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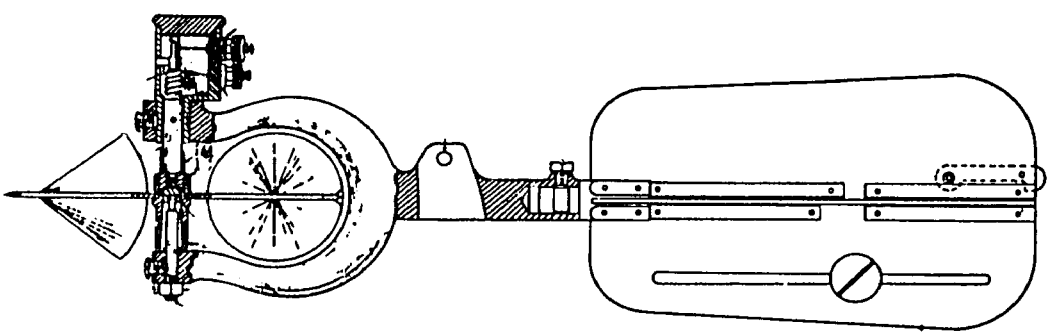
ISLAMABAD, PAKISTAN

USAID

IRRIGATION SYSTEMS MANAGEMENT PROJECT
PHASE II



HYDRAULIC AND SEDIMENT MONITORING MANUAL FOR PROVINCIAL IRRIGATION DEPARTMENTS

APRIL, 1993

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DEVELOPMENT ALTERNATIVES, INC.
ASSOCIATED CONSULTING ENGINEERS-ACE (PVT) LTD

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FOREWORD

Monitoring of canal and drain system performance is an important component of irrigation system management. The Provincial Irrigation Departments (PIDs) have performed water level and flow monitoring and some sediment monitoring since the introduction of canal irrigation systems. The Punjab Manual of Irrigation Practice includes descriptions of procedures and instrumentation for system monitoring. However, that manual was last updated in 1943. Advances in instrumentation and procedures since that time have made possible substantial improvements in accuracy of field measurements and in data analysis.

Hydraulic and sediment monitoring equipment and training have been provided by USAID on a pilot basis under the Irrigation System Management (ISM) Project. The equipment supplied is adequate to meet the routine hydraulic and limited sediment monitoring needs of the PIDs. This manual is specifically addressed to the use and care of the equipment and the analysis of data collected with the equipment. The equipment provided and the procedures recommended are also consistent with the equipment and procedures used by WAPDA.

Criteria, standards, and specifications are provided in this manual for the selection of monitoring sites, instrumentation, procedures for field measurements, and office procedures for data reduction and evaluation. These criteria, standards and procedures should be followed to assure the collection of accurate and reliable hydraulic and sediment data. These data will enable an accurate assessment of irrigation system performance, enhance system operation, support planning and scheduling of maintenance activities, and provide information for use in advanced channel design procedures.

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Chapter 1

PURPOSE AND SCOPE

This manual is designed to provide guidelines to the personnel of the Provincial Irrigation Departments (PIDs) for monitoring the operation and performance of their irrigation and drainage systems. The manual provides step-by-step instructions to:

- conduct hydraulic monitoring;
- analyze sediment data;
- survey the cross sectional and longitudinal profiles of the channel;
- analyze and evaluate hydraulic, sediment, and morphological data; and
- prepare periodic performance histories of the system, identify the canal reaches with poor performance and determine remedial measures.

The above tasks will be performed at divisional levels under the control of executive engineers. Mostly sub-engineers (overseers) and occasionally engineers (sub-divisional officers) will be involved in the data collection. Therefore, the instructions in the manual are addressed to the level of sub-engineers. Details of equipment to be used for the data collection also are provided.

Chapter 2 gives a general discussion of hydraulic monitoring and of various measurements required for monitoring. Detailed measurement procedures, office analyses, and evaluations are discussed in subsequent chapters.

Chapter 2

HYDRAULIC MONITORING

The purpose of hydraulic monitoring is to identify any flow changes in the system corresponding to an indicated water level on a seasonal and a long-term basis. This is achieved through:

- Installation and operation of water level monitoring devices at key locations in the system;
- Periodic current meter flow measurements at the selected locations;
- Establishment of new and/or revised stage-discharge relationships at the selected locations;
- Verification of empirical discharge coefficient relationships for control structures including outlets;
- Maintenance of continuous stage and discharge records (daily basis) at key locations;
- Measurement of the characteristics of suspended sediment and bed material
- Analysis of suspended sediment and bed material samples;
- Survey of water surface profiles, longitudinal profiles of canal beds and cross sectional profiles within a selected study reach;
- Preparation of performance history of the system; and
- Cataloging and computerization of the field observation and office analysis.

Hydraulic monitoring including the preparation of performance histories will be done at divisional levels under the control of the executive engineers. The sub-engineers and sub-divisional officers (assistant engineers) should be trained to perform the monitoring.

The sediment analysis should be done by a special unit established in the office of the superintending engineer. This unit should consist of two research assistants and one office assistant familiar with computerization of the basic data and results of the analysis.

Monitoring Responsibilities

Divisional Level

1. Install and operate water level sensors at selected locations on the canals, distributaries, and minors. A water level recorder provides a continuous record of the water levels. In the case of non-recording staff gages, the gages should be read at least twice a day.

2. Make current meter discharge measurements at sites with no control structures. Initially make at least four measurements in each cropping season (at different discharge rates) to establish stage-discharge relationships. Later, the number of measurements may be reduced to two during each cropping season. The timing of the measurements should best represent the flow conditions in the channel during a particular season.

3. Make current meter discharge measurements on headworks and other control structures in the system three or four times (in different cropping seasons) during a year to check the discharge tables and/or empirical discharge relationships established for these structures.

4. Measure flow in water courses at different flow rates and water surface levels in the main channel (distributary or minor) using pygmy current meters, standardized flumes, or other appropriate devices.

5. Collect suspended sediment and bed material samples at selected locations and send to the laboratory in the circle office for analysis.

6. Survey water surface profiles within a selected reach at least twice a year when the canals are running at full capacity and determine encroachment on freeboard.

7. Analyze the discharge and gage height data.

8. Compare the measured discharges in the system and water courses with those derived from the empirical relationships established for control structures and outlets.

9. Check the reliability of the system in providing water according to delivery schedules and equitable distribution according to authorized discharges of outlets using the discharge and gage data.

10. Survey longitudinal and cross sectional profiles of the canals, distributaries, and minors during the closure periods.

11. Evaluate the data and identify the channels that demonstrate poor performance.

12. Update the performance history of canals after every five years with respect to silting, scouring, shortages at tail outlets, breaches, encroachments of freeboard, berm growth, etc.

13. Define remedial measures to upgrade the performance of the problematic canals in consultation with the superintending engineers.

14. Properly document the basic data and evaluation results for submission to the circle office.

Circle Level

1. Operate a sediment analysis laboratory to analyze the sediment data collected in the field, and to provide total concentration and particle size distributions of suspended sediment samples and particle size distribution of bed material samples to the respective executive engineers.

2. Review the field data collection procedures periodically and provide technical guidance.

3. Properly computerize and/or file the data for future use.

4. Review the performance history of the irrigation systems, prepared by the executive engineers.

5. Review the special reports prepared by the executive engineers identifying the canals with poor performance and determine remedial measures in consultation with the chief engineer and the executive engineers.

Chapter 3

WATER LEVEL MEASUREMENTS

The water surface elevation of a canal at a specific location is referenced to a predetermined or arbitrary datum. The "gage height," more commonly termed the "stage," is the height of water surface above the established datum. In this manual, the term "gage height" is used because it is more appropriate when used with a reading on a gage. The gage height is expressed in feet and hundredths of a foot or in meters and centimeters.

Measuring Devices

A number of devices are available to measure water levels (gage heights). The gage height data will be obtained either by direct systematic observations on a staff gage (non-recording gage) or by using a water level recorder which gives a continuous graph of gage height versus time. The data from a staff gage are termed as "observed gage heights," while those from a recorder, as "recorded gage heights."

Staff Gage

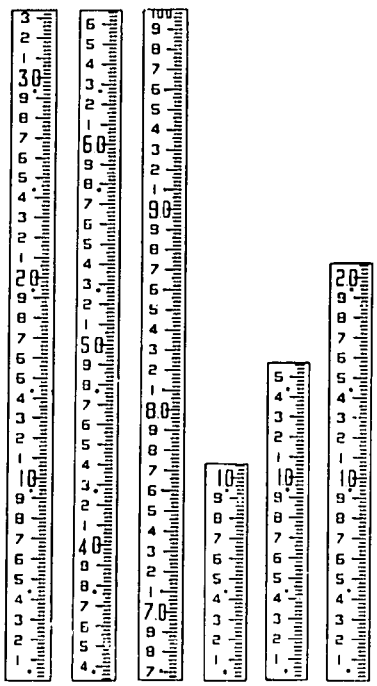
Figure 1 shows different styles of staff gages commonly in use. The Style A is provided. The gage plate is a porcelain enameled iron plate, 4-inches wide, marked at every foot, tenth, and 0.02 foot interval with a total gage reading. The gage is available in 3.33-foot sections for numbering to 13.33 feet. This gage is used as a vertical gage. Gage plates in 2.50 - foot sections are also used in Pakistan.

A gage may be installed on a slope. Usually, an inclined staff gage consists of a graduated heavy timber securely attached to a permanent foundation. The graduation spacing should conform to the slope of the canal bank and should be done carefully with a survey level. The graduation may be painted, however, it is preferable to use metallic staples and numerals for the graduation.

The enameled pieces are screwed on wooden battens 2" x 6" and about 3.0 to 3.5 feet long, and then fixed to angle irons/channels attached to concrete pillars, to serve as a staff gage. Figure 2 shows an installation of a vertical gage. The gage pieces should be installed in steps depending upon the maximum and minimum gage heights to be observed. In some cases, it may be more convenient to fix the wooden battens to an angle iron driven into the bed or bank of the canal. In these cases, the concrete piers are not required.

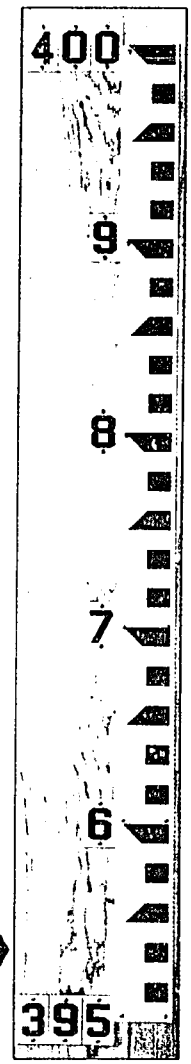
Style C

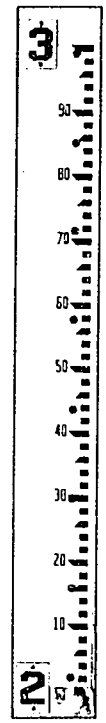
Two and one half inches wide, graduated to hundredths and marked at every foot and every tenth. Numbered 3½ foot sections are available to 20 feet, higher numbering on special order. Also available for 1, 1½, 2, and 5 foot applications.



Style E

Three and one half inches wide, graduated in feet and tenths, unnumbered. Separate figures are fastened on a plank, wall or pier to number any elevations desired. Available in 1, 2, and 5 foot sections.





Style M

Metric gage, 65 mm wide. Divided into centimetres with each decimetre numbered. Gages for any elevation may be assembled by using separate figures. Available in 1 metre sections.

Style A

Four inches wide, marked at every foot, tenth and 0.02 foot with total elevations. Available in 3½ foot sections for numbering to 13½ feet, higher numbering on special order.

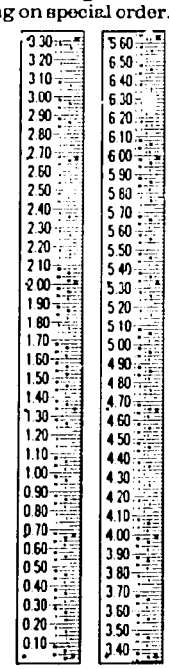


Figure 1 : Porcelain Enameled Iron Gages

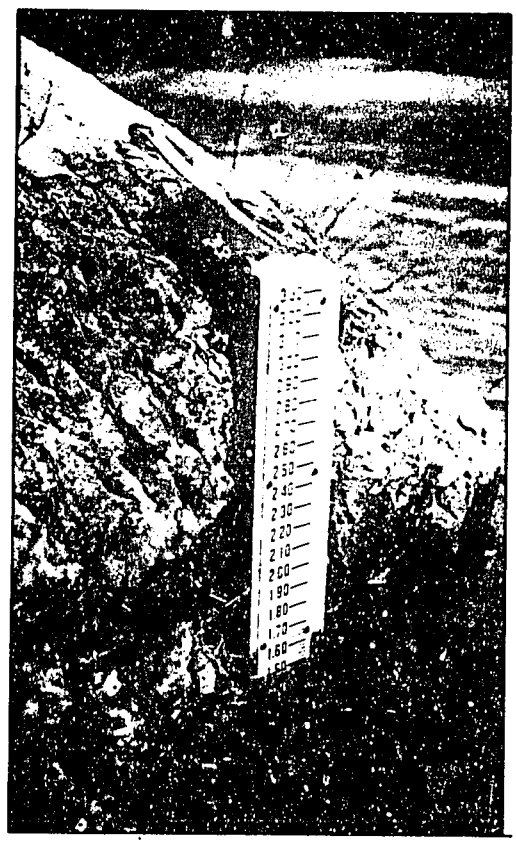


Figure 2 : Vertical Staff Gage

Water Level Recorder

A water level recorder produces a graphic or punched tape record of the rise and fall of a water surface with respect to time. It consists of a time element and a gage height element which, when operating together, produce on a chart or a tape a record of the fluctuations of the water surface. The time element is controlled by a clock, operated by a weight, by a spring, or by electricity. The gage height element is actuated either by a pressure device or by a float, with accessories to correlate the water level with time. For this project, Stevens A-71 recorders are recommended. This recorder is equipped with a negator spring driven clock with a chart speed of 2.4 inches per day. The chart is 10-inches wide and 25 yards long. With gage scale ratio of 1:6, two inches on the chart represent a one foot change in the gage height. Thus, the 10-inch width represents 5 feet of gage height. The smallest division represents 0.05 foot. The pitch circumference of the float pulley is 18 inches. The diameter of the float is 8 inches. Figure 3 shows a water level recorder.

The water level recorder is installed either in a masonry or concrete stilling well with a walk-in type shelter or over a galvanized-iron pipe with a look-in type shelter. Both the well and pipe protect the float from direct contact with the flowing water. For the irrigation system, a pipe well is recommended.

A pipe well should be large enough for the free action of the float and counterweight. A 18-inch diameter pipe is recommended. In order to effectively eliminate wave action and surges in the pipe due to the flowing water, the area of the water inlet hole should be about 1/1000 the area of the pipe. For a 18-inch diameter pipe, an inlet hole of 0.5 inch diameter is suggested.

The pipe should be installed at a bridge pier (Figure 4) or on the bank of a canal, supported by a suitable masonry or angle-iron frame structure. The bottom of the pipe should not contact the bed of the canal and should be below the minimum anticipated gage height. Generally, the bottom consists of a hollow inverted cone truncated at its lower end to form a circular entrance, about 2 inches in diameter. This shape serves to eliminate wave action and the danger of silting of the well. An entrance door near the bottom of the pipe is useful for cleaning silt.

A look-in type instrument shelter is required over the pipe. This could be of a simple wooden construction, large enough to accommodate the A-71 recorder. A shelter about 36 inches long, 24 inches wide, and 24 inches high is desirable. The shelter can be anchored to the well by bolting the floor at four corners to the small angles welded to the top of the well. Figure 5 shows a typical construction for a shelter. The size of the shelter is for a Stevens F-type recorder.

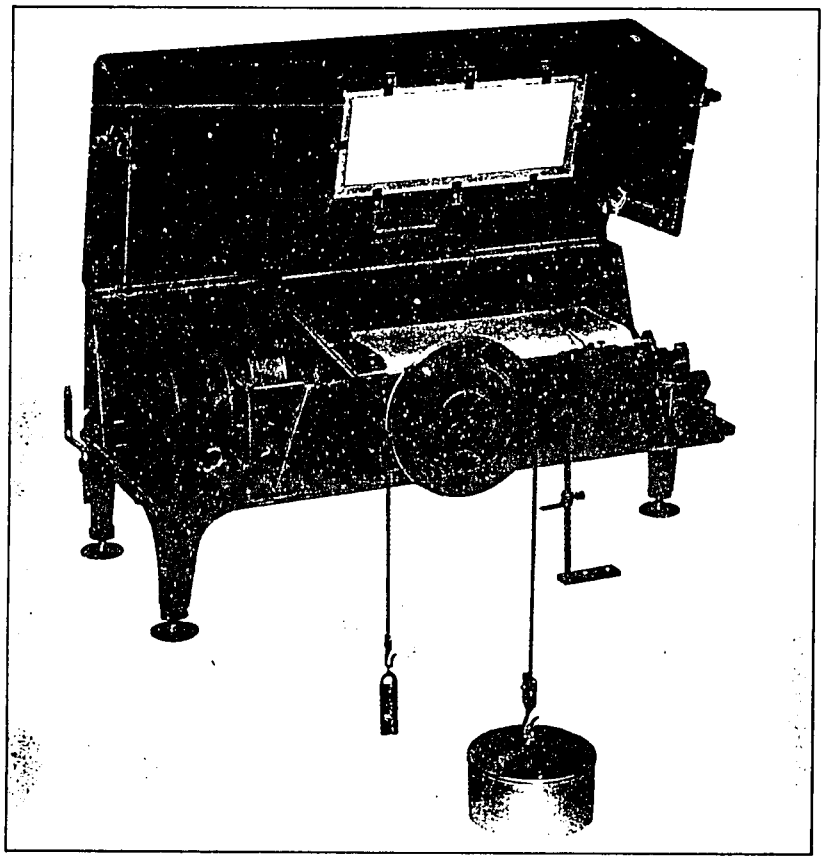


Figure 3 : Water Level Recorder

Figure 4 : Water Level Recorder on a Pipe-Well

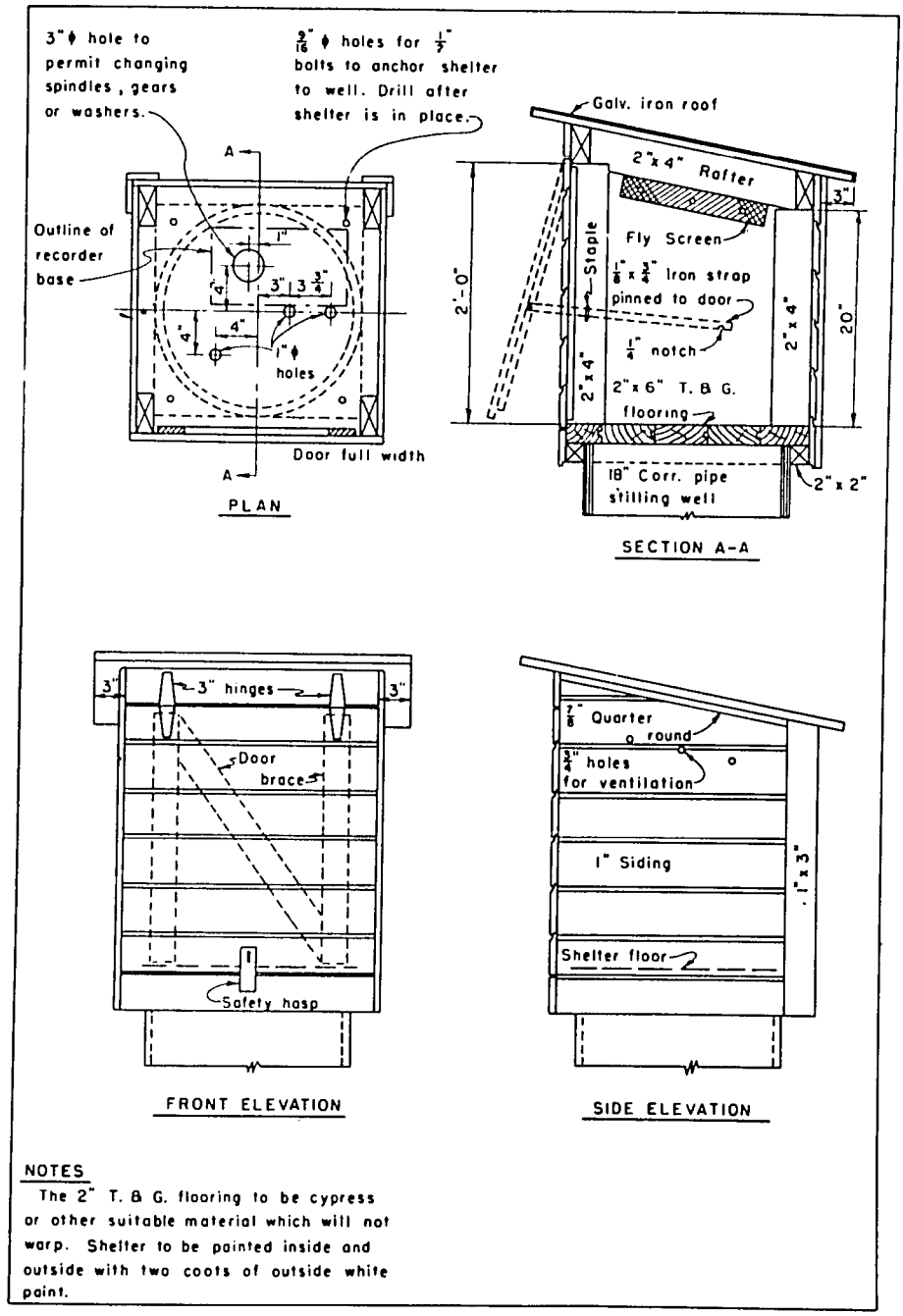


Figure 5 : A Typical Look-in F-Type Recorder Shelter

The pipe well should be vertical and in the water during all operating stages in the canal. A reference staff gage should also be installed near the well. This gage is necessary because there is a possibility that the gage height indicated by the recorder may not be representative of the stage in the canal due to clogging of the intake by sediment or other reasons. The gage can be painted on the outside of the pipe or a separate enameled staff gage can be installed. The recorder and this reference gage should be set to the same datum.

The instructions for installation and operation of Stevens A-71 recorder are provided with the instrument from Leupold and Stevens, Incorporated.

Datum of Gage

All gages in the system should be set to the Survey of Pakistan Datum (SPD). To eliminate the possibility of negative values of gage height, the elevation of the zero of the gage should be below the elevation of no flow in the canal or on the control.

Only one datum should be used for the gage height record for the life of the station. For this requirement, it is necessary to establish at least two or three reference marks that are independent of gage structure. The reference marks should be about 100 to 200 feet away from the gage structure. A concrete block with a 0.5-inch diameter iron bar, buried about two feet below ground should be used as a reference mark. All gages should be periodically (about once a year) checked by running levels using the reference marks to maintain a fixed datum. The locations of the reference marks should be described in sufficient detail to locate them for future surveys. The reference marks should be spread well apart so that if one is disturbed, the others can be used.

Levelling for establishing the gage datum should be done in a closed circuit, that is, started from the reference mark and finished at the reference mark. If only one setting is needed to check the staff gage and/or recorder levels, the instrument should be pulled up after one set of readings and reset for a second set. For a stream gaging station with a water level recorder, the following procedure is recommended to set the recorder to the SPD.

1. Reference marks should have been set to the SPD.

2. Determine the elevation of the shelf of the recorder at the float tape hole, using reference mark(s).

3. Calculate the elevation of the pointer of the index bracket fixed on the shelf by carefully measuring the distance between the shelf and the pointer and adding it to the shelf SPD level. This pointer is called the reference point.

The tape reading against the pointer should be subtracted from the SPD reading of the pointer, to get the zero of the gage.

For periodic checking of the gage datum, the following procedure should be used.

1. Determine the elevation of the shelf at the float tape hole as follows:

   a. Measure down to the water surface from the edge of the shelf using a steel tape with a weight at its end. The tape should be dusted so that it shows water line distinctly. Reading should be made at least twice.

   b. Add the measured distance to the recorder tape reading which is indicating water level in terms of SPD. This gives elevation of the shelf to the gage datum.

2. Take level rod readings of reference mark(s) with edge of the tape hole in the shelf as the back sight. Compute level of the shelf. It should be within 0.01 foot of the original reading.

3. To check whether the pointer has been disturbed, carefully measure the distance between the shelf and the pointer, add to the shelf SPD level.

4. Add tape reading to the original datum.

5. The difference between the readings in steps 3 and 4 should be within .01 foot. If it is greater, the pointer has been disturbed. Readjust to the original datum.

The readings of the gage height prior to and after the levelling should be recorded on the recorder chart and level notes. Careful notes should be made of any changes made.

Selection of Gage Site

General locations of the stream gaging stations should be determined from a consideration of the need for discharge data to monitor the operation and performance of the irrigation system. A precise location for a station is selected to take advantage of the best locally available conditions for stage and discharge measurements and for developing a stable stage-discharge relationship.

The shape of the stage-discharge relationship in a canal will be controlled by a reach below the gage which eliminates the effect of all other downstream conditions on the velocity of flow at the gage. If a gage is installed upstream of a control structure such

as a weir, this structure will control the relationship. The following criteria should be followed in selecting a gage site.

1. The general course of the canal is straight for about 4 to 5 times the width of the canal, upstream and downstream from the gage site.

2. The canal bed is not subject to scour and deposition and is free of aquatic growth.

3. The canal banks are stable and clear of excessive weed growth.

4. The gage is far enough upstream from diversions and cross drainages to avoid any variable influence.

5. A satisfactory reach for measuring the flow is available near the gage.

6. The gage can be reached during the rainy season.

7. When installed above a control structure, the gage should be located a distance at least four times the maximum anticipated head over the crest in order to avoid the effect of the surface draw-down that occurs at the crest. In this case, the zero of the gage should be set at the crest elevation. When installed as a tail gage, it should be sufficiently far downstream from the structure to avoid turbulence effects.

Operation of Gages

Staff Gage

A gage observer should be employed to systematically record and report observed gage heights to the sub-engineer in charge of the gage. Because the canal supply does not change frequently, the staff gages should be read in the morning and in the afternoon. The observation times should be decided by the executive engineer. However, if fluctuations are expected during a day, the number of observations should be increased.

A record book containing sufficient pages for a full-year of weekly records should be used to record the observed gage heights in duplicate. The original copy should be removed and sent to the divisional office through sub-divisional office. The second copy should remain in the book, which will form the permanent record of the staff gage readings. A format of the gage book is shown in Figure 6. Record upstream and downstream gage heights at canal structures; if the gage is not at a structure, record in the "upstream" column.

Sample Note-Book for Gage Height

Figure 6

_____ IRRIGATION DEPARTMENT
_____ CIRCLE _____ DIVISION

_____ at _____
near

Gage Heights for the Week Ending Thursday _____ ,19 _____

DAY AND DATE	TIME	GAGE HEIGHT		REMARKS
		UPSTREAM	DOWNSTREAM	
Friday	AM			
	PM			
Saturday	AM			
	PM			
Sunday	AM			
	PM			
Monday	AM			
	PM			
Tuesday	AM			
	PM			
Wednesday	AM			
	PM			
Thursday	AM			
	PM			

_____ Observer

_____ Engineer _____ Sub-Engineer

The sub-engineer should check the gage and take a reading during his routine visits. He should contact the observer, record his reading in the book under the "Remarks" columns. At that time, he also should inspect the gage book to check for discrepancies in the observer's readings. Such visits by a sub-engineer are very important. He should also check that the observer does not falsify the gage height data.

The following instructions should be provided to the gage observers by the sub-engineers.

1. Enter the name of the province, circle and divisional offices.

2. Enter the name of gaging station and the date of the last day of the week.

3. Make observations twice a day and record in the book with the time of observation as directed by the executive engineer. However, when a gradual change in canal supply is expected, the gage observers should be instructed to take more observations.

4. Record the gage height by approaching the gage and making sure that flow near the gage is not disturbed. Observe the value to the nearest hundredth of a foot (.01 foot).

5. Be careful to record each gage height with the time, date, and any "remarks" related thereto, in the proper columns. Do not overwrite or erase. Make the entry directly in the gage book. Avoid recording of data elsewhere for late entry or trusting your memory. Always write by placing carbon paper below the first sheet so that a duplicate is prepared simultaneously.

6. If a gage is damaged for some reason, write those reasons under the "Remarks" column and inform the sub-engineer immediately.

7. While on duty, keep the gage book always with you.

8. If for any reason (e.g., sudden illness or other emergency) you are unable to read the gage, keep the spaces for that period blank and give a note under "Remarks" explaining the reason. If you ask some one else to read the gage during your absence, clearly state this under "Remarks" and also inform the sub-engineer.

9. At the end of each week, sign the weekly record and mail the top copy to the sub-engineer.

Water Level Recorder

The Stevens A-71 recorder is a strip-chart recorder which provides a continuous record of gage height. Figure 7 shows a trace of gage height, typical of a natural stream during high flows.

General instructions for installation and operation are provided by Leupold and Stevens, Inc., with the instrument. The normal inspection procedure is:

- check float for leakage;
- check water surface elevation on the outside staff gage with the recorded elevation on the chart and the elevation indicated on the tape against the index bracket;
- change recorder chart;
- fill recorder pen;
- wind, set, regulate, and maintain the clock; and
- inspect and clean the well for sediment deposition.

A list of questions is provided below. These questions should be typed and placed as an inspection book in the instrument shelter. The visiting party should mark these questions before leaving the gaging station.

1. Was the recorder working properly when you reached the station?

2. Did you mark pen lines on the chart by raising the float and note the following information on the chart?

    - outside staff gage reading

    - inside index bracket reading

    - recorded gage height

    - time indicated by recorder chart

    - time on your watch

3. Did you remove the old chart and put on a new chart?

4. If you removed an old chart, did you provide the information listed in Item 2 above at the end?

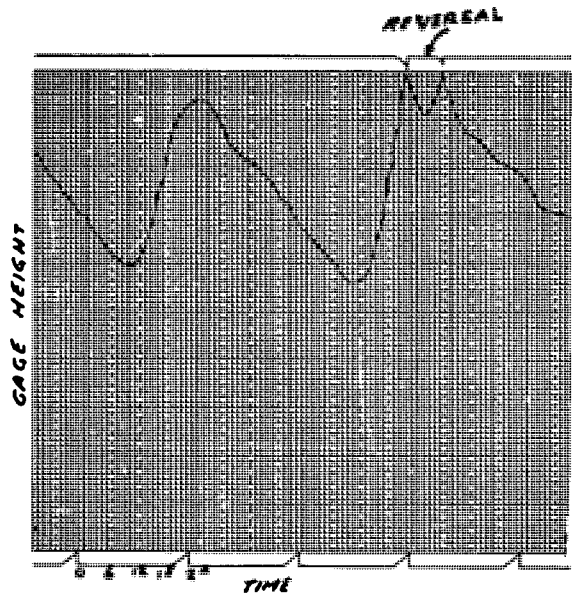


Figure 7 : Recorder Chart Showing Time Markers and Reversal Indication

5. If you installed a new chart, did you provide the information listed in Item 2 above at the start and mark the chart by raising the float?

6. If you did not remove the chart, did you correct the pen setting, both for time and gage height differences?

7. Did you wind the clock and regulate it?

8. Did you fill the pen?

9. Did you check that the reversal on the chart occurs at the appropriate limit?

10. Did you make sure the pen is marking, the chart is placed correctly, the setscrew on the drum is fastened, the knurled screws clamping the pulley are tight and the recorder is working properly before leaving the station?

11. Have you written reasons for non-functioning of the recorder if it was not functioning at the time of your arrival at the station?

Some important steps to ensure a continuous operation of the recorder are given below.

Clock: Check the negator spring and wind if necessary.

Pulley: The float pulley is clamped to the shaft by two knurled screws marked "R" and "L" (Figure 3). Use both hands and turn the screws in opposite directions simultaneously when clamping or releasing the float pulley.

Placement of Chart: To place a new chart, slacken the paper (old chart) and take out the writing plate behind the chart drum. Lift out the supply roll, remove the knurled washernut from the end opposite the flange, and remove the old core. Slip the new chart on the supply cylinder, flush end toward the flange, and set the knurled washernut tightly. Place the supply roll in its bearings, flange to the left.

There is a small shaft close to the base, below the writing plate, with a knurled disk on its right end marked with the letters "A" and "R". Pull this disk to the right and turn it until the letter "R" (for Replace) is down. This depresses the friction roller, freeing it from the chart drum. If the letters on the disk are not visible, pull out the disk and turn it clockwise (facing the right end of the recorder) to a stop for R and counterclockwise to a stop for A.

Crease the chart about 3/4 inches from the edge so that it stands out radially from the supply roll. Pull the chart towards you, guiding the chart underneath the chart drum.

The creased edge should pass between the chart drum and the friction roller and pass over the top to the take-up roller.

Hold the end of the chart about one inch beyond the take-up roller with the left edge of the chart abutting against and square with the flange of the take-up roller.

Press the half-tube clamp on to the take-up roller, binding the chart to the roller. After the chart is in position, turn the take-up roller at least one full turn while holding the chart taut with the supply roll.

Replace the writing plate. While holding the take-up roller, turn the supply roll to make the paper tight. Push the lettered disk to the left to restore the friction roller to its operating position against the drum. The recorder cover will not close unless the disk is pushed all the way.

Time Adjustment of Chart: Mark a point on the chart on which it is desired to place the pen. Pull out the lettered disk and turn it until the letter A (Adjustment) is opposite to the index mark on the base. This frees the friction roller from the chart drum. The chart can now be turned forward by turning the take-up roller or backward by turning the supply roller by its knurled shaft end.

After correct adjustment has been obtained, push the lettered disk to the left to restore the friction roller to its operating position.

Removal of Chart: After writing necessary data/information on the chart, lift the pen. Pull the lettered disk to the right and turn it counter-clockwise to a stop. Run the chart forward until the graph is just beyond the front edge of the writing plate. Cut the chart with a knife using the edge of the writing plate as a guide. Lift the take-up roller out of its bearing and remove the chart.

Stylus: The stylus moves laterally across the width of the chart, at a right angle to the direction of chart feed. For the 1:6 scale, it traverses 5 feet across the 10-inch wide chart. It reverses at each margin of the chart to accommodate high or low stages. The reversals occur exactly 10 inches apart.

When setting a chart, make sure that the reversals coincide with the margins of the chart and the gage height increases with the rise of the float. If the reversal does not coincide, small adjustments should be made by setting pivot screws of the stylus or changing the lateral position of the pen by a set screw. Otherwise, adjust the position of the stylus to reverse exactly on the left margin line.

With the pen on the exact time of setting, loosen the knurled screws marked "R" and "L" on the float pulley. This releases the pulley and stylus can be moved. First move the

stylus between the margins to make sure the reversal positions are correct and also check that the trace is parallel to the lines indicating time. If not, recheck that the chart is properly fixed on the take-up roller. After this, move the stylus to a position corresponding to the required gage height value. Tighten the knurled screws. Now the stylus will trace the movement of the float. The gage height value should increase with the rise of the float.

General: All bearings and rubbing parts should be oiled once a year. Ball bearings have been oiled in the factory and this should suffice for 5 years. However, if the instrument is subjected to dust, all bearings should be cleaned and oiled frequently.

Chapter 4

DISCHARGE MEASUREMENTS

Discharge (streamflow) is defined as the volume rate of flow of water including any sediment or other solids that may be dissolved or mixed with it. The discharge is expressed in cubic feet per second (cfs or ft^3/s) or cubic meters per second (cms or m^3/s) for large streams and liter per second (l/s) for small streams.

Discharge measurements will be required to establish stage-discharge relationships at gaging stations in the canal system or to check the empirical discharge formulas of control structures. Initially, frequent measurements will be necessary to establish the relationships. Later, measurements will be made to verify the relationships. There are a number of methods available to make discharge measurements depending upon the instrumentation and procedures of measurement. The method of discharge measurements discussed in this manual is limited to wading and boat equipment using the conventional current meter method. However, a brief discussion on discharge measurements by the indirect method using a control structure is also provided.

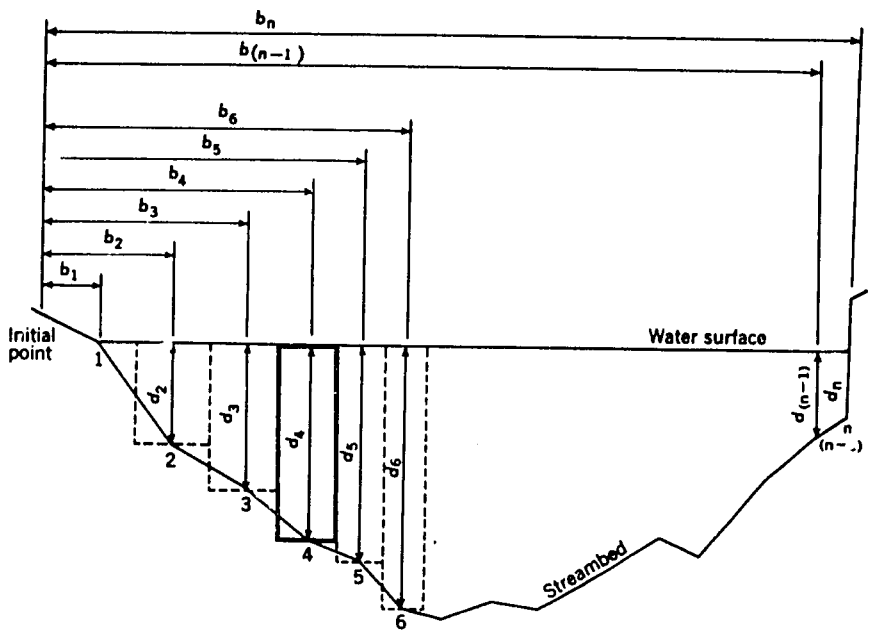
Current Meter Method

A current meter measurement is the summation of the products of the partial areas of the streamflow cross section and their respective average velocities. This direct method of discharge measurement also is called the velocity-area method.

General

In the velocity-area method, mid-section computational procedure should be used to compute the partial areas (see Figure 8). Overall accuracy of the measurement is generally increased by increasing the number of partial cross sections. About 25 to 30 partial cross sections are adequate, depending on the variability and complexity of the cross sectional shape and flow patterns. Partial cross sections should be spaced so that no partial section contains more than 10 percent of the total flow and ideally about 5 percent of the flow. However, the minimum width of the partial section should not be less than one foot for a Price AA type current meter and 0.5 foot for a pygmy current meter.

The depths and velocities should be observed at selected verticals. A partial section should extend laterally from half the distance from the preceding current meter location to half the distance to the next, and vertically from the water surface to the sounded bed (Figure 8). The following equations show the computations.



EXPLANATION

1, 2, 3, ... n	Observation points
$b_1, b_2, b_3, \ldots\ldots b_n$	Distance, in feet, from the initial point to the observation point
$d_1, d_2, d_3, \ldots\ldots d_n$	Depth of water, in feet, at the observation point
Dashed lines	Boundary of partial sections; one heavily outlined discussed in text

Figure 8 : Definition Sketch of Midsection Method of Computing Cross-Section
: Area for Discharge Measurements

$$q_i = [(bi-b_{i-1})/2 + (b_{i+1}-bi)/2]di \times vi$$
$$= [(b_{i+1} - b_{i-1})/2]di \times vi$$

in which

q_i = discharge through partial section "$_i$"
N_i = mean velocity at vertical "$_i$"
di = depth of water at vertical "$_i$"
b_{i+1} = distance from initial reference point to next vertical
b_{i-1} = distance from initial reference point to preceding vertical
bi = distance from initial reference point to vertical "$_i$"

For current meter measurements by wading or using a boat outfit, the procedures of measuring the width, depth, and velocity are nearly the same. A brief description of the instruments used for these measurements and the procedure of measurements is provided below.

Instruments and Equipment

The instruments and equipment used for current meter measurements can be categorized as: current meters, sounding equipment, width-measuring equipment, equipment assemblies, and miscellaneous equipment.

Current Meters: A current meter is an instrument used to measure the velocity of flowing water. The principle of operation is based on the proportionality between the velocity of the water and the resulting angular velocity of the meter rotor. By placing a current meter at a point in a stream and counting the number of revolutions of the rotor during a measured interval of time, the velocity of water at that point is determined. In order to determine the velocity of the water from the revolutions of the rotor of a current meter in a measured time period, a pre-established relationship is available in the form of equation(s) and as a rating table. A new current meter is factory-rated and comes with a rating table.

As discussed in the subsequent sections, the current meter may be suspended by a rod or a cable for velocity measurements. It has been determined during the calibration of the current meters that the suspension by rod or cable does not affect the measured velocity.

A Price AA and a Pygmy are shown on Figure 9. The Price AA current meter is a vertical-axis current meter with major components including yoke, tail piece, bucket wheel, bucket wheel hub, shaft, pivot, pivot bearing, gears, contact chamber, and binding posts (see Figure 10). The rotor of the current meter is 5 inches in diameter and 2 inches high with six cone-shaped cups mounted on a stainless steel shaft. The pivot bearing supports the rotor shaft. The contact chamber houses both the upper part of the shaft and two slender bronze wires (one for single contact and the other for penta

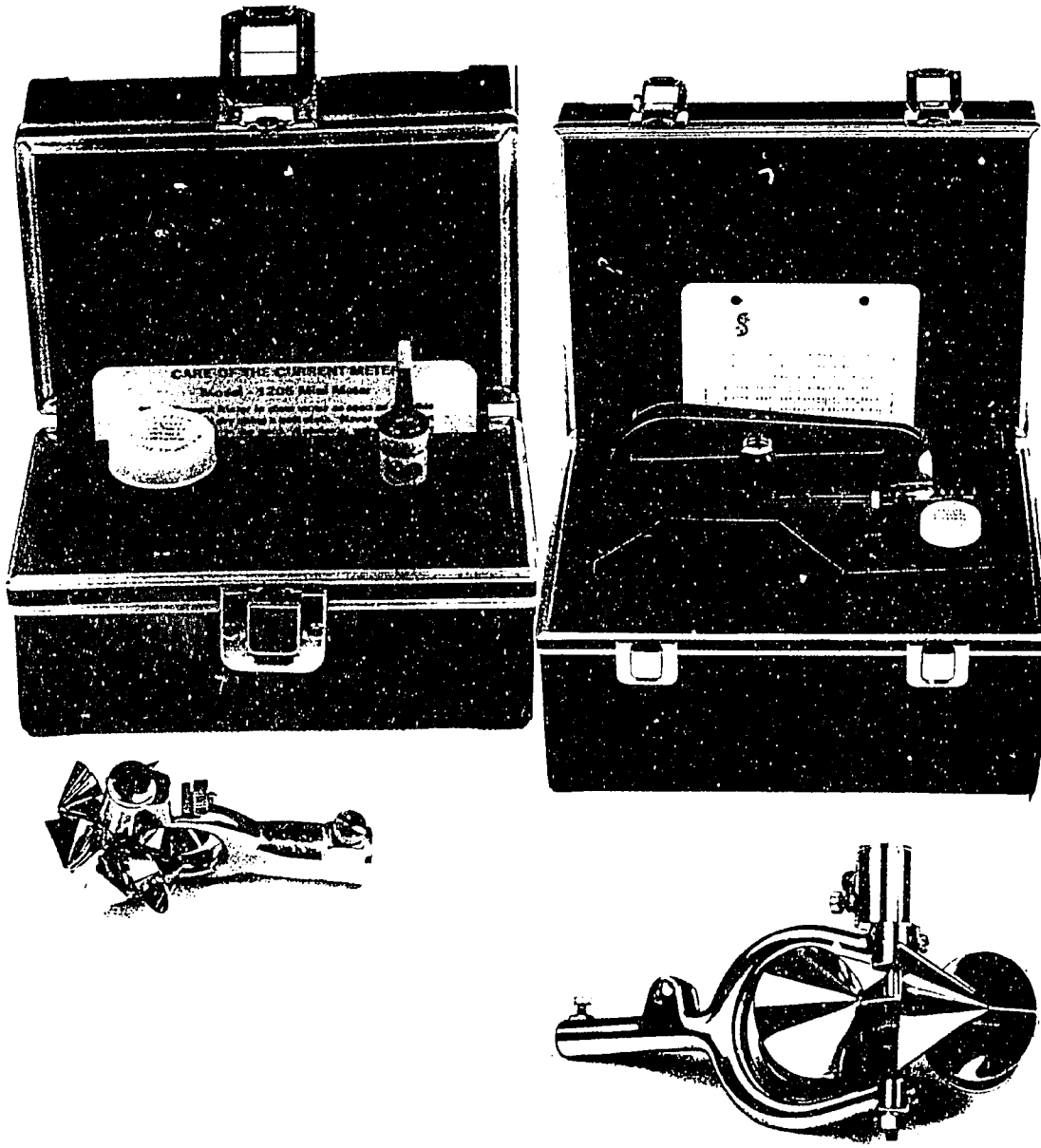
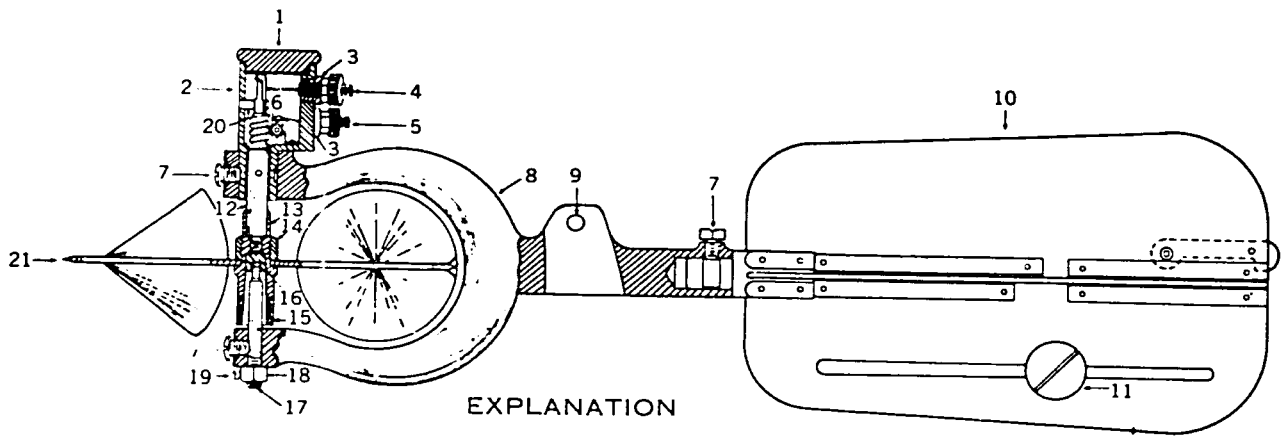


Figure 9 : Current Meters



EXPLANATION

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

Figure 10 : Price AA Current Meter Assembly

contact) attached to the binding posts. For single contact, with each revolution an eccentric contact on the shaft makes contact with a bead of solder at the end of the bronze wire. For penta contact (lower binding post), with a special reduction gear, a contact is made each time the rotor makes five revolutions. This type of meter can measure velocities in the range of 0.1 to 20.0 feet per second.

The pygmy meter is two-fifths as large as the standard meter and has neither a tail piece nor a pentagear. The contact chamber is an integral part of the yoke of the meter. It can be suspended with a wading rod only. The meter is used in shallow depths and can measure velocities in the range of 0.05 to 3.0 feet per second.

To insure reliable observations of velocity, the current meter should be kept in good condition. The sub-engineer making flow measurements should examine the current meter before and after each measurement with regard to the following details.

1. **Balancing with Cable Suspension.** In order to balance the assembled current meter, suspend it from a hanger, align the tail piece in such a manner that the balancing weight is vertically below the center line of the meter, and then move the balance weight along the slot in the vane of the tail piece to a position that meter will balance freely in a horizontal position. The wire used for electrical circuit should be so flexible that it will not interfere with the free swinging and balancing of the meter. The length of the wire should be such that it will not touch the bucket wheel when the meter is in a horizontal position.

   In wading measurement, the meter should be assembled with the axis of the bucket wheel parallel to the rod. Care should be taken to hold the rod in an exactly vertical position while making a velocity measurement.

   Care should also be taken with the rod suspension as well as with the cable suspension to eliminate all possibility of interference with the rotation of the bucket wheel by the connecting wire leading to the contact chamber.

2. **Shaft Alignment:** The shaft of a current meter may be bent (i) if the meter receives a sharp blow, (ii) if the bucket wheel is raised too forcibly, or (iii) if an attempt is made to unscrew the cap of the contact chamber when the bucket wheel is in the raised position. When raising the bucket wheel from the pivot by means of the bucket raising nut, the cups should always be held stationary and the bucket-raising nut turned. The bucket wheel should never be raised from the pivot by spinning the wheel with the bucket raising nut held stationary. This may cause the shaft to bend or the yoke to become sprung. Before making a flow measurement, spin the bucket-wheel slowly and watch the movement of the metal frame to which the cups are fastened.

A faulty movement indicates either the bucket-wheel or the shaft is bent. A meter with a bent shaft should not be used.

3. **Spin Test.** The spin test is a common method for determining the condition of a meter. In making a spin test, the meter should be held with the shaft in a true vertical position and the bucket wheel protected from air currents. The bucket wheel is then given a quick turn to start it spinning. As the rotating bucket wheel nears the stopping point, carefully note whether the stop is abrupt or gradual. A meter spinning for about 1.5 minutes with a gradual stop is in good condition. If the rotor stops abruptly, the cause of trouble should be sought and corrected before using the meter. The duration of spin before and after a measurement should be recorded. If the spin is one minute, the meter can be used for high velocities without introducing appreciable error. For spin less than one minute, the meter should be repaired. During the measurements, the meter should periodically be observed when it is out of water to be sure that the rotor spins freely.

4. **Pivot and Bearing.** After every discharge measurement, the pivot and all the bearing surfaces should be cleaned, dried, and oiled. A pivot having a rough point should be replaced. The pivot requires replacement more often than the other parts and should be examined after each measurement.

   The pivot and pivot bearing should be kept separated except during measurements, by use of the raising nut provided in Price AA meters and by replacing the pivot with a brass plug in the pygmy meter.

5. **Oiling of Current Meters.** Take the following steps when oiling current meter.

   a. Release raising nut, do not use force to tighten the raising nut at the raised or lower limits.

   b. Release the set screws in the yoke, holding the contact chamber and pivot.

   c. Carefully remove the contact chamber from the yoke. Do not remove the cup at this stage.

   d. Remove the pivot from the yoke.

   e. Clean and dry the air pocket and pivot bearing with a stick covered with a soft cloth.

f. Clean the pivot hole in the yoke.

g. Clean and dry the acme threads and shaft.

h. Inspect the pivot and pivot bearing, replace the pivot if worn or pitted.

i. Remove the cap of the contact chamber, shake out any water that may be trapped within the chamber, and occasionally clean the chamber thoroughly by allowing hot water to flow into it under pressure

j. Clean and dry the inside of the chamber, using a cloth-covered stick where required. Clean the hole in the bearing from the bottom because this will not bend the wires or affect their adjustments. Cleaning the hole from the top may result in bending the contact wires.

k. Lightly, oil the shaft, the pivot bearing, the pivot hole in the yoke and the pivot.

l. At this stage, the meter has been oiled. Now assemble the meter first by replacing the pivot and tightening the set screw that holds it in place. Make sure that the pivot lock nut bears against the yoke, and that the set screw bears against the flattened portion of the pivot. Fit the contact chamber over the end of the shaft and into its hole in the upper limb of the yoke. Do this slowly and carefully without applying much force, otherwise the penta gear or the shaft may be damaged. Align the binding posts properly and tighten the set screw holding the contact chamber in place. Check the contact wires to ensure that the adjustments of both contact wires are correct. Replace the cap and move the wheel and hub assembly up and down to be sure that there is no excessive movement. The movement should be adjusted by the pivot lock nut. The correct adjustment is achieved when the pivot lock nut is given a quarter turn from a position where there is no movement of the hub assembly and the shaft is tight against the cap of the contact chamber.

m. After oiling and reassembly, check spin. If not to be used immediately, separate the pivot and bearing.

6. **Rating of Current Meter:** A meter should be repaired and/or re-rated (a) after general use of about one year or after about 150 measurements, even though the bearings may still be in good condition and the cups relatively smooth, (b) at any time that the cumulative small dents and minor damages

cause it to be in "rough" or "poor" condition, and (c) after any major damage and repair.

The rating of a current meter is a relationship between the angular velocity of the rotor and the velocity of water that spins the rotor. The rating is established by first towing the meter at a constant velocity through a long water-filled tank, and then relating the linear and rotational velocities of the current meter. The tank is generally rectangular, about 450 feet long, 12 feet wide, and 12 feet deep. Circular tanks also are in use. An electrically driven car rides on rails extending the length of the tank. The car carries the current meter at a constant rate through the still water in the tank. The average velocity of the moving car is determined for each run by making an independent measurement of the distance it travels during the time that the revolutions of the rotor are counted. The distance, time, and revolutions are recorded on a strip-chart. Eight pairs of runs are usually made for each current meter. A pair of runs consists of two traverses of the tank, one in each direction, at the same speed. At least 15 minutes should elapse after each run before starting another to allow the surge to settle down. The minimum velocity is limited by practical considerations in running the car. The maximum velocities for Price AA and Pygmy meters are approximately 10 and 5 feet per second. Figure 11 shows a standard USGS rating table.

Wading Rod. A conventional wading rod kit consists of a base plate, four 2-foot graduated sections in 0.1-foot increments (lower section to fit the base plate), an adjustable sliding support capable of holding Price AA and Pygmy current meters, and a flexible two-conductor wire with one end having a two-hole connector for the head set and the other end suitable for connecting the current meter to the rod. Figure 12 shows the parts of the wading rod and assembled rods holding Price AA and Pygmy current meters.

Sounding Reel. A sounding reel has a drum for winding the sounding cable, a crank and ratchet for raising and lowering the weight or holding it in any desired position, and a depth indicator. The sounding reel provided under this project is shown on Figure 13. The reel is made of aluminum, brass, bronze, and stainless steel. The reverselay two-

DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY
Water Resources Division
RATING TABLE FOR TYPE M ...CURRENT METER NO. 3684
SUSPENSION Rod RATED February 16, 1962

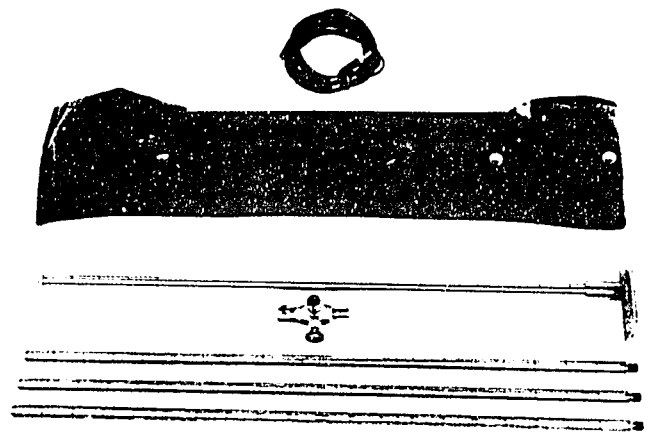
INDEX 377-376
EQUATIONS. V = 2.250N + 0.030(2.280)+2.604N + 0.040
Limits of Actual Rating. 0.25 to .8.0 feet per sec
at Bureau of Standards, Wash., D.C. Condition of Meter New

NO. 3684

Time in Seconds	VELOCITY IN FEET PER SECOND — Revolutions 3	5	7	10	15	20	25	30	40	Time in Seconds
40	.199	.311	.424	.592	.874	1.15	1.44	1.72	2.28	40
41	.195	.304	.414	.579	.853	1.13	1.40	1.68	2.23	41
42	.191	.298	.405	.566	.834	1.10	1.37	1.64	2.17	42
43	.187	.292	.396	.553	.815	1.08	1.34	1.60	2.12	43
44	.183	.286	.388	.541	.797	1.05	1.31	1.56	2.08	44
45	.180	.280	.380	.530	.780	1.03	1.28	1.53	2.03	45
46	.177	.275	.372	.519	.764	1.01	1.25	1.50	1.99	46
47	.174	.269	.365	.509	.748	.987	1.23	1.47	1.94	47
48	.171	.264	.358	.499	.733	.968	1.20	1.44	1.91	48
49	.168	.260	.351	.489	.719	.948	1.18	1.41	1.87	49
50	.165	.255	.345	.480	.705	.930	1.15	1.38	1.83	50
51	.162	.251	.339	.471	.692	.912	1.13	1.35	1.79	51
52	.160	.246	.333	.463	.679	.895	1.11	1.33	1.76	52
53	.157	.242	.327	.455	.667	.879	1.09	1.30	1.73	53
54	.155	.238	.322	.447	.655	.863	1.07	1.28	1.70	54
55	.153	.235	.316	.439	.644	.848	1.05	1.26	1.67	55
56	.151	.231	.311	.432	.633	.834	1.03	1.24	1.64	56
57	.148	.227	.306	.425	.622	.819	1.02	1.21	1.61	57
58	.146	.224	.302	.418	.612	.806	1.00	1.19	1.58	58
59	.144	.221	.297	.411	.602	.793	.983	1.17	1.56	59
60	.142	.218	.292	.405	.592	.780	.968	1.15	1.53	60
61	.141	.214	.288	.399	.583	.768	.952	1.14	1.51	61
62	.139	.211	.284	.393	.574	.756	.937	1.12	1.48	62
63	.137	.208	.280	.387	.566	.744	.923	1.10	1.46	63
64	.135	.206	.276	.382	.557	.733	.909	1.09	1.44	64
65	.134	.203	.272	.376	.549	.722	.895	1.07	1.41	65
66	.132	.200	.269	.371	.541	.712	.882	1.05	1.39	66
67	.131	.198	.265	.366	.534	.702	.870	1.04	1.37	67
68	.129	.195	.262	.361	.526	.692	.857	1.02	1.35	68
69	.128	.193	.258	.356	.515	.682	.845	1.01	1.33	69
70	.126	.191	.255	.351	.512	.673	.834	.994	1.32	70
	3	5	7	10	15	20	25	30	40	

Time in Seconds	VELOCITY IN FEET PER SECOND — Revolutions 50	60	80	100	150	200	250	300	350	Time in Seconds
40	2.84	3.40	4.52	5.64	8.44	11.24	14.04	16.84	19.64	40
41	2.77	3.32	4.41	5.50	8.24	10.97	13.70	16.43	19.16	41
42	2.71	3.24	4.31	5.37	8.04	10.71	13.37	16.04	18.71	42
43	2.64	3.17	4.21	5.25	7.85	10.46	13.06	15.67	18.27	43
44	2.59	3.09	4.11	5.13	7.68	10.22	12.77	15.31	17.86	44
45	2.53	3.03	4.02	5.02	7.51	10.00	12.48	14.97	17.46	45
46	2.47	2.96	3.94	4.91	7.34	9.78	12.21	14.65	17.08	46
47	2.42	2.90	3.85	4.81	7.19	9.57	11.95	14.34	16.72	47
48	2.37	2.84	3.77	4.71	7.04	9.37	11.71	14.04	16.37	48
49	2.33	2.78	3.70	4.61	6.90	9.18	11.47	13.75	16.04	49
50	2.28	2.73	3.62	4.52	6.76	9.00	11.24	13.48	15.72	50
51	2.24	2.68	3.55	4.43	6.63	8.82	11.02	13.22	15.41	51
52	2.19	2.62	3.49	4.35	6.50	8.66	10.81	12.96	15.12	52
53	2.15	2.58	3.42	4.27	6.38	8.49	10.61	12.72	14.83	53
54	2.11	2.53	3.36	4.19	6.26	8.34	10.41	12.48	14.56	54
55	2.07	2.48	3.30	4.11	6.15	8.19	10.22	12.26	14.29	55
56	2.04	2.44	3.24	4.04	6.04	8.04	10.04	12.04	14.04	56
57	2.00	2.40	3.18	3.97	5.93	7.90	9.86	11.83	13.79	57
58	1.97	2.36	3.13	3.90	5.83	7.76	9.70	11.63	13.56	58
59	1.94	2.32	3.08	3.84	5.73	7.63	9.53	11.43	13.33	59
60	1.91	2.28	3.03	3.77	5.64	7.51	9.37	11.24	13.11	60
61	1.87	2.24	2.98	3.71	5.55	7.38	9.22	11.06	12.89	61
62	1.84	2.21	2.93	3.65	5.46	7.27	9.07	10.88	12.69	62
63	1.82	2.17	2.88	3.60	5.37	7.15	8.93	10.71	12.48	63
64	1.79	2.14	2.84	3.54	5.29	7.04	8.79	10.54	12.29	64
65	1.76	2.11	2.80	3.49	5.21	6.93	8.66	10.38	12.10	65
66	1.73	2.08	2.76	3.43	5.13	6.83	8.52	10.22	11.92	66
67	1.71	2.04	2.71	3.38	5.05	6.73	8.40	10.07	11.74	67
68	1.68	2.02	2.68	3.33	4.98	6.63	8.28	9.92	11.57	68
69	1.66	1.99	2.64	3.29	4.91	6.53	8.16	9.78	11.40	69
70	1.64	1.96	2.60	3.24	4.84	6.44	8.04	9.64	11.24	70
	50	60	80	100	150	200	250	300	350	

Figure 11 : A Typical Current Meter Rating Table



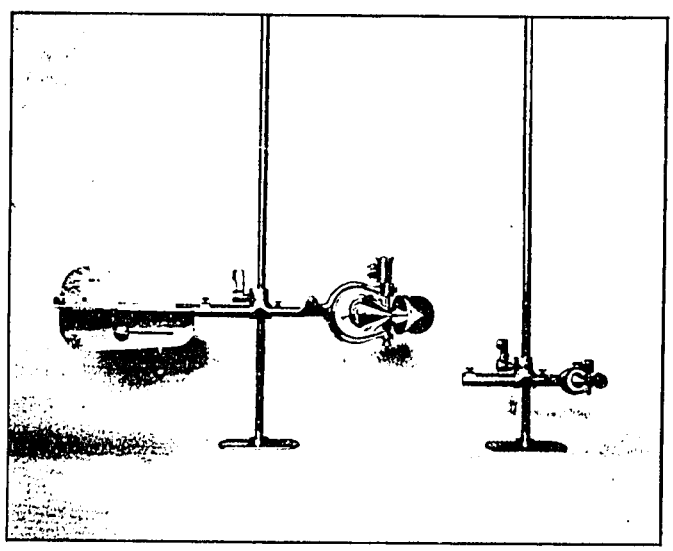


Figure 12 : Wading Rod Set

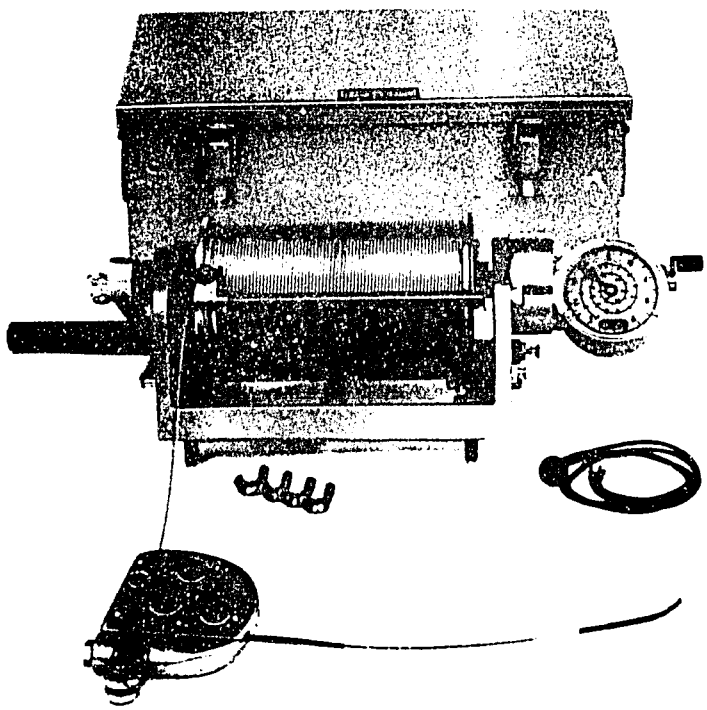


Figure 13 : Sounding Reel

conductor cable is of 0.10 inch diameter with a maximum load capacity of 100 pounds. The cable length is about 80 feet. The cable is connected to the meter through a "B" connector and a hanger strap. The current meter is supported on a hanger as shown on Figure 14.

Hanger. The hanger supports the current meter with its lower end fixed to a sounding weight and the upper end to the sounding cable through a connector. The hanger for boat measurements is 1/8-inch thick, 3/4-inch wide, and 1-foot long. It has a threaded hole for a 3/8-inch weight pin and a smooth 3/8-inch hole for the connector. Three holes 7/32-inch in diameter are at 4.9, 5.0, and 9.8 inches above the hole for the weight. The lower two holes are used for supporting the meter so that its horizontal axis is 0.5 foot from the bottom of the C-15 (upper hole) and C-30 (lower hole) sounding weights. The third hole keeps the horizontal axis of the meter 0.9 foot above the bottom of the C-50 weight. If the meter is supported in the middle hole with a C-50 weight, the distance is about 0.6 feet.

Sounding Weight. A Columbus-type sounding weight, C-50 (50 pounds) is used to suspend the current meter. The weight maintains a steady position in flowing water. The weight is streamlined, cast of antimonial lead and has removable aluminum-alloy tail vanes. The shape of the slot for the hanger permits the hanger to tip 15° forward and 5° backward from the vertical. This limitation in the angles prevents the current meter from striking the weight.

Tag Line. A tag line is used for measuring the distance from an initial point on the river (canal) bank to any point in a cross section across the river. Two types of tag lines are shown on Figure 15. Light duty tag line is 300 feet in length and is made of 0.04-inch diameter stainless steel cable wound on a heavy plastic reel and mounted on a hardwood stake. The tag line is tagged with a heavy brass bead every 2 feet for the first 50 feet, every 5 feet from 50 to 200 feet, and every 10 feet from 200 to 300 feet.

Heavy duty tag line is 500-foot Lee Au-type tag line wound on an 8-inch diameter open reel with opposing handle. The cable is 1/16-inch diameter stranded cable and is marked with brass beads every 2 feet for the first 50 feet, every 5 feet from 50 to 200 feet, every 10 feet from 200 to 300 feet, and every 50 feet from 300 to 500 feet. The cable has a heavy duty hook on both ends for attaching to trees or other sturdy objects.

Headset. The revolutions of the meter rotor during the observation of velocity are counted through an electric circuit that is closed each time the contact wire touches the single or penta eccentric of the current meter. A battery and headphone are parts of this circuit, and a click is heard in the headphone each time the circuit is closed. The

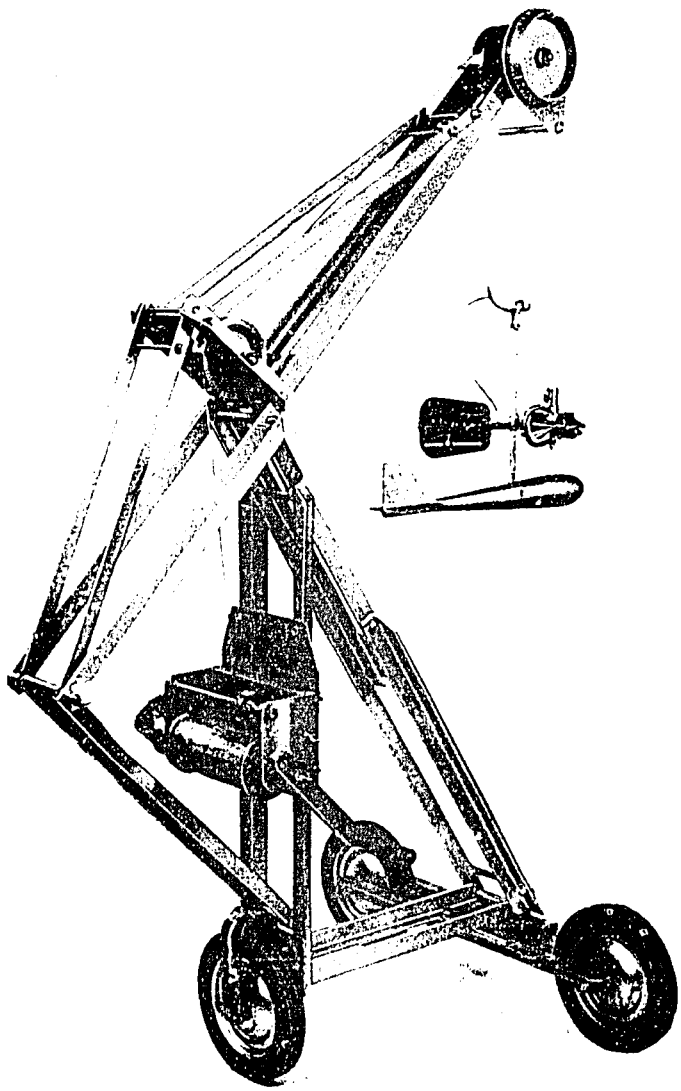


Figure 14 : Current Meter Assembly With Sounding Weight (Crane or Boat)

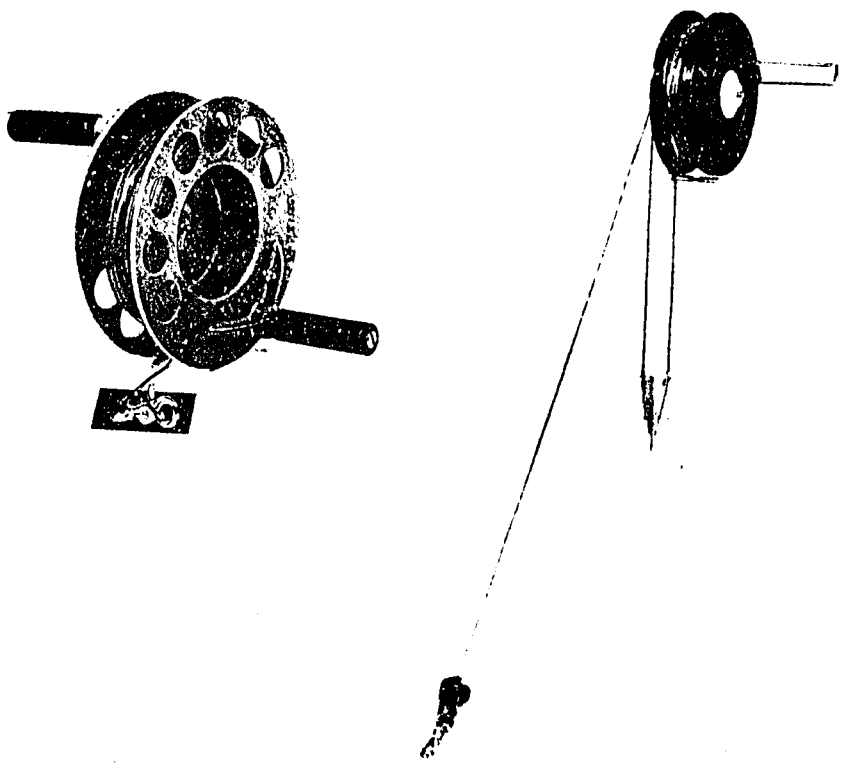


Figure 15 : Tag Lines

headphone provided under this project is shown on Figure 16. It consists of a flexible headband, a built-in compartment for a 1.5 volt dry cell battery,
and a flexible wire with a two-pole connector for connecting to two-conductor wire from a current meter mounted on a wading rod or from a sounding rail.

Stop Watch. A stop watch is used to determine the time in which a specific number of revolutions of the meter rotor are counted. A stop watch is shown on Figure 17. It is an electronic digital stop watch reading to .01 second. The battery life of this stop watch is about two years.

Wader/Hip Boots. Waders or boots are needed when wading measurements are made.

Boat Improvisement Set. Discharge measurements by boat require special equipment to hold the boat at a desired location and to suspended the current meter. This type of equipment is shown on Figure 18.

A crosspiece reaching across the boat is clamped to the sides of the boat and a boom attached to the center of the crosspiece extends out over the bow. The crosspiece is equipped with a guide sheave and clamp arrangements at each end to attach the boat to the tag line and make it possible to slide the boat along the tag line from one station to the next. A small rope can be attached to these clamps so that in an emergency a tug on the rope will release the boat from the tag line. The crosspiece also has a clamp that prevents lateral movement of the boat along the tag line when readings are being taken.

The boom consists of two structural aluminum channels, one telescoped within the other to permit adjustment in length. The boom is equipped with a reel plate on one end and a sheave over which the meter cable passes on the other end. The sheave end of the boom is designed so that by adding a cable clip to the sounding cable, a short distance above the connector, the sheave end can be retracted when the meter is to be raised out of the water. The raised meter is easy to clean and is in a convenient position when not being operated.

Boat. Flat bottom, fibre glass, 16-foot long and 6-foot wide boats are used to make discharge measurements.

Measurement of Velocity

The method of making a current meter measurement at a canal cross section requires determination of the mean velocity in each of the selected verticals. The mean velocity should be determined by the two-point or six-tenths depth methods discussed below.

Figure 16 : Headphone Set

Figure 17 : Stop Watch

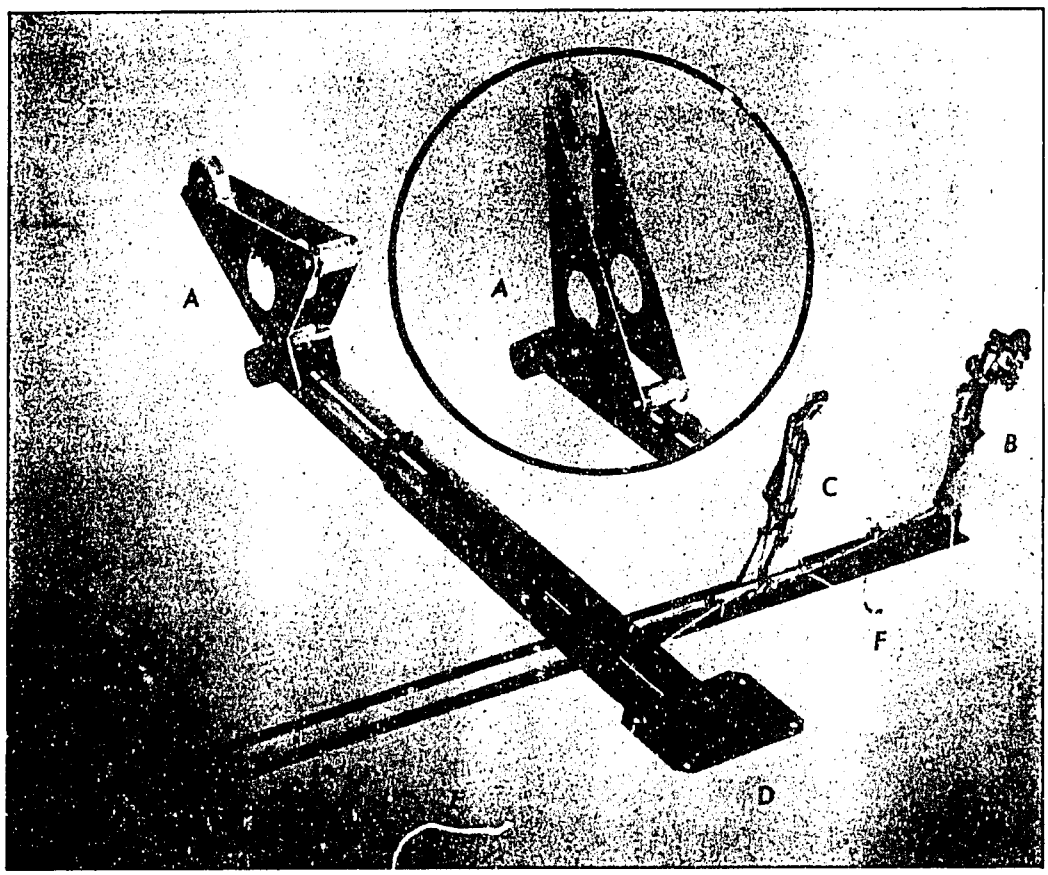


Figure 18 : Boat Improvisement Set

Two-Point Method. This method is generally used by the United States Geological Survey (USGS) and, on the average, gives mean velocity that is within one percent of the true mean velocity in a vertical. The velocity observations are made at 0.2 and 0.8 of the depth below the surface. The average of these two observations is taken as the mean in the vertical.

In some cases, the verticals velocity distribution curve may have been distorted by submerged objects (aquatic growth, etc.) or by turbulence immediately downstream from a control structure. As a rule, such locations should be avoided for a discharge measurements. However, if such a cross section has to be used, the two-point method will not give a reliable value of the mean velocity in the vertical. In these cases, an additional velocity observation should be made at 0.6 of the depth. The mean velocity should be computed by averaging the 0.2- and 0.8-depth observations and then averaging that result with the 0.6-depth observation. A rough criterion for whether or not the velocities of the 0.2 and 0.8 depths are adequate to determine mean velocity, is that the 0.2-depth velocity should be greater than the 0.8-depth velocity but less than twice as great.

Six-Tenths Depth Method. In this method, the velocity in a vertical is observed at 0.6 of the depth below the surface and is taken as the mean velocity in the vertical. This method should be used in shallow depth canals while wading or where the distance between the meter and the sounding weight does not permit placing the meter at 0.8 of the depth.

Limitations. The two-point method should be used for depths greater than 1.5 feet when wading and greater than 3.0 feet when making a boat measurement using a C-50 weight with the current meter suspended at a distance of 0.6 feet above the bottom of the weight.

The USGS recommends a minimum depth of 2.5 feet for the two-point method when wading using a Price AA current meter and 1.5 feet when wading using a Pygmy current meter. For reasonably accurate results, these limits can be relaxed and the two-point method may be used for a depth of 1.5 feet and more with a Price AA current meter and a depth of 1.0 feet and more with a Pygmy current meter.

The 0.6-depth method should be used for the depth between 1.0 and 1.5 feet for the Price AA current meter and between 0.5 and 1.0 feet for the Pygmy current meter. In a cable-suspended current meter, the limiting depth for the 0.6-depth method is about 1.5 feet if the horizontal axis of the meter is about 0.6 feet above the bottom of the weight. If the axis of the meter is 0.9 foot, the limiting depths for the two-point and 0.6-depth methods are about 4.5 and 2.3 feet.

In certain cases, if the two-point and 0.6-depth methods cannot be used because of shallow depths, the velocity may be observed at a specified depth and the following

coefficients may be used to obtain the mean velocity (that is, mean velocity = observed velocity x coefficient).

Observation Depth/Total Depth	Coefficient
.05	0.862
.10	0.862
.20	0.870
.30	0.885
.40	0.903
.50	0.935

Measurement of Width

The distance to any point along the tag line should be measured from an initial point on the bank from where the measurement is started. However, very often, it is convenient to indicate the distance of each vertical with respect to the zero of the tag line. The water edge at the starting bank need not to correspond to the zero of the tag line. The total width is the difference between the readings at the water edges on the two banks.

Measurement of Depth

The depth at each vertical should be measured by a wading rod or a sounding weight suspended by a cable from a boat.

Measurement of Discharge

The first step is to select a measurement cross section of desirable qualities. The general considerations in selecting a cross section are:

1. A straight reach with streamlines parallel to each other.

2. A relatively uniform stream bed and free of aquatic growth.

3. Relatively uniform flow, free of eddies, slack water, and excessive turbulence.

4. A measuring section relatively close to the gage.

5. For wading measurements, velocities greater than 0.5 feet per second and depths greater than 0.5 feet.

It is often impossible to meet all of the above criteria. In that case, the sub-engineer must exercise his judgement in selecting the best of the available sites or seek the advice of the engineer.

The procedure for wading and boat measurements and precautions during the measurement are discussed below.

Wading Measurement. This type of measurement is preferred for shallow and relatively slow moving streams because this affords a much better selection of available cross sections and allows for elimination of problems presented by bed roughness, horizontal flow angles, and poor flow conditions. The limits of wading are set by safety considerations. As a "rule-of-thumb," wading can be performed if maximum flow per unit width is no more than 8 to 12 cubic feet per second per foot (cps/ft) depending upon the individual.

As stated earlier under the sub-section entitled "Measurement of Velocity", the USGS recommends a minimum depth of 2.5 feet for the two-point method when using the Price AA current meter. However, for the purpose of this manual, the following guidelines are provided because some minors may be shallow.

VELOCITY CRITERIA FOR WADING

Depth	Meter	Velocity	Velocity Method
1.5 or more	Price AA	No restrictions	.2, .8
1.0 to 1.5	Pygmy	Velocity < 2.5 fps	.2, .8
1.0 to 1.5	Price AA	No restrictions	0.6
0.5 to 1.0	Pygmy	Velocity < 2.5 fps	0.6

Before making a wading measurement, canal cross sections in the vicinity of the gage should be examined and one with a uniform bed, smooth flow and no aquatic growth should be selected. The equipment needed for this type of measurement is listed below.

1. Tag line

2. Wading rod set

3. Price AA and/or Pygmy current meter with at least one extra pivot and rating table in a meter carrying case

4. Stop watch

5. Headphone set with lead wires

6. Waders

7. Miscellaneous tools such as screw driver, cutting pliers, metallic tape, insulation tape, meter oil, etc.

8. Notebook and pencil

9. Thermometer

10. Keys for the recorder cabin, if there is one

After selection of the cross section, the sub-engineer should proceed as follows (assuming Price AA current meters will be used).

1. Stretch the tag line perpendicular to the flow and fix it properly at both banks so that it does not get loose during the observation. The tag line should be about one to two feet above the surface of the water in the middle of the canal.

2. Fix the wading rod sections properly, with base plate and slider. Do not use pliers or wrenches for tightening or loosening. During the measurement, the base plate or some section may become loose. Check the base plate and section frequently during the measurement and tighten if necessary.

3. Take out the current meter from the meter carrying case. Joint the two tail pieces and fix on one end of the slider on the wading rod. Fix the current meter on the opposite end and tighten the set-screws. Make sure that the vertical piece of the tail, the yoke of the current meter and the wading rod are properly aligned (see Figure 12).

4. Unlock the "raising nut" of the meter and check the spin.

5. Connect the headphones to the current meter through a double-conductor lead wire. One connection should be made with the contact post and the other with the body of the current meter.

6. If the connections are properly made, a revolution of the meter should give a "click" in the headphone. If there is no "click," check first that the slender bronze wire attached to the binding post of the meter touches the eccentric contact on the shaft during a revolution, adjust the wire to ensure a contact. If the adjustment of the wire is okay, check your headphone. This should be done by making contact between two wires of the double-conductor lead wire.

7. Take out the measurement form and write down the name of the station, the date, the party's name, the current meter number, etc., as shown on figure 19.

8. If it is a recording station, mark the recorder as shown on Figure 20, and write down the information on the measurement note. Clean the sediment prior to measurement, if needed.

9. Record the starting time, the edge of water with references to tag line beads, and the bank from which the measurement is started (left or right, looking downstream).

10. Decide the number of verticals at which the depth and velocity measurements will be made, based on the criteria discussed previously.

11. Place the wading rod in a vertical position with the bucket wheel of the meter facing upstream, at the first selected vertical, and observe the depth of water. Depending upon the depth, make velocity observations by two-point or six-tenths depth method based on the criteria mentioned earlier. However, if the Price AA current meter is being used based on the average depth criteria, do not change to the Pygmy meter for a shallower depths at some sections. The Price AA meter can be used at depths as shallow as 0.5 foot.

12. Observe the number of revolutions and the time interval according to the rating table for the current meter (see Figure 11). The time interval should be from 40 to 70 and the number of revolutions should be any value from the figures of 3, 5, 7, 10, 15, 20, 25, 30, 40, 50, 60, 80, 100, 150, 200, 250, 300, 350. This facilitates finding the velocities directly from the rating table.

13. Record the data according to the specimen on Figure 19.

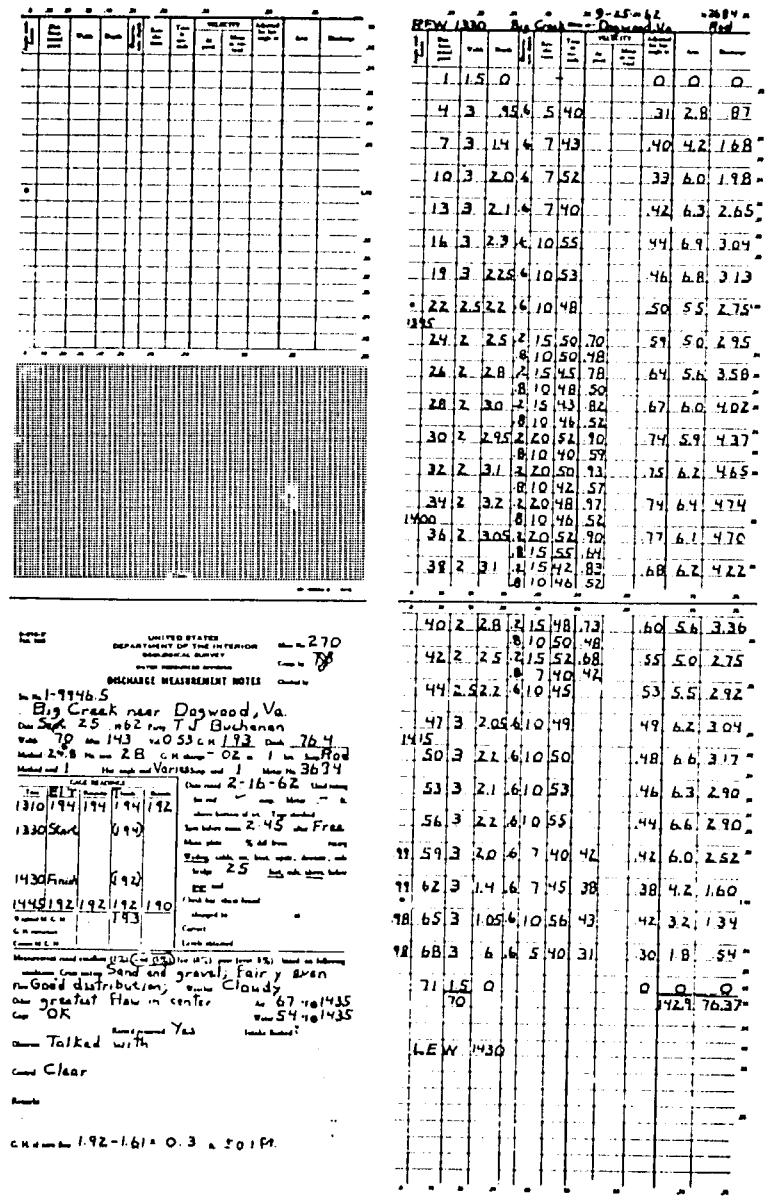


Figure 19 : Computation Notes of Current Meter

Measurement by Midsection Method

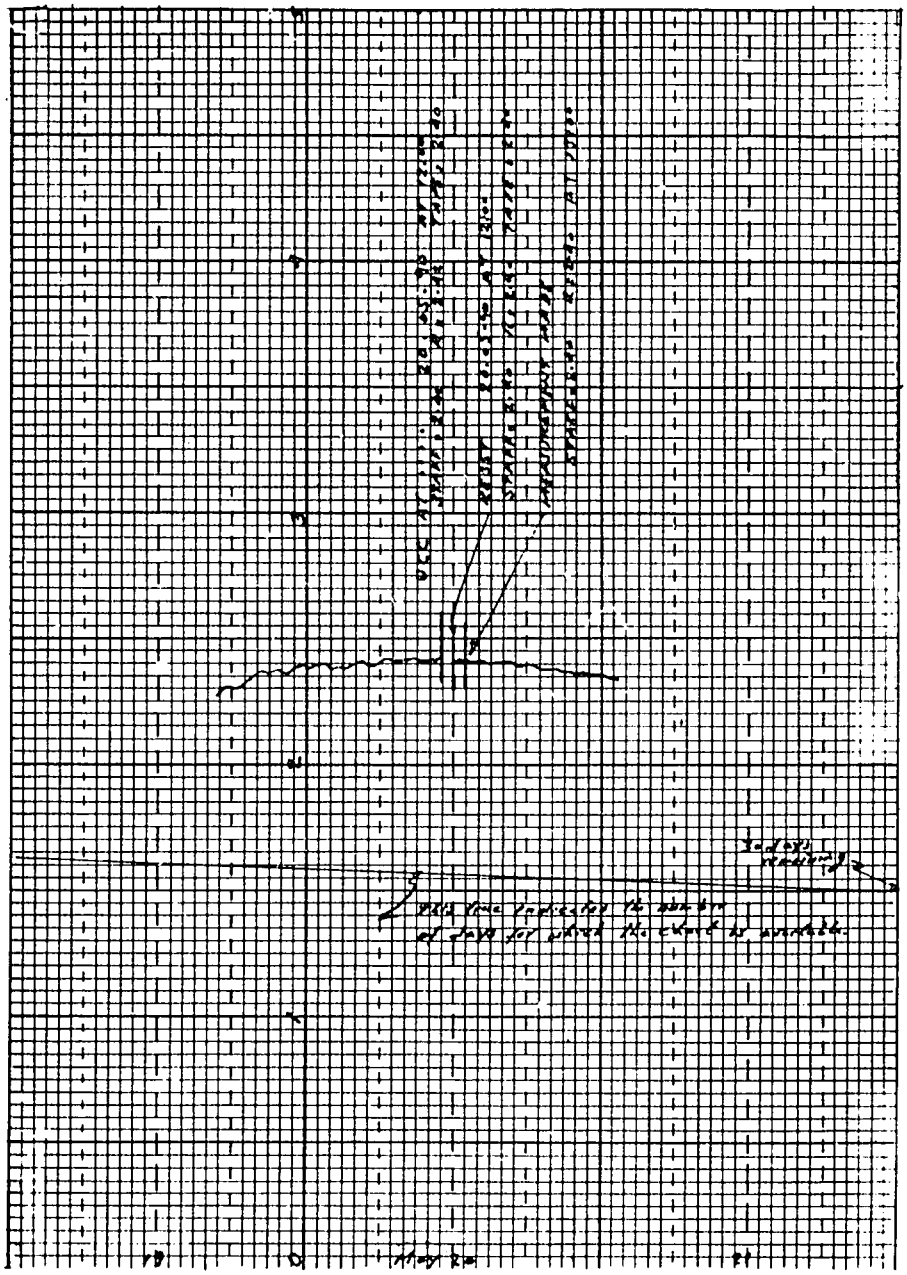


Figure 20 : Recorder Chart Indicating "Checking" at the Time of Measurement

14. Use waders if the water is cold, dirty or you feel like wearing these. Any uneasiness during the measurement will affect the accuracy of the measurements.

15. During observation, stand in a position that least affects the velocity of water passing the current meter. This position is usually obtained by facing the bank, with the water flowing against the side of the leg, standing about half a foot downstream from the tag line and about 1.5 feet from the wading rod (see Figure 21). Care must be taken to keep the meter always pointing upstream and the rod in a vertical position.

16. In some cases, it may not be possible to stretch the tag line perpendicular to the flow or at some verticals, the flow may not be perpendicular. In these cases, the velocity measured by the current meter should be multiplied by the cosine of the horizontal angle to determine the velocity component normal to the tag line. A template is printed on the measurement form as a series of marked points with values of the cosine of the horizontal angle. By orienting the measurement form or the clipboard with the form, with the direction of the flow and the tag line, the cosine value can be determined (see Figure 22).

17. Record the distance along the tag line, the depth, and the velocities at each vertical properly.

18. If the velocity between the edge of the water on one or both banks and the first or last vertical is not zero, estimate this velocity as a percent of the first or last vertical. The area representing this velocity make a triangle (if depths are zero at the edges) or a trapezoid. You can avoid this estimation by selecting the first or last vertical near the edge so that the flow in the triangular area is negligible.

19. In sandy beds, scoured depressions may occur due to your feet. This can affect the observed depths and velocities. In such cases, the meter should be placed ahead of and upstream from the feet.

20. At the end of the last vertical, note down the time of finish and the distance of the water's edge.

21. Go to the gage (or recorder) and write down the gage values.

22. Remove the tag line and fold it properly avoiding twists.

23. Check the "spin" of the current meter and oil it as discussed earlier.

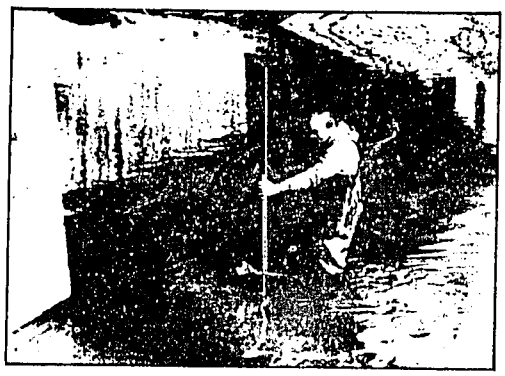


Figure 21 : Wading Measurement

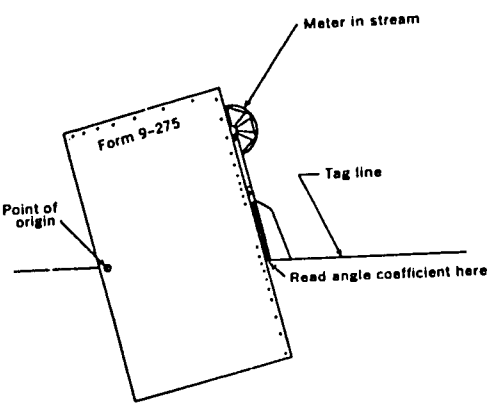


Figure 22 : Measurement of Horizontal Angle

Boat Measurement. Discharge measurements by boat should be made on the canals that are too deep to wade. A heavy duty tag line spans the measuring section and is used as a means of holding the boat in position and also of measuring the width of the canals. The tag line can be strung across the section using a nearby bridge or by a boat (rowing across the canal).

Before making a boat measurement, the canal reach near the gage should be examined and one with a uniform bed, smooth flow, no berm erosion, no bank overgrowth, and no aquatic growth should be selected. The equipment needed for this type of measurement is listed below.

1. Type AA current meter with one or more extra pivots and a rating table, in a meter carrying case

2. Headphone set with lead wires

3. Stop watch

4. Boat equipment including crosspiece and boom

5. Miscellaneous items, plugs, screw drivers, pliers, wrenches, meter oil, metallic tape, electric tape, etc.

6. Heavy duty tag line

7. Sounding weight

8. Weight hanger with pin

9. Sounding reel with double-conductor cable

10. Boat with oars, oarlocks and a piece of rope

11. Sufficient number of J-bolts or C-clamps to attach the cross beam to the gunwales of the boat and the boom to the cross beam.

12. Keys of the recorder cabin, if there is one.

Figure 23 shows the equipment assembled for a boat measurement. After the selection of the cross section, the sub-engineer should proceed as follows.

1. Span the tag line across the section. First fix the free end of the tag line to a tree or other object near the bank. If a tree is not available, use a wooden

Figure 23 : Equipment Assembled in a Boat

stake or an iron rod of proper length. Make sure the end of the tag line is properly anchored. Put the tag line reel into the boat, row the boat to the opposite bank heading somewhat upstream and simultaneously letting out the tag line. Because there will be a strong drag on the tag line, try to let out a sufficient length of the tag line to avoid drag. A nearby bridge is very helpful for stretching a tag line.

2. Fix the crosspiece to the boat by J-bolts or C-clamps. Adjust the length of the boom and fix it to the crosspiece by a bolt and a circular gun metal plate.

3. Fix the sounding reel on the boom, loosen the sounding cable so as to take the B-connector to the upstream end of the boom after passing through the guide-pulley.

4. Take out the current meter and fix the tail.

5. Check the "spin" of the current meter after unlocking the raising nut.

6. Attach the weight hanger with the C-50 weight and fix the current meter in the appropriate hole. The weight pin should not extend out of the hole in the weight.

7. Connect the B-connector with the weight hanger. The tails of the current meter, sounding weight and B-connector should be in the same direction. Join the inner insulated core of the meter cable with the single or penta binding post of the meter as required.

8. Take your position in the boat and raise the weight with the help of the reel and the lock on the reel.

9. Pass the tag line through the guide sleeves of the crosspiece. Now the boat can be stationed at any desired distance from the left or right bank.

10. Connect the wires from the headphone with the two posts provided on the reel. If the connections are correct, a revolution of the meter will produce a "click."

11. If no "click" is heard, proceed as follows.

    a. Check the headphone connection and the battery by touching the two wires from the headphone. A "click" indicates the headphone is okay.

    b. Check the lead wire connection with the reel.

c. Touch the inner core wire of the cable with the outer wires. If the "click" is heard, the connection up to the B-connector is correct. If no "click" is heard, the meter cable may be twisted and short circuited. Check the cable within the B-connector by unscrewing the connector, and the end connected to the reel. If the cable is short circuited, you have to replace it.

d. If the above part of the circuit is working, check the binding post connection with the shaft of the meter. The contact post should always be on the right side of the shaft and should make an instantaneous contact.

12. Take out the measurement form and write down the name of the station, the date, the party, the current meter number, the weight used, and other information as shown on Figure 19.

13. If it is a recording station, mark the recorder as shown on Figure 20, and write down the information on the measurement note. If sediment cleaning is required, do it before starting the measurement.

14. Record the starting time, the edge of water with reference to tag line beads and the bank from which the measurement is started.

15. Decide the number of verticals at which the depth and velocity measurements will be made, based on the criteria discussed previously.

16. Lower the current meter at the first selected vertical until the horizontal axis of the meter is flush with the water surface. Set the scale on the reel to read zero. Lower the meter until the weight touches the bed of the canal. Record the dial reading plus the distance from meter axis to the bottom of the weight as the depth of water. Because the canal beds are sandy and there is sand movement, note the depth the instant the weight touches the bed. A repeated churning with the weight may cause scour and give incorrect depth readings.

17. Make velocity observations using the two-point or six-tenths depth methods as dictated by the depth and distance of the current meter above the bottom of the weight. The number of revolutions and the time period should be as discussed under "Wading Measurement."

18. Record the data according to Figure 19.

19. Follow steps number 16 to 18 and 20 to 23 given under "Wading Measurements."

The two common factors affecting the accuracy of a boat measurement are the upstream and downstream movement of the boat caused by variable wind or non-uniform water velocity and the vertical movement of the boat, caused by wave action. The wave action may be significant downstream of control structures, therefore, a measurement immediately below such structures should be avoided.

Factors Affecting the Accuracy

The factors that commonly affect the accuracy of a discharge measurement are discussed below.

1. **Equipment.** The measurement equipment should be properly assembled and maintained in good condition. Current meters are especially susceptible to damages. These should be carefully handled. The equipment should be properly packed and stored in a vehicle during transportation.

2. **Measurement Section.** The basic characteristics of the measurement section affect measurement accuracy. As far as feasible, the section should be deep enough to permit use of the two-point method for velocity observations. The presence of a bridge or a control structure near the section may adversely affect the distribution of velocity.

3. **Spacing of Verticals.** An insufficient number of verticals can affect the accuracy. Efforts should be made to make observations at 25 to 30 verticals. Also, the first and last vertical should be located fairly close to the banks and spacing should be reduced at changes in the depth.

4. **Change in Gage Height.** On a canal the gage height is most likely to be constant during the measurement. If a measurement has to be made during a changing stage, a smaller number of verticals may be observed to obtain a mean gage height that is representative of the measured discharge.

5. **Measurement of Depth and Velocity.** Inaccuracy in measurement can result if the current meter is not at a proper depth in the vertical, giving velocities not representative for 0.2 and 0.8 depths. Movement of the boat caused by the shifting of persons sitting in the boat affects the velocity. Scour in sandy beds caused by the sounding weight or by the feet of the observer can give inaccurate depths.

6. **Wind.** Wind may affect the accuracy of a discharge measurement by obscuring the angle of the current, by creating waves that make it difficult to sense the water surface prior to sounding the depth, and by affecting the velocity at 0.2-depth. In a boat measurement, wind-caused waves may induce vertical

movement and oscillating horizontal movement that affects the operation of the current meter.

Gage Height During Discharge Measurement

Generally, the gage height during a measurement on the canal will be nearly constant. The representative gage height corresponding to the measured discharge will be the average of the two gage height readings taken at the beginning and end of the measurement. However, if some fluctuations are expected, a weighted mean gage height should be calculated. This is done by observing the gage height at a 10- or 15- minute interval during the measurement and also recording the time on the left margin of the measurement. This procedure will enable determination of average gage height and corresponding discharge during the 10- or 15- minute intervals. The computations are made as follows.

WEIGHTED MEAN GAGE HEIGHT

Time	Gage	Discharge	Mean Gage	Calculations
9:00	H_1			
		Q_1	$\frac{H_1 + H_2}{}$	$Q_1 \times \frac{H_1 + H_2}{}$
9:15	H_2			
		Q_2	$\frac{H_2 + H_3}{}$	$Q_2 \times \frac{H_2 + H_3}{}$
9:30	H_3			
		Q_3	$\frac{H_3 + H_4}{}$	$Q_3 \times \frac{H_3 + H_4}{}$
9:45	H_4			
		Q_4	$\frac{H_4 + H_5}{}$	$Q_4 \times \frac{H_4 + H_5}{}$
10:00	H_5			
	Total	ΣQ_1		$\Sigma Q_1 \times \frac{H_1 + H_2}{}$

$$\text{Weighted Gage Height} = \frac{\Sigma Q_1 \cdot \frac{H_1 + H_2}{2}}{\Sigma Q_1}$$

Measurement of Discharge at Controls

Precalibrated measuring controls in the irrigation system include weirs and outlets. Flumes are also used for measurement of discharge in water courses. A brief discussion of these control structures is provided below.

Weirs

A weir impounds flow behind an overfall with loss of practically all momentum. The discharge is measured by the total potential energy behind the overfall. However, if the approach velocity is significant, necessary correction is required.

Gated weirs are located at falls and regulators. Gage height-discharge tables based on empirical relationships generally exist. A typical relationship for fully opened gates is:

$$Q = C*B*(H + He)^{3/2}$$

in which

Q = discharge
B = width of crest
H = head over the crest
He = velocity head
C = coefficient

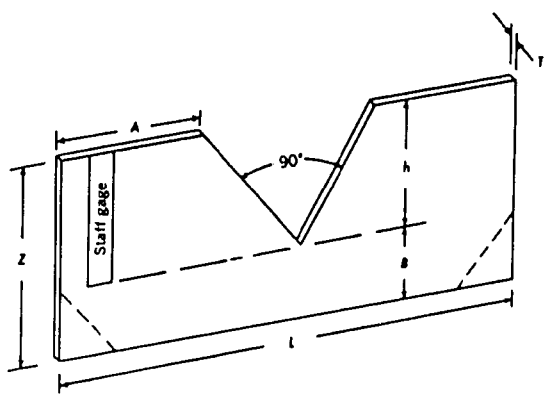
The value of the coefficient varies with the type of standing wave formed downstream from the weir. Empirical relationships also are available for partially opened gates.

The flow in main channels, branches, distributaries or minors is regulated at these weirs using the discharge tables. Therefore, these tables play a key role in the distribution system. Periodic current meter measurements should be made to check the calibration of these weirs.

Portable Weir Plates

Usually in water courses, depths are shallow and velocities are low. Though the use of a pygmy current meter is feasible under these conditions, a portable weir plate is a useful device to measure the discharge.

A 90° V-rated weir can be used in water courses. Figure 24 shows three recommended sizes. A weir made of 10- to 16-gage galvanized iron sheet will produce a free-flowing nappe having the effect of a sharp-crested weir and will give satisfactory performance.



Corners may be trimmed if desired

Weir	Z	h	B		A	T	Weight (lb)
Large	1.75	1.00	0.75	4.0	1.0	16 ga.	24
Medium	1.25	.80	.45	3.0	.7	14 ga.	17
Small	.75	.47	.28	2.0	.53	10 ga.	8

Figure 24 : Portable Weir Plate

A free-flowing nappe exists when there is free circulation of air on all side of the nappe. The notch is cut, without sharpening, leaving a flat even edge.

In earth channels, the metal plate is forced firmly into the soft bottom and sides of the channel, normal to the direction of flow. Canvas attached on the downstream or upstream side prevents leakage under or around the weir. For relatively large weir plates, rods may be driven into the bed, and eyebolts, properly placed, can be used to stabilize the plate. The minimum distances of the sides of the weir from the channel banks should be at least twice the head on the weir and should be measured from the intersection points of the maximum water surface with the edges of the weir. The minimum distance from the crest to the pool bottom should be at least twice the head on the weirs and should be measured from the point at the notch to the channel floor.

The weir plate should be levelled by using a carpenter's level. A staff gage should be placed far enough upstream from the weir so that it is not in the drawdown region. Generally at a distance of about four times the head, the drawdown effect is negligible. A carpenter's level can also be used to set the zero of the staff gage level with the weir crest.

The cone formula is considered reliable for small weirs used in measuring water for irrigation. The formula is

$$Q = 2.49\ H^{2.48}$$

in which

Q = discharge over weir in cubic feet per second

H = head over the weir in feet.

Portable Flumes

A variety of flumes have been developed and used for measuring discharges when depth are shallow and velocities are low. A particular flume should be selected carefully based on factors such as amount of sediment necessary to pass, expected discharge range, and shape of the channel cross sections. The commonly used flume in Pakistan is the "cutthroat" flume.

The cutthroat flume consists of a converging inlet section and a diverging outlet section. The width of the throat and the length of the flume are variable. The convergence ratio is 3:1 and the divergence ratio is 6:1. The floor of the flume is level. A definition sketch of the cutthroat flume dimensions in terms of throat width and flume length is given in Figure 25.

A portable flume should be made of light material, generally welded 1/8-inch sheet aluminum. The flume is installed by placing it in a pit dug in the channel and by filling in around the flume to prevent any water from bypassing it. A carpenter's level is used to level the floor.

The flume may be operated as a free-flow, single-head measuring device, or operated under submerged conditions where the head in the convergence section (h_u) and the head near the downstream end of the diverging section (h_d) are measured. Free-flow is indicated if the submergence ratio, h_d/h_u, is less than the submergence transition, S_t, given in the following table for various sizes of flumes. Normally, the flume is operated under free-flow conditions.

Under free-flow conditions, the following formula can be used to compute discharge:

$$Q_f = C_f W^{1.025} (h_u)^{n_f}$$

where:

Q_f = discharge in cfs,
C_f = coefficient depending on flume dimensions,
W = throat width in feet,
h_u = upstream depth in feet,
n_f = exponent depending on flume dimensions.

Values of C_f, n_f, S_t for a variety of flume dimensions are given below. Values for other flume dimensions can be interpolated.

Summary of Coefficients, Exponents, and Transition Submergence for Cutthroat Flumes

(Skogerboe, Utah State University, 1987, "Cutthroat Flow Measuring Flumes")

Flume	12" x 9.0'	3" x 4.5'	2" x 3.0'	1" x 1.5'
C_f	3.500	0.960	0.719	0.494
n_f	1.560	1.720	1.840	2.150
S_t	0.800	0.700	0.650	0.600
Flume	**24" x 9.0'**	**6" x 4.5'**	**4" x 3.0'**	**2" x 1.5'**
C_f	7.110	1.960	1.459	0.974
n_f	1.560	1.720	1.840	2.150
S_t	0.800	0.700	0.650	0.600
Flume	**48" x 9.0'**	**12" x 4.5'**	**8" x 3.0'**	**4" x 1.5'**
C_f	14.900	3.980	2.979	1.975
n_f	1.560	1.720	1.840	2.150
S_t	0.800	0.700	0.650	0.600
Flume	**72" x 9.0'**	**24" x 4.5'**	**16" x 3.0'**	**8" x 1.5'**
C_f	22.000	8.010	6.040	4.030
n_f	1.560	1.720	1.840	2.150
S_t	0.800	0.700	0.650	0.600

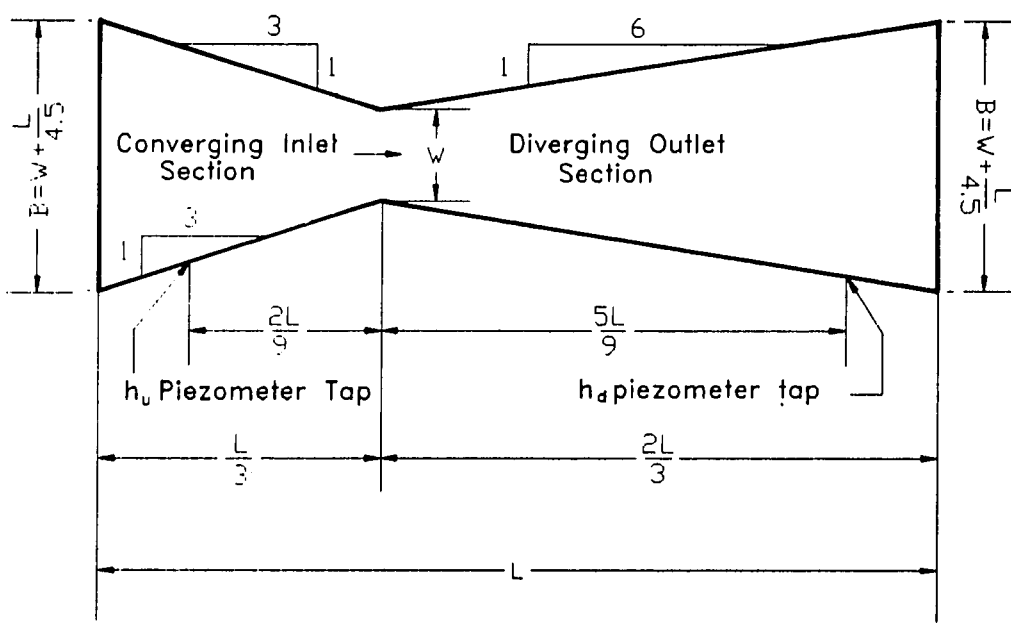


Figure 25 : Cutthroat Flume

New Permanent Controls

In the Northwest Frontier and Balochistan provinces, the irrigation channels are small, relatively steep, and mostly lined. Routine current measurements may not be of acceptable accuracy on these channel because of shallow depths and high velocities. Construction of permanent control structures such as weirs and flumes will provide better water measurements. However, periodic, carefully performed current measurements should be made to check the theoretical rating of these structures.

Irrigation Outlets

An outlet is a device at the head of a watercourse which connects it with the distributing channel. In the irrigation departments, the outlets are classified as: modular (discharge independent of water levels in the distributary and the watercourse within reasonable limits), semi-modular (discharge dependent upon the water level in the distributary and independent of the water level in the watercourse for a minimum working head required for its functioning) and non-modular (discharge function of difference in water levels in the distributary and the watercourse). The description of various types of outlets under the three categories are available in the manuals of irrigation practices prepared by the PIDs. These manuals also provide empirical relationships for calculating the discharge. The relationships do not provide correct discharge through the outlets if excessive sediment deposits occur in the distributing channels and pass through the outlets. Also, the local farmers may tamper with the outlets. Therefore, periodic measurements of the watercourses should be made using pygmy current meters, portable weirs or portable flumes depending upon the magnitude of flow to be measured. Likewise, the geometry of the outlets should be checked periodically with a y-rod.

Chapter 5

MEASUREMENT OF SEDIMENT

A knowledge of sediment movement and its deposition in an irrigation system is important both for evaluating the performance of the system and to rehabilitate and/or to redesign the system. The amount of sediment carried by the system varies seasonally. Hence, periodic sediment measurements are necessary.

Sediment in the canals is transported in suspension, saltation (sediment particles making short jumps, leaving the bed for short instants of time and returning further downstream), and rolling and sliding on the bed. These modes of transportation may occur simultaneously. For practical purposes, the total load ("load" denotes the material being transported) in a canal is defined as the "bed load" (material moving on or near the bed) plus the "suspended load" (material moving in suspension). Generally, all "suspended load" cannot be sampled because of limitations of the sampling instruments, which cannot sample the "suspended load" near the bed. Therefore, the total load also is defined as the "measured load" (measured by a suspended sampler) and "unmeasured load" (suspended load near the bed plus bed load). The suspended samplers and method of sampling discussed in this chapter will provide data to estimate the "measured load".

Sediment data defining the magnitude and characteristics of the suspended sediments and the characteristics of the sediment deposited on the bed of the canal (bed material) are required to define the procedures for the rehabilitation and redesign of the system. In this manual the discussion on the measurement of sediment characteristics is confined to the type of equipment provided.

Sampling Equipment

Hand-held samplers to collect suspended sediment and bed material have been provided. Both types of samplers are designed for use in wadable streams.

Suspended Sediment Sampler

A number of samplers are available in this category from different countries. The sampler provided is designated as a "US DH-48" sampler. This is a hand-held, depth-integrating sampler developed by the Federal Inter-Agency Sedimentation Project sponsored by the U.S. Water Resources Council. The sampler is designed to be used in a sampling procedure called depth-integration, in shallow water with a wading rod. However, if a longer wading rod is used, it can be used from a boat if the velocity is not high.

The sampler consists of a streamlined aluminum casting, 13-inches long, which partially encloses a pint bottle. The sampler weighs about 4 pounds. An intake nozzle threaded into the nose of the sampler body, extends horizontally. A streamlined projection, pointing toward the rear on the side of the sampler head, accommodates the air exhaust port from which air escapees from the bottle as the sample is being collected. The sample bottle is held in place and sealed against a rubber gasket in the sampler head, by a hand-operated spring-tensioned clamp at the rear of the sampler. The instrument can sample to within 3.5 inches of the stream bed. The sampler is provided with a brass nozzle of 0.25 inch inside diameter. Figure 26 shows a USDH-48 sampler.

Bed Material Sampler

The sampler provided is the "USBMH-53" sampler developed by the Federal Inter-Agency Sedimentation Project sponsored by the U.S. Water Resources Council. It is a hand-held, piston-type, manually-operated core sampler designed for use in shallow, wadable streams for collecting bed material samples.

The sampler contains a cylinder 2 inches in diameter and 8 inches long which is pressed into the stream bed to collect the sample. A piston is located inside the cylinder. The overall length of the sampler is 46 inches. A handle for pressing the cylinder into the bed, is located at the top of the sampler frame. As the cylinder is pressed into the stream bed, the piston retracts and holds the sample in the cylinder by means of a partial vacuum. The sample is pushed out of the cylinder by the piston. Figure 27 shows a USBMH-53 sampler.

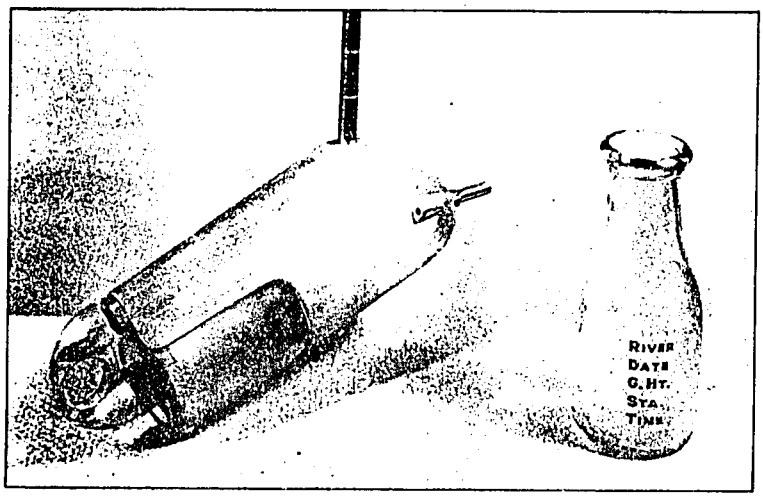
Penetration of the sampler in fine-grained sediment is easy. However, penetration is usually difficult in sandy beds and may be limited to about 9 to 18 inches.

Sampling Procedure

Sediment samples should be taken at or near a stream gaging station because of the obvious relation of sediment movement to the flow in the canal. However, special samples may be required at other specific locations. Suspended sediment samples should be taken with each discharge measurement.

Suspended Sediment Sampling

The suspended sediment samples will be required to determine (1) the concentration of suspended sediment at a given location and instant in time, (2) the quantity of suspended sediment transported per unit time at a given gaging station, and (3) the particle size distribution of the suspended sediment. The canals usually carry a mixture of sand (particle size diameter from .062 mm to 2.0 mm, very fine to very coarse sand), silt (particle size diameter from .004 mm to less than 0.62 mm, very fine silt to coarse silt) and clay (particle size less than .004 mm). The silt and clay particles are usually



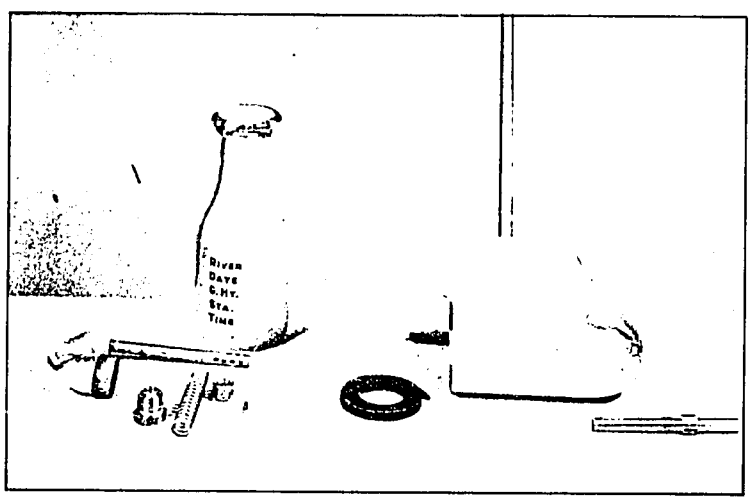


Figure 26 : USDH-48 Sampler

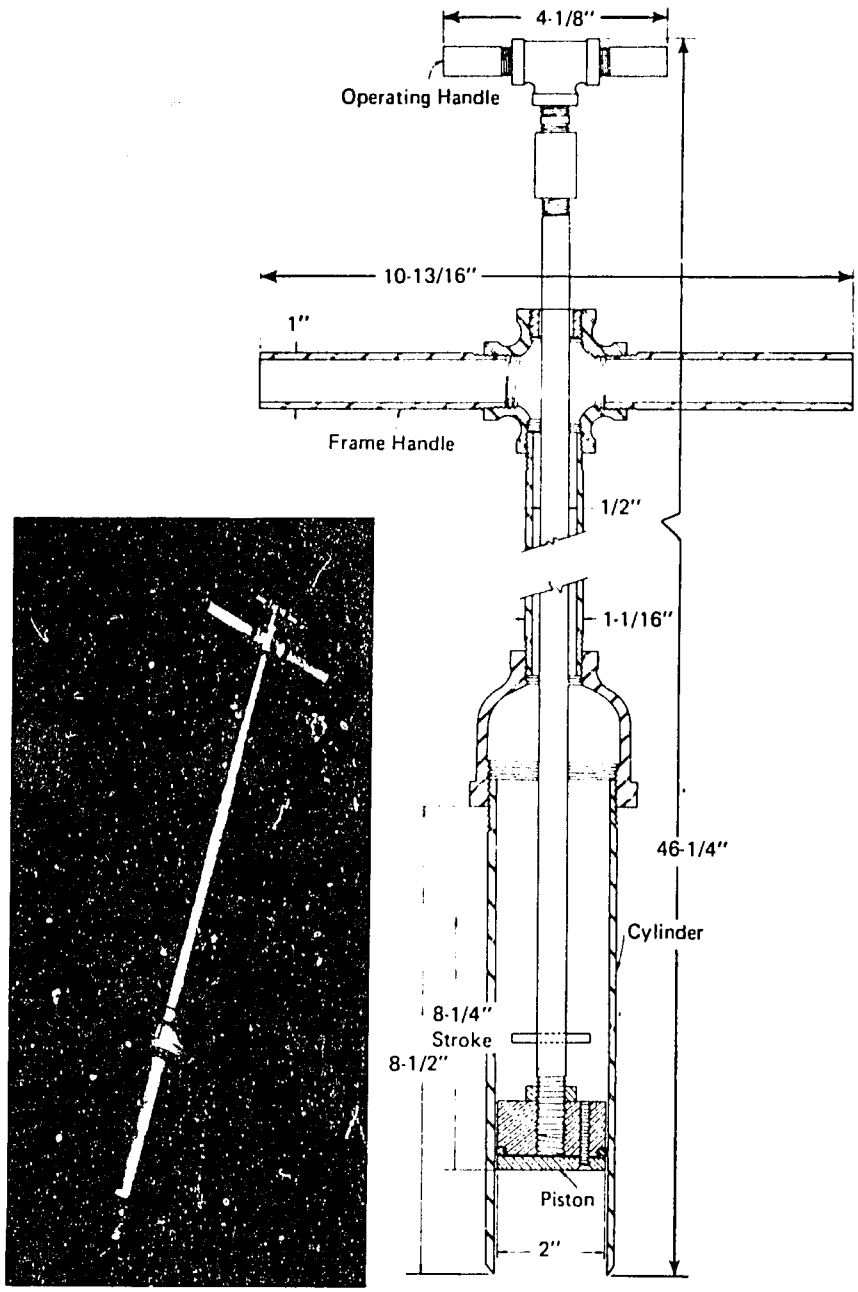


Figure 27 : USBMH-53 Sampler

distributed fairly uniformly in a cross section. However the distribution of sand varies significantly both laterally and vertically in the canal.

The depth integration method is used to collect sediment samples when the purpose of the sampling is to provide information on the quantity and particle size distribution of the sediment only. The spatial distribution of the water-sediment mixture at depths at various verticals across the canal is not of interest for the purpose of evaluating the general characteristics of the sediment. In the depth-integration method, the sampling is continuous and the sampler is lowered and raised at a uniform velocity (transit rate) throughout the depth at a selected vertical.

Sampling Requirement

The basic requirements for depth integration are given below:

1. Sampling should be continuous

2. Because the sampler takes in water-sediment mixture at a velocity immediately near the nozzle, the full depth should be sampled with a uniform transit rate while lowering or raising the sampler. This is to ensure that the volume of sample collected from every element of depth at a vertical is represented in the total sample volume for the vertical in the same proportion as the water discharge through each corresponding element has to the total discharge through the width represented by the vertical.

3. Transit rate at the vertical depends upon the depth and velocity of flow. The maximum transit rate should not exceed 0.4 (mean velocity in the vertical), and the minimum should be sufficiently fast to keep from overfilling the sample container. For practical purposes, the transit rate should be such that a sample of about 350 to 400 milliliter (ml) is obtained in a two way integration. This will ensure the requirement discussed as Item 2. Figure 28 gives some guidance on the transit rate.

4. The capacity of sample container is about 470 ml. However, due to the inclined position of the sampler with the vertical, about 440 ml of the water-mixture is retained even if the container is filled during the sampling period. Therefore, the period of submergence of the sampler should only be sufficient to provide a sample of 350 to 400 ml. In the field this can be ensured if the container is filled up to just above the start of the tapered portion.

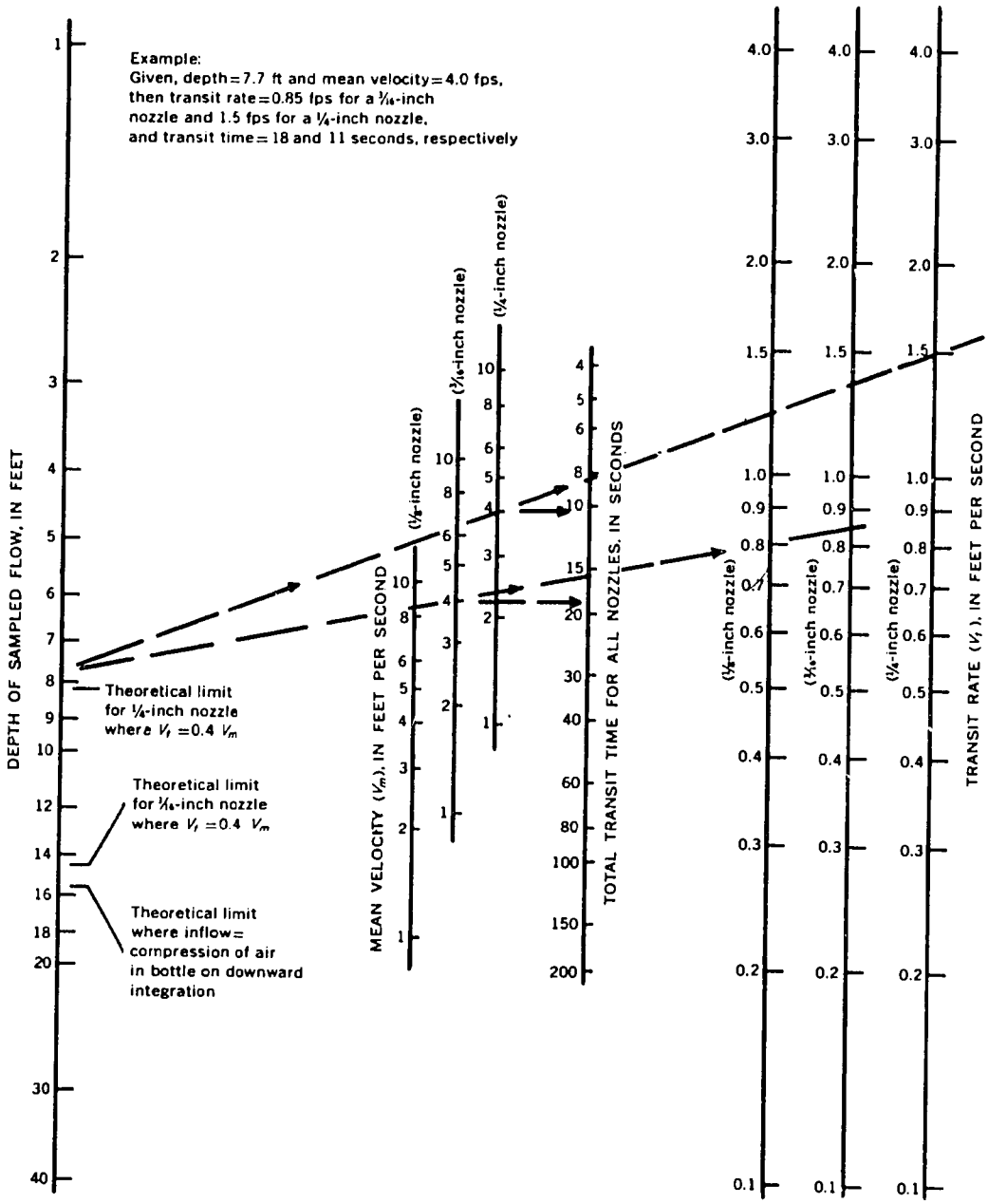


Figure 28 : Two-way Suspended-Sediment Sampling Transit Time, Assumed Sample Volume is 395 ML

5. During sampling, the sampler should not be held near the bottom of the canal when changing the transit direction, because this may cause more coarse particles getting into the container.

6. While taking out the sample container from the sampler do not spill the sample. It should be covered with a lid or a paper-stopper and labeled. The information on the label should include: station name, date, time, subsection location from bank, gage height, water temperature and your initial.

7. Always use clean containers. If during sampling a sample is discarded for some reason, make sure that no previous sediment particles are sticking in the container.

Discharge-Weighted Suspended Concentration. Generally, a representative suspended sediment concentration is needed for the cross section at a stream gaging station to determine instantaneous concentrations and sediment-discharge on a monthly or annual basis. Two depth-integration methods are commonly used, the equal-discharge-increment (EDI) method, and the equal-width/equal-transit-rate (ETR) method. Each method has its merits and demerits. For the sediment sampling on the canals, the EDI method is recommended. This method requires a knowledge of the lateral distribution of discharge which comes from the discharge measurements. The cross-sectional area should be divided into three subsections for canals/distributaries with widths equal to or greater than 15 feet, each of which conveys the same discharge. A sample should be taken at the vertical in each subsection where half of the subsection discharge is on one side and half is on the other side. In each individual subsection, a vertical transit rate should be selected that will provide a sample volume between 350 to 400 ml.

The above procedure provides a set of subsamples of nearly the same size and representing the same proportion of the total water discharge through the sampled zone of the cross section. The samples can be combined to provide a single composite sample. If the volumes of the subsamples are significantly different, each sample should be analyzed separately, and the concentrations of the three subsamples should be averaged to give mean concentrations corresponding to the flow at the time of sampling.

For small canals/distributaries (less than 15 feet in width), one sample should be taken at the vertical in the canal where half of the flow is on one side and half is on the other.

Sample Handling and Preservation. After taking a sample it should be examined. Sampling error may frequently occur in sand-bed canals in the dune regime where the nozzle of the sampler may accidentally pick up sand from the downstream side of the dune. Therefore, the set of samples taken at one time should be inspected and any anomaly in the sediment contents should be investigated. If required, the sampling

should be repeated. The cost of field and laboratory work, to say nothing of the future embarrassment of a bad record, is sufficient incentive to re-sample.

Spilling of the sample during labeling should be avoided. Water temperature must be observed at the time of sampling. The preferred method to obtain the correct water temperature is to submerge the thermometer some distance out in the stream during the discharge measurement. The thermometer should be held under water for about one minute to allow the temperature of the thermometer to equalize with the water temperature.

The sample containers should be transported in wooden boxes to avoid breakage. In the laboratory or before transportation, the samples should be stored in a cool, dark place to avoid organic growth. The samples should be analyzed within about two to four weeks after field sampling.

Bed Material Sampling

Data on the size of material making up the canal bed are required to study the long range changes in the canal conditions and for use in computations of bed load. Bed material samples should be taken at the surface of the bed.

Sampling Procedures. The BMH-53 sampler is placed in a vertical position on the canal bed with the piston extended to the open end of the cylinder. The cylinder is then pushed the full 8 inches into the bed while the piston is still positioned at the bed surface. An effort should be made to seat the cylinder completely because this will ensure a minimum disturbance of the top one or two inches when the sampler is recovered. If may be necessary in case of coarse sand to pull out the piston rod to create a partial vacuum above the sample. This will help to draw the sample into the cylinder and may also reduce some of the required cutting pressure. The sampler should then be withdrawn from the bed and held in an inclined position above the water with the cylinder end highest to avoid loss of sample.

Location and Number of Sampling Verticals. Bed material samples should be taken with the discharge measurements and suspended sediment sampling. The locations and number of the samples should be the same as for the suspended samples, that is, three in large canal and one in small canals. Sometimes, it may not be possible to take bed material samples from a boat because of the water depth greater than the height of the BMH-53 sampler. In such cases, it is recommended that a scoop-type bed material sampler, designed by the Punjab Irrigation Research Institute and available locally, should be used.

Sample Inspection and Labeling. The samples should be inspected in the field for any significant variation from one location to another which is not consistent with the flow conditions. If required, the sampling should be repeated. The bed material from the sampler should to be stored in containers and labeled. The information on the label should include: station name, date, time, gage height, water temperature, stationing from a reference bank, bed form (if possible), flow condition, sampler used, and initials of the observer.

Chapter 6

MORPHOLOGICAL DATA

Morphological data should be collected on the canal reaches that indicate some performance problems based on evaluation of hydraulic monitoring data and visual inspection, and should include:

1. Survey of water surface profiles at full supply level.

2. Longitudinal bed profiles during the closure periods.

3. Cross-sectional profiles during the closure periods.

4. Survey of free-board at selected locations to indicate differences between the water surface in the canals and the berms and/or service road.

Survey Equipment

Automatic survey levels and levelling staff are provided to perform the survey. Metallic tapes (of cloth containing threads of bronze) also are provided. The tapes are 100-feet long with 0.1 foot markings.

Levelling Procedure

At all canal reaches to be surveyed, permanent or semipermanent benchmarks should be established. The elevations of these benchmarks should be determined with respect to the SPD. The levelling can be performed by two persons; an instrument man and a rodman.

Profile levelling determines the elevations of points at known distances along a line. The points should be so selected that the profiles give a reasonably accurate representation of the changes in the canal cross sections and the bed profiles. The observation points should be more closely spaced where changes in the profiles occur.

For checking the freeboard, direct differential levelling should be done. This will provide difference of elevation between two points. The level should be set up at some convenient point so that a staff reading can be taken at both locations for which the difference in elevation is needed.

Setting Up the Level

Levelling is essentially a determination of the difference of elevation between two points by reading a staff held on those two points. If the elevation of one of the points is known, the elevation of the other is determined by adding or subtracting this difference. Therefore, at the instant the readings are made, it is required that the line of sight should be horizontal. In a properly adjusted instrument, this line is horizontal only when the bubble is at the center of the bubble tube attached to the level.

The first step in setting up the level is to spread the tripod legs so that the tripod head will be approximately horizontal. Some tripods have a bull's eye which can be used to set the head horizontal. The legs should be spread enough to prevent the instrument from being blown over by a gust of wind, and they should be pushed into the ground far enough to make the level stable.

The telescope should be set horizontal with the help of levelling screws - three or four depending upon the type of instrument. The levelling procedure is normally given in the instructions for the instrument.

Running Levels

A closed-circuit level should be done starting from a benchmark and finishing at the same benchmark. The "Height of Instrument (HI)" method should be used. The method consists of first setting up the instrument at a convenient location such that a leveling staff placed at the benchmark and at a point where the elevation is required, is visible through the telescope. The first reading should be taken at the benchmark and is called a backsight (BS). The BS reading added to the elevation of the benchmark gives the HI. After the HI has been established, the levelling staff can be placed at desired locations. The readings on the staff are called foresights (FS). These readings subtracted from the "HI" give the elevation of the desired locations. More than one setting may be required from the benchmark to the canal reach to be surveyed. The intermediate points are called the turning points (TP).

In a closed-circuit survey, the difference between the sum of backsights and the sum of foresights should be zero. The staff readings should be taken up to 0.01 feet.

Sources of Errors

The principal sources of errors in levelling are instrumental defects, faulty manipulation of the levelling staff (not held vertically), settlement or disturbance of the level during the work, errors in sighting, failure to level the instrument on all axes, mistakes in reading the staff or in recording or in computing, errors due to natural sources (refraction

caused by heat on a hot day) and personal errors. The detection of these errors and remedial instructions are available in many text books on surveying.

Chapter 7

LABORATORY METHODS FOR SEDIMENT ANALYSIS

This chapter describes methods and procedures to determine suspended sediment concentrations and particle size distributions of the water samples, and particle size distributions of bed material samples collected from canals. The methods and procedures are provided for the use of the following equipment.

1. Analytical Balance
2. Electric Oven
3. Bottom Withdrawal Tube
4. Pipette Set
5. Evaporating Dishes
6. Sieve Sets

For sediment analysis, it is important that as soon as the samples are received in the laboratory, they should be inspected for general condition. Samples showing organic growth should be discarded and the field staff should be notified to be careful in preserving the samples. Loose caps should be replaced and bottles with dirty exteriors should be cleaned. The samples should be placed in a cool dark room. If evaporation loss is expected, the bottles with samples should be weighted as soon as received from the field.

Unit of Measurement and Definition

The sediment concentration in a sample is expressed as a ratio of the dry weight of the sediment to the weight of the water-sediment mixture designated, as "parts per million (ppm)."

$$\text{ppm} = \frac{\text{weight of sediment} \times 1{,}000{,}000}{\text{weight of water-sediment mixture}}$$

However, in sediment analysis literature, the commonly used term for the concentration is "milligram per litre (mg/l)." In a laboratory, it is more convenient to obtain the weight than to determine the volume. The conversion from "ppm"to "mg/l" can be made using the following relationship:

$$\text{mg/l} = A\ (\text{ppm})$$

in which "A" can be determined from the following table.

PPM	A	PPM	A	PPM	A
0-7,950	1.00	69,300-83,700	1.05	140,000-152,000	1.10
8,000-23,700	1.01	83,800-97,900	1.06	153,000-165,000	1.11
23,800-39,100	1.02	98,000-111,000	1.07	166,000-178,000	1.12
39,200-54,300	1.03	112,000-125,000	1.08	179,000-191,000	1.13
54,400-69,200	1.04	126,000-139,000	1.09	192,000-209,000	1.14

The factor "A" is based on specific gravities of water and sediment respectively equal to 1.000 and 2.65 grams per cubic centimeter and a temperature range of 0° to 29°C. The sediment concentration is generally reported to one mg/l for concentrations up to 1,000 mg/l and up to three significant figures for higher concentrations.

A suspended sediment usually consists of a range of particle sizes. For practical purposes a particle size in fluvial sediment (fluvial means pertaining to streams) is defined as the sediment particle diameter obtained by standard methods of preparation, dispersion and analysis of a sediment sample. The particle-size distribution is a frequency distribution of the relative amounts of particles in a sample that are within specified size ranges or a cumulative frequency distribution of the relative amounts of particles coarser or finer than specified sizes. Relative amounts are usually expressed as percentages by mass. The selection of particle-size ranges (or classes) can be made with the help of the following table prepared by the American Geophysical Union.

Class Name	Size (mm)	Class Name	Size (mm)
Cobbles	256-64	Coarse silt	0.062-0.031
Gravel	64.0-2.0	Medium silt	0.031-0.016
Very coarse sand	2.0-1.0	Fine silt	0.016-0.008
Coarse sand	1.0-0.5	Very fine silt	0.008-0.004
Medium sand	0.50-0.25	Coarse clay	0.004-0.002
Fine sand	0.25-0.125	Medium clay	0.002-0.001
Very fine sand	0.125-0.062	Fine clay	less than-0:001

Determination of Suspended Sediment Concentration

A sample may contain a small or large quantity of sediment. The procedure and method of analysis may depend upon the quantity. In some cases more than one sample may be needed for determining reasonably accurate concentration.

The most commonly used methods are "evaporation" and "filtration". The equipment for both the methods is provided. The filtration method is faster and may be used for samples ranging up to about 10,000 mg/l of sediment that is relatively coarse grained, and about 200 mg/l of sediment that is mostly clay. The evaporation method may be used where the concentration is more than these limits. Usually, an experienced analyst can guess the range of concentration in a sample to select the proper method of analysis.

Evaporation Method

As stated earlier, this method is best suited for high concentrations. A correction for dissolved solids is required, especially for low concentrations. The laboratory procedure is discussed below.

Equipment: For a satisfactory analysis, the minimum equipment required is:

1. Container (usually a glass bottle) with water-sediment sample
2. Two pan balance, accuracy 0.1 gram for weighing bottles
3. Analytical balance, accuracy 0.1 milligram
4. Distilled water
5. A vacuum source
6. Evaporating dishes
7. Drying oven (convection type)
8. Glass beakers of various sizes
9. Pipette
10. Graduated cylinders of various sizes
11. Wash bottle
12. Desiccator
13. Enamelled tray
14. Enamelled bucket
15. Analysis forms, etc.

Analytical Procedure: The following procedure is recommended to determine the total concentration by the evaporation method. As discussed in Chapter 5 under "Discharge-Weighted Suspended Concentration," the three samples taken at one discharge rate can be combined and the composite sample should be analyzed or each sample should be analyzed separately if the volumes of the samples are significantly different. The step-by-step procedure to analyze the sample is given below.

1. Arrange samples according to gaging station and at a given station in chronological order.

2. Prepare a set of consecutively numbered analysis forms for each sampling location. A recommended format of the analysis form is shown on Figure 29.

3. Remove the label attached to the sampling bottle and transfer the name of gaging station, location of station, day, time, gage height, sampling location in the canal cross section and any remarks on the label. It is also recommended that a log book of all samples processed in the laboratory should be maintained. The log book should indicate the date of receipt of samples and date of analyses for each station.

4. As discussed earlier, if the bottle containing the sample was weighed as soon as received, write the weight of the bottle plus mixture on the analysis form.

5. Make sure that the sediment has settled in the bottle. This may take three to four days.

6. Decant excess water with the help of a syphon and pour into a glass beaker, taking care that 35 to 40 cc of the mixture is left in the bottle and settled sediment remains undisturbed.

7. Using decanted water, wash the mixture (remaining in the bottle) into a graduated cylinder, making sure no sediment remains sticking to the sides of the bottle.

8. Dry the bottle thoroughly and weigh to the nearest 0.1 gram.

9. If the volume of the sediment mixture in the graduated cylinder is less than 50 cc. bring it to 50 cc. by adding more decanted water. If the volume is more than 50 cc., note the exact volume of the mixture in the graduated cylinder.

10. Transfer the mixture into a preweighed evaporating dish and wash the cylinder thoroughly with distilled water, into the dish.

_____ IRRIGATION DEPARTMENT

_____ CIRCLE _____ DIVISION

SEDIMENT ANALYSIS FORM FOR TOTAL CONCENTRATION

_____ Canal At _____ Sampler _____

Data collected _____ Date Analyzed _____ Canal Water Temperature _____

Label Number	Gage Hieght	Sampling Location	Sampling Location	Sampling Depth	Total Depth	Computation		PPM
						Bottle & Mixture = Bottle = Mixture =	Dish & Sediment = Dish = Sediment = Diss. Corr. = Net =	
						Bottle & Mixture = Bottle = Mixture =	Dish & Sediment = Dish = Sediment = Diss. Corr. = Net =	
						Bottle & Mixture = Bottle = Mixture =	Dish & Sediment = Dish = Sediment = Diss. Corr. = Net =	

Dissolved Solid Correction ____cc
W (Sample & Dish) =
W (Dish) =
Difference =

Analyzed By : _____

Computed By : _____

Checked By. _____

Figure 29.

11. Place the dish into an electric oven and dry overnight at 105°-110°C. Do not boil sediment out of the evaporating dish. This requires drying at temperatures slightly below the boiling point until all visible moisture has evaporated.

12. Remove the dish from the oven and place it in a desiccator until cool. When cool, weigh the sample immediately to the nearest 0.1 milligram.

13. Filter the decanted water by filtration process, take 50 cc. of the water or a volume equivalent to the mixture in the graduated cylinder, transferred to the evaporating dish.

14. Transfer this volume to a preweighed evaporating dish, evaporate the water, cool in a desiccator and weigh to nearest 0.1 milligram.

15. Record all data on the analysis form and compute the sediment concentration in PPM as follows:

Wt. of bottle + mixture = WI
Wt. of bottle = W2
Wt. of mixture = WI - W2
Tare wt. of first dish, L1 = T1
Wt. of suspended sediment plus dissolved solids plus dish = SI
Tare Wt. of second dish, L2 = T2
Wt. of dissolved solid plus dish = S2
Wt. of sediment + dissolved solid = S1 - T1
Wt. of dissolved solid = S2 - T2
Net. wt. of suspended sediment = (S1-T1) - (S2-T2)

$$\text{Total concentration} = \frac{(S1-T1) - (S2-T2)}{W1-W2} \times 10^6 \text{ (PPM)}.$$

It should be noted that the above equation is valid when equal volumes of sediment mixture and decanted water are used. Otherwise, the dissolved correction should be computed using any convenient volume size and determining the correction as weight per cubic centimeter.

Filtration Method

Because of the relatively high sediment concentration in the canal, this method may not be used often. However, as stated earlier, the method has some advantages for low concentration samples. The laboratory procedure is discussed below.

Equipment: The following equipment and supplies are the minimum requirements.

1. Water-sediment sample in a glass bottle
2. Two pan balance (sensitivity 0.1 gram)
3. Analytical balance (sensitivity 0.1 milligram)
4. Distilled water
5. A vacuum source
6. Evaporating dishes
7. Drying oven (convection type)
8. Glass beakers of various sizes
9. Graduated cylinder of various sizes
10. Filtering funnel
11. Wash bottle
12. Desiccator
13. Enamelled tray
14. Enamelled bucket
15. Filter paper, analysis forms, etc.

Analytical Procedure: The following are step-by-step instructions to determine total concentrations by this method.

1. Follow the steps 1 to 8, given under the "Evaporation Method."

2. Install suitable filter paper in the filtering funnel and place over a cylinder.

3. Transfer the sample slowly to the filtering funnel and wash the cylinder thoroughly with distilled water into the funnel.

4. When the filtration is complete, remove the filter paper carefully from the funnel and place in a preweighed evaporating dish. (Note: if "ashless" filter paper is not used, the filter paper must also be preweighed.)

5. Place the dish into the oven and dry slowly. Do not create a draft that blows the sediments off the filter.

6. Remove the dish from the oven and cool in a desiccator.

7. When cool, weigh immediately to the nearest 0.1 milligram.

8. Record all data on the analysis form and compute the sediment concentration as follows:

Wt. of bottle + mixture = WI
Wt. of bottle = W2
Wt. of mixture = W1 - W2
Tare weight of evaporating dish = T1
Wt. of suspended sediment + dish = S1
Wt. of suspended sediment = S1 - T1

$$\text{Total concentration} = \frac{S1 - T1}{W1 - W2} \times 10^6 \text{ (PPM)}$$

Suspended Sediment Particle - Size Analysis

Particle-size analysis of suspended sediment being transported by the canal should be made preferably for the samples corresponding to different discharge rates. However, in the canal system, the variation in flow rates may not be frequent. About one-third of the samples taken should be analyzed for particle-size distribution.

A given sediment sample usually carries a range of particle sizes. This requires separation of fine material (silt and clay) from the coarse material (sand) at a size of 0.062 mm. After the separation, the particle size distribution determinations are made for the fine and coarse materials separately. The size determination should be made for sizes of 1.0, 0.50, 0.125, 0.062 mm (coarse material) and 0.044, 0.031, 0.022, 0.016, 0.011, 0.008 and 0.004 mm.

A number of methods or their combination are available to determine the complete range of the particle sizes. The following methods are discussed in this manual.

1. Sieve 2. Pipette 3. Bottom Withdrawal Tube

The recommended quantities of sediment in the sample, desirable range in concentration and particle-size range are given below.

Method	Size Range (mm)	Concentration (PPM)	Quantity (gram)
Sieve	0.062-32	-	-
Pipette	.002-.062	2,000-5,000	1.0-5.0
BW tube	.002-.062	1,000-3,000	0.5-1.8

If the quantity of sediment is not sufficient to use the above methods, either the analysis should be confined to determination of percentages of fine and sand or a sufficiently large quantity of water-sediment mixture should be collected at a specific location.

The step by step procedures for separating the fines and sands, and for analyzing particle-size distributions using pipettes, bottom withdrawal tubes, and sieves are discussed below.

Procedure for Separating Fines and Sands

Equipment: The equipment required for this analysis includes all the items listed for the "Evaporation Method," plus a sieve set.

Analytical Procedure: The step-by-step procedure to separate the fines and sands is given below.

1. Follow the steps 1 to 8 given under the "Evaporation Method."

2. Carefully note down the volume of the mixture in the graduated cylinder. This volume should be used to determine the dissolved solid correction.

3. Place a sieve number 230 (U.S. Standard, 0.062 mm) on a beaker, thoroughly shake the graduated cylinder, and allow the mixture to pass through the sieve. The sieve is thoroughly washed with distilled water so that all the fine particles pass through. The sieve should be tilted, rotated and tapped gently to facilitate the washing procedure.

4. If only the total concentration of the fines is required, follow the steps 9 to 14 given under the "Evaporation Method" using the mixture in the beaker. If the particle size distribution also is required, keep the sample in the beaker for analysis by the bottom withdrawal or pipette method. Remove the sieve and wash the contents in a preweighed evaporating dish, using distilled water.

5. Evaporate the water in an oven, cool in a desiccator and weigh to the nearest 0.1 milligram.

6. There may be some organic matter contents in the sand. Add about two ml of 30 percent hydrogen peroxide solution per gram of the dry sand in the sample and bring to about 40 ml by adding distilled water. Allow to stand for a few hours to oxidize the organic matter. If no sediment is attached, remove floating organic matter by skimming. Destroy the hydrogen peroxide by slowly bringing sample to a boil.

7. Oven dry the sand sample, cool and weigh to nearest 0.1 mg.

8. Determine concentrations of fine and sand as follows (assume no organic matter).

Wt. of bottle + mixture = W1
Wt. of bottle = W2
Wt. of mixture = W1 - W2
Tare weight of first evaporation dish = T1
Wt. of fine sediment plus dissolved solids plus dish = S1
Tare Wt. of second evaporation dish = T2
Wt. of dissolved solids plus dish = S2
Wt. of fine sediment + dissolved solids = S1 - T1
Wt. of fine sediment = (S1 - T1) - (S2 - T2)
Tare weight of third evaporating dish = T3
Wt. of sand + dish = S3
Wt. of sand = S3 - T3

$$\text{Concentration of fine sediment} = \frac{(S1 - T1)-(S2 - T2)}{W1 - W2} \times 10^6$$

$$\text{Concentration of sand} = \frac{S3 - T3}{W1 - W2} \times 10^6$$

Sieve Method

The samples usually contain a high concentration of fine material (silt and clay), and a small amount of sand. A minimum of about 0.02 gram of sand is required for an accurate sieve analysis. Therefore, use of a composite sample is recommended whenever possible. The sieve method is used with the pipette and bottom withdrawal tube methods. Therefore, a complete description of the method is provided under the pipette method.

Pipette Method

The pipette method is probably the most accurate and routinely used method for analyzing particle size distributions. The fundamental principle is to determine the concentration of a suspension at a predetermined depth as a function of settling tine. Particles having a settling velocity greater than that of the size at which separation is desired will settle below the point of withdrawal after elapse of a certain time. The time and depth of withdrawal are pre-determined on the basis of Stokes Law. The method is applicable for sizes less than 0.062 mm.

Equipment: The equipment and supplies for sieve-pipette analysis to determine a complete particle-size distribution includes:

1. Glass bottle(s) containing the water-sediment mixture

2. A 50 or 25 ml pipette apparatus that can be raised or lowered, mounted on a movable carriage (see Figure 30)
3. Two pan balance, accuracy 0.1 gram
4. Analytical balance, accuracy 0.1 milligram
5. Distilled water
6. A vacuum source
7. Sedimentation cylinder, 1,000 ml capacity, with rubber stopper
8. Stirring rod with a perforated plastic disk 50 mm in diameter attached to one end
9. Thermometers
10. Evaporating dishes
11. Drying oven
12. Glass beakers of various sizes
13. Graduated cylinders of various sizes
14. Wash bottle
15. Desiccator
16. Stop watch
17. Sieve set
18. Miscellaneous items; enamelled tray, enamelled bucket, analysis forms, hydrogen peroxide, sodium oxalate, etc.

Analytical Procedure: The following step-by-step procedure should be followed.

1. Arrange samples collected at one sampling station in a chronological order and select the samples taken on one day, decide whether to compose the samples or analyze separately, preferably compose to obtain a sufficient quantity of sand to determine the particle size distribution.

2. Since more than one composite sample may be analyzed at one time, prepare a set of numbered analysis forms. An example of the form is shown on Figure 31.

3. Remove the labels from the sampling bottles and enter the information on the analysis form (Figure 31).

4. If the bottles were weighed when received, enter the weights of the bottle + the mixture on the form, otherwise weigh the bottles now and write down the weight of the bottle + mixture.

5. Make sure that the sediment has settled in each bottle, decant excess water with the help of a syphon and pour into a glass beaker, taking care that the sediment is not disturbed. Remove as much of the native water

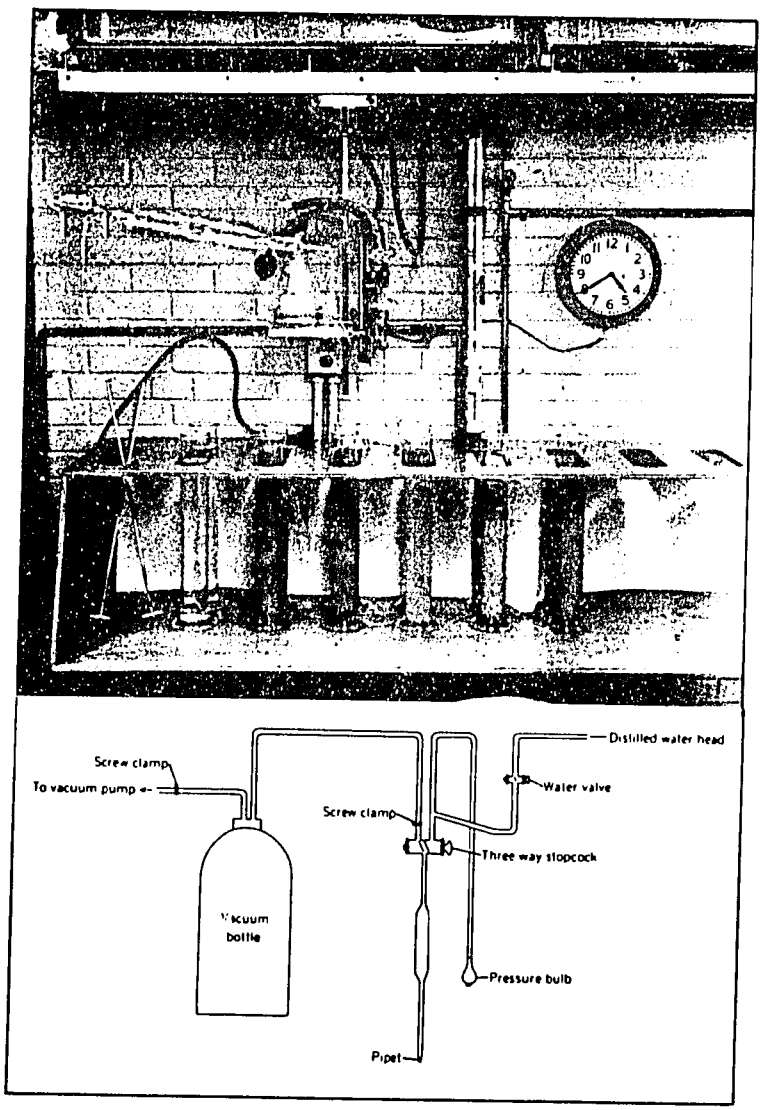


Figure 30 : Pipette Apparatus

_____ IRRIGATION DEPARTMENT
_____ CIRCLE _____ DIVISION
PARTICULAR SIZE ANALYSIS, SIEVE - PIPETTE METHOD

Canal At _____ Sampler _____ Data Collected _____ Water Temp. _____
Gate Hieght _____ Sampling Depth _____ Sampling Time _____ Sampling Location _____

Analysis Data
Date _____ Analyzed By _____ Computed By _____ Checked By _____

Water - Sediment Mixture				Dissolved Correction	Results
No.	Bottle + Mixtur		Bottle	Disp. Agent = _____	
				Volume = _____	No of Sample Compound = _____
				Tare Dish = _____	Wt of Sediment Mixture = _____
				Dish + Agent = _____	Net Sediment = _____
				Net Agent = _____	Mean Concentration = _____
Total Bottles + Mix =			gpm	Correction = _____	Sand > 0.062 = _____
Total Bottles + Mix =			gpm		Silt, between 0.062-0.055 _____
Sediment Mix =			gpm		Clay < 0.0055 = _____

Sieve Analysis

Particle Size, mm											Pan
Container No.											
Weight-gm	Gross										
	Tare										
	Net										
% of Total											
% Finer than											

Pipette Analysis

Cylinder Volume = cc Pipette No. and Volume = cc Volume Factor =

Particle Size, mm		Conc									
Clock Time											
Temperature											
Fall Distance											
Settling Time											
Dish No.											
	Gross										
	Tare										
	Net										
	D. Corr										
	Net Sed										
	Finer than										
% Finer than											

as possible without disturbing the sediment. This is essential in order to avoid correcting for dissolved solids. Also the sediment particles may not fall freely in native water because of the coagulating effect of sodium salts.

6. If more than one sample, compose these in a beaker; using distilled water, make sure all sediment is transferred to the beaker.

7. Dry the empty sampling bottles thoroughly, weigh to nearest 0.1 gram and determine the total weight of the sediment mixture for the composite sample.

8. Add a known volume of N/10 (10 percent normality) sodium oxalate ($Na_2 C_2 O_4$) as a dispersing agent in the composite sample and mix it thoroughly so that each particle may have a free fall.

9. Place a 230 sieve over a beaker, pass the sample through the sieve which retains the particles of .062 mm and above, and wash the sieve with distilled water so that all particles less than 0.062 mm pass through. The sieve should be tilted, rotated and tapped gently to facilitate the washing process.

10. Transfer the sediment retained on the 230 sieve to an evaporating dish of known tare weight. Wash the sieve with distilled water into the dish making sure no sediment is left sticking to the sieve.

11. Place the dish in an oven, dry overnight at 105°-110°C, taking care the sediment is not blown out of the dish.

12. Remove the dish from the oven, and place it into a desiccator until cool.

13. When cool, weigh the dish to the nearest 0.1 milligram, and subtract the weight of dish to determine the weight of the sand particles.

14. Add the weight of the sediment computed in step 13 to the weight of the fine particles (clay and silt) to obtain the total weight of sediments. The percentages of various particles sizes should be computed on this weight.

15. Use the sieve set and dry sand to determine particles sizes. Transfer the dry sand into a nest of 3-inch diameter sieves to obtain separates finer than 1.0, 0.5 (No. 35), 0.25 (No. 60), 0.125 (No. 120) and 0.062 (No. 230). The sand particles retained on the No. 35 sieve are of 0.5 mm diameter and above, and so on. Weigh the sediment retained on each sieve carefully to the nearest 0.1 milligram. Record the data on the analysis form (Figure 31).

16. Take a known volume of N/10 sodium oxalate and heat in an evaporating dish of pre-determined tare weight overnight at 105° to 110°C.

17. Place the dish in a desiccator and when cool, weigh and determine the dissolved correction for sodium oxalate in grams per ml.

18. Transfer the sample in the beaker in step 9, to a graduated cylinder, wash the beaker into the cylinder with distilled water, making sure no sediment remains sticking to the sides of the beaker. Use a cylinder of 1,000 ml capacity if the concentration is heavy or use a cylinder of 500 ml capacity.

19. Raise the level in the cylinder to 1,000 ml (or 500 ml) by adding distilled water.

20. Suspend the sediment in the cylinder by vigorously shaking the cylinder while turning it end over end. Then agitate thoroughly with a stirring rod to make it homogenous.

21. After stirring, immediately lower the intake end of the pipette to a depth of 10 cm from the water surface and take a "zero-time" withdrawal by filling the pipette in about 6 to 10 seconds. Note the water temperature. This withdrawal gives the total concentration of fines. The pipette may be marked at 10 cm above its intake to facilitate a quick withdrawal.

22. Empty the pipette into an evaporating dish of predetermined tare weight, wash the pipette with distilled water. Blow off the pipette to remove water sticking to the intake.

23. Dry the dish in an electric oven overnight at 105-110°C, cool in a desiccator and when cool, determine the weight of the sediment plus the dish to the nearest 0.1 milligram.

24. Compute the weight of fines as follows:

    Volume of sample in pipette = X
    Volume of cylinder = Y
    Volume factor = Y/X
    Wt. of dish = T1
    Wt. of sediment + dispersing agent + dish = S1
    Wt. of sediment + dispersing agent = S1 - T1
    Dispersing agent correction = X (grams/ml)
    Wt. of sediment = [S1-T1-X (grams/ml)][Volume Factor]

25. Shake the cylinder thoroughly, place on the table and start the stop watch.

26. Note the temperature of the water, determine the time schedule for withdrawal for various particle sizes for the observed temperature. Figure 32 shows

timings at withdrawal for particle sizes of 0.0442, 0.0312, 0.0221, 0.0156, 0.110, 0.0078, 0.0055 and 0.0039 mm corresponding to various temperatures.

27. Make withdrawals at 10 cm depth at the scheduled times, transfer the pipette sample to the evaporating dishes of known tare weights, washing the pipette every time with distilled water.

28. Dry the dishes in an oven at 105 to 110°C overnight, cool in a desiccator and weigh to the nearest 0.1 milligram.

29. Make computations for each withdrawal as shown in step 24.

30. Complete the analysis form. The computations should be made for total concentrations in PPM and percentages finer than for each size.

Bottom Withdrawal Tube (BWT) Method

The BWT method is suitable for samples with low concentrations. The method makes direct application of the Oden theory, which depends on Stokes Law. The theory assumes four conditions: (1) that the size of the particles vary by infinitesimal amounts, (2) that the temperature (or viscosity) of the sedimentation media remains constant, (3) that complete dispersion of the particles exist in the sedimentation media, and (4) that the particles do not interfere with each other during descent. Assuming a tube as a settling media, particles accumulating at the bottom of the tube at any time "t" will consist not only of particles with fall velocities great enough to fall the entire length of the tube but will also consist of smaller particles which had a shorter distance to fall. Figure 33 shows a plot of time (as the abscissa) and percentage by weight of material remaining in suspension (as the ordinate). The curve is known as the Oden Curve.

If tangents are drawn to the curve at any two points corresponding to times t_1 and t_2, and the tangents allowed to intersect the ordinate axis at W_1 and W_2, then the difference between the percentage W_2 and W_1 will represent the amount of material in a size range with limits determined by the settling times t_1 and t_2.

Time Chart for Pipette Analysis.

	Size of Particles in mm. Time in Hours-Minutes-Seconds.							
T°C	.0442	.0312	.0221	.0156	0.011	.0078	.0055	.0039
10	1.14	2.23	4.58	9.58	20.00	39.54	1-20-12	2-39-20
10.5	1.13	2.27	4.54	9.49	19.45	39.21	1-19-06	2-37-13
11	1.12	2.25	4.50	9.41	19.30	38.48	1-18-0	2-35-06
11.5	1.11	2.24	4.46	9.39	19.12	38.15	1-16-54	2-32-54
12	1.10	2.22	4.41	9.37	18.54	37.42	1-15-48	2-30-42
12.5	1.09	2.20	4.38	9.23	18.45	37.12	1-14-45	2-28-39
13	1.08	2.17	4.34	9.09	18.36	36.42	1-13-42	2-26-36
13.5	1.08	2.16	4.31	9.02	18.18	36.12	1-12-45	2-24-42
14	1.07	2.14	4.27	8.55	18.00	35.42	1-11-48	2-22-48
14.5	1.06	2.12	4.24	8.48	17.45	35.15	1-10-48	2-20-59
15	1.05	2.10	4.20	8.41	17.30	34.48	1-9-48	2-19-06
15.5	1.05	2.09	4.17	8.35	17.15	34.21	1-8-57	2-17-15
16	1.04	2.07	4.13	8.27	17.00	33.54	1-8-06	2-15-24
16.5	1.03	2.06	4.10	8.22	16.48	33.27	1-7-15	2-13-42
17	1.02	2.04	4.07	8.15	16.36	33.00	1-6-24	2-12-00
17.5	1.01	2.03	4.04	8.09	16.24	32.36	1-5-33	2-10-24
18	1.00	2.01	4.01	8.01	16.12	32.12	1-4-42	2-8-48
18.5	1.00	2.00	3.57	7.57	16.00	31.48	1-3-54	2-7-37
19	0.59	1.58	3.55	7.51	15.48	31.24	1-3-06	2-6-26
19.5	0.57	1.57	3.52	7.45	15.36	31.00	1-2-21	2-4-28
20	0.57	1.55	3.49	7.40	15.24	30.36	1-1-36	2-2-30
20.5	0.57	1.54	3.47	7.35	15.18	30.30	1-0-54	2-1-12
21	0.56	1.52	3.44	7.29	15.06	29.54	1-0-12	1-59-38
21.5	0.55	1.51	3.41	7.24	14.54	29.33	1-0-0	1-57-54
22	0.55	1.50	3.38	7.18	14.42	29.12	0-58-42	1-56-48
22.5	0.54	1.49	3.36	7.13	14.30	28.51	58-03	1-55-27
23	0.53	1.47	3.33	7.08	14.18	28.30	5[illegible]-24	1-54-06
23.5	0.53	1.46	3.31	7.03	14.09	28.12	56-42	1-52-48
24	0.52	1.44	3.28	6.58	14.00	27.54	56-00	1-51-44
24.5	0.52	1.43	3.26	6.53	13.54	27.36	55-24	1-18-12
25	0.51	1.42	3.23	6.49	13.42	27.18	54-48	1-49-00
25.5	0.50	1.41	3.22	6.44	13.36	27.00	54-06	1-47-15

	Size of particles in mm. Time in Hours-Minutes-Seconds.							
T°C	.0442	.0312	.0221	.0156	.011	.0078	.0055	.0039
26	0.50	1.40	3.19	6.40	13.24	26.36	53.24	1-45-30
26.5	0.49	1.39	3.17	6.36	13.15	26.18	52.54	1-44-51
27	0.49	1.38	3.14	6.31	13.06	26.00	52.54	1-44-12
27.5	0.48	1.37	3.12	6.27	12.57	25.52	51.48	1-42-57
28	0.48	1.35	3.10	6.22	12.48	25.48	51.12	1-41-42
28.5	0.48	1.35	3.09	6.15	12.42	25.21	50.27	1-40-42
29	0.47	1.34	3.07	6.14	12.36	24.54	50.06	1-39-42
29.5	0.47	1.33	3.05	6.10	12.27	24.39	49.36	1-38-45
30	0.46	1.32	3.02	6.06	12.18	24.24	48.08	1-37-40
30.5	0.45	1.31	3.01	6.02	12.09	24.09	48.36	1-36-42
31	0.45	1.29	2.59	5.58	12.00	23.54	48.08	1-35-36
31.5	0.44	1.28	2.57	5.55	11.54	23.39	47.36	1-34-36
32	0.44	1.28	2.55	5.51	11.48	23.24	47.06	1-33-36
32.5	0.42	1.24	2.46	5.47	11.39	23.09	46.36	1-32-36
33	0.39	1.19	2.37	5.43	11.30	22.54	46.06	1-31-36
33.5	0.39	1.18	2.35	5.40	11.24	22.39	45.36	1-30-36
34	0.38	1.17	2.33	5.36	11.18	22.24	45.00	1-29-36
34.5	0.38	1.16	2.32	5.32	11.09	22.09	44.36	1-28-33
35	0.38	1.15	2.30	5.28	11.00	21.54	44.06	1-27-30
35.5	0.37	1.15	2.29	5.24	10.54	21.36	43.33	1-26-27
36	0.37	1.14	2.27	5.20	10.48	21.18	43.00	1-25-24
36.5	0.36	1.13	2.26	5.17	10.39	21.00	42.27	1-24-21
37	0.36	1.12	2.24	5.13	10.30	20.42	41.54	1-23-18

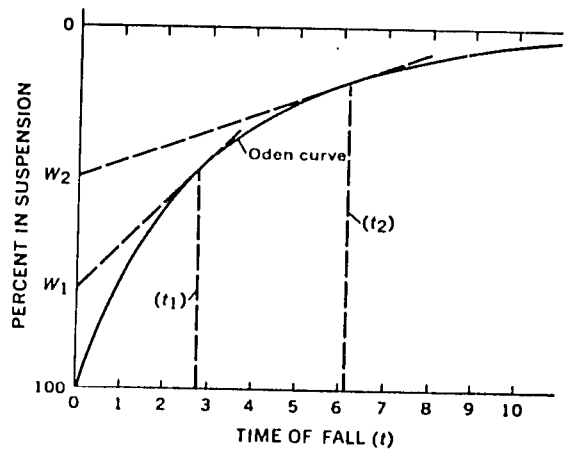


Figure 33 : Oden Curve Concept

Equipment: The equipment required for this method includes all the items listed for the "Pipette Method," and a BWT with adequate provisions for mounting the tube. Figure 34 shows an arrangement for the BWT method. The lower end of the tube is provided with a short piece of rubber tube slipped snugly over the small end of the tube and closed with a pinch clamp. This arrangement facilitates the withdrawals.

Analytical Procedure: The following step-by-step procedure should be followed.

1. Follow the steps 1 to 17 listed under the analytical procedures for the "Pipette Method," except that the analysis form is as shown on Figure 35.

2. Transfer the sample in the beaker (fine material, in step 9 of the "Pipette Method") to the BWT, wash the beaker with distilled water and bring the volume to the 100 cm mark of the tube. Care should be taken that in the washing process, the total volume of the sample should not increase above 500 to leave room for the water to be added in the BWT at the last stage.

3. Figure 36 shows different possible time schedules. Depending upon your experience with a particular site, select a time schedule so that a well defined Oden curve can be drawn. For samples with a fair percentage of clay, a time schedule of 120 minutes is generally followed while for predominantly coarse silt samples, a schedule of 40 minutes may be adequate. It is important to note that if a sample contains a low percentage of sand, the whole sample may be analyzed with a BWT. This will avoid the sieve analysis for material above 0.062 mm.

4. For this example, the particles of 0.062 mm and above have been separated by sieving. Therefore, for clay and silt particles, select the schedule "F" given in Figure 36. The water temperature of the 5th and 10th withdrawals should be noted. The average of these should be taken as the average temperature of the analysis.

5. After choosing a suitable time schedule, the sample in the BWT is thoroughly mixed by putting one hand on the open end of the tube and the tube is inverted up and down in an inclined position for about three minutes.

6. Fix the tube in the clamps of the wooden stand, start the stop watch just when the tube attains a vertical position.

7. As per schedule "F" (Figure 36), withdraw a column of 10 cm after 4 minutes into a graduated glass cylinder and note the volume of the withdrawal. Transfer the withdrawal into a preweighed numbered dish, and

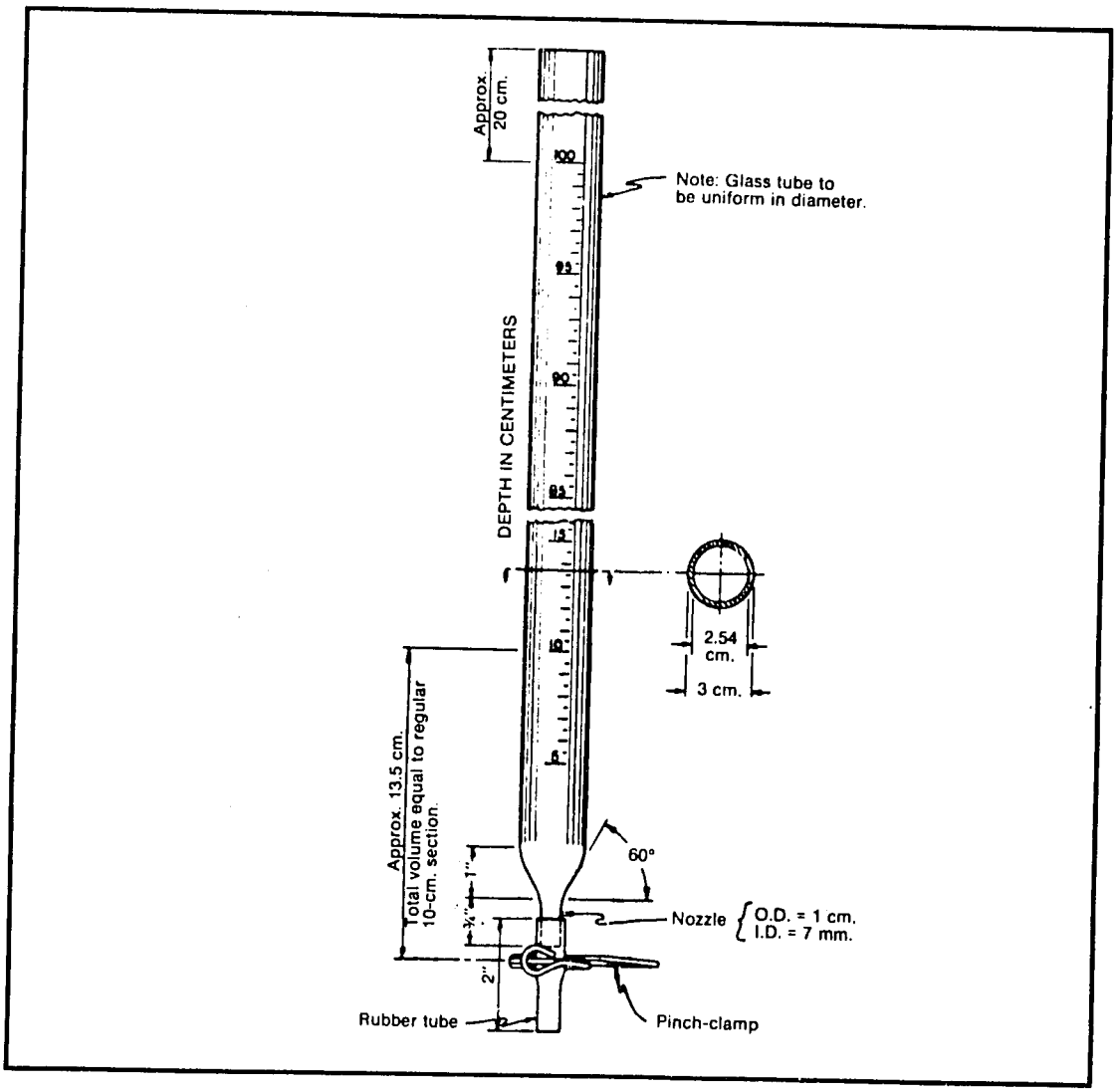


Figure 34 : Bottom Withdrawal Tube

IRRIGATION DEPARTMENT

_____ CIRCLE _____ DIVISION

PARTICLE SIZE ANALYSIS, SIEVE - BOTTOM WITHDRAWL METHOD

Canal at _____ Sampler _____ Data Collected _____ Water Temp. _____

Gate Hieght _____ Sampling Depth _____ Sampling Time _____ Sampling Location _____

Analysis Data

Date _____ Analyzed By _____ Computed By _____ Checked By _____

Water - Sediment Mixture			Dissolved Correction		Results	
No.	Bottle + Mixture	Bottle	Disp. Agent =		No of Sample Composed =	
			Volume =	cc	Wt of Sediment Mixture	gm
			Tare Dish =	gm	Net Sediment =	gm
			Dish + Agent =	gm	Mean Concentration =	ppm
			Net Agent =	gm	Sand ≥ 0.062 =	%
Total Bottles + Mix =		gpm	Correction =	gm/cc	Silt, between .062 - .0055	%
Total Bottles =		gpm			Clay < 0.0055 =	%
Sediment Mix =		gpm				

Sieve Analysis

Particle Size, mm										Pan
Container No.										
Weight-gm	Gross									
	Tare									
	Net									
% of Total										
% Finer than										

Bottom Withdrawl Analysis.

Temp fifth withdrawl (T_5) = Temp. Tenth Withdrawl (T_{10}) = Avg Temp =

No.	Clock Time	Elps. Time. (min)	Fall Ht. (cm)	Vol Samp (ml)	Dish No.	Wieght (gm) Gross	Tare	Sed.	Disc. Corr.	Net	Cumu. Wt Read. Up.	Depth Fac--tor	Sed in Susp 100 cm Fall	% Sed in Sus--pen	Time to Settle 100 cm
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
												100/4	(12)x(13)		(3)x(13)
0															
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															

Settling Time Schedule for Bottom Withdrawl Tube Method.

	Elapsed Time Min-Sec.	Time to Settle 100 cm Min.		Elapsed Time Min-Sec.	Time to Settle 100 cm Min.		Elapsed Time Min-Sec.	Time to Settle 100 cm Min.
A	0-15	0-28	D	0-27	0-50	G	0-15	0-28
	0-27	0-56		0-48	1-00		0-50	1-04
	0-48	1-14		1-24	2-00		1-24	2-00
	1-45	2-92		3-00	5-00		3-00	5-00
	2-24	4-80		10-0	20-0		5-00	10-0
	3-00	7-50		16-0	40-0		16-0	40-0
	4-48	16-0		27-0	90-0		30-0	100-0
	7-30	37-0		35-0	175-0		80-0	400-0
	10-0	100-0		40-0	400-0		120-0	1200-0
B	0-27	0-50	E	0-54	1-00	H	4-30	5-00
	0-48	1-00		4-00	5-00		10-0	12-50
	1-24	2-00		10-0	14-30		17-0	25-0
	3-00	5-00		24-0	40-0		30-0	50-0
	7-30	15-0		50-0	100-0		50-0	100-0
	10-0	25-0		80-0	200-0		100-0	250-0
	12-0	40-0		90-0	300-0		250-0	833-0
	16-0	80-0		100-0	500-0		300-0	1500-0
	20-0	200-0		120-0	120-0		400-0	4000-0
C	0-27	0-50	F	4-00	4-44	I	0-90	0-17
	0-48	1-00		6-00	7-50		0-15	0-31
	1-24	2-00		10-00	14-30		0-42	1-00
	3-00	5-00		24-0	40-0		2-32	4-20
	7-30	15-0		50-0	100-0		7-30	15-0
	20-0	50-0		80-0	200-0		25-0	62-0
	27-0	90-0		90-0	300-0		75-0	250-0
	30-0	150-0		100-0	500-0		200-0	1000-0
	40-0	400-0		120-0	1200-0		400-0	4000-0

wash the cylinder into the dish with distilled water taking care that no sediment remains sticking to the sides of the cylinder. In this withdrawal, the particles fall a height of 90 cm.

8. Continue withdrawals after 6, 10, 24, 50, 80, 90, 100 and 120 minutes (now total of nine withdrawals, the ninth withdrawal has a fall height of 10 cm). Take the tenth withdrawal also at 120 or 122 minutes because of zero fall height.

9. As in step 7, the withdrawals should be taken into graduated glass cylinders, note the volume of each withdrawal, transfer to preweighed, numbered dishes and wash cylinders into the dishes with distilled water.

10. Dry the dishes in an electric oven at 105°-110°C overnight, transfer to a desiccator, when cool weigh to the nearest 0.1 milligram.

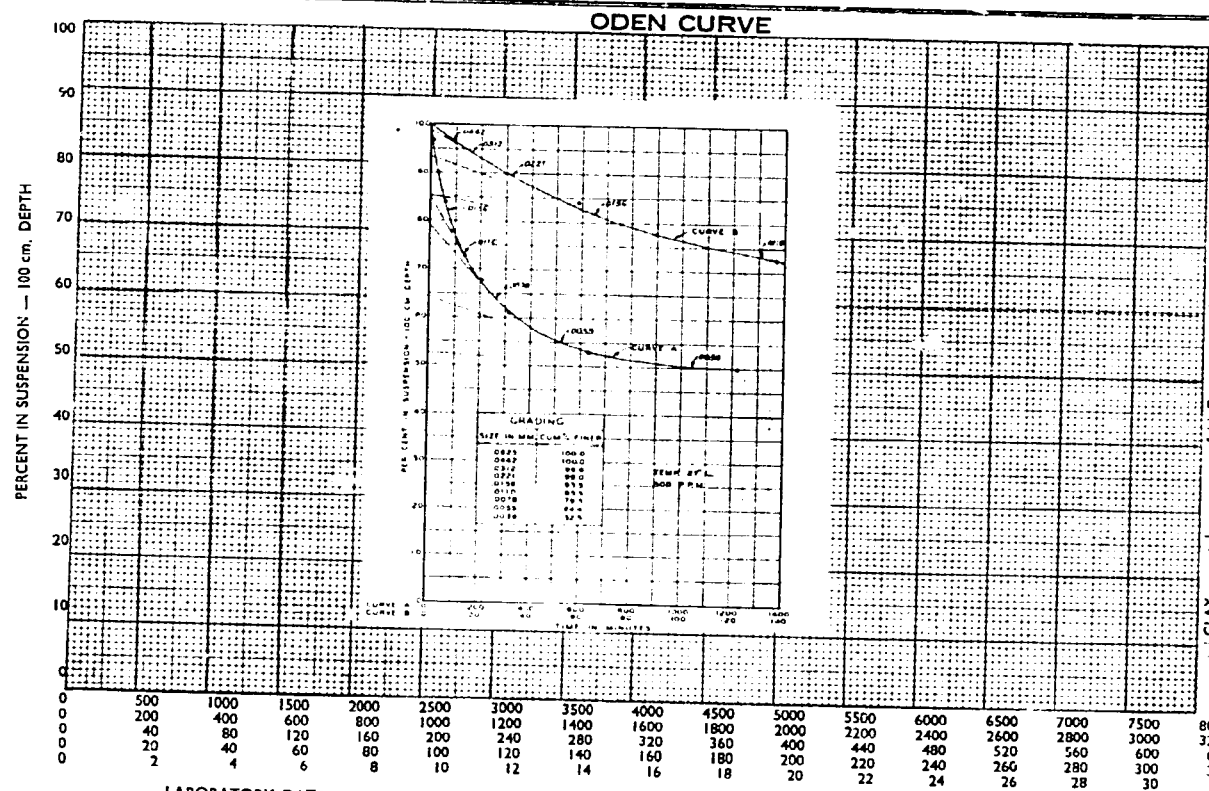
11. Calculate the net sediment and percent in suspension as shown on Figure 35. A correction for sodium oxalate, used as dispersing agent, is required.

12. Combine the results of the sieve analysis with those of the BWT at this stage. Plot the data from columns 12 and 13, Figure 35 to draw an Oden curve (Figure 37). Two curves are shown on Figure 37. The upper curve is an enlarged version of the upper portion of the lower curve to facilitate the determination of the gradation of coarse particles. The choice of the horizontal scale is arbitrary to draw a smooth curve through the plotted points.

13. The sieve analysis generally provides particle size distributions of three or four sizes. Draw the Oden curve properly such that the results of sieving and percentages read from the Oden curve are the same.

14. Compute the percentage from the Oden curve with the help of the time chart shown on Figure 38. Read the time in minutes from this chart corresponding to the required particle size (for which the percent finer is required) and the temperature of the analysis (average of 5th and 10th withdrawals).

15. Transfer the time determined in step 14 above, to the appropriate time scale of the Oden curve (same scale as used to draw the curve), draw a vertical meeting the curve, and mark the size of the particle in mm at the crossing point.



GRADING

SIZE IN m. m.	CUMUL % FINER
1.0	
0.50	
0.25	
0.125	
0.0625	
0.0442	
0.0312	
0.0221	
0.0156	
0.0110	
0.0078	
0.0055	
0.0039	
0.00276	
0.00195	

LABORATORY DATA

Lab. No. _____ Temp., °C _____

Date of Test _____ Time _____ M.

Total Percent Sediment by Weight _____

Plotted by : _____ Checked by : _____

FIELD DATA

_____ River at/nr _____

Date _____ Time _____ M.

Gage Height _____ Ft. Discharge _____ C.F.S.

Figure 37

BOTTOM WITHDRAWAL SEDIMENTATION TUBE ANALYSIS

TIME TABLE TO BE USED WITH THE ODEN CURVE

Time in min. required for spheres having a specific gravity of 2.65 to fall 100 cm. in water at varying temperatures. Terminal fall velocity for particles 0.00195 to 0.0625 mm. computed according to Stokes' Law; terminal fall velocity for coarser particles taken from curves prepared at The California Institute of Technology.

Temp. °C.	Particle Diameter in mm.														
	1.00	0.50	0.25	0.125	.0625	.0442	.0312	.0221	.0156	.0110	.0078	.0055	.0039	.00276	.00195
10	0.115	0.243	.592	1.73	6.22	12.4	24.9	49.7	99.6	200	399	802	1594	3182	6380
11	0.114	0.240	.577	1.68	6.03	12.1	24.2	48.3	96.9	195	388	780	1551	3095	6206
12	0.113	0.237	.568	1.65	5.87	11.7	23.6	46.9	94.2	189	377	758	1507	3007	6031
13	0.112	0.233	.552	1.62	5.72	11.4	22.9	45.7	91.6	184	367	737	1466	2927	5868
14	0.111	0.232	.552	1.59	5.57	11.1	22.3	44.5	89.2	180	357	718	1428	2850	5715
15	0.110	0.228	.543	1.56	5.42	10.8	21.7	43.3	86.9	175	348	698	1391	2776	5566
16	0.109	0.227	.538	1.53	5.27	10.6	21.2	42.2	84.6	170	339	681	1354	2703	5421
17	0.108	0.225	.528	1.50	5.15	10.3	20.6	41.1	82.5	166	330	664	1330	2969	5285
18	0.107	0.222	.522	1.48	5.02	10.0	20.1	40.1	80.5	162	322	647	1288	2570	5154
19	0.107	0.220	.515	1.45	4.88	9.77	19.6	39.1	78.5	158	314	631	1256	2507	5026
20	0.106	0.218	.508	1.41	4.77	9.53	19.2	38.2	76.6	154	306	616	1225	2445	4904
20.5	0.106	0.217	.505	1.40	4.72	9.43	19.0	37.8	75.8	153	303	609	1212	2418	4849
21	0.105	0.217	.503	1.39	4.67	9.32	18.7	37.3	74.9	151	299	602	1198	2391	4794
21.5	0.105	0.215	.500	1.38	4.61	9.21	18.5	39.9	74.0	149	296	600	1179	2362	4735
22	0.104	0.213	.497	1.37	4.55	9.10	18.3	36.4	73.0	147	292	587	1168	2332	4675
22.5	0.104	0.213	.492	1.35	4.50	8.99	18.1	36.0	72.2	145	289	580	1155	2305	4621
23	0.104	0.212	.488	1.34	4.45	8.88	17.8	35.5	71.3	143	285	574	1141	2277	4566
23.5	0.104	0.210	.487	1.33	4.39	8.78	17.6	35.1	70.5	142	282	567	1128	2251	4514
24	0.103	0.210	.485	1.32	4.33	8.67	17.4	34.7	69.6	140	279	560	1114	2225	4461
24.5	0.103	0.210	.480	1.31	4.29	8.58	17.2	34.3	68.9	139	276	554	1102	2200	4411
25	0.103	0.208	.478	1.30	4.25	8.48	17.0	33.9	68.1	137	273	548	1090	2175	4361
25.5	0.102	0.208	.475	1.29	4.20	8.38	16.9	33.6	67.4	136	270	541	1078	2151	4312
26	0.102	0.207	.472	1.28	4.15	8.28	16.7	33.2	66.6	134	265	534	1065	2126	4263
27	0.101	0.205	.467	1.26	4.05	8.10	16.3	32.4	65.1	131	260	524	1042	2076	4169
28	0.101	0.203	.462	1.24	3.97	7.93	15.9	31.7	63.7	128	255	512	1019	2034	4079
29	0.100	0.202	.455	1.22	3.89	7.77	15.6	31.1	62.3	125	249	501	997	1990	3991
30	0.0998	0.200	.450	1.20	3.80	7.60	15.3	30.4	61.0	123	244	491	976	1948	3507
31	0.0991	0.199	.445	1.18	3.71	7.43	14.9	29.8	59.7	120	239	481	955	1908	3825
32	0.0987	0.197	.442	1.17	3.65	7.28	14.5	29.2	58.5	118	234	471	936	1869	3747

Figure 38

16. Draw a tangent from the above size-point to meet the vertical scale. The reading on the vertical scale represents the percentage finer than this particular size.

General precautions for this method are that the pinch-clamp should be opened quickly to full width about one second before the selected withdrawal time and then closed slowly as the last of the sample is being withdrawn. A full opening is required at the start to produce a rush of water clearing any deposited sediment in the narrow neck of the tube. It should be remembered that the total elapsed time is the time when the pinch clamp is closed. The samples should be taken in a 100 ml cylinder to eliminate the possibility of losing a part of the sample from splashing.

In both pipette and BWT analysis, distilled water has been recommended in order to obtain a free fall of the particles. In some cases, a true picture of sedimentation may be required. For this purpose, the aggregates of soil particles which appear in the natural streams should not be broken. The native water (decanted water from the samples) should be used as the settling media.

The construction of the Oden curve and drawing of the tangents is very important and greatly affect the result of the analysis. The slope of the curve should never be zero or negative over the period of time covered by the analysis. A tangent at a point is difficult to draw if the slope is too flat or too steep. The horizontal scale should be properly selected to minimize this difficulty. The use of two curves (one an enlargement of the upper portion of the main curve) is recommended.

Particle Size Analysis of Bed Material

Bed material samples will be obtained using US BMH 53 samplers. About 100 grams of sample is sufficient for analysis. The particle size distribution should be determined by sieving. A set of 3-inch diameter and 8-inch diameter sieves are provided. The following steps should be followed:

1. Arrange samples at one sampling station in a chronological order and select the samples to be analyzed.

2. Transfer the field data to the analysis form shown on Figure 39.

3. Dry the sample in the oven if required.

4. Transfer the dry sample to a nest of sieves. For particles greater than 5.6 mm, use 8-inch diameter sieves. For smaller sizes, a set of 3-inch diameter sieves is provided.

5. Weigh the sediment retained on each sieve carefully to the nearest 0.1 milligram. The sediment from the sieve should be carefully brushed into the weighing pan.

6. Record the data as shown on form 39.

The gradation curve for the bed material should be prepared on a form as shown on Figure 40.

_____ IRRIGATION DEPARTMENT

_____ CIRCLE _____ DIVISION

PARTICULAR SIZE DISTRIBUTION, BED MATERIAL SIEVE ANALYSIS

_____ Canal At _____ Data Collected

Gate Hieght _____ Sampling Time _____ Sampling Location _____

Data Analyzed _____ Date Analyzed _____ Checked By. _____

Particle Size	Sieve No.	Container No.	Weight (gm)			% of Total	% Finer
			Gross	Tare	Net		

NO. SP-2:56
COOKE LOCK COMPANY, INC. HOLYOKE, MASSACHUSETTS

Gradation Curve for Bed Material

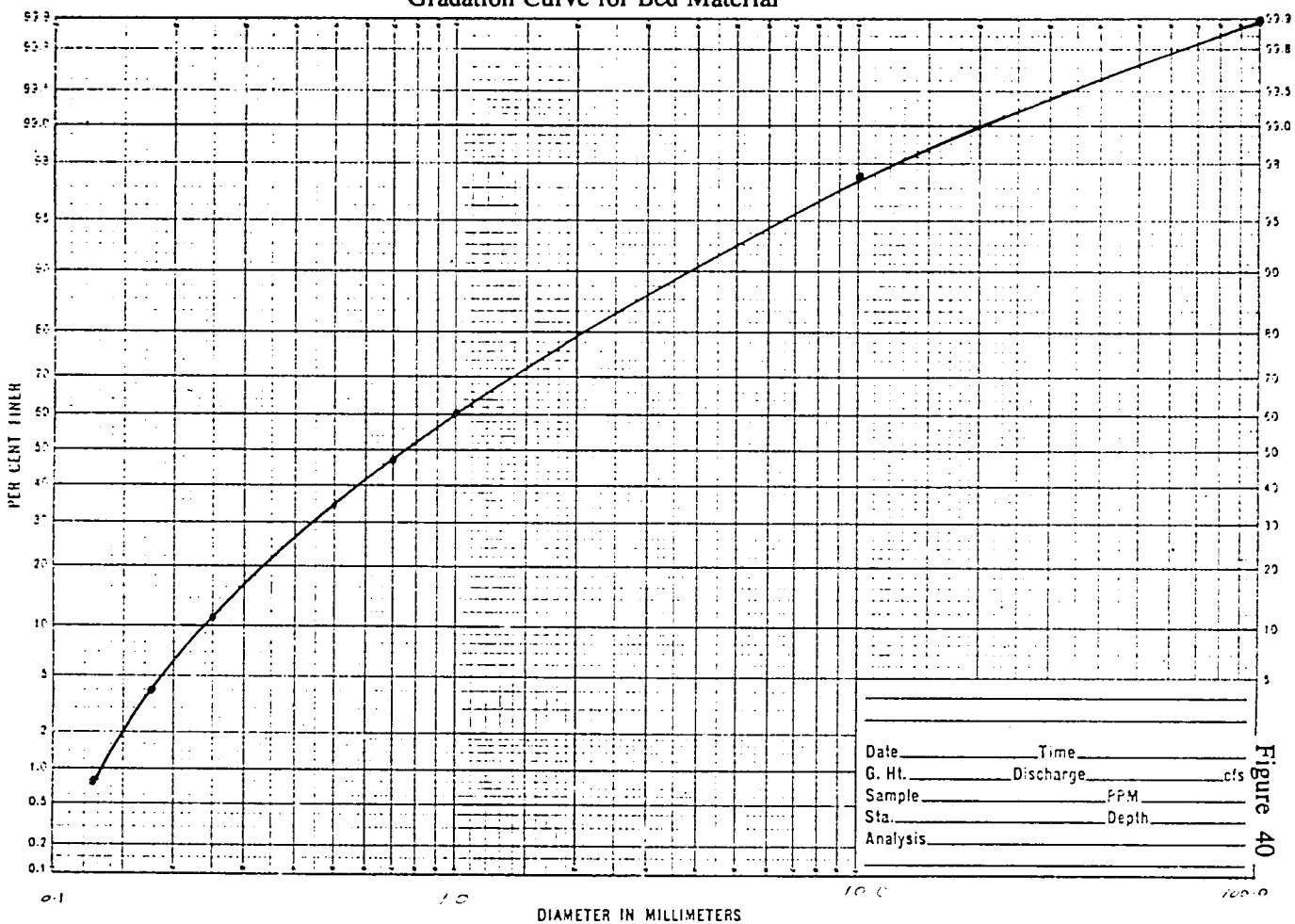


Figure 40

Chapter 8

PERFORMANCE HISTORY

A performance history of the irrigation system under the control of an executive engineer should be prepared after every 5-year period based on the information and data collected through monitoring efforts. This performance history should clearly indicate any problem in the system. A channel reach should be considered problematic if any of the following conditions are observed.

- The canal cannot pass the design discharge;
- Frequent shortages exist at the tail;
- Periodic silt clearance is required;
- Inequitable distribution of flow in outlets;
- Berms are overgrown;
- Heavy silt passes through outlets; or
- Frequent breaches occurred during the 5-year period.

The executive engineer in charge of the system should identify the reasons for the above problems and prepare a report for the review of his superintending engineer. The superintending engineer, in consultation with the executive engineer, should determine the remedial measures to improve the performance of the system.

Generally, a channel reach may have to be redesigned if chronic shortages exist at the tail and heavy silt is drawn through the outlets. If a canal is carrying flow higher than the design capacity and also some modification is needed to outlets, it may need to be rehabilitated. In some reaches periodic clearance of silt may solve the problem. Overgrowth on the banks should be removed periodically.

Basic data used for evaluating the performance of systems are discussed below.

Hydraulic Data

The periodic water levels and flow data collected at key locations should be compared to determine, whether for a given water level at a location, the flow has increased or decreased. A decreased flow will indicate silting in the channel reach whereas an

increase in the flow will indicate scour. The water level data also should be used in conjunction with the canal survey data to dctermine any encroachment on the canal freeboard. The periodic flow measurements downstream from a control structure should be used to evaluate the performance of the structure by comparing the observed flow with the rated flow (generally determined from empirical relationships).

Sediment Data

Long-term changes in the water levels can occur because of changes in the quantity and quaiity of the sediment entering the system at diversion points. The periodic measurements of the total concentration of the suspended sediment should be used to determine whether the quantity of sediment carried through the system has increased or decreased over a period of time. The particle size distribution of the suspended sediment and bed material also should be reviewed to check the quality of the sediment. An increase in coarse particles is likely to increase siltation near the tail reaches of the system.

Morphological Data

Periodically surveyed longitudinal and cross sectional profiles should be compared to determine depth of scour and siltation in various canal reaches.

Visual Observation Data

The data collected should be used to determine whether the canal has overflowed and whether any breaches have occurred due to restricted canal capacity caused by heavy overgrowth or damage to canal banks.

Chapter 9

FIELD DATA CATALOGING AND OFFICE ANALYSIS

Hydraulic and sediment data form the basis for any future rehabilitation or design studies for the irrigation system. Therefore, every effort should be made that these data are properly collected in the field, well documented and properly stored. This chapter provides guidelines for reviewing, interpreting, analyzing and compiling the data.

Initial Scrutiny and Compilation

Field Procedures

The personnel responsible for data collection should be thoroughly familiar with the necessary techniques and precautions. At the time of actual data collection, the following checks should be made before leaving the site:

1. **Flow Measurement:** Review the entries on the measurement form. All entries should be clearly made, and no entry left blank. If an entry is not applicable, mark it with a dashed line. Make sure the recorder, if any at the site, is properly marked. Any problem during the measurement or factors affecting the accuracy of the measurement or gage readings should be documented. Do not depend upon your memory to write down these factors later or in discussions with the superiors. It is recommended that the flow computations should be made before leaving the site.

2. **Sediment Sampling:** Make all entries on the label. Do not leave a blank entry. Because samplers provided are for wadable canals, there may be a tendency to use these in deeper canals. This may affect the representativeness of the sample. Also check the contents of the bottles and compare the samples at one site for any excessive coarse material in any bottle. Discard the sample which is not representative.

3. **Surveying:** At each setting of the instrument, the entries in the level book should be checked before removing the instrument. If errors due to hot weather are possible and the levelling work has to be done, properly document the field conditions. Preferably, the levelling should be performed in the morning hours or in the evening. Do not leave the site before completing your calculations. The closing error in the levelling should be checked before leaving.

4. **Visual Observation:** When checking for vegetative growth on berms, canal bed, etc., and encroachment on freeboard, do not depend upon your memory. Use a field note book to document your observations systematically.

Field personnel should prepare a list of data including pertinent remarks and dates of observation before sending them to the divisional offices. If feasible, a copy of the data should be retained by the sub-divisional officer (SDO). A log book of each gaging station should be prepared by the SDO. The log book should contain a complete history of the station since its installation. All remedial work undertaken at the gaging stations (fixing staff gages or cleaning silt from stilling wells) should be documented in this log book in chronological order.

Office Procedure

The divisional office should maintain the following files for the field data received from each station. The data should be filed in a chronological order.

1. Discharge measurement notes.
2. Staff gage weekly sheets.
3. Recorder charts.
4. List of sediment samples received from the field.
5. Sediment sample analysis results received from the circle office.
6. Survey notes on canal longitudinal and cross sectional profiles.
7. Survey notes on freeboard computations.
8. Visual observations of canal conditions including history and causes of breaches, if any, in a canal reach.

The executive engineers should review the data before filing and initial each data sheet. Any missing entry or remedial measures that have been undertaken, and have not been reported, should be immediately discussed with the concerned field office. If an executive engineer has some doubts about a field observation (discharges, gages, survey, etc.), he should inform the concerned SDO in writing and keep his response on file.

Analysis and Computations of Flow Record

The basic procedure for the analysis and computation of flow records consists of the following steps.

1. Determination of daily gage heights.

2. Establishment of stage - discharge relationships.

3. Determination of mean daily discharges.

4. Documentation.

Daily Gage Heights

The gage height records will be either a continuous recorder chart or staff gage height observations made twice a day. Daily water level fluctuations are not expected in the canals because of general irrigation practices in Pakistan. The canals are running either at a full supply level or at a reduced level depending upon the demand. Therefore, weighted mean gage heights during the day will generally be not required.

Observed Gage Height Data: First check the data for the following.

a. Any abrupt rise or fall due to mistakes on the part of the gage observer.

b. Any reported change in gage datum due to refixing of the gage.

c. Any remark by the observer as to the accuracy of the data, for example, obscured gage markings, water surface below the gage plate and observations made with the help of a graduated rod, gage read from a distance, etc.

If there is a datum correction, clearly identify the gage height record with the new datum. The change in the datum should be treated as a correction to the stage-discharge relationship based on the old datum. If discharge measurement data are available at the station, the gage height on the measurement note should be tallied with the gage height sheet. This is an important step because if the gage observer was not present at the time of the measurement, this will provide a check on his reliability.

Mean daily gage height should be computed as the average of the two readings. If more readings have been taken because of gradual changes in the canal discharge, the mean daily gage height is not of much significance, the mean daily discharge should be computed directly from the gage data as discussed under "Mean Daily Discharges".

Recorded Gage Height Data: On a water level recorder chart, a continuous trace of gage height data is available. First, the gage heights on the measurement notes should be tallied with the gage height on the chart. Then the following steps should be followed:

a. Determine the differences between the recorder and index bracket readings and recorder and outside staff gage at the time of the first setting on the chart. If the index bracket and the outside gage has not been disturbed, the two differences should be same. The difference should be equal to zero because at the first setting the recorder is set to the outside and index readings.

b. Determine the differences at the next checking. If there is a difference, check whether the checking was made when the recorder was in "reversal" or in "normal" (see Figure 20 for the definition of "reversal" and "normal"). If the checking is in "normal", the difference is called "index correction". If the difference at the first checking is zero and the next checking is "x", the error of "x" is distributed linearly between the two settings.

   If the next checking is in reversal, the difference is called the total correction and consists of the reversal correction plus the index correction. The reversal correction should be computed from the "reversal" and subtracted from the total correction to determine the index correction. The index correction should be distributed linearly between the two settings. The reversal correction is applied in the period of reversal (Figure 20). If a "reversal" occurs between two settings, and there is an index correction distributed linearly, two corrections (reversal and index) should be applied in the reversal period.

c. The time correction on a chart is the difference between actual watch time and the time indicated by the time-scale of the recorder. The chart may be slow or fast moving. The correction should be applied linearly between two settings. Minimum time correction is one hour. Time correction less than 30 minutes should be neglected and more than 30 minutes should be treated as one hour and added to the other whole-hour correction if any.

d. Before computations of mean daily gage heights the above corrections should be applied and the trace should be adjusted for any abrupt change due to silting of inlets or other reasons.

e. Mean daily gage height for normal flow days should be computed by placing a set-square marked with a line on the tracing such that the area bounded by the tracing and the line, above and below the line, are equal and by reading the recorder chart at the crossing of the line and the line of the chart representing mid-day.

f. For the days with changes in gage height, the mean daily gage is not of much significance. The mean daily discharge should be computed as discussed under "Mean Daily Discharges."

Summary of Gage Heights: After the mean daily gage heights have been computed and checked, these should be copied on a form similar to that shown on Figure 41. The days on which the discharge measurements were made should be identified on this form. The days for which mean gage heights are not computed should be indicated by a letter "S", meaning that the days were sub-divided to determine the daily flow.

Stage-Discharge Relationships

The development of a stage-discharge relationship, generally known as a rating curve involves the following steps.

1. Listing discharge measurements.

2. Plotting measurements.

3. Drawing a rating curve.

4. Computing a rating table.

5. Comparing measurements with the rating.

Listing Discharge Measurements: The discharge measurements having been tallied with the gage record should be listed in a chronological order on a form shown on Figure 42. Care should be taken to copy all the pertinent remarks from the measurement notes on this form, which will be helpful in ascertaining the reasons for any deviations of a specific measurement from the general trend of other measurements.

The discharge figures should be written up to three significant figures and up to two decimal places. The time should be written as hour and minutes. The "Meas. Rated" means the rating of the measurement (excellent, good, fair or poor, see Figure 19) as judged by the field staff. At this stage, the gage heights of the measurements

File No. _____

Daily Gage Height, In _____ And Discharge, In _____ of

At _____ River

Near _____

Gage Heights and Discharge Measurements By _____

Discharges Computed By _____

For Year Ending _____ 19____

Used Rating Table Dated _____

Gage Read _____ Times Daily

Drainage Area _____

Day	Gage height	Discharge	Gage height	Discharge	Gage height	Discharge	Gage height	Discharge	Gage height	Discharge	Gage height	Discharge
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												
28												
29												
30												
31												
Total												

Day	Gage height	Discharge	Gage height	Discharge	Gage height	Discharge	Gage height	Discharge	Gage height	Discharge	Gage height	Discharge
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												
28												
29												
30												
31												

Day	Period	Time	Season	Place	Gr. Limits	Computed	Checked
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
31							

Figure 41 : Summary of Daily Gage Height and Discharge Data

File No._____

Sheet_____of_____

LIST OF DISCHARGE MEASUREMENTS

Discharge Measurements: River_____Station_____, during the calendar year 19____

No.	Date	Made by--	Width	Area	Mean Velocity	Gage height	Discharge	Rating		Method		Meas. secs.	G.H. change	Time	Meas. rated*	Water Temp.	Remarks
								Shift adj	Percent diff.								

Figure 42

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should be compared with the gage data on Figure 41, to be certain that the gages refer to the same datum.

Plotting Measurements: The discharge values and the corresponding gage heights should be plotted on a rectangular coordinate graph paper as shown on Figure 43. Other types of paper such as logarithmic or semi-logarithmic also can be used. However, the main advantage of this type of paper is that the trend in a sequence of measurements and their departures from a best-fitted curve can be easily identified.

The points should be plotted such that a rating curve can be drawn in three portions - low flow, medium flow and high flow. The medium flow curve should represent an expanded version of the lower part of the high flow curve. Similarly the low flow curve should represent the expanded version of the lower part of the medium flow curve. The scales of each portion (vertical and horizontal axis scales) should be such that the portions of the rating curve occupy roughly diagonal positions on the paper and there is some overlapping between low and medium and medium and high flow curves. The readings taken from the overlapping parts of the two portions for a common gage value, should be equal.

It is highly desirable that the discharge measurements cover the whole range of measured canal stages. However, in most cases this cannot be achieved. Therefore, the maximum and minimum observed or recorded gage heights should be compared with the maximum and minimum gage heights against which the measurements have been made. This will help in determining the extent to which the rating curve has to be extrapolated for low and high flows.

Drawing the Rating Curve: Before drawing the rating curve, the listing and plotting of measurements should be checked.

Most rating curves have the general shape of a parabola. The general shape is expressed as:

$$Q = a\,(G - e)^b$$

in which

Q = discharge
G = gage height
a = intercept equal to Q, when (G - e) = 1.0
b = slope of a straight line on log-log paper, and
e = the gage height when flow in the channel is zero, that is, equal to "G" when Q = 0

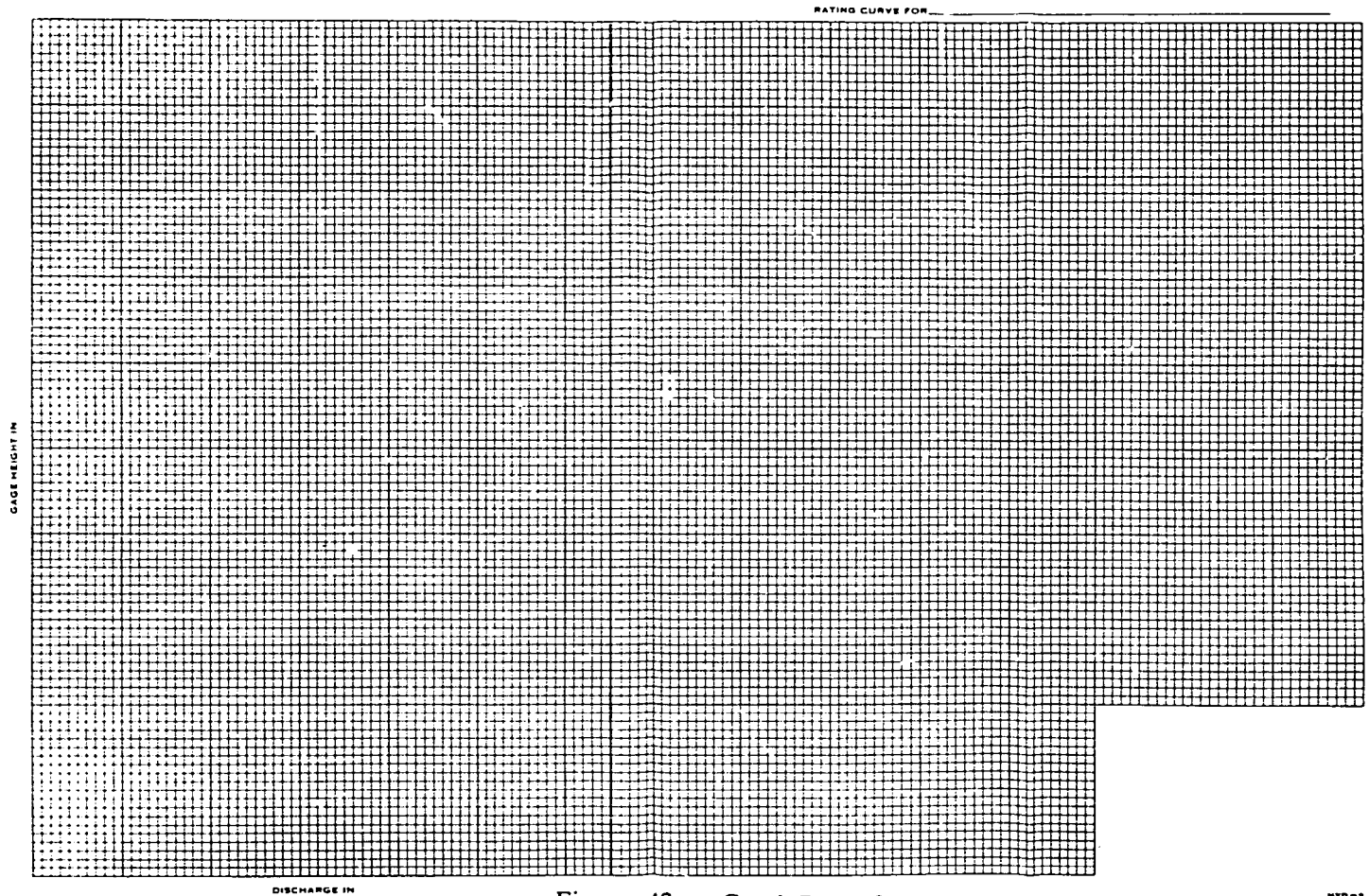

Figure 43 : Graph Paper for Plotting Rating Curves

If the rating curve at a station is of a permanent nature (for example, stations upstream of control structures), the value of "e" is constant and the curve with the ordinate represented by (G-e) plots as a straight line on the logarithmic paper. For gaging stations where the hydraulic characteristics control the curve, the value of "e" may be variable depending upon the silting and scouring of the downstream channel. In these cases, the rating curve is variable and should be checked through periodic measurements.

After having checked the plot, draw an approximate best fit curve through the plotted points, (assuming a rating curve is to be developed for a new gaging station where an old curve does not exist). Carefully, check the rising and falling trend of the measurements along this curve. The measurements made in high flows should indicate some scouring conditions and those in low flows, some deposition. If some of the measurements do not show consistent trends, recheck the gage heights, discharge computations, and the field conditions at the time of these measurements.

It should be realized that the discharge measurements are not error free. Therefore, using this preliminary rating curve compute the shift adjustment (deviation of a plotted point from the curve on gage height scale) as the rating curve gage height minus the measured gage height for each measurement. The positive values will show scour in the controlling reach of the canal and negative values will indicate a deposition. Also compute the percentage differences for each measurement, as: (measured discharge minus rating curve discharge) divided by rating curve discharge.

Because of inherent measuring errors, the shift should be considered as a combination of deviations caused by scour or deposition, and deviation due to measuring conditions or observer error. If the percentage differences are about $\pm$ 5 percent, the deviations should not be attributed to scour or deposition. The preliminary curve should be finalized after any minor adjustments.

If the percentage differences are significantly higher than 5 percent and there is no reason to consider that the differences are because of any measuring error, a best fitted curve should be drawn with due consideration to scour during high flows and deposition during low flows.

The rating curve should be checked by the executive engineer before developing a rating table.

For existing gaging stations or for the control structure, old rating curves are available. These should be plotted (if old plots are not available) on rectangular paper along with the most recent measurements. The shifts and percentage differences should be computed and reviewed critically. This review should determine whether a change in the rating has occurred and a new rating is required or the old rating is still applicable.

At control structures, scour and deposition does not occur. However, the stream bed immediately upstream of a structure may be affected. This will change the velocity of approach and thus slightly affect the rating. This should be checked periodically.

Extension of rating for low flows should be made using the procedure shown on Figure 44. The extension for high flows should be made on logarithmic paper. The vertical scale should be at gage height minus gage height of zero flow. The value of gage height of zero flow estimated as in Figure 44 may be used.

Computing Rating Table: A rating table is prepared from the rating curve to simplify the process of converting gage heights to discharges.

Values of discharge for each one tenth foot gage height should be read from the curve (larger intervals may be used for medium and high flows) and listed on the form shown as Figure 45 (sheet 1 of 2). The difference between each pair of adjacent numbers should be written under the "Difference" column. The differences may be slightly adjusted by trial and error until the differences shows a consistent rising trend. Sometimes, it is helpful to compute the second differences which also show a smooth variation, although not necessarily increasing with increasing discharges. The final rating table should be reviewed and checked by the executive engineer. A low flow portion of the table can be expanded to provide discharge directly for .01 foot changes, using the form shown as sheet 2 of 2, Figure 45.

If computer facilities are available and the preliminary curve indicates that scour and disposition corrections are not required (especially above the control structure) a best curve should be drawn through computerized regression analysis. In this case, there is no need to develop a rating table. The regression equations should be directly used with the mean daily gage heights to compute the mean daily discharges.

Comparing Measurements with Rating: After finalizing the rating table, the shift adjustments and the percentage differences should be recomputed. If the percentage differences are within $\pm$ 5 percent, a zero shift adjustment should be adopted. If the differences are significantly higher for some measurements, which are believed to be correct, the executive engineer or an experienced engineer under his command should decide how much of the deviation of the plotted discharge from the adopted curve is to be assigned to the error in the measurement and how much to the actual scour or deposition. Based on this judgement, the columns indicating "shift adj" and "Percent diff." (Figure 42) should be completed. The shift adjustments should be transferred to the form shown on Figure 41. As a guideline, it is recommended that the percent

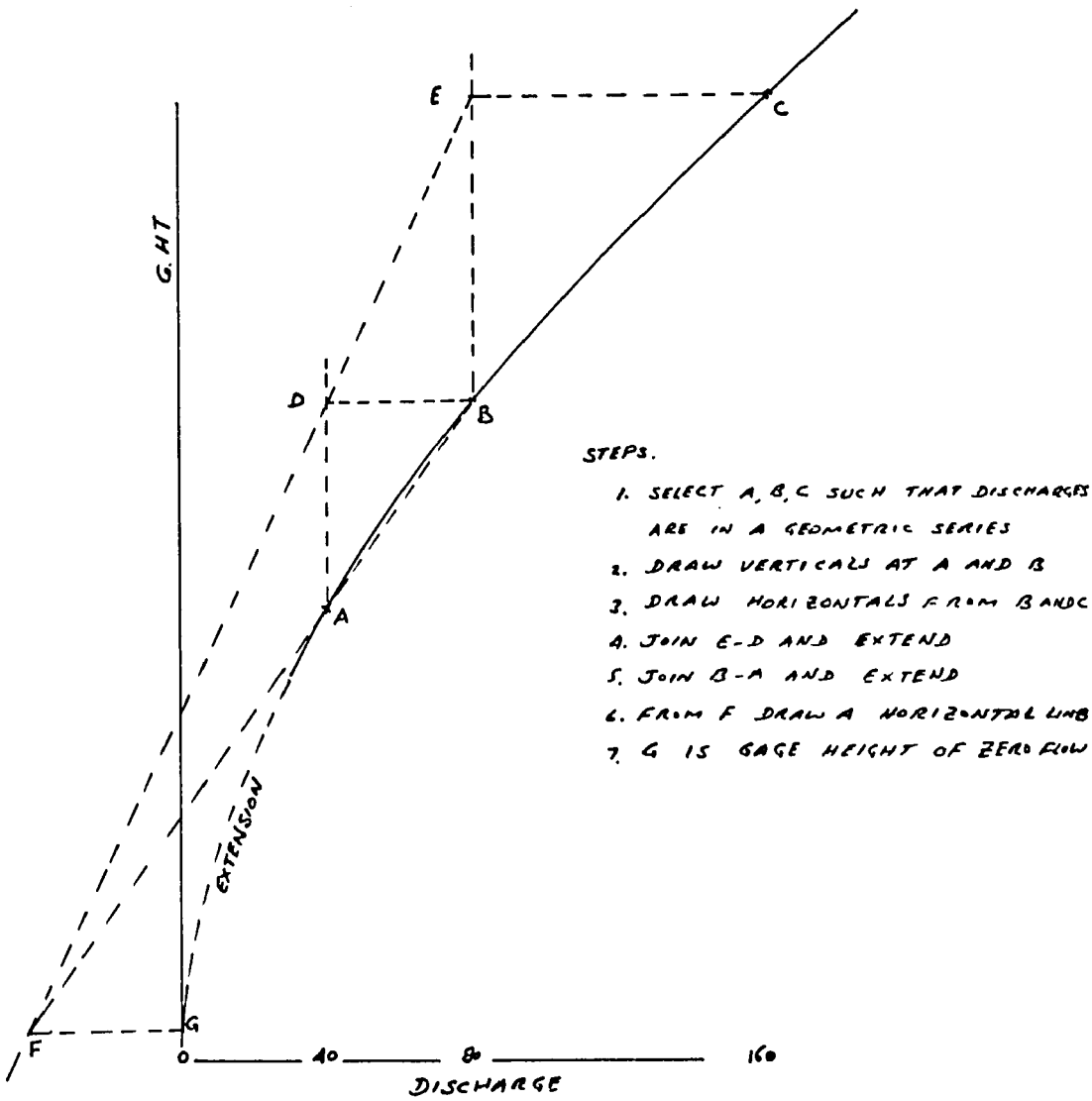

Figure 44 : Extension of Low Flow Rating Curve

Figure 45

SHEET 1 of 2

Rating table for .....

..... *, from* ....., *19* ....., *to* ....., *19* .....

Gauge height	Discharge	Differ-ence	Gauge height	Discharge	Differ-ence	Gauge height	Discharge	Differ-ence	Gauge height	Discharge	Differ-ence	Gauge height	Discharge	Differ-ence
.00			.00			.00			.00			.00		
.10			.10			.10			.10			.10		
.20			.20			.20			.20			.20		
.30			.30			.30			.30			.30		
.40			.40			.40			.40			.40		
.50			.50			.50			.50			.50		
.60			.60			.60			.60			.60		
.70			.70			.70			.70			.70		
.80			.80			.80			.80			.80		
.90			.90			.90			.90			.90		
.00			.00			.00			.00			.00		
.10			.10			.10			.10			.10		
.20			.20			.20			.20			.20		
.30			.30			.30			.30			.30		
.40			.40			.40			.40			.40		
.50			.50			.50			.50			.50		
.60			.60			.60			.60			.60		
.70			.70			.70			.70			.70		
.80			.80			.80			.80			.80		
.90			.80			.90			.90			.90		

The above table is not applicable for ice or obstructed channel conditions. It is based on ..... discharge measurements made during .....

.....

and is ..... well defined between ..... and .....

.....

.....

.....

..... *Computed by* .....

..... *Checked by* .....

..... *Date* .....

6—7847

Figure 45

Rating table for SHEET 2 OF 2

..... *Dated* ....., *19*.....

from ..... *to* ..... ; *from* ..... *to* .....

from ..... *to* ..... ; *from* ..... *to* .....

Gage height	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	Differences
.0											
.1											
.2											
.3											
.4											
.5											
.6											
.7											
.8											
.9											
.0											
.1											
.2											
.3											
.4											
.5											
.6											
.7											
.8											
.9											
.0											
.1											
.2											
.3											
.4											
.5											
.6											
.7											
.8											
.9											

mputed by ..... /...../*19*.....; *Checked by* ..... /...../*19*..... *Remarks* .....

.....

.....

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the percent difference should be taken about 5 percent. This is done on the assumption that the measurement is rated "good".

Mean Daily Discharges

Mean daily gage heights and shift adjustments transferred to the form shown on Figure 41 should be checked and reviewed by the executive engineer. Because the silting or scouring in the canals will be slow process, the shift adjustments between the days of flow measurements (for which the adjustments were computed) should be distributed linearly over time.

Computations of mean daily discharges on the form (Figure 41) should be made by first algebraically adding the shift adjustment (which could have a negative or positive sign) to the mean daily gage height and by looking up the discharge corresponding to this corrected gage height from the rating table. For the sub-divided days, if the observed gage height data are available, the following procedure should be followed (assuming 6 readings during the day).

Date	Time	Gage ft.	t	Avg. Gage ft.	Discharge	Avg. Disch.
24-9-91	18:00	0.80				
	24:00	1.10*				
25-9-91	08:00	1.50	8	1.30	Q_1	
	10:00	2.50	2	2.00	Q_2	$\frac{\Sigma T_i x Q_i}{24}$
	12:00	3.00	2	2.75	Q_3	
	14:00	4.50	2	3.75	Q_4	
	16:00	5.00	2	4.75	Q_5	
	18:00	6.00	2	5.50	Q_6	
	24:00	6.21*	6	6.11	Q_7	
26-9-91	08:00	6.50				

[* Linear interpolation]

For a station equipped with a water level recorder, hourly gage height data should be derived from the chart, adjusted for shifts and then applied to the rating table. A typical form for these computations is shown on Figure 46.

Figure 46

Computation of Mean Daily Discharges

Gage Height, in , and Discharge, in Cubic per Second, for 19.....

of .....

Hour	Gage		Discharge	Gage		Discharge	Gage		Discharge	Gage		Discharge	Gage		Discharge
0															
2															
4															
6															
8															
10															
12															
14															
16															
18															
20															
22															
24															
Mean															
0															
2															
4															
6															
8															
10															
12															
14															
16															
18															
20															
22															
24															
Mean															
0															
2															
4															
6															
8															
10															
12															
14															
16															
18															
20															
22															
24															
Mean															

The mean daily discharges are added to find totals and divided by number of days to determine means. The "totals" should be shown to the full number of places added. The daily discharge in cubic feet per second should be shown to the following significant figures:

Above 100	-	three significant figures
10 to 99	-	two significant figures
1.0 to 9.9	-	two significant figures
0.0 to 0.9	-	significant figures

Documentation

After the computations of daily discharge, an annual history of the operation of the gaging station should be written. This history should include but not limited to the following.

Station Name
Equipment On-site
Equipment Used for Flow Measurements
Datum Correction
Control
Gage Height Record
Rating Curve and Table
Discharge Computations
Remarks

In the annual history of operation, particular emphasis should be placed on the field operation of equipment, any difficulty in flow measurement and sediment sampling and the range of flow in the canal system. If shift adjustments are required, the causes of the silting and scouring, and the method of estimating the shift adjustment should be clearly defined.

The annual history should also be prepared for the sites where only periodic flow measurements are made, for example, to check the empirical relationships for control structures, flow in water courses and near the tail of minors and distributaries, etc. This should include the reasons for making the flow measurements and the conclusions reached.

Analysis of Sediment Data

Generally, the sediment transport capacity of a canal depends on the particle size distribution of the suspended sediment and bed material and form roughness (produced by sand ripples and waves) of the canal bed. The sediment data collection program

recommended in this manual provides information on the sediment characteristics. The form roughness is not discussed.

The results of the sediment analyses, received from the circle office should be properly filed. At the end of the year, an annual summary report should be prepared for each regular sampling station or for each site where a special sediment sampling program may have been implemented.

The summary should include but not be limited to the following.

Station Name
Equipment Used
Method of Sampling
Problems during Sampling
Tabulation of Data including:
Date, sampler used, discharge, flow area, average velocity, average depth, total suspended concentration, particle size distribution of suspended and bed material.
Remarks

Analysis of Morphological Data

As mentioned earlier, the morphological data will be collected at selected canal reaches. Therefore, for each survey, a report should be prepared which should include the following basic information.

1. Location of study reach
2. Reasons for selecting the reach
3. Flow condition at the time of survey
4. Equipment used
5. Tabulation of data
6. Exhibits showing the most recently surveyed and all previously surveyed longitudinal and cross-sectional profiles
7. Discussion of silting or scouring based on the exhibits, estimated rise or scour in the channel bed and changes in bed profiles.
8. Discussion of berm encroachment.

Storage of Information/Data

All basic data and analysis forms should be kept in the divisional offices. The circle office should be provided the final tabulated data and information in the form of reports.

If computer facilities are available in the circle office, the following basic data should be computerized.

A. Discharge and Sediment Data

1. Listing of measurements

2. Mean daily gage heights, shift adjustments and mean daily flows
3. Rating tables
4. Tabulation of data prepared for the sediment reports

B. Morphological Data

1. Survey data for longitudinal profiles
2. Survey data for cross sectional profiles.

ACKNOWLEDGEMENTS

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