Council.

Dates 11 September, 1981.

The Grassholme Channels

P. A. Carling.

CONTENTS

Page

SUMMARY

1. The design and construction of four experimental channels at Grassholme reservoir in Teesdale, U.K. are "briefly described.
2. Basic calibration procedure is detailed.
3. The problem of obtaining valid replication between channels is examined using published data obtained for previous experiments in the channels. It is concluded that replication may be obtained by careful experimental design.
4. The limitations of the existing configuration of pipework and channel design are discussed and solutions suggested.
5. Finally a list of the main components of the channels and suppliers is appended for convenience. Alternative materials and suppliers could well be found for most items.

INTRODUCTION

Experimental channels were required in order to conduct controlled experiments which were not feasible in the variable regime of natural streams.

DESIGN

Four channels were constructed in order to replicate experiments or to conduct various experiments simultaneously. Each channel consists of four 3 m long sections constructed of a timber frame with fibre glass skin. A smooth-walled interior especially on the side walls was required to minimise wall drag. A minimum width of 1 m was required, to reduce the need to correct hydraulic parameters for wall drag. Each channel is of oblong section 0.47 m deep.

Additional and wider channels would have been preferable but cost, manoeverability, space and water supply restricted the design.

Ideally the channels should be of variable gradient to simulate the various natural stream channel gradients and to obtain greater control over the hydraulic parameters of the channels. However, cost and the need to complete the channels rapidly resulted in each channel being of fixed gradient. The gradient (0.014) is similar to that of natural streams in Teesdale.

A guaranteed water supply of 6 million gallons per day (0.32 m^3 sec) is available as compensation flow from Grassholme Reservoir to the River Lune; with this discharge a maximum water velocity of 100 cm sec and depths of 10 cm were possible in each channel.

In each 12 m channel only 9 m is usable for experiments. Approximately 3 m are required for a stilling pool and baffle system at the upstream end to stabilise the flow and for a tailgate at the downstream end to control water-level.

Water is supplied from a manifold to each channel via pipes. Discharge was controlled through valves. After passing through each channel water runs directly into the Lune as compensation flow. Metal mesh traps at the foot of each channel retain experimental material. Adjustment of individual channel valves allows less than 1.5 m.g.d. (0.08 m^3 sec^{-1}) through each channel. Additional water, surplus to requirements, runs to waste as overflow from a manifold.

COMPONENTS

A list of the main components, a plan view and section of the pipe work and channels are appended (Appendix 1. and Figs. 1 & 2).

CONSTRUCTION

The scaffolding support framework for the channels and pipework was built by contractors during October and November 1979. The assembly of the channels and pipework was concluded by members of the F.B.A. and occupied 2 - 3 members of staff from October to January. The anticipated time-scale for operations is given in Table 1 and the actual sequence of events is summarised in Table 2.

CALIBRATION

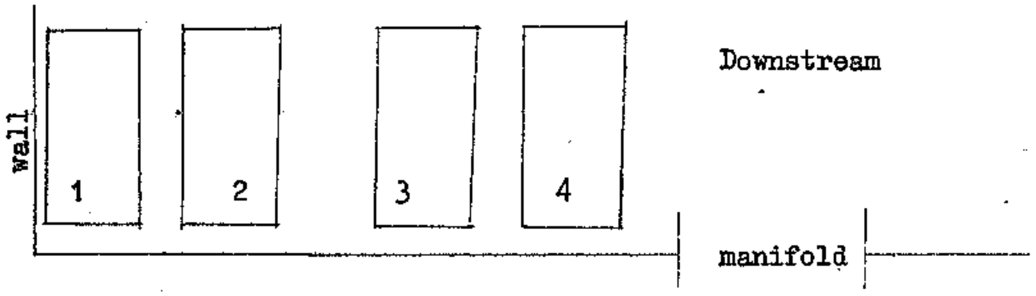
The discharge through each channel had to be calibrated against individual valve settings. In practical terms it will always be quicker and more exact to calibrate channels for individual experiments. However an order of magnitude discharge may be obtained for known valve settings as described below.

Channels are grouped hydrodynamically in two groups.

(1) Channel 1 and 2 numbered sequentially away from the wall.

(2) Channel 3 and 4 numbered sequentially away from the wall.

i.e.



As the length of pipe differed between the two groups, 1 and 2, 3 and 4 were calibrated separately. Adjusting valves on 1 affects the discharge in 2, but not in 3 and 4. Further, the relationship between valve settings on channels is non-linear. e.g. Channels 1 and 2 set with valve turns at 9 and 8 respectively will have similar discharges. However, this is not true for high and low discharges e.g. to obtain constant "equal" discharge of 0.25 - 0.30 m^3 sec^{-1} , Channel 1 would be set on 18 valve turns and Channel 2 on 36 valve turns.

Calibration equations and an example are given below. Tailgates were adjusted to give local current speeds of 1.00 m sec^{-1} with maximum local water depth not exceeding 0.10 m for maximum discharge. Velocity is a function both of valve settings, tailgate adjustment and bed roughness so that complete calibration is not practical. Mean velocity is most appropriately determined for each experiment using the relationship $\bar{U} = \frac{Q}{D}$ where D is the depth (equal to cross-sectional area as channels 1 m wide).

<u>Channel 1</u>

$Q = 0.0186 \log T^{3.0869}$ $r^2 = 0.93$

<u>Channel 2</u>

$Q = 0.0200 \log T^{1.7010}$ $r^2 = 0.93$

<u>Channel 3</u>

$Q = 0.0240 \log T^{1.7963}$ $r^2 = 0.97$

<u>Channel 4</u>

$Q = 0.0239 \log T^{1.7234}$ $r^2 = 0.99$

T = Number of 180° turns on valves

Q = discharge as $m^3 sec^{-1}$

Example calculated valve setting for discharge

Required 0.01 m^3 sec^{-1} in Channel 2.

$$\left(\frac{0.01}{0.02}\right)^{\frac{1}{1.701}} = \log T = 0.67$$

Antilog = 4.63 valve turns

On the nomogram (Fig. 4) read 0.01 on column Q_2 matches. 4.63 turns on valve using interpolation. Approximate valve setting (T_1) on Channel 1 is also indicated as is the appropriate discharge Q.

Discharge measurements were made as follows:

(1) Low Plows. The stilling pool above the baffle was sealed off from channel downstream. When the valve was opened to a known setting the volume of water accumulated in the rectangular pool over a given time period gave the discharge from the valve.

(2) High Flows. A salt dilution gulp injection method (Church, 1975) was used to estimate discharges over a gravel bed at high valve settings. However this method is not suitable when fish are present in the channels. When fish are present the velocity is obtained by current-metering at 0.6D in the vertical. Velocities at this depth are generally representative of the depth-mean velocity and may be used to estimate sectional discharge. The channel width is divided into 10 subsections and velocity and cross-sectional area are determined for each section. The product of velocity and cross-section area summed across the channel width gives the discharge.

If it is assumed that the distribution of current speed with depth is log-normal in turbulent flow then the von Karman-Prandtl equation can be used to estimate velocity at any point in the vertical as follows;

$$\ln Z = \frac{X}{U_*} U_Z + \ln z_o$$

where Z is the height above the bed, X is von Karman's constant (0.40) U_* is the shear velocity and z_0 is a characteristic roughness length of the bed material usually taken as $d_{65}/^{30}$, where d_{65} is the grain-size diameter of the bed material at the 65 percentile on a cumulative frequency curve. From an initial measure of velocity at a given height above the bed and an estimate of z_0 velocity can be determined for any value of Z.

EXPERIMENTAL GRAVEL

Gravel used as bed material has been obtained from both private and commercial sources (See Appendix 1).

PERFORMANCE

With all four channels in use some 0.04 to 0.05 m^3 sec^{-1} can be fed into each channel. The maximum theoretical supply 0.08 m sec cannot be supplied with the present pipework and manifold system because of frictional losses to pipe-bends and constrictions. If only one channel is operated discharges of up to 0.10 m^3 sec^{-1} may be achieved with sectional averaged Froude numbers up to 1.0. Supercritical flow is difficult to sustain with a stable bed and can be obtained only in the lower 2 m of the channel by lowering the tailgate. Strictly uniform flow where the water surface slope is parallel to the bed slope is also unattainable as the bed slope cannot be varied. Velocities of up to O.65 m sec^{-1} are possible using all four channels and up to 1.0 m sec^{-1} using only one channel. Maximum average depth is 0.10 m.

The main reason for using four channels is to replicate biological experiments. The crucial question remains whether each channel is hydraulically similar to its neighbours. Possible sources of variation between channels are, velocity, depth, substratum, water temperature especially as influenced by shading which increases from channel 1 to channel 2. In addition any biological material introduced to the channels should be of comparable quality. Ottaway & Clarke (1981, and unpubl. report, 1981) report on two investigations concerned with the downstream displacement of brown trout (Salmo trutta L.) and Atlantic salmon (S. salar L.) fry by increases in discharge. To test the degree of replication obtainable data have been taken for Ottoway & Clarke (1981) experiments 2 and 3 concerned with trout. In both experiments significant correlations were found between the average number of trout fry moving out of the four channels and the average velocity. Although the velocities used in each channel were not identical they are broadly comparable at each velocity increment. A one-way analysis of variance (Freund, 1962) suggests that at the level $p < 0.001$ there is no significant difference in the velocities between channels so that hydraulically the channels were similar. A two-way analysis of variance (Dixon & Massey, 1969) was conducted on the instantaneous rate of trout fry leaving the channels each day over a nine day or 10 day experimental period. This gave a 9 x 4 or 10 x 2 matrix . The null hypothesis was that there was no significant difference in either (i) row or (ii) column data.

Acceptance of this hypothesis would indicate that (i) there is no variation in the rate of emigration day to day, (ii) that results are comparable between channels. For experiment 2 the analysis (9 x 4 matrix) indicated that there was no significant difference from day to day in the instantaneous emigration rate hut that individual channel data were comparable.
For trout experiment 3 (9 x 4 matrix) there was no significant difference in the daily emigration rates and individual channel data were not comparable at the significance level $p < 0.001$. In experiment 2, using a 10 x 2 matrix so as to include only data for velocities above a critical threshold (0.20 m sec^{-1}) and from only the two channels used to obtain high discharge, the differences in emigration rate were found to be significant whilst the individual channel data sets were compatible.

The combinations of data that can be analysed in this manner are legion as the experimental design and results expressed as instantaneous emigration rates are quite complicated. The analyses do suggest that in future experiments particular attention should be paid to obtaining valid replication between individual channels.

WATER TEMPERATURE AND DISSOLVED OXYGEN

A thermograph was installed 5 m down channel number 4 (Fig. 1) at the end of October 1980 and run until the end of May 1981. In addition mercury thermometer readings were obtained occasionally at the infall, 5 m downstream and the outfall of each channel. There was no temperature difference between channels or along the channel length.

Intragravel water temperatures at 7 - 8 cm depth over the period November - May were not significantly different from the surface water temperatures.

Mean monthly temperatures and the standard deviation based on daily temperatures are given in Table 3. Dissolved oxygen concentration was determined by Winkler analysis for samples obtained on 25 April 1980 (Table 3).

DISCUSSION

The experimental channels have proved valuable for controlled biological experiments which could not be conducted in the unregulated flow regime of the natural streams. At present, physical experiments on siltation are being conducted. Experiments on sediment stability and sediment transport are curtailed at present by the inability to vary the gradient of the channels. This limitation reduces the value of existing investigations and constrains the range of the hydraulic "climate" that can be investigated.

The configuration of the present pipework for water supply and the necessity of using a manifold to collect water from a gauging plate is unsatisfactory. The restricted space available for pipework means that long radius bends could not be used in the pipework. Consequently frictional losses to 90° bends and constrictions results in less water being delivered to the channels than is available. In addition using the present pipe configuration each channel cannot be operated independently and complete calibration is impossible.

To correct these short-comings consideration should he given to building one or more additional variable gradient experimental channels (of 30 m length) with direct piped water-supply to each channel or to a central manifold with an improved pipework configuration. This cannot be done at the same location. The additional channels would need to be positioned at a suitable adjacent site.

It should be noted that a relatively large guaranteed water supply is available at this site, a supply which is unlikely to be easily or cheaply supplied elsewhere. Full advantage should be taken to utilise this "unique" supply efficiently.

ACKNOWLEDGEMENTS

Mr. N.A. Reader and Mr. N. Hywel-Jones are thanked for their assistance in assembling the channel sections and pipework in bleak winter conditions. Mrs. D. Jones typed the manuscript.

REFERENCES

Church, M. (1975). Electrochemical and fluorometic tracer techniques for stream flow measurements. British Geomorphologioal Research Group Technical Bulletin No. 12. 72 pp.

Dixon, W.J. & Massey, S.J. (1969). Introduction to Statistical Analysis. McGraw-Hill.

Freund, J.E. (1962). Mathematical Statistics. Prentice Hall.

Ottaway, E.M. & Clarke, A. (1981). A preliminary investigation into the vulnerability of young trout (*Salmo trutta* L.) and Atlantic salmon (*S. salar* L.) to downstream displacement by high water velocities. J. Fish Biol.

Ottaway, E.M. & Forrest, D.R. (1981). Further observations on the downstream displacement of young trout (*Salmo trutta* L.) by high water velocities. Unpubl. report to customers.

TABLE 1. GRASSHOLME CHANNELS - ANTICIPATED ORDER OF EVENTS - TIMING WAS OF NECESSITY ADJUSTED

October 4th week	November 1st week	November 2nd week	November 3rd week	November 4th week	December 1st week	December 2nd week	December 3rd week	December 4th week	January 1st week	January 2nd week
Platform & manifold complete. Awaiting pipe from N.W.A. Baffle material ordered & designs roughed out.	2/11/79 NWA indicates no pipework available. 5/11/79 FBA orders pipe delivery time 3-4 weeks. Gravel ordered.	No progress possible, fieldwork assumes priority. Gravel should be delivered before end of month i.e., before any snow.			Pipework arrives & installed. Scaffolding made good by Grayston's. Baffles & traps measured and commissioned locally.		No progress anticipated until 2nd week in January.			Baffles arrive and channels filled with gravel

January 3rd week	January 4th week	February 1st week	February 2nd week	February 3rd week	February 4th week	March 1st week	March 2nd week	March 3rd week	March 4th week
Calibration of valves to give required discharge, velocity, depths.	Overspill period allowing for delays, settling down period for gravel, minor modifications.					Allen-type experiments begin approx. March 1st.			

TABLE 2. Approximate Sequence of Erection - Channel Construction.

2.11.79	Estimate obtained for pipework. Delivery date 3.12.79.
19.11.79	Planning permission obtained.
20.11.79	Baffles installed in channels.
30.11.79	Tailgates installed.
6.12.79	N.W.A. supply valves.
13/14.12.79	Scaffolding constructed.
7.1.80	Pipework delivered to Grassholme
8.1.80	Channel sections positioned on scaffolding.
14.1.80	Gravel delivered.
18.1.80	Gravel put in channels.
24.1.80	Chute brought from Windermere.
25.1.80	End plates bolted on channels and manifold
28.1.80	Chute put in position.
29.1.80	Channels operational.

TABLE 3. Temperature and Dissolved Oxygen

	Temperature 0°C		Dissolved Oxygen 25 April 1980.		
	$\bar{x}$		Concentration mg l^{-1}		Temperature 0°C
Nov 1980	6.26	0.65	i	12.71	6.5
Dec	3.85	0.37	ii	11.34	11.0
Jan 1981	2.79	0.74	iii	13.32	11.0
Feb	3.32	0.34	i	13.00	11.0
March	4.21	1.08	ii	12.67	11.0
April	6.80	0.48	iii	11.76	11.0
May	8.11	0.55			

(i) = infall to channel, (ii) = 5 m downstream, (iii) = outfall.

APPENDIX 1.

Components used in Channel Construction

1. Scaffold platform for channel support - 12 m long x 6 m wide and 1.4 m high.
2. Scaffold support for manifold and chute - 3 m long, 1.5 m wide and 2 m high.
3. Scaffold to support pipework 9 m long, 1.5m wide and 0.60 m high.
   All scaffolding and hoard walks on hire from Grayston Group, Harwood Works, Thornaby, Stockton, Cleveland TS17 7SL.
4. 20 Channel sections 3 m long x 1 m wide x 0.48 m deep. The manifold was constructed by adapting one 3 m channel section. End plates of mild steel, 3 mm thick, were bolted on each end to enclose 1.44 m capacity. Two square outlets (30 cm) were cut in the base and reinforced with steel plates. Channel sections supplied by Poly-glass Ltd., 11 South Ed., Morecambe, Lancashire LA4 5KB.
5. Steel chute to feed manifold. 2 m wide, 1.10 m long with 0.40 m high side walls. A flange 10 cm high and 2 m long is welded on to the underside to fit over a scaffold bar to locate the chute in its correct position. Manufactured at Windermere Iron Works, Windermere, Cumbria.
6. Four steel mesh traps 1 m high, 0.5 m wide and 1 m deep required to trap experimental material moving downstream. Manufactured by Barnard Castle Iron Works, Barnard Castle, Co. Durham.

7. Tailgates and steel end plates at inflow of each channel built by Barnard Castle Iron Works.
8. Rubberised Hair Sheet to use as upstream baffles to steady flow - Hairlok Ltd., Magna Works, Cathie Rd., Bedford, Bedfordshire.
9. Gravel. Tilcon Ltd., Northern Region Commercial Office Quarries, Sherburn Hill, Durham, DH6 1PS. 20 tonnes marine gravel 0 mm - 40 mm (rounded pebbles). 10 tonnes River Tyne gravel - courtesy of Tom Buffey N.W.A.
10. Pipework. Tube 12 inch (30 cm) diameter Class B - Plastic Constructions Ltd., Tyseley Ind. Estate, Seeleys Rd., Greet, Birmingham, B11 2LP. (Supplied from local depot at B.I.P. Ltd. see below).
11. Specialist Pipework. British Industrial Plastics Ltd., Aycliffe Ind. Estate, Darlington, DL5 6AN.

    1 x 6 m length 8 inch straight
    1 x 6 m length 12 inch straight
    2 x 12 inch/D/90 LRB/X - CS
    2 x 12 inch x 8 inch/D/C0R/x - F
    2 x 8 inch/D/A/CS - F
    2 x 8 inch x 8 inch/D/ET/X - X - F
    2 x 8 inch/D/90 LRB/X - F
    4 x 8 inch 90° Elbows
    All flanges to Table 'E' All pipe Class B.

12. 4 Valves 8 inch (20 cm) on loan from N.W.A.

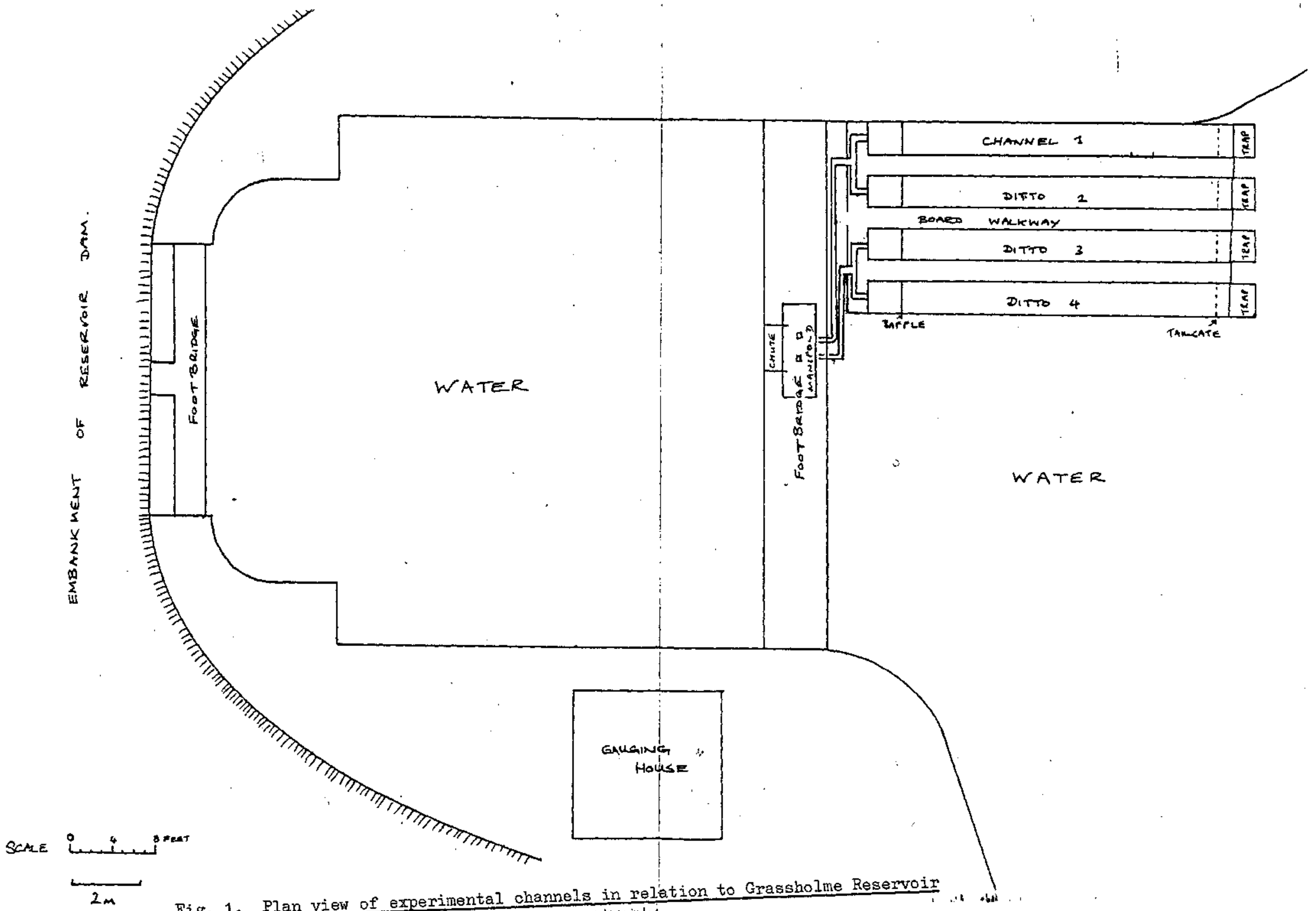


Fig. 1. Plan view of experimental channels in relation to Grassholme Reservoir outfall.

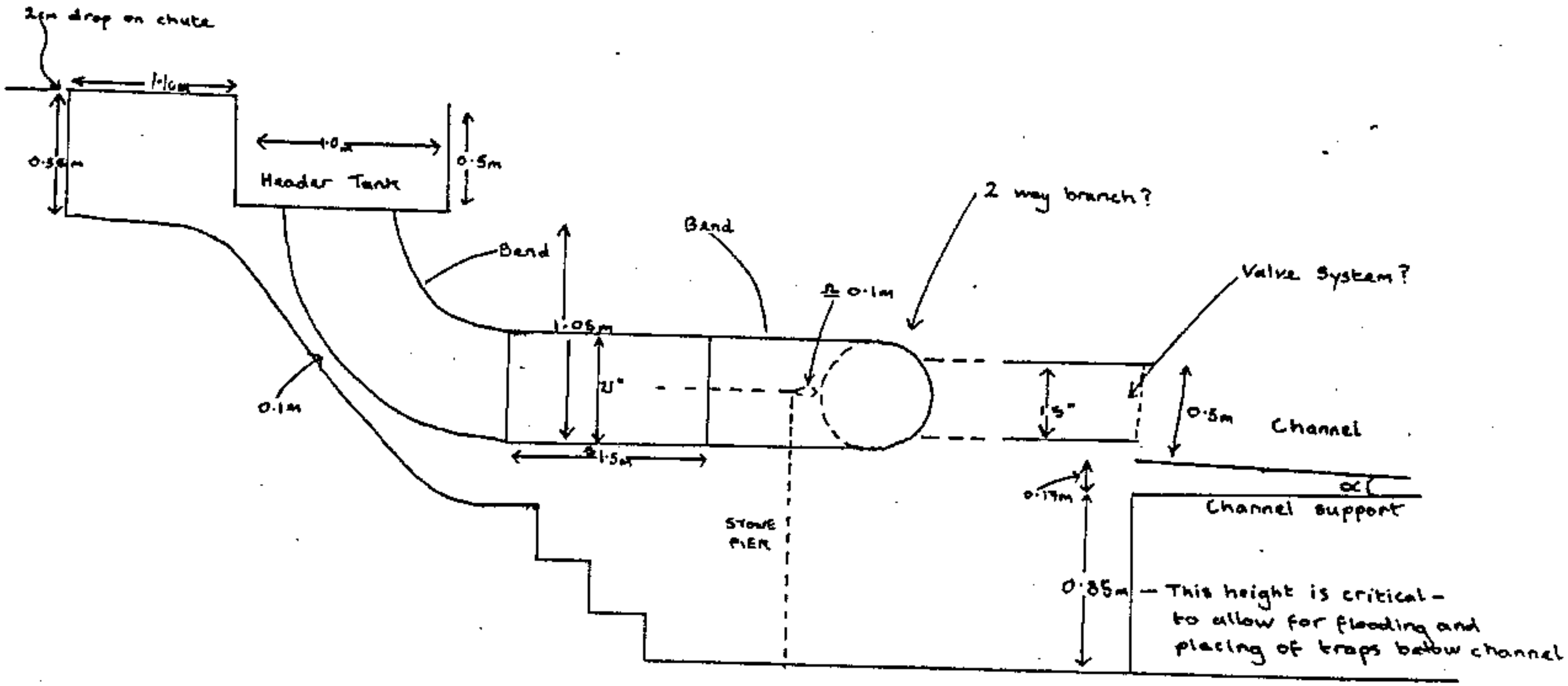


Fig. 2. ROUGH PLAN OF GRASSHOLME CHANNELS

SIDE VIEW

Scale ≏ 40mm = 1m

Fig 3

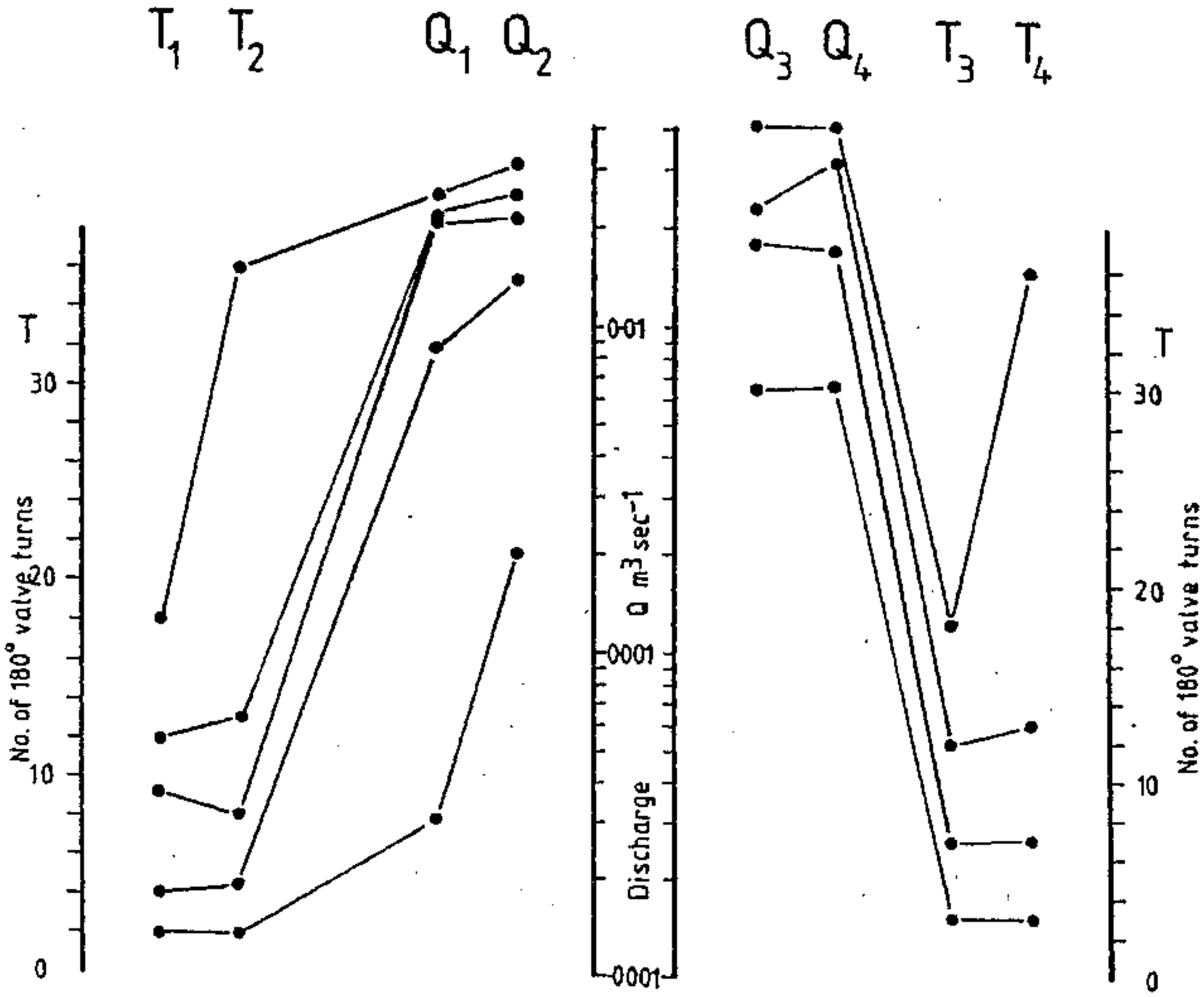


Fig. 3. Nomogram relating approximately the number of valve turns (T) in each channel and discharge (Q). Subscripts refer to individual channels.