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Calibration of Grassholme Channels, 1982

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CONTENTS

SUMMARY

1. The report describes calibration of the Grassholme channels for the biological experiments of spring - summer 1982. It also seeks to establish relationships which will be of value in future managment of the channels for experimental purposes.

2. The approximate discharge in any channel ($Q \ ls^{-1}$) can be estimated from the equation $Q = [Q_{max} \frac{V_o}{V_o + a}]^{1-m_i V_1}$, where V_o is the number of 180^o valve turns on the valve of the channel, V_1 is the number of turns on the adjacent channel, $Q_{max} = 150$, $a = 16.5$, $m_1 = 0$, $m_2 = 0.01$, $m_3 = 0$ and $m_4 = 0.005$.

3. The tailgate settings are difficult to measure accurately during moderate or high channel discharges. However, the length of the threaded rod (used to adjust the tailgate) above the channel crossbar is easily measured and can be used to predict tailgate settings from the equations:

   $y_i = b_i \ x_i + a_i, \ i = 1 \ .... \ 4$

   Where y_i = tailgate setting (cm in channel i,) including 0.2 cm of rubber sheeting; x_i = length of threaded rod (cm) in channel i and a_i and b_i are:

   -43.84, 0.99 respectively for channel 1

   -38.68, 0.91 respectively for channel 2

   -34.30, 0.84 respectively for channel 3

   -47.56, 1.04 respectively for channel 4

4. For each channel there is a linear relationship between water velocity and depth as discharge setting is varied. Depth and velocity in each channel can be related to valve turns and tailgate settings by multiple linear regressions.

5. There is a complex pattern of variation in depth and velocity along the length of each channel but depth and velocity measured on a cross-section 5.5 m from the upstream end of the channel are reasonable approximations to the mean values for the whole channel length.

6. There is statistically significant variation in depth and velocity across the width of the channel, with greater depths and velocities in mid-channel than close to the channel sides. The variation in depth is very small, whereas the variation in velocity is substantial (c. ± 20% of the mean value).

7. Analysis of the effects of treatments, repetition of treatments, channels and position down and across channel showed that all effects contributed significantly to total variability in water velocity and depth. There were also many significant interactions of effects which suggest that the channel system does not behave in a simple fashion. However, in the analysis of variance the experimental treatments accounted for over 90% of the total sum of squares for velocity and over 85% for depth at the 5.5 m transect. The effects of repetition of treatment and channel accounted for less than 5% of the total sums of squares at the 5.5 m transect.

INTRODUCTION

The construction and general mode of operation of the Grassholme experimental channels have been described, together with some information on the relationship between valve settings and discharges in the channels and a brief account of channel performance (Carling, unpub. 1981). Ottaway & Clarke (1981) described pilot experiments in the channels and gave a brief description of the channels. Adjustment of the channels to give any specified pattern of water depth or velocity is complex and tedious because it involves a number of variables. Since some variables are not controllable and variables may interact, valve settings were initially determined on an ad hoc basis to suit individual experiments. This method was used during 1982 but additional observations were made in order to gain more detailed understanding of the channel system and, as far as possible, to develop a guide to future short-cuts in attaining suitable channel settings for any given purpose.

THE CHANNELS

The general layout and dimensions of a channel are shown in Fig. 1. Excluding the bare area between the top end of the channel and the grid, and the area at the foot of each channel occupied by the tailgate, the working area of the channel is 0.99 m x 10.70 m = 10.59 m^2. The gradient in each channel is 0.014.

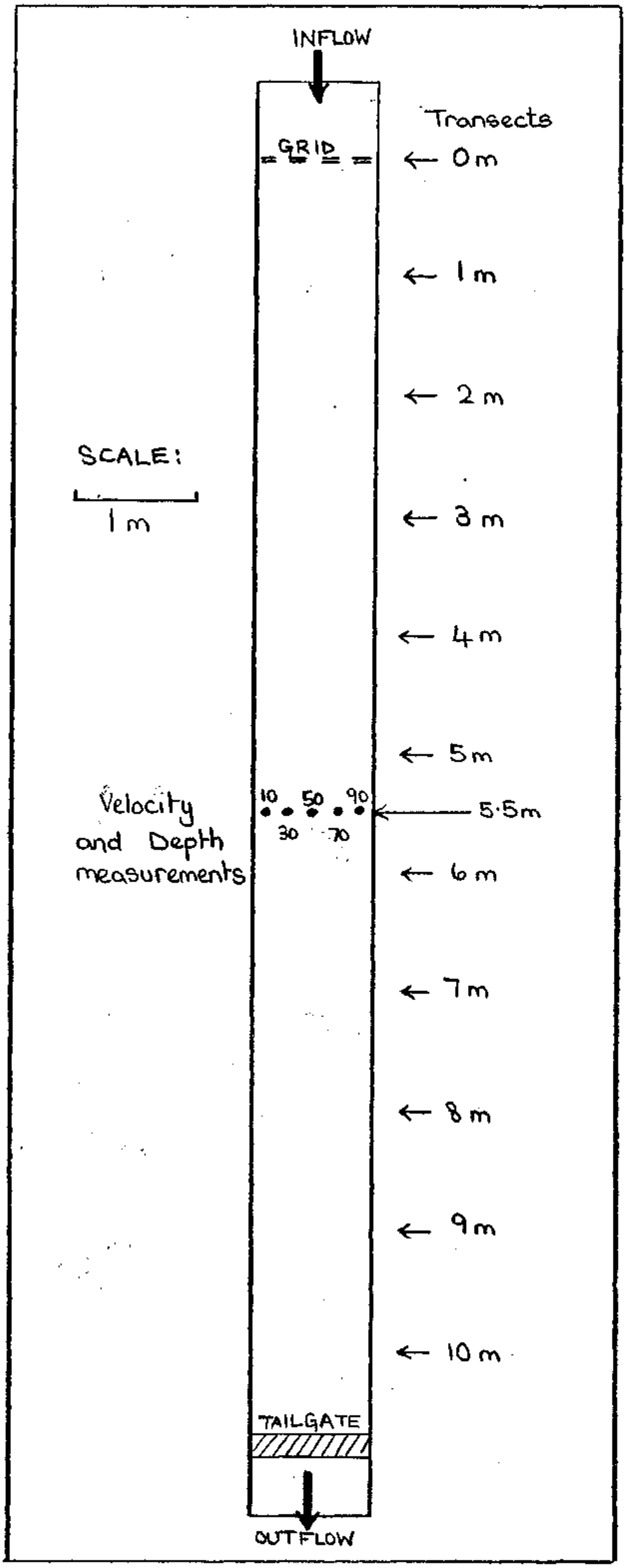

Fig. 1. Scale diagram of channel. Note that only the experimental portion of the channel (10·7m between grid and tailgate) contains bed material.

Compensation water from Grassholme Reservoir passes through a "header tank" which is a spare channel section 0.99 m wide, 3 m long and 0.47 m deep with the open ends blanked off. From the header tank water is drawn off in two pipes. Each pipe then divides and each branch feeds a single channel. The pipe arrangement is assymetrical (Fig. 2) and the pipe feeding each channel is controlled by a gate valve. Water surplus to requirements overflows from the header tank and returns to the river. The discharge to each channel is controlled by manipulation of the valve. There are, however, three complications:

1. It is not possible to attain the highest discharges in all four channels at the same time.

2. There is some interaction between the supplies to each pair of pipes.

If the valve on a channel is initially set to provide a given discharge, depth or velocity and the valve for the other channel which is fed by the same pipe is opened, then the discharge in the first channel may be modified.

3. The overflow level of the header tank is approximately 1.3 m above the level of the valves feeding the channels. Provided that the reservoir compensation discharge is at its statutory minimum value of 340 l s^{-1}, the depth of overflowing water above the rim of the header tank varies by only a few cm. The head above the valves can then be considered constant for practical purposes, regardless of the setting of the channel valves. However, if the reservoir compensation valve is opened to give a discharge greater than 340 l s^{-1} the depth of overflowing water at the header tank can be as high as 30 cm. A change in head of this magnitude did not have a detectable effect on the relationship between the setting of the channel valves and

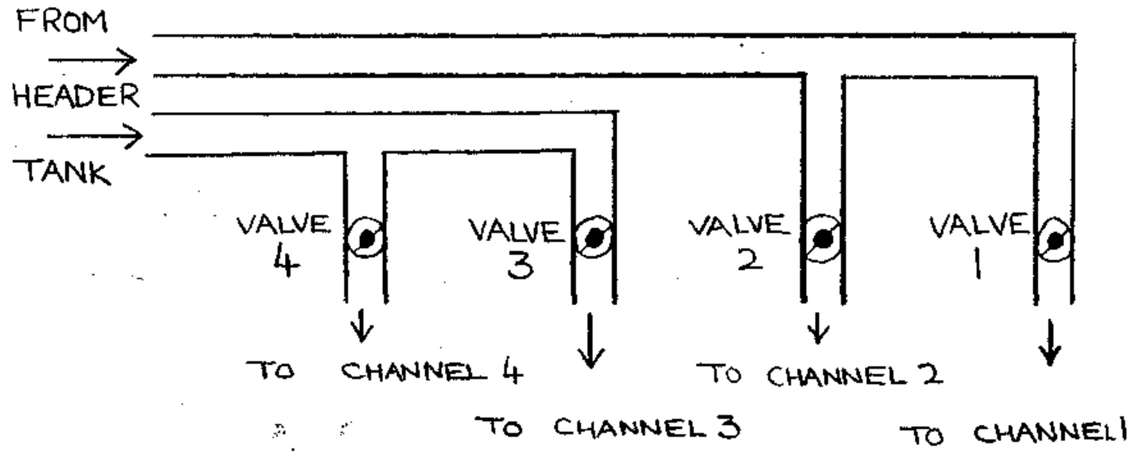

Fig. 2. Diagram to show layout of pipes feeding the channels.

discharge in the channels.

Once the discharge (Q) in a channel has been set, the product of mean water depth ($\bar{D}$) and mean water velocity ($\bar{U}$) has been determined since $Q = W \bar{U} \bar{D}$, where W is the channel width. However, the relative contributions of $\bar{U}$ and $\bar{D}$ to Q can be modified by adjusting the tailgate. In general, lowering the tailgate gives a reduction in $\bar{D}$ and an increase in $\bar{U}$.

EXPERIMENTAL DESIGN

Ottaway & Clarke (1981) defined their experimental regimes in terms of mean surface water velocity and mean water depth. They aimed for similar, synchronised stepwise increases in velocity and depth in all four channels although the highest discharge could only be achieved in two channels at any one time. The gravel used was natural river gravel containing a number of boulders which are likely to have complicated the flow pattern and added considerably to variation of depth and velocity within and between channels.

In later work the main aims were:

1. To obtain comparability between channels. They were, therefore, filled to a depth of 12.5 cm with a mix of washed Dogger Bank gravel. This gave a relatively well-sorted bed (Table 1).
2. To establish a set of regimes which was more acceptable statistically than that used by Ottaway & Clarke. The former design had two major disadvantages. Firstly, only two channels were subject to the highest velocity treatment. Secondly, as the flow was increased in all four channels through the course of each experiment, the separate effects of velocity and time were rendered indistinguishable. The modified

TABLE 1. Composition of the gravel used in the channels from Carling (in press, 1984). Statistics of the frequency distribution are: Arithmetic mean = 15.57 mm, Standard deviation = 8.10 mm, Skewness = 0.54, Kurtosis = 2.22. Note that the ø scale is an expression of particle sizes on a $\log_2$ basis and ø = 0 when particle size = 1 mm.

Particle size range (mm)	ø	% composition
32 - 16	- 4.5	41.71
16 - 8	- 3.5	34.73
8 - 4	- 2.5	22.84
4 - 2	- 1.5	0.69
2 - 1	- 0.5	0.01
1 - 0.5	+ 0.5	0.03

design (Table 2) avoids these problems. Channels run at low velocity at the start of each experiment, for a settling-in period, and run at the same low velocity at the end. During the experimental treatments the velocities follow a "Latin square" arrangement.

3. To achieve or approach the target velocities chiefly by valve manipulation, accompanied by minimal modification of tailgate settings. This point is discussed in detail below (see "Methods").
4. To seek to obtain the required velocities without excessive changes in depth, especially to avoid the lowest velocities being accompanied by extremely shallow depths (<5.0 cm). In addition, the repeatability of the channel settings and the interrelationships between the various variables and their consequent effects were examined as far as possible.

METHODS

Depths were measured directly, to the nearest 0.5 cm. Tailgate settings were recorded initially as the vertical height of the top edge of the tailgate above the channel floor, to the nearest 0.1 cm. Velocities were measured at 0.6 of depth and the results were expressed in cm s^{-1}. An "Ott" portable current meter was used throughout the routine calibration, but a "Streamflo" miniature current meter was used during investigation of some specific problems. Data obtained from the "Streamflo" are indicated in text and tables.

It was clear that at any given channel setting there was a tendency for velocity to decrease and depth to increase with distance down the channel. Therefore, during the basic calibration, all measurements of water depth and velocity were made on a transect across the channel at a point 5.5 m downstream of the grid. Additional information on

TABLE 2. General design of the 1982-3 channel experiments. (A) gives details of the four treatments, denoted by the letters a-d. Each treatment is a combination of a target velocity and a target depth. Channel settings were found which came reasonably close to achieving these targets (see below). (B) gives the five "regimes" or combinations of treatments to be used in experiments with biological material. Note that regime 1 (lowest velocity in all four channels) was used at the start and finish of each experimental run.

A.

Treatment	Target velocity (cm s^{-1})	Target depth (cm)
a	7.5	5.4
b	25.0	9.8
c	40.0	12.3
d	70.0	16.2

B.

Regime	Channel 1	2	3	4
	Treatments			
1	a	a	a	a
2	a	d	c	b
3	b	c	d	a
4	c	b	a	d
5	d	a	b	c
1	a	a	a	a

spatial variation in depth and velocity within the channels has been obtained. During initial setting of the channels, measurements were made at a single point in mid-channel. One measurement of depth was made and the results of 3 Ott meter runs, each of 30 sec, were obtained. When the initial setting was achieved satisfactorily this sequence of measurements was repeated at 5 points across the transect, at distances of 10, 30, 50, 70 and 90 cm from the left hand edge of the channel, when facing upstream (Fig. 1).

Valve openings were recorded in terms of the number of anticlockwise turns of 180° of the valve key and expressed to the nearest 0.25 turn, though a slight refinement of this approach was achieved by more exact recording of the orientation of the valve key when the valve was in the appropriate setting.

The original aim was to obtain the various required velocities by manipulation of the valves, whilst the tailgates were maintained at a fixed position. This proved impossible. At the lowest discharges clear differences between channels became apparent. As a result of leakage around the tailgates there was considerable variation in depth and velocity between channels and in some channels most of the flow occurred through the gravel. The problem was overcome by constructing a fixed wooden dam 20 cm high downstream of each tailgate to act as an effective control during low discharges. When the highest discharges were used with the original tailgate settings the increasing discharge was reflected more by increasing depth than by increasing velocity and it was necessary, at the highest discharges only, to modify the balance between depth and velocity by lowering the tailgate. The need to adjust the tailgates during the experimental runs led to problems in accurately measuring the tailgate height when a large amount of water was passing over it and an alternative technique was devised (see "Variables").

VARIABLES

1. Valve turns and discharge

The relationship between number of 180° valve turns and estimated discharge is complicated by interaction within the system of feed pipes and valves to the individual channels. Variation in header tank level was found to have negligible effect.

When two or more channels are operated at the same time there is some interference within each pair of channels (i.e. between channels 1 and 2 and between channels 3 and 4) over most of the discharge range. The demands of Channels 1 and 3 are dominant over those of channels 2 and 4 respectively, but there is no evidence of interference between adjacent pairs of channels.

The discharge ($Q\ l\ s^{-1}$) in any channel can be predicted from the valve turns on that channel (V_o) and on the other channel of the pair (V_1) by means of the equation,

$$Q = \left[Q_{max}\ \frac{V_o}{V_o + a}\right]^{1 - m_i V_1}$$

where $Q_{max} = 150$, $a = 16.5$ and m_i is channel specific, $m_1 = 0$, $m_2 = 0.01$, $m_3 = 0$ and $m_4 = 0.005$. This model accounts for 94.5% of the variance but gives errors on the estimates of discharge of up to $\pm 16\ l\ s^{-1}$. Despite this, the equation is valuable in making first approximations to the valve settings needed to achieve any given combination of discharges within the channels.

Observed data points and calculated curves are shown in Figures 3, 4, 5 & 6.

It should be noted that the total discharge required to run all four channels at maximum discharge is more than 400 l s^{-1} and this exceeds the maximum guaranteed supply of 340 l s^{-1}.

2. Velocity and depth

Once a given discharge has been achieved within a channel, the balance between water depth and velocity can be adjusted, within limits, by the tailgate setting. Three aspects of the balance between velocity and depth have been considered.

a. Setting the tailgate.

The general arrangement of the tailgate is shown in Figure 7. The channel crossbar is a fixed bar with a threaded insert. The tailgate is raised or lowered by adjusting the threaded rod relative to the crossbar. There should be a simple relationship between tailgate height and the length of the threaded rod above the channel crossbar, though the precision of this will be diminished by the presence of the chain which provides a flexible link between the threaded rod and the tailgate.

Direct measurement of tailgate height is difficult during moderate to high discharges. In contrast, the portion of the threaded rod above the channel crossbar is always above water and its length can be measured readily. Details of the relationship between tailgate height and the length of the threaded rod are shown, for each channel, in Figure 8. The linear regressions account for almost all of the variance of tailgate height and can be used as a precise means of predicting tailgate height from the length of the threaded rod.

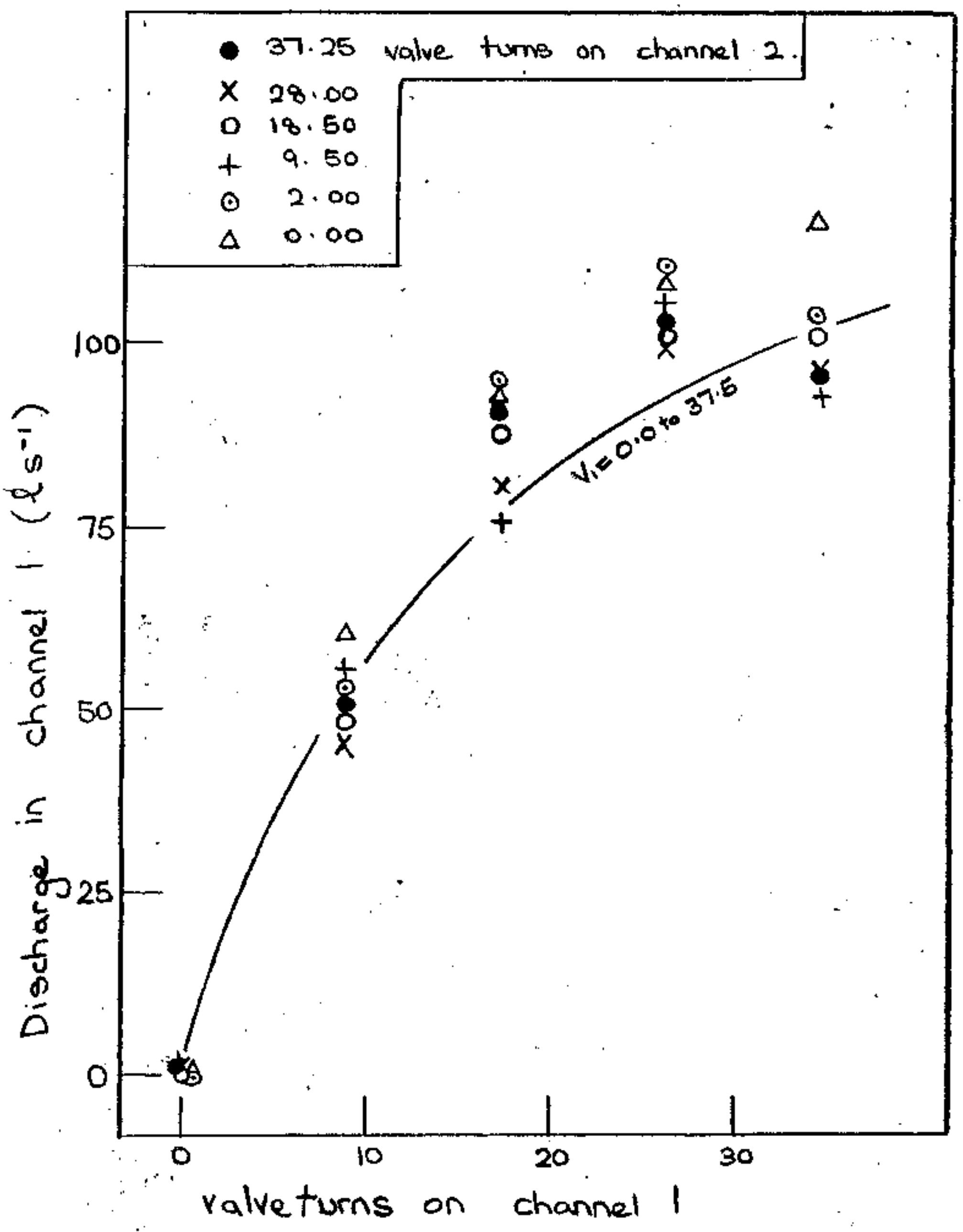

Fig. 3 Discharge (Q) against valve turns (V_0) in channel 1, the related valve turns in channel 2 (V_1) are indicated by symbols. The calculated curve is also shown.

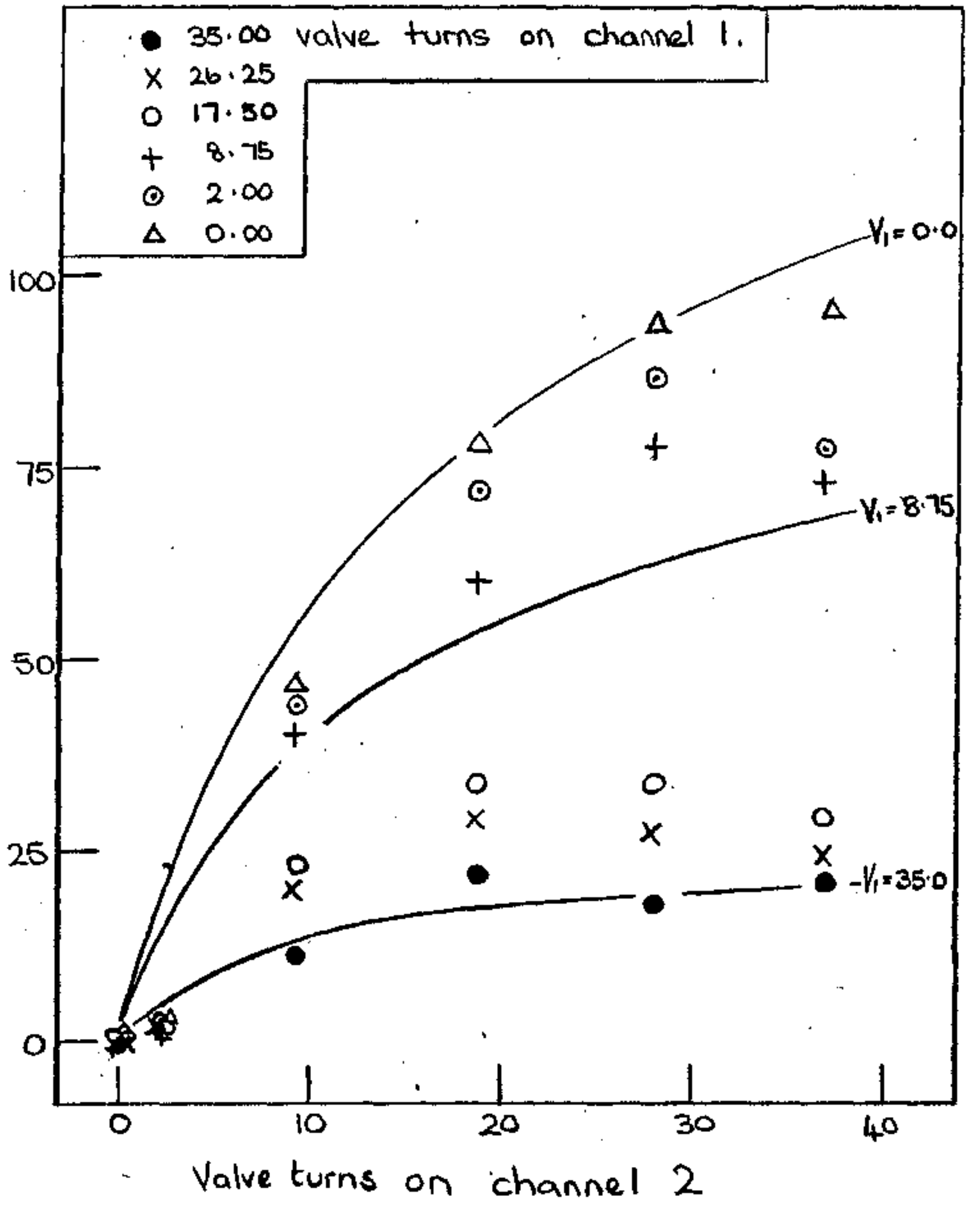

Fig. 4 Discharge (Q) against valve turns (V_0) in channel 2 (V_1), the related valve turns in channel 1 are indicated by symbols. A selection of the calculated curves is also shown.

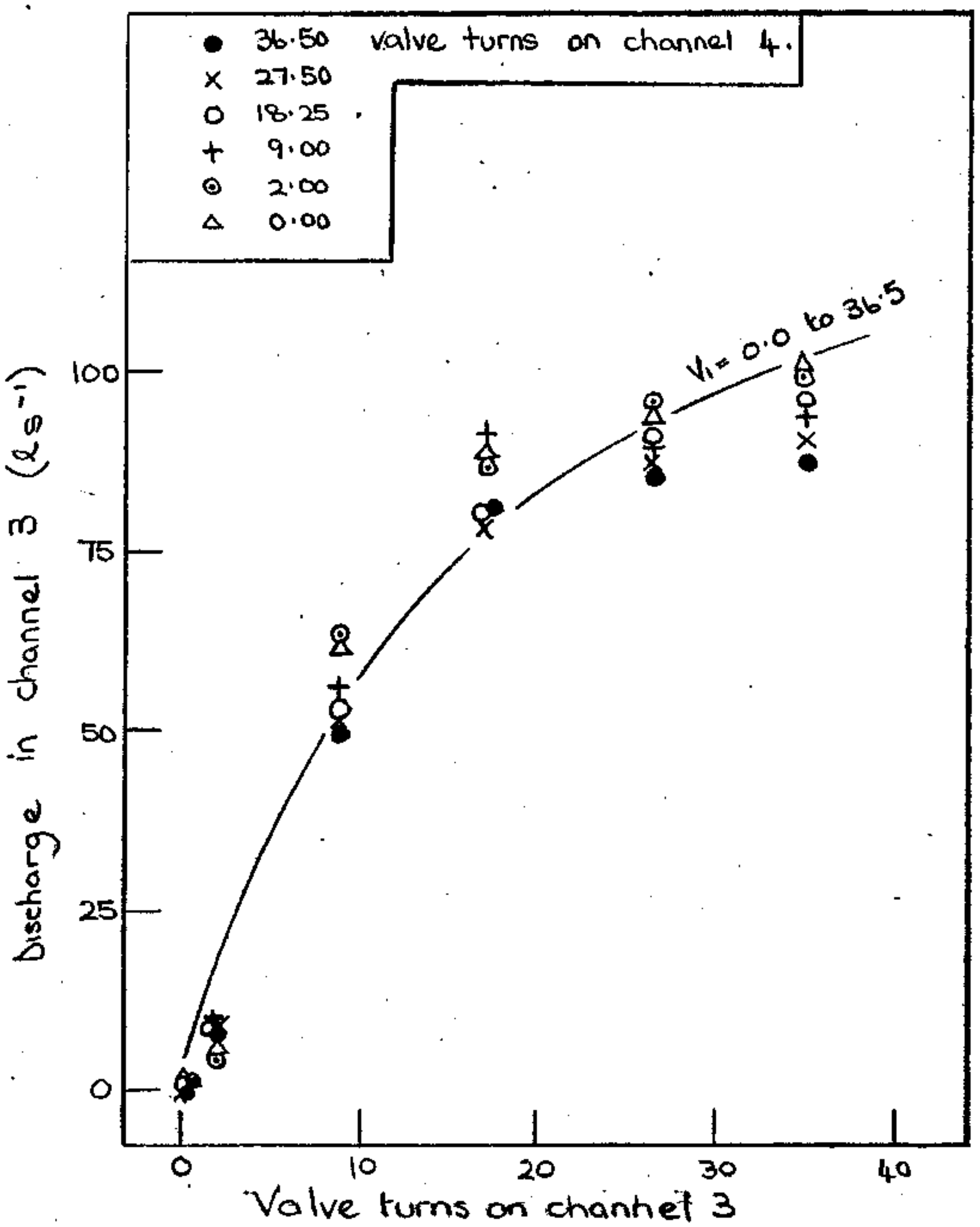

Fig. 5. Discharge (Q) against valve turns (V_0) in channel 3, the related valve turns in channel 4 (V_1) are indicated by symbols. The calculated curve is also shown.

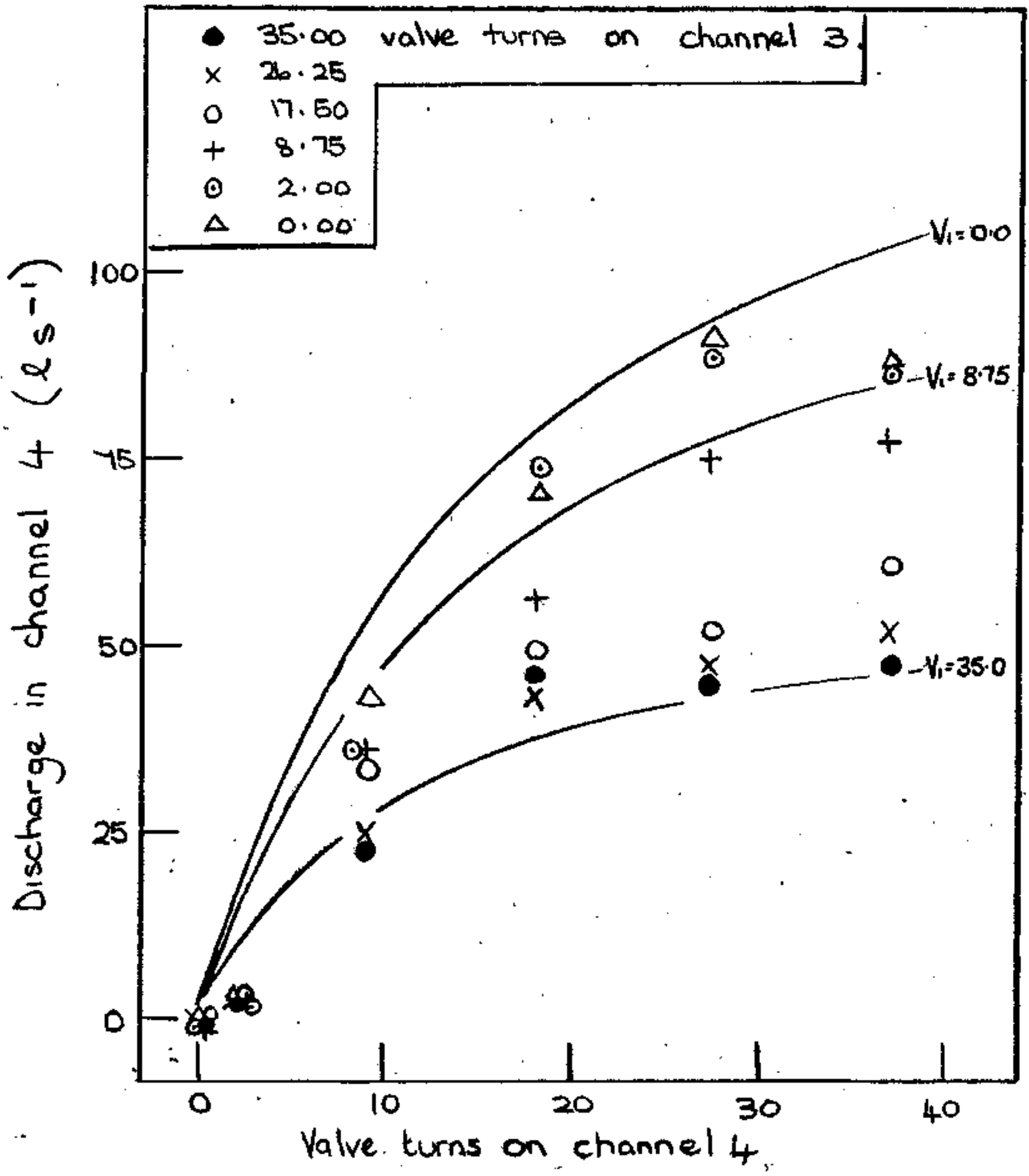

Fig. 6. Discharge (Q) against valve turns (V_0) in channel 4 (V_1), the related valve turns in channel 3 are indicated by symbols. A selection of the calculated curves is also shown.

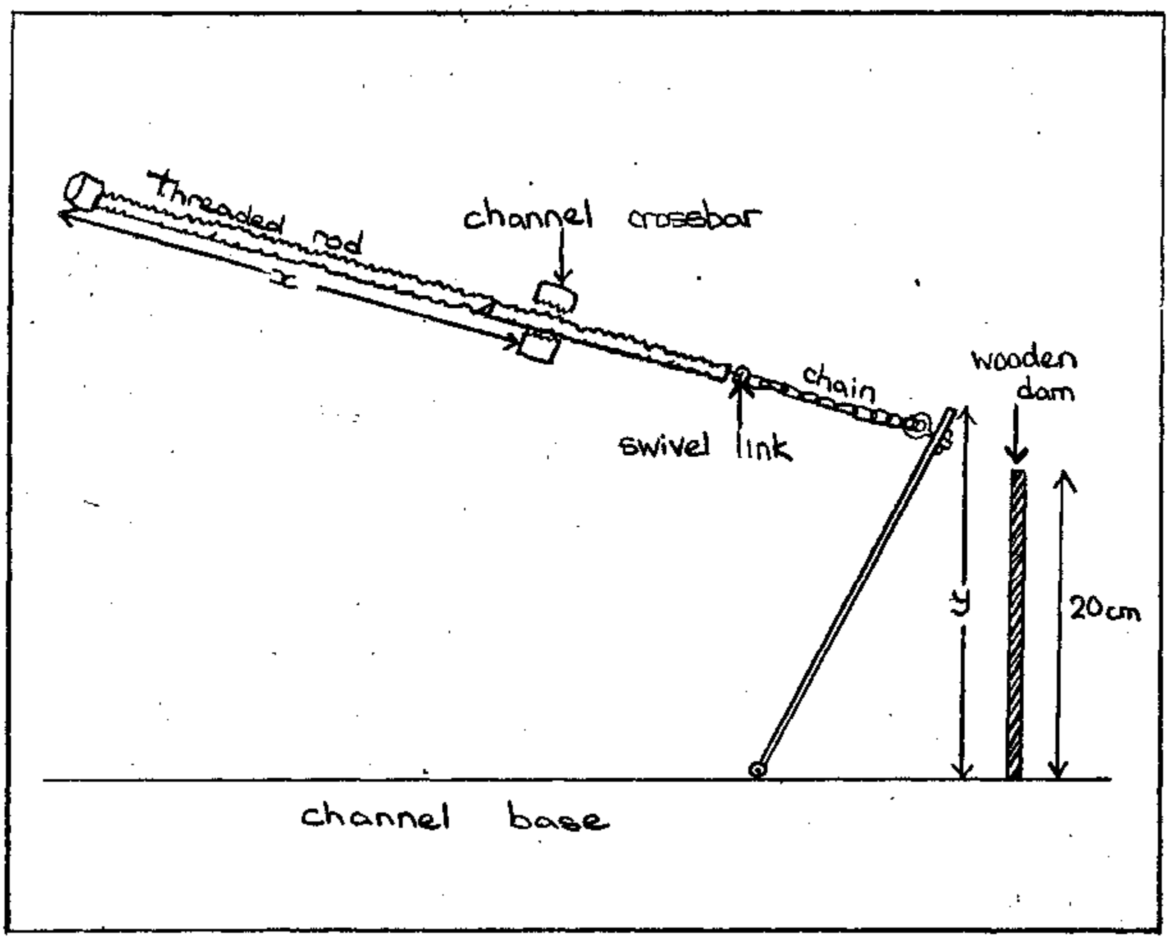

Fig. 7. Diagram, not to scale, of channel tailgate arrangement in longitudinal section. y and x are the tailgate height and length of the threaded rod respectively.

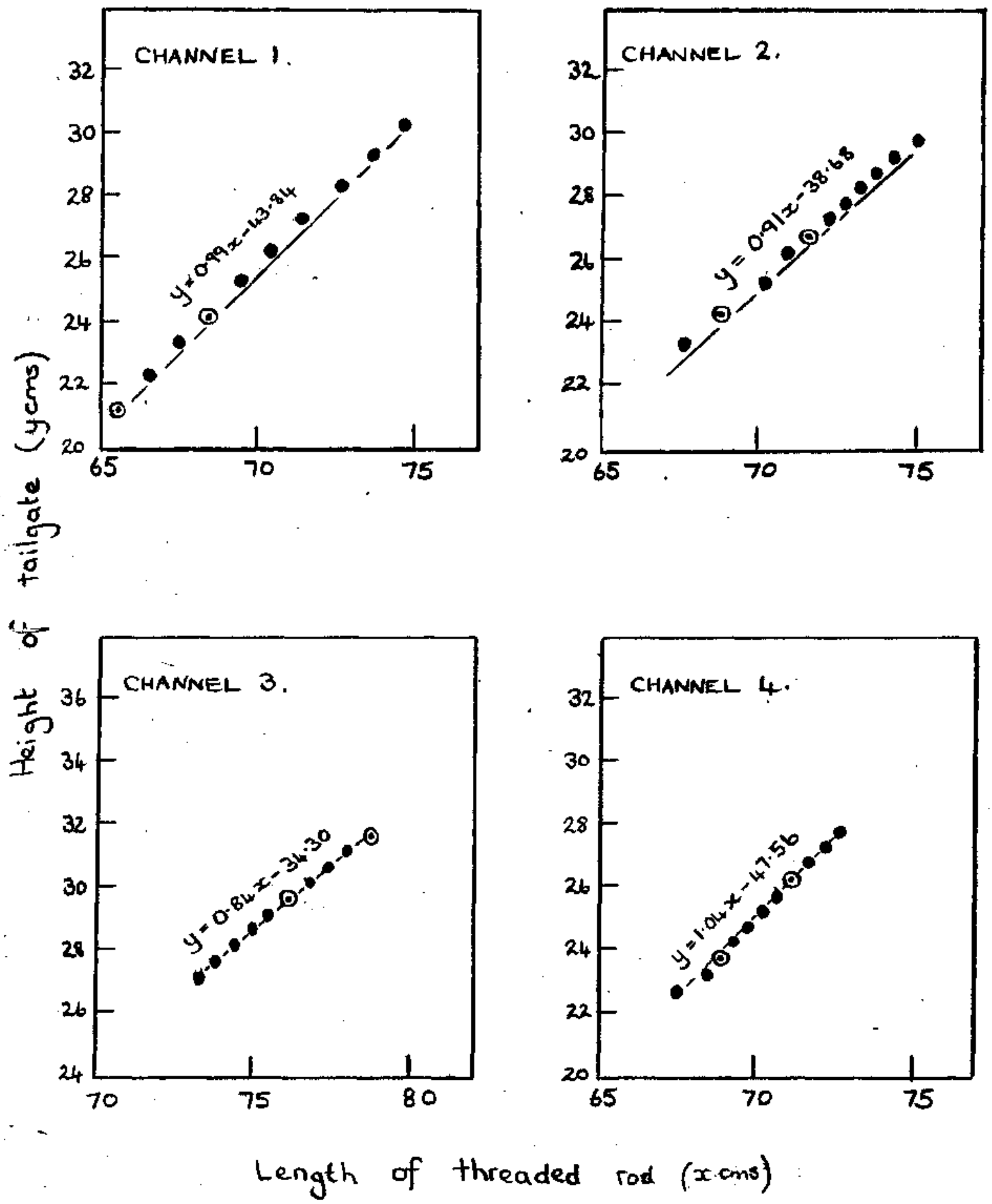

Fig. 8 Relationship, for each channel, between tailgate height plus 2mm of rubber (y) and the lenght of threaded rod on the upstream side of the channel crossbar (x) The calculated regressions of y upon x are also shown. The open symbols indicate the two settings used during the 1982 calibration.

To predict a tailgate setting (y cm) from the length of the threaded rod (x cm), the regression equation for y in terms of x can be used. The length of the threaded rod can be adjusted until the predicted tailgate setting is the required value. A separate equation for each channel is required and the equations are given in Fig. 8.

The wooden dam (see Figure 7) was an essential addition to the system but its installation led to potential problems during use of the channels for biological experiments. The gap between the tailgate and the dam created a water-filled space in which fish fry dispersing from the channel were likely to lodge. To avoid this, butyl rubber sheeting was used to form a flexible bridge over the gap between the top of the tailgate and the top of the dam. This raised the effective top of the tailgate, at any given setting, by 2 mm. Allowance for this has been made by adding 0.2 cm to the measured tailgate height to give the tailgate values plotted in Fig. 8.

b. The relationship between depth and velocity on the 5.5 m transect at standard tailgate settings.

In most of the biological work in the channels a set of standard tailgate settings was used, except at the highest discharges (see Appendix 1). Within each channel, at the standard tailgate setting, depth and velocity at the 5.5 m transect were linearly related and details of the appropriate regression lines are shown (Fig. 9). These relationships have value in making adjustments to channel settings. Once the required discharge has been approximated by setting the valves with the tailgate at the standard height, then finer adjustment of the valves can be made in order to achieve a depth at the 5.5 m transect which corresponds to the target velocity.

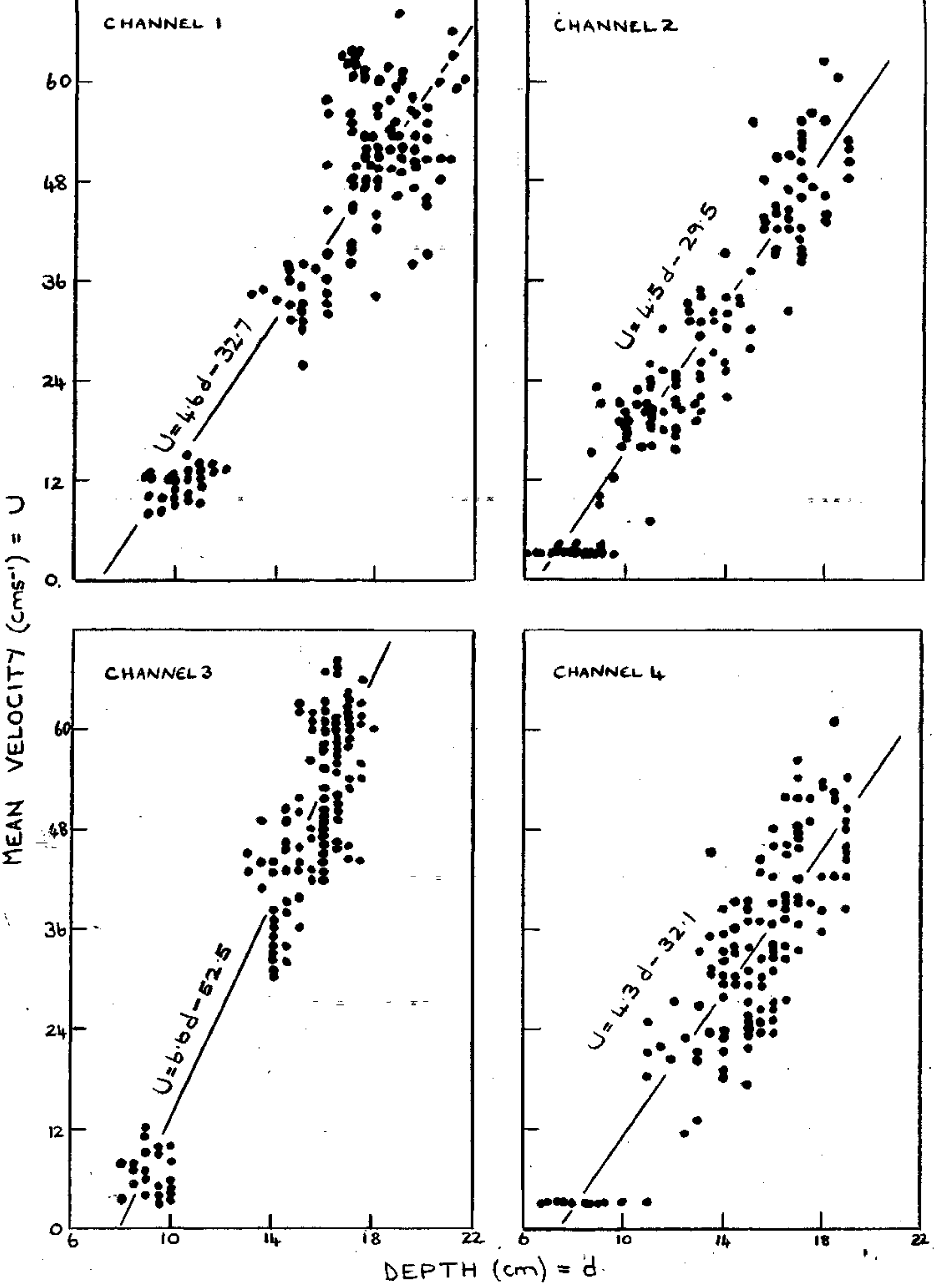

Fig. 9. Depth (cm) and Mean Velocity (cms^{-1}) at 0·6 of depth in each channel
Note that at each point where depth was measured three separate velocity determinations were made. The regression line for each channel is based on 450 original points. However only the 150 mean points for each channel are shown on the graph

This does not eliminate the need for final checking by direct measurement of velocity but it reduces the number of time-consuming velocity measurements which are required.

c. Effect of tailgate height on velocity and depth at the 5.5 m transect.

During September a series of trials was made in channels 3 and 4 on the effects of tailgate setting upon water velocity and depth. In each channel the four experimental valve settings were used in turn, in combination with five different tailgate settings, one of which approximated to the standard experimental setting. For each combination of valve and tailgate settings, the water depth and velocity on the 5.5 m transect were determined. In addition, depth and velocity were determined at several points in mid-channel at intervals along the channel length, though at low valve and tailgate settings the water was too shallow at the upper end of each channel to permit collection of data on velocity. The data on variation in depth and velocity along the length of each channel are described later.

Plots of mean depth against tailgate setting for both channels and a range of valve turns are given in Fig. 10 and similar plots of mean velocity against tailgate setting in Fig. 11. Also shown are the calculated regression lines, one for each combination of channel and number of valve turns. Details of the regression equations are given in Table 3. All lines in Fig. 10 and in Fig. 11 are significantly different in both intercept and gradient.

An attempt was made to combine the effect of tailgate setting and valve turns into multiple regression equations. Separate equations, one for each channel, explained 90% of the variation in depth and 85% of the variation in velocity. The equations are given in Table 4.

TABLE 3. Linear regression equations relating depth and velocity on the 5.5 m transect to tailgate setting at each of four valve settings.

$d = a + bx$ $u = r + sx$

d = depth (cm)

u = velocity (cm s^{-1})

x = tailgate setting (cm)

Valve setting (180° turns)	a	b	r	s
Channel 3				
1.50	-14.05	0.72	22.57	-0.53
5.75	-18.36	0.97	162.08	-4.06
14.25	-17.56	1.04	194.71	-4.58
35.00	-17.52	1.09	242.37	-5.72
Channel 4				
3.75	-14.29	0.86	16.28	-0.36
7.75	-10.41	0.85	59.00	-1.28
33.00	-6.79	0.86	117.47	-2.50
36.50	-7.00	0.88	121.82	-2.55

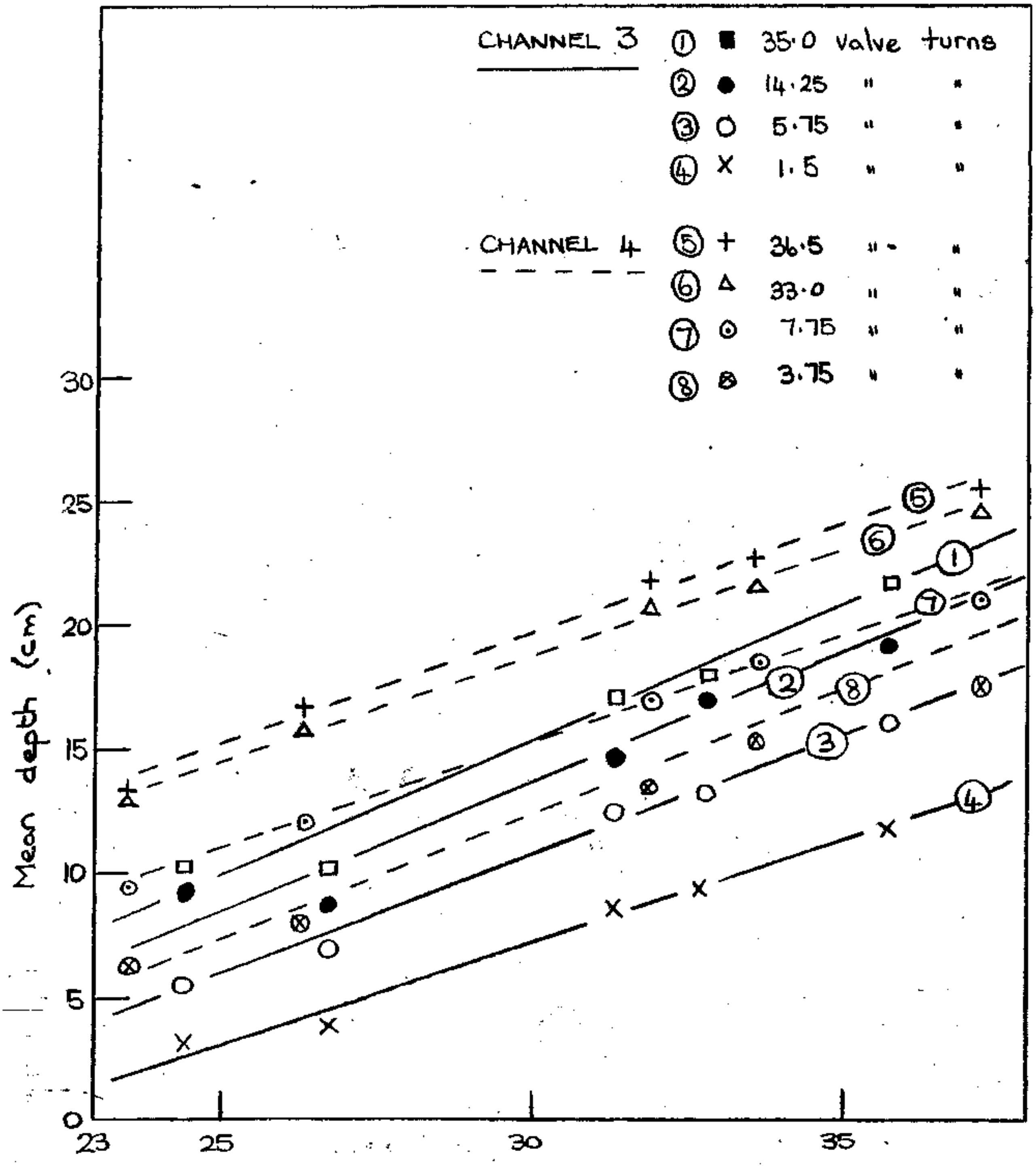

Fig. 10 Mean depth (cm) against tailgate setting (cm) on the 5·5 m transect at four valve settings in channels 3 and 4. The summary of each regression line is given in Table 3.

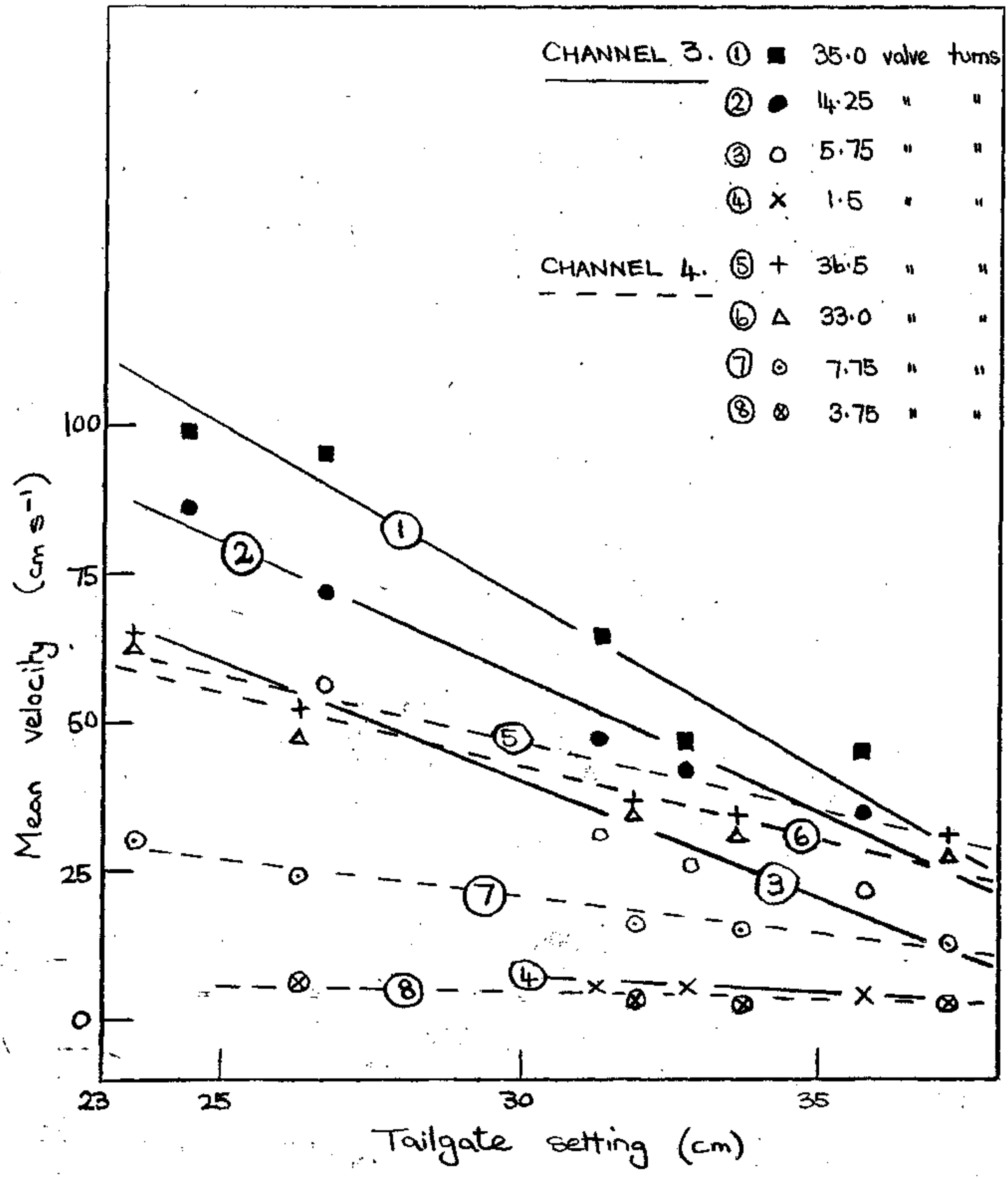

Fig. 11. Mean velocity (cms⁻¹) against the tailgate setting (cm) on the 5·5 m transect at four valve settings in channels 3 and 4. The summary of each regression line is given in Table 3.

TABLE 4. Multiple linear regression equations relating depth and velocity on the 5.5 m transect to tailgate setting and valve setting.

$d = a + bx + cv$ $u = r + sx + tv$

where d = depth (cm)

u = velocity (cm s^{-1})

x = tailgate setting (cm)

v = valve setting (180° turns)

	a	b	c	r	s	t
Channel 3	-19.05	0.94	0.20	184.16	-5.08	1.21
Channel 4	-13.55	0.86	0.21	60.57	-1.76	1.04

If for any reason, it is desired to use a tailgate setting other than the standard one on channels 3 or 4, the multiple regression equation will give a useful prediction of depth or velocity for any given valve setting.

PATTERNS OF VELOCITY AND DEPTH WITHIN CHANNELS

A full analysis of the patterns of spatial variation of depth and velocity within channels at various discharges requires the collection of very large quantities of data and this was not possible within the context of the present contract. However it is necessary to have some information on variation in velocity and depth along the length of each channel and on variation of velocity and depth with distance across the channel.

1. Variation of velocity and depth with distance down the channel.

At low discharges a "ponding" effect in the downstream half of the channel can be seen. A tendency for depth to increase and velocity to decrease with distance down the channel would be expected, but at low discharges, at least, the gradients of these trends may well show spatial discontinuities.

In each channel under each discharge treatment the water depth and the velocity at 0.6 of depth were measured in mid-channel (i.e. 50 cm from the channel sides) at 1 m intervals along the length of the channel and also at the 0.5, 5.5 and 10.5 m transects. At the lowest discharge (Treatment "a" - see Table 2 and Fig. 12) velocities were measured with the "Streamflo" meter. All other velocities were measured by "Ott" meter.

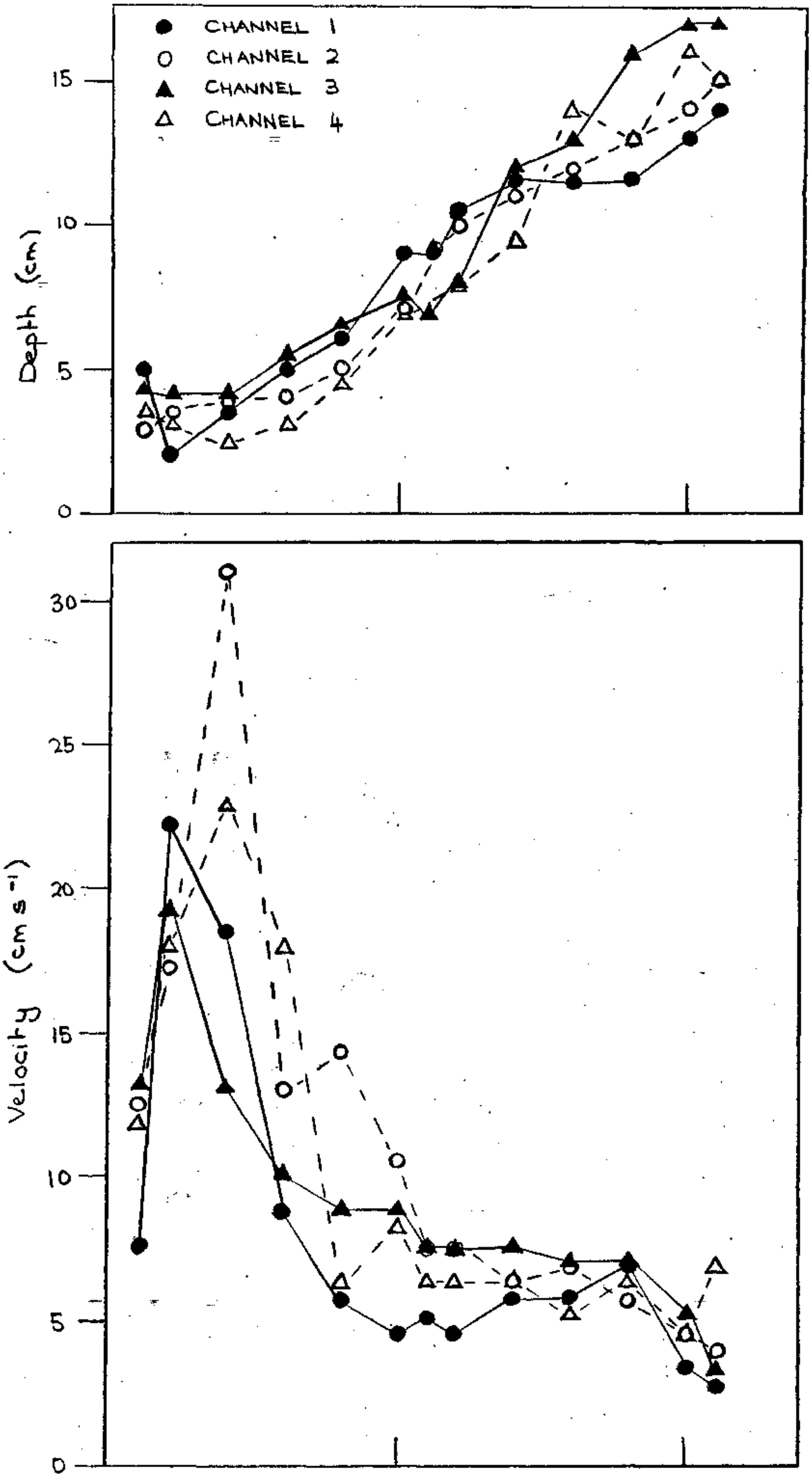

Fig. 12. Observed water velocities at 0.6 of depth and water depth 50 cm from the channel side at different distances downstream of the grid. Treatment "a". Data from "Streamflo" meter.

During treatment "a" depths at the upstream ends of the channels were too shallow for use of the "Ott" meter and use of the "Streamflo" became essential, even though the results from this meter must be treated with some caution. In the present discussion the "Streamflo" data are assumed reliable.

The recorded velocities and depths are shown in Figs. 12, 13, 14 & 15. The following points arise:

a. The data points show appreciable scatter both within and between channels and this is particularly evident for depths at the downstream ends of the channels and for velocities at the upstream ends.

b. There is considerably turbulence for 0.5 - 3m downstream of the point of entry of the water. Velocity at 0.6 of depth appears to be relatively low at the 0.5 m transect and then increases with distance downstream to reach a peak between the 1.0 and 3.0 m transects. The position of the peak moves downstream with increasing discharge. The depth data show a minimum value which corresponds to the velocity peak.

c. Downstream of the velocity peak there is a general trend of increasing depth and decreasing velocity with distance downstream.

d. The data from treatment "a" (Fig. 12) show a steep decrease in velocity from the 2 m transect downstream to the 4 or 5 m transect and a less steep velocity gradient in the downstream half of each channel. This discontinuity reflects the "ponding" effect which can be seen at low discharges. It is not apparent at higher discharges (Figs. 13, 14 & 15).

No simple mathematical expressions adequately described the data. Consequently, the data points have been joined by straight lines (Figs. 12 to 15) and the average water velocity and depth in each channel under each treatment have been estimated from the area of the appropriate polygon.

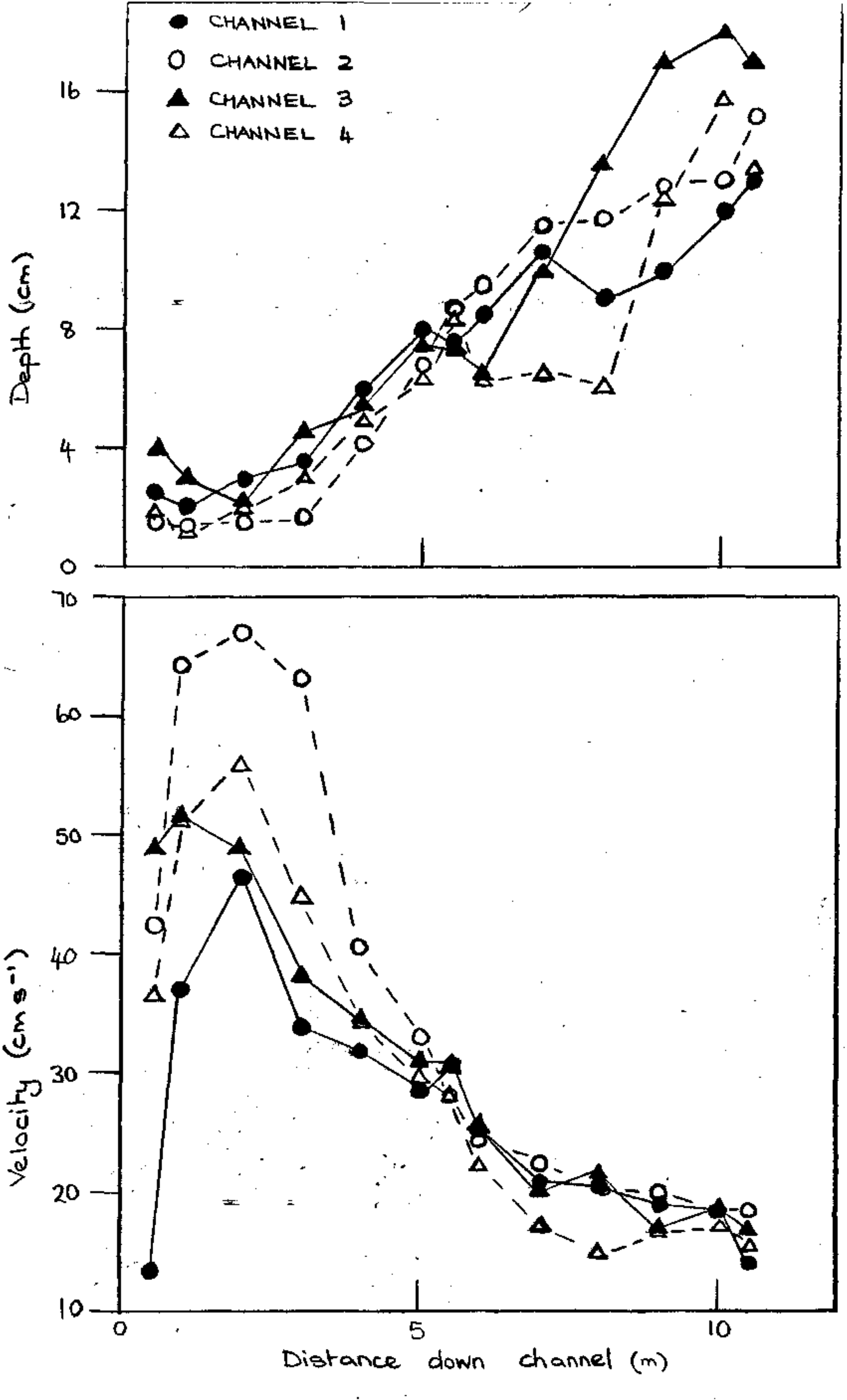

Fig. 13. Observed water velocities at 0·6 of depth and water depths 50 cm from the channel side at different distances downstream of the grid. Treatment "b". Data from "OH" meter.

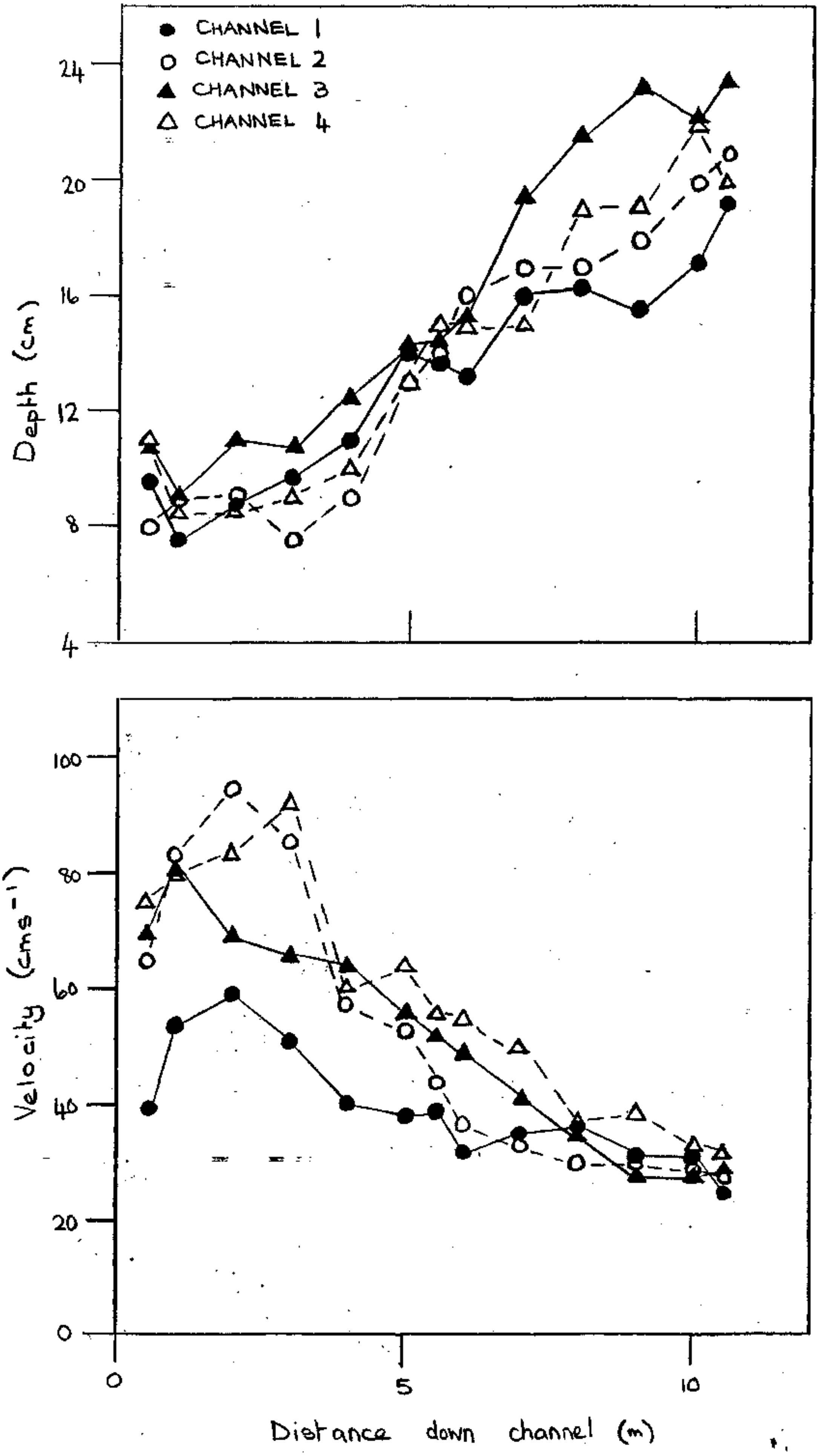

Fig. 14. Observed water velocities at 0·6 of depth and water depths 50cm from the channel side at different distances downstream of the grid. Treatment "c". Data from "OH" meter.

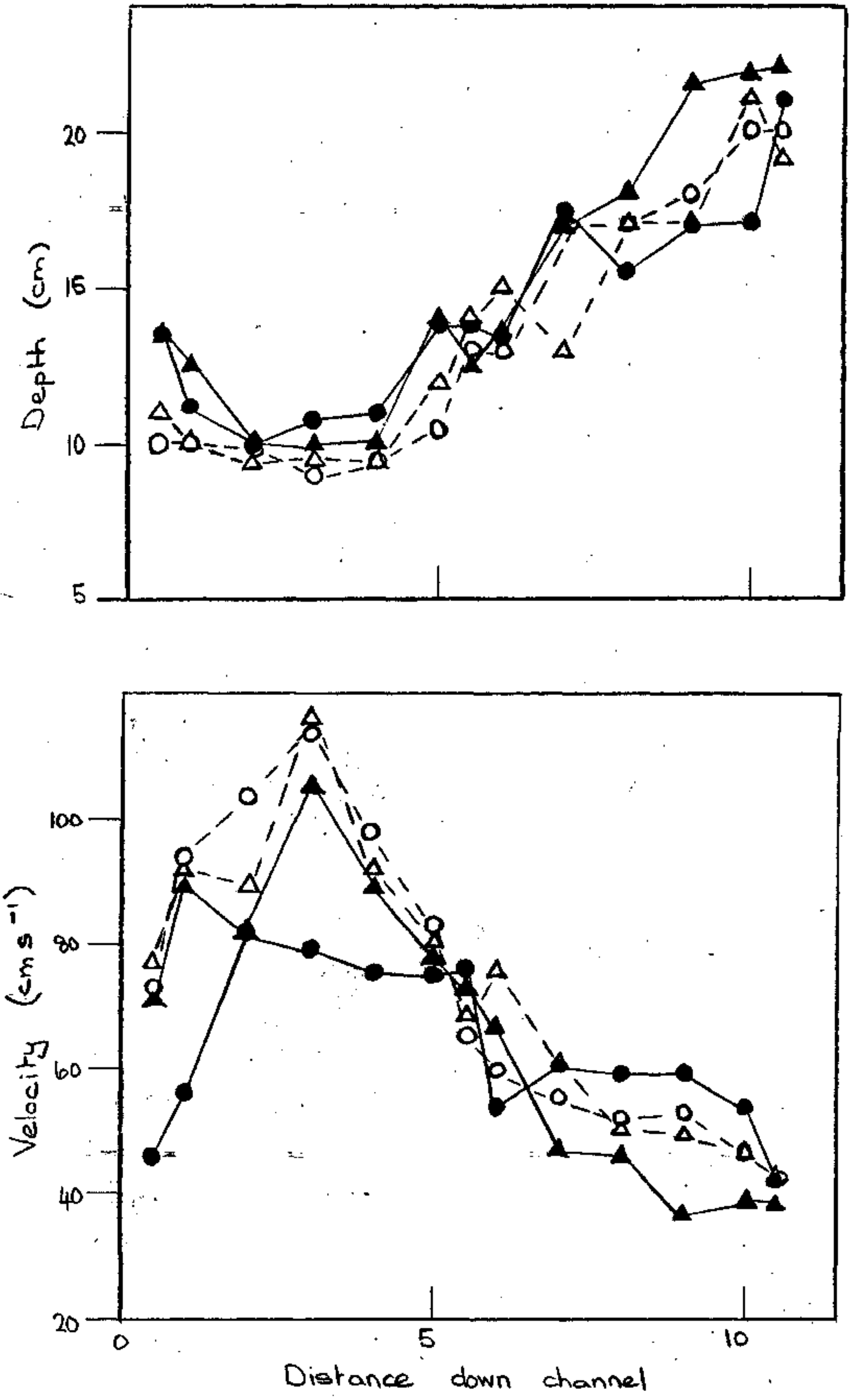

Fig. 15. Observed water velocities at 0.6 of depth and water depths 50 cm from the channel side at different distances downstream of the grid. Treatment "d". Data from "OH" meter.

Comparison of these averages with velocities and depths observed on the 5.5 m transect (Table 5) shows that the latter are a reasonable approximation to the former. The values on the 5.5 m transect are generally within ± 20% of the channel velocity average and within ± 15% of the channel depth average. Overall, the velocities at the 5.5 m transect are 4.5% lower than the channel average and depths are underestimated by less than 0.1%.

In subsequent investigation of variation in velocity and depth across the channel width, data were collected along the channel length. The analysis of variance of the data is more fully described in the next section. Of the relative effects of channel, treatment, distance down and distance across the channel, about 70% of the sum of squares for depth and 40% for velocity were attributable to position down the channel length. This indicates the extent to which a velocity treatment cannot be applied uniformly to the channel length.

2. Variation of velocity and depth across the channel.

Water velocity measurements at 0.6 of depth at a fixed point in a transect show very good repeatability, but there is variation between different points on the transect.

Variation in velocity and depth across the width of each channel was examined at the 0.5 m, 2.0 m, 5.5 m and 7.0 m transects for treatments "b", "c" and "d". Shallow depths and malfunction of the "Streamflo" meter precluded investigation of treatment "a". At the 0.5 m and 7.0 m transects measurements were made at 0.6 of depth at distances of 5, 10, 30, 50 cm from the side of the channel and on the 2.0 and 5.5 m transects at distances of 10, 30 and 50 cm. The data points for velocity are shown in Figures 16, 17, 18 and 19.

TABLE 5. Estimates of average velocity and depth along the whole channel length and observed velocity and depth at the 5.5 m transect. The percentage error incurred by taking velocity and depth at the 5.5 m transect as estimates of means for the channel is also shown.

Channel	Treatment	Average velocity ($cm\ s^{-1}$) (a)	Velocity at 5.5 m transect ($cm\ s^{-1}$) (b)	$\frac{b-a}{a}$ %	average depth (cm) (c)	Depth at 5.5 m transect (cm) (d)	$\frac{d-c}{c}$ %
1	a	5.8	4.5	-22.4	7.7	8.5	10.4
	b	27.8	30.4	9.3	11.3	11.5	1.8
	c	40.5	39.0	- 3.7	13.0	13.7	5.4
	d	65.3	75.7	15.9	13.9	13.8	-0.7
2	a	-	-	-	-	-	-
	b	36.8	27.9	-24.2	11.5	12.5	8.7
	c	52.9	44.1	-16.6	13.5	14.0	3.7
	d	74.9	65.5	-12.6	13.5	13.0	-3.7
3	a	10.2	10.6	3.9	9.3	7.5	-19.4
	b	30.8	30.4	-1.3	12.8	11.5	-10.2
	c	51.6	52.7	2.1	16.0	14.5	-9.4
	d	67.5	73.2	8.4	14.8	12.5	-15.5
4	a	-	-	-	-	-	-
	b	30.2	27.9	-7.6	10.5	12.3	17.1
	c	59.1	55.2	-6.6	14.0	15.0	7.1
	d	74.2	68.1	-8.2	13.4	14.0	4.5

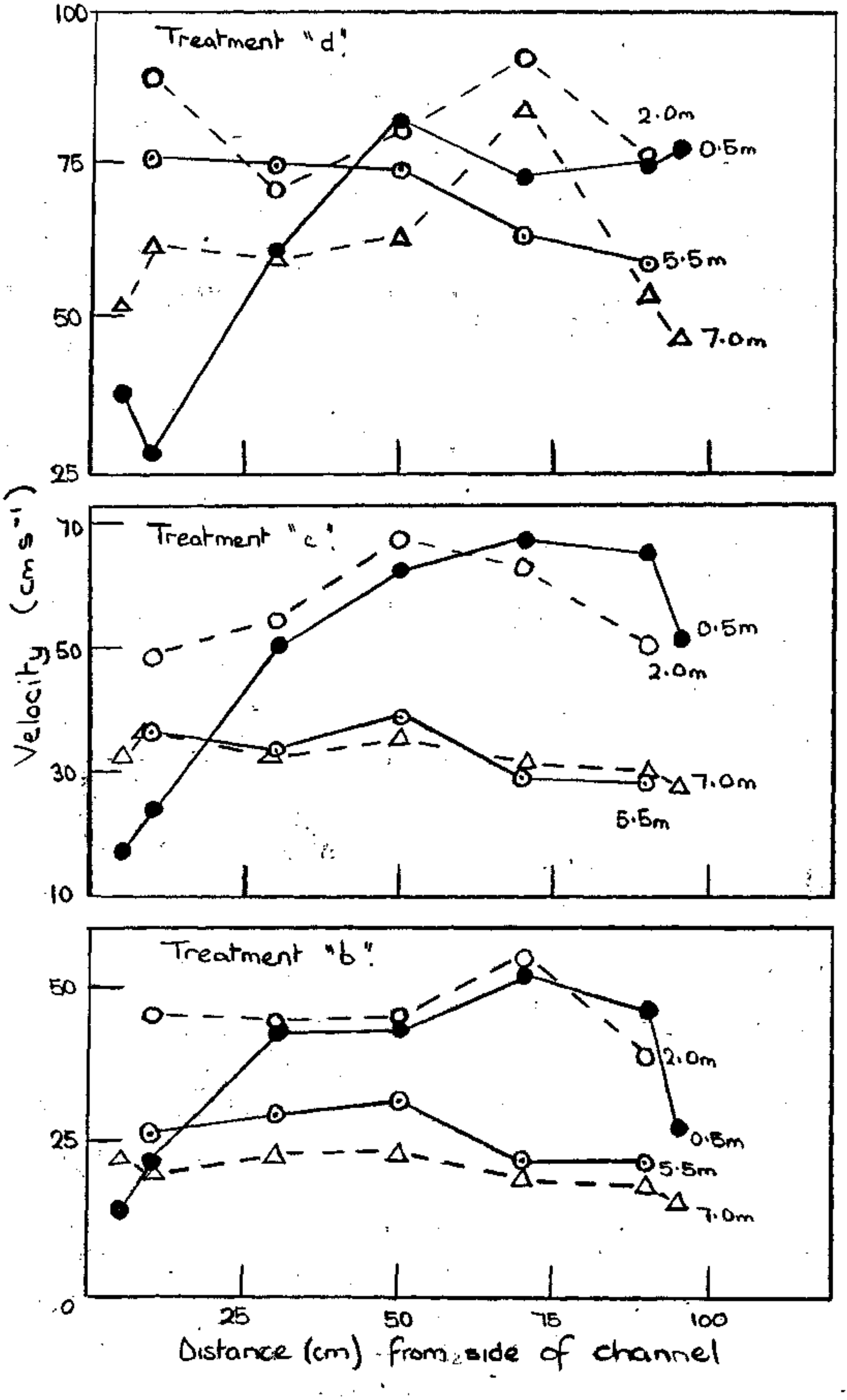

Fig. 16. Variation in water velocity at 0.6 of depth across four transects of Channel I under treatments "d", "c" and "b".

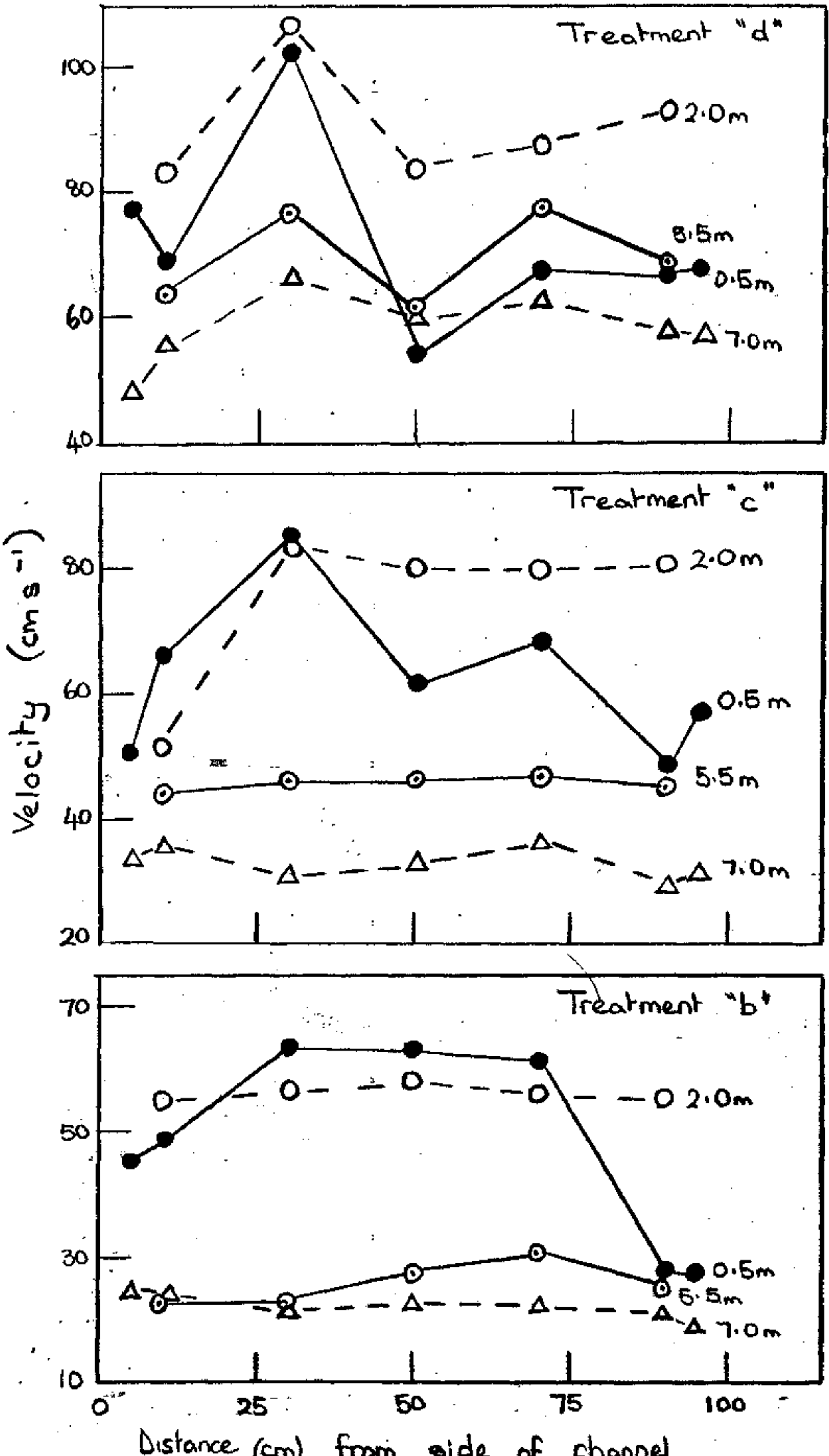

Fig. 17. Variation in water velocity at 0.6 of depth across four transects of channel 2 under treatments "d", "c" and "b".

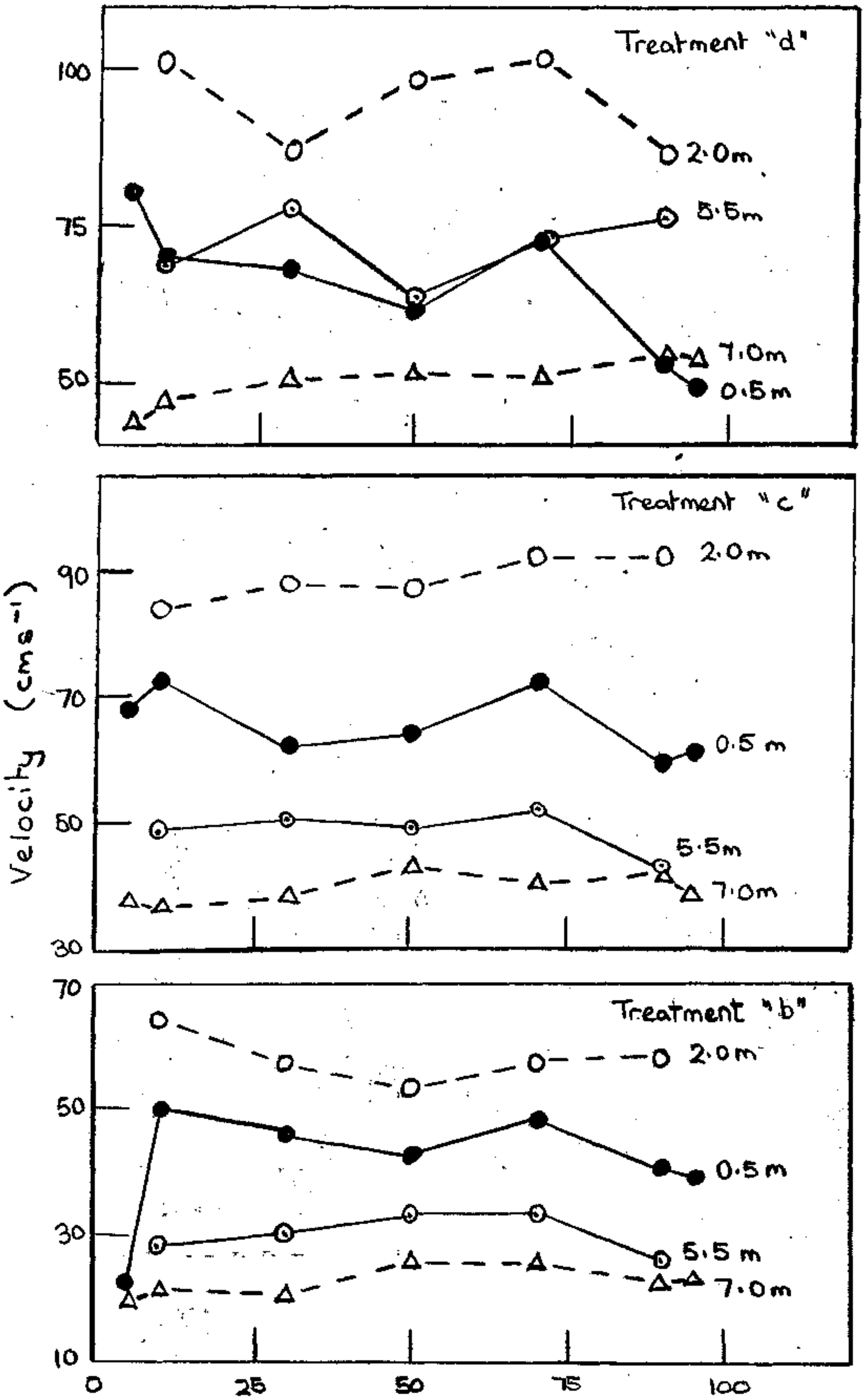

Fig. 18. Variation in water velocity at 0·6 of depth across four transects of channel 3 under treatments "d", "c" and "b".

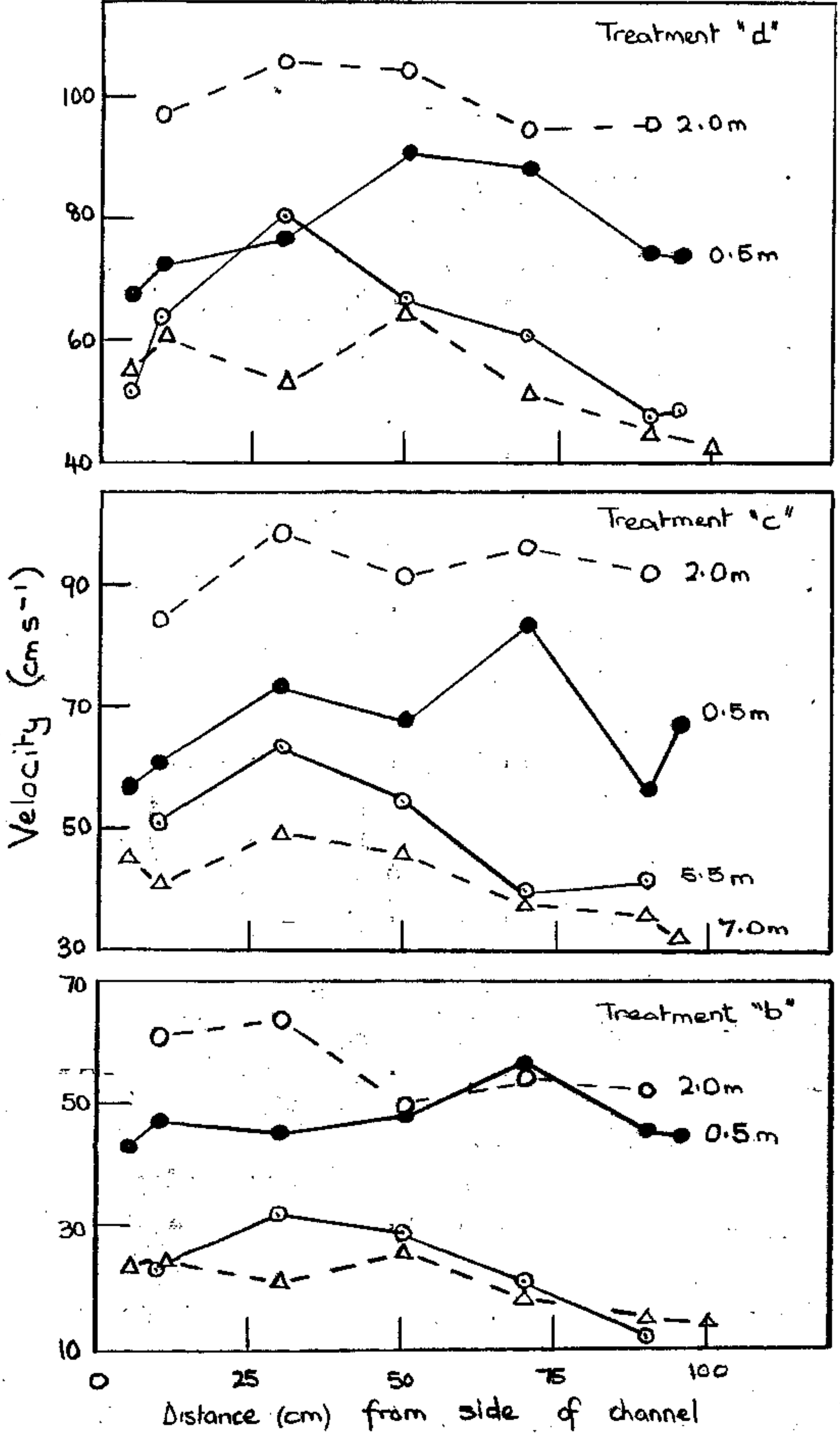

Fig. 19. Variation in water velocity at 0.6 of depth across four transects of channel 4 under treatments "d", "c" and "b".

Univariate analyses of variance were used to examine the effects of the factors channel, treatment, distance down the channel and distance across the channel upon depth and velocity. All main effects and two-way interactions were tested. Each of the factors had a significant effect on both depth and velocity. In particular, the analyses were able to distinguish an overall effect of increased depth and increased velocity in mid-channel relative to channel sides. Although significant the increase in depth was small, mid-channel water being on average 1 cm deeper than water at the channel side when all other factors were equal. However, the increase in velocity at mid-channel was sizeable, being on average 10 cm s^{-1} higher than at the channel sides. The effect of channel and the interaction between channel and distance across the channel were significant for both depth and velocity. This indicates that individual channels have different average levels and an individual pattern of variability in depth and velocity across the channel (See Figs. 20 and 21).

Many other two-way interactions were significant in both the depth and velocity analyses and these were not removable by transformation of the data, which is sometimes possible. This indicates that there is no simple structure to the pattern of variability in depth and velocity in the channels.

REPEATABILITY OF CHANNEL SETTINGS

During March - April 1982, a total of three calibration exercises were carried out:

1. Initial calibration - 8-9 March 1982.

Valve and tailgate settings were empirically adjusted to give velocities and depths at the 5.5 m transect in each channel which approximated to the target values (Table 2). The appropriate settings for the various regimes were recorded (Appendix 1).

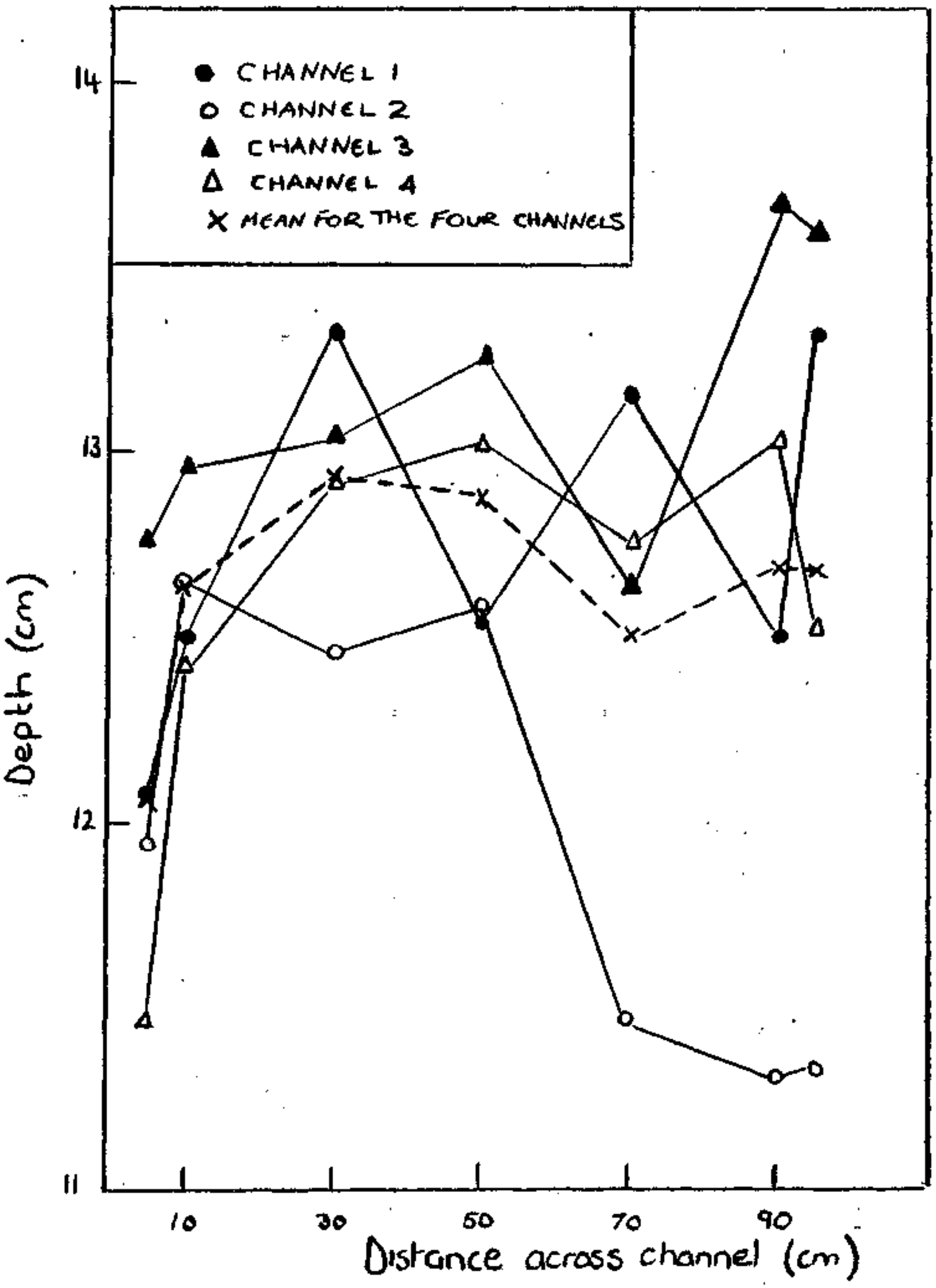

Fig.20.

Variation in depth (cm) with distance (cm) across the channel

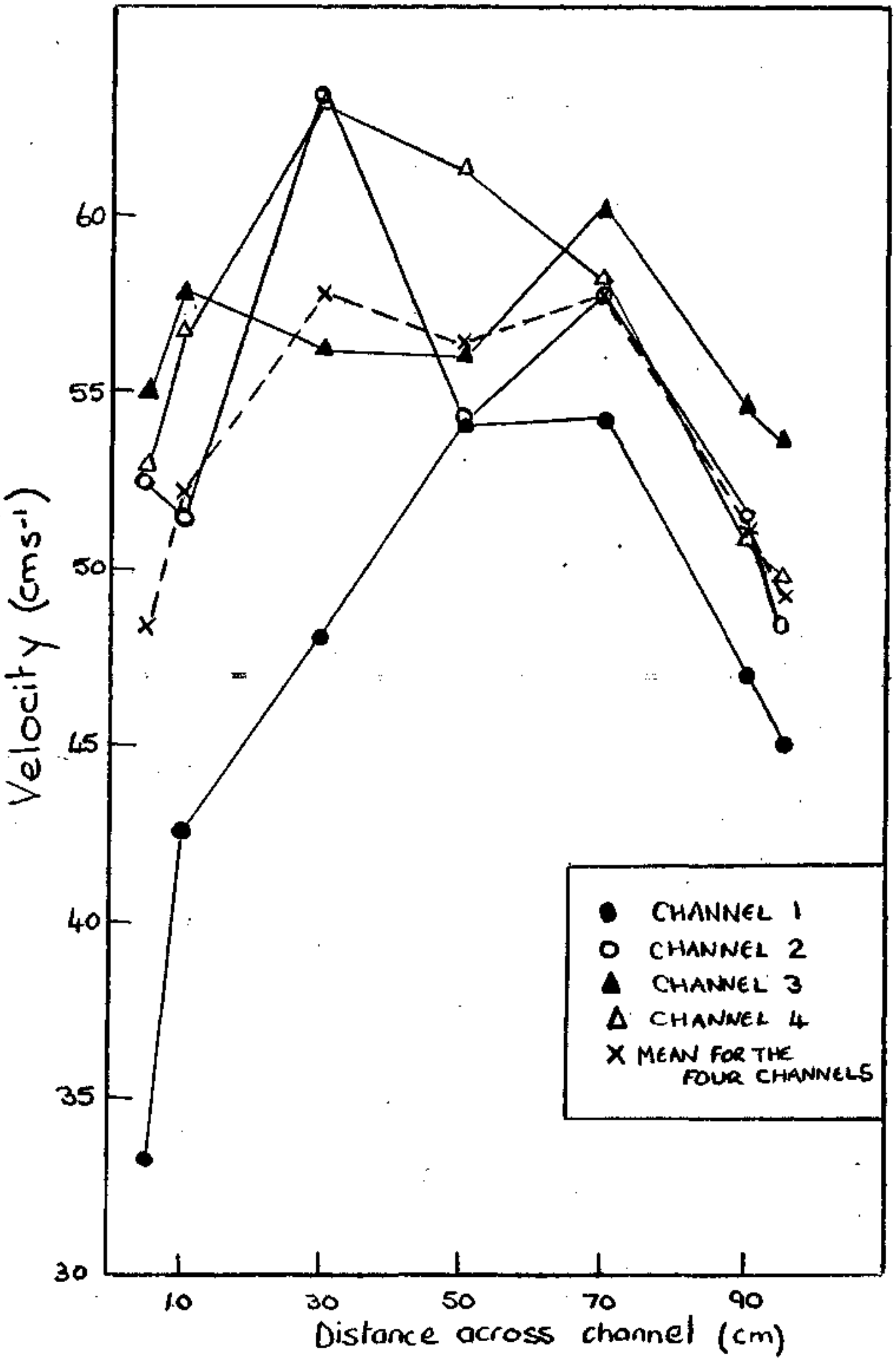

Fig. 21.

Variation in water velocity (cms⁻¹) with distance (cm) across the channel

2. Check on initial calibration - 10-22 March 1982.

Immediately after the initial calibration the experimental regimes and measurements of velocities and depths were repeated. A single modification to the channel settings was made, namely an increase of the channel 3 tailgate setting from 27.5 to 29.5 cm for treatment "d" (see Table 2). This revised setting reduced the velocity in channel 3 at treatment "d" to bring it closer to the target values.

3. Repeated calibration check, following changes in channel structure and head on header tank. 25 March - 6 April, 1982.

On 22 March 1982 rubber sheeting was fitted to the tailgates (see above) and on 24 March the compensation flow from Grassholme reservoir was reduced from 1230 to 340 l s^{-1}. The experimental procedure in the channels was repeated to test whether these two changes had affected the repeatability of the channel settings.

The results of these three calibrations are summarised in Appendix 2. Note that for each channel and treatment the depth was measured at five points across the 5.5 m transect and three measurements of velocity were made at each of the five points. These have been averaged in Appendix 2, but the original data points were used for analysis of variance. The following general points arise:

a. Between repetitions of any treatment in any channel, the average depths achieved usually differed from one another by less than 2 cm. This is small relative to the accuracy of the depth measurements.

b. Within any given treatment the range of average depths achieved generally varied between channels by less than 2 cm.

c. The observed average depths for all treatments cover a narrower range (7.0 - 16.2 cm) than the target depths (5.4 - 16.2 cm). As the main object of the biological experiments is to study the effect of velocity rather than depth, this smaller than expected range of depths is advantageous.

d. Between repetitions of any treatment in any channel, the average velocities achieved differed from one another by less than 10 cm s^{-1} for treatments "a", "b" and "c". However, for channels 1 and 3 under treatment "d" the data points covered a range of 15-20 cm s^{-1}.

e. Variation in average velocity within treatments and between channels covered a range of 10 cm s^{-1} or less for treatments "a", "b" and "c". Under treatment "d" the variation between channels was larger (up to 30 cm s^{-1}).

(f) Under treatments "a" and "b" the observed average velocities were close to the target values. Agreement between observed and target velocities was less close under treatments "c" and "d", though still adequate for our purposes.

(g) The observed average velocities at the four treatments are fairly evenly spaced within the range of available velocities.

Comparison of the observed average velocities and depths from the calibration check of 25 March - 6 April with those from the two previous calibration exercises (Appendix 2) suggests that neither the addition of the rubber sheeting nor the change of water level in the header tank had any appreciable effect on the channel settings.

An analysis of variance was carried out to examine the effects of repetition, treatment, channel and distance across channel on depth and velocity at the 5.5 m transect. The second sets of readings for treatment "a" for 8-9th March and 25th March-6th April were omitted, since the analysis requires equal numbers of readings in each analysis of variance cell. For both depth and velocity all main effects and most two and three way interactions were significant ($p<0.05$). The interactions were not removable by transformation and this again suggests that no simple structure underlies the pattern of depth and velocity in the channels. In particular, repetition of calibration made a significant contribution to the total variance, implying that the repetitions resulted in changed depths and velocities. However, a summary of the contributions of the various factors and interactions to the total sum of squares for velocity (Table 6) shows that treatment contributed over 90% of the total sum of squares, whereas the contributions of repetitions (0.01%) and channels (1.10%) were small. Similarly, for depth, treatment accounted for over 85% of the total sum of squares, whilst repetitions and channels accounted for much smaller percentages (2% and 0.6% respectively). Therefore, although statistically significant, the effect on depth and velocity at the 5.5 m transect of differences between channels and between repetitions of treatment and of various interactions are small compared to the effects of experimental treatment.

TABLE 6. Summary of contributions to the total mean corrected sum of squares of depth and velocity at the 5.5 m transect.

	Sum of squares (%)	
Effect	Depth	Velocity
main effects:		
treatment (T)	86.08	92.26
repetition (R)	2.07	0.01
distance across channel(D)	0.85	0.33
channel (C)	0.59	1.10
two-way interactions:		
T.R	0.96	0.94
T.D	0.75	0.16
R.D	0.12	0.13
T.C	1.68	1.28
R.C	1.29	0.96
D.C	1.76	0.99
all 3 way interactions:	3.06	1.43
residual	0.79	0.41
Total	100.00	100.00

CONCLUSIONS & DISCUSSION

The various calibration exercises have provided adequate information to permit any desired combination of discharges in the four channels to be approximated without the need for direct measurement of the discharges. However, more accurate adjustment of the discharges will still require an iterative process of fine adjustment of the valves in conjunction with direct measurements of water depth and velocity.

Once appropriate discharges have been achieved, the balance between depth and velocity can be adjusted by manipulation of the tailgate and suitable relationships for this purpose have been obtained.

The complexity of the pattern of velocity and depth within these relatively simple channels is demonstrated by the analyses of spatial variation in depth and velocity and by the analysis of variance on the repetitions of experimental treatment.

Measurements of depth and velocity on the 5.5 m transect give a good estimate of average depth and velocity in the whole channel and treatment is the overwhelming contributor to variation in velocity on the 5.5 m transect. However, though it is reasonable to define the experimental treatments in terms of their effects at the 5.5 m transect, it is important to bear in mind the fact that there is substantial spatial variation in depth and velocity within any given channel and treatment.

Variation of velocity with distance above the channel bed material has not been examined. Instead the assumption (widely used in hydraulics) that velocity at 0.6 of depth is a good estimate of mean velocity over the depth range has been accepted. This is reasonable because the bed material is well-graded and of relatively small particle size. However, it is desirable to obtain some idea of the relationship between velocity at 0.6 of depth and velocity close to the channel bed (where salmonid fry are most likely to be stationed).

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APPENDIX 1

VALVE & TAILGATE SETTINGS

Table i. Number of valve turns and tailgate settings used to achieve the required velocities. (Refer to Table 3 for the target velocities in each regime).

Regime	Channel			
	1	2	3	4
1				
No. valve turns	1.75	2.75	1.75	3.0
Ht. tailgate (cm)	24.0	26.5	31.5	26.5
2				
No. valve turns	1.25	37.25	14.25	7.75
Ht. tailgate (cm)	24.0	24.0	31.5	26.5
3				
No. valve turns	6.25	18.25	35.0	3.75
Ht. tailgate (cm)	24.0	26.5	29.5	26.5
4				
No. valve turns	9.25	10.5	1.50	36.5
Ht. tailgate (cm)	24.0	26.5	31.5	23.5
5				
No. valve turns	35.0	4.0	5.75	33.0
Ht. tailgate (cm)	21.0	26.5	31.5	26.5
1				
No. valve turns	1.75	2.75	1.75	3.0
Ht. tailgate (cm)	24.0	26.5	31.5	26.5

APPENDIX 2

TABLES OF DATA COLLECTED DURING TESTS ON REPEATABILITY OF CHANNEL SETTINGS

TABLE i. Water depths (cm) at the 5.5 m transect. Note that the values given are averages of depths measured at five points across the transect.

	Channel	1	2	3	4	Mean
Treatment	Target depth (cm)					
a†	5.4	8.14	8.06	8.94	8.06	8.30
a†	5.4	8.34	8.30	8.80	8.00	8.36
a*	5.4	9.00	8.00	8.00	7.50	8.13
a+	5.4	8.88	8.90	8.68	8.40	8.26
a+	5.4	8.46	9.18	8.38	9.10	8.78
b†	9.8	10.70	12.60	13.10	11.30	11.93
b*	9.8	-	11.00	-	11.00	-
b+	9.8	12.76	12.00	12.34	11.84	12.24
c†	12.3	13.80	15.20	15.80	16.20	15.25
c*	12.3	15.00	-	15.00	-	-
c+	12.3	14.60	15.42	14.66	15.54	15.06
d†	16.2	14.90	13.70	-	14.00	-
d*	16.2	14.50	-	14.00	-	-
d+	16.2	14.06	14.10	13.80	14.00	13.99

† Calibration of 8-9 March 1982

* Calibration of 10-22 March 1982

\+ Calibration of 25 March - 6 April 1982

APPENDIX 2

TABLE ii. Mean water velocity (cm s^{-1}) at 0.6 of depth on the 5.5 m transect. Note that the values given are averages of three measurements at each of five points across the transect.

	Channel	1	2	3	4	Mean
Treatment	Target velocity (cm s^{-1})					
a†	7.5	7.30	10.26	7.95	7.30	8.20
a†	7.5	7.01	8.77	7.90	7.30	7.75
a*	7.5	10.56	5.59	9.81	6.34	8.08
a*	7.5	11.81	8.57	10.56	9.57	10.13
a+	7.5	7.38	6.98	8.18	4.84	6.85
a+	7.5	5.37	7.73	6.34	6.43	6.47
b†	25.0	22.28	23.07	25.30	21.19	22.96
b*	25.0	24.44	22.00	26.15	31.00	25.90
b+	25.0	23.59	24.38	29.85	23.07	25.03
c†	40.0	36.70	38.06	43.70	46.73	41.30
c*	40.0	42.68	37.84	44.96	56.65	45.53
c+	40.0	38.23	43.08	47.93	46.27	42.86
d†	70.0	62.00	65.42	-	62.51	-
d*	70.0	76.88	57.50	63.49	83.15	70.26
d+	70.0	68.90	61.32	72.15	61.78	64.50

† Calibration of 8-0 March 1982

* Calibration of 10-22 March 1982

\+ Calibration of 25 March - 6 April