REPORT NO. T-7

CURRENT METER DISCHARGE MEASUREMENTS FOR STEADY AND UNSTEADY FLOW CONDITIONS IN IRRIGATION CHANNELS

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FOREWORD

The International Irrigation Management Institute (IIMI) has collaborated with the Punjab Irrigation Department in providing field training on discharge calibration of various flow control structures. This training has always involved using of the current meter for measuring the discharge rate.

IIMI maintains a field staff at Bahawalnagar for developing a Decision Support System (DSS) for the Fordwah Eastern Sadiqia Irrigation and Drainage Project in southeastern Punjab using funds provided by the Government of The Netherlands under the project, ***"Managing Irrigation for Environmentally Sustainable Agriculture in Pakistan".***

The staff working at the Bahawalnagar Field Station have become quite proficient in making discharge measurements for the prupose of calibrating various flow control structures. Their experience is reflected in much of this manual.

The canals in Pakistan experience discharge fluctuations everyday; often, these fluctuations are 10-20 percent in a day and occasionally as much as 50 percent. To cope with these discharge fluctuations, IIMI has developed a unique procedure for unsteady flow discharge measurements using a current meter that is contained in the final section of this training manual.

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1. INTRODUCTION

Some portions of this manual have been distributed previously as a handout during various training courses. These materials have been improved based on experiences gained over the past two years, or more.

A unique approach has been developed for unsteady flow discharge measurements using a current meter, which is described in the final section of this manual. This has been necessitated by the daily discharge fluctuations that occur in the canals of the Indus Basin Irrigation System.

2. TYPES OF CURRENT METERS

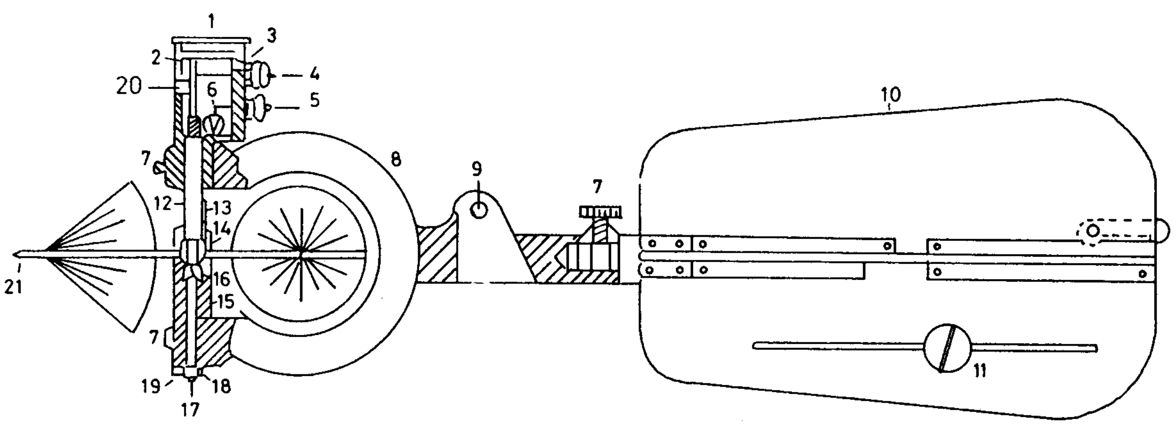
There are many countries that manufacture good quality current meters. One of the more recent innovations is the electro-magnetic current meter that displays the velocity measurement. The electronic types of current meters will be used much more in the future.

Electronic (electro-magnetic) current meters are now available that contain a sensor with the point velocity being digitally displayed. Some of the earlier models had considerable electronic noise under turbulent flow conditions. Fortunately, present models yield more stable velocity readings and have been used in irrigation channels. Undoubtedly, these instruments will be further improved in the near future.

Current meters with a rotating unit that is sensing the water velocity are either vertical-shaft or horizontal-shaft types. The vertical-axis current meter has a rotating cup with a bearing system that is simpler in design, more rugged, and easier to service and maintain than horizontal-shaft (axis) current meters. Because of the bearing system, the vertical-shaft meters will operate at lower velocities than horizontal-axis current meters. The bearings are well protected from silty water, the bearing adjustment is usually less sensitive, and the calibration at lower velocities where friction plays an important role is more stable (Hagan, 1989).

2.1 Vertical Axis

Two of the commonly used vertical-axis current meters are the Price Type A Current Meter and the Price Pygmy Current Meter, which is used for shallow flow depths and low velocities. A diagram for the Price Type A Current Meter is shown in Figure 1. A comparision of the relative size between these two current meters is illustrated in Photograph A. Usually, the larger current meter is employed when the flow depth is greater than 1.5 feet (45 cm). When the depth of water is less than 1.5 feet and the velocities are low, then the pygmy current meter should be used, which would usually be the case for tertiary irrigation channels (e.g., watercourses). Using a pygmy current meter in a lined rectangular cross-section of a watercourse (Photograph B) provides an accurate

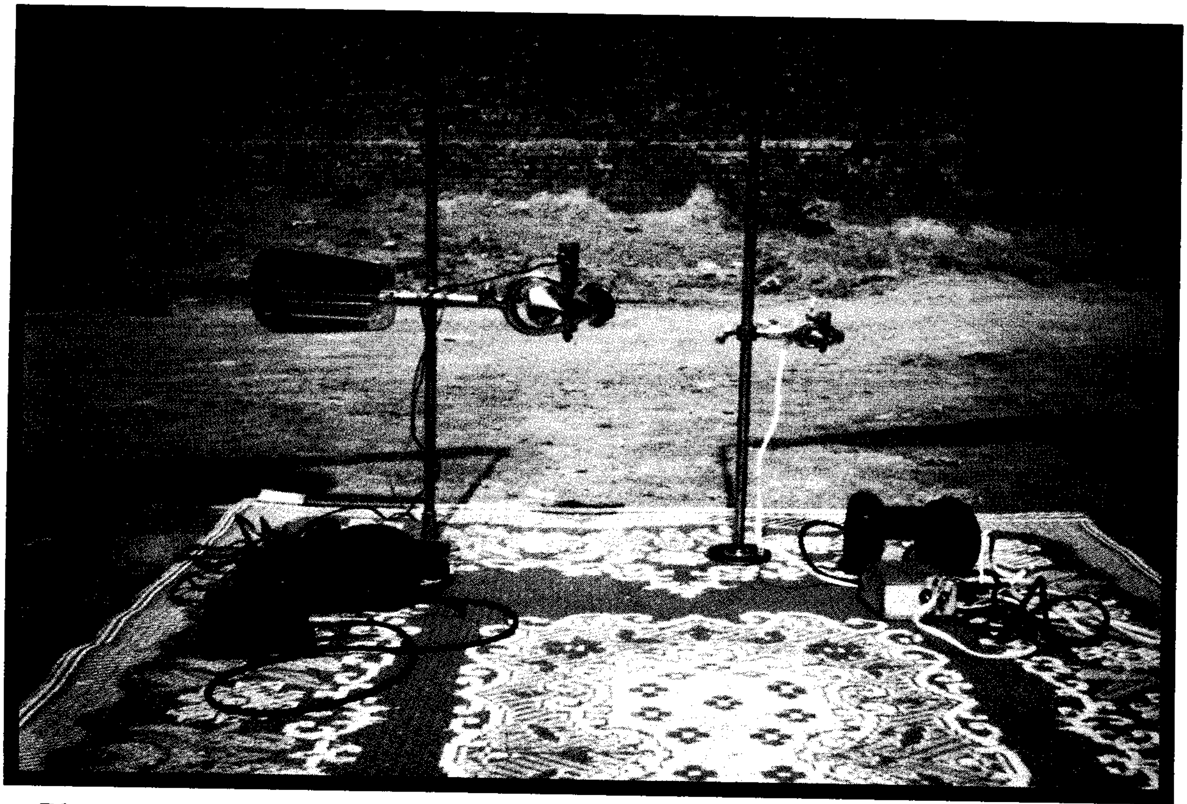


EXPLANATIONS

1	Cap for contact chamber	11	Balance weight
2	Contact chamber	12	Shaft
3	Insulating bushing for contact binding post	13	Bucket wheel hub
4	Single-contact binding post (upper)	14	Bucket wheel hub nut
5	Penta-contact binding post (lo er)	15	Raising nut
6	Penta-gear	16	Pivot bearing
7	Set screws	17	Pivot
8	Yoke	18	Pivot adjusting nut
9	Hole for hanger screw	19	Keeper screw for pivot adjusting nut
10	Tailpiece	20	Bearing lug
		21	Bucket wheel

Source: Don M. Corbett et al. 1943

Figure 1. Assembly diagram for a Price Type A Current Meter.



Photograph A. Relative Size of Price Type A and Pygmy current meters.

Photograph B. Using a Pygmy current meter in a lined rectangular cross-section of a watercourse.

measurement of the discharge. The large current meter is commonly used for measuring discharge rates in the secondary channels (minors and distributaries), as well as the principal channels (branch canals and canals). If an observer face difficulty in countering the revolution then connection must be shifted to lower nut (see Photograph C) (1 click=5 revolution) and in final calculation of clicks, they mist be multiplied by 5 before consulting the velocity rating table.

2.2 Horizontal Axis

The horizontal-shaft current meters use a propeller. These horizontal-axis rotors disturb the flow less than the vertical-axis cup rotors because of axial symmetry with the flow direction. Also, the horizontal-shaft current meters are less sensitive to the vertical velocity components. Because of its shape, the horizontal-axis current meter is less susceptible to becoming fouled by small debris and vegetative material moving with the water (Hagan, 1989).

There are some rugged, high quality horizontal-axis current meters that give excellent results. Some common horizontal-axis current meters are the Ott (Germany), the Neyrpic (France) and the Hoff (U.S.A.). Some recent models have proven to be both accurate and durable when used in irrigation channels.

An example of a horizontal axis current meter is shown in Figure 2. The propeller is shown in Photograph D, while the digital velocity counter is shown in Photograph E. The complete assembly is illustrated in Photograph F and the assembled vertical and horizontal axis current meters are shown in Photograph G.

3. CURRENT METER RATINGS

Usually, a current meter is calibrated in a towing tank. The current meter is attached to a carriage that travels on rails (tracks) placed on the top of the towing tank. Then, a series of trials are conducted wherein the current meter is towed at different constant velocities. For each trial, the constant velocity of the carriage is recorded, as well as the revolutions per second (rev/s) of the current meter. This data is plotted on rectangular coordinate graph paper to verify that a straight-line relation exists; then, the equation is determined by regression analysis. Table 1 is an example of a velocity rating in metric units based on the rating equation for one particular current meter:

$$\textbf{Velocity (m/s)} = \textbf{0.665 (rev/s)} + \textbf{0.009} \tag{1}$$

The velocity in English units is:

$$\textbf{Velocity (ft/s)} = \textbf{Velocity (m/s) 3.281 (ft/m)} \tag{2}$$

$$\text{Velocity (ft/s)} = 3.281\ \text{(ft/m)}\ [0.665\text{(rev/s)}+0.009]\text{(m/s)}$$

$$\textbf{Velocity (ft/s)} = \textbf{2.182 (rev/s)} + \textbf{0.029} \tag{3}$$

The name of major parts are as below:

1.	Base plate	2.	Wading rods
3.	Propeller	4.	Counter
5.	Wire	6.	Pointer

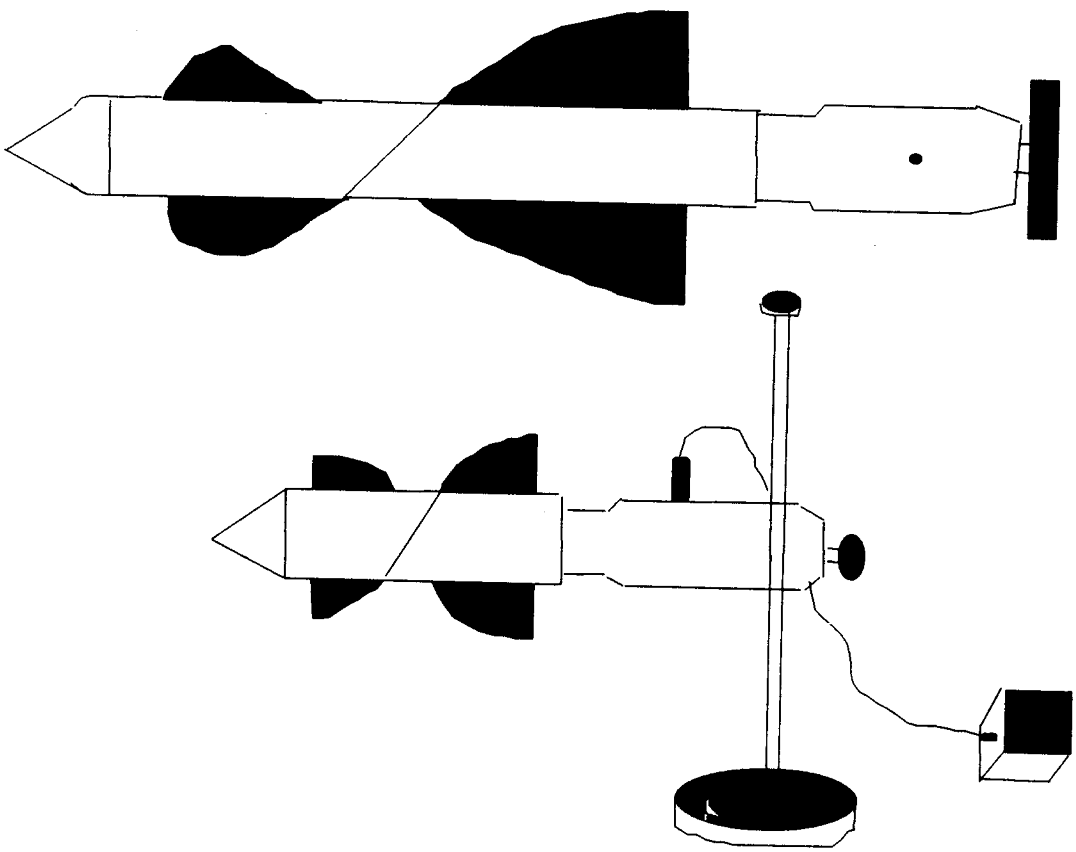
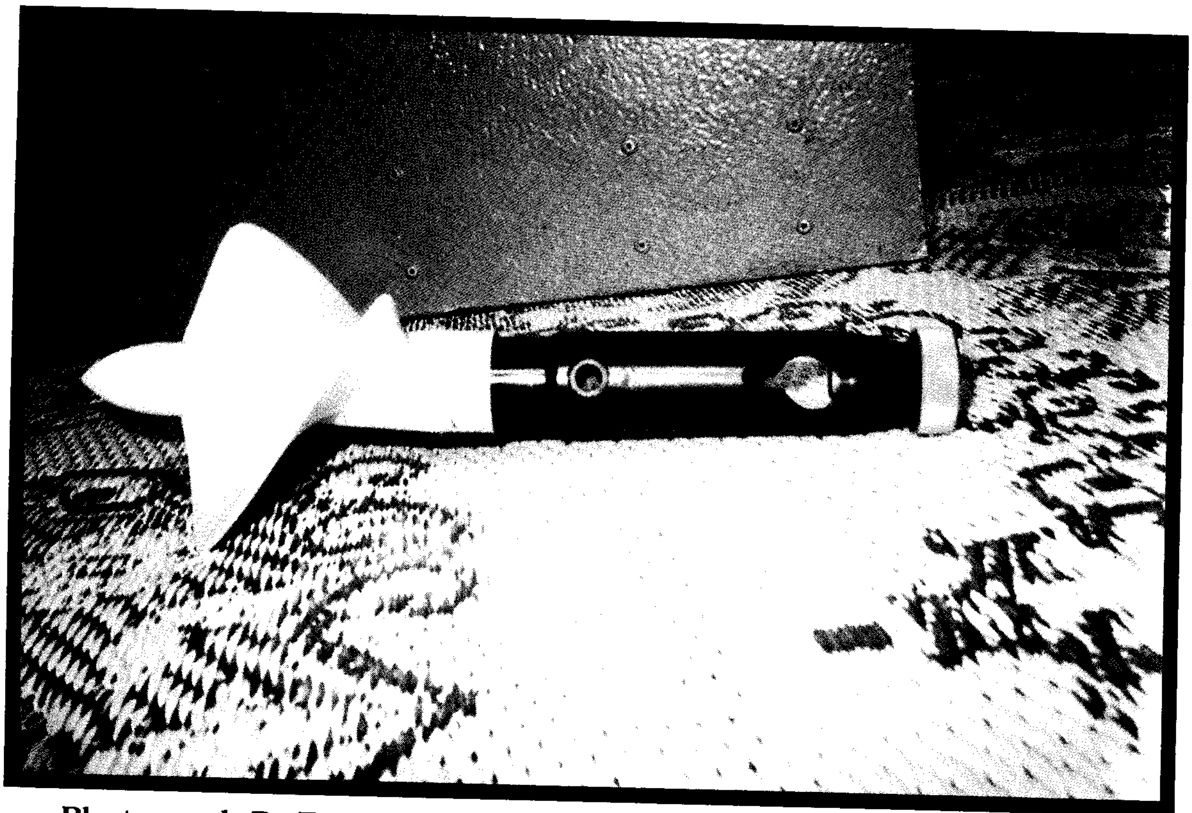
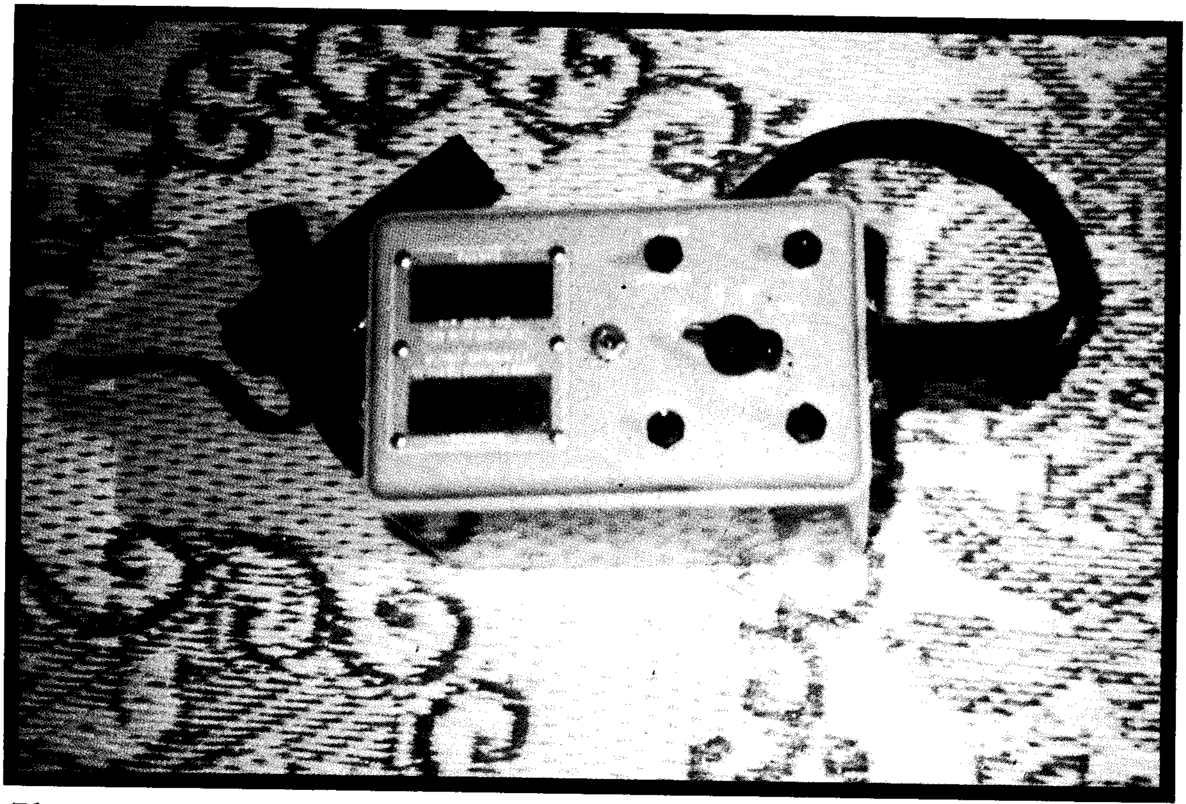


Figure 2. Example of a horizontal axis current meter.

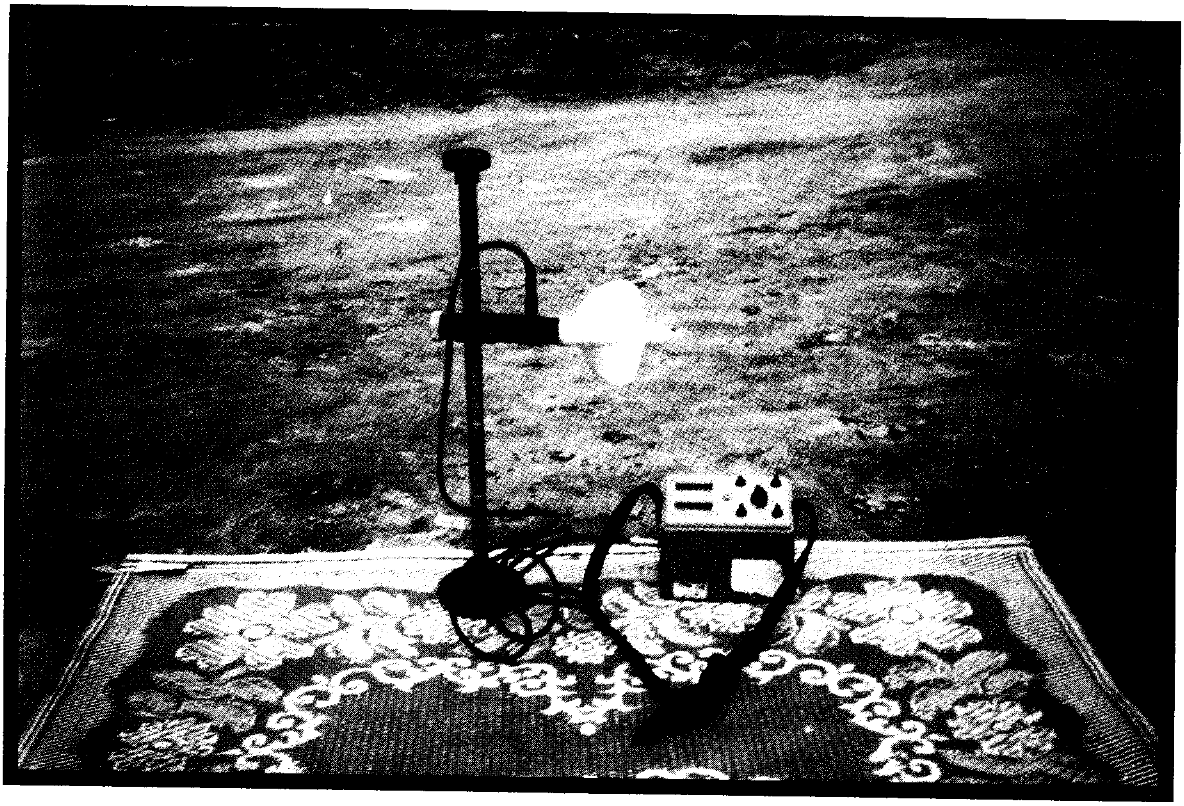
Photograph C. For high velocity measurement use lower nut connection.



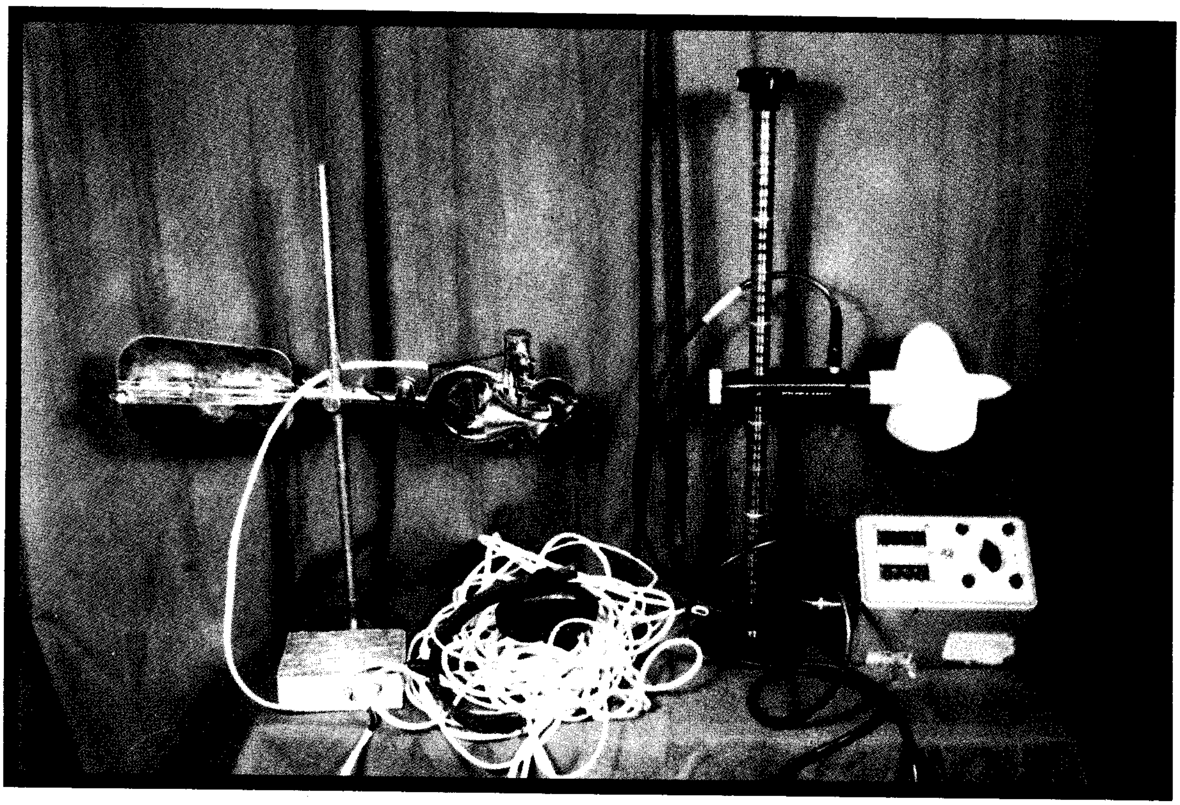
Photograph D. Example propeller of a horizontal axis current meter.



Photograph E. Example digital velocity counter for a horizontal axis current meter.



Photograph F. Example of an assembled horizontal axis current meter.



Photograph G. Vertical and horizontal axis current meters.

Table 1. Velocity rating for an example current meter in metric units.

Velocity in meters per second (m/s)

TIME seconds	REVOLUTIONS										
	5	10	15	20	25	30	40	50	60	80	100
40	0.092	0.175	0.258	0.342	0.425	0.508	0.674	0.840	1.007	1.339	1.672
41	0.090	0.171	0.252	0.333	0.415	0.496	0.658	0.820	0.982	1.307	1.631
42	0.088	0.167	0.247	0.326	0.405	0.484	0.642	0.801	0.959	1.276	1.592
43	0.086	0.164	0.241	0.318	0.396	0.473	0.628	0.782	0.937	1.246	1.556
44	0.085	0.160	0.236	0.311	0.387	0.462	0.614	0.765	0.916	1.218	1.520
45	0.083	0.157	0.231	0.305	0.378	0.452	0.600	0.748	0.896	1.191	1.487
46	0.081	0.154	0.226	0.298	0.370	0.443	0.587	0.732	0.876	1.166	1.455
47	0.080	0.151	0.221	0.292	0.363	0.434	0.575	0.716	0.858	1.141	1.424
48	0.078	0.148	0.217	0.286	0.355	0.425	0.563	0.702	0.840	1.117	1.394
49	0.077	0.145	0.213	0.280	0.348	0.416	0.552	0.688	0.823	1.095	1.366
50	0.076	0.142	0.209	0.275	0.342	0.408	0.541	0.674	0.807	1.073	1.339
51	0.074	0.139	0.205	0.270	0.335	0.400	0.531	0.661	0.791	1.052	1.313
52	0.073	0.137	0.201	0.265	0.329	0.393	0.521	0.648	0.776	1.032	1.288
53	0.072	0.135	0.197	0.260	0.323	0.385	0.511	0.636	0.762	1.013	1.264
54	0.071	0.132	0.194	0.255	0.317	0.378	0.502	0.625	0.748	0.994	1.241
55	0.070	0.130	0.190	0.251	0.311	0.372	0.493	0.614	0.735	0.976	1.218
56	0.068	0.128	0.187	0.247	0.306	0.365	0.484	0.603	0.722	0.959	1.197
57	0.067	0.126	0.184	0.242	0.301	0.359	0.476	0.592	0.709	0.942	1.176
58	0.066	0.124	0.181	0.238	0.296	0.353	0.468	0.582	0.697	0.926	1.156
59	0.065	0.122	0.178	0.234	0.291	0.347	0.460	0.573	0.685	0.911	1.136
60	0.064	0.120	0.175	0.231	0.286	0.342	0.452	0.563	0.674	0.896	1.117
61	0.064	0.118	0.173	0.227	0.282	0.336	0.445	0.554	0.663	0.881	1.099
62	0.063	0.116	0.170	0.224	0.277	0.331	0.438	0.545	0.653	0.867	1.082
63	0.062	0.115	0.167	0.220	0.273	0.326	0.431	0.537	0.642	0.853	1.065
64	0.061	0.113	0.165	0.217	0.269	0.321	0.425	0.529	0.632	0.840	1.048
65	0.060	0.111	0.163	0.214	0.265	0.316	0.418	0.521	0.623	0.828	1.032
66	0.059	0.110	0.160	0.211	0.261	0.311	0.412	0.513	0.614	0.815	1.017
67	0.059	0.108	0.158	0.208	0.257	0.307	0.406	0.505	0.605	0.803	1.002
68	0.058	0.107	0.156	0.205	0.254	0.302	0.400	0.498	0.596	0.791	0.987
69	0.057	0.105	0.154	0.202	0.250	0.298	0.395	0.491	0.587	0.780	0.973
70	0.057	0.104	0.152	0.199	0.247	0.294	0.389	0.484	0.579	0.769	0.959

Equation 3 is presented in Table 2 for the velocity in English units (ft/s). Thus, Tables 1 and 2 represent the identical rating for a particular current meter, which in this case is the rating for a new Price Type A current meter. Over time, depending on the care and maintenance of this current meter, the rating would be expected to change.

4. CARE OF EQUIPMENT

Accuracy in velocity measurements can only be expected when the equipment is properly assembled, adjusted, and maintained. The current meter should be treated as a delicate instrument that needs meticulous care and protective custody, both when being used and when being transported. The required treatment of a current meter is analogous to a surveyors careful attention with a transit or level.

The current meter necessarily receives a certain amount of hard usage that may result in damage, such as a broken pivot, chipped bearing, or bent shaft that will result in the current meter giving velocity readings that are lower than actual velocities. Observations of velocities near bridge piers and abutments, water depth readings taken at cross-sections having irregular bed profiles with the current meter attached to the measuring line, and the periodic occurrence of floating debris represent the greatest hazards to the equipment (Corbett and others, 1943).

Damage to current meter equipment during transportation is generally due to careless packing or negligence in protection. A standard case is provided by all manufacturers of current meter equipment, which should always be employed before and after taking a discharge measurement. In particular, the equipment case should always be used when transporting the current meter, even when the distance is relatively short. Transportation of assembled equipment from one location to another is one of the most common sources of damage (Corbett and others, 1943).

In some countries, it is common to see current meter equipment without a case. Also. during transport, this equipment will be placed on the floor of the vehicle. In one case. there was a 30 percent variation in velocity measurements among seven current meters as a result of improper care and protection.

The following instructions are useful for providing better performance and enhancing the longevity of the current meter:

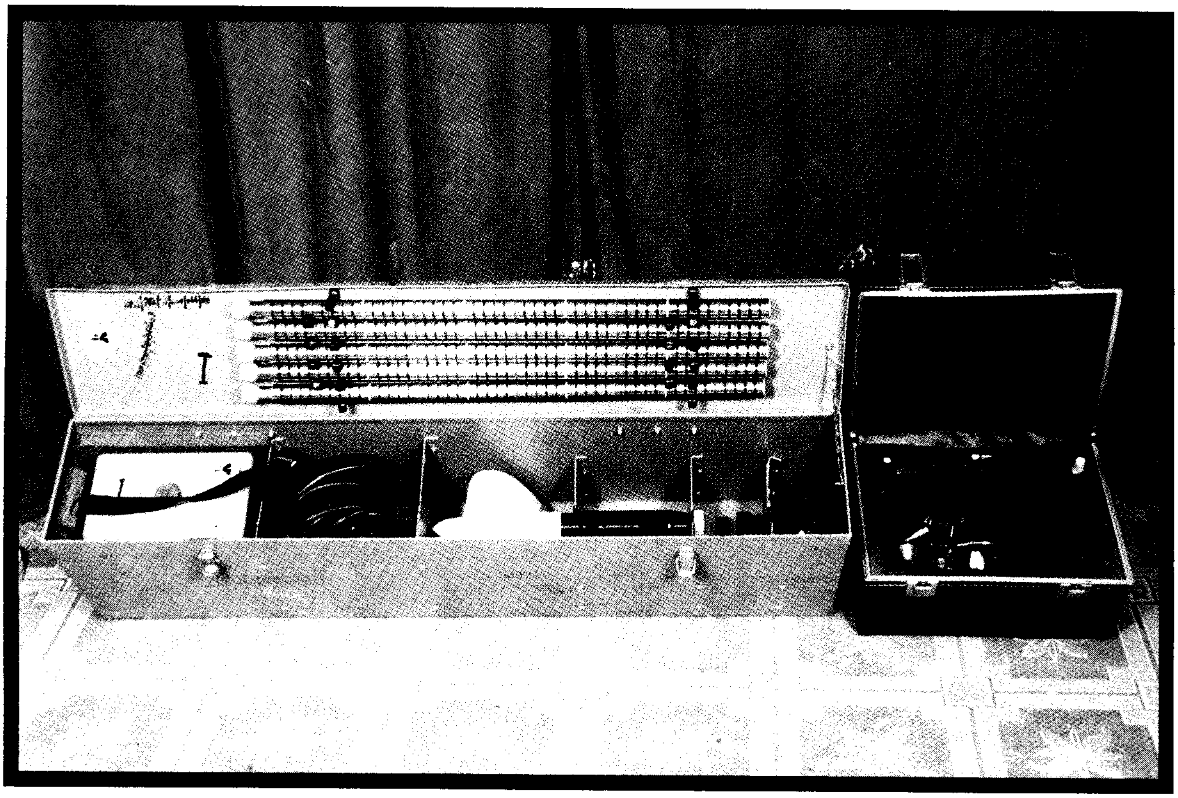
1. The equipment case must always be used when transporting the current meter (Photographs H);

2. The stop watch should always be carried in a container;

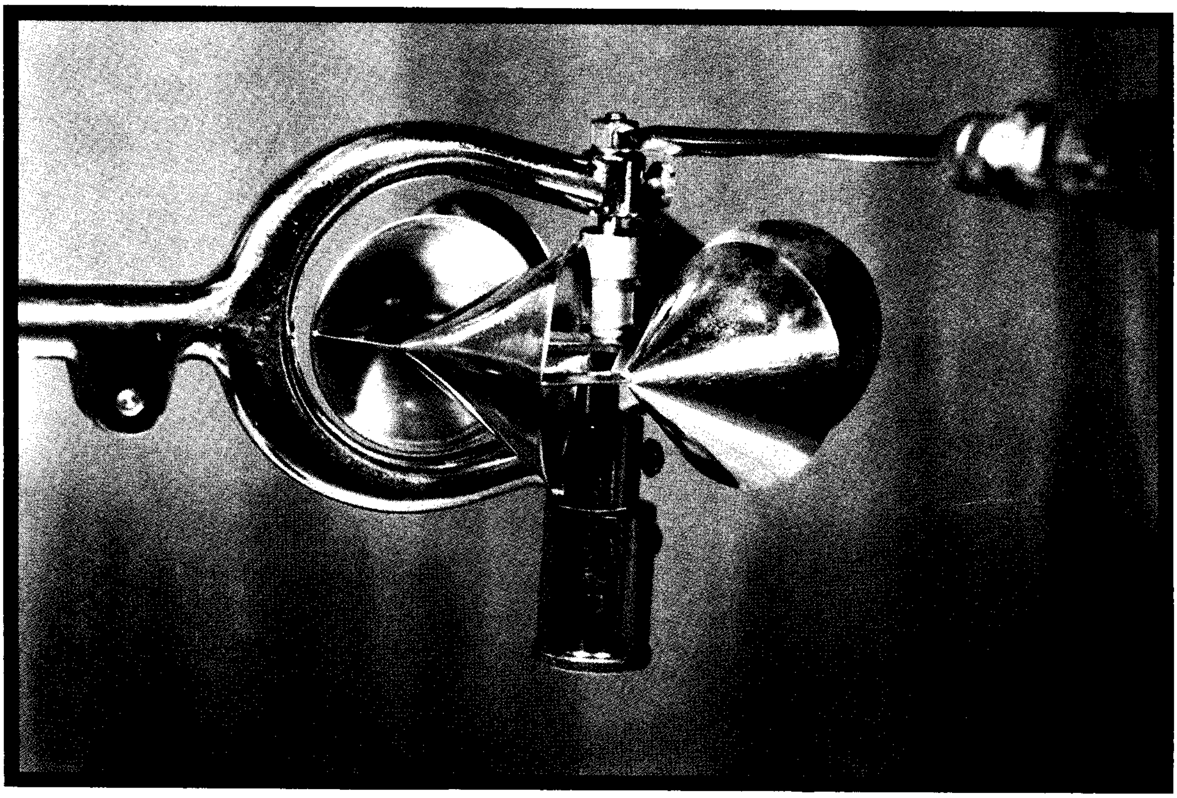
Table 2. Velocity rating for an example current meter in English units.

Velocity in feet per second (ft/sec)

Time in Sec	Revolutions										
	5	10	15	20	25	30	40	50	60	80	100
40	0.302	0.575	0.847	1.120	1.393	1.666	2.211	2.757	3.302	4.393	5.484
41	0.295	0.561	0.827	1.093	1.359	1.626	2.158	2.690	3.222	4.287	5.351
42	0.289	0.549	0.808	1.068	1.328	1.588	2.107	2.627	3.146	4.185	5.224
43	0.283	0.536	0.790	1.044	1.298	1.551	2.059	2.566	3.074	4.089	5.103
44	0.277	0.525	0.773	1.021	1.269	1.517	2.013	2.509	3.004	3.996	4.988
45	0.271	0.514	0.756	0.999	1.241	1.484	1.969	2.453	2.938	3.908	4.878
46	0.266	0.503	0.741	0.978	1.215	1.452	1.926	2.401	2.875	3.824	4.772
47	0.261	0.493	0.725	0.958	1.190	1.422	1.886	2.350	2.815	3.743	4.672
48	0.256	0.484	0.711	0.938	1.165	1.393	1.847	2.302	2.757	3.666	4.575
49	0.252	0.474	0.697	0.920	1.142	1.365	1.810	2.256	2.701	3.591	4.482
50	0.247	0.465	0.684	0.902	1.120	1.338	1.775	2.211	2.647	3.520	4.393
51	0.243	0.457	0.671	0.885	1.099	1.313	1.740	2.168	2.596	3.452	4.307
52	0.239	0.449	0.658	0.868	1.078	1.288	1.707	2.127	2.547	3.386	4.225
53	0.235	0.441	0.647	0.852	1.058	1.264	1.676	2.087	2.499	3.323	4.146
54	0.231	0.433	0.635	0.837	1.039	1.241	1.645	2.049	2.453	3.262	4.070
55	0.227	0.426	0.624	0.822	1.021	1.219	1.616	2.013	2.409	3.203	3.996
56	0.224	0.419	0.613	0.808	1.003	1.198	1.588	1.977	2.367	3.146	3.925
57	0.220	0.412	0.603	0.795	0.986	1.177	1.560	1.943	2.326	3.091	3.857
58	0.217	0.405	0.593	0.781	0.970	1.158	1.534	1.910	2.286	3.039	3.791
59	0.214	0.399	0.584	0.769	0.954	1.138	1.508	1.878	2.248	2.988	3.727
60	0.211	0.393	0.575	0.756	0.938	1.120	1.484	1.847	2.211	2.938	3.666
61	0.208	0.387	0.566	0.744	0.923	1.102	1.460	1.818	2.175	2.891	3.606
62	0.205	0.381	0.557	0.733	0.909	1.085	1.437	1.789	2.141	2.844	3.548
63	0.202	0.375	0.549	0.722	0.895	1.068	1.414	1.761	2.107	2.800	3.492
64	0.199	0.370	0.540	0.711	0.881	1.052	1.393	1.734	2.075	2.757	3.438
65	0.197	0.365	0.533	0.700	0.868	1.036	1.372	1.707	2.043	2.715	3.386
66	0.194	0.360	0.525	0.690	0.856	1.021	1.351	1.682	2.013	2.674	3.335
67	0.192	0.355	0.518	0.680	0.843	1.006	1.332	1.657	1.983	2.634	3.286
68	0.189	0.350	0.510	0.671	0.831	0.992	1.313	1.633	1.954	2.596	3.238
69	0.187	0.345	0.503	0.661	0.820	0.978	1.294	1.610	1.926	2.559	3.191
70	0.185	0.341	0.497	0.652	0.808	0.964	1.276	1.588	1.899	2.523	3.146



Photograph H. Horizontal axis and Price Type A current meters placed in an appropriate case.



Photograph I. Release the keeper screw.

3. If several sounding weights are to be carried, a box should be used with separate compartments;

4. The revolution counter's battery has to be in good form;

5. Protect the digital-type current meters from water, sunlight and heat;

6. Check all of the cable connections to be sure that they are properly adjusted; and

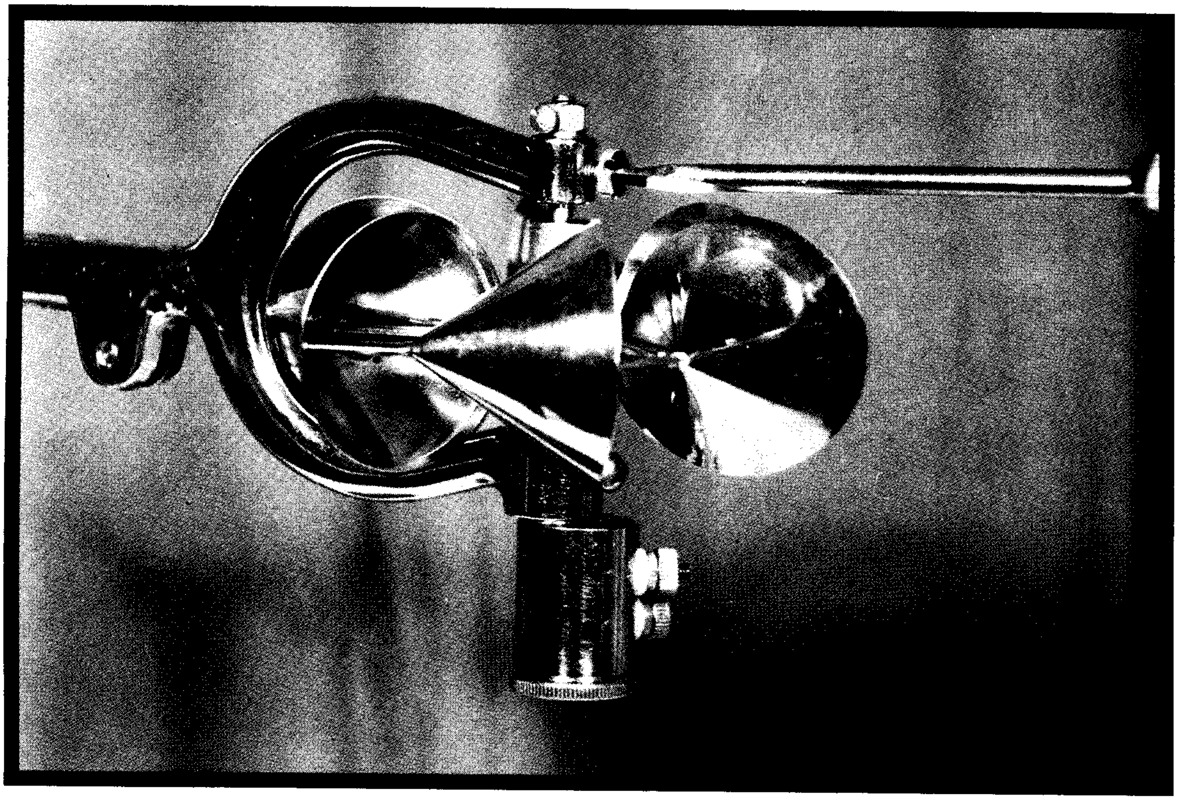
7. The head set assembly should be packed carefully to avoid an accidental short circuit, which may discharge the battery.

Before leaving the office for current metering in the field, make sure that a complete set of current meter equipment is at one place for inspection before being transported. For example:

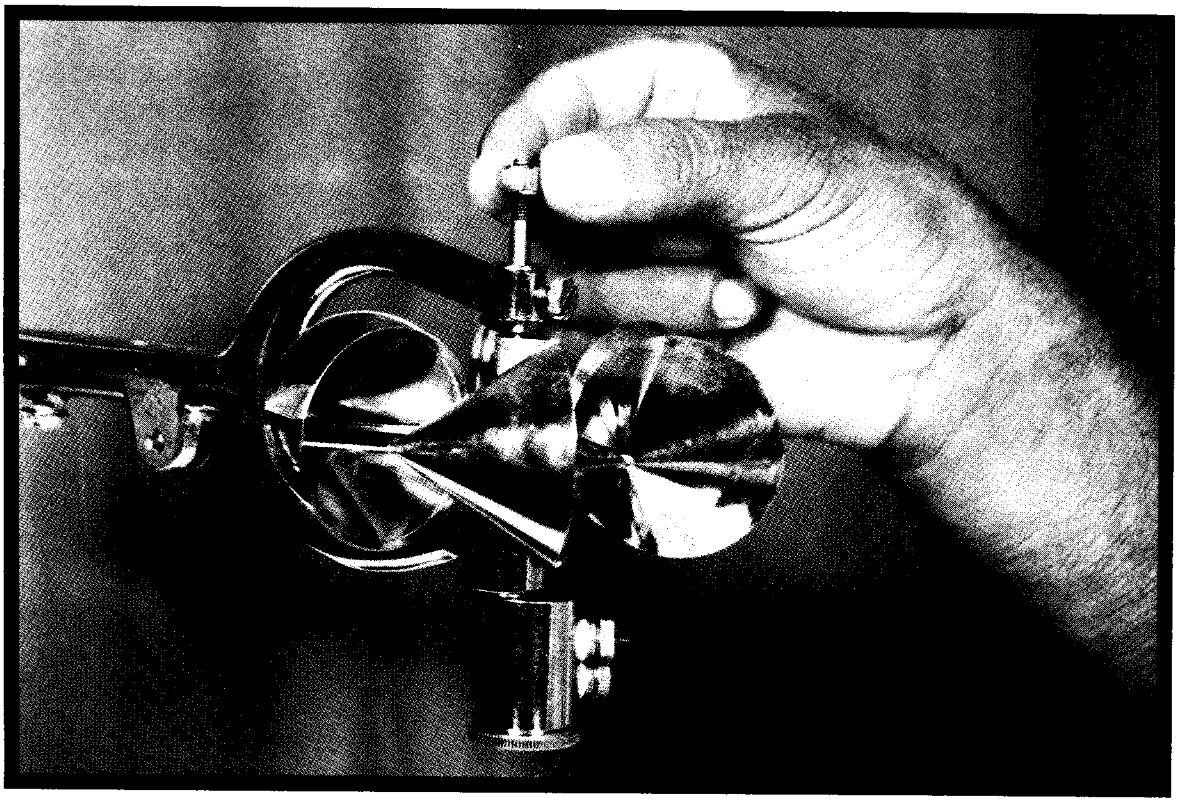
1.	Base plate	2.	Steel Rods
3.	Headphone	4.	Battery
5.	Stop Watch	6.	Wire
7.	Cups	8.	Tailpiece
9.	Balance weight	10.	Yoke
11.	Screws	12.	Pointer

The pivot and pivot bearing of the current meter must be protected to insure proper results when using this instrument. A knurled nut is provided beneath the bucket wheel to raise it and provde clearance between the pivot and pivot bearing when the instrument is in transit. The knurled nut has a left-hand thread, so rotate the nut in the direction in which the impeller would rotate when placed in water until you feel resistance, and the impeller no longer rotates freely. The upper end of this shaft to which the bucket wheel is mounted now bears against the under side of the contact chamber cap, and a separation exists between the pivot and pivot bearing. Reverse the above to bring the pivot and pivot bearing into contact again when preparing to use the meter.

Before adjusting the pivot, make sure that the current meter has been properly oiled. Then, hold the meter in an inverted position with the pivot uppermost. Release the keeper screw for the pivot adjusting nut and unscrew the nut a few turns. Release the set screw and advance the pivot until all of the vertical play in the hub assembly is eliminated. (See Photographs I, J and K).



Photograph J. Unscrew the nut a few turns.



Photograph K. With pivot movement, eliminate the vertical play.

5. METHODS OF EMPLOYING CURRENT METERS

5.1 Wading

The wading method involves having the hydrographer stand in the water holding a wading rod with the current meter attached to the rod (Photograph L). The wading rod is graduated so that the water depth can be measured. The rod has a metal foot pad which sets on the channel bed. The current meter can be placed at any height on the wading rod and is readily adjusted to another height by the hydrographer while standing in the water.

A tag line is stretched from one bank to the other, which can be a cloth or metal tape. This tag line is placed perpendicular to the flow direction. The zero length on the tag line does not have to correspond with the edge of the water on one of the banks. This tag line is used to define the location of the wading rod each time that a current meter measurement is made.

The wading rod is held at the tag line. The hydrographer stands sideways to the flow direction and is thus facing towards one of the banks. The hydrographer stands 5-10 cm downstream from the tag line and approximately 50 cm aside from the wading rod. During the measurement, the rod needs to be held in a vertical position and the current meter must be parallel with the flow direction. Usually, the notekeeper can signal to the hydrographer whether or not the rod is vertical in relation to the flow direction (Photograph M).

If the flow velocity at the bank is not zero, then this velocity should be estimated as a percentage of the velocity at the nearest measuring point (vertical). Thus, the nearest measuring point should be as close to the bank as possible in order to minimize the error in the calculated discharge for the section adjacent to the bank (Corbett and others, 1943).

5.2 Bridge

Many of the larger irrigation channels have bridges at various locations, such as headworks and check structures (cross regulators), but they may not be located at an appropriate section for current meter measurements. However, culverts often prove to be very good locations, with the current meter measurements usually being made on the downstream end of the culvert where parallel streamlines are more likely to occur. In some cases, wooden foot bridges have been placed by nearby inhabitants in order to cross the canal. Bridges often have piers, which tend to collect debris on the upstream face. that should be removed prior to undertaking current meter measurements.

Photograph L. The Wading Method for using a current meter.

Photograph M. The Notekeeper signaling the Hydrographer regarding the verticalness of the wading rod.

2. Before taking the depth, check the counter reading, which should be zero at the point where the centerline of the current meter cups are touching the water surface.

3. Add the height between the bottom of the weight and the center of the current meter cups in the depth.
The weight attached to the current meter should be 0.5' to 1.0 foot lower depending upon the depth of channel. If the distance from the weight to the current meter is less then 0.5 feet, erratic results will occur.
A rule of thumb is that the size of the weight in pounds should be greater than the maximum product of velocity and depth in the cross-section. Usually, in medium canals, a 40-50 pound wieght is used.

4. A gauge at site (discharge measurement) should be firmly installed to check the fluctuations in water level (decrease or incease) passining through the section.

5. For the structure, the upstream and downstream water depths must be noted together with the gate position with refrence to bench (white mark). It is worth mentioning here that the structure gates should not be moved at least 3/4 hour prior to beginning the discharge measurement. The upstream and downstream water depths must be noted after every half an hour untill the discharge measutrement is completed.

6. The velocity measurement starts from the left edge of water (LEW), keeping in mind at each section that if the depth is less then 2.5 feet, the velocity will be measured at 0.6 of the water depth below the water surface.

7. Each measurement must be listed instantaneously in the discharge measurement form.

8. After completing all the measurements, the calculation must be completed in the field. Any procedural mistake can be identified at the site, and then corrected, which will bring precision in the calculations as well as save time.

Note: If the maximum depth in the cross section is less then 10 ft and the velocity is low, use a rod for measuring the depths as well as supporting the current meter. For greater depths, use a cable suspension with a reel and sounding weight.
Boat measurements are not recomended at velocities less then 1 fps when the boat is subjected to wave action. The-up-and-down movement of the boat (and the meter) seriously affects the velocity observations.
If a weight heavier than 10-15 kg is required in order to have a stable, nearly vertical, cable line, then a crane-and-reel assembly is used. The reel is mounted on a crane designed to clear the handrail of the bridge and to guide the meter cable line beyond any interference with bridge members. The crane is attached to a movable base for convenience in transferring the equipment from one measuring point (vertical) to another (Corbett and others, 1943).

6. VELOCITY MEASUREMENT METHODOLOGIES

6.1 Vertical Velocity Method

The most complete method for establishing the mean velocity at a vertical is to take a series of current meter velocity measurements at various depths in the vertical. Often, the current meter is placed below the water surface at one-tenth of the water depth and a velocity measurement is made, then the current meter is placed at two-tenths of the water depth; this procedure is continued until the velocity has finally been measured at nine-tenths below the water surface. Of particular importance are the velocity measurements at relative water depths of 0.2, 0.6 and 0.8 because they are used in the simpler methods (see sketch shown in Figure 4).

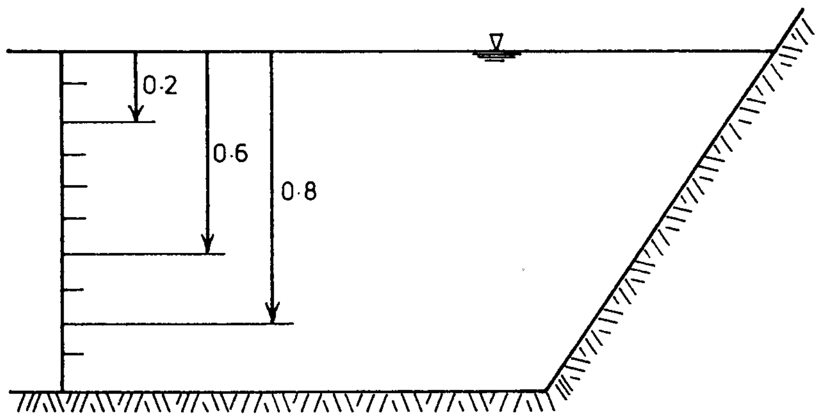


Figure 4. Schematic showing principlal flow depths used for placement of a current meter for measuring velocity.

When the above field procedure has been completed for a number of verticals in the cross-section, the data is plotted on rectangular coordinate graph paper. The relative water depth, which varies from zero at the water surface to unity at the channel bed, is plotted on the ordinate starting with zero at the top of the ordinate scale and unity at the bottom of the ordinate scale. Velocity is plotted on the abscissa. A smooth curve can be fitted on the data points for each vertical, from which the mean velocity for the vertical can be determined. Also, the relative water depth(s) corresponding with the mean velocity on the velocity profile can be compared between each vertical.

Because the field procedure and data analysis are time consuming, simpler methods are commonly used which are described in the following sections. However, the Vertical Velocity Method provides an opportunity to determine whether or not the simpler procedures are valid, or if some adjustments are required.

6.2 Two Points Method

The most common methodology for establishing the mean velocity in a vertical is the Two Points Method. Based on many decades of experience, a current meter measurement is made at two relative water depths i.e. 0.2 and 0.8. The average of the two measurements is taken as the mean velocity in the vertical.

In some field cases, it can be quite obvious that the velocity profile is distorted. For example, measurements taken downstream from a structure may have very high velocities near the water surface that can be visually observed, or near the channel bed which can be sensed by the hydrographer when using the Wading Method. If there is any suspicion that an unusual velocity profile might exist in the cross-section, then the Vertical Velocity Method should be used to establish an appropriate procedure for determining the mean velocity in a vertical for that particular cross-section.

6.3 Six-Tenths Depth Method

For shallow water depths, say less than 75 cm for the larger current meters and 45 cm for the small current meters, the Six-Tenths Depth Method is used. However, shallow is a relative term that is dependent on the type (size) of current meter being used, as well as irregularities in the channel beds (e.g., rocks and boulders). A single current meter measurement is taken at a relative water depth of 0.6 below the water surface, which means 0.4 relative water depth from the bed of channel and the resulting velocity is used as the mean velocity in the vertical.

In irrigation canals, this method is commonly used at the first vertical from each bank, while the Two Points Method is used at all of the other verticals in the cross-section. Frequently, the first vertical from each bank has a low velocity so that the discharge in each section adjacent to the left and right (looking downstream) banks represents a very small portion of the total discharge in the cross-section. In situations where shallow flow depths exist across most of the cross-section, and the Six-Tenths Depth Method must be used because of the type of current meter that is available, then it can be expected that there will likely be considerable error, say more than ten percent.

6.4 Three Points Method

This method is used when the velocities in the vertical appear to be abnormally distributed, such as having an unusual velocity distribution. The Three Point Method combines both the Two Point Method and the Six-Tenths Depth Method. Therefore, current meter measurements are taken at 0.2, 0.6 and 0.8 of the flow depth, d (Figure 4) The mean velocity in the vertical is obtained by first averaging the velocities measured at 0.2 and 0.8 of the flow depth (Two Points Method); then, averaging this result with the velocity measured at 0.6 flow depth. Thus, the mean velocity, V, in the vertical would be:

$$\bar{V} = \frac{\frac{(V_{0.2}+V_{0.8})}{2}+V_{0.6}}{2} \qquad \textbf{(4)}$$

The flow depth should exceed 2.5 feet (0.76 m) when considering the use of this method (USGS, 1980).

6.5 Surface Method

The surface method for measuring velocity is used on occasion with a float. The vertical velocity curve measured at the location is used to develop a reliable estimate of an appropriate coefficient that can be multiplied by the surface velocity (measured by the float) to obtain the mean velocity in the vertical. A coefficient of 0.85 is commonly used. This surface or float method should be considered when it is impossible to use a current meter because of excessive velocities and depths, or where velocities and depths are too low for a current meter measurement (USGS, 1980).

7. VELOCITY AT VERTICAL WALLS

Vertical walls are frequently encountered in irrigation systems. Usually, this occurs in rectangular channels lined with concrete or brick-and-mortar. Even earthen canals will likely have some structures with a rectangular cross-section. In some cases, there may be a vertical retaining wall along only one side of the canal to stabilize the embankment. In such cases, visual observation will usually disclose that the velocity at the vertical wall is significantly greater than zero.

Hagan (1989) reports some laboratory data that is useful in estimating the mean velocity at a smooth vertical wall A definition sketch is provided in Figure 5, while this laboratory data is plotted in Figure 6. For example, if the water depth at the vertical wall is denoted by d_w, and current meter measurements are made in a vertical located at a distance d_w from the wall, then the mean velocity at the wall will be the ratio 0.65 multiplied by the mean velocity measured in the vertical at the horizontal distance d_w from the wall.

The basic relationship between the parameters shown in Figure 5 is:

$$\frac{\bar{v}_w}{\bar{v}_x} = \frac{\bar{v}_w / \bar{v}_{d_w}}{\bar{v}_x / \bar{v}_{d_w}} \tag{5}$$

and

$$\bar{v}_w = \bar{v}_x \left(\frac{\bar{v}_w / \bar{v}_{d_w}}{\bar{v}_x / \bar{V}_{d_w}} \right) \tag{6}$$

As mentioned in the above paragraph, the ratio $\bar{v}_w / \bar{v}_D \doteq \mathbf{0.65}$, which corresponds to a relative horizontal distance, x/d_w, of zero in Figure 6 because x = 0 at the wall. Consequently,

$$\bar{v}_w = \frac{0.65\ \bar{v}_x}{\bar{v}_x / \bar{v}_{d_w}} \tag{7}$$

where d is the depth of flow measured at the vertical wall; x is the horizontal distance from the wall towards the center of the channel (x equals zero at the wall); $\bar{v}_d$ is the mean velocity in the vertical at x = d; $\bar{v}_x$ is the mean velocity measured in the vertical at a horizontal distance x from the wall, where $x \leq d$; $\bar{v}_w$ is the calculated mean velocity in the vertical at the wall, where x = 0; $\bar{v}_x / \bar{v}_D$ is the relative mean velocity in the vertical at a horizontal distance x from the wall; and. $\bar{v}_w / \bar{v}_d$ is the relative mean velocity in the vertical at the wall, where x = 0. The ratio $\bar{v}_x / \bar{v}_d$ is obtained from Figure 6 after having measured $\bar{v}_x$ in the field.

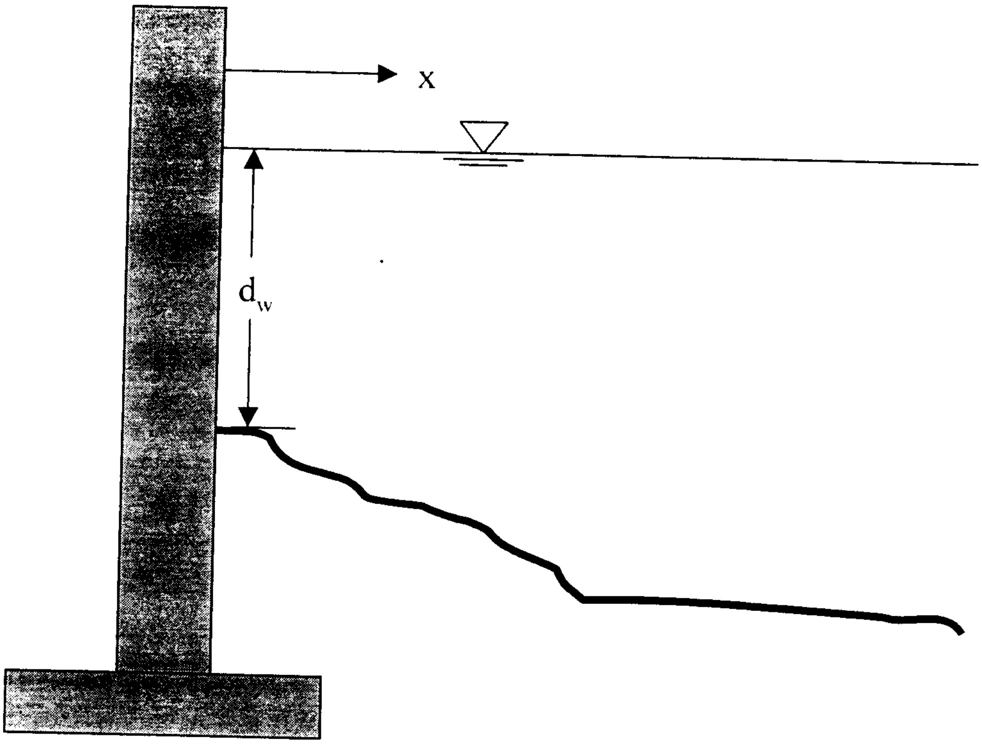


Figure 5. Definition sketch for determining the mean velocity at a vertical wall.

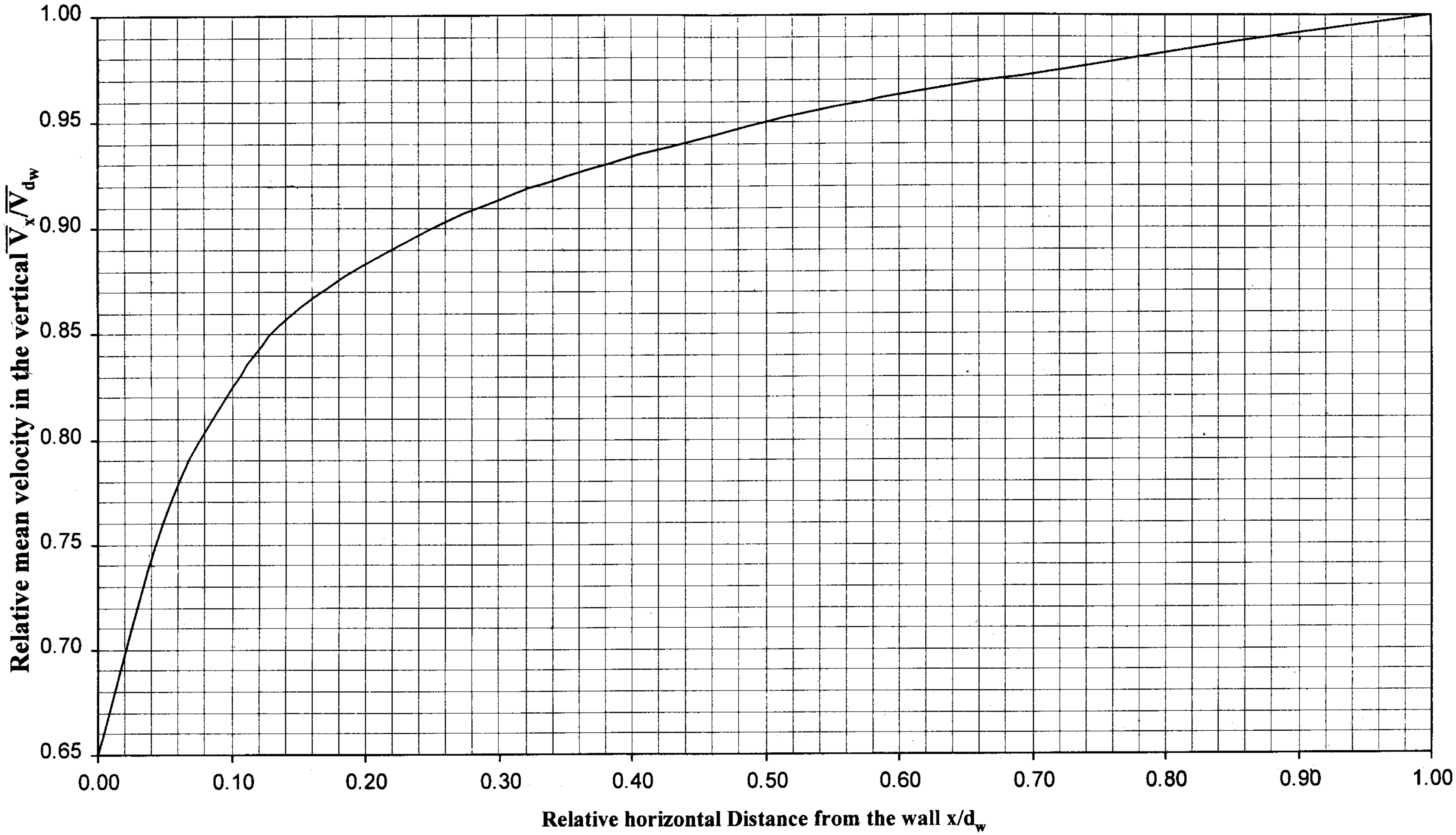


Figure 6. **Relative mean velocity near a vertical wall.**

The accuracy of the estimated mean velocity at the wall will be enhanced by measuring the mean velocity in a vertical located as close to the vertical wall as the current meter equipment will allow. Thus, if a current meter measurement could be made at a distance $d_w/4$ from the wall, then the estimated mean velocity at the vertical wall would be the mean velocity measured at $d_w/4$ from the wall multiplied by the ratio 0.65/0.90, which is obtained $x/d_w = (d_w/4)/d_w$ from Figure 6. In this example, the relative horizontal distance from the wall is $x/d_w = (d_w/4)d_w = 0.25$, which is a value located along the abscissa in Figure 6, where the corresponding value on the curve for the ordinate is:

$$\bar{v}_x \,/\, \bar{v}_{d_w} = 0.90 \qquad \textbf{(8)}$$

so, from Equation 7,

$$\bar{v}_w = \frac{0.65\bar{v}_x}{0.90} = (0.65/0.90)\bar{v}_x \qquad \textbf{(9)}$$

8. COMPUTATIONAL PROCEDURES

A current meter measurement is the summation of the products of the subsection areas of the stream cross-section and their respective average velocities. The continuity equation is used:

$$q = a * v \qquad \textbf{(10)}$$

$$Q = \sum_{i}^{n} (a * v) \qquad \textbf{(11)}$$

where:

q is the discharge from an individual section;
a is an individual section area;
v is the mean velocity of the flow normal to the section; and
Q is the total discharge from the cross-section.

8.1 Mid-Section Method

In the Mid-Section Method of computing a current meter measurement, it is assumed that the velocity sample at each vertical represents the mean velocity in a rectangular subsection. The subsection area extends laterally from half the distance from the preceding observation vertical to half the distance to the next, and the vertical from the water surface to the sounded depth.

The cross-section is defined by depths at verticals 1,2,3,4,...n in Figure 7. At each vertical, the velocities are sampled using a current meter to obtain the mean velocity of each section. The subsection discharge is then computed for any section at vertical x by use of the equation,

$$q_x = v_x\left[\frac{(b_x - b_{(x-1)})}{2} + \frac{(b_{(x+1)} - b_x)}{2}\right]d_x \tag{12}$$

$$q_x = v_x\left[\frac{b_{(x+1)} - b_{(x-1)}}{2}\right]d_x \tag{13}$$

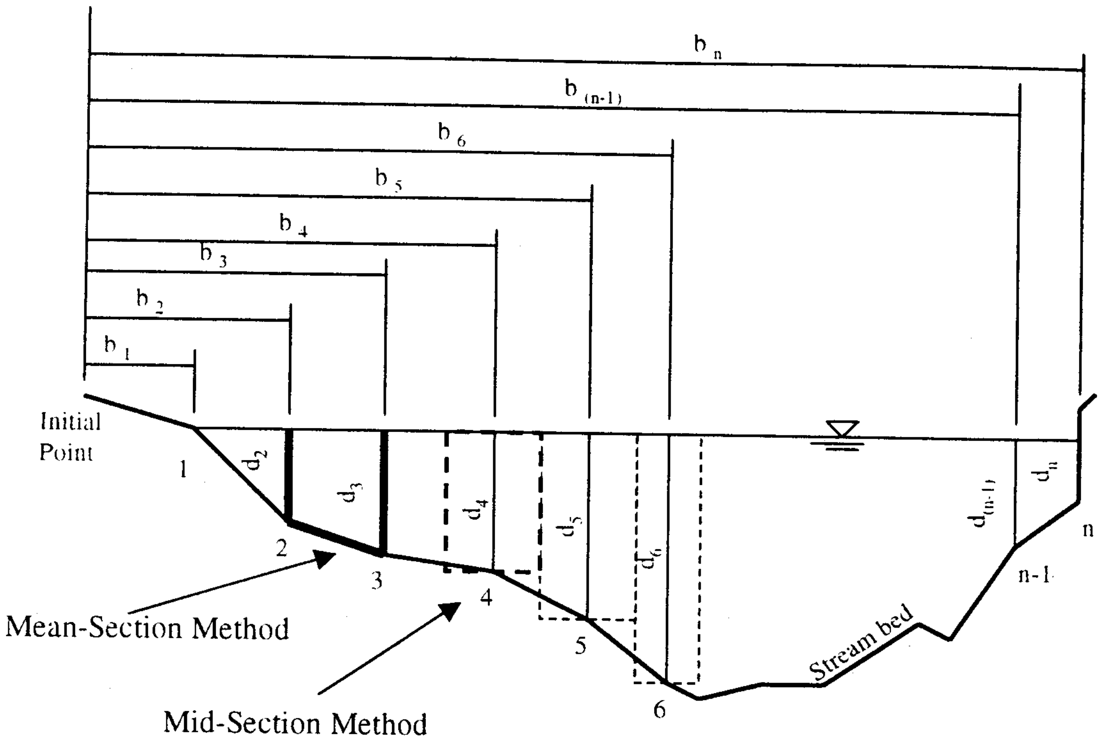
where:

q_x	=	discharge through section x;
v_x	=	mean velocity at vertical x;
b_x	=	distance from initial point to vertical x;
$b_{(x-1)}$	=	distance from initial point to preceding vertical;
$b_{(x+1)}$	=	distance from initial point to next vertical ; and
d_x	=	depth of water at vertical x.

Thus, for example, the discharge through section 4 (heavily outlined in Figure 7) is

$$q_4 = v_4\left[\frac{b_5 - b_3}{2}\right]d_4 \tag{14}$$

The procedure is similar when x is at an end section. The "preceding vertical" at the beginning of the cross section is considered coincident with Vertical 1; the "next vertical" at the end of the cross section is considered coincident with vertical n. Thus (Rantz 1982),



1, 2, 3 .... n	Observation verticals
b_1, b_2, b_3 .... b_n	Distance in feet or meters from the initial point to the observation vertical
d_1, d_2, d_3 .... d_n	Depth of water in feet or meters at the observation vertical
-----------------	Boundaries of subsections

Figure 7. **Definition sketch of Mid-Section Method and Mean-Section Method of computing cross-sectional area for current meter measurements. (Adapted from Buchanan and Somers, 1969.)**

$$q_1 = v_1 [\frac{b_2 - b_1}{2}] d_1 \tag{15}$$

$$q_n = v_n [\frac{b_n - b_{(n-1)}}{2}] d_n \tag{16}$$

Looking at Figure 7, Equation 15 would be zero because $d_1=0$. Therefore, the small area in Figure 6 defined by Equation 15 is assumed to be zero, which is commonly accepted because the discharge would be very small; but, in some cases, this is not true when there is some velocity near the bank.

For the last section depicted in Figure 7 and represented by Equation 16, the velocity v_n cannot be measured, so it has to be estimated using the procedure in Section 7 on velocity at vertical walls.

8.2 Mean-Section Method

Both the Mid-Section and Mean-Section methods will give nearly identical results for a flow cross-section having a rather smooth perimeter with gradually changing flow depth. For this situation, the Mid-Section Method is usually recommended (USGS, 1980) because the computations are simpler.

For a cross-section having an irregular perimeter. there is an advantage in using the Mean-Section Method. As illustrated in Figure 7, some error is introduced in calculating the cross-sectional area using the Mid-Section Method; also, as stated in the previous section, there are some difficulties in calculating the discharge in the first and last sections in the cross-section.

From Figure 7, as an example, the cross-sectional area between Verticals 2 and 3 for the Mean-Section Method would be calculated as:

$$a_{2-3} = \left[\frac{d_2 + d_3}{2}\right] (b_3 - b_2) \tag{17}$$

The mean velocity in Section 2-3 would be:

$$\bar{V}_{2-3} = \frac{\bar{V}_2 = \bar{V}_3}{2} \tag{18}$$

Thus, the calculated discharge in Section 2-3 would be:

$$q_{2\text{-}3} = a_{2\text{-}3} * \bar{V}_{2\text{-}3} = \left[\frac{d_2 + d_3}{2}\right](b_3 - b_2)\left[\frac{\bar{V}_2 + \bar{V}_3}{2}\right] \quad (19)$$

For the first section in Figure 7 represented as the area between verticals 1 and 2, the triangular area becomes:

$$a_{1\text{-}2} = d_2(b_2 - b_1)/2 \quad (20)$$

Now, the representative velocity is a vector acting at the centroid of the triangular area, which accurs at one-third of the height of a triangle that is represented by b_2 - b_1, in this case. So, the velocity needs to be calculated at the centroid, which is located at (b_2 - b_1)/3. Thus, the mean velocity is:

$$V_{1\text{-}2} = \frac{V_2 - V_1}{3} = \frac{V_2}{3} \quad (21)$$

Combining Equations 18 and 19:

$$q_{1\text{-}2} = \frac{d_2(b_2 - b_1)}{2}\left[\frac{V_2}{3}\right] = d_2(b_2 - b_1)V_2/6 \quad (22)$$

Thus, the Mean-Section Method does have an advantage in more correctly calculating the discharge in the end sections.

The greatest advantage of the Mean-Section Method comes from placing verticals at the breaks in the slopes across the cross-section. This will be illustrated in Section 9.

9. CURRENT METERING PRACTICES

9.1 Selection of Measuring Cross-Section

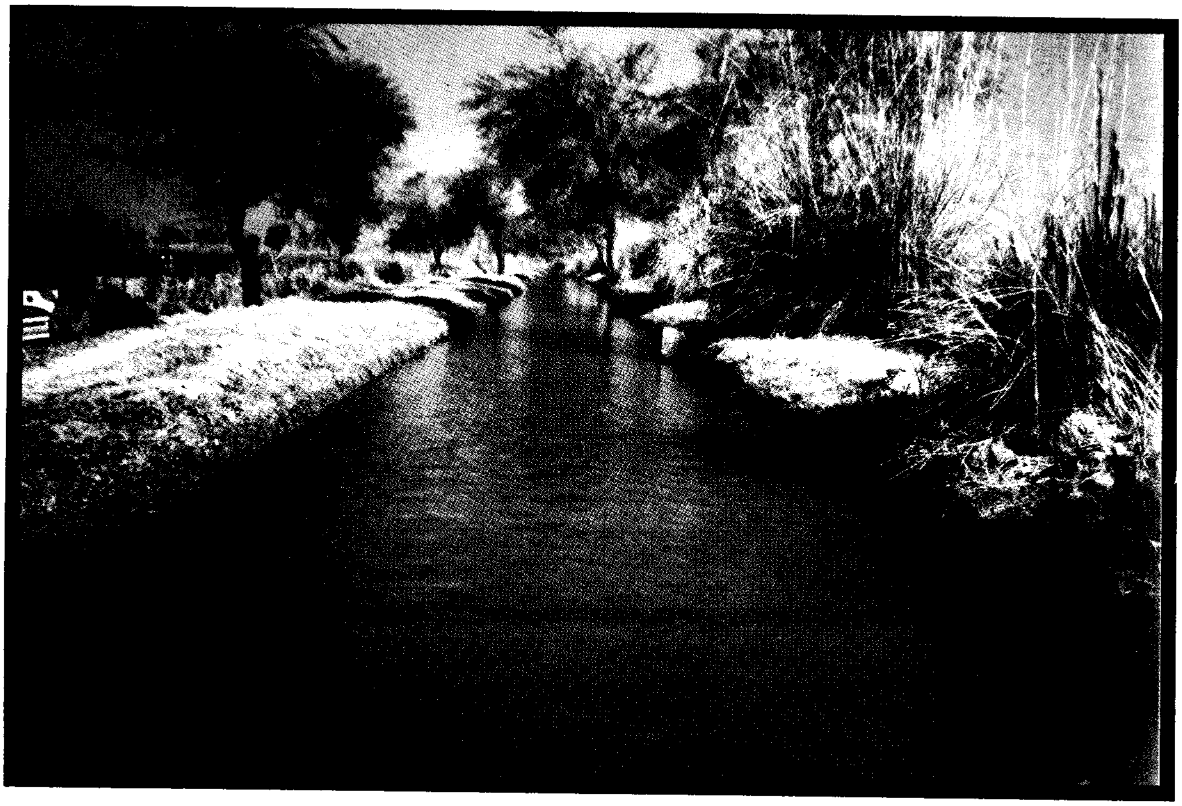
The most commonly used criterion in selecting a channel cross-section for current meter measurements is that it be located in a straight reach where parallel streamlines exist (Photograph P). A channel bend (Photograph Q) would be avoided because of curvilinear streamlines that makes it difficult to place the current meter accurately along the streamline, which would result in underestimating the discharge. In addition, a cross-section having large eddies and excessive turbulence would be avoided. Other important criteria is avoiding cross-sections where the flow depths are shallow and the flow velocities are too low. A cross-section is needed that has no aquatic growth that can foul the current meter. Finally, a cross-section is preferred where the channel bed is not highly irregular so that the area of the cross-section can be accurately determined; also, an irregular bed will affect the velocity profiles.

9.2 Current Metering Near a Structure

Often, current metering is done downstream of a flow control structure, such as a headworks, cross regulator, or fall structure. The advantage of this location is that it is a safe place -- if any mishap occurs, the hydrographer can easily come out of the water and reach the channel bank. The only disadvantage of the downstream location is for the case where there are two or three off-takes and each channel has to be measured individually, then the measurement error will increase, perhaps reaching 10-12 percent.

Usually, a cross regulator is used to control water levels so that the appropriate discharge enters each offtaking channel. For this case, if the total discharge must be determined, then an upstream location is better. The disadvantage of a location upstream from a flow control structure, then, is if any mishap occurs, the hydrographer could be seriously injured by passing through the gates of the structure. If it is necessary to do current metering upstream, then select the current metering point at least 800 - 1000 feet upstream from the flow control structure.

A good procedure for maximizing accuracy is to take a current meter measurement both upstream and downstream of a flow control structure, as well as all offtaking channels. If steady flow conditions existed while all of the current meter measurements were being made, then the consistency of the discharge measurements can be checked using a simple water balance by summing all inflows and all outflows. A good balance wouild indicate that good procedures are being used; however, this is not indicative of the accuracy for these measurements since there could be a consistent error, such as the current meter needing recalibration. Because this procedure requires many hours to complete during a day, there will be more difficulties if unsteady flow conditions existed during the current meter measurements.



Photograph P. Suitable reach for current metering.

Photograph Q. Avoid channel bends for current metering because of curvilinear streamlines.

9.3 Subdivision of Cross-Section into Verticals

The current meter is used to measure the mean velocity of each vertical in the cross-section. In addition, the spacing of the verticals is used in determining the cross-sectional area of each section, where a section is defined as the cross-sectional area of flow between two verticals (Mean-Section Method). In this procedure, the velocity is measured at each vertical and then the average of the velocities on two consecutive vertical is used as the mean velocity. The area is calculated for that section from the same two verticals (see Table 3 page 40).

The measuring cross-section should be subdivided into twenty or more verticals for a relatively smooth channel bed. For an irregular channel bed, more verticals are needed, not only to better define the cross-sectional area of flow, but also because an irregular bed causes more variation in the velocity distribution. At the same time, verticals do not need to be spaced closer than 0.3 m (one foot) (Corbett and others, 1943).

An example earthen canal cross-section is illustrated in Figure 8. The most important verticals for defining the cross-sectional area of flow are shown for this particular example.

9.4 Precautions

Based on field experience, certain precautions can be stated regarding current metering practices.

1. The rod (Wading Method) must be straight (vertical) while measuring water depths.

2. The measuring tape must be straight (level) across the channel cross-section because an inclined tape would indicate a width greater than the true width, which is perpendicular to the flow.

3. When counting the current meter revolutions, do not move the rod or the fin; otherwise, the number of revolutions will be erroneous.

4. Before starting the current metering, go to the flow control structure and take the diffierence between the upstream while mark and free water surface in case of free flow, while for the case of submerged flow, also measure the difference between the downstream white mark and the downstream free water surface. This should be checked two or three times, or more, during the current metering. A little bit of difference can be ignored, but if the difference is more than 0.02 cm, the current metering has to be done again, or the discharge has to be adjusted with reference to the head ratio (see the procedure for unsteady flow conditions).

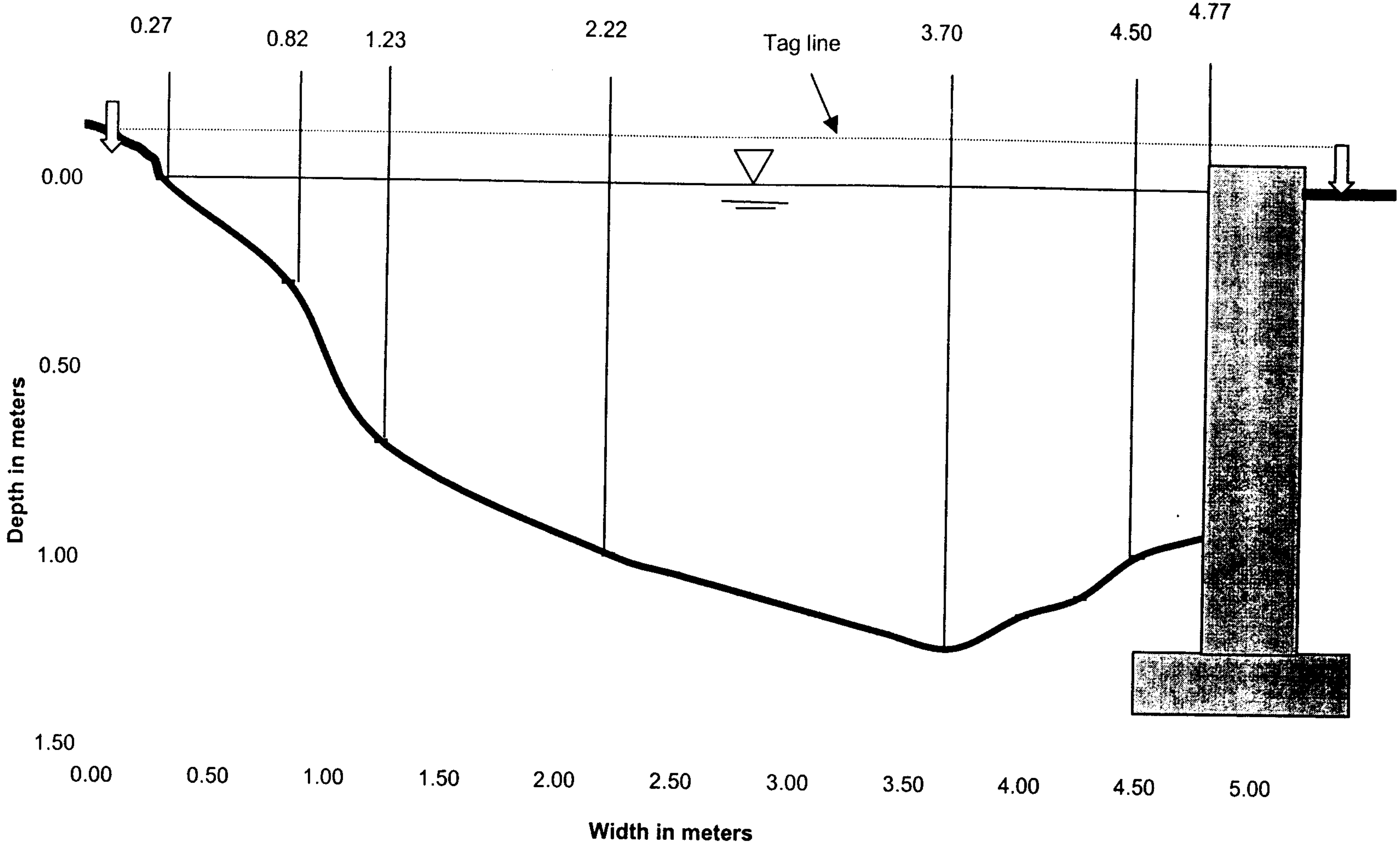


Figure 8. **Example earthen canal cross-section showing location of verticals for defining the flow area.**

5. The upper and lower plates, along with the different parts of the rod, must be tightly screwed together.

6. The white round sign on the upper plate of the rod must coincide with the sharp front edge of the fin so that the fin remains quite vertical when the fin is in the water.

7. If the current meter shows fluctuations in the revolutions during a fixed period of time (40-70 seconds), pull out the fin and check if there is any grass or debris lodged in the fin, remove it and also check nearby for any grass or algae, which should also be removed.

8. If benchmark elevations are not available at the flow control structure for measuring upstream and downstream flow depths, then establish the necessary benchmarks using a surveyor's level instrument.

9. Take much care in the recording of depths, distances, velocities, aras, in finding the mean velocity, and calculating the discharge.

10. Take care that water level fluctuations are not created upstream of the measuring site, especially cattle cause fluctuations when they cross the irrigation channel. Also, care should be taken that no restriction in the flow of water is created downstream from the current metering site because of backwater effects and disturbances to the velocity distribution.

11. Do not undertake current metering very close to a bend, head regulator, drop structure, or outlet because the water depth is not constant, but oscillates, and velocity fluctuations occur.

12. If the water velocity is high, fix a rope acros the canal to restrict the thrust of water on the body of the hydrographer.

9.5 Selecting the Depth(s) of Observation

If the water depth is 75 cm, or more than 75 cm, the Two-Points Method is used. For this case, the propeller or cups are set at a depth of 0.2 and 0.8 of the total depth as measured from the free water surface. Where the depth of water is less than 75 cm, then the Six-Tenths Method is used. For this case, the depth of observation will be 0.6 of the total depth measured from the free water surface.

For tertiary channels (watercourses), using a pygmy current meter, if the water depth is 45 cm, or more than 45 cm, the Two Point Method is used. In this case, the propeller or cups are set at a depth of 0.2 and 0.8 of the total water depth as measured from the free water surface. Where the depth of water is less than 45 cm, then the Six-Tenths Method is used. For this case, the depth of observation will be set at 0.6 of the total depth as measured from the free water surface.

9.6 Measurement Of Water Depths

The water depth must be known at each vertical in order to calculate the cross-sectional area of flow for two sections, one on each side of the vertical. Accurately determining the flow areas is just as important as accurate velocity measurements.

The greatest sources of error in measuring the depth of water are: (1) an irregular channel bed; and (2) a channel bed that is soft so that a weight or a wading rod sinks into the soft material, thereby indicating a water depth greater than actually exists. Another source of error can occur when reading a wading rod because water piles up on the upstream edge and is much lower on the downstream edge, thereby requiring the hydrographer to sight across the rod, looking both upstream and downstream, in order to obtain an appropriate reading.

9.7 Procedure

The current meter is used to measure the velocity at selected depth(s) in order to derive the mean velocity of each vertical in the cross-section. In addition, the spacing of the verticals is used in determining the cross-sectional area of each section, where a section is defined as the cross-sectional area of flow between two verticals. The measuring cross-section should be subdivided into twenty or more verticals for a relatively smooth channel bed.

First of all, a tape is stretched across the channel width just above the water surface and the two ends are tied to iron pegs, one on each bank. The initial point of the tape does not have to read zero, but can be any value. Then, the depths of water are measured every 10 cm near the banks of the channel. For most of the channel width, the flow depth is measured every 20 - 30 cm. One person records these depths on a specific form. When all of the depths have been taken, then the location of each vertical is specified. No section is greater than 60 cm in width.

Now, the current metering is undertaken at the center of each section when using the Mid-Section Method, or at each vertical if the Mean-Section Method is used. For the triangular section adjacent to each bank (first and last section), the current meter is placed at the centroid of the triangular across-section; in other words, two-thirds of the section width from the edge of the channel. If the depth at the center of the section is not know, then measure this depth during current metering.

The revolutions are counted two times, each measurement being for the same time period. If the number of revolutions are the same, or the difference is 1 or 2 revolutions, then the measurement is considered correct, but if the difference is more than 2 revolutions, the procedure is repeated.

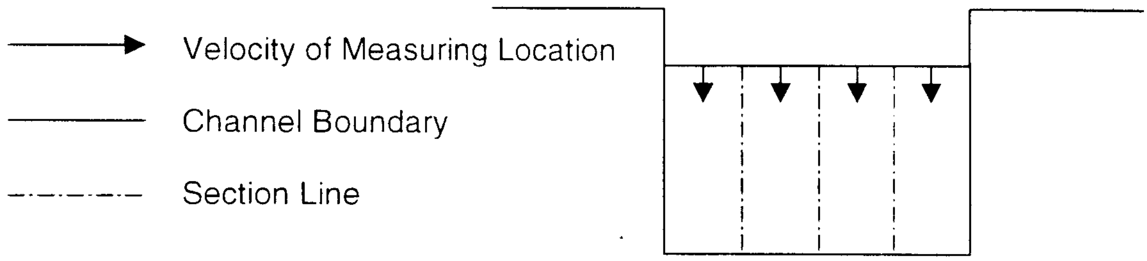
With the revolutions and the number of seconds, a current meter velocity rating table can be used to determine the measured velocity. Then, the mean velocity in the vertical, and for each section, can be determined. The product of mean velocity and section area is equal to the discharge for that section. The sum of all the discharges for each of the sections will show the total discharge for the channel. If this discharge was calculated in cumecs, then if can be converted to cusecs if multiplied by 35.315.

9.8 Current Metering in Small Lined Channels

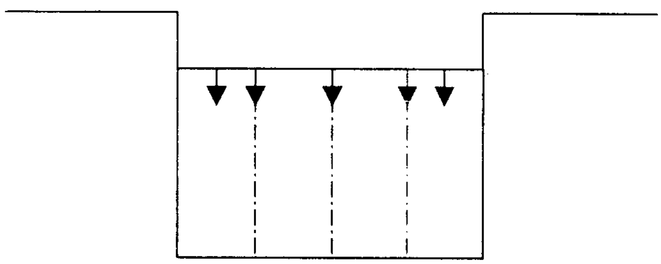
For small lined watercourses (tertiary channels), the discharge can be measured using a pygmy current meter. To do this current metering, the lined channel is divided into 3 - 6 sections or verticals. The velocity is measured in the center of every section when using the Mid-Section Method (Figure 9 a). Calculate the area of each section and multiply by the measured velocity for the section. In this way, the discharge can be obtained for each section. Repeat this procedure in each section. After calculating the discharge for each section, the discharges can be summed to arrive at the discharge for the lined channel.

For the Mean-Section Method (Figure 9 b), the velocity would be measured in each vertical between the walls. In the two end sections, the velocity would also be measured as close to the well as possible in order to arrive at a better estimate of the mean velocity at each wall (see Section 7).

To measure the discharge of a small unlined (earthen) channel (e.g. watercourse), often flow measuring flumes of different sizes are used. But sometimes an unlined watercourse may be too large for a portable flume. In this case, the discharge is measured using a pygmy current meter. The procedure will be the same as for much larger earthen channels, except there may be only 6 - 10 sections or verticals (see Figure 10).



(a) **Mid-Section Method**



(b) **Mean-Section Method**

Figure 9. Mid-Section Method and Mean-Section Method for current metering in small rectangular lined channels

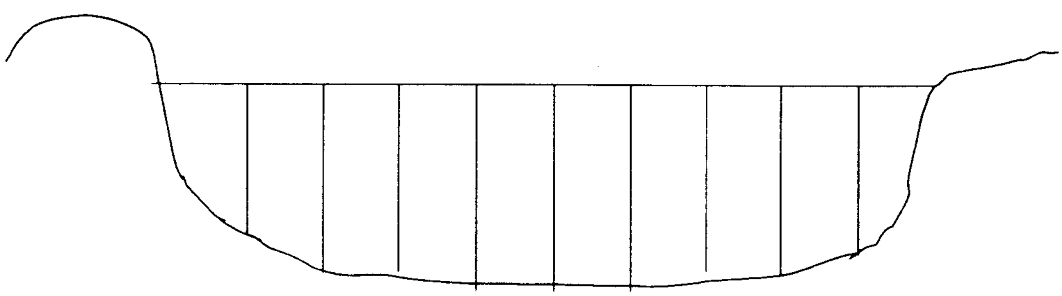


Figure 10. Example of the cross-section for a small earthen channel having only nine verticals (ten sections)

9.9 Cleaning and Maintenance of Current Meter

A few suggestions are listed below for the proper cleaning and oiling of a current meter after completing a discharge measurement.

1. Rinse the current meter in clear water as soon as possible after use, then carefully dry using a soft cloth.

2. Never put a wet current meter in its carrying case.

3. Lubricate the current meter after approximately eight hours of habitual use and at least once a week when the use is infrequent.

4. Lubricate the pivot and pivot bearing and upper cap contact chamber after use.

5. If the current meter is not used for more than one month, then again oil the moving parts.

9.10 Recalibration of Current Meter

There are some indicators for when a current meter should be recalibrated and a new velocity rating table prepared. First of all, after 50 discharge measurements, the current meter should be recalibrated. Also, if any part of the current meter has been damaged, such as the pivot, then the current meter should be recalibrated.

10. STEADY FLOW DISCHARGE MEASUREMENT

The usual procedure for calculating the discharge based on current metering measurements will be illustrated. The basic assumption is that steady flow exists during the time period of the measurements; in other words, the discharge does not vary during the time required to complete the field measurements. The example calculations will be done in metric units. For this example, the computational procedure will employ the Mean-Section Method.

10.1 Recording of Data

Hagan (1989) discusses the various formats for the recording of data and computational procedures. A format is illustrated in Figure 11 for the Mean-Section Method. This format is used for calculating the discharge rate in the cross-sectional area of flow between two verticals. The procedure is described in the following section.

Date:________________ **Channel:**______________________ **Station:**______________________

Distance from start point	Depth	observed Depth	Revolu-tions	Time (s)	**Velocity**			Area	Mean Depth	Width	Flow rate
					At point	Mean in vertical	Mean in section				

Observers:____

No.______of______pages Computations ____________________ Checked ____________________

Figure 11. Format for recording current meter measurement data and for calculating discharge

10.2 Computational Procedure for Mean-Section Method Using Metric Units

The computational procedure for a current meter discharge measurement is illustrated in Table 3. Figure 8 was used in this example, with the major verticals being at readings of 0.82, 1.23, 2.22, 3.70 and 4.50 m along the tag line. Intermediate verticals were selected as listed in the first column in Table 3.

Note in Figure 8 that the water surface was contained between 0.27 and 4.77 m along the tag line. The first cross-section was contained between 0.27 and 0.82 m along the tag line. In Table 3, the velocity at the bank was roughly estimated to be 10% of the mean velocity in the vertical at 0.82 m along the tag line; often, the velocity at the bank is listed as zero. Because of the shallow water depth at 0.82 m, the Six-Tenths Method was used in making the current meter measurement, which resulted in a velocity of 0.208 m/s, obtained from Table 1. The discharge in this cross-section was less than 0.5% of the total discharge.

For the last cross-section, which contains a vertical wall, a set of current meter measurements were made at 4.50 m along the tag line, at 0.2 an d 0.8 times the depth, with the mean velocity in the vertical being 0.553/ms. The distance, from the vertical wall was 0.27 m (4.77 - 4.50). the depth of water, d_w, at the vertical wall was 0.92 m. Thus, x/d was 0.27m/0.92 m = 0.29. From Figure 6, the relative mean velocity in the vertical was 0.91, whereas the relative mean velocity at the wall was 0.65. The equation used for calculating the mean velocity at the vertical wall is shown at the bottom of Table 3.

11. UNSTEADY FLOW DISCHARGE MEASUREMENT

11.1 Unsteady Flow Conditions

The canals in Pakistan normally operate under unsteady flow conditions. At any cross-section, the discharge is continually changing, with fluctuations of 10-20 percent occurring in a single day. Sometimes, the daily fluctuations are even greater. The literature on current meter discharge measurements pertains to steady-state flow conditions. Thus, there is a need to modify the usual procedures in order to accommodate unsteady flow conditions.

Usually, current meter measurements in an irrigation channel are undertaken in order to calibrate flow control structures. The first step in developing a procedure for unsteady flow is to identify the type of flow condition passing through the flow control structure, such as listed in Table 4. If free flow conditions exist, then the upstream flow depth, h_u, needs to be monitored periodically (say every 15-20 minutes) during the current meter measurement, whereas both h_u and the downstream flow depth, h_d, needs to be monitored for submerged flow conditions. The ratio of the hydraulic head (h_u or h_u - h_d) at the beginning, of the test, to the hydraulic head at any later time, t, can be used to adjust the current meter velocity measurement at time t to conform with the discharge at the beginning of the test.

Table 3. Example of Computational Procedure for a Current Meter Discharge Measurement during Steady Flow Conditions.

Date: 17 May 1995 Channel: Sunburn Disty. Station: 0+126

Distance from initial point	Depth	Depth of obser-vation	Revolu-tions	Time in sec-onds	Velocity			Section			
					At point	Mean in vertical	Mean in section	Area	Mean Depth	Width	Discharge
0.27	0				10%	.02					
							.152	.074	.135	.55	.011
0.82	0.27	0.6	20	67	.208	.208					
							.224	.197	.48	.41	0.044
1.23	0.69	0.2	20	54	.255						
		0.8	20	61	.227	.240					
							.258	.238	.745	.32	.062
1.55	0.86	0.2	25	58	.296						
		0.8	25	68	.254	.274					
							.302	.317	.905	.35	.096
1.90	0.95	0.2	25	50	.342						
		0.8	30	65	.316	.329					
							.358	.309	.965	.32	.111
2.22	0.98	0.2	30	49	.416						
		0.8	30	57	.359	.388					
							.431	.280	1.00	.28	0.121
2.50	1.02	0.2	40	53	.511						
		0.8	40	62	.438	.474					
							.490	.315	1.05	.30	0.154
2.80	1.08	0.2	40	49	.552						
		0.8	40	59	.460	.506					
							.531	.332	1.105	.30	0.176
3.10	1.13	0.2	40	43	.628						
		0.8	40	56	.484	.556					

Table 3 (complete)

Distance from initial point	Depth	Depth of observation	Revolutions	Time in seconds	Velocity At point	Velocity Mean in vertical	Velocity Mean in section	Section Area	Section Mean Depth Corrected	Section Width	Section Discharge
3.10	1.13				.	.556					
							.568	.346	1.155	.30	0.197
3.40	1.18	0.2	50	52	.648						
		0.8	55	66	.513	.580					
							.600	.360	1.20	.30	0.216
3.70	1.22	0.2	50	49	.688						
		0.8	50	61	.554	.621					
							.612	.352	1.175	.30	.215
4.00	1.13	0.2	50	51	.661						
		0.8	50	62	.545	.603					
							.590	.276	1.105	.25	.163
4.25	1.08	0.2	50	55	.614						
		0.8	50	63	.537	.576					
							.564	.256	1.025	.25	.144
4.50	0.97	0.2	40	47	.575						
		0.8	40	51	.531	.533					
							.474	.255	0.945	.27	.121
4.77	0.92	V = 0.556 (0.65/0.91) = .397									
											1.831
										SAY	1.83

Observers:____________________________

Computations __________________ Checked__________________

Table 4. Head Ratio and Flow Depth Corrections.

Date: 17 May 1995 Channel: Sunburn Distry Station: 0+126

Structure: Gate Flow Conditions: Submerged Orifice

Crest Elev: 162.132 H_u BM Elev: 163.083 h_d BM Elev: 162.857

Flow Condition	Head Ratio
Free Orifice Flow	$[(h_u)_o/(h_u)_t]^{0.5}$
Submerged Orifice Flow	$[(h_u - h_d)_o/(h_u - h_d)_t]^{0.5}$
Free Open Channel Flow	$[(h_u)_o/(h_u)_t]^{1.5}$
Submerged Open Channel Flow	$[(h_u - h_d)_o/(h_u - h_d)_t]^{1.5}$

Clock Time	h_u Tape/Gauge	h_u	h_d Tape/Gauge	h_d	h_u - h_d	Head Ratio	h_d Corr-ection
09:15	0.093	0.775	0.321	0.404	0.37	1.000	0.000
09:30	0.088	0.780	0.320	0.405	0.375	0.995	-0.001
09:46	0.097	0.771	0.322	0.403	0.368	1.004	+0.001
10:00	0.103	0.765	0.324	0.401	0.364	1.010	+0.003
10:14	0.110	0.758	0.326	0.399	0.359	1.017	+0.005
10:28	0.114	0.754	0.327	0.398	0.356	1.021	+0.006
10:46	0.118	0.750	0.328	0.397	0.353	1.025	+0.007
11:02	0.119	0.749	0.328	0.397	0.352	1.027	+0.007
11:18	0.121	0.747	0.329	0.396	0351	1.028	+0.008

Observers ______________________________

The downstream flow depth, h_d, should always be monitored, even under free flow conditions, in order to adjust the flow depth readings obtained during the current meter measurements if taken downstream from the structure being calibrated. If the current meter measurements are taken upstream from the flow control structure, then the monitored values of h_u would be used to adjust the flow depths measured while conducting the current meter discharge méasurement.

11.2 Recording of Data

For unsteady flow discharge measurements, there are two forms that are required. First of all, the form shown in Figure 12 is used to record the flow condition, along with the values of h_u and h_d for the flow control structure at different clock times, beginning about 15-30 minutes prior to beginning the first measurement with the current meter and ending with the last current meter reading.

A form has been developed (Figure 13) for calculating the discharge. There are two main features in this format: (1) taking the actual measured point velocity and multiplying by the head ratio obtained from the form shown in Figure 12, but corrected for the time lag of the water from the flow control structure to the cross-section being current metered; and (2) correcting the mean depth based on computations that uses the form in Figure 12 for determining the correction.

11.3 Computational Procedure

The computational procedure for a current meter discharge measurement using the Mid-Section Method in metric units is illustrated in Table 5. Figure 8 was used in this example, with the major verticals being at readings of 0.82, 1.23, 2.22, 3.70 and 4.50 meters along the tag line. Intermediate verticals were selected as listed in Table 5.

Note in Figure 8 that the water surface is contained between 0.27 and 4.77 meters along the tag line, just as in the previous example. The first cross-section is contained between 0.27 and 0.82 meter along the tag line. In Table 5, the velocity at the bank is roughly estimated to be 10 percent of the mean velocity in the vertical at 0.82 meter along the tag line; often, the velocity at the bank is listed as zero. Because of the shallow water depth at 0.82 meter, the Six-Tenths Depth Method was used in making the current meter measurement, which resulted in a velocity of 0.208 m/s that was obtained from Table 1. Since this first section has a triangular section, the appropriate velocity occurs at the centroid, which in this case is 2(0.02+0.208)/3. The discharge in this cross-section is less than 0.6 percent of the total discharge.

HEAD RATIO AND FLOW DEPTH CORRECTIONS

Flow Condition	Head Ratio
Free Orifice Flow	$[(h_u)_o/(h_u)_t]^{0.5}$
Submerged Orifice Flow	$[(h_u - h_d)_o/(h_u - h_d)_t]^{0.5}$
Free Open Channel Flow	$[(h_u)_o/(h_u)_t]^{1.5}$
Submerged Open Channel Flow	$[(h_u - h_d)_o/(h_u - h_d)_t]^{1.5}$

Channel____________________ Tape measurement gate____________________

Date____________________ Flow condition ____________________

Clock Time	h_u Tape/Gauge	h_u	h_d Tape/Gauge	h_d	$h_u - h_d$	Head Ratio

Observers ____

Figure 12. Head Ratio Correction Form.

Date:____________ Channel:____________ Station:____________

Distance from initial point	Depth	Clock Time in minutes	Depth of observation	Revolutions	Time in seconds	Velocity					Area	Mean Depth	Width	Discharge
						At point			Mean in vertical	Mean in section				
						Actual	Head Ratio	Corrected						

Observers:____________

No____ of____ pages Computations ____________ Checked____________

Figure 13. Blank form for unsteady flow discharge measurement using Mean-Section Method.

Table 5. Example of Computational Procedure for a Current Meter Discharge Measurement during Unsteady Flow Conditions.

Date: 17 May 1995 Channel: Sunburn Disty. Station: 0+126 m Page 1 of 3

Distance from initial point	Depth	Clock Time in minutes	Depth of obser-vation	Revolu-tions	Time in sec-onds	Velocity					Section			
						At point	Head Ratio	Corr-ected	Mean in vertical	Mean in section	Area	Mean Depth Corr-ected	Width	Disch arge
0.27	0					10%			.02					
										.152	.074	.135	.55	.011
0.82	0.27	9:24	0.6	20	67	.208	.998	.208	.208					
										.224	.197	.48	.41	.044
1.23	0.69	9:29	0.2	20	54	.255	.997	.254						
		9:31	0.8	20	61	.227	.996	.226	.240					
										.257	.238	.745	.32	.061
1.55	0.86	9:36	0.2	25	58	.296	.995	.294						
		9:38	0.8	25	68	.254	.996	.253	.274					
										.301	.317	.905	.35	.095
1.90	0.95	9:43	0.2	25	50	.342	.998	.341						
		9:45	0.8	30	65	.316	1.000	.316	.328					
										.358	.309	.965	.32	.111
2.22	0.98	9:49	0.2	30	49	.416	1.004	.418						
		9:51	0.8	30	57	.359	1.004	.360	.389					

Observers: ____________________

Computations ____________________ Checked ____________________

Table 5 (continued)

Date: 17 May 1995 Channel: Sunburn Disty. Station: 0+126 m Page 2 of 3

Distance from initial point	Depth	Clock Time in minutes	Depth of observation	Revolutions	Time in seconds	Velocity					Section			
						At point			Mean in vertical	Mean in section	Area	Mean Depth Corrected	Width	Discharge
						Actual	Head Ratio	Corrected						
2.22	0.98								.389					
										.434	.282	1.006	.28	.122
2.50	1.02	9:56	0.2	40	53	.511	1.007	.515						
		9:58	0.8	40	62	.438	1.008	.442	.478					
										.494	.317	1.058	.30	.157
2.80	1.08	10:02	0.2	40	49	.552	1.009	.557						
		10:05	0.8	40	59	.460	1.010	.465	.511					
										.540	.335	1.116	.30	.181
3.10	1.13	10:10	0.2	40	43	.628	1.013	.636						
		10:12	0.8	40	56	.484	1.014	.491	.568					
										.579	.352	1.172	.30	.204
3.40	1.18	10:18	0.2	50	52	.648	1.017	.659						
		10:21	0.8	50	66	.513	1.018	.522	.590					
										.612	.366	1.221	.30	.224
3.70									.633					

Observers:____________________

Computations ____________________ Checked____________________

Table 5 (complete)

Date: 17 May 1995 Channel: Sunburn Disty. Station: 0+126 m Page 3 of 3

Distance from initial point	Depth	Clock Time in minutes	Depth of obser-vation	Revolu-tions	Time in sec-onds	Velocity					Section			
						At point			Mean in vertical	Mean in section	Area	Mean Depth Corr-ected	Width	Disch arge
						Actual	Head Ratio	Corr-ected						
3.70	1.22	10:27	0.2	50	49	.688	1.019	.701						
		10:29	0.8	50	61	.554	1.020	.565	.633					
										.624	.360	1.200	.30	.225
4.00	1.13	10:34	0.2	50	51	.661	1.021	.675						
		10:36	0.8	50	62	.545	1.022	.557	.616					
										.602	.282	1.130	.25	.167
4.25	1.08	10:40	0.2	50	55	.614	1.023	.628						
		10:43	0.8	50	63	.537	1.024	.550	.589					
										.578	.262	1.049	.25	.151
4.50	0.97	10:49	0.2	40	47	.575	1.025	.589						
		10:52	0.8	40	51	.531	1.025	.544	.566					
										.482	.262	0.970	.27	.126
4.77	0.92	11:03	V = 0.556 (0.65/0.91) = 0.397											
														1.879
													Say	1.88

Observers:__________

Computations __________ Checked__________

For the last cross-section, which contains a vertical wall, a set of current meter measurements were made at 4.50 meters along the tag line, with the mean velocity in the vertical being 0.553 m/s. The distance, X, from the vertical wall is 0.27 meter (4.77-4.50). The depth of water, d_w, at the vertical wall is 0.92 meter. Thus, X/d_w is 0.27 m/0.92 m = 0.29. From Figure 6, the relative mean velocity in the vertical is 0.91, whereas the relative mean velocity at the wall is 0.65. The equation used for calculating the mean velocity at the vertical wall is shown at the bottom of Table 5.

The monitoring data for the flow depths upstream and downstream from the flow control structure are listed in Table 4. The last two colums contain the calculated head ratios and h_d corrections, respectively. The head ratio has been plotted against clock time in Figure 14.

The current meter measurement was taken 126 meters downstream from the flow control structure. After completing the current meter measurements, the average velocity can be calculated using the actual point velocity measurements in Table 5, which is 0.486 m/s. Thus, the lag time between the flow control structure and the cross-section where the current meter measurements were taken becomes:

$$\textbf{Time Lag} = \frac{\textbf{Distance from Flow Control Structure to Current Meter Cross-Section}}{\textbf{Mean Velocity in Current Metered Cross-Section}}$$

To obtain the appropriate head ratio requires that the time lag be subtracted from the recorded clock time, then this adjusted clock time for each current meter measurement is used in Figure 14 to obtain the appropriate head ratio, which is recorded in Table 5. Finally, the actual point velocity measured by the current meter is multiplied by the head ratio to obtain the corrected point velocity in Table 5.

The mean depth is recorded in Table 5 under the third column from the right. This mean depth takes into account the h_d correction in Table 4. Again, the recorded clock time in Table 5 minus the lag time is used to obtain the appropriate h_d correction from Table 4 and then applied in Table 5 to arrive at the column Mean Depth Corrected.

In this particular example, the difference between assuming steady-state versus unsteady flow conditions amounts to 2.7 percent of the discharge, which is not so significant, but still important. Often, the variation will be much greater.

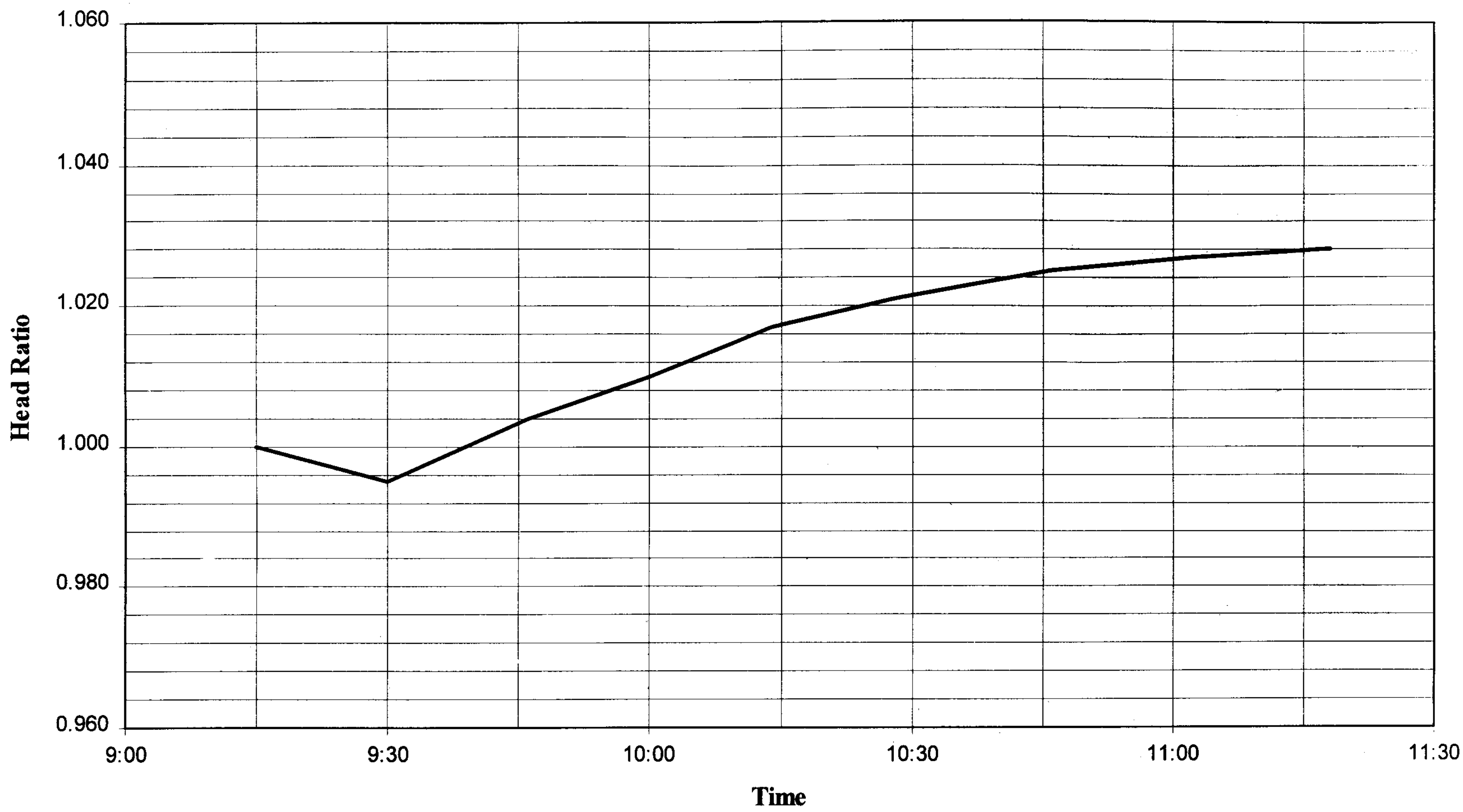


Figure 14. Example of Head Ratio variation at flow control structure during a current meter discharge measurement.

11.4 Computation Procedure for Mid-Section Method in English Units

Another example will be provided, this time using the Mid-Section Method. The measurements and computations are in English units.

In the field of irrigation and water management, the discharge measurement has a key role. If an observer is keeping an eye on small procedural details, it will increase the accuracy. The key steps in making a discharge measurement are how a person takes the vertical and then locates the point where the velocity will be measured, which means how close to the actual area, A, and velocity, V, (revolutions) have been measured. The verticals close to the banks must be more (slope changes occur more near the banks compared with the bed of the channel) and depth must be observed at each point where the slope is changing. Looking at Figure 8, the depths were observed at each point where the slope is changing. These vertical locations will help in more precisely calculating the area.

It is quite clear that the first section between two vertical is triangular and the area of this section will be calculated as 1/2*H*B[1] and the centriod will be two-thirds of the horizontal distance from the apex (channel bank) of the triangular end section. For a rectangular section, the area should be calculated with the equation; $(d_2+d_3)/2*B$ and the velocity measuring point will be in the center of the width. The observer should not miss a depression or raised spot while measuring the water depth along the channel bed.

First of all, the same form is used for the Head Ratio Correction (Figure 12). Forms are available for discharge measurements near a gated flow control structure shown in Figure 15 (two pages) and near an ungated outlet structure in Figure 16. Using these forms, the example is portrayed in Table 6 for the Head Correction Ratio and Table 7 for the unsteady flow discharge computations.

H = perpendicular
B = base of the triangle

DISCHARGE MEASUREMENTS:

Structure Section Name: .... Location : .... feet up / down stream of the structure Date : ..../............./ 199..

Team headed by : .... Method : Wading cable/ cross bridge/ Boat Flow Condition : ....

Start at : ....am/pm

Finished at : .... am/pm

Current Meter :	Model/ Type :	Date of Last Calibration :

Computed discharge:
1. Formula: ....
2. Cafficent of discharge :
(Cd) :..................

Structure Status		
Gauges	Level at Start	Level at End
U/S:		
D/S:		

	Gate W/M	Spindle Height	Gate Opening	Width	Area
Gate 1					
Gate 2					
Gate 3					
Gate 4					
Gate 5					

Up stream W/M Elevation:..............................

Down stream W/M Elevation:..........................

	U/S W/M	D/S W/M	Hu	Hd
Start Time				
End Time				

No of Section	Distance from initial point (ft)	Width (ft)	Depth (ft)	Mean Depth (ft)	Clock Time in minutes	No. of Rev. per..................secs. Oberserved depths 0.2 (ft)	0.6 (ft)	0.8 (ft)	Velocity (ft/s) Oberserved depths 0.2 (ft/sec)	0.6 (ft/sec)	0.8 (ft/sec)	Mean (ft/sec)	Head Ratio	Corrected Velocity (ft/sec)	Area (ft sq)	Area of section (ft sq)	Disch-arge (cft/sec)

Computations:.. Checked:.................................. No. 1 of page Total Discharge: [ ]

Remarks:..

Figure 15. Blank Form for unsteady flow discharge measurement using Mid-Section Method in English Units.

DISCHARGE MEASUREMENTS:

No of Section	Distance from initial point (ft)	Width (ft)	Depth (ft)	Mean Depth (ft)	Clock Time in minutes	No. of Rev. per---------------secs. Oberserved depths 0.2 (ft)	0.6 (ft)	0.8 (ft)	Velocity (m/s) Oberserved depths 0.2 (ft/sec)	0.6 (ft/sec)	0.8 (ft/sec)	Mean (ft/sec)	Head Ratio	Corrected Velocity (ft/sec)	Area (ft sq)	Area of section (ft sq)	Disch-arge (cft/sec)

Computations:------------------------------------ Checked:------------------------------- No. of page Total Discharge:

Remarks:---

Figure 15 (Continued).

DISCHARGE MEASUREMENTS:

Outlet RD: ---------------------------------- Location : -------------- ft down stream of the structure Date : -----------/------------/ 199--

Start at : --------------am/pm

Team headed by : -------------------------------- Channel Name:--- Flow Condition : ------------------- Finished at : ---------- am/pm

Current Meter : Model/ Type : Date of Last Calibration :

Computed discharge:	Crest R. L. (ft) : -------------------------------------
1. Formula: --	Area of Outlet : ------------------------------------
2. Coefficient of discharge :	Up stream W/M R.L. (ft):---------------------------
(Cd) :--	Down stream W/M R. L. (ft):-----------------------

Time	U/S W/M (ft)	D/S W/M (ft)	Hu (ft)	Hd (ft)
Start Time				
End Time				

No of Section	Distance from initial point (ft)	Width (ft)	Depth (ft)	Mean Depth (ft)	Clock Time in minutes	No. of Rev. per--------------secs. Oherserved depths 0.2 (ft)	0.6 (ft)	0.8 (ft)	Velocity (ft/s) Oherserved depths 0.2 (ft/sec)	0.6 (ft/sec)	0.8 (ft/sec)	Mean (ft/sec)	Area (sq ft)	Area of section (sq ft)	Disch-arge (cfs)

Computations:---------------------------------- Checked:------------------------------ No. 1 of page Total Discharge:

Remarks:--

Figure 16. Discharge measurement form for outlet.

Table 6. Head Ratio Corrections for Example of Mid-Section Method on English Units.

Flow Condition	Head Ratio
Free Orifice Flow	$[(h_u)_o/(h_u)_t]^{0.5}$
Submerged Orifice Flow	$[(h_u - h_d)_o/(h_u - h_d)_t]^{0.5}$
Free Open Channel Flow	$[(h_u)_o/(h_u)_t]^{1.5}$
Submerged Open Channel Flow	$[(h_u - h_d)_o/(h_u - h_d)_t]^{1.5}$

Channel: Gujjiani Distributary   Tape measurement gate: 0.54

Date: 14/03/1996   Flow condition : Free orifice flow

Clock Time	h_u Tape/Gauge	h_u	h_d Tape/Gauge	h_d	$h_u - h_d$	Head Ratio
08:15	1.41	6.59	-	-	-	1.000
08:30	1.43	6.57	-	-	-	1.001
08:45	1.45	6.55	-	-	-	1.003
09:00	1.46	6.54	-	-	-	1.004
09:15	1.48	6.52	-	-	-	1.005
09:30	1.50	6.50	-	-	-	1.007
09:45	1.51	6.49	-	-	-	1.008
10:00	1.50	6.50	-	-	-	1.007
10:15	1.47	6.53	-	-	-	1.005
10:30	1.45	6.55	-	-	-	1.003

Observers: Shahzad Mahmood

Table 6 continue

Clock Time	h_u Tape/Gauge	h_u	h_d Tape/Gauge	h_d	h_u - h_d	Head Ratio
10:45	1.43	6.57	-	-	-	1.001
11:00	1.41	6.59	-	-	-	1.000
11:15	1.40	6.60	-	-	-	0.999
11:30	1.39	6.61	-	-	-	0.998
11:45	1.38	6.62	-	-	-	0.998
12:00	1.37	6.63	-	-	-	0.997
12:15	1.36	6.64	-	-	-	0.996

Observers: Shahzad Mahmood

Table 7. Discharge measurement, an example of Mid-section Method.

DISCHARGE MEASUREMENTS:

Structure. Section Name: Gujjiani Distributary Head — Location : 214 meter down stream of the structure — Date : 14 / 03 / 1996

Team headed by : Khalid Mahmood — Method : Wading — Flow Condition : Free Oriface flow — Start at : 08 : 15 am — Finished at : 12 : 15 am

Current Meter :	Large	Model/ Type :	Valport (Horizontal Axis)	Date of Last Calibration :	December 1991

Computed discharge: 391.64 cfs
1. Formula:
Q= Cd*W*Go*(2G*(Hu-Go/2)) ^ 0.5
2. Cofficent of discharge(Cd) : 0.57

Structure Status		
Gauges	Level at Start	Level at End
U/S:	6.55 ft	6.60 ft
D/S:	4.47 ft	4.49 ft

	Gate W/M	Spindle Height	Gate Opening	Width	Area sft
Gate 1	0.54 ft	4.52 ft	3.98 ft	9.97 ft	39.810
Gate 2	----	----	----	----	----
Gate 3	----	----	----	----	----
Gate 4	----	----	----	----	----
Gate 5	----	----	----	----	----

Up stream W/M Elevation:------ 8.00 ft--------

Down stream W/M Elevation:------------------------

	U/S W/M	D/S W/M	Hu	Hd
Start Time	1.41 ft	0.85 ft	6.59 ft	
End Time	1.36 ft	0.83 ft	6.64 ft	

No Of Section	Distance from initial point	Width	Depth	Mean Depth	Clock Time in minutes	No. of Rev. per-----50---------secs. Oberserved depths			Velocity (m/s) Oberserved depths			Mean	Head Ratio	Corrected Velocity	Area	Area of section	Disch-arge
	(m)	(m)	(m)	(m)		0.200 (m)	0.600 (m)	0.800 (m)	0.200 (m/sec)	0.600 (m/sec)	0.800 (m/sec)	(m/sec)		(m/sec)	(m sq)	(m sq)	(m ^ 3/sec)
	1.000		0.580														
	1.100	0.100	0.640	0.610											0.061		
	1.200	0.100	0.710	0.675											0.067		
1	1.300	0.100	0.760	0.735	08:45	52,51		51,50	0.285		0.280	0.283	1.001	0.283	0.074	0.474	0.134
	1.400	0.100	0.880	0.820											0.082		
	1.500	0.100	0.950	0.915											0.092		
	1.600	0.100	1.010	0.980											0.098		
	1.700	0.100	1.070	1.040											0.104		
	1.800	0.100	1.100	1.085											0.109		
2	1.900	0.100	1.110	1.105	08:50	75,75		60,62	0.408		0.333	0.371	1.001	0.371	0.110	0.662	0.246
	2.000	0.100	1.130	1.120											0.112		
	2.200	0.200	1.140	1.135											0.227		
3	2.500	0.300	1.150	1.145	08:55	100,101		68,65	0.544		0.363	0.454	1.003	0.455	0.343	0.691	0.315
	2.800	0.300	1.170	1.160											0.348		
4	3.100	0.300	1.200	1.185	09:03	97,98		85,85	0.528		0.461	0.495	1.003	0.496	0.356	0.722	0.358
	3.400	0.300	1.240	1.220											0.366		
5	3.700	0.300	1.250	1.245	09:10	102,105		77,77	0.560		0.419	0.490	1.004	0.491	0.374	0.754	0.371

Computations: Sarfraz Ahmed — Checked by: Khalid Mahmood — No. 1 of 3 page — Total Discharge:

Remarks:...

Table 7 (continue)

DISCHARGE MEASUREMENTS:

No Of Section	Distance from initial point (m)	Width (m)	Depth (m)	Mean Depth (m)	Clock Time in minutes	No. of Rev. per ------50---------secs. Oberserved depths 0.200 (m)	0.600 (m)	0.800 (m)	Velocity (m/s) Oberserved depths 0.200 (m/sec)	0.600 (m/sec)	0.800 (m/sec)	Mean (m/sec)	Head Ratio	Corrected Velocity (m/sec)	Area (m sq)	Area of section (m sq)	Disch-arge (m ^3 sec)
	4.000	0.300	1.290	1.270											0.381		
6	4.300	0.300	1.300	1.295	09:16	110,113		75,77	0.603		0.413	0.508	1.004	0.510	0.388	0.778	0.397
	4.600	0.300	1.300	1.300											0.390		
7	4.900	0.300	1.280	1.290	09:24	113,116		81,82	0.619		0.443	0.531	1.005	0.534	0.387	0.773	0.412
	5.200	0.300	1.290	1.285											0.385		
8	5.500	0.300	1.260	1.275	09:31	131,132		90,93	0.709		0.496	0.603	1.005	0.606	0.382	0.762	0.461
	5.800	0.300	1.270	1.265											0.379		
9	6.100	0.300	1.260	1.265	09:38	130,132		99,102	0.707		0.544	0.626	1.007	0.630	0.379	0.756	0.476
	6.400	0.300	1.250	1.255											0.377		
10	6.700	0.300	1.260	1.255	09:45	135,137		104,102	0.733		0.557	0.645	1.007	0.650	0.376	0.756	0.491
	7.000	0.300	1.270	1.265											0.379		
11	7.300	0.300	1.270	1.270	09:55	132,131		102,103	0.709		0.555	0.632	1.008	0.637	0.381	0.762	0.485
	7.600	0.300	1.270	1.270											0.381		
12	7.900	0.300	1.290	1.280	10:10	114,117		102,104	0.624		0.557	0.591	1.007	0.595	0.384	0.774	0.460
	8.200	0.300	1.310	1.300											0.390		
13	8.500	0.300	1.340	1.325	10:20	125,127		93,91	0.680		0.499	0.590	1.007	0.594	0.398	0.806	0.478
	8.800	0.300	1.380	1.360											0.408		
14	9.100	0.300	1.390	1.385	10:30	122,119		100,103	0.651		0.549	0.600	1.005	0.603	0.415	0.838	0.506
	9.400	0.300	1.430	1.410											0.423		
15	9.700	0.300	1.460	1.445	10:38	119,121		100,100	0.648		0.541	0.595	1.003	0.596	0.433	0.871	0.520
	10.000	0.300	1.460	1.460											0.438		
16	10.300	0.300	1.490	1.475	10:50	123,123		89,92	0.664		0.491	0.578	1.003	0.579	0.442	0.889	0.515
	10.600	0.300	1.490	1.490											0.447		
17	10.900	0.300	1.470	1.480	10:58	118,118		90,93	0.637		0.496	0.567	1.001	0.567	0.444	0.882	0.500
	11.200	0.300	1.450	1.460											0.438		
18	11.500	0.300	1.440	1.445	11:07	127,128		93,94	0.688		0.507	0.598	1.000	0.598	0.434	0.865	0.517

Computations: Sarfraz Ahmed   Checked by: Khalid Mahmood   No. 2 of 3 page   Total Discharge:

Remarks:..

Table 7 (complete)

DISCHARGE MEASUREMENTS:

No Of Section	Distance from initial point (m)	Width (m)	Depth (m)	Mean Depth (m)	Clock Time in minutes	No. of Rev. per-----50----------secs. Oberserved depths 0.200 (m)	0.600 (m)	0.800 (m)	Velocity (m/s) Oberserved depths 0.200 (m/sec)	0.600 (m/sec)	0.800 (m/sec)	Mean (m/sec)	Head Ratio	Corrected Velocity (m/sec)	Area (m sq)	Area of section (m sq)	Disch-arge (m ^ 3/sec)
	11.800	0.300	1.440	1.440											0.432		
19	12.100	0.300	1.410	1.425	11:15	128,130		92,93	0.696		0.501	0.599	1.000	0.599	0.428	0.849	0.508
	12.400	0.300	1.400	1.405											0.421		
20	12.700	0.300	1.390	1.395	11:25	124,126		97,99	0.657		0.531	0.594	0.999	0.593	0.419	0.829	0.492
	13.000	0.300	1.350	1.370											0.411		
21	13.300	0.300	1.340	1.345	11:32	123,122		97,99	0.661		0.531	0.596	0.999	0.595	0.404	0.804	0.479
	13.600	0.300	1.330	1.335											0.401		
22	13.900	0.300	1.330	1.330	11:40	110,110		92,93	0.595		0.501	0.548	0.998	0.547	0.399	0.796	0.436
	14.200	0.300	1.320	1.325											0.398		
23	14.500	0.300	1.310	1.315	11:45	117,119		79,81	0.637		0.435	0.536	0.998	0.535	0.394	0.784	0.420
	14.800	0.300	1.290	1.300											0.390		
24	15.100	0.300	1.290	1.290	11:52	113,116		82,83	0.619		0.448	0.534	0.998	0.532	0.387	0.771	0.411
	15.400	0.300	1.270	1.280											0.384		
25	15.700	0.300	1.220	1.245	11:58	103,105		84,86	0.563		0.461	0.512	0.998	0.511	0.374	0.735	0.376
	16.000	0.300	1.190	1.205											0.361		
26	16.300	0.300	1.090	1.140	12:03	82,82		45,47	0.445		0.253	0.349	0.998	0.348	0.342	0.654	0.228
	16.600	0.300	0.990	1.040											0.312		
	16.700	0.100	0.790	0.890											0.089		
27	16.830	0.130	0.660	0.725	12:09		45,45			0.248		0.248	0.997	0.247	0.094	0.404	0.100
	16.900	0.070	0.570	0.615											0.043		
	17.000	0.100	0.540	0.555											0.056		
	17.100	0.100	0.500	0.520											0.052		
	17.200	0.100	0.450	0.475											0.047		
	17.300	0.100	0.000	0.225											0.023		

Computations: Sarfraz Ahmed Checked by: Khalid Mahmood No. 3 of 3 page Total Discharge: 11.090

Remarks:...

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TRAINING REPORTS

Report #	Title	Author	Year
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