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DEVELOPMENT AND USE OF RECTANGULAR CHANNELS WITH A SINGLE CURRENT METER MEASUREMENT FOR RECORDING FARM WATER DELIVERIES

by

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PART A: FARM WATER DELIVERIES

1 INTRODUCTION

Pakistan has the largest contiguous irrigation system in the world. The Indus Basin Irrigation System supplies water for 16 million hectares of irrigated land in the country. This system has 3 major storage reservoirs, 19 barrages and 12 link canals, feeding water to 45 canal commands serving about 100,000 tertiary irrigation units (watercourses).

For good water management, water delivered to a farm, and sometimes to every field, requires to be measured. Some scientists say that water measurement is another name for water management. Many flow measuring devices and techniques are available that can be used for flow measurement, with each device suitable for a different situation. The researchers or practitioners need a "bag of flow measuring devices and techniques" that can be drawn upon, depending on the situation being confronted. Many devices like sharp/broad-crested weirs, v-notch weirs, cut-throat flumes, broad crested flumes and long throated flumes are used for discharge measurement in rectangular channels. Flow measurement by using a current meter is also one of the reliable methods used for the evaluation of discharges in main and tertiary irrigation units.

In an effort to manage irrigation water, scientists have always taken a keen interest in developing new and better water measuring methods. Flow in a watercourse is measured by using a flume, weir or a current meter. In an irrigation system, discharge-regulating structures in the main and secondary canals can also be calibrated for discharge measurements using a current meter, or other, more sophisticated devices.

2 BACKGROUND

2.1 CURRENT METERS AND THE CHANNELS

Water measuring devices such as flumes and weirs are installed in watercourses for measuring discharge rates, but the farmers are never happy with the installation of these water-measuring devices because they raise the upstream water levels. They think that the flow of the watercourse has been reduced during the process, and they have been deprived of their right to use the allocated water fully. Thus, methods of flow measurement that do not cause the heading up of water (backwater) in the watercourses and with which the farmers feel comfortable are required.

Measuring discharge in a watercourse using a current meter is one of the methods that does not cause the heading up of water. But discharge measurement by a current meter is a lengthy and time-consuming method. A number of water depths and velocity readings have to be noted before the discharge can be calculated. During the process of noting current meter readings, the discharge may change due to one reason or another, which may add to the difficulty in obtaining an accurate discharge measurement.

To measure the discharge using a current meter, the cross-section of a watercourse has to be subdivided into smaller sections bounded on each side by an imaginary vertical line and the velocity is to be measured: (1) in the middle of the section (mid-section method); or (2) in each vertical section (mean section method). When the depth of the water in a segment is more than 45 cm, or 1.5 foot, one reading will not be sufficient. Rather, two readings of the current meter are to be noted if a pygmy current meter is being used. For standard-sized current meters, the flow can be categorized as large if the depth of water in the vertical or mid-section is more than 75 centimeters, and require current meter velocity measurements at 0.2 and 0.8 of the water depth below the water surface. The division of the cross-sectional area having regular sections may not be that difficult. But, if the cross-sectional area of a watercourse is irregular, even the division of the cross-sectional area makes the calculations somewhat unpleasant, which may lead to slightly erroneous calculations. Much time is needed to measure the flow in a channel with a current meter, as a number of velocity readings are to be noted for obtaining the discharge rate.

2.2. FLOW IN RECTANGULAR CHANNELS

For discharge measurements with current meters in watercourses, the installation of Rectangular Channels can overcome the problems of irregularities in the cross-sectional area of a watercourse. The use of Rectangular Channels for flow measurement using a current meter allows the subdivision of the flow cross-sectional area into regular and equal cross-sectional areas, thereby simplifying the procedure for calculating the discharge rate.

Streamlines of water in a non-uniform earthen watercourse are irregular and are not usually parallel with each other. On the other hand, streamlines of water in a uniform earthen watercourse tend to become parallel. The installation of a Rectangular Channel in an irregular watercourse would result in the streamlines of water becoming parallel soon after the water enters a Rectangular Channel. The velocity of water near the boundary of a watercourse would be a minimum due to the friction at the wall, but at the center of the channel the velocity of water would tend to reach a maximum. The theme of this study is based on the presumption that there should be some relationship in the average velocity of water and the velocity of water at the center in a Rectangular Channel. If so, by determining one value of velocity in the center, V_c, and multiplying this with an appropriate factor determined in the laboratory, the mean velocity in small channels could be estimated. This research study is an effort to correlate velocity at the center with the overall average velocity of water, V_{mean}, in a Rectangular Channel.

3 CURRENT METERING IN RECTANGULAR CHANNELS

3.1 USING A CURRENT METER FOR VELOCITY MEASUREMENTS

The current meter is a reliable device for measuring the velocity of water in a regular or irregular channel. Revolving cups or a propeller in moving water is a necessary part of a current meter. The conical cups are fixed on a vertical shaft, while propellers are fixed on a horizontal shaft of the current meter. The moving water causes the cups or the propeller of the current meter to revolve. The number of revolutions of the cups or the propeller over a specific time period can be counted with the help of headphones and a stopwatch. The electro-mechanical counters are connected with the current meter. The number of revolutions of the cups of a current meter immersed in moving water is directly related with the velocity of water by a simple mathematical relationship. The relationship between the number of revolutions and the velocity of water in a channel may differ from one current meter to another current meter. If the number of revolutions of a current meter per unit of time is known, the velocity of water can be determined by this mathematical relationship, or the rating table provided by the manufacturer for the current meter.

The concept behind this research effort was to evaluate if a single point velocity measurement could be laboratory calibrated to provide the mean velocity, Vmean, in a Rectangular Channel; then, the width of the Rectangular Channel can be multiplied by the depth of water to calculate the cross-sectional area of flow, Aw. Finally, the continuity equation can be used to calculate the discharge rate, Q:

$$Q = A_w V_{mean} \qquad (1)$$

The velocity of water at one point, Vp, can be determined by using the following towing tank calibration when using the pygmy current meter:

$$V_p = (0.961 * \frac{\text{No.of Revolutions}}{\text{Time}}) + 0.05 \qquad (2)$$

where, Vp is the velocity at the point where the current meter is positioned in feet per second, while the time is measured in seconds to complete a selected number of revolutions.

The velocity of water at one point can also be determined by using the standard velocity rating table that is provided by the manufacturer when purchasing a pygmy current meter, which is identical to Equation 2.

The average velocity in the channel may be calculated by using the following formula when the cross-sectional area is divided into n sections:

$$V_{Mean} = \frac{\sum_{i=1}^{n} (v_i a_i)}{\sum_{i=1}^{n} a_i} = \frac{\sum_{i=1}^{n} (v_i a_i)}{A} \qquad (3)$$

Where: Vmean is the average velocity in the channel (L/T);
vi is the velocity in the ith section (L/T);
ai is the cross-sectional area of the ith section (L2); and
A is the overall cross-sectional area of the flow (L2).

3.2. RECTANGULAR CHANNEL REQUIREMENTS

Like any other flow measuring flume, Rectangular Channels are also required to be installed in a perfectly horizontal position so that its floor slope is zero when being used for discharge measurements. Needless to mention, any deviation from a horizontal position for a Rectangular Channel would produce erroneous results. Using a carpenter's level can aid/assist in the installation of a level Rectangular Channel.

The centerline of the Rectangular Channel should coincide with that of the watercourse for accurate installation. The watercourse section in which the Rectangular Channel is installed should be straight. An hydraulic structure should not be present in the watercourse within 30 meters or 100 feet upstream or downstream of the Rectangular Channel. The installed Rectangular Channel must be checked for leakages along the sides and beneath the floor; otherwise, erroneous results will be obtained.

PART B: LABORATORY TESTS

4 DESIGN OF RECTANGULAR CHANNELS

Five Rectangular Channels of different dimensions were fabricated by a local workshop in order to investigate the correct current meter position for velocity measurements. The mild steel sheets (gauge 14) were used for constructing the Rectangular Channels. The width to length ratio of the Rectangular Channels was fixed as 4:9. Four piezometers were installed along one side of the experimental Rectangular Channels to measure the depth of flowing water. The piezometer holes of 3/8-inch diameter were drilled at the distances of 1/2, 2/3, 3/4 and 5/6 of the channel length from the inlet. These piezometer holes were drilled with the centerline at a one-inch interval from the bottom of the channel floor. Against each hole, a stilling well with their centerline was attached to the outside wall having a size equal to a 3-inch width and 4-inch length. A schematic diagram of a Rectangular Channel is shown in Figure 1. The dimensions of the Rectangular Channels tested in the watercourse constructed at the Outdoor Hydraulic Laboratory for these studies are given in Table 1.

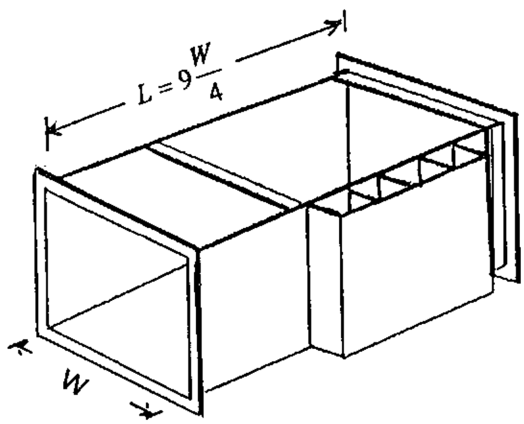

Figure 1. A schematic diagram of an experimental Rectangular Channel used for current meter measurements in the Outdoor Hydraulics Laboratory.

Table 1. Dimensions of Rectangular Channels used with a current meter for velocity measurements.

Width Of Channel (Inches)	Length of Channel (Inches)	Distance of Piezometers from Channel Entrance (Inches)			
		P_{Z1}	P_{Z2}	P_{Z3}	P_{Z4}
		1/2 of Channel Length	2/3 of Channel Length	3/4 of Channel Length	5/6 of Channel Length
8	18	9	12	13+1/2	15
12	27	13+1/2	18	20+1/4	22+1/2
18	40+1/2	20+1/4	27	30+3/8	33+3/4
24	54	27	36	40+1/2	45
27	60+3/4	30+3/8	40+1/2	45+9/16	50+9/16

5 HYDRAULICS OF FLOW THROUGH RECTANGULAR CHANNELS

Water is conveyed from the distributary (secondary) canals through watercourses to the farmer's fields. The water streamlines in the watercourses become parallel if the watercourse is uniform for sufficient length. Since the slope of the watercourse is fairly uniform, the flow becomes uniform and steady. For a Rectangular Channel having approximately the same cross-sectional dimensions as that of the watercourse, the streamlines of water flowing in the Rectangular Channel will remain parallel.

Hypothetically, the dimensions of the cross-sections of the Rectangular Channels were nearly the same as that of the watercourse in which it was placed. As such, the flow streamlines should ideally be parallel even after water enters into the Rectangular Channel. The flow is contracted to some extent, as the cross-sectional area of a Rectangular Channel is contracted to some extent. (Later, observations showed that the flow is contracted to some extent when it enters the Rectangular Channel, becomes parallel in the middle of the channel, and finally, the streamlines start diverging slowly after the flow reaches the middle of the channel).

The velocity of water flowing in a Rectangular Channel is minimal near the walls and near the floor due to the friction between the water and the channel boundaries. The velocity increases with the increasing distance from the boundaries of the Rectangular Channel, both upwards and sidewards. Due to the friction between the water and the construction material of the Rectangular Channels, the velocity of water decreases with the depth and with an increasing distance from the water surface. The velocity at the water surface is slightly less due to friction between the air and water. Theoretically, the maximum velocity will occur at the middle of a Rectangular Channel. The velocity of water in the center should be related with the average velocity of water in the flow cross-section.

6 EXPERIMENTAL DESIGN

6.1. Water Channel

A masonry watercourse having a length of 125 feet was constructed in the Outdoor Hydraulic Laboratory, facilitating the circulation of water in the case the pump does not work. The watercourse, having a depth of 2 feet and a width of 2.6 feet with zero slope was constructed in the Laboratory. As the slope of the watercourse is zero, water in this channel moves in the direction of the hydraulic slope instead of the channel slope. A gate installed at the tail of the watercourse, to vary the depth of the water in the watercourse, is shown in Figure 2.

Near the head of the watercourse, a baffle (shown in Figure 3) was installed to dampen the water surface fluctuations in the watercourse and reduce the turbulence. Arrangements were made so that controlling various valves can also vary the discharge of water in the watercourse. The photograph in Figure 4 shows a Rectangular Channel installed in the Outdoor Hydraulic Laboratory for this study.

6.2. V-notch Weir

A V-notch Weir is a sharp-crested weir placed perpendicular to the sides of the channel to measure the flows in the watercourse for comparison with other methods of flow measurement. A V-notch weir (Figure 5) is one of the most precise discharge-measuring devices and suitable for a wide range of flows (M. G. Bos, 1989). The V-notch was used to measure and compare water flows passing through the Rectangular Channels in these experiments. The weir installed in the Outdoor Hydraulic Laboratory was fabricated and installed in a way that allowed the full contraction of the flow. A weir having an approach channel, and with the bed and sides sufficiently distant from the edges of the V-notch, allow an approach velocity parallel to the weir face, which is called a fully-developed weir. The dimensions of the v-notch installed in the Outdoor Hydraulic Laboratory are shown in Figure 5. A tank having the dimensions of 5-ft x 7-ft was constructed at the beginning of the channel approaching the V-notch. A photograph of the V-notch Weir and the rectangular watercourse constructed in the Outdoor Hydraulic Laboratory is shown in Figure 6.

6.3. Current meter

A pygmy current meter with a vertical rotating shaft was used to measure the local velocity of water flowing in the Rectangular Channels. Before using the current meter, it was re-calibrated in the Current Meter Rating Laboratories of the Punjab Irrigation Department (PID) situated at the Shahrah-e-Quaid-e-Azam, Lahore. The rating tables checked by the laboratories were used to note the speed of the water in the Rectangular Channels at different points. It was noted that both rating tables (the manufacturer's rating table and PID's rating table) are the same. This fact was also confirmed in the Laboratory by comparing the discharges obtained from the V-notch Weir installed at the head of the channel and the discharges calculated from the current meter velocity readings in the Rectangular Channels. The average velocities in the Rectangular Channels were calculated by the Mean Section Method for use in discharge calculations. The photograph in Figure 7 shows the pygmy meter used for this experiment.

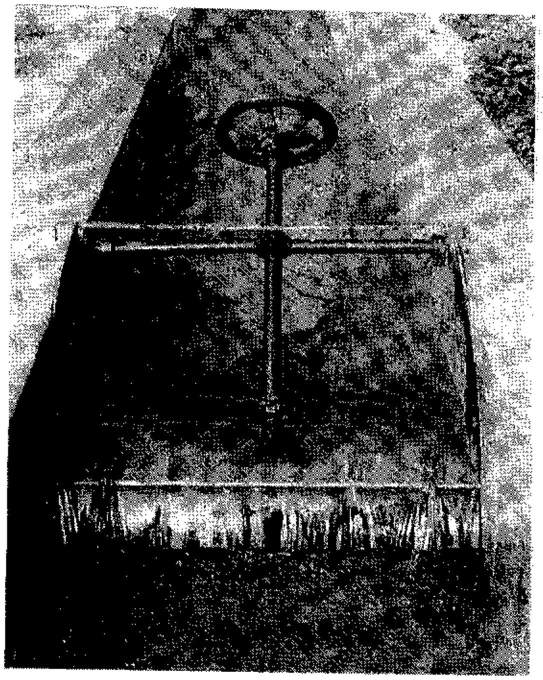

Figure 2. The adjustable gate at the end of the watercourse in the Outdoor Hydraulic Laboratory to control upstream water depths.

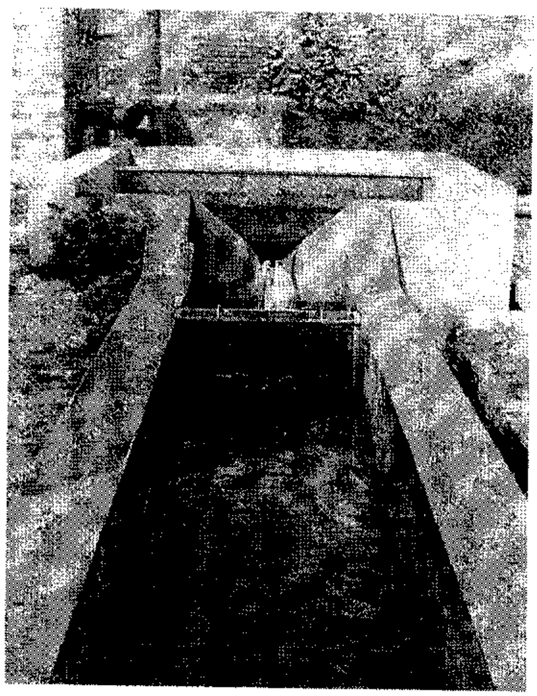

Figure 3. The baffle installed at the beginning of the rectangular watercourse to still the turbulence.

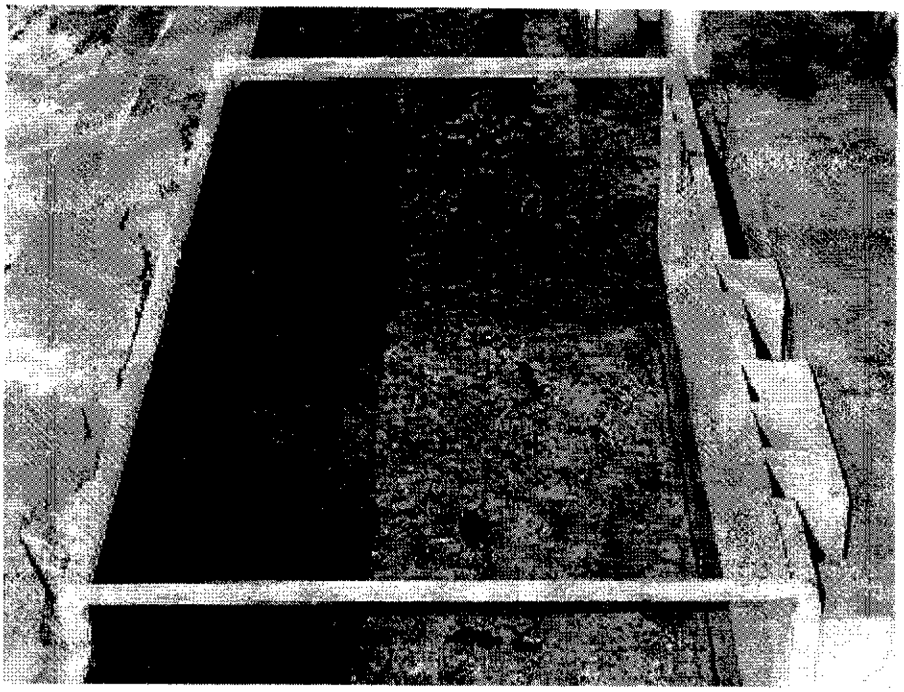

Figure 4. A Rectangular Channel installed in the Outdoor Hydraulic Laboratory.

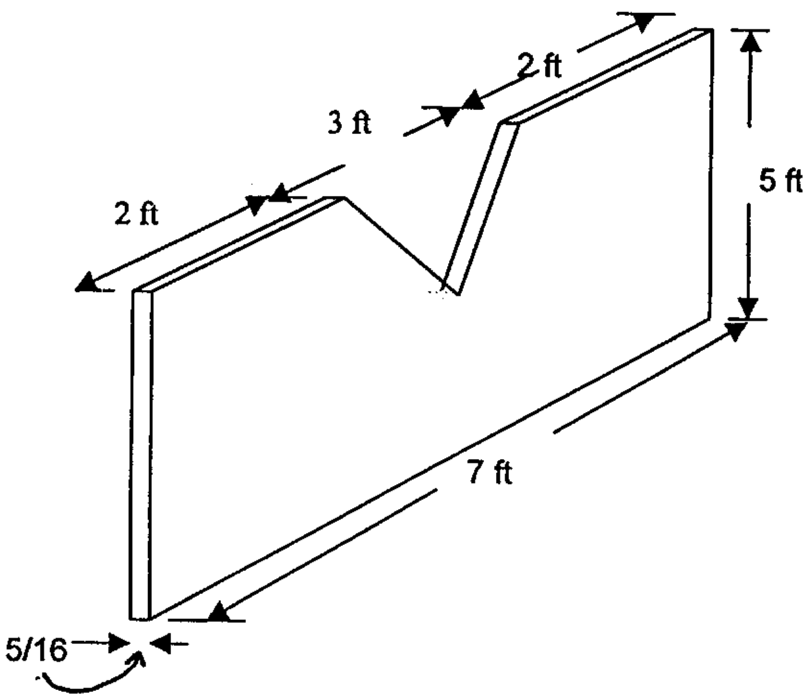

Figure 5. Dimensions of the V-notch Weir used in the Outdoor Hydraulic Laboratory.

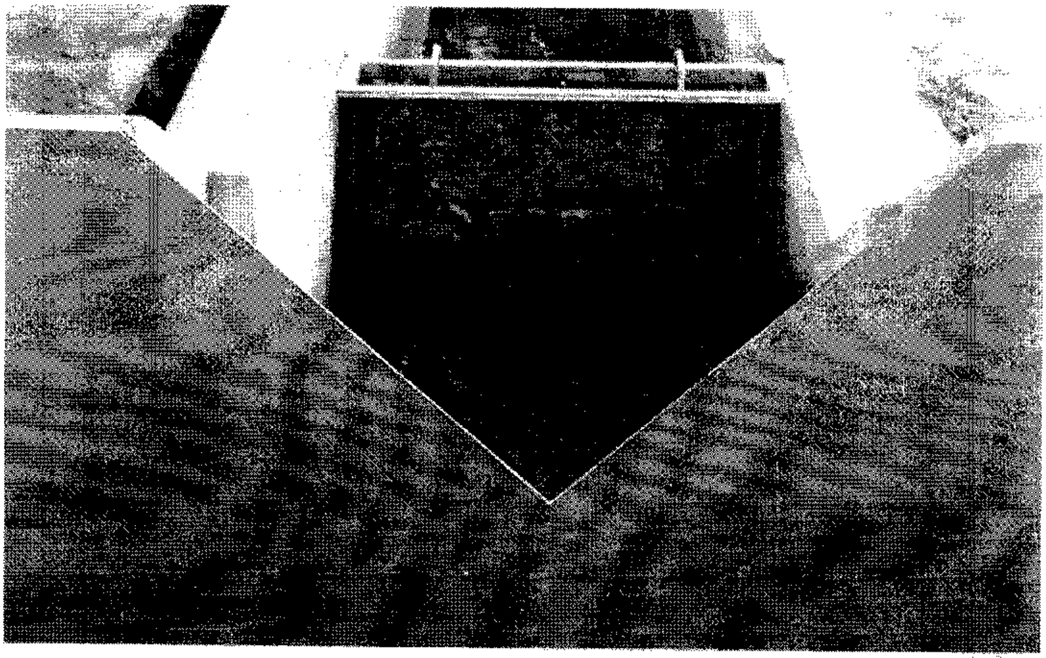

Figure 6. Downstream view of the V-notch Weir and the baffle constructed in the Outdoor Hydraulic Laboratory.

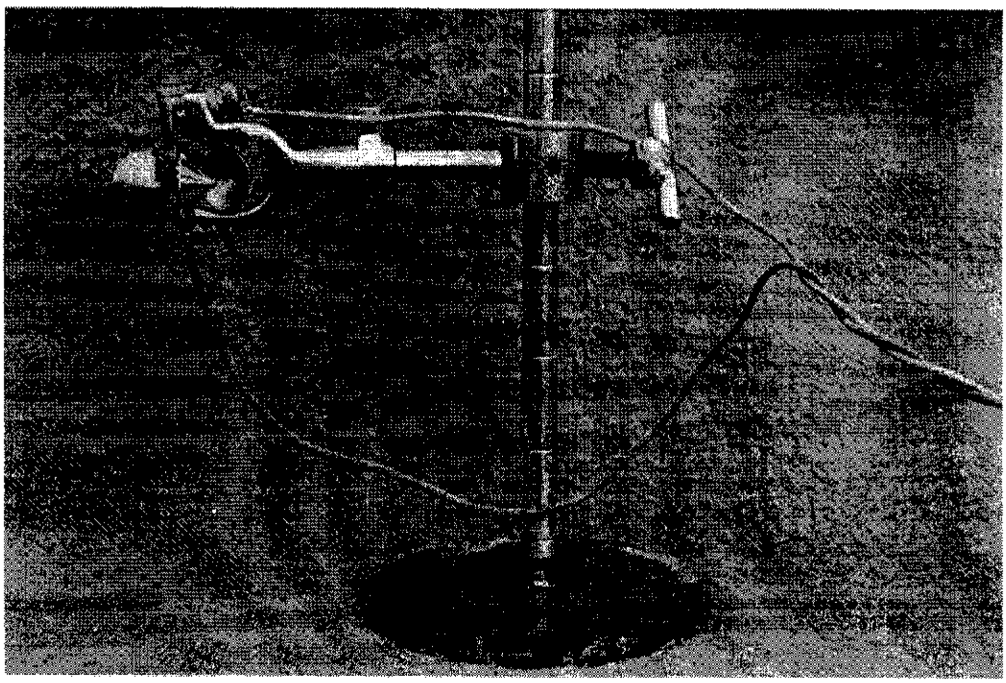

Figure 7. The pygmy current meter used for measuring water velocity during the experiments.

6.4 VELOCITY/DISCHARGE MEASUREMENTS IN RECTANGULAR CHANNELS

For study and analysis, the Rectangular Channels were installed in a rectangular watercourse constructed in the Outdoor Hydraulic Laboratory. The velocities of the water were measured in the Rectangular Channels at the relative depths of 0.2, 0.4, 0.5, 0.6, and 0.8 below the water surface with the help of a pygmy current meter. The pygmy current meter was placed in the middle vertical of the flow cross-section of the Rectangular Channel. Twenty sets of readings were noted for each size of Rectangular Channel by placing the current meter at 1/2, 2/3, 3/4 and 5/6 of the length of the Rectangular Channels; in other words, five hydraulic conditions evaluated at four locations. Since five sizes of Rectangular Channels were hydraulically calibrated, there were one hundred sets of data.

To compare and validate the use of the current meter for discharge measurements, the cross-sectional area of the flow for each Rectangular Channel was divided into six sections of equal widths. One set of readings was taken for each Rectangular Channel at six-tenths of the water depth from the surface of the water. These readings were used to calculate the velocity of water flowing through the Rectangular Channel. The discharge obtained by this method was compared with the discharge of water obtained with the V-notch Weir. The consolidated data are given in Table No. 2. The tables in the annexes show the discharge calculations of water flowing through these Rectangular Channels. The velocity profiles indicating different velocities at different depths are given in Annexes B-F, and graphically represented in the figures in these annexes.

6.5. PROCEDURE

The Rectangular Channels were installed in the rectangular watercourse constructed in the Outdoor Hydraulic Laboratory. Water discharging from the tube-well was diverted to the watercourse. The discharge and depth of the water running in the watercourse was varied for different downstream gate and valve settings. Flow measurements were noted for each experiment with the help of the V-notch Weir. The pygmy current meter was used to measure the velocity of the water flowing in the Rectangular Channels at different locations and at different depths.

The appropriate depth for placing the current meter was determined by placing it in the center of the width and length of the Rectangular Channels, and different sets of velocity readings using a current meter at 0.2, 0.4, 0.5 0.6 and 0.8 of the depth of the water were noted. The second, third and fourth sets of readings were obtained at each piezometer location, while the velocity measurements were kept at 0.2, 0.4, 0.5 0.6 and 0.8 of the depth water in the Rectangular Channel, but measured in the center vertical of the flow cross-section.

To decide upon the positioning of the current meter that gives the best results, a pygmy current meter was placed at different distances starting from the mid-length of the Rectangular Channels for measuring the velocity of the water. Details about the placement of the current meter have been discussed earlier. The current meter was placed in the center of the width of the Rectangular Channels. The first set of velocity readings at different depths was noted at the mid-length. The second set of velocity readings was noted by placing the current meter at distance of two-thirds length of the Rectangular Channel from the inlet. Similarly, the third set of velocity readings was noted at the three-fourths-length of the

Rectangular Channel. The fourth set of readings was noted at five-sixths of the length of Rectangular Channel. These cross-sections correspond with the location of the piezometer holes.

7 RESULTS OF HYDRAULIC LABORATORY TESTS

7.1. JUDGING THE ACCURACY OF THE CURRENT METER

During the experimentation, it was essential to evaluate the accuracy of the current meter to determine whether it works properly and to know whether any change has occurred in the current meter rating with the passage of time. This purpose was attained by comparing the velocity of water running in the watercourse by both; current meter measurements and the velocity obtained using a V-notch Weir. A comparison of the velocities measured with a V-notch Weir and a current meter is given in Annex A, which is summarized in Table 2. The table shows very small differences in the velocities measured in the Rectangular Flume by the current meter and those obtained by using the V-notch Weir. This shows that the current meter worked quite satisfactorily during these experiments.

Table 2. Comparison of discharges measured with a current meter and a V-notch Weir.

Sr. No.	Rectangular Channel Size (inches)	Discharge measured by V-notch weir (cusecs)	Discharge measured by current meter (cusecs)	Percentage Difference (%)
1	8	0.306	0.303	-0.99
2	12	0.604	0.601	-0.50
3	18	1.110	1.140	2.63
4	24	1.298	1.279	-1.49
5	27	1.171	1.162	-0.78

Note: See Tables A1 to A5 in Annex A for more detailed information.

7.2. SELECTION OF CROSS SECTION FOR CURRENT METER PLACEMENT

The velocity measurements were noted at different positions from the inlet of the Rectangular Channel. Figure 8 shows graphs between relative velocities versus the position of the current meter or stilling well locations. The graphs from Well No. 1 to Well No. 2 are straight lines and these lines run parallel. The graphic lines between Well No. 2 and Well No. 3, and Well No. 3 and Well No. 4 are not parallel; rather, these graphic lines cross each other. The above fact indicates that the depths of the water noted in Well Nos. 1 and 2 can be used for the calculation of water discharges passing through the Rectangular Channels, and that noted in Well Nos. 3 and 4 may not lead to comparably accurate results. For simplicity, the installation of one stilling well in the middle (mid-length) of the Rectangular Channel is considered sufficient to note the depth of the water in the Rectangular Channel; hence, only one stilling well at the mid-length (L/2) is being proposed.

7.3. SELECTION OF CURRENT METER PLACEMENT DEPTH

A review of the velocity profiles corresponding with the current meter data sets are contained in Annexes B-F (with one Annex for each size of Rectangular Channel), which discloses that all four piezometer locations provide good velocity profiles. In a few cases, one of the data points appears to have some error; but in most cases, all of the data points provide meaningful, curvilinear velocity profiles. However, piezometer locations 1 and 2 are slightly preferable.

Again, when reviewing the velocity profiles in the annexes, the relative depths of 0.4, 0.5 and 0.6 of the water depth as measured from the floor of the Rectangular Channel would provide good locations for the current meter placement. One of the principal advantages of

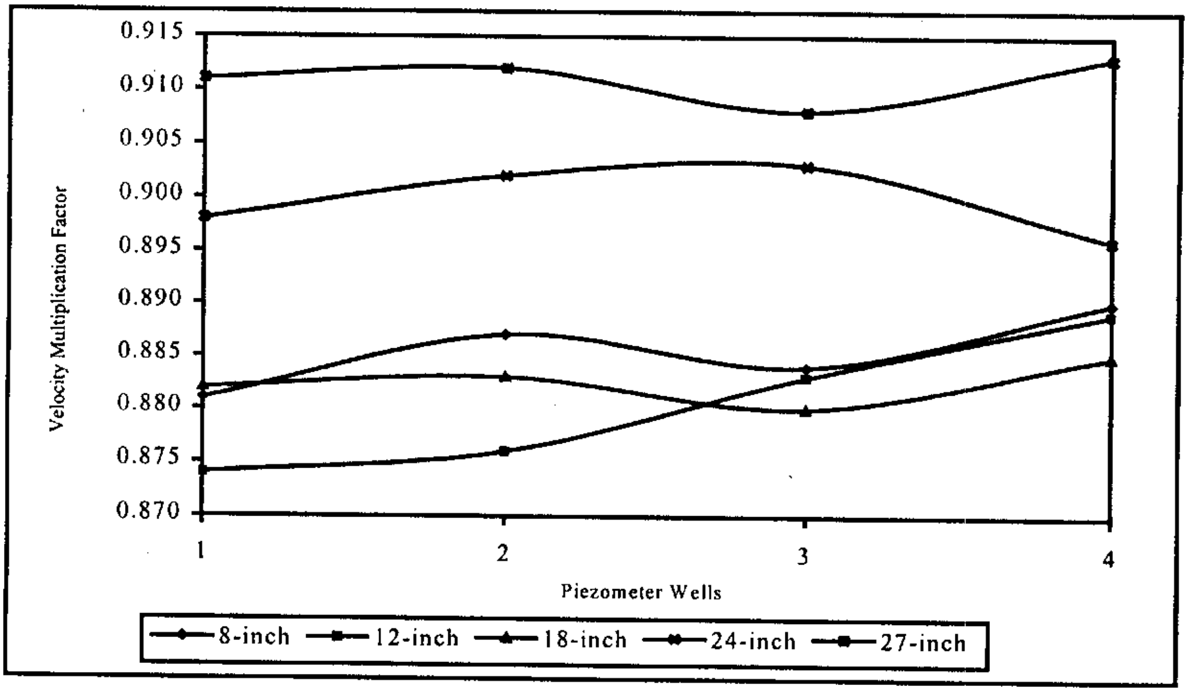

Figure 8. Velocity Multiplication Factor for different sizes of Rectangular Channels for all four piezometer wells.

using 0.5 of the water depth is that the 0.4 and 0.6 depths bound the 0.5 depth. Therefore, if there is some error in the 0.5 depth current meter measurement, it can easily be detected from the velocity profiles; also, a comparison of the velocity profiles for four piezometer locations for the same discharge rate allows a comparison of the shapes of the four velocity profiles, which also assists in detecting erroneous velocity data points.

7.4. Velocity Ratings

A summary of the results contained in the Annexes B, C, D, E and F are presented in Table 3, where the Velocity Multiplication Factor, C_{vmf}, is listed for each hydraulic run, of which there are five for each size of Rectangular Channel. Table 3 also lists the mean value of C_{vmf} for each size. A few values were adjusted for Piezometer 1 (P_z1), which was located at the mid-length of the Rectangular Channels. The basis for these adjustments was a comparison of the velocity profiles at all of the piezometer locations during a hydraulic run; fortunately, only four of the twenty-five values required some adjustments.

The highest and the lowest values of the C_{vmf} for each set of five hydraulic runs are plotted in Figure 9, which portrays the range of variability in C_{vmf} for each Rectangular Channel size.

Table 3. Velocity Multiplication Factor for adjusting the current meter measurement at 0.5 water depth to the mean velocity for different sizes of Rectangular Channel.

Flume Size (inches)	1st Piezometer	2nd Piezometer	3 rd Piezometer	4th Piezometer
8	0.883	0.888	0.882	0.889
	0.878	0.878	0.878	0.888
	0.869	0.881	0.885	0.890
	0.897	0.893	0.879	0.883
	0.880	0.895	0.896	0.898
Average	**0.881**	**0.887**	**0.884**	**0.890**
12	0.871	0.868	0.880	0.890
	0.874	0.889	0.891	0.884
	0.873	0.881	0.881	0.896
	0.858	0.860	0.868	0.885
	0.893	0.884	0.893	0.893
Average	**0.874**	**0.876**	**0.883**	**0.889**
18	0.888	0.880	0.880	0.872
	0.875	0.882	0.873	0.891
	0.890	0.894	0.896	0.900
	0.889	0.888	0.881	0.881
	0.886	0.872	0.872	0.881
Average	**0.882**	**0.883**	**0.880**	**0.885**
24	0.886	0.886	0.895	0.886
	0.904	0.904	0.913	0.889
	0.896	0.916	0.892	0.892
	0.906	0.906	0.899	0.901
	0.899	0.889	0.915	0.901
Average	**0.898**	**0.902**	**0.903**	**0.896**
27	0.926	0.909	0.909	0.909
	0.900	0.928	0.909	0.909
	0.930	0.935	0.935	0.935
	0.898	0.890	0.890	0.898
	0.900	0.897	0.894	0.912
Average	**0.911**	**0.912**	**0.908**	**0.913**
Overall Average	**0.889**	**0.892**	**0.892**	**0.894**

Note. Shaded values were adjusted based on analyzing the velocity profile for all four piezometer locations during each hydraulic run.

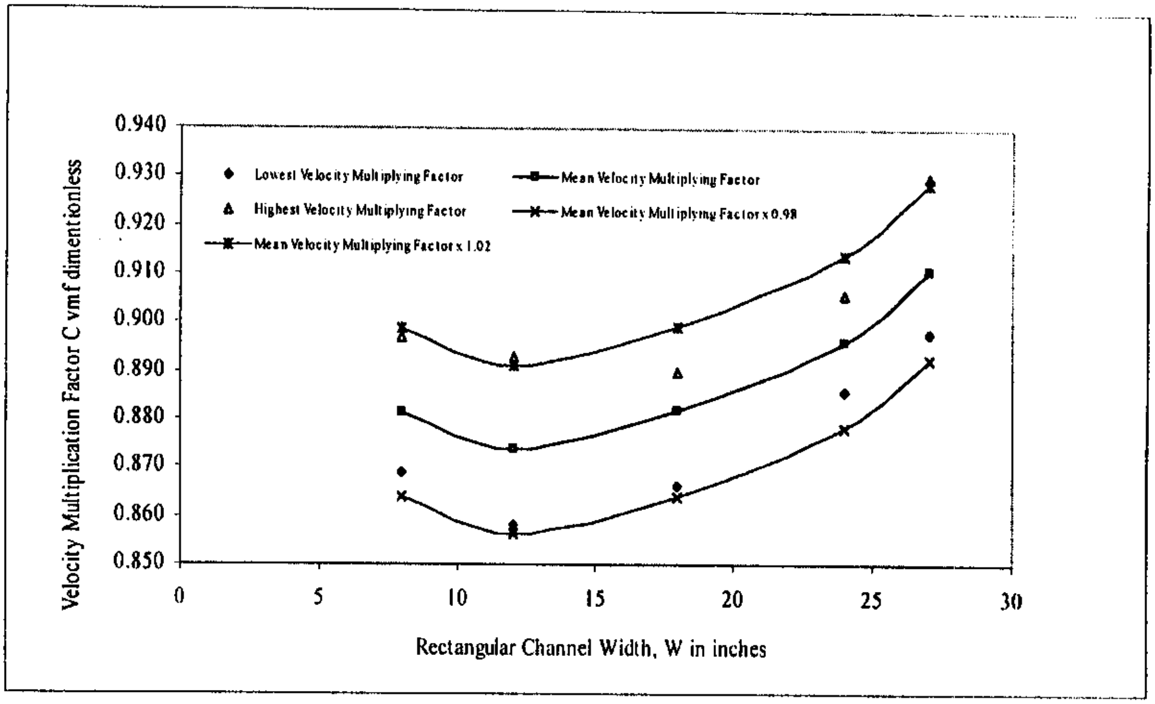

Figure 9. Velocity Multiplication Factor for various sizes of Rectangular Channels.

A curvilinear relationship exists for the mean values of C_{vmf}, with the 8-inch Rectangular Channel being an anomaly where in the only hypothesis would be that the width of the current meter is significant when compared to the width of the Rectangular Channel, so that the current meter measurement represents the velocity across about half of the channel width, and thereby, decreasing the amount of adjustment in calculating the mean velocity (higher value of C_{vmf}).

The curves drawn in Figure 9 represent two percent greater, along with two percent less, than the mean curve. This demonstrates that the maximum range in variation of C_{vmf} for each size is four percent, or less. Thus, the use of a Rectangular Channel in conjunction with a single current meter measurement has the potential for being quite accurate. The greatest source of inaccuracy will be the velocity rating for the current meter. In numerous cases, these ratings are never, or rarely, checked in laboratory for the current meter velocity rating to be in error by ten percent or more.

8 SUMMARY OF FINDINGS

Based on the results presented in Table 3 and Figure 9 some additional sizes of the Rectangular Channel have been selected in English units, as well as a series of sizes in metric units. The Velocity Multiplication Factor, C_{vmf}, for each size, is listed in Table 4. These values of C_{vmf} were obtained by interpolation from the mean curve in Figure 9, except for the largest sizes (30-inch and 76-cm), where the mean curve was extrapolated. These values are appropriate when the current meter is placed at the centroid (middle of the Rectangular Channel at half of the water depth) of the mid-length flow cross-section.

The mean velocity, V_{mean}, is obtained from the relationship:

$$V_{mean} = C_{vmf}\,(V_c) \tag{4}$$

where, V_c is the value of the current meter velocity measurement at the centroid of the flow cross-section located half-way along the length of the Rectangular Channel.

The discharge rate, Q, in the Rectangular Channel is obtained from the continuity equation:

$$Q = A_w V_{mean} \tag{1}$$

where, A_w is the cross-sectional area of the water at the mid-length, which is represented by:

$$A_w = W d_{L/2} \tag{5}$$

with W being the width of the Rectangular Channel, whereas $d_{L/2}$ is the water depth measured in the stilling well for Piezometer 1 located at the mid-length (L/2).

Table 4. Velocity Multiplication Factor, C_{vmf}, for selected sizes, W, of Rectangular Channel.

English units		**Metric Units**	
Rectangular Channel Size , W, in inches	Velocity Multiplication Factor, (dimensionless)	Rectangular Channel Size , W, in centimeters	Velocity Multiplication Factor, (dimensionless)
12	0.874	30	0.874
16	0.878	36	0.875
18	0.882	44	0.881
20	0.887	52	0.888
24	0.898	60	0.897
27	0.911	68	0.910
30	0.932	76	0.931

PART C: USE OF RECTANGULAR CHANNELS

9 FABRICATION OF RECTANGULAR CHANNELS

Water is conveyed from the distributaries to the farmers' fields through small water channels called watercourses. For flow measurements in these watercourses, Rectangular Channels can be installed at places of interest. Every flow-measuring flume has some constriction, but the Rectangular Channels have no (or very little) constriction; also, they are very easy to fabricate. The walls of the Rectangular Channel should be constructed in a way that would allow the walls to be parallel to each other and vertical with the floor. The floor of the Rectangular Channel should be horizontal and the width-to-length ratio should be 4:9. The widths of the Rectangular Channels can be made according to the widths of watercourses in which it is to be placed, but preferably using a standard width, W, as listed in Table 4. However, intermediate sizes can be selected. Certainly, selecting a width nearly equal to that of the watercourse will ensure that the flow of the water has little contraction when placed in a watercourse. In order to make the Rectangular Channel robust, an angle iron can be welded along the rims of the structure. An angle iron bar can also be welded around the center of the Rectangular Channel at the mid-length. This will also help in placing the current meter at the proper location.

A stilling well having the dimensions of a 3-inch width x 4-inch length is required to be welded/fixed in the middle of the Rectangular Channel, as shown in Figure 10. The bottom of the stilling well needs to be closed. A piezometer hole having a diameter of 3/8 inch in the center of the stilling well (piezometer) is drilled so that the water can enter the stilling well freely to represent the depth of the water in the Rectangular Channel. The center of the piezometer hole (tap) should be one-inch above the floor of the Rectangular Channel.

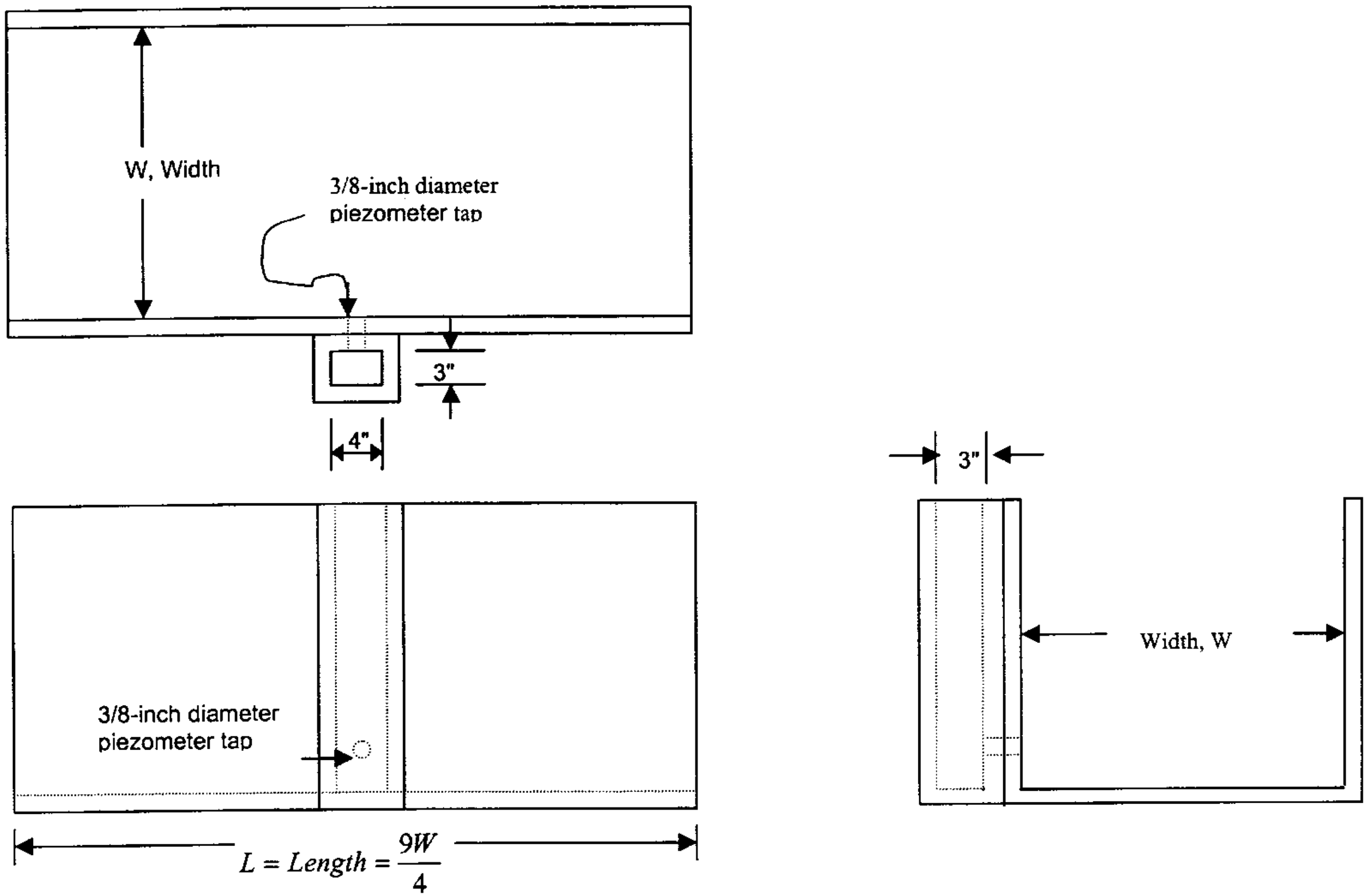

Figure 10. Fabrication of Rectangular Channel for placing current meter for flow measurements.

10 PROCEDURE FOR FLOW MEASUREMENTS

10.1 INSTALLATION OF RECTANGULAR CHANNELS IN WATERCOURSES

The essence of installing Rectangular Channels for the measurement of flow is that their bottom (floor) must be horizontal, as explained earlier. A deviation from the installation of flumes so that its bottom is other than horizontal would give erroneous results. Using a carpenter's hand level can ensure horizontal installation of Rectangular Channels. Like the installation of any other flume, reference points have to be marked on the top of the walls prior to installation of the rectangular flume. For this purpose, first of all, place the Rectangular Channel at a place on the soil (loose) which has been specially prepared to be perfectly horizontal. Adjust the bottom level of the Rectangular Channel using a carpenter's hand level until the floor of the Rectangular Channel is perfectly level. Mark at least three such areas in the base of the Rectangular Channel, which are at zero level with the help of a carpenter's level. Without dislocating the channel, mark at least two points on the top of the Rectangular Channel, which are at zero level. These are reference points, which would help in the installation of the Rectangular Channel in a watercourse for discharge measurements. Now, install the Rectangular Channel at a leveled position in the watercourse in such a way that these marked points at the top are at zero level. This would ensure that the bottom of the Rectangular Channel is perfectly at level as well.

10.2 CURRENT METER PLACEMENT FOR VELOCITY MEASUREMENT

Place the current meter exactly at L/2, as well as in the middle of the Rectangular Channel at half of the depth of the water flow to be measured. The current meter should be placed in the cross-section corresponding with the piezometer hole, which is also in the middle (mid-length) of the Rectangular Channel. Measure the velocity using the current meter by counting the number of revolutions over an interval of time, usually 40–70 seconds. Determine the number of revolutions made by the current meter. Now, calculate the velocity of the water passing through the Rectangular Channel installed in the watercourse by using the relationship provided by the manufacturer of the current meter being used. Multiply the velocity thus noted by the Velocity Multiplying Factor, C_{vmf}, to determine the mean velocity, V_{mean} (Equation 4). Multiply the width, W, of the Rectangular Channel by the depth of water in the stilling well, $d_{L/2}$, for calculating the cross-sectional area of the flow, A_w (Equation 5). Multiplying the average velocity of the flow passing through the Rectangular Channel by the cross-sectional area of flow will determine the discharge rate (Equation 1).

11 CARE OF THE INSTRUMENTS

11.1. Cleaning and Maintenance

11.1.1 Current Meter

A current meter is a very delicate device. The proper maintenance of the current meter for its functioning and long life is essential. The current meter can produce accurate results only if it is properly maintained. The current meter needs meticulous care and protective custody at the time of transportation and while in custody. Damage to the current meter may occur when mishandled. The damages to the current meter include a broken pivot, chipped bearing, and bent shaft. The damages in the current meter may produce erroneous velocities (less than the actual). Variations in velocity measurements may occur up to 30 percent as a result of mishandling current meters (Mushtaq et al. 1977).

To safeguard the current meters, a protection case comes with every current meter at the time of purchasing. The equipment should be properly packed in this box whenever being transported. The transportation of the equipment from one location to another is one of the most common causes of damage (Corbett et al., 1943). Careless packing or negligence in its protection may also cause damage to the current meter. The current meter should always be properly protected and placed in its box while transporting, even if the distance to which it is to be carried is small.

The pivot and pivot bearing of the current meter must be protected from sudden jerks to ensure an accurate and prolonged use of the equipment. Rusting is a very common damage to the current meter. Proper oiling of the pivots will increase the life of the current meter. The proper usage of current meters demands that there is no play in the cups.

The following instructions are useful for providing better performance and enhancing the life of current meters:

1. The individual parts of the current meter should be cleaned and dried after the current meter is used for velocity measurements;

2. The moving parts of the current meter should be oiled properly;

3. The battery should be placed separately;

4. Disconnect all the wires before packing the current meter;

5. The headphone set assembly should be properly placed in its proper box; and

6. While transporting the current meter, it should be properly placed in the current meter box, placing every part at its proper place.

11.1.2 Rectangular Channel

Rectangular Channels are the structures wherein the current meter is placed for making velocity measurements. The velocity is measured at only one point; the centroid of the mid-length cross-section. The Rectangular Channel may contain sediment deposits, especially if the water contains high sediment concentrations. The Rectangular Channel needs to be cleaned prior to making water measurements. Some foreign material may accumulate in the Rectangular Channel that must be removed from the channel. With the passage of time, sediment or other material may clog the piezometer hole and the stilling well. Frogs have often been seen in the piezometer wells of the Rectangular Channels when installed in the field. The piezometer wells of a Rectangular Channel must be cleaned from all types of debris and sediment; otherwise, it may lead to erroneous results. After a year of use, encrustation may occur on the metal surfaces, which need to be scraped clean with a wire brush and then to repaint the metal surface.

11.2 Local Testing of Current Meters

While using a current meter for discharge measurement, the question of whether the current meter is functioning properly may arise. One way to answer this question is to test the current meter for accuracy at the workshop. The current meter can also be tested locally for its proper functioning. The procedure is explained below.

Measure the velocity at the centroid (V_c) by the current meter in a Rectangular Channel installed for the purpose. Calculate the average velocity in the Rectangular Channel by multiplying V_c with the appropriate Velocity Multiplication Factor C_{vmf}. Let this velocity be V_l. Take a complete set of current meter measurements using the usual vertical measuring velocities at 0.2, 0.4, 0.5, 0.6, and 0.8 of the water depth. Draw a graph of the velocity profile for each vertical on rectangular coordinate graph paper. Calculate the average velocity for each vertical by integrating the area under the velocity profile curve and dividing this by the depth of water. Then, calculate the discharge rate in the same manner commonly employed when current metering a canal or river. Calculate the average velocity by dividing the discharge by the cross-sectional area of water flowing in the Rectangular Channel. If this velocity corresponds within three percent of the velocity measured by the above method, the current meter is working satisfactorily; otherwise, the current meter needs to be re-calibrated.

11.3 Data Recording

To measure the velocity and calculate the discharge, data can be recorded on the worksheet shown in Table 5 as presented on the next page.

11.4 Computation of Velocity and Discharge

The velocity in a Rectangular Channel can be computed if the number of revolutions of the current meter over a measured time period are known, as well as the velocity rating for the particular current meter being used. For a pygmy current meter, the velocity at any point, V_p, may be calculated using the following standard relationship:

$$V_p = (0.961 * \frac{\text{No.of Revolutions}}{\text{Time}}) + 0.05 \quad (2)$$

where, V_p is the velocity at the point being measured in feet per second (L/T) and time (T) is in seconds to complete the number of revolutions (R).

When the current meter is positioned to measure the velocity at the centroid of the mid-length cross-section, V_p becomes V_c. The average or mean velocity can be calculated using the following relationship:

$$V_{mean} = C_{vmf}(V_c) \quad (4)$$

where the value of C_{cmf} is obtained from Table 4 for the size of the Rectangular Channel being used. In order to calculate the discharge rate passing through the Rectangular Channel, the cross-sectional area of flow in the channel can be calculated from:

$$A_w = Wd_{L/2} \quad (5)$$

where W is obtained from Column 2 of Table 5 and $d_{L/2}$ is obtained from Column 3. Then, Equations 4 and 5 can be combined to obtain the discharge rate, Q:

$$Q_w = A_w V_{mean} \quad (1)$$

The following example illustrates the calculation of discharge rate passing through a Rectangular Channel by using a current meter as developed in this report.

Example

What will the discharge passing through a Rectangular Channel in cubic feet per second be if the current meter has revolved 60 times in 49 seconds in a Rectangular Channel having a width of two feet? The water level noted in the stilling well has been noted to be 1.31 feet.

Solution

Velocity Multiplication Factor, C_{vmf}	= 0.898 from Table 4	
Velocity of water at centroid	= 0.961*(60/49)+0.05	= 1.227 feet per second
Average velocity of water	= 1.227 * 0.898	= 1.102 feet per second
Cross-sectional area of flow	= 1.31 feet (2 feet)	= 2.62 square feet
Discharge of water	= 2.62 square feet	= 1.102 feet/sec)
	= 2.887 cubic feet per second	
	= 2.89 cfs (cusecs)	

Table 5: Recording data for velocity measurement and discharge calculation.

Sr. No. (1)	Width of Rectangular Channel W (2)	Depth of water in stilling well $d_{L/2}$ (3)	Current Meter Depth $d_{0.5}$ (4)	No. of Revolutions R (5)	Time T (6)	Velocity of Water (v_c) (7)	Mean Velocity V_{mean} (8)	Cross-Sectional Area of Water A_w (9)	Discharge of Water Q (10)

$A_w = Wd_{L/2}$ $V_{mean} = C_{vmf} (V_c)$ $Q = A_w V_{mean}$

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