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ABSTRACT

A description is given of the installation of prefabricated, timber, flat-vee weirs to measure the discharge rates in the principal runoff streams from waste rock dumps at the abandoned mine site at Rum Jungle, Northern Territory. Details are presented of the tapping point, stilling well, stilling well/tapping point connection and the technique used to measure gauge height.

The relationship between discharge rate and gauge head for the weir structure installed is discussed. The high gradient and high silt load of the runoff streams have led to silt deposition behind the weirs. Information is given on the silt levels and their effect on the discharge/gauge head relationship. The total error on the discharge from uncertainties in stream bed depth, uncertainties in the discharge coefficient and uncertainties in the measured gauge height, is estimated to be less than 10% in the range 5 x 10^{-2} m^3 s^{-1} to 0.9 m^3 s^{-1}, the upper rate being just greater than the maximum discharge rate observed. The error on the total discharge in an event, a parameter of interest in estimating runoff coefficients and total pollution loads, was in general less than this.

(continued)

The weirs have proved robust under field conditions; the weir on White's runoff channel is still in use five years after installation in October 1975, and that on the Intermediate runoff channel, in use three years after installation in November 1977.

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TAILINGS; RUM JUNGLE; NORTHERN TERRITORY; WASTE DISPOSAL; RIVERS; DAMS; WATER POLLUTION; RAIN WATER

CONTENTS

1. INTRODUCTION

The concentration of heavy metal salts in runoff water from the waste rock dumps at the abandoned Rum Jungle mine in the Northern Territory presents a source of pollution to the East Finniss River that runs through the mine site (Davy 1975). In any attempt to assess the significance of this source of pollution, or the effectiveness of any rehabilitation schemes designed to mitigate the pollution, it is important to measure the total runoff and the pollution load in the runoff. It is also of interest, to any modelling studies which purport to describe the mechanisms that lead to pollution of the runoff, to see the extent to which runoff and pollution levels in the runoff correlate with rainfall patterns. Both requirements imply measurement of runoff over a period long enough for trends to emerge for good estimates to be made of the total runoff and the total pollution load in this runoff.

The waste rock dumps were constructed in such a way that much of the runoff drains into a principal runoff channel that carries the water away from them (see, for example, Figure 1). These channels are normally dry and contain water only during or immediately following rainfall on the dump. Since much of the rain that falls in this area during the 'wet season' appears in the form of short-lived rainstorms of high intensity, flow in the runoff channels is characterised by an increase from zero flow to a peak within a few minutes, followed by a decrease to zero flow over a period of a few hours. During the latter half of the wet season, when monsoonal conditions apply, rain is frequently lighter and more continuous over periods of a few days. Under these conditions, flow in the runoff channel is also more continuous.

The wide range of flow conditions ($\sim 3 \times 10^{-2}$ m^3 s^{-1} to ~ 1 m^3 s^{-1} in a channel about 3 m wide), the rapid change in flow rate near peak flow, the intermittency of discharge events in the channel and the comparative remoteness of the mine site make the use of on-the-spot measurement techniques (such as propellor-driven water velocity meters) reasonable for scoping studies, but quite inadequate for quantitative work. Also, the expectation that the concentration of pollutants tends to vary inversely as the flow rate, implies that the measurement accuracy at low flow needs to be similar to that at high flow, to obtain reasonable accuracy on estimates of total pollution load.

Smith and Lavis [1969] faced similar problems of difficulty of access and the need for good accuracy over a flow range of about 1.4×10^{-2} m^3 s^{-1} to 2 m^3 s^{-1} when they were investigating the hydrology of a small (100 hectare) catchment area in the North of England. They concluded that a flat-vee weir of the type developed at the Hydraulic Research Station (HRS), Wallingford, had most of the properties of discharge range, of accuracy throughout the range and of ability to match the stream gradient that they sought. They further demonstrated that such a structure could be prefabricated in marine ply and constructed at the gauging site using the minimum of heavy building equipment and manpower. It was, therefore, decided to use the same design and similar construction techniques in installing gauging stations, initially on the principal runoff channel on White's waste rock dump at Rum Jungle and, later, on the principal runoff channel of the Intermediate waste rock dump. Bonham [1972] has indicated that a sloping crest weir sited at a suitable bend in a stream may be better for gauging streams with a high sediment load than a flat-vee structure.

This report describes the installation of flat-vee weirs at these two sites and the instrumentation associated with the weirs. It also contains details on the relationship between discharge rate and gauge height for these particular weirs and how this relationship depends on the bed depth behind the weir. As the stream gradients are high, about 1:22 for White's principal runoff channel and 1:20 for the Intermediate channel, and the waste rock dumps consist of unconsolidated material, there is considerable transport of this material down the stream bed during a discharge event. The effect of silt levels behind the weir on the discharge relations is discussed, together with the effect of any changes in these levels on the accuracy of discharge rate estimates. Finally, estimates are given of the accuracy to be expected in the measured discharge rates.

2. WEIR DESIGN AND INSTALLATION

The design of the weir block and prefabricated channel followed closely that of Smith and Lavis [1969] (see Figures 2, 3 and 4). The walls and floor of the channel, and the skin of the weir block were constructed of 'Structural Grade' marine ply, while the timber framing was treated to withstand termite infestation.

A weir site was chosen on each of the White's and Intermediate principal runoff streams where the stream gradient was least, and sufficient area on the stream bed was cleared to accommodate each weir. Construction of these two weirs started early in the wet season when there was little or no water flow in the runoff streams. The foundations of the construction were timber beams (0.3 x 0.15 x 4.57 m for White's, and 0.2 x 0.10 x 6.0 m for the Intermediate weir), which were laid level to better than 0.1% and cemented in position. The assembly of the weirs then proceeded in a series of stages exemplified by Figures 3 and 4. In both weirs the hollow between the floor of the weir and the weir block was filled with large boulders to reduce any tendency of the timber structure to float.

Concrete wings were constructed at the entrance of the weir channel (see Figure 4) to prevent erosion and any tendency of the stream to bypass the weir. Similarly, the stream bed immediately downstream of the weir was rock-filled and some of the rocks were cemented into place to prevent erosion and undermining of the weir structure. Moreover, it was found necessary to cover the timber floor of the weir with stainless steel sheeting at the point where the 1:5 slope met the floor to prevent damage to the timber from stones washed through the weir.

The stilling well for White's weir was a cylinder of PVC, 0.3 m in diameter and 1.42 m high, connected to the piezometric tapping point by flexible PVC tube, 20 mm i.d. The actual position of the tapping point could be varied, as indicated in Figure 5a. The reason for doing this stemmed from uncertainty as to the silt level that might build up behind the weir after it has been in use for some time. For the bulk of the discharge measurements, the tapping point was 1.38 m upstream of the weir crest and positioned such that its bottom edge was at the level of the vee of the weir. The stilling well for the Intermediate weir was a concrete cylinder, 0.525 m in diameter and 1.22 m high, connected to the tapping point via 50 mm i.d. PVC tubing (see Figure 5b). The tapping point in this weir was 50 mm in diameter, 1.0 m upstream of the weir crest, with its lowest point 0.8 mm below the level of the vee of the weir. Experience with silt levels on White's weir indicated that this position for the tapping point avoided undue problems with silting up. As there was no stream flow through the weirs for the bulk of the measurement period, stainless steel gauze was fitted over the tapping point orifice to prevent ingress of any small wildlife to the stilling well.

The weir on White's principal runoff channel was installed in October 1975 and that on the Intermediate channel in November 1977.

3. INSTRUMENTATION

Water levels in the stilling well were recorded using a Fieldman 300 F level recorder which used a 203 mm diameter, PVC-foam-filled float to provide drive to a pen recorder. The specifications for this instrument are given in Table 1, but it is of interest to emphasise some details of the instrument.

The 250 mm chart width represented a 1 m change in level of the float. In practice, the greatest changes in level were measured to be about 0.3 m in White's weir and 0.17 m in Intermediate. However, since there was frequently a gap of some days or even weeks between discharges through the weir, followed by a drop in level in the stilling well due to evaporation, it was convenient to offset the zero level of the level recorder position. The drive to the pen recorder also drove a ten turn, 5 KΩ precision potentiometer such that zero and full scale readings on the potentiometer corresponded to zero and full scale positions of the pen on the chart recorder. The potentiometer provided an analogue signal which was fed to a datalogger that recorded the level reading each five minutes.

The chart drive was quoted as accurate to ±1 in 750 (see Table 1). Apart from one period when the coupling to the chart drive malfunctioned, the chart speed conformed to this accuracy. As an independent check on the chart speed, an impulse from the data logger drove a solenoid operated pen which put a hatch mark on the chart each time the data logger sampled the level. In practice, since the discharge events were quite short (typically about three hours), such timing accuracy was not really necessary to provide timing information during the events but only to indicate when the events occurred. In general, this information was provided by the data logger and the chart recording of water level changes was used only as a back-up.

4. RATING FOR WEIR

4.1 Discharge Relations

The weirs installed on White's principal runoff channel and on the Intermediate runoff channel were both of the flat-vee type studied in some detail at the HRS at Wallingford [HRS 1970a, 1970b, 1970c]. The weirs had 1:10 cross slope, 1:2 upstream slope and 1:5 downstream slope. Further details on the weir specifications are given in Table 2, while Figure 2 shows a schematic diagram of the weir installation.

The discharge relations for these flat-vee weirs are [HRS 1970a]:

$$Q = 0.8\, C_D\, n \sqrt{g}\, [H^{5/2} - \underline{(H-H^1)}^{5/2}] \qquad (1)$$

$$H = h+\alpha \frac{V^2}{2g} - k_H \qquad (2)$$

$$V = Q/(h+P)b \qquad (3)$$

where Q = rate of discharge ($m^3\ s^{-1}$),

H = total head (m),

V = velocity of discharge at gauge point ($m\ s^{-1}$),

C_D = discharge coefficient,

α = Coriolis energy coefficient,

k_H = head correction factor,

g = acceleration due to gravity, and

H^1, h, b, P, n are the parameters indicated on Figure 2.

The portion underlined in equation (1) is included when $h > H^1$ and omitted when $h \leq H^1$.

The HRS investigations showed that, although α could be as much as 16%

greater than unity at small gauge heights, the error on the discharge rate, in assuming α to be unity, was about 0.1%. As this error decreases with increasing gauge height, it is reasonable, in view of other sources of error, to take $\alpha = 1$. The HRS investigations also showed that, for a weir with a 1:10 cross slope, the head correction factor was 0.8 mm. It is clear, therefore, that a first estimate for the total head H is the gauge head h. This can be used to estimate the rate of discharge Q from equation (1) and, from this, the discharge velocity V from equation (3). A revised estimate of the total head can then be obtained using this estimate for the velocity in equation (2) and an improved estimate of the rate of discharge obtained by substituting the revised value for the total head in equation (1).

Such a calculation converges quite rapidly and can be used to provide a calibration curve (or table) of discharge rate for a given gauge height and particular value of bed depth P. Table 3 and Figure 6 show the discharge rate as a function of gauge height for parameters appropriate to the weirs and for a bed depth P = 0 which is believed to be appropriate to White's weir (see Section 4.2). Table 3 also gives values for the total head, stream velocity at the gauging point and the Froude number in the approach channel to the weir.

4.2 Silt Levels

The average gradients of the principal runoff streams on White's and Intermediate overburden dumps are about 1:22 and 1:20 respectively. These steep slopes, together with the fact that the weathered overburden material is friable and easily eroded, means that the silt burden carried by the runoff streams is high. This silt will drop out of suspension whenever the stream velocity drops as it does, for example, immediately upstream of the weir. Silt build-up in flat-vee weirs has been studied at the HRS [HRS 1970b, White 1971, Ackers and White 1973] and, in particular, the relationship between stream velocity at which sediment is transported, the size of the particles transported and the density of these particles.

If the silt in a stream is of uniform size and density, there will be a well defined value of the bed depth for a given discharge; the greater the discharge, the greater the bed depth. If, after stable bed depth conditions have been attained at a given discharge, the discharge rate drops, the bed depth under the lower discharge conditions will nevertheless reflect the earlier, higher discharge conditions. In a stream with variable sized silt and variable flow, the silt level behind a weir will reflect the highest discharge and the particles in the silt will tend to be those particles which just dropped out of suspension at the stream velocity appropriate to that discharge. Smaller particles will tend to be carried by the stream flow over the weir. However, in practice, smaller particles will also be lodged behind and beneath larger particles so that the silt will contain a wide distribution of particle size.

As discussed above, the runoff streams from White's and Intermediate overburden dumps flow only after rainstorms on the dump, with flows characterised by a rapid rise to a full discharge shortly after the onset of rain and followed by a much slower decrease to zero flow. It would, therefore, be expected that, after a number of discharge events, the silt level would reflect the silt distribution from events with high peak flow and that the silt level would be relatively stable over the long term. In particular, the silt level and hence the bed depth P, would not change during an event, unless that event was one of exceptionally high flow.

This expectation of comparatively stable silt levels appears to be borne out in practice. Figure 7 shows silt levels measured behind White's weir over a six-week period in the wet season of 1978-79. Although there are detailed changes in the shape of the stream bed, the average bed depth shown in Table 4 changes little. As discussed below, it is the average bed depth that is important when discharge through the weir is being estimated for a given measured gauge height.

4.3 Discharge Relations at Low Flow

The rate of discharge Q for a given gauge height h can be calculated simply from equations (1), (2) and (3) if the coefficient of discharge C_D and the bed depth P are well defined. Since equation (1) is in essence an empirical relationship, the consistency of the value of C_D must be established experimentally. On the other hand, shoals appear at low flow, due to silting behind the weir, and consequent variation in the bed depth across the stream at the gauging point introduces some uncertainty as to what value of P is appropriate to the discharge relations.

The HRS has evaluated C_D over a range of small discharges. When the head correction factor k_H is included in the definition of the total head, the value of C_D remains constant within 2% [HRS 1970b] for flows with Froude numbers less than 0.25. In some of the experiments reported by HRS, the bed depth P was a few centimetres each side of $P = 0$, conditions close to those experienced with the weirs at Rum Jungle.

Measurements with a variety of bed levels and bed shapes [HRS 1970a] showed that the value of P appropriate to the evaluation of the discharge rate is the average value of the bed depth across the stream at the gauging point. The question becomes, then, one of being able to measure the gauge head accurately when silt deposits around the tapping point on the weir wall. Fortunately, the silt deposited near the wing walls of the weirs at Rum Jungle was rather coarse so that, even when it seemed to block the tapping hole, enough water flowed through the coarse sediment for reliable measurement of the gauge height. Occasionally, finer silt deposited in the tapping point necessitated flushing of the stilling well and the connection pipe to the tapping point.

4.4 Discharge Relations at High Flow

For a given rate of discharge Q, the Froude number, $F_r = V/\sqrt{g(h+P)} = Q/b\sqrt{g}(h+P)^{3/2}$, becomes higher as the value of the bed depth P diminishes. Hence a silted weir no longer acts as an effective control at a rate of discharge which is lower than one which is not silted. Moreover, the constancy of the discharge coefficient C_D has been tested for flows in flat-vee weirs which have only a limited range of Froude numbers in the approach channel.

Figure 8 shows the Froude number in the approach channel to a flat-vee weir as a function of the gauge height h for a bed depth of P = 0, the conservative value used for the weir on White's principal runoff channel. Figure 9 shows a frequency distribution of gauge heights measured at this weir during the 1975-76 wet season. It can be seen from Figure 9 that, although there were a few events with gauge heights of ~ 0.3 m and hence Froude number $F_r \gtrsim 0.6$, most of the events measured corresponded to much smaller gauge heights and Froude numbers. Of the 55 events recorded in that wet season, only eight were associated with Froude numbers greater than 0.5 and of these, only four had Froude numbers between 0.6 and 0.7.

The HRS investigation [HRS 1970a] showed that the discharge coefficient C_D for a weir with a 1:10 slope remains constant within about 3% for Froude numbers up to 0.25. They also showed [HRS 1970c] that the discharge coefficient of a 2D triangular profile weir (i.e. no cross slope) changes by less than 2% for Froude numbers in the approach channel up to 0.5. Now, for large gauge heights, discharge through a flat-vee weir will approach that through a 2D structure. This can be most easily seen by considering the forms of the discharge relationship for a flat-vee weir at large gauge height

$$\begin{aligned} Q &= 0.8\sqrt{g}\, n\, C_D\, [H^{5/2} - (H-H^1)^{5/2}] \\ &= 0.8\sqrt{g}\, n\, C_D\, H^{5/2}\left[1 - \left(1 - \frac{H^1}{H}\right)^{5/2}\right] \\ &= C_D\sqrt{g}\, b\, H^{3/2} \end{aligned}$$

which is the expression for discharge through a 2D triangular profile weir. The value of C_D for a 1:10 weir can be taken as 0.62, while that for a 2D weir is

0.633 [HRS 1970a], some 2% higher. With increasing gauge height and Froude number, the behaviour of the discharge coefficient, in both flat-vee weirs of 1:10 cross slope and 2D weirs, indicates [Bettess 1980] that any change in it will be less than 5% for Froude numbers less than 0.7. For Froude numbers greater than this, the weir would tend no longer to act as a control [Bettess 1980].

Any change in the actual value of the bed depth P from the assumed bed value will also change the discharge appropriate to a given measured gauge height. Figure 10 shows the fractional change in the calculated discharge from the discharge calculated for $P = 0$ and for a variety of bed depths varying a few centimetres from $P = 0$; the percentage change has been plotted as a function of the gauge height h. It can be seen that, even at the higher gauge heights encountered, the variation in the calculated discharge is less than 4% for a 1 cm decrease in average bed depth. Table 4 illustrates that the standard deviation in the average bed depth in White's weir, measured over the six-week period in February-March 1979, was about 0.4 cm. Hence, errors in calculated rates of discharge at high discharges due to the variation in the bed depth due, in turn, to changes in silt level from event to event through the wet season, should be less than 5%.

4.5 Estimate of Error in Calculated Discharge Rate

The main sources of the uncertainty in the value of the rate of discharge calculated from the gauge head are:

(a) uncertainty in the value of the discharge coefficient C_D,

(b) uncertainty in the bed depth P, and

(c) uncertainty in the measured value of the gauge height h.

From the discussion in Sections 4.3 and 4.4, the value of C_D is known to within 3% accuracy for Froude numbers less than 0.25 and is expected to be constant within 5% for Froude numbers up to 0.7. From Figure 8, these two Froude number ranges can be seen to correspond to gauge height ranges of $h < 0.1$ and $0.1 \leq h \leq 0.33$ m.

It can be seen from Table 4 that the standard deviation in the average bed depth was ∼0.4 cm over a six-week period; it would be reasonable to assume that the average bed depth does not vary by more than 1 cm. It would also seem to be reasonable to take a bed depth of 0 for White's weir, rather than the value of ∼0.6 cm measured over the six-week period, as the change in calculated discharge is quite small and the smaller value of P will give slightly larger values of the runoff volume and, hence, a conservative estimate of the total pollution in the runoff. Figure 10 shows that the fractional variation in the rate of discharge for a change of 1.0 cm in P is less than 1.5% for $h \leq 0.1$ m and that, in the range $0.1 \leq h \leq 0.33$, the fractional change is approximated by $\Delta Q/Q = 15\ h$.

It can be seen from Figure 6 that, in the range $h \leq 0.1$ m, the discharge is given to an accuracy of a few per cent by the expression

$$Q = 16.0\ h \quad , \tag{4}$$

and in the region $0.1 \leq h \leq 0.33$, by the expression

$$Q = 12.7\ h^{2.39} \quad . \tag{5}$$

Although neither of these expressions is accurate enough to evaluate the rate of discharge for a given head, they are good enough to provide estimates of the errors arising from uncertainties in the head measurement. The major uncertainty in the measurement of the gauge head arose from digitisation of the analogue signal by the 8-bit ADC in the data logger used to record the field measurements. Calibration of the ADC showed that a one-unit change in the ADC corresponded to 0.005 m change in the gauge height. Simple analysis shows that the standard deviation in the gauge height expected from digitisation is:

$$\Delta h = \frac{0.005}{\sqrt{12}}\ \text{m} \quad .$$

This can be used in expressions (4) and (5) to obtain estimates of the percentage variations in the calculated discharge due to uncertainties in the gauge height.

The total uncertainty in this calculated discharge is obtained by adding the contributions from the above sources:

$$s(Q)/Q = \sqrt{\left(9 + 1.3 + \frac{0.13}{h^2}\right)} \qquad h \leq 0.1\ \text{m} \tag{6}$$

$$= \sqrt{\left(25 + 231\ h^2 + \frac{0.12}{h^2}\right)} \quad 0.1 \leq h \leq 0.33\ \text{m} \quad . \tag{7}$$

These are graphed in Figure 11.

It can be seen from Figure 11 that, over the range $0.06 \leq h \leq 0.33$, the fractional error in the discharge is less than 7%. This implies that the error on the estimated total discharge in an event is likely to be less than 10%, since although a discharge event will cover a range of gauge heights from zero to some maximum, most of the total discharge will be associated with the larger gauge heights. In practice, the error for each discharge was evaluated using an expression of the form (6) or (7) to take account of the detailed shape of the discharge event. The total discharge in an event and the accuracy to be associated with this quantity are important in estimating the fraction of rain incident on the dump that appears as runoff and the average level of pollution that can be ascribed to runoff water from the dump.

5. SUMMARY AND CONCLUSIONS

Installation of a prefabricated timber channel and weir block has proved to be a practical way of providing a gauging station on a stream in an area of limited access. The flat-vee type of weir chosen has also proved to be a gauging structure with sufficient accuracy over the wide range of water discharge rates required for measurement of runoff rates from the dumps of overburden material at Rum Jungle, Northern Territory. The timber structure has shown itself to be more than robust enough for the measurement program envisaged, with the weir on the principal runoff channel for White's dump still in use five years after installation in October 1975, and that on the Intermediate runoff channel in use three years after installation in November 1977.

The relatively high gradient of the runoff streams and the high silt load in the streams has led to deposition of silt in the approach channels to the weirs. The apparent stability of the levels after a short, initial settling down period, and reference to the work of the HRS on flat-vee weirs of the type used, have allowed a bed depth to be defined and used in calculating discharge rates from measured gauge heads. Silting of the tapping point which occurred only occasionally did not present a significant practical problem.

Silting of the approach channel and the consequent small values of bed depth imply Froude numbers for a given discharge which are higher than would be encountered in approach channels with greater bed depth. The highest Froude number encountered in a typical wet season set of discharge events was 0.68, while 85% of the 55 discharge events observed in that wet season had maximum Froude numbers less than 0.5. Hence, the weir acted as a control throughout the whole discharge regime encountered in the runoff streams. From the work of the HRS, the discharge coefficient could be assumed constant within 3% up to Froude numbers of 0.5 in the approach channel, and within 5% for Froude numbers up to 0.7.

When the accuracy of the discharge coefficient, the effect of possible variations in bed depth and the accuracy on gauge head readings in the field are taken into account, the estimated discharge at a given gauge height has an accuracy of better than 10%. As any discharge event spanned a range of gauge heads and as the accuracy of the discharge estimates depends on gauge head, the accuracy of the total discharge estimate, which was important in estimating runoff fractions and total pollution loads, varied somewhat from event to event. However, in most cases of practical interest, the accuracy of the total discharge was better than 10%. This accuracy was more than sufficient for the program of work on characterising the behaviour of the overburden dumps.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Ackers, P. and White, W. J. [1973] - J. Hydraulic Div., Proc. Am. Soc. Civ. Eng., 99:2041.

Bettess, R. [1980] - private communication.

Bonham, A.J. [1972] - Civ. Eng. Trans., I. E. Aust., Vol. CE14(2)142-146.

Davy, D.R. (ed.) [1975] - AAEC/E365.

Hydraulic Research Station, Wallingford, report [1970a] Ex473.

Hydraulic Research Station, Wallingford, report [1970b] Ex476

Hydraulic Research Station, Wallingford, report [1970c] Ex477.

Smith, K. and Lavis, M.E. [1969] - J. Hydraulic Div., 8:217-226.

White, W.J. [1971] - J. Hydraulic Div., Proc. Am. Soc. Civ. Eng., 97:395.

TABLE 1

SPECIFICATION OF FIELDMAN 300 F LEVEL RECORDER

Chart width	250 mm
Chart speed	0.4 inches per hour
Chart length	22 m
Float level displacement for full scale chart movement	1.0 m
Float	PVC foam filled 203 mm diameter
Level accuracy	0.25% full scale
Timing accuracy	±1 in 750
Power supply	6 V dry cell
Pen	Capillary

TABLE 2

WEIR SPECIFICATIONS

Weir breadth (b)	2.134 m
Upstream slope	1:2
Downstream slope	1:5
Cross slope (1:n)	1:10
Height from bottom of vee to top of shoulder (H^1)	0.107 m
Distance from floor of channel to bottom of vee	0.457 m
Distance from weir crest to start of timber approach channel:	
White's	1.68 m
Intermediate	3.89 m
Tapping orifice in wall:	
White's	20 mm
Intermediate	50 mm
Tapping position height:	
White's	level with bottom of vee
Intermediate	0.8 mm below vee
Tapping position-distance from weir crest:	
White's	1.38 m
Intermediate	1.00 m

TABLE 3

VELOCITIES, DISCHARGE RATES AND FROUDE NUMBERS AS A FUNCTION OF GAUGE HEIGHTS FOR BED DEPTHS APPROPRIATE TO WEIRS ON WHITE'S AND INTERMEDIATE PRINCIPAL RUNOFF CHANNELS

Gauge Height m	Bed Depth P = 0.0 cm			Bed Depth P = -2.5 cm		
	Velocity $\mathrm{m\ s^{-1}}$	Froude Number	Discharge Rate $\mathrm{m^3\ s^{-1}}$	Velocity $\mathrm{m\ s^{-1}}$	Froude Number	Discharge Rate $\mathrm{m^3\ s^{-1}}$
0.02	0.0186	0.042	0.000795			
0.04	0.0560	0.089	0.00477	0.160	0.418	0.00513
0.06	0.106	0.138	0.0136	0.192	0.327	0.0143
0.08	0.168	0.190	0.0287	0.260	0.354	0.0305
0.10	0.243	0.245	0.0519	0.351	0.409	0.0561
0.12	0.331	0.305	0.0847	0.461	0.477	0.0933
0.14	0.422	0.360	0.126	0.574	0.541	0.141
0.16	0.512	0.409	0.175	0.688	0.598	0.198
0.18	0.601	0.452	0.231	0.804	0.652	0.262
0.20	0.689	0.492	0.294	0.922	0.704	0.344
0.22	0.776	0.528	0.364	1.047	0.757	0.436
0.24	0.862	0.562	0.441			
0.26	0.948	0.594	0.526			
0.28	1.03	0.624	0.618			
0.30	1.12	0.653	0.717			
0.32	1.21	0.681	0.824			
0.34	1.30	0.710	0.941			

TABLE 4

MEAN BED DEPTHS MEASURED IN WHITE'S WEIR

FEBRUARY-MARCH 1979

Distance of section above weir crest at which measurements were made (m)	Bed Depth Average Across Section (cm)				Time Average Bed Depth (cm)
	18/2/79	3/3/79	13/3/79	29/3/79	
0.45	0.20	1.05	0.52	0.70	0.62±0.35
1.06	0.00	-0.10	0.52	0.59	0.25±0.30
1.62	0.49	0.26	0.64	-0.26	0.28±0.35

Note: Positive measurements mean distance of bed below vee of weir

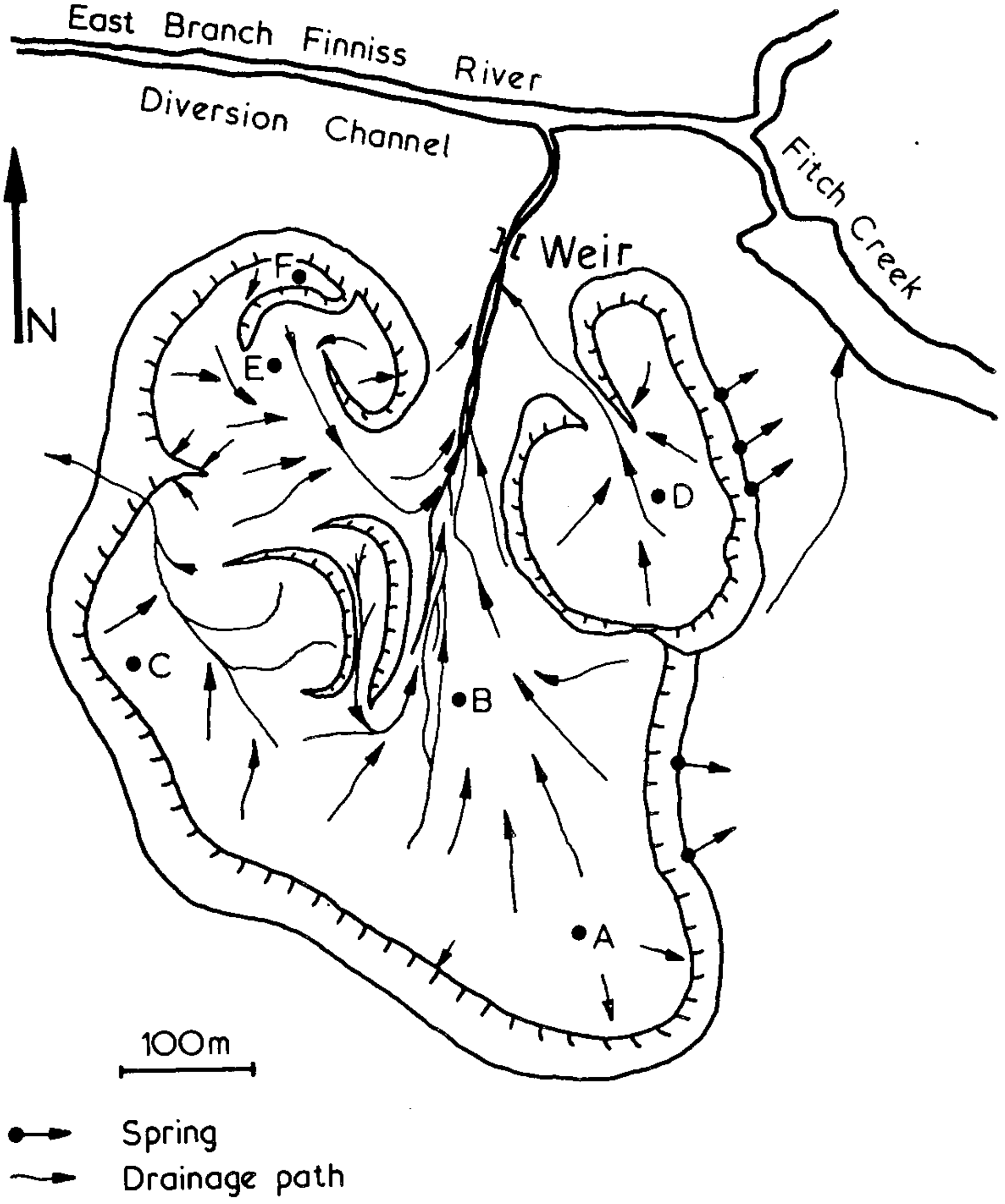


FIGURE 1. WHITE'S OVERBURDEN DUMP

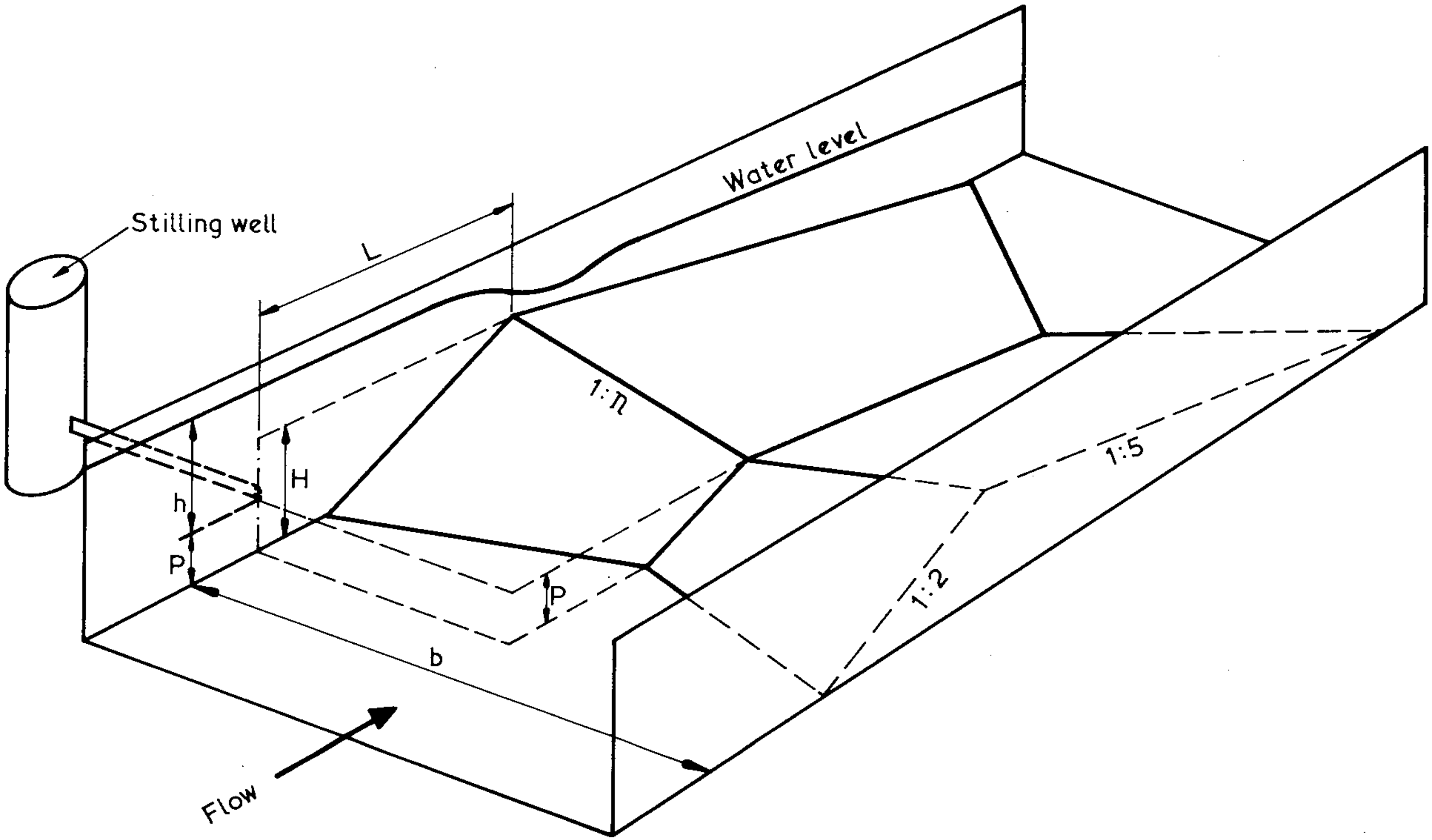
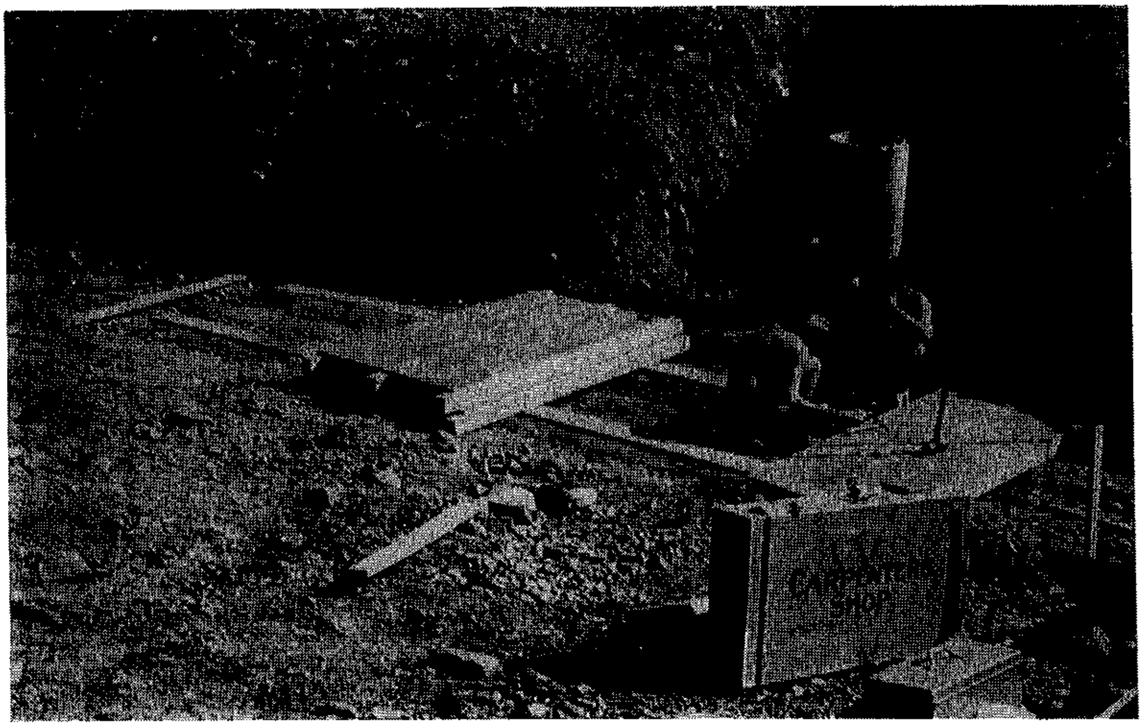
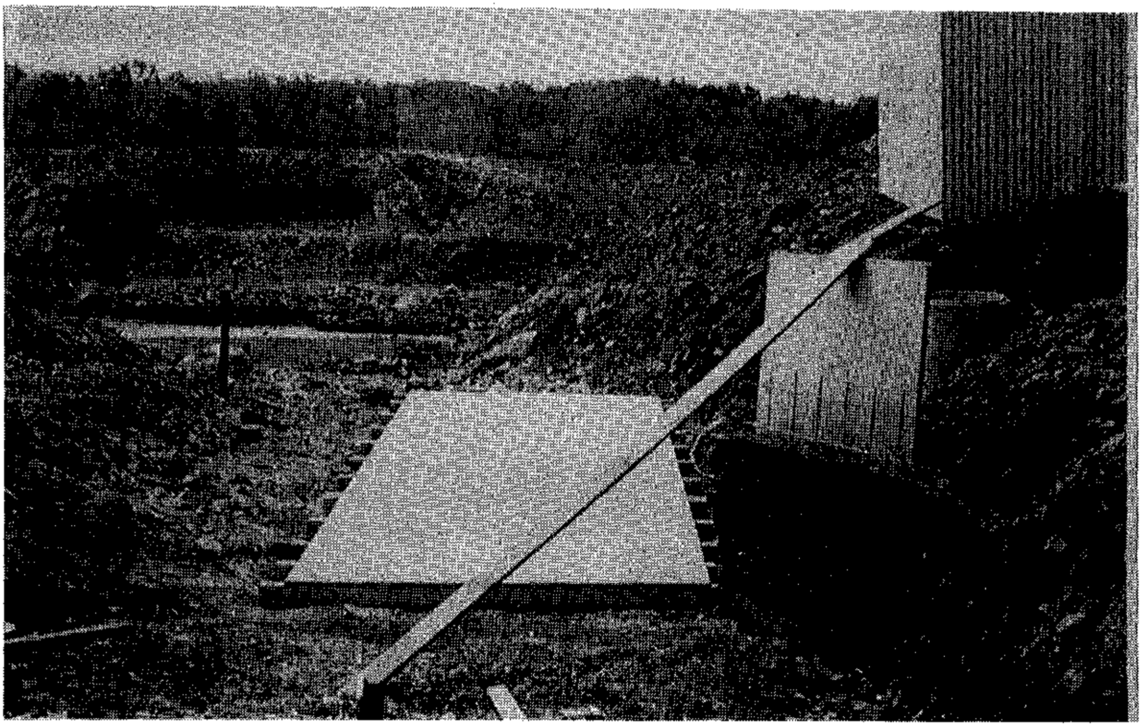


FIGURE 2. SCHEMATIC DIAGRAM OF WEIR

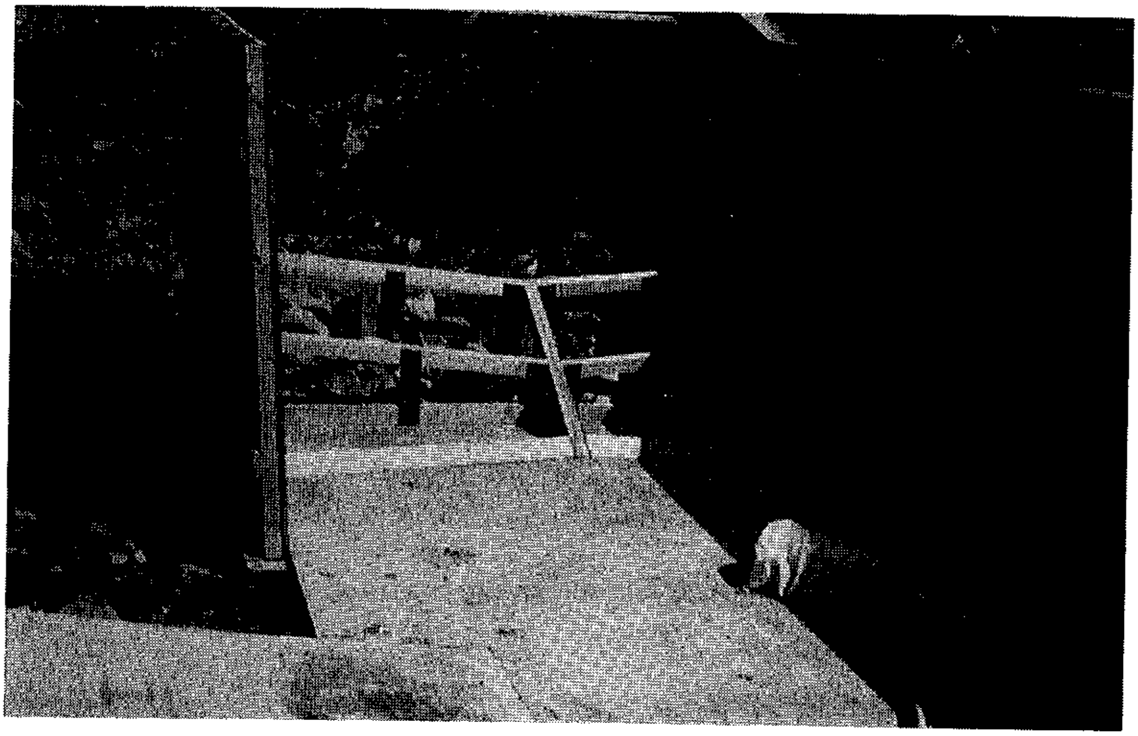


(a) Foundation timbers in position



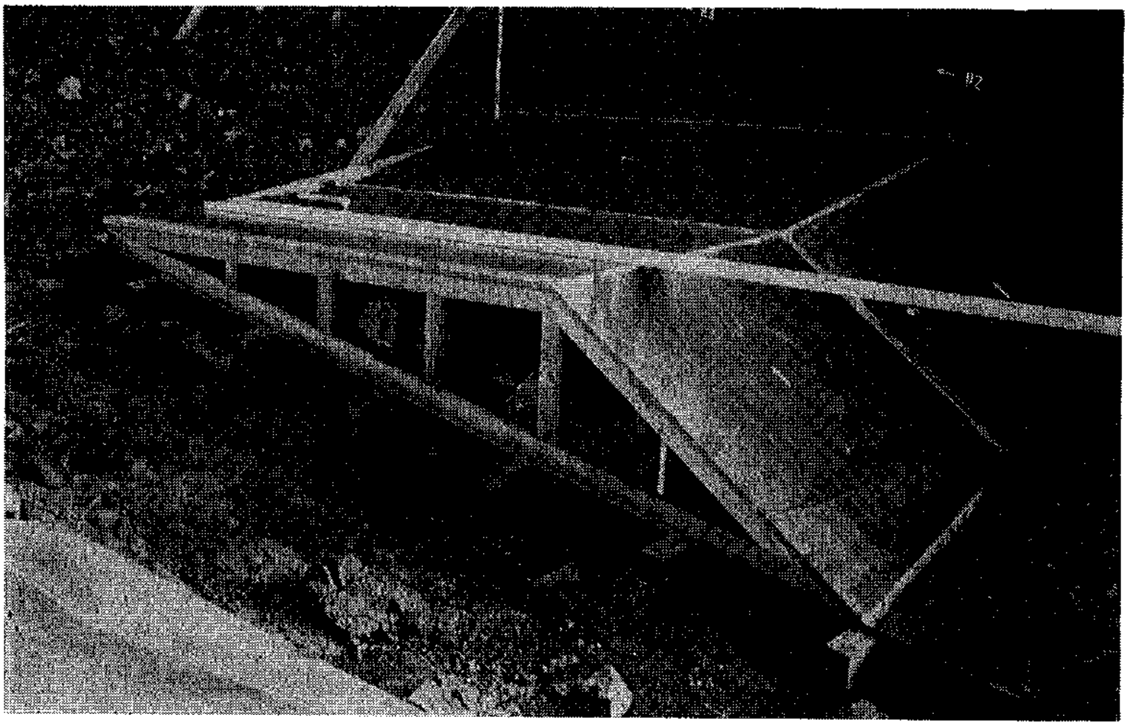
(b) Weir base positioned

FIGURE 3. STAGES IN WEIR INSTALLATION ON INTERMEDIATE PRINCIPAL RUNOFF CHANNEL

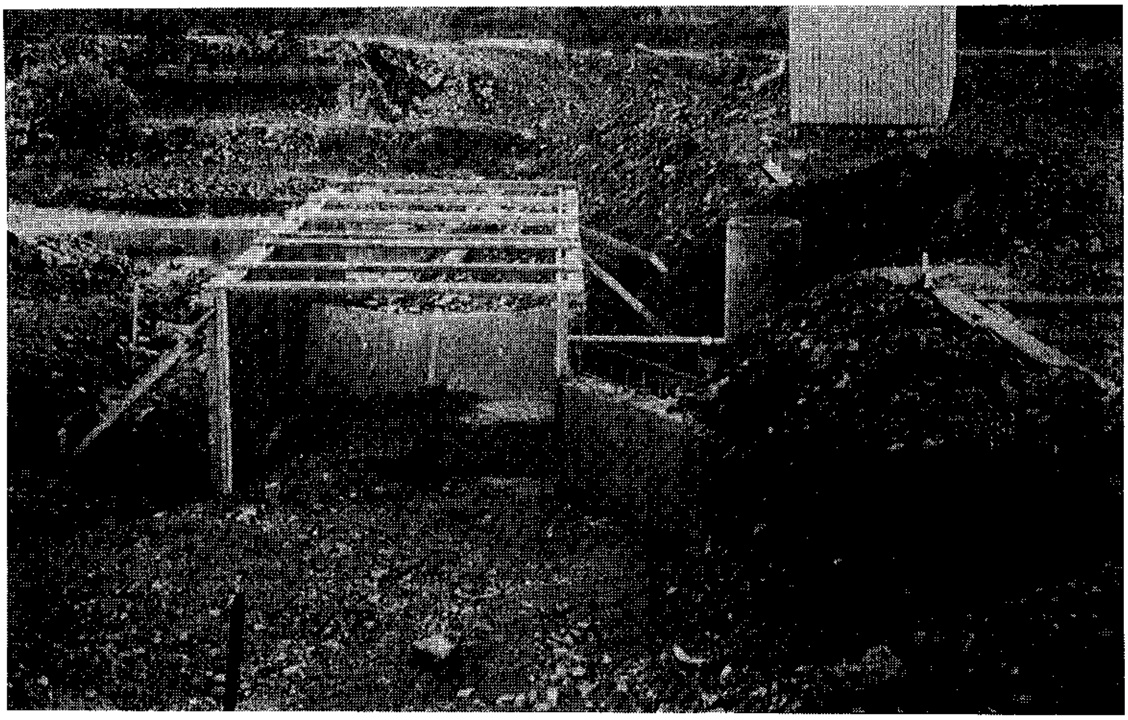


(c) Frame for weir block positioned in timber channel

FIGURE 3. (Continued)

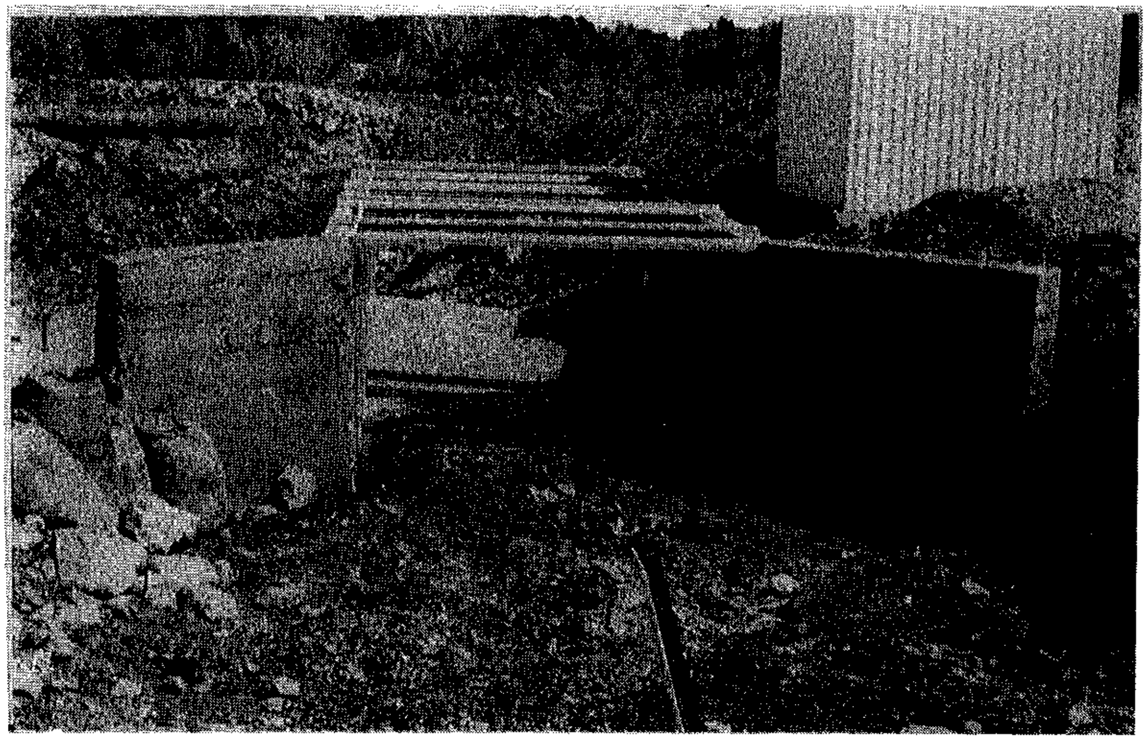


(a) Weir block filled with boulders



(b) Completed weir block and channel, showing piezometric tapping pipe to stilling well

FIGURE 4. STAGES IN WEIR INSTALLATION ON INTERMEDIATE PRINCIPAL RUNOFF CHANNEL



(c) Completed installation with instrument shed over stilling well and wing walls on approach to weir channel.

FIGURE 4. (Continued)

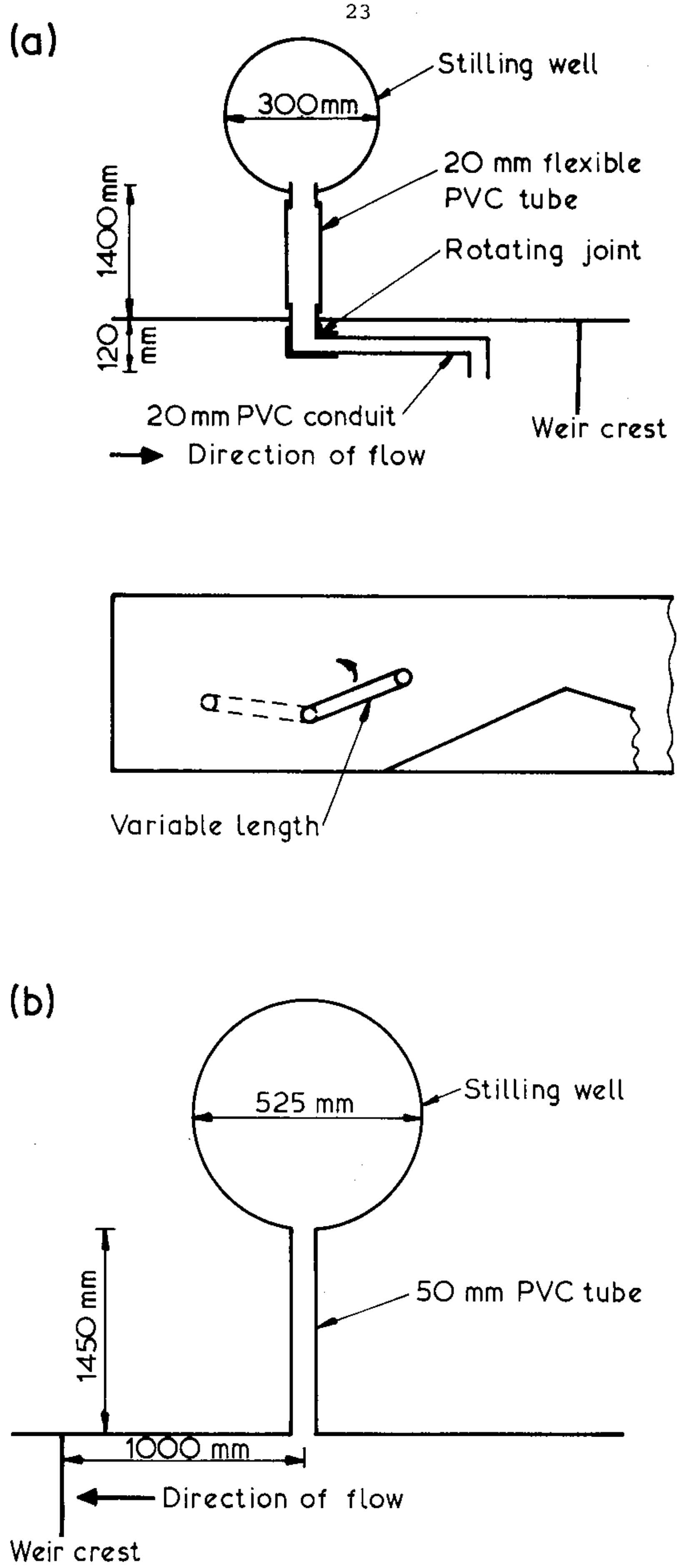


FIGURE 5. SCHEMATIC DIAGRAM OF STILLING WELL CONNECTIONS TO TOPPING POINT: (a) WHITE'S (b) INTERMEDIATE

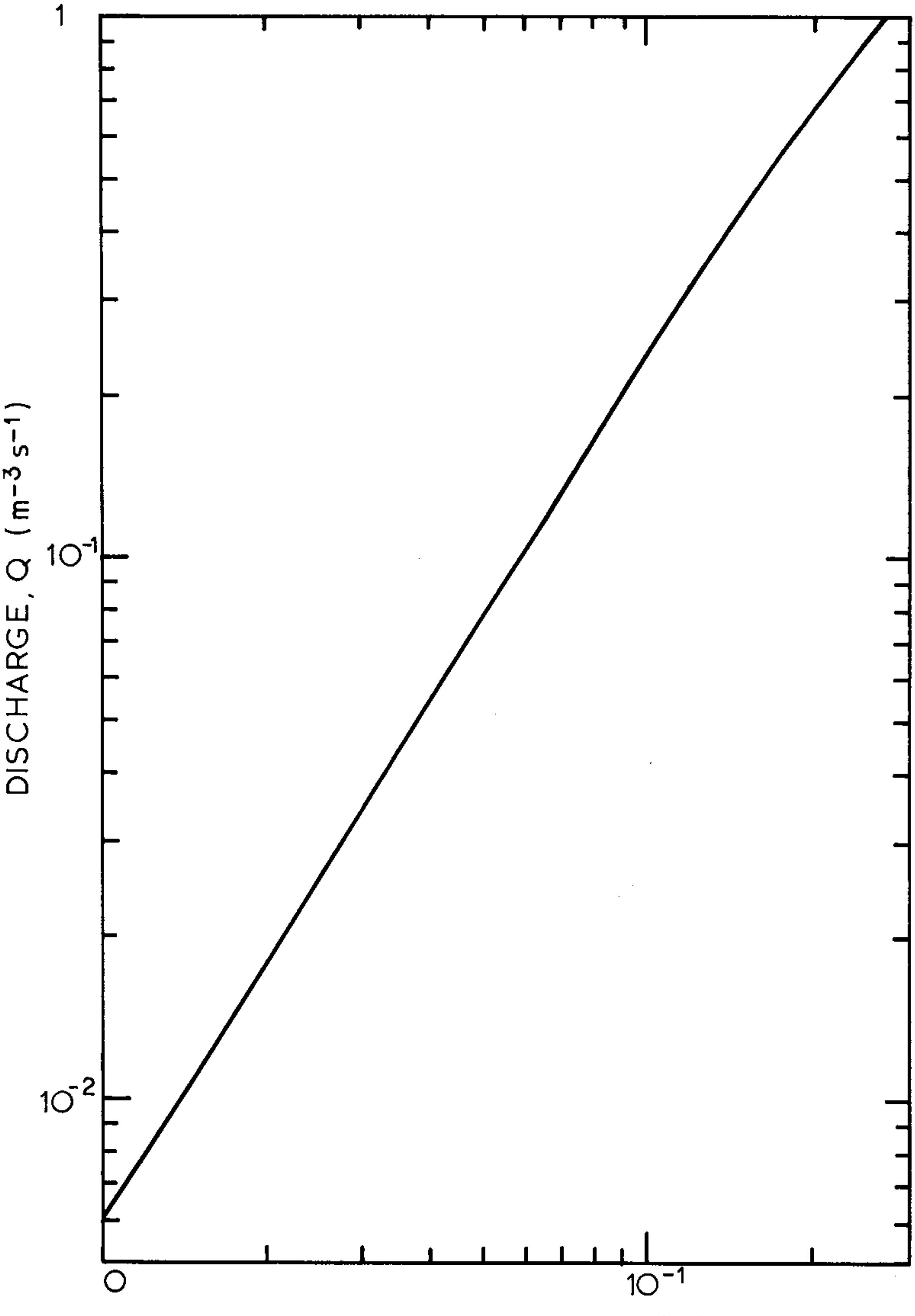


FIGURE 6. DISCHARGE RATE AS A FUNCTION OF GAUGE HEIGHT FOR A BED DEPTH OF P=O

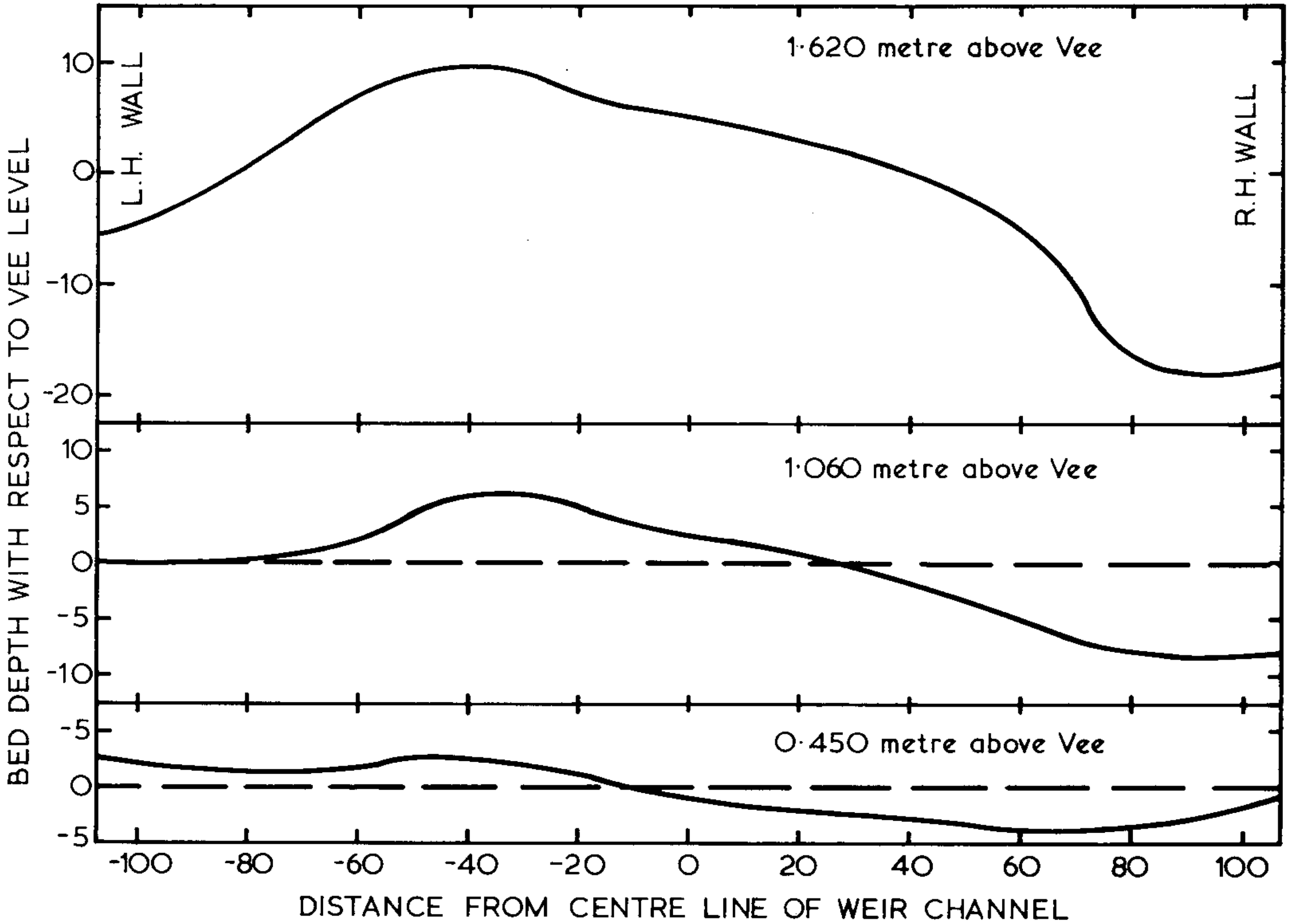


FIGURE 7. AVERAGE POSITION OF SILT PROFILE AT VARIOUS DISTANCES ABOVE WEIR CREST; WHITE'S WEIR, FEBRUARY-MARCH 1979

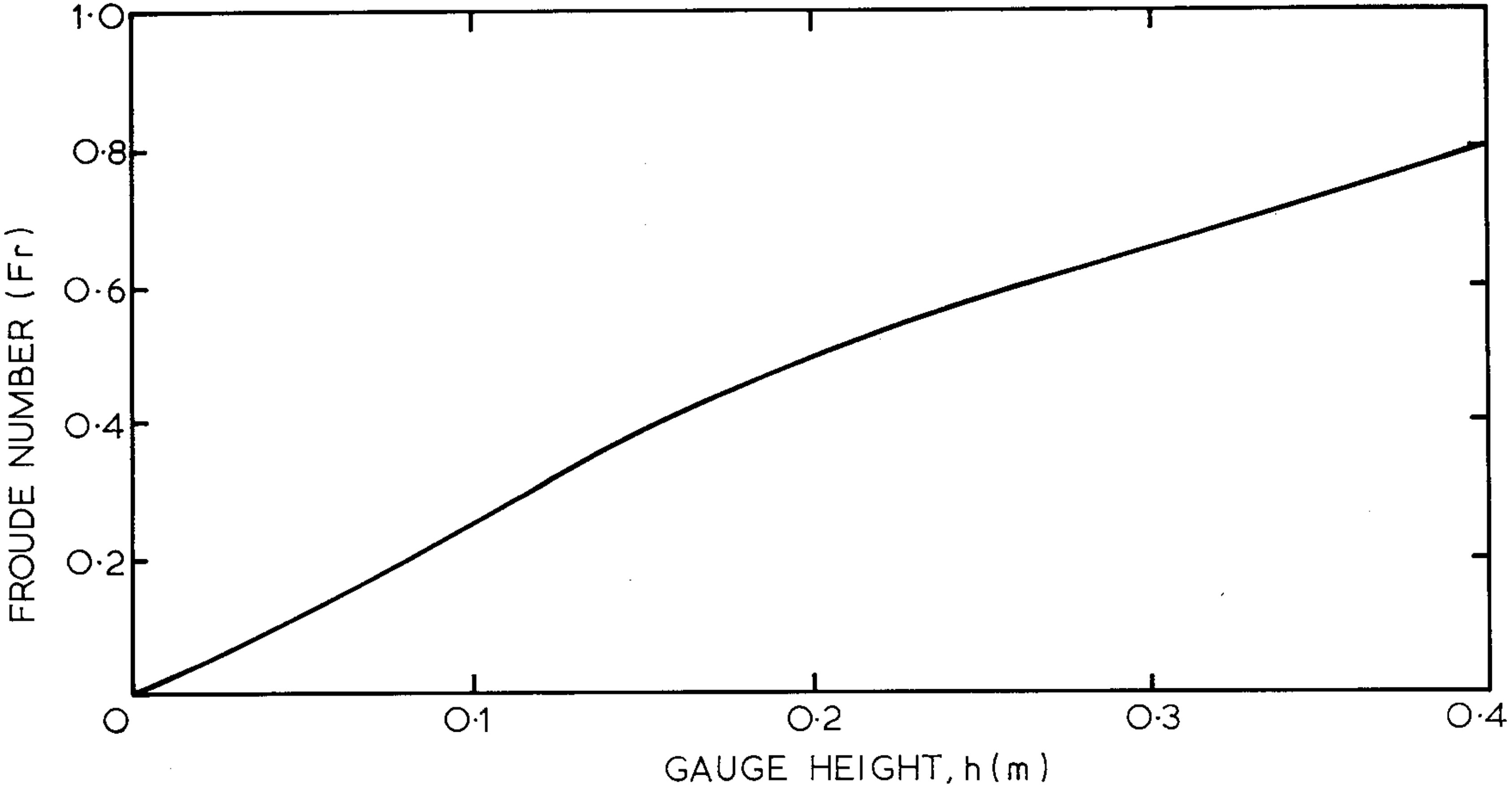


FIGURE 8. FROUDE NUMBER IN THE APPROACH CHANNEL AS A FUNCTION OF GAUGE HEIGHT, h, CALCULATED FOR A BED DEPTH P = 0 GAUGE

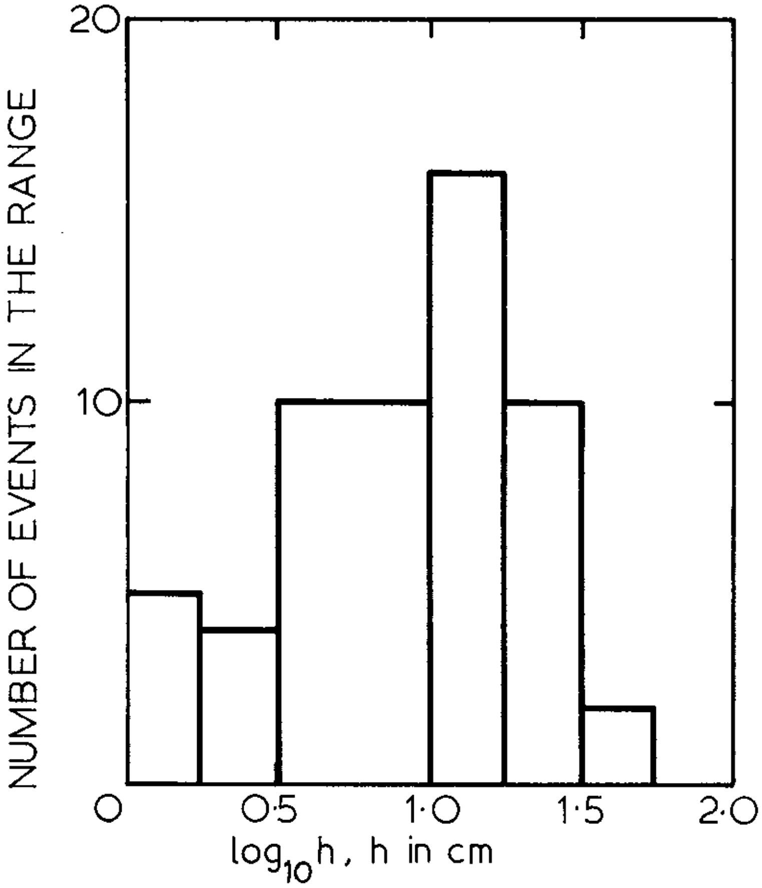


FIGURE 9. FREQUENCY DISTRIBUTION OF EVENTS OF VARIOUS GAUGE HEIGHTS; WHITE'S WEIR, 1975-1976 WET SEASON

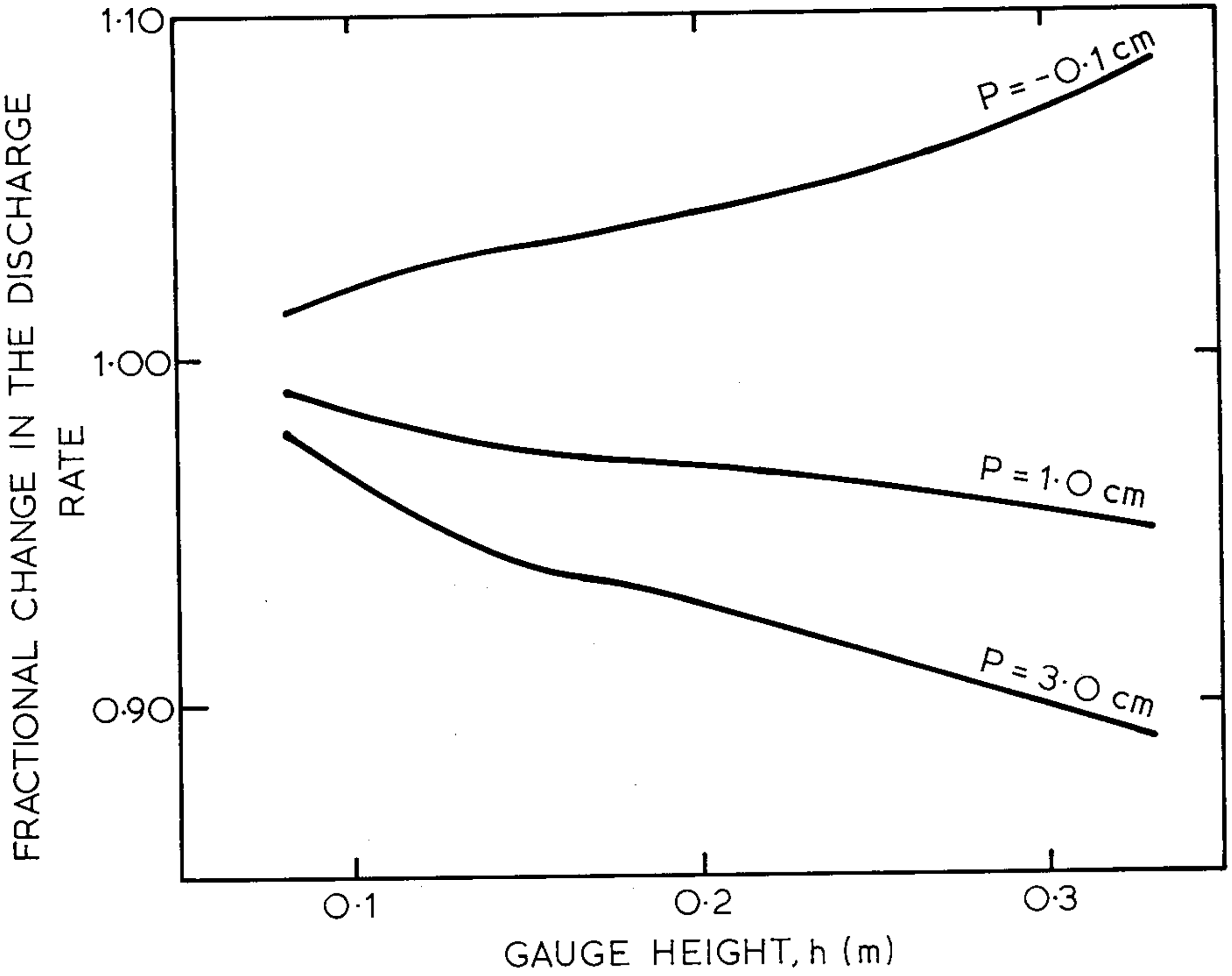


FIGURE 10. FRACTIONAL CHANGE IN THE DISCHARGE RATE Q WITH CHANGE IN BED DEPTH P AS A FUNCTION OF GAUGE HEIGHT h

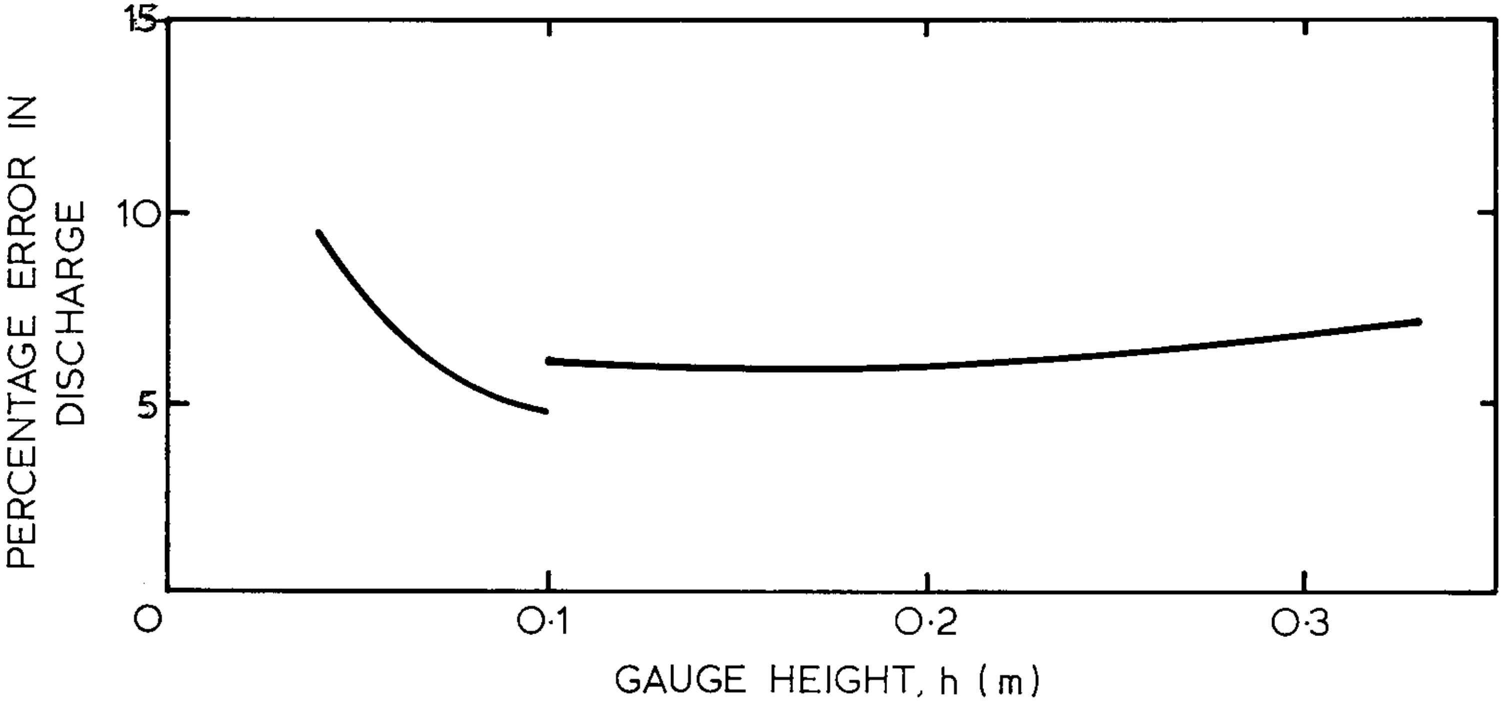


FIGURE 11. ESTIMATED TOTAL PERCENTAGE ERROR IN DISCHARGE RATE AS A FUNCTION OF GAUGE HEIGHT