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ABSTRACT

This document is an instructional module package prepared in objective form for use by an instructor familiar with the principles of liquid flow and the methods of measuring open channel and fuel pipe flow rates. Included are objectives, instructor guides, student handouts, and transparency masters. The module addresses the basic flow formula, and measurement of flow rates using a batch method, parshall flume, weirs, partially filled pipe, venture meters, magnetic flow meter, rotometer and ultrasonic velocity sensing methods. (Author)

FLOW MEASUREMENT

Training Module 3.315.2.77

Prepared for the

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by

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September, 1977

GLOSSARY OF VERBS

Flow Measurement Module No. ____

Describe. To represent by words written or spoken for the knowledge or understanding of others, to transmit an image of the identifying features, the nature and characteristics of objects, events and action.

Explain. To make plain or clear, to present in detail by words written or spoken for the knowledge or understanding of other, to transmit an image of the identifying features, the nature and characteristics of objects, events and actions.

Identify. To establish the identity of, pick out or single out an object in response to its name by pointing, picking up, underlining, marking, matching or other responses.

Indicate. To state or express without going into detail. The identity of, pick out or single out an object in response to its name by pointing, picking up, underlining, marking, matching or other responses.

Locate. To stipulate the position of an object in relation to other objects.

Select. To choose something from a number or group usually by fitness, excellence, or other distinguishing features.

Module No:	Module Title: Flow Measurement
	Submodule Title:
Approx. Time: 12 hours	1. Liquid flow 2. Flow Measurement Units Batch Process 3. Flow measurement Units Open Channel 4. Flow Measurement Units Full Pipe 5. Flow Measurement Units Preventive Maintenance 6. Flow Measurement Units Safety

Overall Objectives:

The overall objective is the introduction to the principles of flow measurement units used in open channels, full pipe, the preventive maintenance necessary to maintain proper functioning of meters and the safety necessary to operate and maintain the equipment.

Instructional Aids:

Handout
AV (overhead transparancy)
Calculators

Instructional Approach:

Discussion
Demonstration
Exercise

References:

Handbook for Monitoring Industrial Wastewater, U. S. Environmental Protection Agency Technology Transfer, August 1973.

Class Assignments:

Give handouts to be read

Module No:	Topic: SUMMARY

Instructor Notes:	Instructor Outline:
Charts, graphs and figures are used as handouts and overhead transparancies masters.	I. Flow Measurement A. Purpose B. Basic flow formula Q = A x v II. Principles of Flow Measurement A. Batch Process $Q = \frac{v}{t}$ B. Open Chennel 1. Parshall flume 2. Weirs a. Rectangular b. Cipolletti c. Triangular 3. Level detection a. Float gauges b. Hook gauge c. Staff gauge d. Ultrasonic e. Instream transmitter f. Air bubbler 4. Partially filled pipes a. Open end pipe b. California pipe flow c. Pressure conduits (full pipe) 1. Venturi meter 2. Flow nozzle 3. Orifice meter 4. Magnetic meter 5. Pitot tube 6. Ultrasonic

Module No:	Topic: SUMMARY

Instructor Notes:	Instructor Outline:
	III. Preventive Maintenance A. Cleaning B. Checking for deterioration C. Replacing components D. Changing charts IV. Safety

Module No:	Module Title: Flow Measurement
	Submodule Title: Liquid Flow
Approx. Time: 1 Hour	Topic: Introduction

Objectives:

Upon completion of this module the learner should be able to describe the basic principle of flow of liquid using the relationship of average flow velocity, cross-sectional area of flow and volume of flow.

Instructional Aids:

Handout
AV (overhead transparancy)
Calculators

Instructional Approach:

Discussion
Demonstration
Exercise

References:

Handbook for Monitoring Industrial Wastewater, U. S. Environmental Protection Agency Technology Transfer, August 1973.

Class Assignments:

Give handouts to be read

Module No:	Topic: Introduction
Instructor Notes:	**Instructor Outline:**
Discuss the derivation of Q = AV	I. Flow measurement A. Purpose B. Basic flow formula $Q = A \cdot v$ II. Give 3 exercise problems.

Module No:	Module Title: Flow Measurement
	Submodule Title: Flow Measurement Units
Approx. Time: 1 hour	Topic: Batch Process

Objectives:

Upon completion of this module the learner should be able to determine the flow rate by the change in level of fluid in a tank.

Instructional Aids:

Handout
AV (overhead transparancy)
Calculators

Instructional Approach:

Discussion
Demonstration
Exercise

References:

Handbook for Monitoring Industrial Wastewater, U. S. Environmental Protection Agency Technology Transfer, August 1973.

Class Assignments:

Give handouts to be read

Module No:	Topic: Batch Process
Instructor Notes:	**Instructor Outline:**
Batch Process depends upon a specific volume of water measured in a unit time.	I. Principle of flow measurement devices using a batch process. $Q = \frac{v}{t}$ Q = Flow rate V = Volume t = Time

Module No:	Module Title: Flow Measurement
	Submodule Title: Flow Measurement Units
Approx. Time: 3 hours	Topic: Open Channel

Objectives:

Upon completion of this module the learner should be able to identify components, explain the purpose of each component, how the compound works and its importance in flow measurement units used in open channels.

a. Parshall flume
b. Weirs
c. Partially filled pipe

Instructional Aids:

Handout
AV (overhead transparancy)
Calculators

Instructional Approach:

Discussion
Demonstration
Exercise

References:

Handbook for Monitoring Industrial Wastewater, U. S. Environmental Protection Agency Technology Transfer, August 1973.

Class Assignments:

Give handouts to be read

Module No:	Topic: Open Channel

Instructor Notes:	Instructor Outline:
1. Identify the primary unit.	I. Flow in open channels
2. Identify the secondary unit.	A. Parshall flume
3. Discuss the difference between suppressed and unsuppressed weirs.	B. Weir 1. Rectangular 2. Cipolletti 3. Triangular
4. Demonstrate use of namographs	C. Level detection Units 1. Float gauges 2. Hook gauges 3. Staff gauges 4. Ultrasonic 5. Instream transmitter 6. Air bubbler
5. Give all the formulas	II. Three pipes flowing partly full A. Horizontal or sloped open end pipe B. California pipe flow method

Module No:	Module Title: Flow Measurement
	Submodule Title: Flow Measurement Units
Approx. Time: 4 hours	Topic: Full Pipe

Objectives:

Upon completion of this module the learner should be able to identify components, explain the purpose of each component, how the component works and its importance in flow measurement units used in full pipe flow.

a. Venturi meters
b. Magnetic flow meter
c. Rotameter
d. Ultrasonic - velocity sensing

Instructional Aids:

Handout
AV (overhead transparancy)
Calculators

Instructional Approach:

Discussion
Demonstration
Exercise

References:

Handbook for Monitoring Industrial Wastewater, U. S. Environmental Protection Agency Technology Transfer, August 1973.

Class Assignments:

Give handouts to be read

Module No:	Topic: Full Pipe

Instructor Notes:	Instructor Outline:
1. Identify the primary unit 2. Identify the secondary unit 3. Give the formulas to each flow measuring device	I. Pressure conduits (full pipe and flow) A. Venturi meter B. Flow nozzle C. Orifice meter D. Magnetic meter E. Pitot tube F. Ultrasonic

Module No:	Module Title: Flow Measurement
	Submodule Title: Flow Measurement Units
Approx. Time: 2 Hours	Topic: Preventive Maintenance

Objectives:

Upon completion of the module the learner should be able to describe the preventive maintenance procedures for flow measurement units.

a. Parshall flume
b. Weirs
c. Ultrasonic level sensing
d. Pneumatic (bubbler)
e. Venturi meters
f. Magnetic flow meter
g. Rotameter
h. Ultrasonic velocity sensing
i. Orific
j. Pitot tube

Instructional Aids:

Handout
AV (overhead transparancy)
Calculators

Instructional Approach:

Discussion
Demonstration
Exercise

References:

Handbook for Monitoring Industrial Wastewater, U. S. Environmental Protection Agency Technology Transfer, August 1973.

Class Assignments:

Give handouts to be read

Module No:	Topic: Preventive Maintenance

Instructor Notes:	Instructor Outline:
Describe the process of preventive maintenance of each unit described in this module.	1. Discuss the necessity for preventive maintenance of flow measuring devices. A. Cleaning B. Checking for deterioration C. Replacing worn components D. Changing charts

Module No:	Module Title: Flow Measurement
	Submodule Title: Flow Measurement Units
Approx. Time: 1 Hour	Topic: Safety

Objectives:

Upon completion of this module the learner should be able to describe the safety procedures in operation and maintenance of flow measurement units.

Instructional Aids:

Handout
AV (overhead transparancy)
Calculators

Instructional Approach:

Discussion
Demonstration
Exercise

References:

Handbook for Monitoring Industrial Wastewater, U. S. Environmental Protection Agency Technology Transfer, August 1973.

Class Assignments:

Give handouts to be read

Module No:	Topic: Safety

Instructor Notes:	Instructor Outline:
	1. Discuss the need for safe operation of flow measuring devices. A.. Shock electric power B. Improper balance C. Improper entry into manholes

FLOW MEASUREMENT

In operating treatment plants the need to know the flow rates of the influent water and the flow rates within the unit process is very important. The process is very important. The design and monitoring treatment processes requires knowledge of flow rates, flow variability, and total flow. A variety of flow measuring devices and methods is available. The selection of the proper measuring method or device will depend on such factors as cost, type, and accessibility of the conduit, hydraulic head available, type and character of the water.

Most measuring devices measure the velocity of the flow or the change in depth of water. The basic formula used by the metering devices using velocity as the basis for determining the flow rate (Q) is:

$Q = A \times v$

Where

Q = Flow rate in cubic fee/second

A = The cross-sectional area of the channel containing the water in square feet

v = The velocity of flow in the channel in feet/second

$Q = A \times v$ is a formula that is obtained by continuing 3 formulas:

1. $Q = \frac{V}{t}$ — Q = Flow rate; V = Volume of water delivered; t = Time needed to deliver

2. $V = A \times L$ — A = Cross sectional area of channel

And — L = Distance the water traveled

3. $L = v \times t$ — v = Velocity

By substituting in equation #2 for L

Then $v = A \times v \times t$

By substituting in equation #1 for v

Then $Q = \frac{A \times v \times t}{t}$

Cancelling t since it is in the numerator and denominator than

$Q = A \times v$

The difficulty in using this formula is on circular pipes flowing partially full and only the depth of water in the pipe can be measured.

Example

Water flowing through a 12 inch pipe has a velocity of 3 ft./sec. What would be the rate of flow.

Solution

$Q = A \times v$

$= .785 \times D^2 \times v$

$= .785 \times (1\ \text{ft.})^2 \times 3\ \text{ft./sec.}$

$= 785 \times 1\ \text{ft.}^2 \times 3\ \text{ft./sec.}$

$= 2.36\ \text{ft.}^3/\text{sec.}$

Exercise

1. An 8" sewer line is flowing ½ full at a velocity of 2.4 ft./sec. Calculate the flow rate delivered by the sewer.

2. A 6" sewer line is flowing ¼ full. The distance distance between each manhole is 300 feet. The tracer dye placed in the upstream manhole took 2 minutes, 4 seconds to reach the next manhole. Calculate the flow rate.

3. Calculate the average velocity in a 1" copper pipe if the time needed to fill a 5 gallon bucket 25 seconds.

There are two basic types of flow systems: Flow in open channels such as in sewers, streams, rivers, and channels and flow in completely filled pressure conduits. There are two types of open channel flow to consider: Steady flow which indicates a constant rate of discharge, and unsteady flow which is indicative of a variable rate of discharge with time. A flow is said to be uniform if the velocity and depth are constant along the conduit and non-uniform if the velocity, the depth, or both, change along the conduit. The installation of flow measuring devices should be at a location where the flow is uniform.

Batch Process

A convenient flow measuring method is to be able to determine the rate of flow a tank fills up or empties. The formula to use is:

$$Q = \frac{v}{t}$$

Q = Flow rate

v = Volume of water emptied or filled

t = Time it took to do so

This method can be used also to determine if pumps are delivering at the pumping rate indicated.

Example

It has been determined that the on cycle for pump A is 20 seconds. The wet well has a diameter of 8 feet and the level of water changes 3 ft. when the pump goes on and when it goes off. Calculate the pumping rate.

Solution

Calculate the rate of discharge

$$Q = \frac{v}{t}$$

$$= \frac{.785 \times 8 \times 8 \times 3}{20}$$

$$= 7.5\ ft^3/sec.$$

The pump is pumping at a rate of 7.5 ft^3/sec. or 56 GPS.

This type of measurement should be undertaken when measuring the change in level of the liquid in the tank is not a dangerous operation and when the flow into the well is slow and steady.

Flow in Open Channels

The flow in open channels such as sewers, streams and partially filled pipes can be measured by:

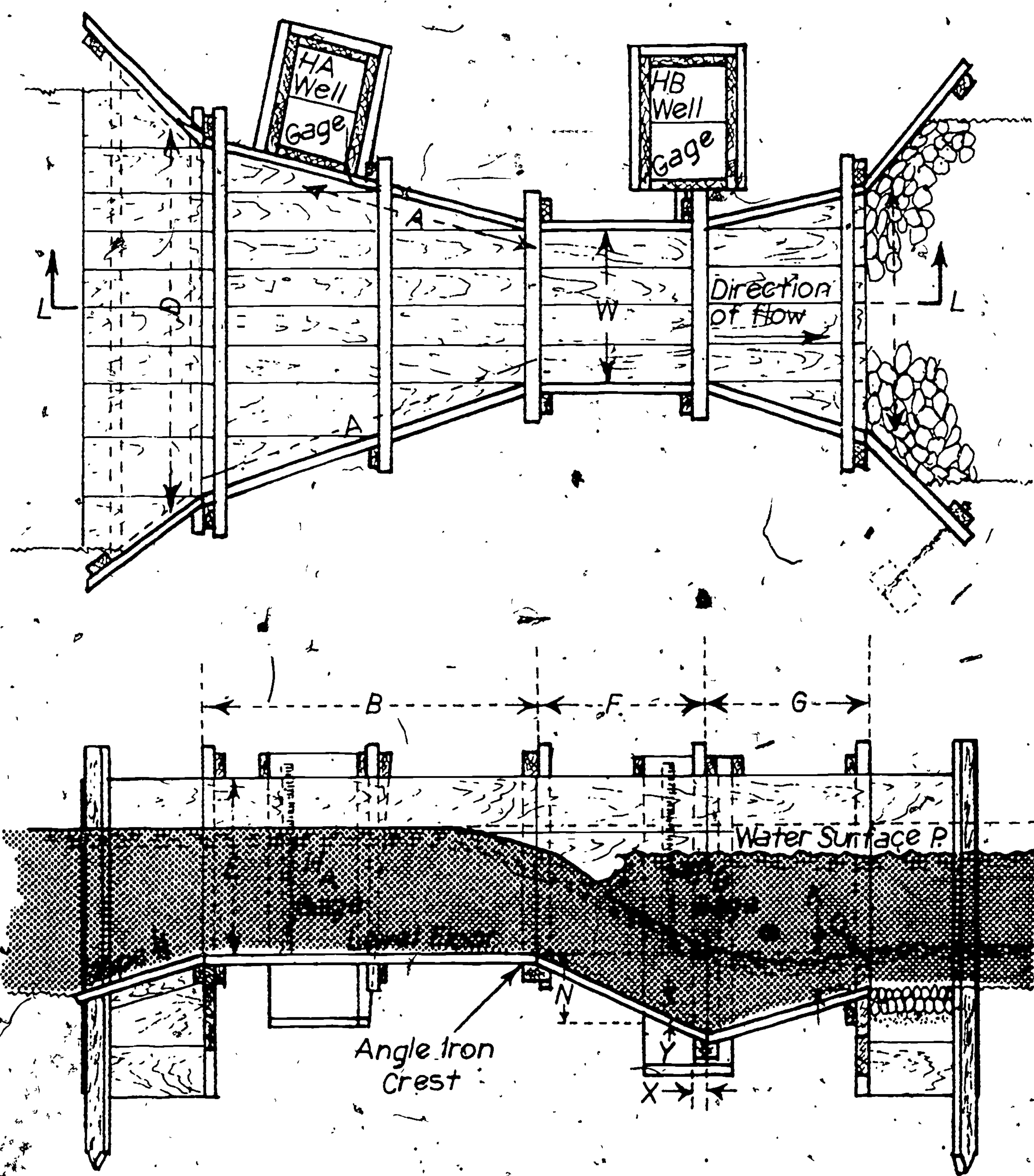
a. Using the formula Q = A x V and

b. Using measuring devices (flow meters).

The operating methods, types and makes of flow meters are too numerous to count and explain. The most common in use that could be used in water and wastewater systems is:

A. Parshall flume

The parshall flume is made up of 3 sections (Figure 1)



HA Well Gage
HB Well Gage
A
A
W
L
L
Direction of flow
B
F
G
Water Surface P
Level Floor
N
Y
X
Angle Iron Crest

Figure 1

1. The converging section
2. The throat
3. The diverging section

Although there are other sections to the flume they are basically attachments that provide easy of operation and data interpretation. Such attachments are a:

1. Stilling well with floats
2. Instream transmitter
3. Ultrasonic level change indicator

The basic principle of operation of the parshall flume is that the liquid has to converge to the throat so as to pass through. This convergence causes a rise in the depth of the liquid in the converging section which can be measured and use to calculating the flow rate using the formula

$$Q = 4\ WH^{h}$$

Where

Q = Flow rate in cubic fee/second

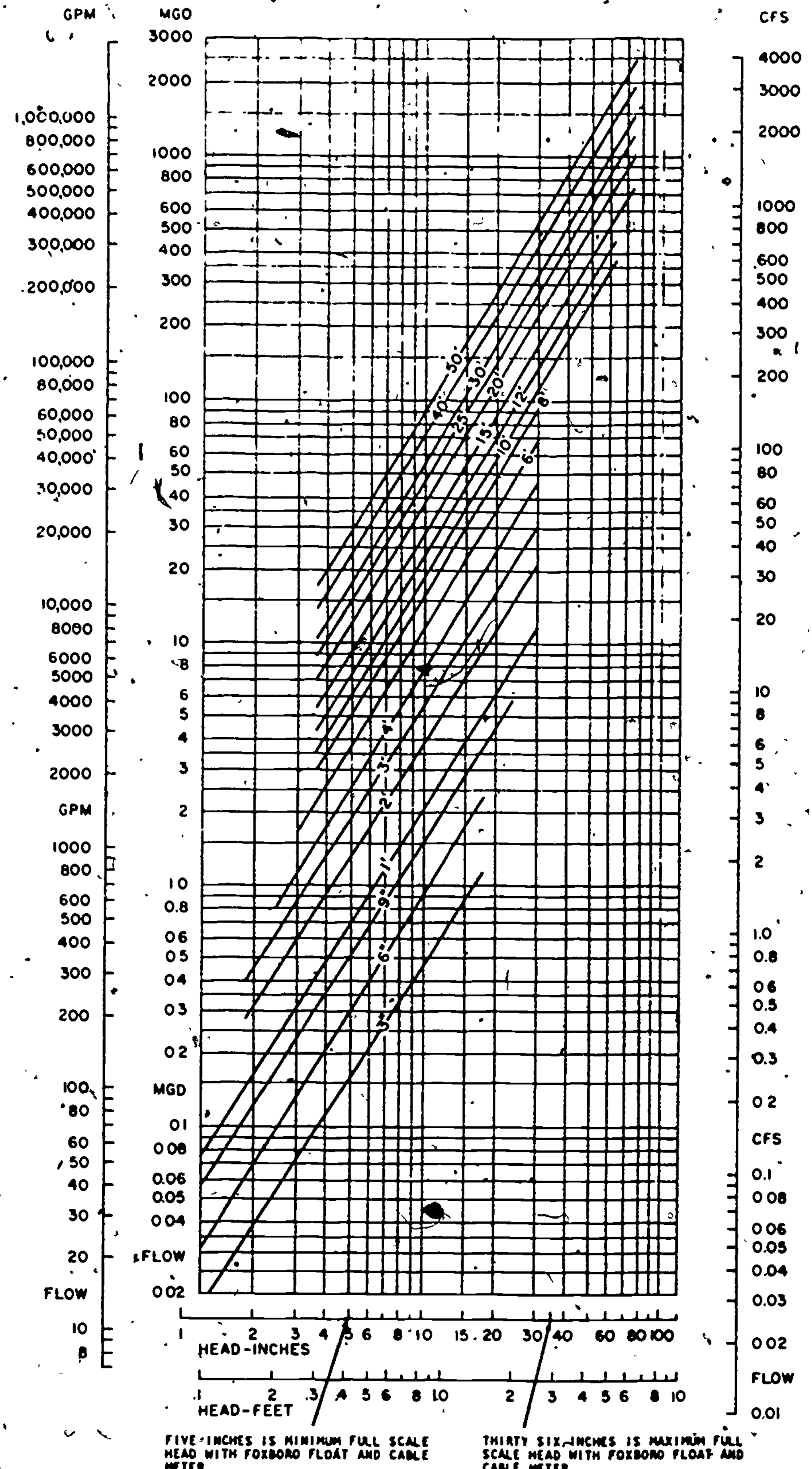
W = Width of the throat in feet

H = Height of water in the converging section in feet

$h = 1.522\ W^{0.026}$

The size of flume installed should be comparable to the flow rate anticipated. That is a 3" flume will not provide an accurate flow rate if the head is above 18 inches. A 9 inch flume or larger is preferable.

In placing a flume it is essential that the liquid entering the converging throat is not turbulent. The flow should be free flow and not under pressure.



FLOW CURVES FOR PARSHALL FLUMES

Figure 2

A flow curve is provided to facilitate the determination of the flow rate using a parshall flume. See Figure 2.

B. Weirs

The weir is a commly used device for measuring waste flows inasmuch as it is generally easy to install at low cost. Essentially, it is a dam, or other obstruction placed in a partly filled pipe, channel or stream. The water level at a given distance upstream from the weir is proportional to the flow. Commercially available weirs consist of a vertical plate with a sharp crest, the top of the plate being either straight or notched. Weirs can be installed at pipe outlets, in manholes or in open channels. Figure 3 shows three common types of sharp crested weirs with complete end contractions while Figure 4 shows a sharp crested weir profile. Proper form of the crest is important for accurate measurements, the water flowing over the crest being called the nappe. The main problem associated with rectangular weirs is that the flow will be contracted when it passes over the weir. Thus, the effective width of the weir is smaller than the width of the crest. The Cipolletti weir, which has sloping sides, was developed in order to compensate for this contraction and to be able to use the width of the crest for flow calculation. In order to design a weir that operates satisfactorily, the following general requirements should be considered:

1. The weir should consist of a thin plate about 1/8 to 1/4 inch thick with a straight edge or a thick plate with a knife edge, the sharp edge being important for preventing the nappe from adhering to the crest. The height of the weir from the bottom of the channel to the crest should be at least 2 times the expected head of water above the crest, this ratio

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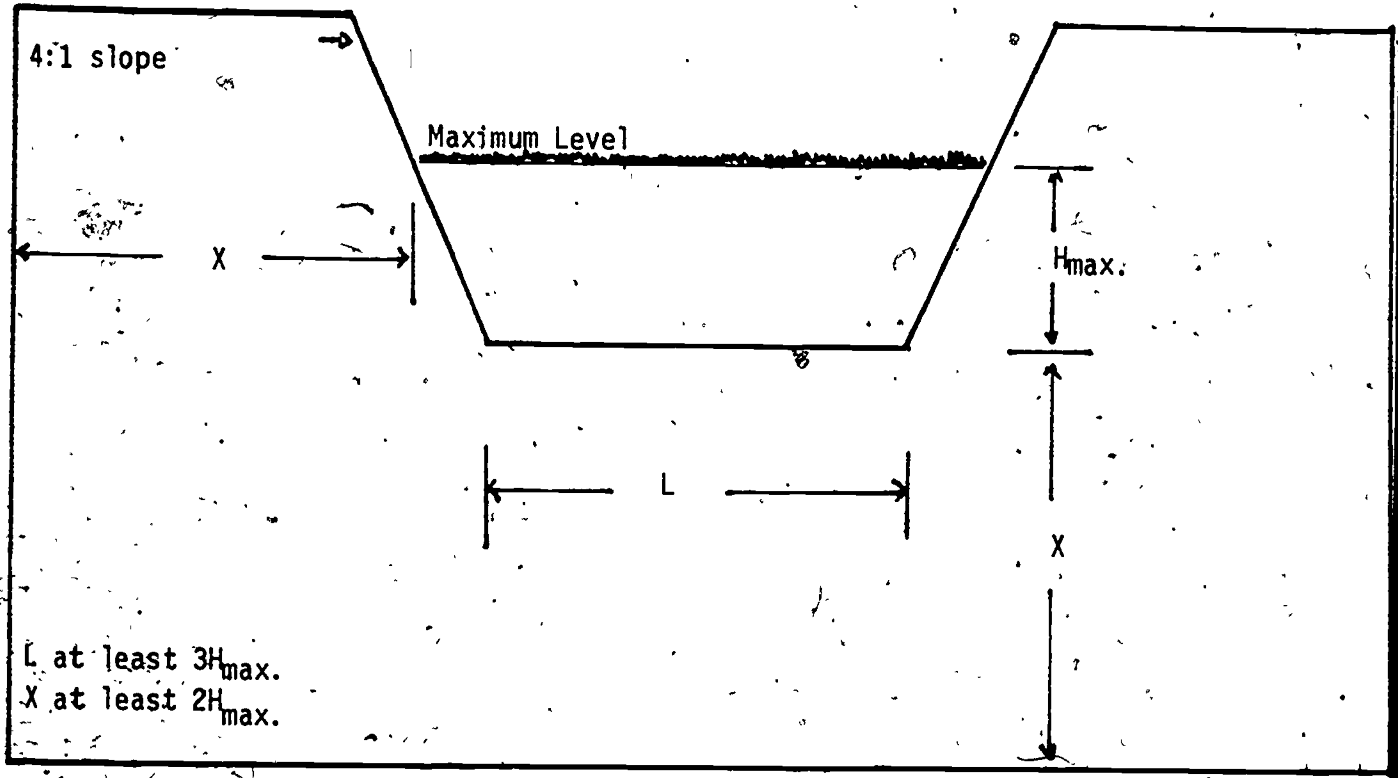
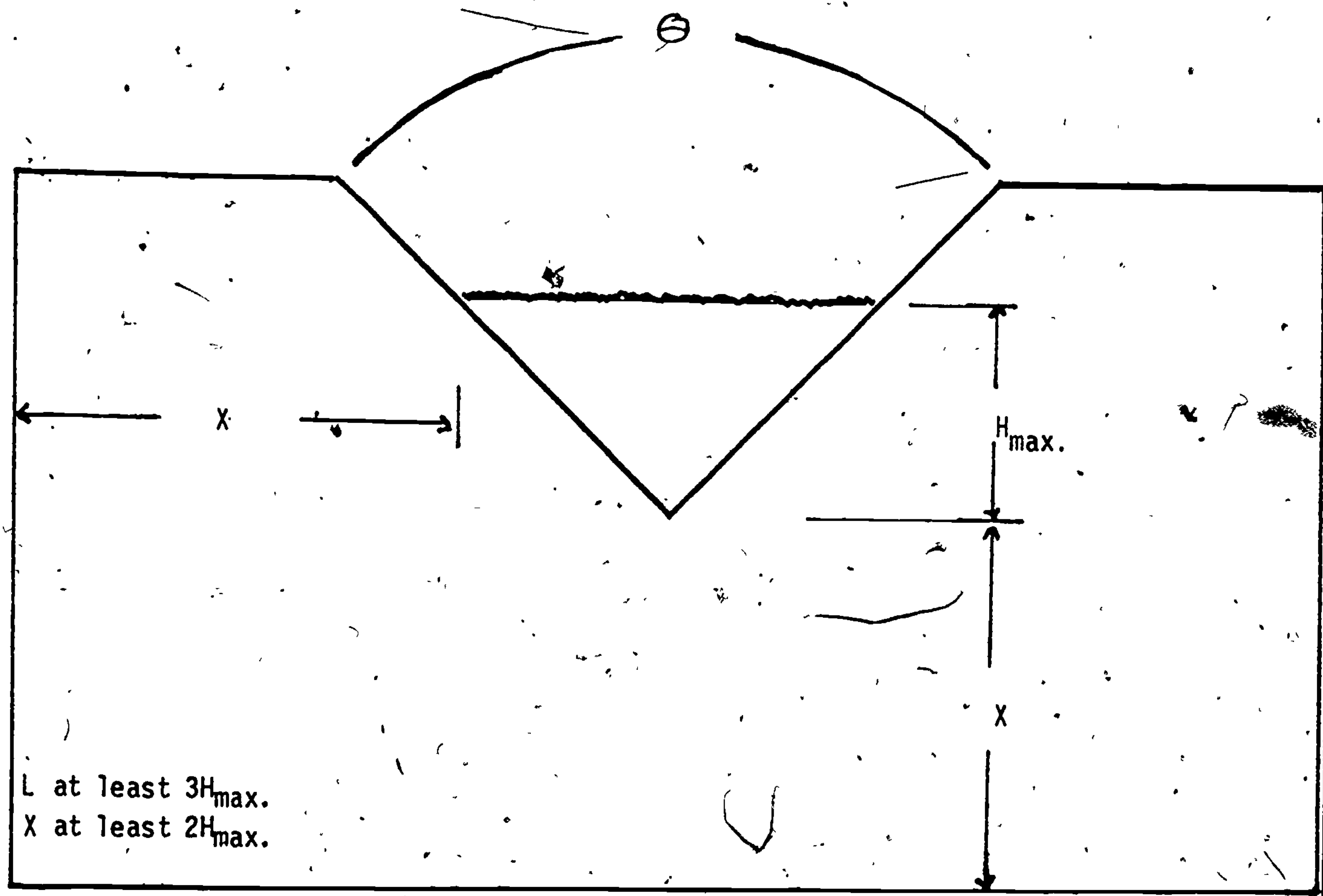


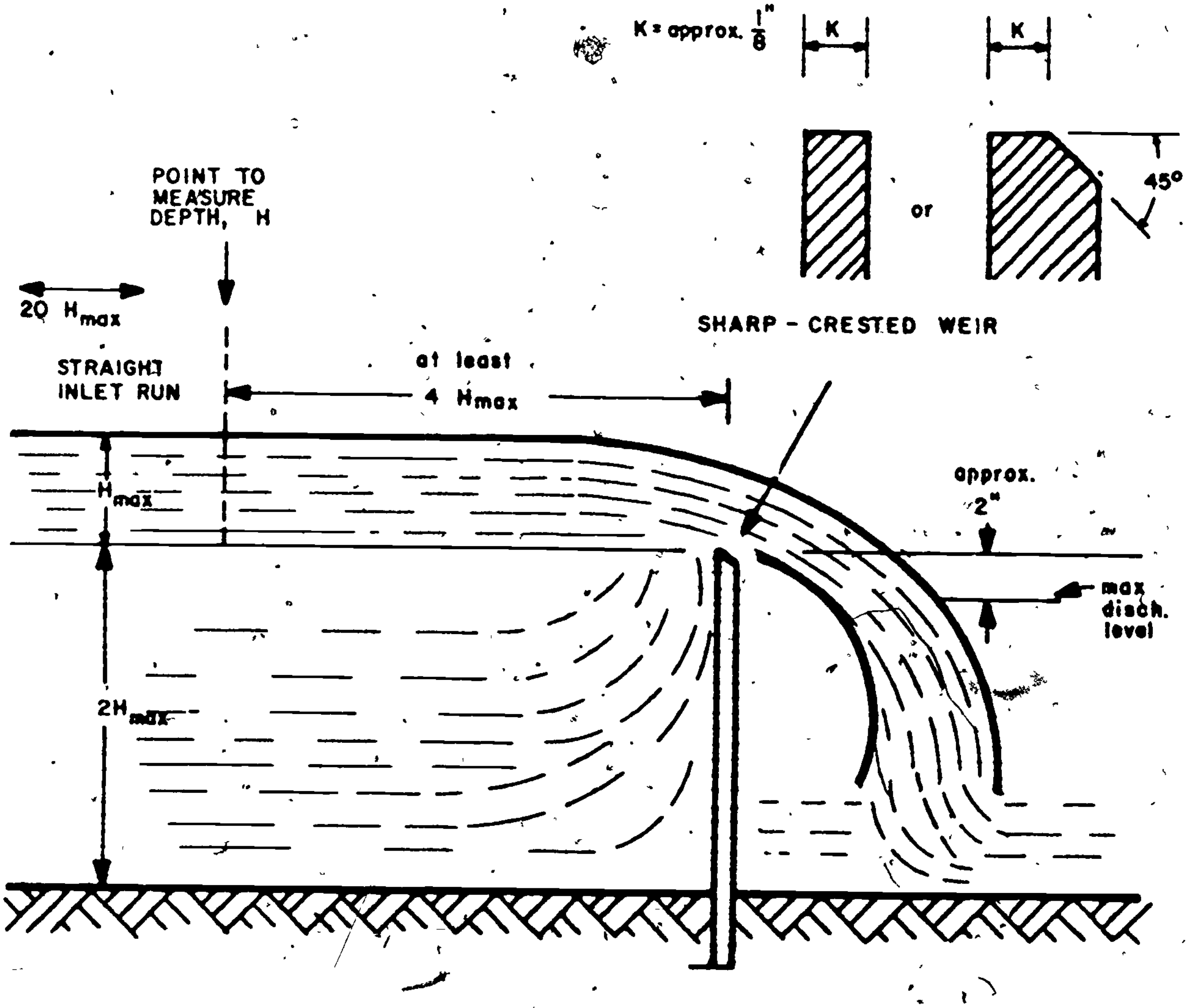
CIPOLLETTI WEIR

Figure 3



TRIANGULAR OR V-NOTCH WEIR

Figure 3



PROFILE OF SHARP-CRESTED WEIR

Figure 4

being necessary to lower the velocity of approach. Also, the upstream velocity of flow should be greater than 0.3 ft/sec.

2. It is important to ventilate the weir to prevent a vacuum from forming on the underside of the falling water.
3. The connection of the weir to the channel should be waterproof. Therefore, the joint between the weir plate and channel should be packed with a chemically inert cement or asphalt type roofing compound. Grease compounds should not be used if oil concentrations are to be measured.
4. The weir must be exactly level to insure a uniform depth of flow.
5. The crest of the weir must be kept clean. Fibers, stringy materials and larger particles tend to cling to the crest and should be removed periodically. In water with high suspended solids concentrations, considerable sedimentation in the channel of approach will take place. Sediment influences the measurements and makes representative sampling more difficult.
6. The device for measuring the head should be placed upstream at a distance of at least 2.5 times the head on the weir and should be located in a quiet section of the sewer away from all disturbances.
7. The weir should be located at the end of a straight stretch of the channel with little or no slope. The velocity of approach should be low and uniformly divided over the channel; however, the weir will usually lower the velocity sufficiently for measurement.
8. The weir size should be selected after the preliminary surveys have determined the expected flow rates in the sewer.

The common formula for flow over a weir is:

$q = 2/3 \sqrt{2g} \; H^{3/2}$

Where

q = Flow per unit of width, cfs.

g = Gravity (32 ft/sec.^{2})

H = Head above crest (upstream), feet

A coefficient C, is usually included to compensate for the non-uniformity of flow. Thus, the equation for the flow per unit of width becomes:

$q = C_W \, 2/3 \sqrt{2g} \; H^{3/2}$

Where

C_W = Non-uniformity coefficient (≤ 1)

Permanently installed weirs should be calibrated after installation inasmuch as coefficients in the weir formulas may vary due to many factors. However, reasonable flow estimates for the various types of weirs are available, and when used properly, produce little error.

Rectangular Weirs

Rectangular weirs may be straight or notched. A straight weir is called a suppressed weir without end contractions. A notched weir may have one or two end contractions. If the crest height is greater than 5 H, the approach velocity may be neglected. In a suppressed weir, the water flows over the full width of the weir and problems may develop when a vacuum forms under the nappe.

The most common type of rectangular weir is the notched weir with end contraxtions. If the end contractions are standard, that is, the width of each end contraction is at least 2.0 times the head above the crest, the Francis formula is applicable in computing the flow as follows:

$$Q = 3.33\ LH^{3/2}$$

Where

Q = Flow, cfs

L = Effective width of the weir, ft.

H = Head, ft.

Figure 5 presents a nomograph of the Francis Formula and can be used for a suppressed weir or a weir with standard end contractions. The conventional calculations are not applicable when estimating discharges with very low heads that cause the nappe to cling to the weir face.

Cipolletti Weir

The Cipolletti weir is of trapezoidal form with end slopes of one horizontal to four vertical, which corrects for the slide contraction of the nappe over the crest. Thus, no correction is necessary for the crest width as in the rectangular contracted weir. The general equation for the Cipolletti type of weir is:

$$Q = 3.367\ LH^{3/2}$$

Where

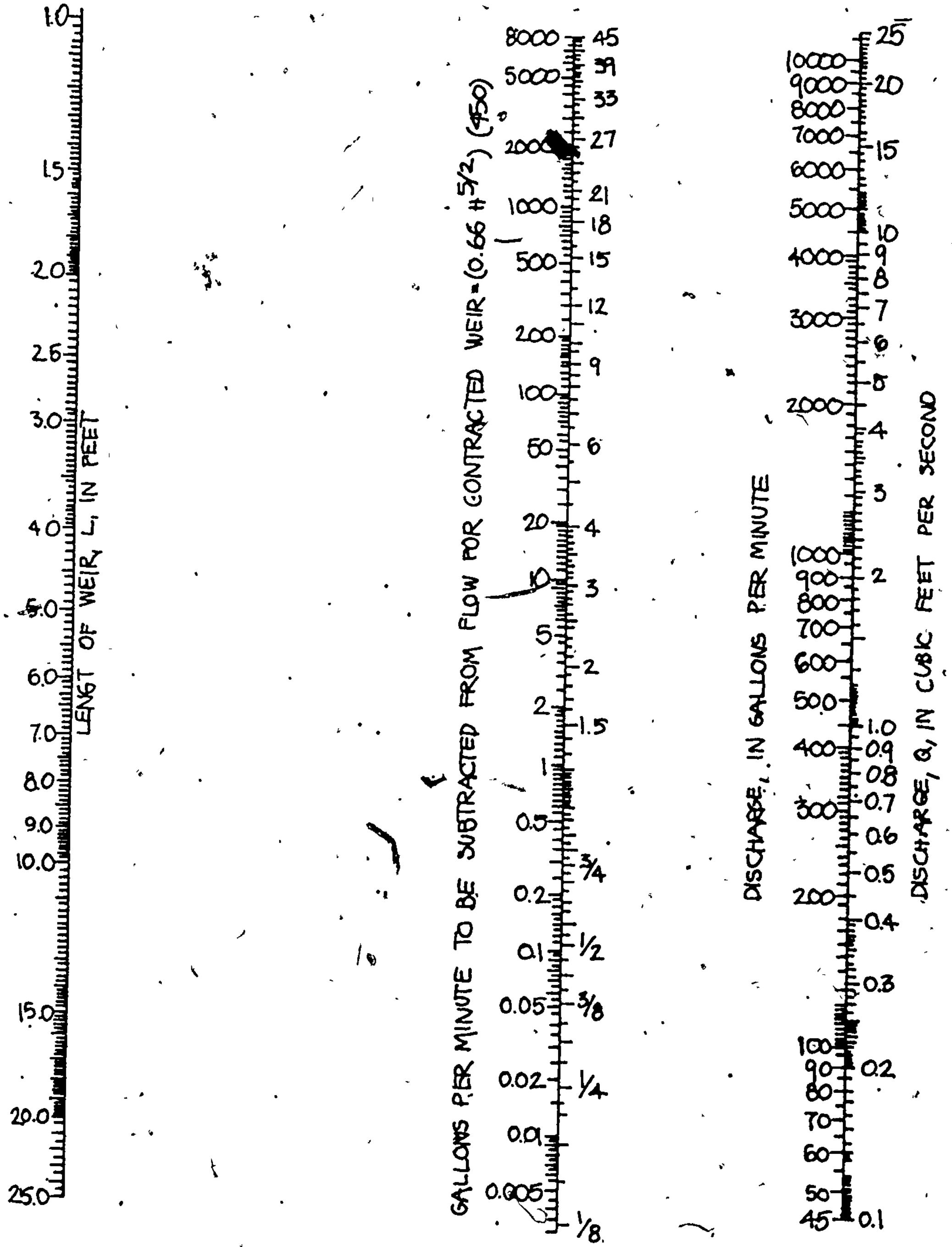
Q = Discharge, cfs.

L = Length of the weir opening at the base, feet

H = Measured head, feet

Velocity Head Correction

When the velocity of approach for a suppressed, contracted, or Cipolletti weir is too high to neglect, a correction factor can be introduced



NOMOGRAPH FOR CAPACITY OF RECTANGULAR WEIRS (3)

FIGURE 5

into the flow equation. The correction factor extends the use of the basic formula for weirs to include the velocity head as follows:

$$h = \frac{V^2}{2g}$$

Where

h = Velocity head, ft.

V = Approach velocity, ft./sec.

g = Gravity (32 ft./sec.^{2})

Then the term $H^{3/2}$ in the basic equations is converted to:

$$H^{3/2} = (H + h)^{3/2} - h^{3/2}$$

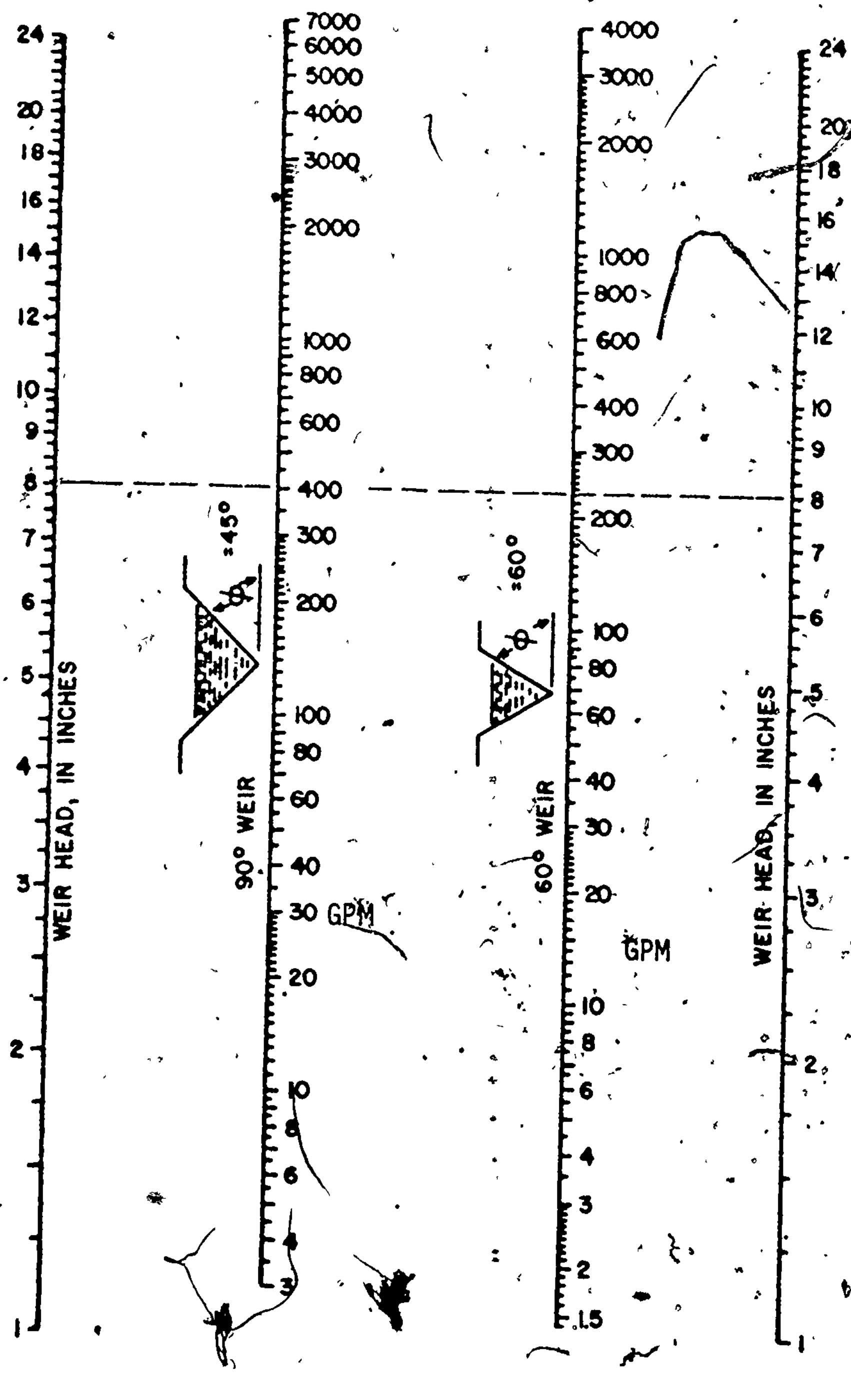
Triangular Weirs

The triangular weir of V-notch type is of value in measuring low flows. It should be used for flows less than 1 cfs. (450 gpm) and is not recommended if the flow is greater than 2 cfs. The V-notch weir may be constructed of any angle, the most commonly used angle, Q, for V-notch weirs being 90°. The second most popular V-notch weir has an angle of 60°. The end contraction of the weir should be at least 3/4 L, where L is the width of the water surface at maximum elevation. (Figure 6).

The formula for the 90° notch weir is:

$Q = 2.49\ H^{2.5}$ where flow, Q is in cfs.

The API manual (3) recommends against the use of V-notch weirs if $H < 0.3$ ft. since the possibility of forming a vacuum becomes too great.

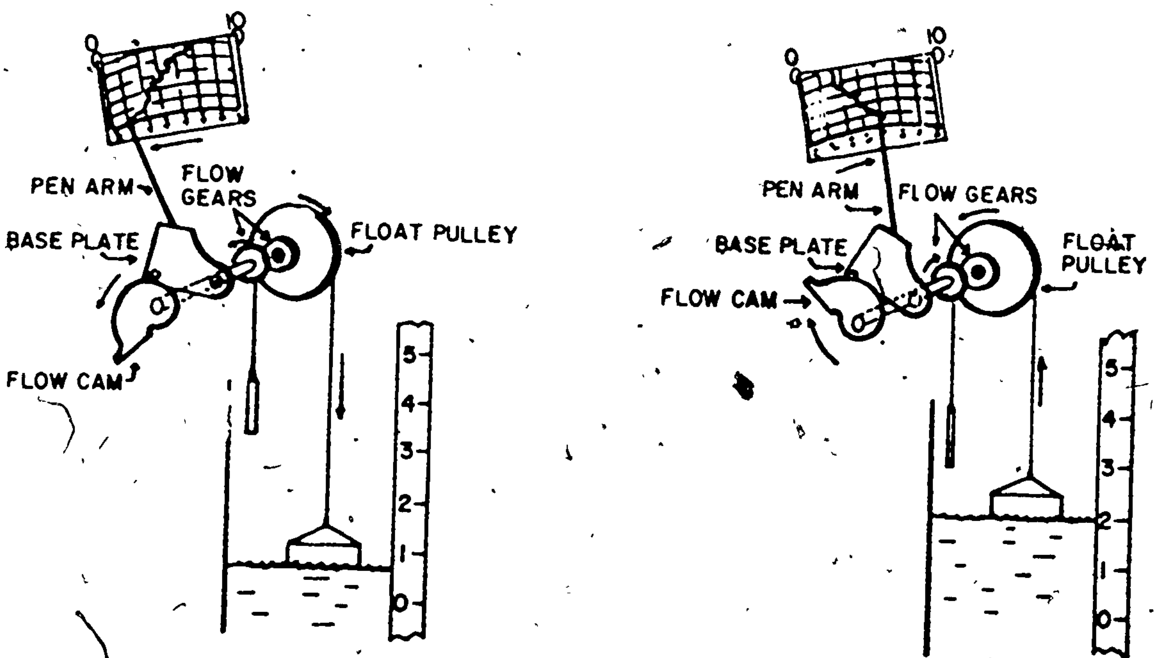


FLOW RATES FOR 60° AND 90° V-NOTCH WEIRS

Figure 6

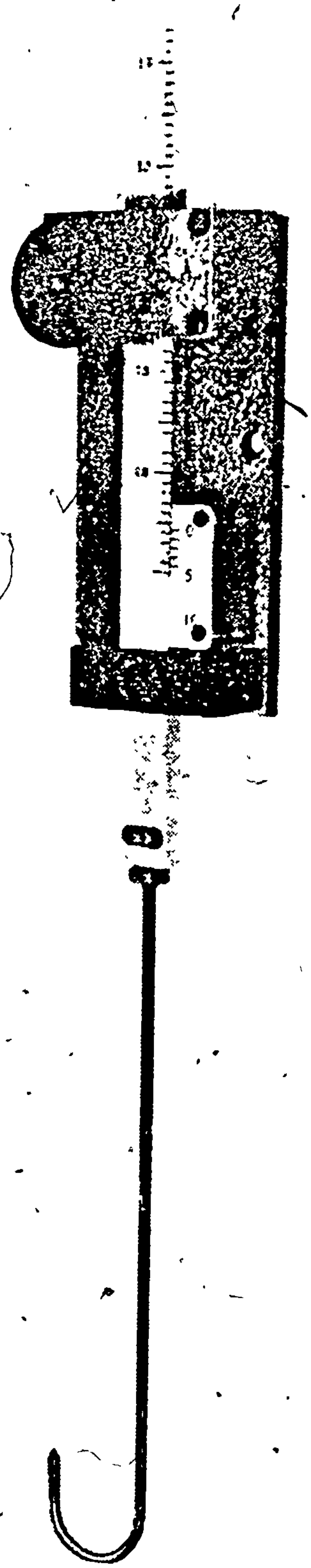
In determining the level change of water in a flume or weir there are many devices used to do so.

1. Staff gauge - This is a ruler marked in ¼" of an inch increments. Commercially available gauges are generally made of 18 gauge metal coated with enamel, white background with batch numerals. They come in any length desired. In using a staff gauge one's eye should be level with the water surface so as to provide proper observation. The main disadvantage of this method is that the flow cannot be read on a continuous basis inasmuch as the system cannot be converted to a control system or totalizing device.
2. Float gauge - Figure 7. It is a means of continuously indicating liquid levels. It consists of a metal float, a pulley mounted on a standard, and a counterweight. The pulley is usually attached to a set of gears and recording chart. As the float rises and falls with the liquid surface so does the needle upon the recording chart moves accordingly. This movement is recorded and according to the recorder setting, speed of movement of chart and chart graduation the flow rate can be determined.
3. Hook gauge - Figure 8. This device is a very cheap method of recording the level change. The gauge (Figure) is manually brought to the water surface and the water level elevation read. It is preferred to use gauges in a stilling well. The main disadvantage of this method is that the flow cannot be read on a continuous basis inasmuch as the system cannot be converted to a control system or totalizing device.



FLOATING WATER ELEVATION MEASURING DEVICE

Figure 7



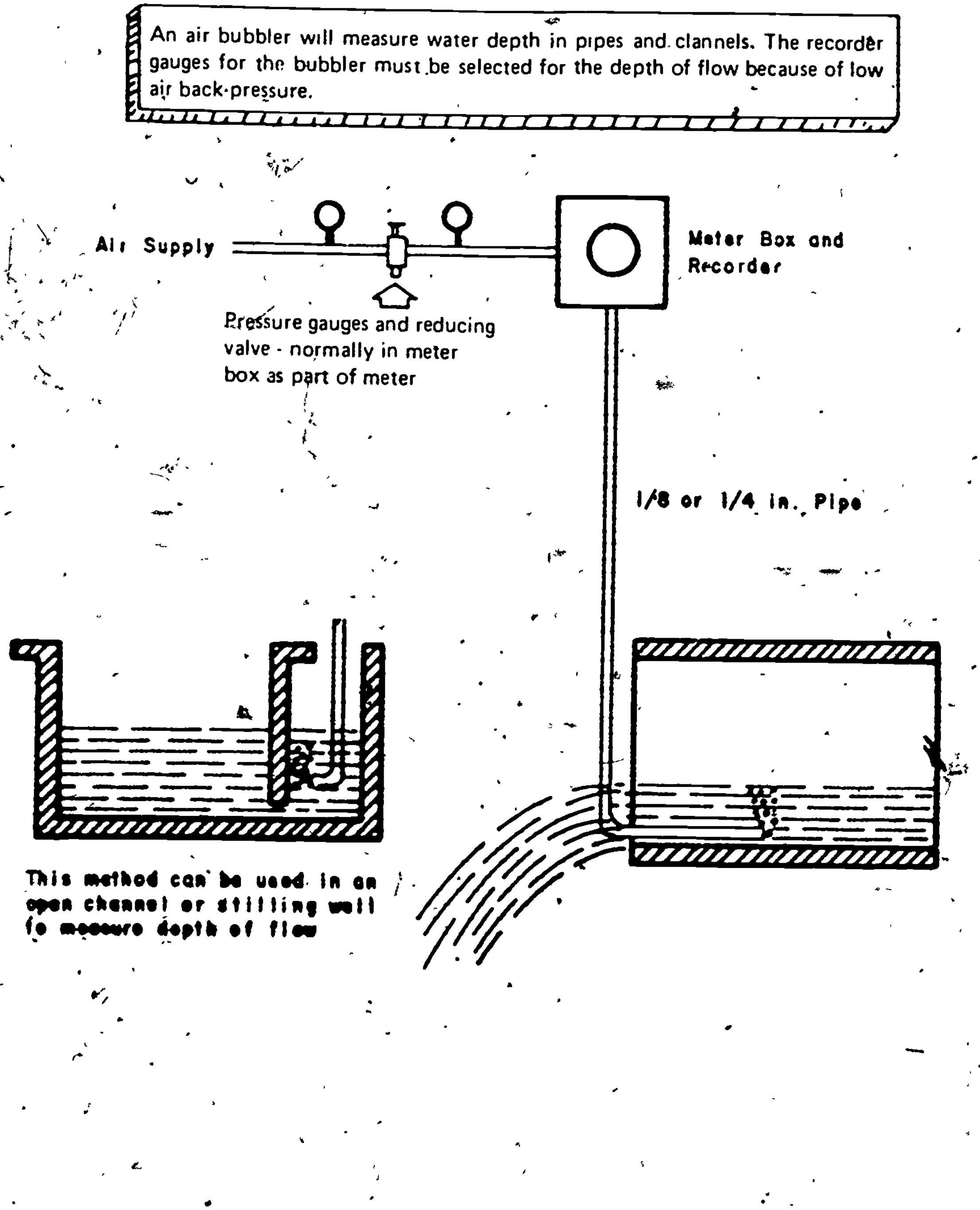
HOOK GAUGE

Figure 8

4. Air Bubbler - Figure 9. This device is a bubbler tube constructed in a side wall cavity of a flume (Figure 9). As the height of the water surface changes, the resistance to the escaping air through the immersed bubbler tube changes. The pressure differential is sensed by a translator which activates an air motor, which in turn, pushes a micro switch over a cam wheel. This action operates the recording chart and pen. The bubbler can be installed at any depth and it is possible to make the apparatus portable using an air cylinder for the air supply.

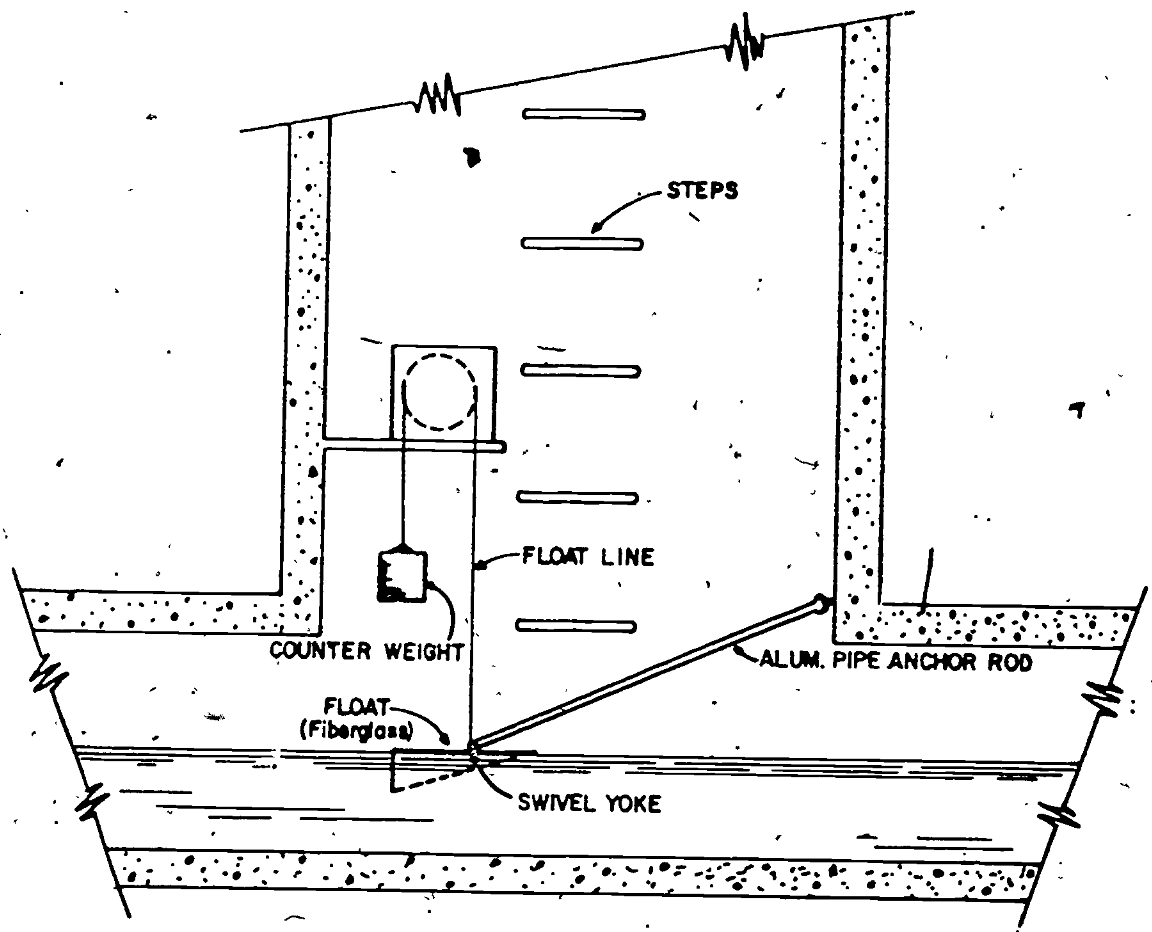
5. Instream Transmitter - Figure 10. This device depends upon a float placed in the channel. That will rise and fall with the liquid surface. The float is attached to a float line, a pulley and a counterweight. The pulley is usually attached to a set of gears and recording chart. As the float rises and falls with the liquid surface so does the needle upon the recording chart move accordingly. This movement is recorded, and according to the recorder setting, speed of movement of chart, and chart graduation the flow rate can be determined.

6. Ultra Sonic - This device functions upon a unit that limits an ultra sonic sound that is reflected back from the surface of the water. By setting the sensor at zero discharge i.e. base line, then as the level of liquid increasing, the sensor will detect the distance from sensor to liquid level subtract the distance from the zero discharge setting and the difference is the level of liquid in the flume or weir. Most devices that utilize a float or ultrasonics in detecting the change in the level of the liquid are also capable of not only providing flow rates a continuously basis but also have the capability of totalizing the flow.



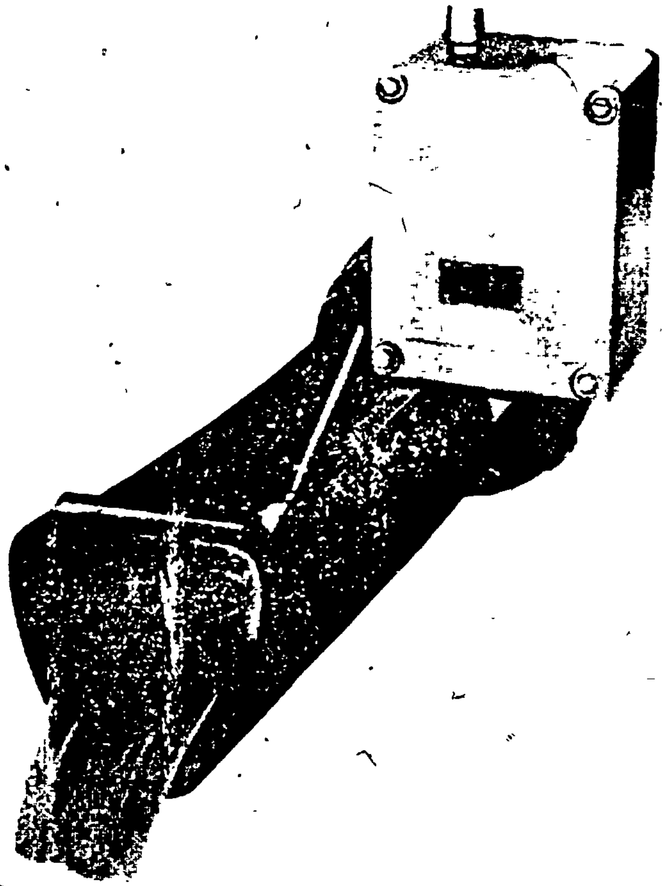
AIR BUBBLER FOR MEASURING WATER DEPTH

Figure 9



RECORDER AND SCOW FLOAT USED IN SEWER MANHOLE (2)

Figure 10



OPEN FLOW NOZZLE WITH INSTREAM TRANSMITTER

Figure 10

Pipes Flowing Partly Full

Horizontal or Sloped Open-End Pipe

It is possible to estimate the flow from filled or partly filled pipes by measuring two characteristic lengths of the stream after it has left the pipe and is freely discharging into the air. This situation is common for the outfall of elevated sewers. The method lacks the precision and accuracy of conventional meters or weirs but is often sufficiently accurate for rough flow estimates and is relatively inexpensive. Figure 11 shows a partly filled sewer freely discharging into the air. The two characteristic lengths to be measured are X and Y. The X-axis should always be parallel to the line of the sewer and the Y-acis should be perpendicular to the ground. The formula for calculated flow is:

$$Q = \frac{1800A\,X}{\sqrt{Y}} \text{ in gallons per minute}$$

Where

A = Wet cross-sectional area of liquid in the pipe in sq. ft.

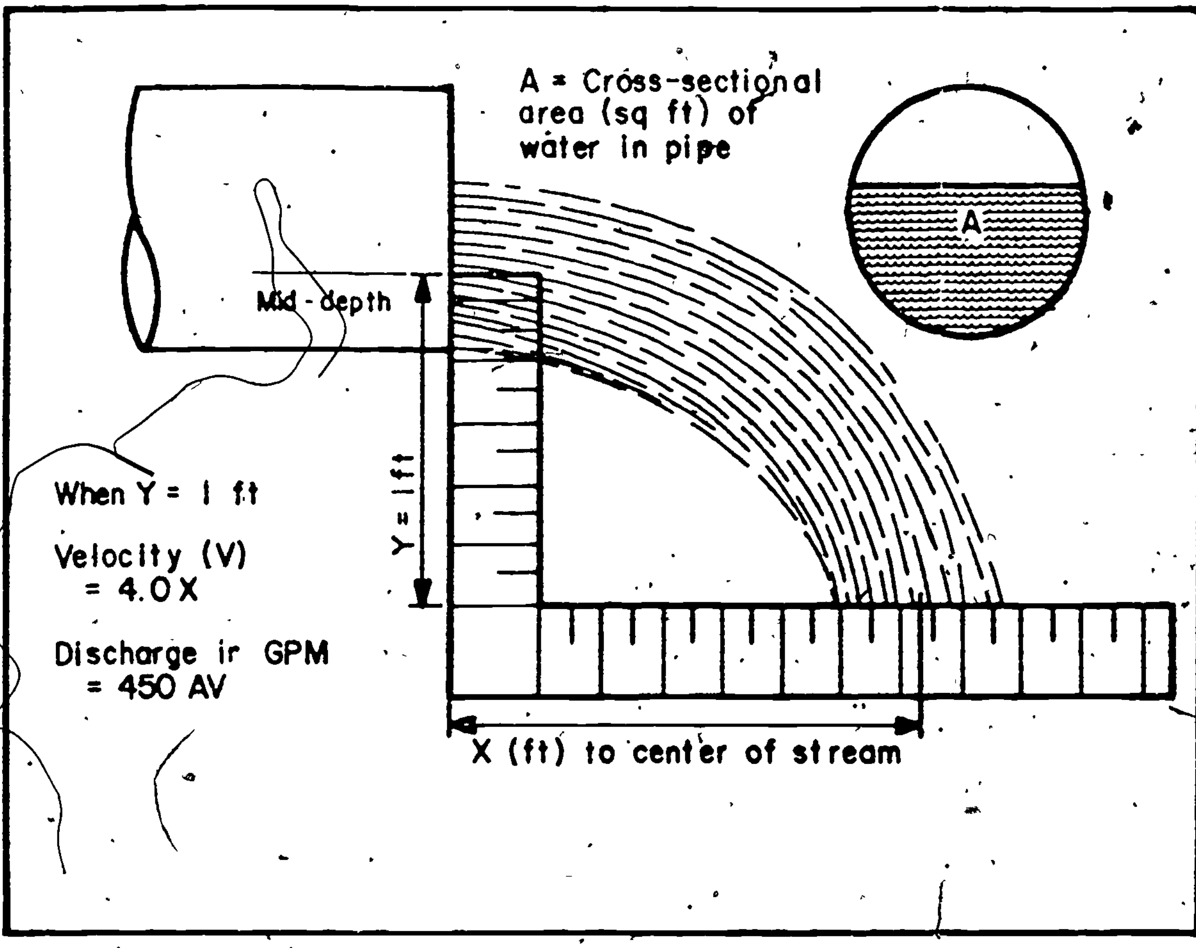
X = Distance between end of pipe and the vertical gage in ft., measured parallel to the pipe

Y = Vertical distance from water surface at discharge end of the pipe and intersection of water surface with vertical gage in ft.

When the pipe is flowing full, A equals the cross-sectional area of the pipe. A modification of this method is shown in Figure 11 where Y is measured from the mid-depth of the liquid and is equal to 1 ft. X is measured to the center of the stream, and the velocity of the liquid leaving th sewer is:

$$V = 4.0\,X \text{ in feet per second}$$

The flow of water discharged from the pipe is determined from:



HOW TO MEASURE DISCHARGE FROM A PIPE

Figure 11

$Q = 450\ AV$ = Gallons per minute

Where A is the wet cross-sectional area in sq. ft. This method is known as the coordinate or trajectory method.

California Pipe Method

The California Pipe Method is used to measure the rate of flow in a partly filled horizontal pipe having free discharge. The horizontal part of the pipe should be at least 6 times the diameter. If the pipe is not horizontal, a horizontal section can be added as shown in Figure 12. Once the diameter of the pipe is known, only the distance from the top of the sewer to the water surface is required in order to obtain the flow rate. The outfall depth is related to the critical depth, thus making the flow determinable. The flow may be calculated by the following equation:

$Q = TW$ = Gallons per minute

Where

$T = 3{,}900\ (1 - \frac{a}{d})\ 1.88$

d = Diameter of sewer, in ft.

a = d minus water depth, in ft.

$W = d^{2.48}$

Values for T and W may be obtained from Tables 1. An air bubbler or a water level recorder may be used for the continuous measurement of the water surface elevation.

TABLE 1

VALUES OF T FOR CALIFORNIA PIPE FLOW FORMULA (4)

$$T = 3900 \left(1 - \frac{a}{d}\right)^{1.88}$$

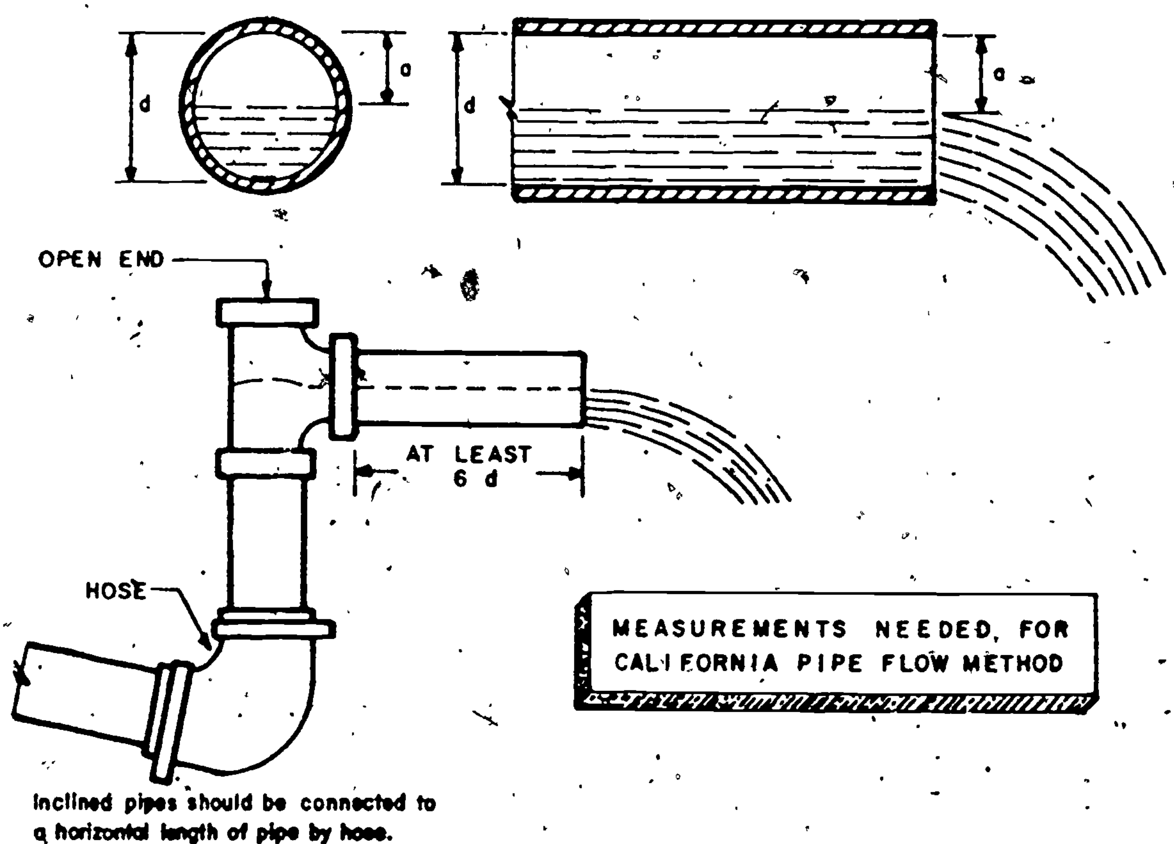
$\frac{a}{d}$	T	$\frac{a}{d}$	T	$\frac{a}{d}$	T
0.00	3900	0.35	1740	0.70	410
0.01	3830	0.36	1690	0.71	380
0.02	3760	0.37	1640	0.72	360
0.03	3690	0.38	1590	0.73	330
0.04	3610	0.39	1540	0.74	310
0.05	3540	0.40	1490	0.75	290
0.06	3470	0.41	1450	0.76	270
0.07	3400	0.42	1400	0.77	250
0.08	3330	0.43	1350	0.78	230
0.09	3260	0.44	1310	0.79	210
0.10	3200	0.45	1270	0.80	100
0.11	3130	0.46	1230	0.81	170
0.12	3070	0.47	1180	0.82	160
0.13	3000	0.48	1140	0.83	140
0.14	2930	0.49	1100	0.84	125
0.15	2870	0.50	1060	0.85	110
0.16	2810	0.51	1020	0.86	97
0.17	2750	0.52	930	0.87	85
0.18	2690	0.53	915	0.88	73
0.19	2630	0.54	905	0.89	61
0.20	2570	0.55	870	0.90	51
0.21	2510	0.56	830	0.91	42
0.22	2450	0.57	800	0.92	34
0.23	2390	0.58	760	0.93	26
0.24	2330	0.59	730	0.94	20
0.25	2270	0.60	700	0.95	14
0.26	2210	0.61	660	0.96	9
0.27	2160	0.62	630	0.97	5
0.28	2100	0.63	600	0.98	3
0.29	2050	0.64	570	0.99	1
0.30	1990	0.65	540		
0.[illegible]	1940	0.66	510		
0.32	1890	0.67	480		
0.33	1840	0.68	460		
0.34	1790	0.69	430		

TABLE 2

VALUES OF W FOR CALIFORNIA PIPE FLOW FORMULA (4)

$$W = d^{2.48}$$

Pipe Diameter Inches	d feet	W
3	0.25	0.032
4	0.33	0.064
6	0.50	0.179
8	0.67	0.370
10	0.83	0.630
12	1.00	1.00
14	1.17	1.48
15	1.25	1.74
16	1.33	2.03
18	1.50	2.73
20	1.67	3.57
21	1.75	4.01
22	1.83	4.48
24	2.00	5.58
27	2.25	7.47
30	2.50	9.70
33	2.75	12.29
36	3.00	15.25

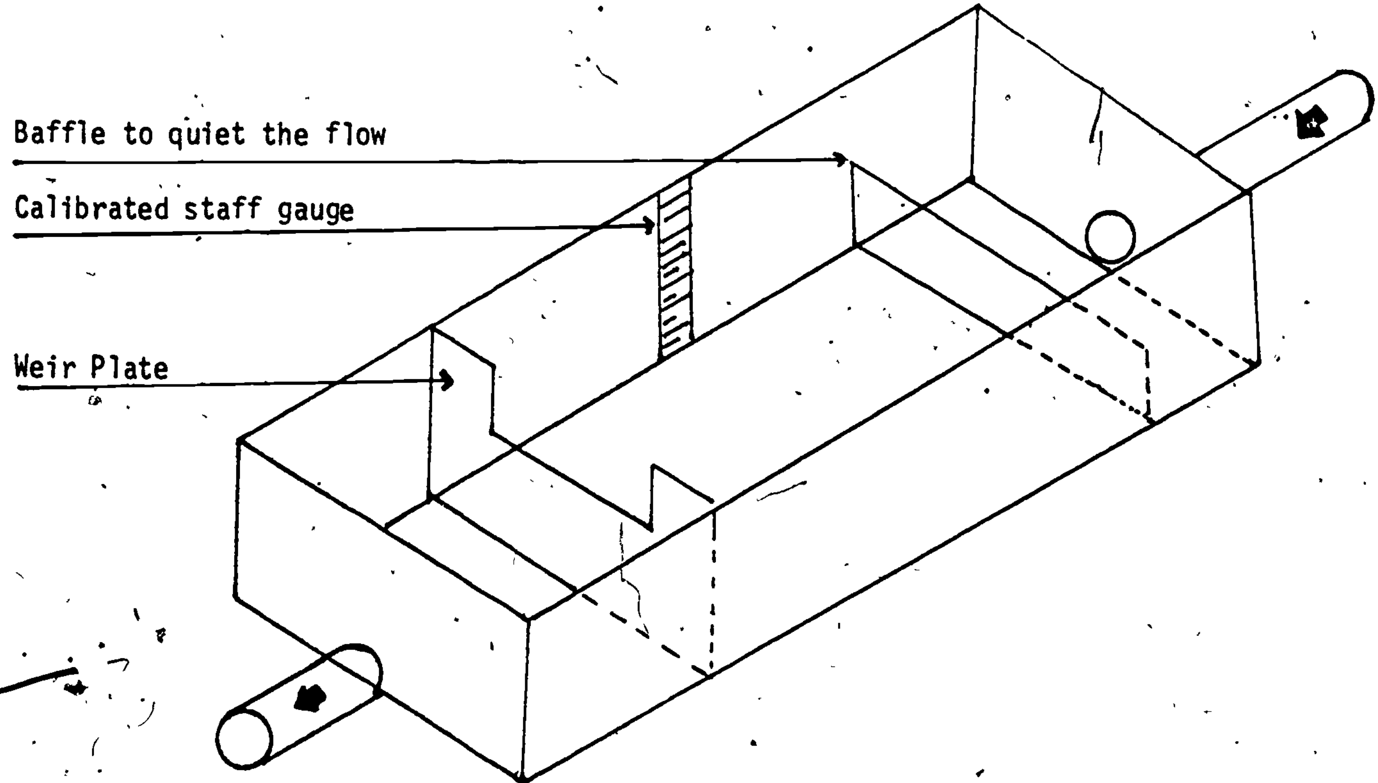


CALIFORNIA PIPE FLOW METHOD

Figure 12

Summary

Flow measurement in open channels is not a difficult task to undertake. The equipment is easy to build, install and operate. Figure 13. By knowing the flow to the plant operation will be a lot more comprehensive. Most of the flow measuring devices used in open channels detect the changes in level of the depth of water by the devices where visual observation is done. Staff gauge, hook gauge or floats or electronic ultrasonic, or pneumatic air bubbler that record the flow rate and total flow automatically.



Weir Stilling Box

Figure 13

Flow in Pressure Conduits

Flow in pressure conduits is also known as full flow. The devices used in determining the flow rate depend upon the flow velocity through the pipe.

Depending on the type of liquid, solid content of liquid, the temperature, the liquid, the type of flow measurement device is used. The most typical flow meters are:

1. Venturi Meter - Figure 14. This device is a pipe segment consisting of a converging section, a throat, and a diverging section. In the venturi tube, a part of the static head is transferred into velocity head. Therefore, the static head in the throat of the tube is less than the static head in the channel. This difference in head is directly related to the flow. The principle that the venturi meter operates is the continuity theory. This theory states that a volume of liquid entering the pipe at one end per unit time, must leave the other end in the same time. If the principle did not apply then if less liquid leaves the pipe than enters it, the volume will build up and the pipe will burst. If more liquid leaves the pipe than enters it, the pipe will eventually empty.

Assuming that two different diametered pipes are connected then from the continuity principle:

$Q_1 = Q_2$

Where Q is the volume entering the pipe

Substituting for Q

$Q_1 = A_1 v_1$

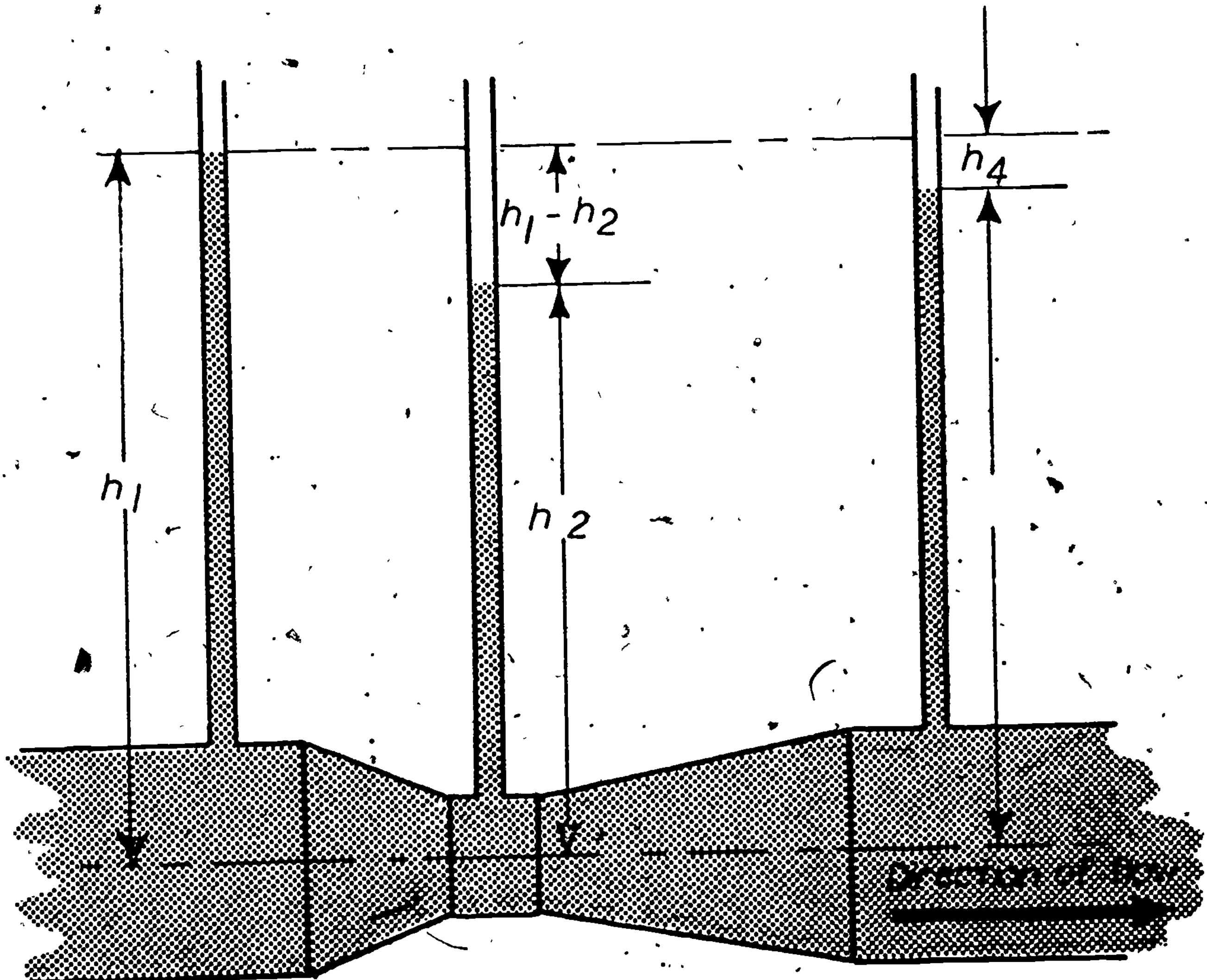
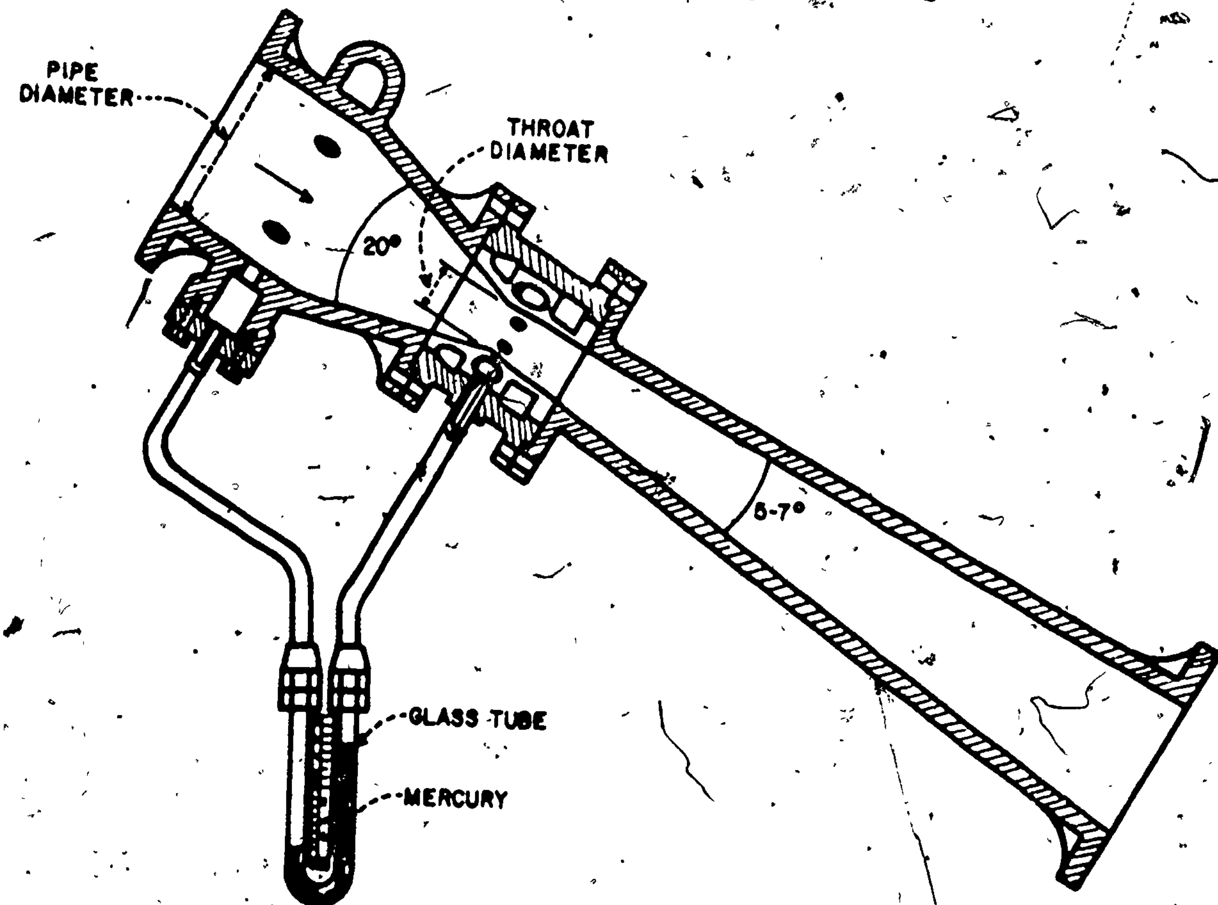


Figure 14



VENTURI METER

Figure 14

And

$Q_2 = A_2 v_2$

Therefore

$A_1 v_1 = A_2 v_2$

In a venturi meter since the cross-sectional area of the pipes are different(converging section and throat) then to make the above equation equal the velocities will be different. By increasing the velocities the pressure exerted will decrease. By decreasing the velocity the pressure will increase.

Example: Two pipes, one 4 inches in diameter and the second 6 inches in diameter. The velocity in the 4 inch pipe is 8 ft/sec. Calculate the velocity in the 6 inch pipe.

Solution

$A_1 v_1 = A_2 \, {}_2$

$$.785 \times \frac{4 \times 4}{12 \times 12} \times 8 = .785 \times \frac{6}{12} \times \frac{6}{12} \times v_2$$

$v_2 = 3.57$ ft/sec.

The venturi meter also utilizes Bernoulli's theory which states that at any point in a liquid system, the sum of:

1. Pressure head
2. Velocity head
3. Potential head

But through experimentation it was also determined that between two points in a liquid system these three sums were not equal the difference was due to friction. In a venturi meter the head loss due to friction is minimal, that in many calculations it is ignored.

Bernoulli's formula is:

$$h_1 + \frac{v_1^2}{2g} + \frac{P_1}{W} = h_2 + \frac{v_2^2}{2g} + \frac{P_2}{W}$$

Where

h = Height of liquid in feet

V = Velocity in ft/sec.

g = Gravitational fuel (32 ft/sec.^{2})

P = Pressure in psi

W = Specific weight of liquid in lbs/ft^3

h_1 and h_2 are equal since the venturi meter should be used on a horizontal plane.

Bernoulli's formula becomes:

$$\frac{v_1^2}{2g} + \frac{P_1}{W} = \frac{v_2^2}{2g} + \frac{P_2}{W}$$

$$v_2^2 - v_1^2 = \frac{P_1 - P_2}{W} \times 2g$$

Since

Q = A x V

Then

$$Q = \frac{A_1 \times A_2}{\sqrt{A_1^2 - A_2^2}} \times \sqrt{\frac{2g\ (P_1 - P_2)}{W}}$$

Since the cross-sectional areas of a meter does not change but the pressures change due to change in velocity then a constant can be obtained for:

$K = \frac{A_1 \times A_2}{\sqrt{A_1^2 - A_2^2}} \times \sqrt{\frac{2g}{W}}$

So

$Q = K \times \sqrt{P_1 - P_2}$

Q = Flow rate in cubic feet/sec.

Where:

A_1 Cross-sectional area of converging area

A_2 Cross-sectional area of throat

Example: A venturi meter has an input diameter of 6 inches and a small diameter of 3 inches. The input pressure (P_1) is 9 psi and the throat pressure of 5 psi. Calculate the flow rate.

Solution

Solve for K using the formula:

$K = \frac{A_1 \times A_2}{\sqrt{A_1^2 - A_2^2}} \times \sqrt{\frac{2g}{W}}$

$A_1 = .785 \times \left(\frac{6}{12}\right)^2$

$= .196 \text{ ft}^2$

$A_2 = .785 \times \left(\frac{3}{12}\right)^2$

$= .049 \text{ ft}^2$

$A_1 \times A_2 = .196 \text{ ft}^2 \times .049 \text{ ft}^2$

$= .01 \text{ ft}^4$

$\sqrt{A_1^2 - A_2^2} = \sqrt{(.196 \text{ ft}^2)^2 - (.049 \text{ ft}^2)^2}$

$= \sqrt{.036 \text{ ft}^4}$

$= .189 \text{ ft}^2$

$\frac{A_1 \times A_2}{\sqrt{A_1^2 - A_2^2}} = \frac{0.1 \text{ ft}^4}{.189 \text{ ft}^2} = 0.53 \text{ ft}^2$

$\sqrt{\frac{2g}{W}} = \sqrt{\frac{2 \times 32 \text{ ft/sec}^2}{62.4 \text{ lbs/ft}^3}}$

$= \sqrt{1.046 \text{ ft}^4/\text{sec}^2}$

$= 1.023 \text{ ft}^2/\text{sec.}$

$K = 0.53 \text{ ft}^2 \times 1.023 \text{ ft}^2/\text{sec.}$

$K = 0.54 \text{ ft}^4/\text{sec.}$

or

$K = 6.48 \text{ ft}^3/\text{sec/in. change in } (P_1 - P_2)$

$Q = K \times \sqrt{P_1 - P_2}$

$\sqrt{P_1 - P_2} = \sqrt{9 - 5}$

$= \sqrt{4}$

= 2 inch change

$Q = \frac{6.48 = \text{ft}^3 \times \text{in.} \times 2}{\text{Sec.}}$

$Q = 12.96 \text{ ft}^3/\text{sec.}$

Example 2

Using the same venturi meter converging area 6" and throat 3", calculate the flow rate if:

1. $P_1 = 11$ psi

   $P_2 = 5$ psi

2. $P_1 = 8$ psi

   $P_2 = 3$ psi

Solution 1

$Q = K \times \sqrt{P_1 - P_2}$

$= 6.48 \times \sqrt{11 - 5}$

$= 6.48 \times 2.45$

$= 15.87 \text{ ft}^3/\text{sec.}$

Solution 2

$Q = K \sqrt{P_1 - P_2}$

$= 6.48 \sqrt{8 - 3}$

$= 14.49\ ft^3/sec.$

This pressure differential is detected by a translator which in turn is recorded to a recording chart.

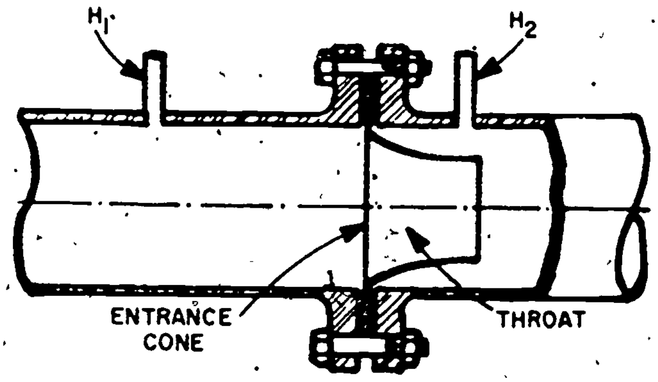
Venturi meters are frequently employed where high pressure recovery is essential or where large amounts of solids in the flow stream would tend to collect in front of an orifice plate.

The meter must be installed downstream from a section of straight and uniform pipe and the required length of straight section depends on the ratio of throat diameter and pipe diameter and should be from 5 to 15 pipe diameters. Manufacturers of venturi meters will routinely size their meters for a specific use. It is important, however, that the meter be installed according to their instructions.

The principle of the venturi meter is applied to many different devices in measuring the flow rate.

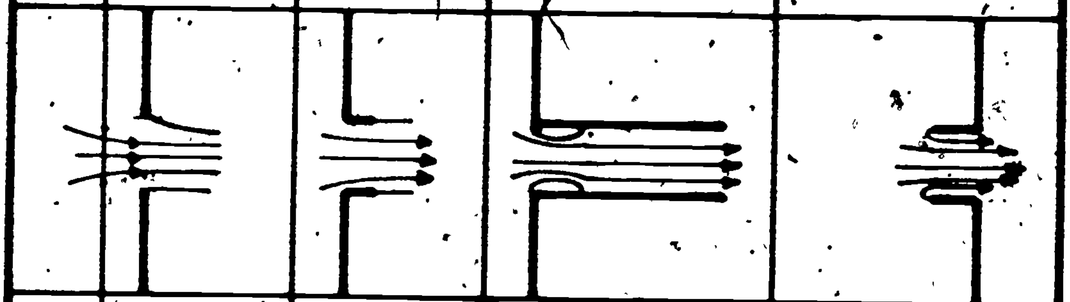
a. Flow Nozzle - Or flow tube. Figure 15. This device is used with slightly moderate amounts of suspended solids. There are different types of nozzles that manufacturers provide specifications, equations, and capacity tables or charts.

b. Orifice Meter - An orifice meter (Figure 16) is a relatively inexpensive, easy to install and reliable flow measuring device. The thin plate orifice being most commonly used. Basically, an orifice is an obstacle placed in the path of the flow in a pipe.



FLOW NOZZLE IN PIPE

Figure 15

ORIFICES AND THEIR NOMINAL COEFFICIENTS				
	SHARP EDGED	ROUNDED	SHORT TUBE	BORDA
				
C	0.61	0.98	0.80	0.51

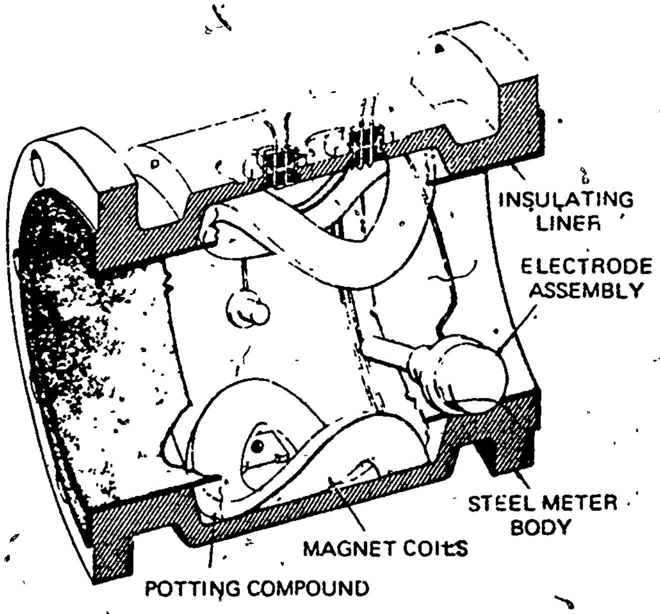
COEFFICIENTS OF SEVERAL TYPES OF ORIFICES

Figure 16

The orifice is quite useful with variations in flow accommodated by varying the throat width. The main disadvantage to the orifice is the large head loss that occurs across the section.

2. Two magnetic flow meters - Several types of magnetic meters (Figure 15) that can be used successfully in places where other types of meters would become clogged by solids. The magnetic flow meter operates according to Faraday's law of induction: THE VOLTAGE INDUCED BY A CONDUCTOR MOVING AT RIGHT ANGLES THROUGH A MAGNETIC FIELD WILL BE PROPORTIONAL TO THE VELOCITY OF THE CONDUCTOR THROUGH THE FIELD. In the magnetic flow meter, the process liquid is the conductor, and a set of electro-magnetic coils in the flow meter produces the field. The induced voltage is drawn off through the flow meter electrode which are in contact with the liquid, and then transmitted to a converter for signal conditioning. In a given meter, the induced voltage is a function only of liquid velocity, and is not affected by temperature, viscosity, turbulence, or conductivity (above a minimum threshhold of 5 micro-ohm). For liquid with conductivity values of 0 - 1 to 5 micro ohms, a special signal converter is needed. When the pipe diameter and measuring the average velocity are known, the flow rate can be determined. $Q = A \times V$. The magnetic flow meter can be used in pipes with a diameter as small as 0.1 inch.

The accuracy of the meter increases with increases in velocity, a one percent accuracy being obtainable for flow velocities from 3 to 30 ft. per second. The magnetic flow meter does not result in head loss; the pressure loss is no greater than for flow through an equivalent length of straight pipe.



MAGNETIC FLOW METER

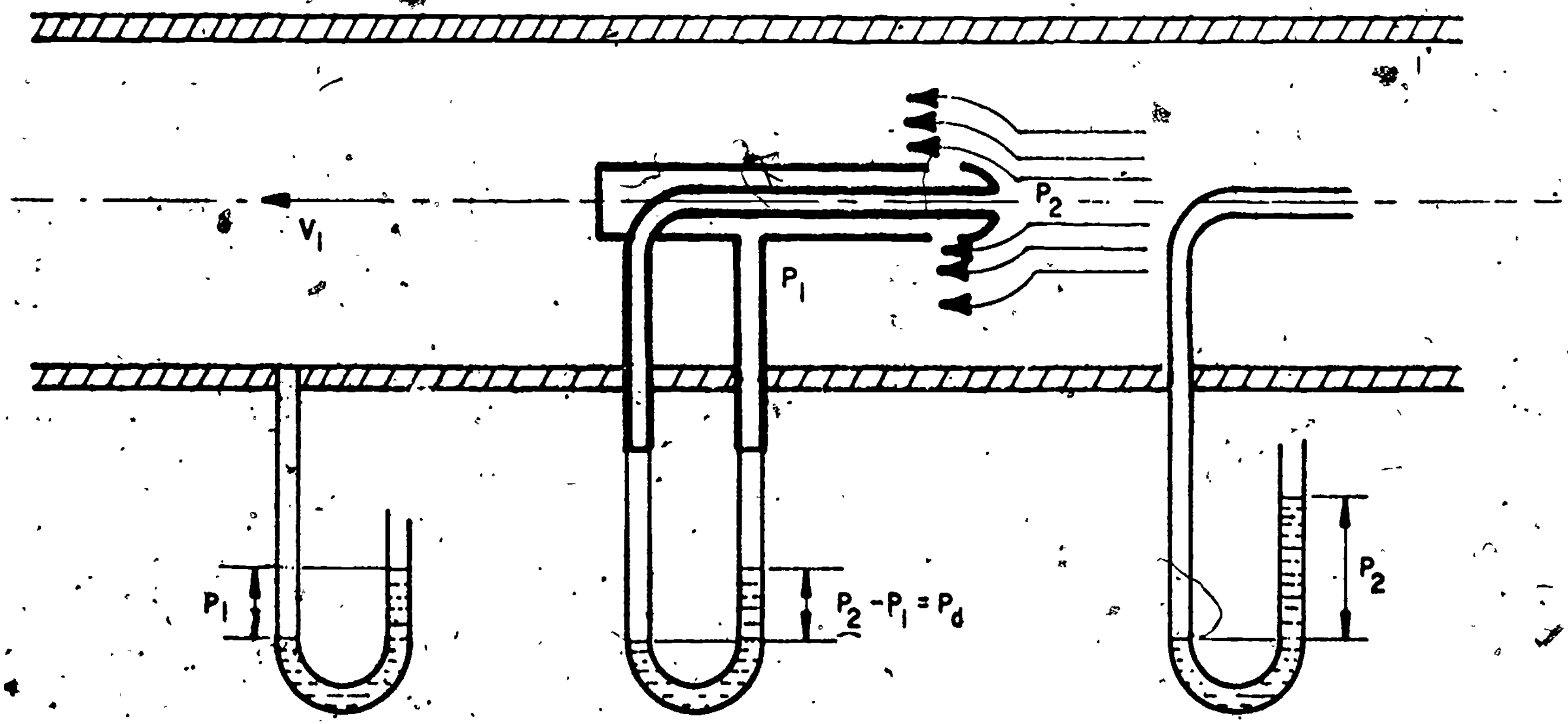
Figure 17

3. Rotameter - Rotameters are tapered tubes in which the fluid flows vertically upward. A metal float in the tube comes to equilibrium at a point where the auxiliary flow is such that the velocity increase has produced the necessary pressure difference. Rotameters are simple, inexpensive and accurate devices for measuring relatively small rates of flow of clear, clean liquids. For this reason they are often used to measure the water rates.

4. Pitot Tube - The pitot tube (Figure 18) operates upon the principle that the velocity of the flow is calculated from the difference in head measured on the manometer. The pressure in the left tube measures the static pressure in the pipe and the right tube measures the stagnation pressure, or the pressure where the velocity is zero. Commercially available pitot tubes consist of a combined piezometer and total head meter. Pitot tube measurements should be made in a straight section upstream free of valves, tees, elbows, and other fittings with a minimum distance of 15 to 50 times the pipe diameter. When a straight section is not possible, a velocity profile should be determined experimentally. Pitot tubes are not practical for use with liquids with large amounts of suspended solids because of the possibility of plugging. In large pipes, the pitot tube is one of the most economical means of measuring flows.

5. Ultrasonic - A typical sonic flow meter consists of:

   a. Flow tube
   b. Two transducer assemblies
   c. A transmitter with a cable to each transducer
   d. Flow totalizer or recorders.



PITOT TUBE MEASURES VELOCITY HEAD

Figure 18

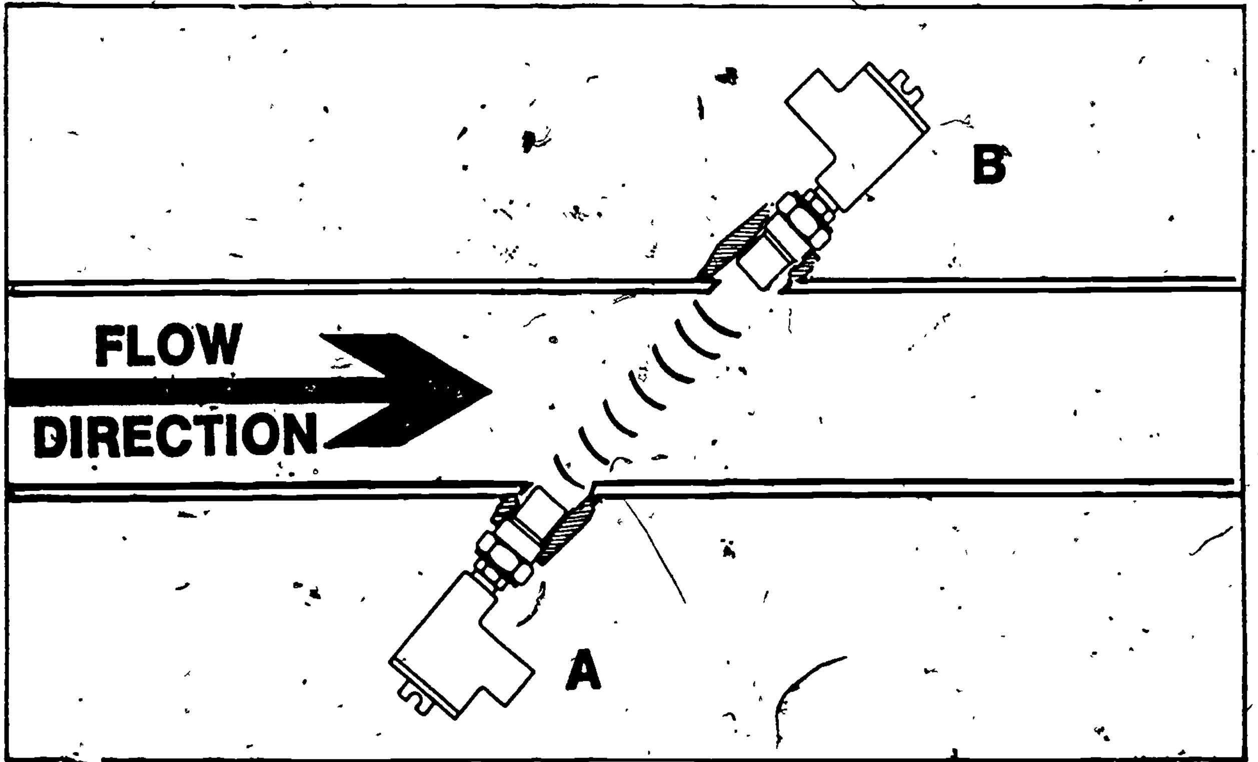


Figure 19

The operating principle of the ultrasonic flow meter (Figure 19) operates on ultrasonic pulses traverses the liquid to be metered at a 45 degree angle to the direction of flow. The speed of sound from A to B represents the inherent speed of sound of the liquid plus a contribution due to the flow rate. The virtually simultaneous measurement from B to A represents the inherent speed of sound of the liquid minus this same contribution due to flow rate. When the B to A determination is electronically subtracted from the A to B determination the speed of sound inherent to the liquid itself cancels out. The difference is proportional to the flow rate alone, independent of the specific liquid being metered.

SUMMARY

Flow measurement in pipes flowing full are not difficult to install and operate. Different flow rates and solids concentration dictate the type, size of flow meter. Flow meters that are used in pipes flowing full depend upon the inverse relationship of velocity and pressure.

Higher velocity = Lower pressure

There are many types and makes not mentioned in this module of flow meters. The basis for most operate upon either the rise in level of water behind an obstruction or the velocity of water going through a specific area.

Preventive Maintenance

Flow meters like any apparatus need constant maintenance. Although there are meters that need less attention than others.

1. Parshall flume - Parshall flumes although are self-cleaning should be checked for biological growths and chemical deposits. Such growth deposits can be removed using a brush and water. Stilling wells collect solids which should be removed. Floats should be cleaned.
2. Weirs - Weirs tend to allow solids to deposit behind them. These deposits will change the height of the weir from the bottom of the channel to the crest. Weirs should be kept clean. Fibers, stringy materials and larger particles tend to cling to the crest. In water with high suspended solids concentrations, considerable sedimentation in the channel of approach will take place. Sediments influence measurements and make representative sampling more difficult. The connection of the weir to the channel should be waterproof. Therefore, the joint between the weir plate and channel should be packed with a chemically inert cement or asphalt type roofing compound. Grease compounds should not be used if oil concentrations are to be measured.

   Weirs should be kept level and to insure a uniform depth of flow.
3. Level sensing devices such as:
   a. Staff gauges need cleaning. Biological growths and chemical deposits should be removed from the surface of the gauge. DO NOT scrub too hard the surface of the gauge. It could cause the removal of the numbers. The surface of the gauge should be checked for rusting and pitting.

b. Float gauge - Float gauge functions in a stilling well. The well should be cleaned of solids that have settled in the well. The float should be checked for rust and pitting. If any painting has to be done a light coat of rust inhibiting paint is preferred. The float should be checked for any water inside the float. The wire attaching the float pulley and counter weight should be checked for loose and broken wire strands. In maintaining the recorder the manufacturers directions should be followed. The recorder that contains ~~an~~ ink pen should be checked for ink level.

c. Hook gauge - The component of the gauge that is placed below the water surface should not be mishandled, that is used to retrieve object from the water. By bending the component the accuracy of the gauge is reduced. Check the gauge for ease of movement vertically. Avoid hard scrubbing when cleaning the gauge. Always clean the unit after use and place in a protected area.

d. Air bubbler - The maintenance necessary to provide the proper functioning of this is system is to:

1. Make sure that biological growths and chemical deposits are removed from the outlet of the air tube.
2. The air is supplied from a cylinder to make sure that air is in sufficient quantity and pressure.
3. The stilling well should be cleaned of solids that have accumulated.
4. Follow manufacturers guidelines in maintaining specific parts of the unit.

5. Check for signs of deterioration such as rusting and pitting.

e. Instream Transmitter - Since these units depend upon a scow float in the flow stream, rags and floating material cling to the floats and will change the accuracy of the floating mechanism. Such material should be removed. Keep the unit clean and check any components for wear. Especially swivel joints.

f. Ultrasonic - This device needs very little maintenance. Check the power input and output of the electronics of the unit. Check for corroded terminals and contacts.

4. Discharge from a pipe. If one is measuring the free discharge from a pipe the outlet should be kept clean. The circumference of the pipe should be smooth and void of jagged edges.

5. Units that operate best full flow such as venturi meters, magnetic flow meters, ultrasonic velocity sensing and orifice meters need very little preventative maintenance. Manufacturers maintenance guidelines should be followed. Sometimes pressure taps get filled with solids which have to be removed. Again follow manufacturers guidelines in cleaning the taps.

6. Rotameters and pitot tubes should not be used for flows with solid contents. They should be checked occasionally for solid buildup.

All flow metering devices be they the primary unit, that is flumes, weirs, ultrasonics, venturi meters, magnetic flow meters and secondary devices such as staff gauges, floats, recorders and power sources should be checked for accuracy at installation and during use. Recalibration may be necessary on occasion.

Operating flow measurement devices safely is an important step in an important step in an operator's duties. While maintaining the unit all power sources should be turned off to the meter or recorder.

If the input is placed in a confined area with poor ventilation i.e. manholes, then proper safetv precautions in working in manholes should be taken such as ventilation, checking of gases (H_2S and methane) in drop sewer manholes

While cleaning flumes and weirs individuals should make sure that safe working conditions should be practiced such as solid footing, improper leaning into the channel, not using safetv harness, improper use of tools.

Safety practices should be an important part of the operators duties

Problems Related to Flow Measurement

1. A sewer line delivers a flow of wastewater to a wet well. The well has a dimension of a radius of 12 ft. The height of water in the well rises 4 ft. in 35 seconds. Calculate the flow rate of the wastewater. Ans. in GPM.

2. Calculate the pumping rate from a well containing 6000 gallons if the time needed to pump the gallons is 150 seconds.

3. A clear well 30 ft. x 12 ft. x 8 ft. gets filled to the 3 ft. level in 2 hrs. 10 seconds. Calculate the flow rate into the well.

4. What size parshall flume would be used to provide a recording 100 GPM up to 3000 GPM.

5. Calculate the flow rate through a 4" parshall flume if the height of the water in the converging section is 3 inches.

6. Determine the approximate flow rate through a rectangular weir 30 ft. weir length and a head of 5 inches. Use the namograph and check the answer using the formula for a rectangular weir.

7. Determine the flow rates if a 90° weir plate is used, and a head of 7 inches is developed.

8. A venturi meter with a 5" converging area and 2" throat develops a pressure differential of 16 psi. Calculate the flow rate.

9. Using the formula for a cipoletti weir with a 5 foot length and a head of 1 foot, calculate the flow rate.

10. A venturi meter with a 9" diameter in the area converging and 6" throat. The difference in pressure at recording times are:

8:00	6 psi
9:00	8 psi
10:00	10 psi
12:00	12 psi
1:00	13 psi
2:00	11 psi

Calculate the average flow rate between 8:00 to 2:00.

Module No:	Module Title: Flow Measurement
Approx. Time: 1 hour	Submodule Title: EVALUATION

Objectives:

The learner will demonstrate the ability to determine correctly the answer to 17 out of 20 problems related to flow measurement, flow measurement devices and operation, and maintenance of flow measuring devices.

Circle the best answer.

1. Flow measurement is
   a. A waste of time
   b. Done because you are told to do so by the government
   c. Important to provide operating control of treatment plants
   d. None of the above
2. Most flow measuring devices depend upon
   a. Measurement of velocity
   b. Measurement of depth of liquid behind an obstruction
   c. All of the above
   d. None of the above
3. A 10" pipe flowing full has a flow velocity of 3.8 ft/sec. Calculate the flow rate delivered by the pipe.
   a. 1.07 GPS
   b. 2231.3 GPD
   c. 52.0 GPS
   d. 15.5 GPS

4. A volume of 1400 gallons is pumped at a rate of 20 GPS. Calculate the number of seconds needed to pump the 1400 gallons.

   a. 1.17 seconds

   b. 466.7 seconds

   c. 28000 seconds

   d. 70 seconds

5. A venturi meter detects

   a. Velocity change between the converging section and throat

   b. The pressure change between the converging sections and throat

   c. The height of the water in the converging area

   d. The height of the water in the throat

6. To measure the flow rate through a parshall flume

   a. The height of water in the converging area is measured

   b. The height of the water in the discharge area is measured

   c. The velocity of the water in the throat is measured

   d. The use of special and complex equipment is needed

7. To measure the flow rate using a weir is to

   a. Measure the height of the crest of the water

   b. Measure the height of the water behind the weir plate

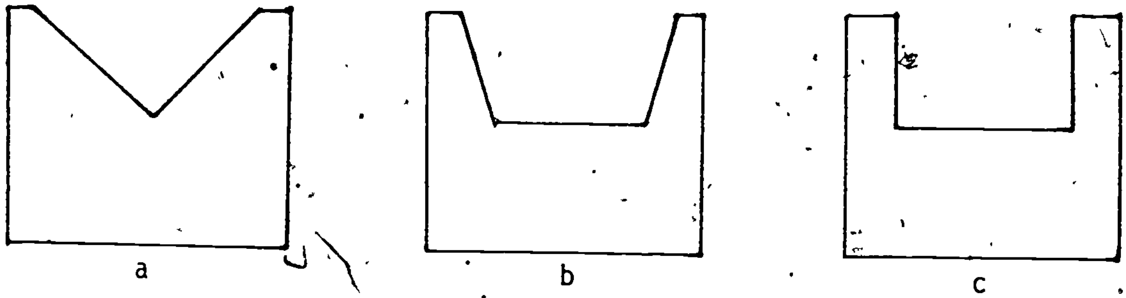
   c. Measure the velocity in the weir box

   d. All of the above

8. The position of the weir need not be level because the water surface is flat. a. True b. False

9. Identify the type of weir

Rectangular	a	b	c
Cipolletti	a	b	c
Triangular	a	b	c



10. Magnetic meters are used to determine the flow in open channels.

    a. True

    b. False

11. A float gauge should be placed

    a. The stream of the converging area of a flume

    b. In a stilling well of a flume

    c. In a stilling well of flume on the discharge side

    d. All of the above

12. Float gauges are connected to a counter weight so as

    a. To provide tension to the cable connected to the float

    b. Allow the float to float on the surface of the water

    c. To cause the pulley to rotate properly

    d. All of the above

13. Air bubbler system records the resistances caused by the height of the water to the escaping air through the immersed bubbler tube change.

    a. True

    b. False

14. In placing, removing or maintaining a flow meter in a manhole the operator should

    a. Check for dangerous gases

    b. Check for oxygen deficiency

c. Ventilate for 5 - 10 minutes

d. All of the above

15. Maintenance of flow meters is unnecessary because the flow rate scoures the units clean.

a. True

b. False

16. Solids buildup in stilling wells does not effect the operation of the float.

a. True

b. False

17. In flow charts and records a common operation and maintenance mistake is to

a. Forget to change chart

b. Forget to add ink to the pen

c. Add too much ink to the pen

d. All of the above

18. Pitot tubes are not used in wastewater flows due to the fact that

a. The flows are not too fast

b. The solids build up at the tube openings

c. The cost of the unit

d. All of the above

19. Using the formula for a cipolleti weir with a 6 foot length and a head of 18 inches, calculate the flow rate. $Q = 3.367\ L \times H^{3/2}$

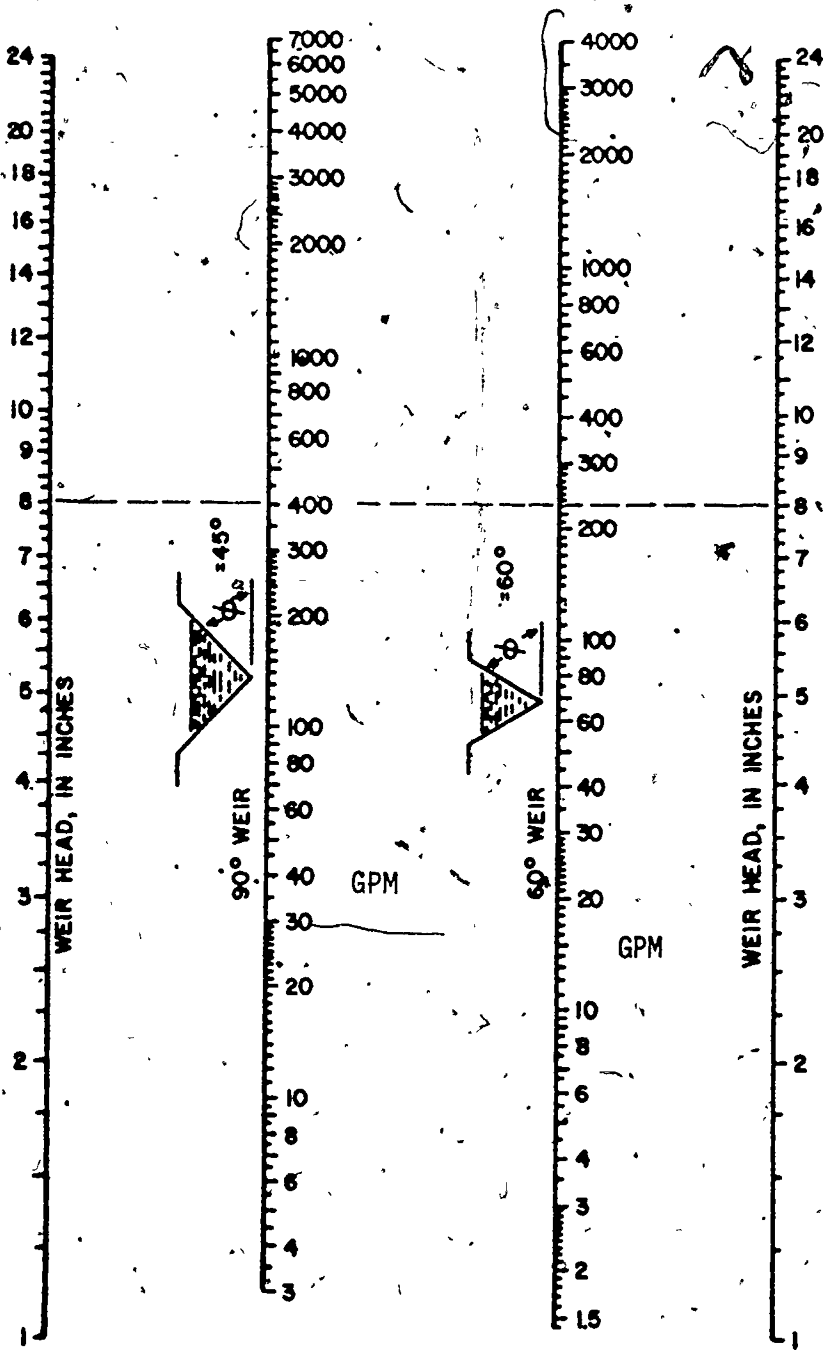
a. 37.11 CFS

b. 26.47 CFS

c. 1542.8 CFS

d. 276.76 CFS

20. The weir head in a 90^0 weir is 0.375 feet. Determine the approximate flow rate. Ans. should be ± GPM of the time answer.



FLOW RATES FOR 60° AND 90° V-NOTCH WEIRS

Module No:	EVALUATION

Instructor Notes:	Instructor Outline:
Answers:	Give evaluation questions

Answers:

1. c
2. c
3. d
4. d
5. b
6. a
7. b
8. b
9. c b. a
10. b
11. b
12. d
13. a
14. d
15. b
16. b
17. d
18. [illegible]
19. a
20. 95 GPM

Give evaluation questions