	AGRICULTURAL TVET COLLEGE	

SMALL SCALE IRRIGATION DEVELOPMENT LEVEL-III

MODEL TTLM

Learning Guide- 15

Unit of competency: Measure water flow in-pipes and open channels

Module Title: Measuring water flow in-pipes and open channels

LG code: AGR SSI3M 15 LO1-LO4

TTLM Code: AGR SSI3 TTLM 1218V1

Nominal duration: 40Hrs

Instruction sheet	Learning guide- 15

This learning guide is developed to provide you the necessary information regarding the following content coverage and topics:–

- Calculate energy losses and energy gradients in pipe flow
- Calculate flow in open channels
- Calculate flows through notches and weirs
- Calculate proportions for an economic section

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to –

- Review measurements
- Review inconsistent data on flow conditions
    - Identify data
    - Estimate data
    - Adjust and justify data
- Prepare pipeline design charts
- Identify the limitation of formulae
- Identify variations in roughness coefficients
- Calculate pipe discharge from reservoir
- Identify the methods used for measuring flows in open channels
- Using the formulae to calculate flows in open channels
- Distinguish the uses of different measuring instruments and devices
- Assess the hydraulic principles in different meters
- Identify the limitations of the meters
- Identify the methods used for measuring flows
- Using the formulae for calculating flows

- Distinguish the applications and characteristics of notches and weirs
- Distinguish the uses of different measuring instruments and devices
- Assess the hydraulic principles
- Identify the limitations of the meters
- Calculate the proportions of rectangular, trapezoidal and circular channels
- Identify the depth of flow using a partial flow chart

Learning Activities

1. Read the specific objectives of this Learning Guide.
2. Read the information written in the "Information Sheets.
3. Accomplish the "Self-check" at the end of each learning outcomes.
4. Ifyouearnedasatisfactoryevaluationproceedtothenext"InformationSheet".How ever, if you acting is unsatisfactory, see your teacher for further instructions or go back to the Learning Activity.
5. Submit your accomplished Self-check. This will form part of your training portfolio
6. Follow the steps and procedure list on the operation sheet
7. Do the "LAP test" and Request your teacher to evaluate your performance

Information Sheet-1	**Calculate energy losses and energy gradients in pipe flow**

Introduction

Flow is the volume of fluid that passes in a unit of time. In water resources, flow is often measured in units of cubic feet per second (cfs), cubic meters per second (cms), gallons per minute (gpm) or other various units. Measurement of flow in water resources is important for applications such as system control, billing, design and many other applications. There are several methods to measure flows in water resources systems.

Open-channel flow is a flow of liquid (basically water) in a conduit with a free surface. That is a surface on which pressure is equal to local atmospheric pressure.

Types characteristics of open channel

- steadiness
- uniformity
- state of open channel flow
- laminar, transitional and turbulent flow
- Critical, subcritical, and supercritical flow.

Pipes flows were introduced in the earliest days of the practice of hydraulics. Their common place use today makes it of great importance that the lows governing the flow in them should be fully understood. Water is conveyed from its source, normally in pressure pipelines, to water treatment plants where it enters the distribution system & finally arrives at the consumer. In addition oil, gas, irrigation water, sewerage can be conveyed by pipeline system.

1.1 Review measurements and compare against expected trend

Basics of water Flow

Whether a flow is laminar or turbulent depends of the relative importance of fluid friction (viscosity) and flow inertia. The ratio of inertial to viscous forces is the Reynolds number. Given the characteristic velocity scale, U, and length scale, L, for a system, is

$$\boldsymbol{Re} = \frac{\mathbf{UL}}{\boldsymbol{V}}$$

Where ν =kinematic viscosity of the fluid.

Re = Reynolds number

L=length of flow

U=friction velocity

$$Fr = \frac{\mathrm{V}}{\sqrt{\mathrm{gd}}}$$

Where Fr = Froud Number

g = acceleration of gravity

For an open channel

P = (2h + w)

For a closed conduit

P = 2(h+w)

Laminar Flow

As a general rule, open channel flow is laminar if the Reynolds number defined by the hydraulic radius,

$$Re = URh/v \text{ is less than } 500.$$

Laminar conditions can persist to higher Reynolds numbers if the conduit is smooth and inlet conditions are carefully designed.

In contrast, the characteristic length scale for groundwater systems is the pore scale, which is typically quite small (< 1 mm), and groundwater flow is nearly always laminar.

Turbulent flow

As the Reynolds number increases above this limit burst of turbulent appear intermittently in the flow.

If the conduit boundary is rough, the transition to fully turbulent flow can occur at lower

Reynolds numbers.

Because this scale is typically large (1 m to 100's km), most surface water systems are turbulent. Turbulent eddies create fluctuations in velocity.

For pipe flow

Flow	R taken as characteristic length	D taken as characteristic length
Laminar Transitionnel Turbulent	$R \leq 500$ $500 \leq R \leq 12,500$ $12,500 \leq R$	$R \leq 2000$ $2000 \leq R \leq 50,000$ $50,000 \leq R$

For open channel flow

Flow	R taken as characteristic length
Laminer Transitionnel Turbulent	$R \leq 500$ $500 \leq R \leq 2000$ $\leq R$

1.2 identifying flow conditions

- **Types of flows**

Flow in an open channel is said to be ***steady*** if the depth of flow does not change or if it can be assumed to be constant during the time interval under consideration at a fixed point. In steady flow the flow variables (velocity, pressure, density, flow path etc) do not vary with time at the spatial point in the flow. The discharge Q at a channel section is expressed by

$Q = VA$ Equation **Error! No text of specified style in document.**-1

Where v is the mean velocity and A is the flow cross sectional area normal to the direction of the flow, since the mean velocity is defined as the discharge divided by the cross-sectional area.

$Q = V_1 A_1 = v_2 A_2 = - - - -$ Equation **Error! No text of specified style in document.**-2

It is designate different channel sections. This is the continuity equation for a ***continuous steady flow***.

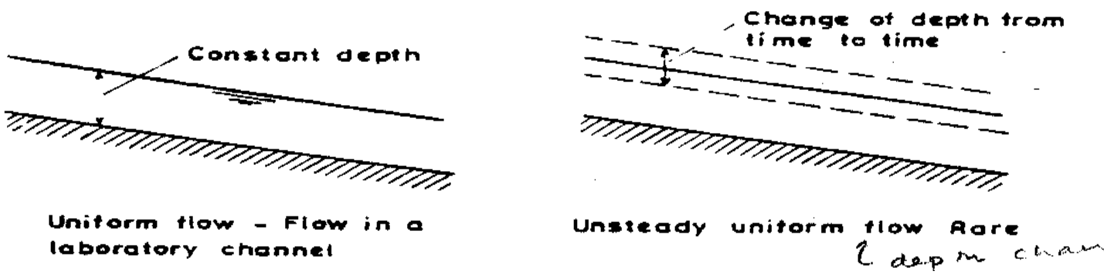


Figure **Error! No text of specified style in document.**-1 steady and unsteady flow

Uniform flow and varied flow: space as the criterion

Uniform flow

Open channel flow is said to be ***uniform*** if the depth of flow is the same at every section of the channel. A uniform flow may be steady or unsteady, depending on whether or not the depth changes with time.

Uniform flow in open channels has the following main characteristics

the depth, water area, velocity, and discharge at every section of the channel are constant;

the energy line, water surface, and channel bottom are all parallel; i.e. their slopes are all equal $S_f = S_w = S_o$

Computation of Uniform flow

For computational purposes, the average velocity of a uniform flow can be computed approximately by one of a number of semi empirical uniform flow equations. All of these equations have the form

$V = CR^x S^y$

Where

V = average velocity

R = hydraulic radius

S = channel longitudinal slope

C = resistance coefficient

X and y coefficients

In fluid dynamics, the Chézy formula describes the mean flow velocity of steady, turbulent open channel flowThe popular two equations are the Chezy equation, developed in 1769, and the Manning equation, developed in 1889.

$V = C\sqrt{RS}$ Chezy Formula

Where V is the mean velocity is m/s, R is the hydraulic radius in m, S is the slope of energy line (m/m), and C is a factor of flow resistance, called Chezy's C.

1.4 The Colebrook Equation:L. Prandtle and Von Karaman in Germany, and G.I. Tylor in expressing mathematical Form the mechanism of turbulence linked the experimental investigation of Nikuradse (1932-

1935) had proved a formula of the type (Colebrook, 1938):

$$\frac{1}{\sqrt{F}} = 2\log\left(\frac{0.113d}{y_1}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots$$

And showed the lower limit of the integration y_1, is a function of the wall particle size k, in

The case of rough pipes in which the flow obeys the square resistance law, and is dependent

On the density ρ, the viscosity μ and the shear stress at the wall τ in the case of smooth pipes.

In 1938, Cyril Frank Colebrook confirmed the substitution of values of y, in the foregoing Equation and adopted the following resistance law

(a)Flow in hydraulically smooth pipes:

$$\frac{1}{\sqrt{F}} = -2\log\left(\frac{2.51}{R_e\sqrt{F}}\right) \text{..}$$

(b) Flow in hydraulically rough pipes:

$$\frac{1}{\sqrt{F}} = -2\log\left(\frac{k}{3.7d}\right) \text{..}$$

Manning equation is the result of a curve fitting process and thus is completely empirical in nature. In application of the Manning equation, it is essential that the system of units being used be identified and that the appropriate coefficient is used. In the SI system of units, the Manning equation is

$V = 1/n\ R2^{/3}\sqrt{S}$

Where n = Manning resistance coefficient. As was the case with the chezy resistance coefficient, n is dimensionless manning coefficient S is slope R is hydraulic radius.

1.3 Prepare pipeline design charts using standard formulae.

Static and Dynamic Equilibrium Static Equilibrium-No water Flow-Water Level static Pressure-static head-horizontal, $\Delta h = 0$, $h1 = h2$

Hazen–William's equation

$$\mathbf{hf = KL}\ \left(\frac{Q}{C}\right)^{1.852} \Big/ D^{4.87}$$

Where: h_f =friction loss expressed as head, m

K = conversion constant = $1.22*10^{10}$

L = length of pipe, m

Q = Volumetric flow rate, l/s

C = Hazen – William friction coefficient (C= 135 for aluminum pipes)

D = Pipe diameter, mm

Bernoulli's Equation

According to principle of conservation of Energy

$h_1 + Z_1 + hv_1 = h2 + Z_2 + hv_2 =$ constant

-This is true for ideal fluid having no viscosity. But for flow of real fluid, there is some friction loss. Considering two points, Bernoulli's Equation for real fluid may be written as

$h_1 + Z_1 + hv_1 = h_2 + Z_2 + hv_2 + h_f$

$h_f = H_1 - H_2$

Head Loss due to Friction

1. Darcy –Weisbach Equation:

This equation states the actual head loss, (hf) as a function of the pipe diameter roughness, length of the pipe and flow velocity and is given as:

$$\mathbf{h}\boldsymbol{f} = \boldsymbol{f}\frac{\boldsymbol{L}}{\boldsymbol{D}}\ \frac{\boldsymbol{V}^2}{\mathbf{2}\boldsymbol{g}}$$

Where h_f= head loss due to friction, m

f = friction factor, which among others, dependent on the viscosity of the fluid and the roughness of the inside of the pipe, dimensionless

L = length of pipe or tubing over which head loss is evaluated, m

D = Diameter of piping or tubing, m

V$\boldsymbol{velocityheadofflow, m} = \frac{\boldsymbol{V}^2}{\mathbf{2}\boldsymbol{g}}$

$$\mathbf{h}\boldsymbol{f} = \frac{\mathbf{8}\boldsymbol{fLQ}^2}{\boldsymbol{g\pi}^{\mathbf{2}\boldsymbol{D}^5}}$$

1.4. Limitations of different flow measurement and formula.

A. Propeller Flow Meter

Operation

- Accuracy – 2% with proper flow rates.
- Accuracy very poor at velocities less than 1.0 fps for 12" and smaller.
- Flow will vary when removed

- Measuring while making adjustments can take hours to stabilize
- Remove debris before it gets to the meter, OR
- Clean the propeller frequently

Advantages

- Easy to use for pipe (pressurized) flow.
- Can have a low relative installation cost.

Disadvantages

- Turbulence in the water makes accurate measurements difficult.
- Material can easily plug the propeller.

B. Open Pipe Discharge

Advantages

- Simple to use, resulting in lower costs.
- Typically the pipe is in-place, no construction required.

Disadvantages

- Velocity and turbulence in the water make accurate measurements difficult.
- Wind can affect readings.
- Messy business (can get wet)

C. Venture Meters

- Installation
- Usually inserted between two flanges.
- Short-upstream end must be same diameter as pipeline.
- Connect holes in meter to piezometer.
- Take the reading

Operation

Measurement of head – measurements are made at the entrance section and throat sections and used in equation.

Head loss – Often, a measurement is taken immediately below constriction to document overall loss through meter. Expect 10 to 20 percent loss.

Table Values of C and K – Need coefficient tables to calculate flow.

Advantages

- Does not obstruct the flow.
- Simple operation. No moving parts.

Disadvantages

- Tubes used to measure pressure can become plugged easily.
- Can be expensive in large installations.

1.5 Roughness coefficients of materials.

Table 1 Values of Hazen William coefficient (C) for various pipe and tubing materials.

Pipe material	Hazen William coefficient (C)
Plastic	150
Asbestos Cement	140
Galvanized steel	135
Aluminum	130
Steel (New)	135
Cast iron coated	130
Cast iron (old ,moderate corrosion, 30yrs age)	100

Table 2 Values of the absolute roughness for various pipe and tubing materials. (Albertson et al, 1960.)

Absolute Roughness (mm)		
Material	Minimum	Maximum
Plastic	0.003	0.03
Commercial and wrought iron	0.03	0.09
Galvanized iron	0.06	0.02
Aluminum	0.1 0.3	
Concrete	0.3	3.0
Riveted steel	0.9	9.0
Corrugated metal pipe	30.0	60.0

1.6. Pipe discharge calculation from reservoirs

Discharge capacity of pipelines

The discharge through a pipeline can be determined by applying the Darcy equation:

$$V= \sqrt{\frac{Hdg}{2fl}}$$

Where v = Velocity of flow of water through the pipe, cm/sec

H = Available head causing flow (difference in elevation between the water level in the pump stand and the outlet point), cm

d = Diameter of pipe, cm

g = acceleration due to gravity, cm/s2

l = Length of pipe, cm

f = Darcy‟s roughness coefficient

Example: Determine the discharge capacity of an underground concrete pipe line of 16 cm diameter pipes. The length of the pipeline is 210 m. The difference in elevation between the water levels at the pump stand and the discharge point is 2.5 m.

Solution: The value of „f‟ is assumed to be 0.009 (Table, with an assumed velocity of flow of 90 cm/s.)

Data given: d = 16 cm l = 21000 cm H = 2.5 m = 2500 cm g = 981 cm/s2

$$V= \sqrt{\frac{Hdg}{2fl}}$$

$$V= \sqrt{\frac{250\ 16\ 981}{2\ 0.009\ 21000}} = 101.88 = 102 \text{ cm} = 1.02 \text{ m}$$

Area of cross section of pipe, a = Area of cross section of pipe, a $=\pi d^2/4$

= π*16*16/4= 0.02 m2

Discharge capacity, q = av = 0.02 *1.02 = 0.0204 m^3/s = 20.4 lt/s

Self-Check 1	Written Test

Name: ___________________________ Date: ________________

Directions: Answer all the questions listed below.

1. Identify the Advantage and limitation of each pipe flow measurement methods?
2. Determine the discharge capacity of an underground concrete by using the given data

Pipe line of 21 cm diameter pipes. The length of the pipeline is 200 m. The difference in elevation between the water levels at the pump stand and the discharge point is 2.5 m. The value of „f" is assumed to be 0.009 (Table, with an assumed velocity of flow of 90 cm/s.)

3. What mean turbulent flow and Laminar flow and differentiate it?

Note: Satisfactory rating - 13points above Unsatisfactory - below 13 points

You can ask you teacher for the copy of the correct answers.

Information sheet 2.	Calculate flow in open channel

INTRODUCTION

Increasing utilization and the value of water makes the understanding of water measuring techniques important and necessary. Accurate flow measurement is very important for proper and equitable distribution of water among water users. Information concerning the volume of available water is very helpful in planning for its future use and distribution.

There are several types of flow measurement devices currently in use across the private, local, state, and federal agencies. Among the major types of measurement devices used in surface water (open channels) and/or closed conduits are: weirs, flumes, current meters, orifices, propeller meters, strain gage, venturi meters, paddle wheels, electromagnetic, turbine meters, ultrasonic meters, pitot tubes, elbow tab meters, vortex shedding, mass meters, and orifice plates. The most common water measurement devices in Utah are sharp crested weirs and parshall flumes. Irrigation water management begins with knowing how much water is available for irrigation. discusses water measurement units and useful factors for converting from one measurement unit to another. The purpose of this fact sheet is to discuss a few basic methods of water measurement.

Methods of measuring irrigation water can be grouped into three basic categories direct, velocity-area, and constricted flow. Choice of method to use will be determined by the volume of water to be measured, the degree of accuracy desired, whether the installation is permanent or temporary, and the financial investment required.

2.1 Identifying the methods used for measuring flows in open channels

Methods used for measuring flows include: container method, tilt tank method, trajectory method

1. The trajectory method of water measurement is a form of velocity area calculations that can be used for determining the rate of flow discharging from a horizontal pipe flowing full. Two measurements of the discharging jet are required to calculate the rate of flow of the water. The first measurement is the horizontal distance, "X", (parallel to the centerline of the pipe) required for the jet to drop a vertical distance "Y" which is the second measurement. By using "Y" equal to either 6 or 12 inches, the rate of flow for full pipes can be calculated by multiplying the horizontal distance "X" (in inches) times the appropriate factor for the nominal pipe diameter. The following table contains water discharge factor where "Y" is measured from the outside of the pipe as indicated in the sketch above.

Nominal Pipe Diameter	Factor When Y=6	Factor When Y=12
2"	5.02	3.52
3"	11.13	7.77
4"	17.18	13.4
6"	43.7	30.6
8"	76.0	52.9
10"	120.0	83.5
12"	173.0	120.0

EXAMPLE: A farmer has a well discharging a full 8" pipe. Thehorizontal distance (X) is 19" while the jet surface drops 12".What is the well yield?

Step 1: Enter the water discharge factor table at 8" nominal pipe diameter. Moving to the right and under the column headed Y = 12" we find the factor to be 52.9.

Step 2: Multiplying this factor 52.9, times the horizontal distance, 19" calculate the well yield to be 1,005 gpm.

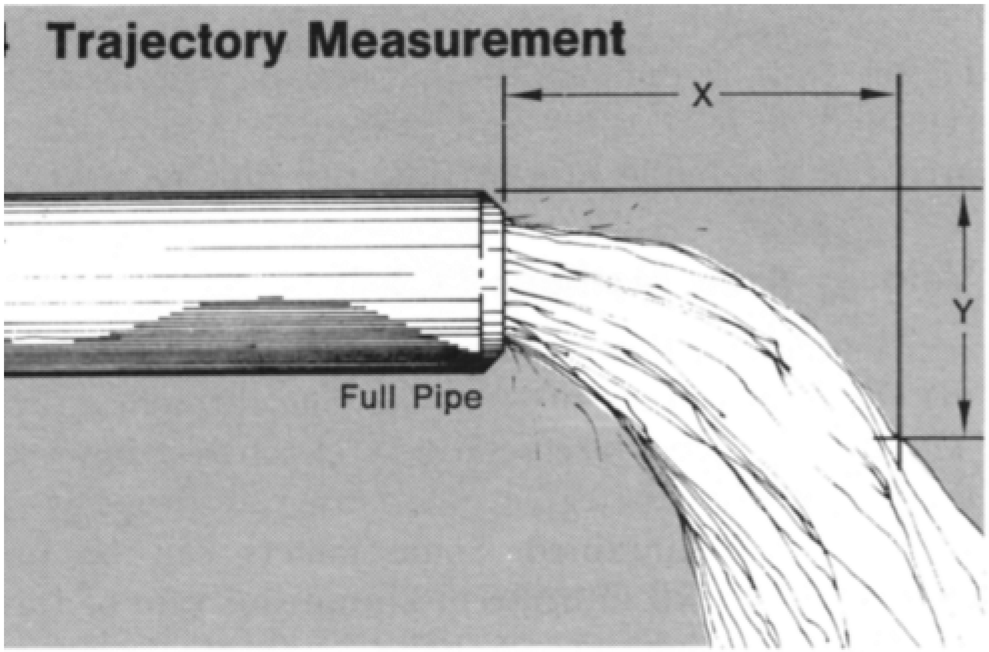


Fig 2.1 trajectory measurement

2. Direct Measurement Methods

Measuring the period of time required to fill a container of a known volume can be used to measure small rates of flow such as from individual siphon tubes, sprinkler nozzles, or from individual outlets in gated pipe. Ordinarily one gallon or five gallon **containers** will be adequate. Small wells can be measured by using a 55 gallon barrel as the container. It is recommended that the measurement be repeated at least three and preferably five times to arrive at a reliable rate of flow per unit of time. are relatively expensive; however, they have a good degree of accuracy if properly installed and maintained. Some meters can be purchased, which will indicate instantaneous rate of flow.

Volumetric Method

A simple method of measuring small irrigation streams is to collect it in a container of known volume for a measured period of time.

$$\textbf{Dischargerate (liters /sec)} = \frac{\textbf{Volumeofcontainer, liters}}{\boldsymbol{Timerequiredforfilling, seconds}}$$

For example, a 20 liter capacity bucket is filled in 10 seconds by the discharge from a Persian wheel, then the rate of flow will be 20/10 = 2 liters /sec. or 120 liters /min.

The float method can be used to obtain an approximate measure of the rate of flow occurring in an open ditch. It is especially useful where more expensive installations are not justified or high degree accuracy is not required. Select a straight section of ditch from 50 to 100 feet long with fairly uniform cross-sections. Make several measurements of the width and depth of the test cross-section so as to arrive at an average cross-sectional area. Using a tape, measure the length of the test section of the ditch. Place asmall floating object in the ditch a few feet above the starting point of the test section and time the number of seconds for this object to travel the length of the test section. This time measurement should be made several times to arrive at areliable average value. By dividing the length of the test section (feet) by the average time required (seconds), one can estimate velocity in feet per second. Since the velocity of water at the surface is greater than the average velocity of the stream, multiply the estimated surface velocity by a correction factor (0.80 for smooth lined ditches, and 0.60 for rough ditches) to obtain the average stream velocity.

Velocity – area methods

The rate of flow passing a point in pipe or open channel is determined by multiplying the cross sectional area of water at right angles to the direction of flow by the average velocity of the water.

Discharge = Area x Velocity

Q = a x v

Where,

Q = discharge rate, m3 /sec

a = Area of cross section of channel or pipe, m2

v = velocity of flow, m/sec.

The cross-sectional area is determined by direct measurements and the velocity of water is determined by float method or current meter

Constriction Flow Methods

Methods employing a constriction of pre-determined dimensions are frequently used for measuring flow in irrigation canals and ditches. Constricting type measuring devices can generally be placed in one of three categories weirs, flumes, and orifices. Generally, only one or two measurements are required where the dimensions of the constriction are known. Using these measurements, rate of flow is determined from either a table, a graph, or by calculation. Due to the wide variety of types and sizes of constricting devices, flow tables are not included in this publication. The local County Extension Director or local Soil Conservation Service District office can obtain such tables or graphs. Basically, a weir measures flow by causing the water to flow over a notch of pre-determined shape and dimensions. They are quite accurate when properly constructed, installed, and maintained. Weirs do have some limitations. First, they require considerable drop (difference in head) between the upstream and downstream water surfaces which is often either not available in flat grade ditches or is undesirable. Second, it is frequently necessary to construct a pool or stilling area above the weir so the water loses its Velocity. Unless the water appears practically still, discharge

2.2 Using the formulae for calculating flows in open channels

Examples of Open channel Flow:

Mention some examples of open channel flows

- storm sewer (partially field sewers),
- flow in rivers,
- flow in irrigation cannels,
- Gutters along residential streets and no roof open channel.

Types of flows

Flow in an open channel is said to be ***steady*** if the depth of flow does not change or if it can be assumed to be constant during the time interval under consideration at a fixed point. In steady flow the flow variables (velocity, pressure, density, flow path etc) do not vary with time at the spatial point in the flow. The discharge Q at a channel section is expressed by

$Q = VA$ Equation **Error! No text of specified style in document.**-3

Where v is the mean velocity and A is the flow cross sectional area normal to the direction of the flow, since the mean velocity is defined as the discharge divided by the cross-sectional area.

$Q = V_1 A_1 = v_2 A_2 = - - - -$ Equation **Error! No text of specified style in document.**-4

It is designate different channel sections. This is the continuity equation for a ***continuous steady flow***.

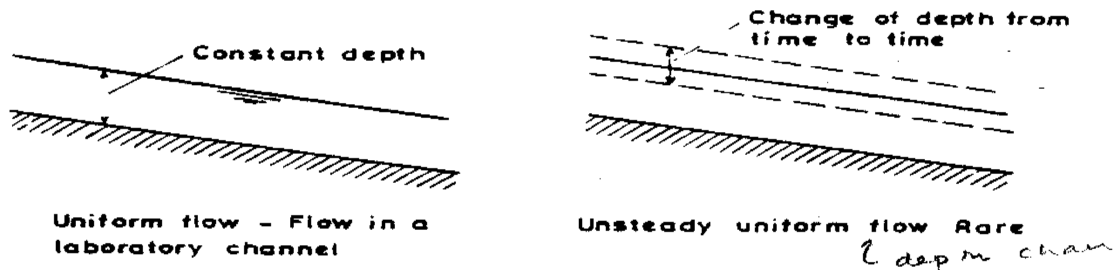


Figure **Error! No text of specified style in document.**-2 steady and unsteady flow

Uniform flow and varied flow: space as the criterion

Uniform flow

Open channel flow is said to be ***uniform*** if the depth of flow is the same at every section of the channel. A uniform flow may be steady or unsteady, depending on whether or not the depth changes with time.

Uniform flow in open channels has the following main characteristics

the depth, water area, velocity, and discharge at every section of the channel are constant;

the energy line, water surface, and channel bottom are all parallel; i.e. their slopes are all equal $S_f = S_w = S_o$

Computation of Uniform flow

For computational purposes, the average velocity of a uniform flow can be computed approximately by one of a number of semi empirical uniform flow equations. All of these equations have the form

$$V = CR^x S^y$$

Where

V = average velocity

R = hydraulic radius

S = channel longitudinal slope

C = resistance coefficient

X and y coefficients

In fluid dynamics, the Chézy formula describes the mean flow velocity of steady, turbulent open channel flowThe popular two equations are the Chezy equation, developed in 1769, and the Manning equation, developed in 1889.

$V = C\sqrt{RS}$ Chezy Formula

Where V is the mean velocity is m/s, R is the hydraulic radius in m, S is the slope of energy line (m/m), and C is a factor of flow resistance, called Chezy's C.

1.4 The Colebrook Equation:L. Prandtle and Von Karaman in Germany, and G.I. Tylor in expressing mathematical Form the mechanism of turbulence linked the experimental investigation of Nikuradse (1932-
1935) had proved a formula of the type (Colebrook, 1938):

$$\frac{1}{\sqrt{F}} = 2\log\left(\frac{0.113d}{y_1}\right) \quad \ldots\ldots\ldots\ldots$$

And showed the lower limit of the integration y_1, is a function of the wall particle size k, in The case of rough pipes in which the flow obeys the square resistance law, and is dependent On the density ρ, the viscosity μ and the shear stress at the wall τ in the case of smooth pipes.

In 1938, Cyril Frank Colebrook confirmed the substitution of values of y, in the foregoing equation and adopted the following resistance law

(a)Flow in hydraulically smooth pipes:

$$\frac{1}{\sqrt{F}} = -2\log\left(\frac{2.51}{R_e\sqrt{F}}\right) \quad \ldots\ldots\ldots\ldots$$

(b) Flow in hydraulically rough pipes:

$$\frac{1}{\sqrt{F}} = -2\log\left(\frac{k}{3.7d}\right) \quad \ldots\ldots\ldots\ldots$$

Manning equation is the result of a curve fitting process and thus is completely empirical in nature. In application of the Manning equation, it is essential that the system of units being used be identified and that the appropriate coefficient is used. In the SI system of units, the Manning equation is

$V = 1/n\ R2^{/3} \sqrt{S}$

Where n = Manning resistance coefficient. As was the case with the chezy resistance coefficient, n is dimensionless manning coefficient S is slope R is hydraulic radius.

2.3 Distinguish the characteristics of open channels.

Types of flows

Open channels flow can be classified into many types and described in various ways. The following classification is made according to the change in flow depth with respect to time and space $\left(\frac{dy}{dt}, \frac{dy}{dx}\right)$.

Steady flow and unready flow: Time as the criterion Flow in an open channel is said to be steady if the depth of flow does not change or if it can be assumed to be constant during the time interval under consideration at a fixed point. In steady flow the flow variables (velocity, pressure, density, flow path etc) do not vary with time at the spatial point in the flow. In steady flow streamline is also the path followed by an individual water particle. The flow is unsteady if the depth changes with time. In most open channel problems it is necessary to study flow behavior only under steady conditions. If, however, the change in flow condition with respect to time is of major concern, the flow should be treated as unsteady. In floods and surges, for instance, which are typical examples of unsteady flow, the stage of flow changes instantaneously as the wave pass by, and the time element becomes vitally important in design of control structures. In unsteady flow the flow variables (velocity, pressure, density, flow path etc) vary with time at the spatial points in this flow.

Examples of unsteady flow:

- Oscillatory sea waves,
- Dam break flood waves,
- Surges due to gate operation,
- Floods.

For any flow, the discharge Q at a channel section is expressed by

$Q = VA$ Equation 5

Where v is the mean velocity and A is the flow cross sectional area normal to the direction of the flow, since the mean velocity is defined as the discharge divided by the cross-sectional area.
In most problems of steady flow the discharge is constant throughout the reach of the channel under consideration; in other words the flow is continuous. Thus, using equation 1-1.

$Q = V_1 A_1 = v_2 A_2 = - - - -$ Equation 6

Where, the subscripts designate different channel sections. This is the continuity equation for a continuous steady flow.

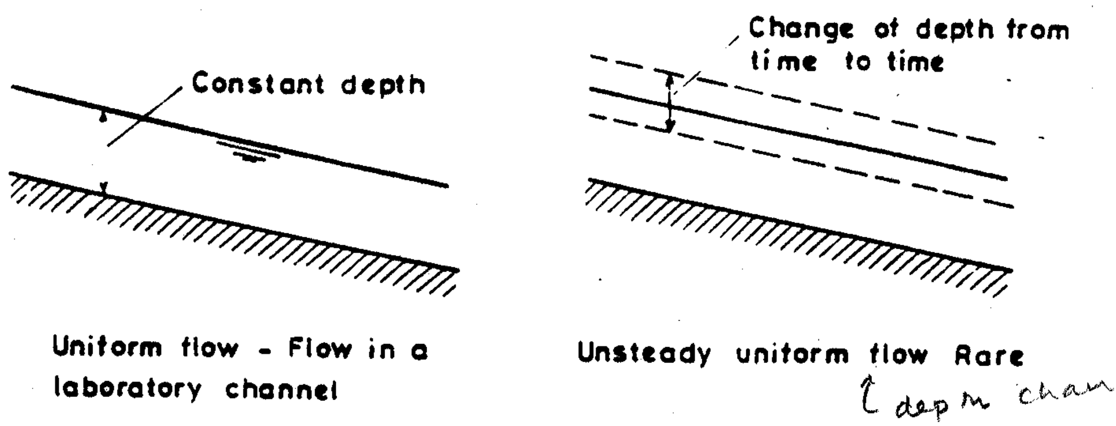


Figure 2.2 steady and unsteady flow

Equation 2.1 obviously invalid, however, where the discharge of a steady flow is non-uniform along the channel, that is, where water runs in or out along the course of the flow. This type of flow is called spatially varied or discontinuous flow. Spatially constant flow occurs when the density and average velocity are the same in all points in a flow field. If these quantities change along or across the flow lines the flow is spatially variable. Examples are side channel spillways, roadside gutters, the flow in uniform canal of constant slope receiving inflow or having outflow (e.g. main drainage channels and feeding channels in irrigation systems).
The law of continuity of unsteady flow requires considerations of the time effect. Hence, the continuity equation for continuous unsteady flow should include time element as a variable (section Uniform flow and varied flow: space as the criterion

Open channel flow is said to be uniform if the depth of flow is the same at every section of the channel. A uniform flow may be steady or unsteady, depending on whether or not the depth changes with time.

Steady uniform flow is the fundamental type of flow treated in open channel hydraulics. The depth of flow does not change during the time interval under consideration. The establishment of unsteady uniform flow would require that the water surface fluctuate from time to time while remaining parallel to the channel bottom.

Obviously, this is a practically impossible condition. The term “uniform flow” is therefore, used here after only to steady uniform flow.

Flow is varied if the depth of flow changes along the length of the channel. Varied flow may be either steady or unsteady. Since unsteady uniform flow is rare, the term “unsteady flow” is used hereafter to designate unsteady varied flow exclusively.

Varied flow may be further classified as either rapidly or gradually varied. The flow is rapidly varied if the depth changes abruptly over a comparatively short distance; otherwise, it is gradually varied. A rapidly varied flow is also known as a local phenomenon; examples are the hydraulic jump and the hydraulic drop. For clarity, the classification of open-channel flow is summarized as:

The flow is laminar if the viscous forces are so strong relative to the inertial forces that viscosity plays a significant part in determining flow behavior. In laminar flow, the water particles appear to move in definite smooth paths, or streamlines, and infinitesimally thin layers of fluid seem to slide over adjacent layers.

The flow is turbulent if the viscous forces are weak relative to the inertial forces. In turbulent flow the water particles move in irregular paths, which are neither smooth nor fixed but which in the aggregate still represent the forward motion of the entire stream. Between the laminar and turbulent status there is a mixed or transitional state.

An open channel flow is laminar if the Reynolds number R_e is small and turbulent if R_e is large.

Numerous experiments have shown that the flow in pipe changes from laminar to turbulent in the range of R_e between the critical value 2,000 and a value as high as 50,000. In this experiment the diameter of the pipe was taken as the characteristic length in defining the Reynolds number. When the hydraulic radius is taken as the characteristic length, the corresponding range is from 500 to 12,500 since the diameter of a pipe is four times its hydraulic radius.

$$R = \frac{A}{P} = \frac{\pi(D/2)^2}{\pi D} = \frac{D}{4}$$

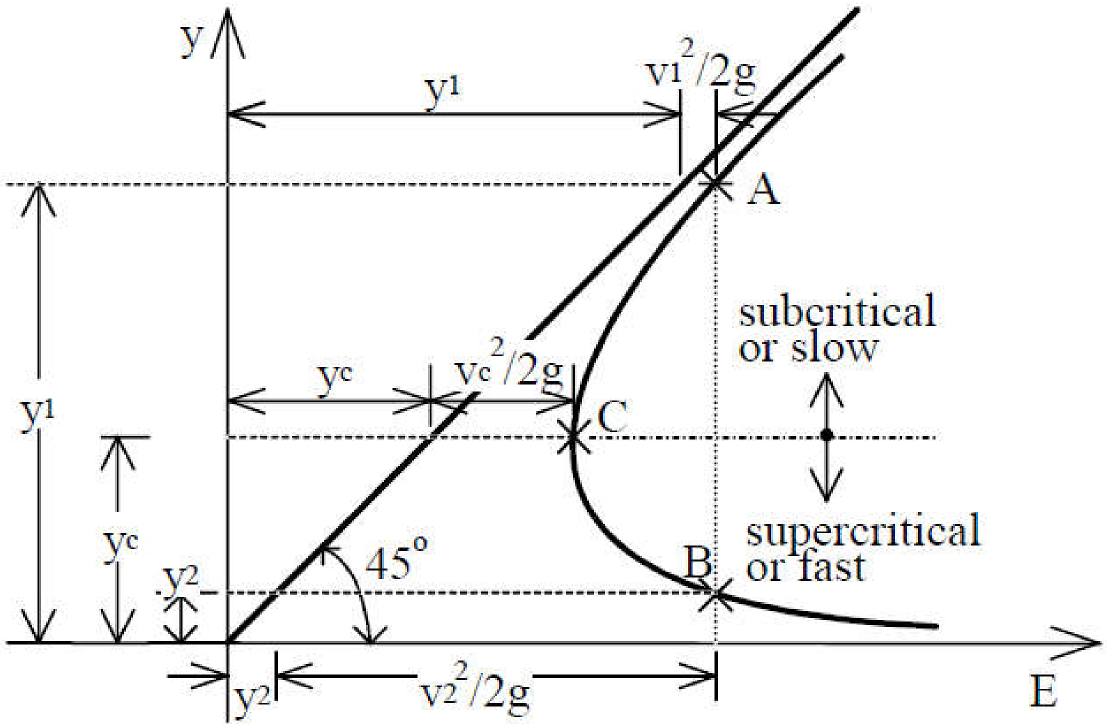


Figure **Error! No text of specified style in document.**-3 Specific Energy Curve

If the flow with E > Emin, there are two possible depths (y1, y2).

- (y1, y2) are called **alternate depths.**

C divides the curve AB into AC and CB regions.

- AC - **subcritical** flow region

- CB - **supercritical** flow region

	Subcritical	Critical	Supercritical
Depth of flow	$y > y_c$	$y = y_c$	$y < y_c$
Velocity of flow	$v < v_c$	$v = v_c$	$v > v_c$
Slope	Mild $S < S_c$	Critical $S = S_c$	Steep $S > S_c$
Froude number	Fr < 1.0	Fr = 1.0	Fr > 1.0
Other	$\frac{v^2}{2g} < \frac{y_c}{2}$	$\frac{v^2}{2g} = \frac{y_c}{2}$	$\frac{v^2}{2g} > \frac{y_c}{2}$

.At any point P on this curve, the ordinate represents the depth, and the abscissa represents the specific energy. Which is equal to the sum of the pressure head y and the velocity head $V^2/2g$.

The curve shows that for a certain discharge Q two flow regimes are possible, viz. slow and deep flow or a fast and shallow flow, i.e. for a given specific energy, there are two possible depths, for instance, the low stage y. and the high stage y_2. The low stage is called the alternate depth of the high stage, and vice versa. At pint C, the specific energy is minimum. It can be proved that this condition of minimum specific energy corresponds to the critical state of flow. Thus, at the critical state the two alternate depths apparently become one, which is known as the critical depth (Y_C). When the depth of flow is greater than the critical depth, the velocity of flow is less than the critical velocity for the given discharge, and, hence, the flow is sub critical. When the depth of flow is less than critical depth the flow is supercritical. Hence, Y_1, is the depth of a supercritical flow, and Y_2 is the depth of a sub critical flow.

The critical state of Flow

The critical state of flow is defined as the state of flow at which the specific energy is a minimum for a given discharge or it is the condition for which the Froude number (Fr^2) is equal to unity.

$$E_S = y + \frac{V^2}{2g}$$

For $Q = \frac{V}{A}$

$$E_S = y + \frac{Q^2}{2g\ A^2}$$

Differentiating with respect to y and noting that Q is a constant.

$$\frac{d\ E_S}{dy} = 1 - \frac{Q^2}{g\ A^3}\ \frac{dA}{dy}$$

The differential water area dA near the free surface (figure 2-5) is equal to $B_S\, dy$ Now $\frac{dA}{dy} = B_S$.

and the hydraulic depth $D = \frac{A}{B_S}$. So the above equation becomes.

$$\frac{dE_S}{dy} = 1 - \frac{Q^2\ B_s}{gA^3} = 1 - \frac{Q^2}{gA^2 D}$$

But $V = \frac{Q}{A}$. Substituting

$$\frac{dE_S}{dy} = 1 - \frac{V^2\ A^2}{gA^2 D} = 1 - \frac{V^2}{gD} = E_{S\ \min imum}$$

At the critical state of flow the specific energy is a minimum, or $\frac{dE}{dy} = 0$. The above equation, therefore, gives.

$$\frac{v^2}{2g} = \frac{D}{2}$$

This is the criterion for critical flow, which states that at critical state of flow, the velocity head is equal to half the hydraulic depth. The above equation may also be written $\frac{V}{\sqrt{gD}} = 1,$ which means $F_r = 1$; this is the definition of critical flow given previously.

2.3 Distinguishing the uses of different measuring instruments and devices

The most common structures used for measurement of water in farm irrigation practices are:

Parshall flume

The Parshall flume is an open channel flow metering device that was developed to measure the flow of surface waters in channel

$Q = Kh_1n$

Where Q= Discharge (m3/sec), h_1 = head u/s of throat at 2/3 of convergence section, n= discharge component which depends on flume size, K= Discharge dependent Coefficient.

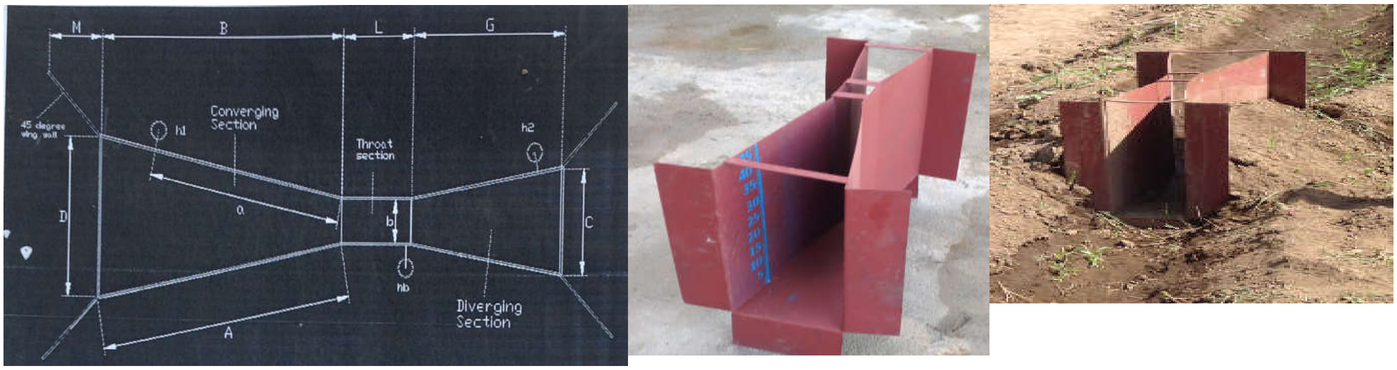


Fig. open chanel flow measuring structures

Discharge characteristics of Parshall flumes

Throat width, b	Discharge range Minimum	Discharge range Maximum	Equation $Q = kh_1^n$ (h_1 is in m & Q is in m^3/s)	Head range, m Minimum	Head range, m Maximum	Modular limit, h_2/h_1
	l/s					
1 in	0.09	5.4	$Q = 0.0604h_1^{1.55}$	0.015	0.21	0.5
2 in	0.18	13.2	$Q = 0.1207h_1^{1.55}$	0.015	0.24	0.5
3 in	0.77	32.1	$Q = 0.1771h_1^{1.55}$	0.03	0.33	0.5
	l/s					
6 in	1.5	111	$Q = 0.3812h_1^{1.58}$	0.03	0.45	0.6
9 in	2.5	251	$Q = 0.5354h_1^{1.53}$	0.03	0.61	0.6
1 ft	3.32	457	$Q = 0.6909h_1^{1.52}$	0.03	0.76	0.7
1.5 ft	4.8	695	$Q = 1.056h_1^{1.538}$	0.03	0.76	0.7
2 ft	12.1	937	$Q = 1.428h_1^{1.55}$	0.046	0.76	0.7
3 ft	17.6	1427	$Q = 2.184h_1^{1.556}$	0.046	0.76	0.7
4 ft	35.8	1923	$Q = 2.953h_1^{1.578}$	0.06	0.76	0.7
5 ft	44.1	2424	$Q = 3.732h_1^{1.587}$	0.06	0.76	0.7
6 ft	74.1	2929	$Q = 4.519h_1^{1.595}$	0.076	0.76	0.7
7 ft	85.8	3438	$Q = 5.312h_1^{1.601}$	0.076	0.76	0.7
8 ft	97.2	3949	$Q = 6.112h_1^{1.607}$	0.076	0.76	0.7

Current meter

Current meter is used as a flow velocity measuring device

The width of the river at measuring point is measured and divided in to sub section

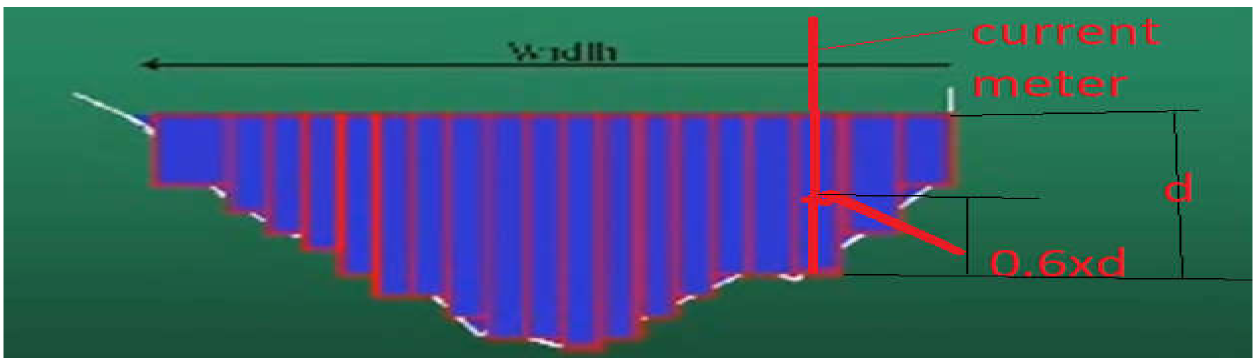


Image.2.1. Flow measuring current meter

The depth of subsection, line left, d_1, and right, d_2, of the current meter measuring point is taken by tape and area of the sub section will be determined. The velocity measurement reading is taken in the middle of subsection at depth of 0.6x water depth from bottom

$d_{avg}=(d_1+d_2)/2$

Asub= d_{avg} x sub section width (for more accuracy plotting is recommended)

Discharge of the sub section $Q_{sub}= V_{sub}*A_{sub}$

Total discharge, Qt, is equal to the sum of sub discharges

$Q_{t-}= Q_{su1}+Qs_{ub2}+\ldots\ldots Q_{sub\ n}$

2.4 Assessing the hydraulic principles in different meters

Meters include: mechanical meters such as:

- the displacement type
- The inferential type.
- pressure meters such as:
- pitot tube
- orifice plate
- Venturi meter.

Flow Measurement by Venturi and Orifice meter

Venturi meter and orifice meter are the commonly used flow meters for measuring mass/volumetric flow rate or velocity of the flowing fluid. These flow meters are also known as variable head meters. They are categorized as *full-bore meter* as measurement of the fluid takes place when it flows through a conduit or channel.

Venturi meter:

The venturi meter has a converging conical inlet, a cylindrical throat and a diverging recovery cone. It has no projections into the fluid, no sharp corners and no sudden changes in contour. The following figure shows the venturi meter with uniform cylindrical section before converging entrance, a throat and divergent outlet.

The converging inlet section decreases the area of the fluid stream, causing the velocity to increase and the pressure to decrease. The low pressure is measured in the center of the cylindrical throat as the pressure will be at its lowest value, where neither the pressure nor the velocity will be changing. As the fluid enters the diverging section the pressure is largely recovered lowering the velocity of the fluid. The major disadvantages of this type of flow detection are the high initial costs for installation and difficulty in installation and inspection.

The *Venturi effect* is the reduction in fluid pressure that results when a fluid flows through a constricted section of pipe. The fluid velocity must increase through the constriction to satisfy the equation of continuity, while its pressure must decrease due to conservation of energy: the gain in kinetic energy is balanced by a drop in pressure or a pressure gradient force. An equation for the drop in pressure due to Venturi effect may be derived from a combination of Bernoulli's principle and the equation of continuity.

The equation for venturi meter is obtained by applying Bernoulli equation and equation of continuity assuming an incompressible flow of fluids through manometer tubes. If *V1* and *V2* are the average upstream and downstream velocities and ρ is the density of the fluid, then using Bernoulli's equation we get,

$$\alpha_2 V_2^2 - \alpha_1 V_1^2 = \frac{2g\,(P_a - P_b)}{\rho} \qquad \text{..........................} \quad (1)$$

...

where *1* and □*2* are kinetic energy correction factors at two pressure tap positions.

Assuming density of fluid to be constant, the equation of continuity can be written as:

$$V_1 = \left(\frac{D_2}{D_1}\right)^2 V_2 \qquad \text{..........................} \quad (2)$$

where *D1* and *D2* are diameter of pipe and throat in meters respectively.

Eliminating *V1* from equation (1) and equation (2) we get,

$$V_2 = \frac{1}{\sqrt{\alpha_2 - \alpha_1 \beta^4}} \sqrt{\frac{2(P_1 - P_2)}{\rho}} \qquad \text{..........................} \quad (3)$$

where β is the ratio of the diameter of throat to that of diameter of pipe.

If we assume a small friction lose between two pressure taps, the above equation (3) can be corrected by introducing empirical factor *Cv* and written as,

$$V_2 = \frac{C_V}{\sqrt{1 - \beta^4}} \sqrt{\frac{2(P_1 - P_2)}{\rho}} \qquad \text{..........................} \quad (4)$$

The small effect of the kinetic energy factors *α1* and *α2* are also taken into account in the definition of *Cv*.

Volumetric flow rate *Qa* can be calculated as:

Qa = V2S2 =

$$Q_a = V_2S_2 = \frac{C_V S_2}{\sqrt{1-\beta^4}} \sqrt{\frac{2(P_1-P_2)}{\rho}} \qquad \text{.........................} \quad (5)$$

where, *S2* is the cross sectional area of throat in m2.

Substituting *(P1 – P2) = ρgH* in above equation (5) we get,

Qa = V2S2 =

$$Q_a = V_2S_2 = \frac{C_V S_2}{\sqrt{1-\beta^4}} \sqrt{2g\Delta H} \qquad \text{...............................} \quad (6)$$

where Δ*H* is the manometric height difference * (specific gravity of manometric fluid – specific gravity of manometric fluid of water).

Orifice meter:

An orifice meter is essentially a cylindrical tube that contains a plate with a thin hole in the middle of it. The thin hole essentially forces the fluid to flow faster through the hole in order to maintain flow rate. The point of maximum convergence usually occurs slightly downstream from the actual physical orifice this is the reason orifice meters are less accurate than venturi meters, as we cannot use the exact location and diameter of the point of maximum convergence in calculations. Beyond the vena contracta point, the fluid expands again and velocity decreases as pressure increases.

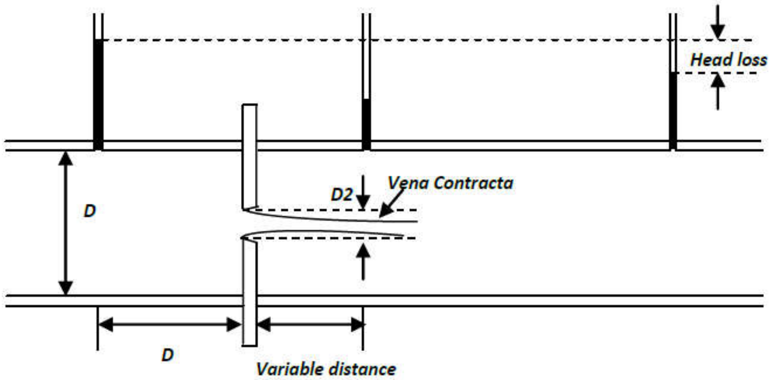

Head loss
D2
Vena Contracta
D
D
Variable distance

fig 2.4orifice meter The above figure 2 shows the orifice meter with the variable position of vena contracta with respect to plate. Orifice meter uses the same principle of continuity equation and Bernoulli principle to calculate the volumetric flow rate, as shown above for venturi meter.

So,

Qa = V2S2 =

$$Q_a = V_2S_2 = \frac{C_oS_2}{\sqrt{1-\beta^4}}\sqrt{2g\Delta H} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Here *Co* is the orifice discharge coefficient.

PITOT TUBE

Pitot tube is widely used for velocity measurement in aircraft. Its basic principle can be understood from fig. 6(a). If a blunt object is placed in the flow channel, the velocity of fluid at the point just before it, will be zero. Then considering the fluid to be incompressible, from eqn. (2), we have,

$$\frac{p_1}{\gamma}+\frac{v_1^2}{2g}=\frac{p_2}{\gamma}+\frac{v_2^2}{2g}$$

Now $v_2=0$.

Therefore,

$$\frac{v_1^2}{2g}=\frac{p_2-p_1}{\gamma}$$

or,

$$v_1=\sqrt{\frac{2g}{\gamma}(p_2-p_1)} \qquad (6)$$

However, as mentioned earlier corrections are to be incorporated for compressible fluids. The typical construction of a Pitot tube is shown in fig. 6(b).

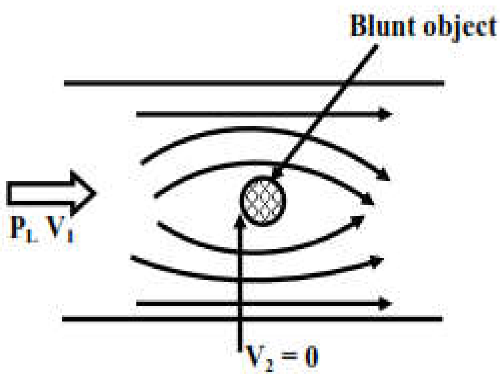


Fig. 6(a) Pitot Tube: Basic Principle

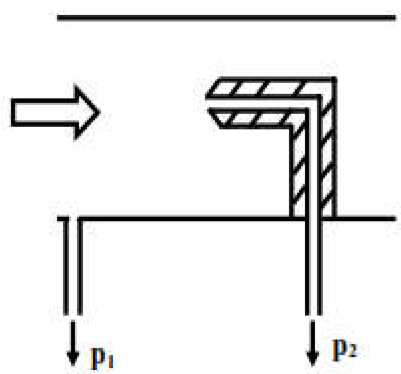


Fig. 6(b) Pitot Tube: Construction

2.5 Identifying the limitations of the meters

Limitations of Orifice Meter

1. The vena-contract length depends on the roughness of the inner wall of the pipe and sharpness of the orifice plate. In certain cases it becomes difficult to tap the minimum pressure (P2) due to the above factor.

2. Pressure recovery at downstream is poor, that is, overall loss varies from 40% to 90% of the differential pressure.

3. In the upstream straightening vanes are a must to obtain laminar flow conditions.

4. Gets clogged when the suspended fluids flow.

5. The orifice plate gets corroded and due to this after sometime, inaccuracy occurs. Moreover the orifice plate has low physical strength.

6. The coefficient of discharge is low.

Advantages of orifice meter

1. Orifices are small plates and easy to install/remove.
2. Offer very little pressure drop of which 60% to 65% is recovered.
3. Orifice meter can be easily maintained.
4. Measures a wide range of flow rates.
5. They have a simple construction.
6. They have easily fitted between flanges.
7. They are most suitable for most gases and liquids.
8. They are inexpensive.
9. Price does not increase dramatically with size.

Disadvantages of orifice meter

1. Requires homogeneous fluid.
2. Requires single phase liquid.
3. Requires axial velocity vector flow.
4. Causes a pressure drop in fluid.
5. Their accuracy is affected by density, pressure and viscosity fluid.
6. Fluid viscosity limits measuring range.
7. Requires straight pipe runs to ensure accuracy is maintained.

8. Pipe line must be fully especially for liquid flow measurement.
9. They have low range-ability.

Advantages of venturi meter

1. Less chances of getting clogged with sediments.
2. co-efficient of discharge is high.
3. Its behaviour can be predicted perfectly.
4. Can be installed vertically, horizontally, inclined.
5. They are more accurate and can be used for a wide range of flows.
6. Around 90% of pressure drop can be recovered.

Disadvantages of venturi meter

1. They are large in size and hence where space is limited, they cannot be used.
2. Expensive initial cost, installation and maintenance.
3. Require long laying length. That is, the venturimeter has to be proceeded by a straight pipe which is free from fittings and misalignment's to avoid turbulence in flow, for satisfactory operation.
4. Cannot be used in pipes below 7.5 cm diameter.
5. Maintenance is not easy.
6. Cannot be altered for measuring pressure beyond a maximum velocity.

Self-Check 2	**Written Test**

Name: ___________________________ Date: ________________

Directions: Answer all the questions listed below.

1. Identify the Advantage and limitation of each pipe flow measurement methods?(6pt)
2. What mean turbulent flow and Laminar flow and differentiate it?(6pt)
3. What is the limitation of metering structures (pitottub, verture btube and orifice meter)?(7pt)

4. What are the characteristics Uniform flow in open channels ?(5Pt)
5. What are the three Methods used for measuring flows in open channel?(6PT)
6. How you distinguish open channel flow from other type of flow?(5pt)

Note: Satisfactory rating – 17.5points above Unsatisfactory - below 17.5 points

You can ask you teacher for the copy of the correct answers.

Operational Sheet – 2	**Practical-2**

1. Show on the field flow profiles
2. Measure water flow by wires, orifice, area-velocity method, floating methods and others

Flow estimation procedure

The following presents the procedure for measuring the discharge using a floating object.

Equipment: - Measuring tape at least 5 meters long
- 4 Stakes
- Stopwatch or watch capable of measuring time in seconds

Water measurement Floating method Procedure:

1) Select a straight section of the canal at least 10 meters long. The shape of the canal along
   a. this section should be as uniform as possible
2) Place two stakes, one each side, at the upstream end of the selected portion of the canal. They should be perpendicular to the centerline of the canal.
3) Measure 10 meters or more along the canal.
4) Place two stakes at the downstream end of the selected section of the canal, also a perpendicular to the centerline of the canal. These correspond to point B in Figure 10.
5) Place the floating object on the center line of the canal at least 5 m upstream of point A, and start the stopwatch when the object reaches point A.
6) Stop the stopwatch when the floating object reaches point B, and record the time in seconds.
7) Repeat steps 5 and 6 at least four times in order to determine the average time necessary for the object to travel from point A to point B. The object should not touch the canal embankment during the trial, but if it does the operation must be repeated and the time for the bad trial must not be included when calculating the average time.

8) Measure the following in the selected canal section: - the canal bed width, b - the surface water width, a1 - the water depth, h1 The cross-section within the selected portion of the canal will usually not be regular, and so b, a1 and h1 need to be measured in several places to obtain an average value. If working with a canal with a rectangular cross-section the surface water width a1 will equal the bed width b.

9) Calculate the surface velocity, Vs, and then the average flow velocity, V, using the equations given in Section 3.2.1: - Vs = L / t, where t is the travel time is seconds, based on the average of four clear runs of the floating object, and - V = 0.75 ´ Vs.

10) Calculate the wetted area of the cross-section A, using the formula from Section)

    a. $A = \frac{b+a}{2}$ (b, a and h are average values)

11) Calculate the discharge, Q, in the canal, using the formula from section

Q=V*A m3/s or Q=1000*V*Al/s

LAP Test	Practical Demonstration

Name: _______________________________ Date: _________________

Time started: __________________________ Time finished: ________

Instructions: Given necessary templates, workshop, tools and materials you are required to perform the following tasks within 12 hours.

Task 1: measure water by Float method

Information Sheet 3	Calculate flows through notches and weirs

3.1. Identifying the methods used for measuring flows

Open channel flow rate measurement is usually done by measuring a change in water depth. It can be done with a weir or flume. Common types are the sharp crested weir (including V-notch weir, rectangular weir, and cipolletti weir), the broad crested weir, the Parshall flume and venturi flume

A weir is basically an obstruction in an open channel flow path. Weirs are commonly used for measurement of open channel flow rate. A weir functions by causing water to rise above the obstruction in order to flow over it. The height of water above the obstruction correlates with the flow rate, so that measurement of the height of the flowing water above the top of the weir can be used to determine the flow rate by the use of an equation, graph or table. The top of the weir, which is used as the reference level for the height of water flowing over it, is called the crest of the weir.

A weir is basically an obstruction in the flow path in an open channel. The weir will cause an increase in the water depth as the water flows over the weir. In general, the greater the flow rate, the greater will be the increase in depth of flow, the height of water above the top of the weir is the measurement usually used to correlate with flow rate.

The two major types of weir are sharp crested weir and broad crested weir. The crest is the term used for the top of the weir, where the water flows over it. The two diagrams here show a sharp crested weir and a broad crested weir. As you can see by the diagrams, the names are very descriptive. The sharp crested weir has a sharp surface at the crest or top, where the water flows over it, and the broad crested weir has a broad flat surface at the top. The height of the water above the crest of the weir is called the head over the weir and is shown as H in both of the diagrams. It is the parameter that is measured and used to determine the flow rate. There are equations available to calculate flow rate, Q, over the weir for given head over the weir, H. Also for a given weir, Q can be experimentally correlated with H. This contraction can be counteracted or suppressed by designing the weir such that its shape conforms to the shape of the channel. This type of weir is called a **suppressed weir**. With a **contracted weir**, the crest and nappe vary from the channel to such a degree that a significant contraction of flow area does occur. In addition to suppressed and contracted weir types, weirs are also distinguished as either **sharp-crested** or **broad-crested**. A sharp-crested weir has a sharp upstream edge formed so that the nappe flows clear of the crest. Broad-crested weirs have crests that extend horizontally in the direction of flow far enough to support the nappe and fully develop hydrostatic pressures for at least a short distance. Weirs can also be distinguished by their shapes. The most common shapes are shown in The effects of weir shape and other factors previously mentioned are accounted for with modifications to the weir equation such as adjustments the weir coefficient.

Orifices

Orifices are regularly shaped, submerged openings through which flow is propelled by the difference in energy between the upstream and downstream sides of the opening. The stream of flow expelled from the orifice is called the **jet**. When the jet exits the orifice, adverse velocity components cause it to contract to a point after which the flow area remains relatively constant and the flow lines become parallel (see Figure 1-5). This point is called the **vena contracta**.

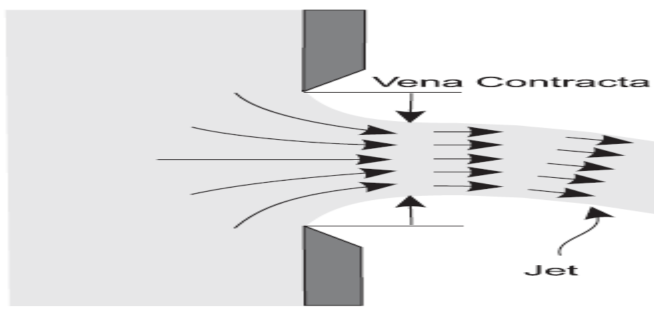


Fig 3.2 orifice

3.2 Using the formulae for calculating flows

Broad-Crested and Sharp-Crested Weirs

Weirs are overflow structures that alter the flow so that:

1. Volumetric flow rate can be calculated,
2. Flooding can be prevented, or
3. Make a body of water more navigable

Types of Weirs:

Main Types of Weirs

1. Sharp-Crested
a. Rectangular
b. Triangular
c. Trapezoidal
2. Broad-Crested
a. Rectangular

Sharp- vs. Broad-Crested Weirs

SHARP-CRESTED WEIR	BROAD-CRESTED WEIR
Critical depth (yc) occurs off the crest of the weir	Critical depth (yc) occurs at the crest of the weir
Usually used to:	Usually used to:
1. Measure the discharge of smaller rivers and canals	1. Measure the discharge of larger rivers and canals
2. Change water elevation of smaller rivers and canals	2. Change water elevation of larger rivers and canals

Calculating flows in Broad crested weirs

Broad crested weirs are widely used for flow measurement and regulation of water depth in rivers, canals and other natural open channels. Broad crested weir flow rate calculations can be made with a rather simple equation if the weir height is great enough to cause critical flow over the weir crest. For a broad crested weir with less than critical velocity over the weir crest, the discharge coefficient will vary from 2.3 to 3.3 depending upon the breadth of the weir crest and the head over the weir.

If there is **critical flow**, then the equation to use is $Q = 1.6 L H^{3/2}$,

Where **Q** is the open channel flow rate in cfs,

L is the weir length (channel width) in ft, and

H is the head over the weir in ft, as shown in the diagram below.

A weir is a notch of regular form through which water may flow. Notch may be rectangular, trapezoidal or triangular.

Rectangular and V-notch weirs are commonly used on the farm.

$$Q = CLH^{m}$$

Where, **Q** = discharge

C = coefficient dependent on nature of crest and approach conditions

L= length of crest

H = head of crest

m = an exponent depending on weir opening

I) Rectangular weir

It is used to measure comparatively large discharges. The length of a rectangular weir may be equal to the width of the channel (suppressed rectangular weir) or less (contracted rectangular weir). The discharge through a rectangular weir may be calculated by the following equation:

Suppressed rectangular weir

$$\mathbf{Q = 0.0184\ LH^{3/2}}$$

Where,

Q = Discharge (liters/sec.)

L = Length of crest (cm)

H = Head over the crest (cm)

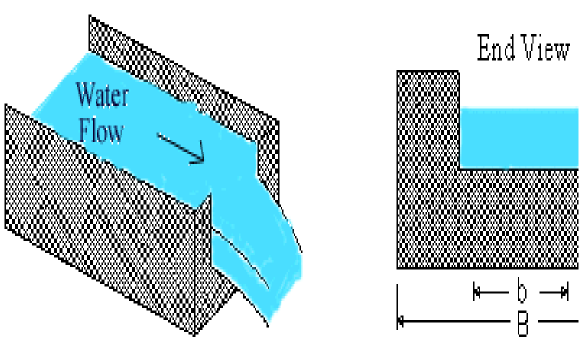


Fig.3.3 rectangular shape weir

Contracted rectangular weir

$$Q = 0.0184 (L-0. 2H) H^{3/2}$$

Where,

Q = Discharge (liters/sec.)

L = Length of crest (cm)

H = Head over the crest (cm)

ii) Trapezoidal or cipolletti weir

The discharge of water through this type of weir may be computed by the formula given below:

$$Q = 0.0186 LH^{3/2}$$

Where,

Q = Discharge (liters/sec.)

L = Length of crest (cm)

H = Head over the crest (cm)

Fig 3.4 Trapezoidal or cipolletti weir

iii) 90^0 V-notch weir

It is commonly used to measure small and medium sized streams. The advantage of the V-notch weir is its ability to measure small flow accurately. The discharge through a 90^0 V-notch weir may be computed by the following formula:

$$Q = 0.0138 H^{5/2}$$

Where, **H** = Head over the crest (cm) **Q** Q= Discharge (liters/sec.)

Fig 3.5 90^0 V-notch weir

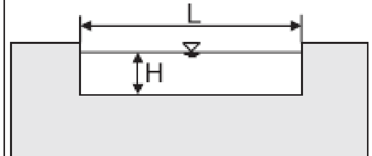
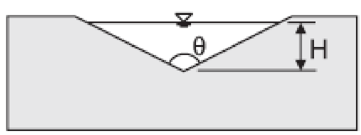
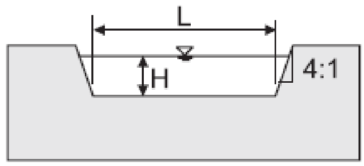
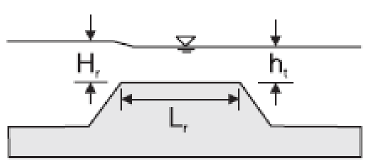
	Weir Type	Figure	Equation	Coefficients
Sharp Crested	Rectangular		Contracted $Q = C(L-0.1iH)H^{3/2}$ Suppressed $Q = CLH^{3/2}$ i = Number of iterations	Metric C = 1.84 English C = 3.367
	V-Notch		$Q = C\left(\frac{8}{15}\right)\sqrt{2g}\tan\theta\left(\frac{H}{2}\right)^{3/2}$	C varies between 0.611 and 0.570 depending on H and Q*
	Cipolletti		Metric $Q = CLH^{3/2}$ English $Q = CLH^{3/2}$	Metric C = 1.86 English C = 3.367
Non-Sharp-Crested	Broad (Side View)		$Q = C_dLH_r^{3/2}$	C_d is a function of H_t, h_t and L_t ranging between 1.25 and 3.1*

Table 3-1 contains information on coefficients for V-Notch weirs.

3.3. Distinguishing the applications and characteristics of notches and weirs

The two major types of weir are sharp crested weir and broad crested weir. The crest is the term used for the top of the weir, where the water flows over it. The two diagrams here show a sharp crested weir and a broad crested weir. As you can see by the diagrams, the names are very descriptive. The sharp crested weir has a sharp surface at the crest or top, where the water flows over it, and the broad crested weir has a broad flat surface at the top. The height of the water above the crest of the weir is called the head over the weir and is shown as H in both of the diagrams. It is the parameter that is measured and used to determine the flow rate. There are equations available to calculate flow rate, Q, over the weir for given head over the weir, H. Also for a given weir, Q can be experimentally correlated with H. The **weir crest** is the top of the weir. For a v notch weir it is the point of the notch, which is the lowest point of the weir opening. The term **nappe** is used for the sheet of water flowing over the weir. The equations to meter flow in this article require **free flow**, which takes place when there is air under the nappe. The drawdown is the decrease in water level going over the weir due to the acceleration of the water. The head over the weir is shown as H in the diagram; the height of the weir crest is shown as P; and the open channel flow rate or discharge is shown as Q.Weirs are notches or gaps over which fluid flows. The lowest point of structure surface or edge over which water flows is called the crest, whereas the stream of water that exits over the weir is called the nappe. Depending on the weir design, flow may contract as it exits over the top of the weir, and, as with orifices, the point of maximum contraction is called the vena contract

Some general terms pertaining to weirs are:

Notch....... the opening which water flows through

Crest....... the edge which water flows over

Nape....... the overflowing sheet of water

Length....... the “width” of the weir notch.

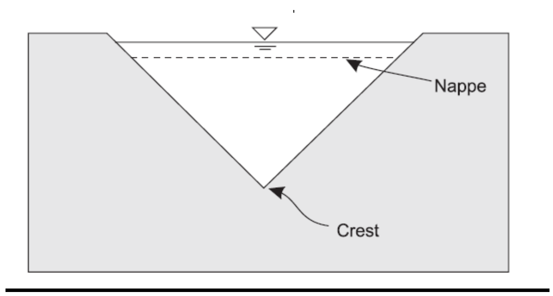


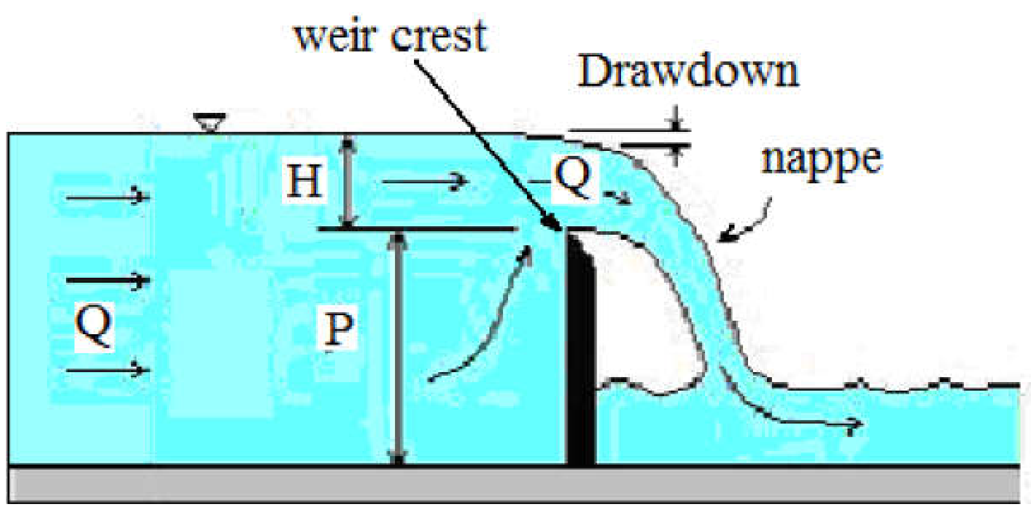
Fig 3.1 common weir

Main Types of Weirs

Sharp-Crested and Broad-Crestedweir, Sharp-Crested can classified as,Triangular,Trapezoidal Rectangular

(1) Sharp-crested weir

A sharp-crested weir consists of a vertical flat plate with a sharp edge at the top(the crest), placed in an open channel so that the liquid must flow over the crest inorder to drop into the pool below the weir. Figure below shows alongitudinal section representing flow over a sharp-crested weir.



FigSharp-crested weir

- A weir with a sharp upstream corner, or edge, such that the water springs clear of the crest

- Those most frequently used are sharp-crested rectangular, trapezoidal, Cipoletti, and triangular or 90° V-notch weirs
- According to the USBR, the weir plate thickness at the crest edges should be from 0.03 to 0.08 inches
- The weir plate may be beveled at the crest edges to achieve the necessary thickness

(2) Broad-crested weir

- A weir that has a horizontal or nearly horizontal crest sufficiently long in the direction of flow so that the nape will be supported and hydrostatic pressures will be fully developed for at least a short distance
- Some weirs are not sharp- nor broad-crested, but they can be calibrated for flow measurement

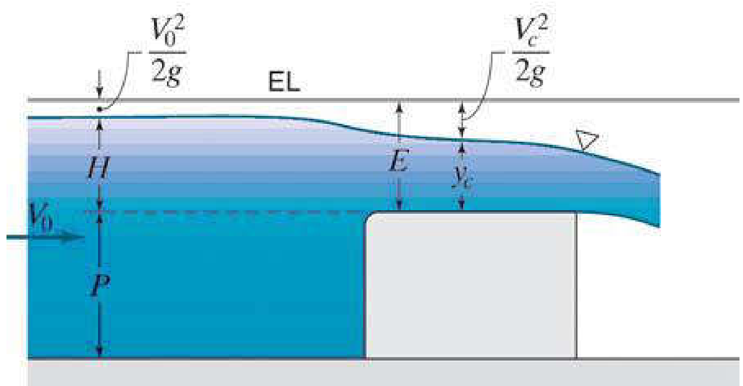


Fig broad-crested weir

Weirs may also be designed as suppressed or contracted

(1)Suppressed weir

- **A rectangular weir whose notch (opening) sides are coincident with the sidesoftheapproachchannel,alsorectangular,whichextendunchanged downstreamfromtheweir**
- **It is the lateral flow contraction that is "suppressed"**

(2) Contracted weir

- **The sides and crest of aweir are far away from the sides and bottom of the approach channel**
- **The nape will fully contract laterally at the ends and vertically at the crest of the weir Also called an"un suppressed "weir**
- **Calibration is slightly more complex than for asuppressed weir**

V-Notch Weirs

The **V-notch,** sharp-crested weir is especially good for measuring low flow rates.The flow area decreases as H increases, so a reasonable head is developed even ata very small flow rate. A V-notch weir (sometimes called a triangular weir) *WaterMeasurement Manual*, as an equation suitable for use with a fully contracted, **90o V-notch**, sharp-crested weir if it meets the conditions summarized below the equation.

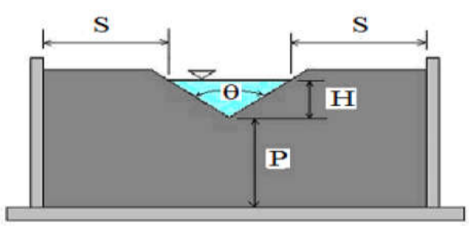


Fig v-notch 2.

3.4. Distinguishing the uses of different measuring instruments and devices

Weirs have been in use as discharge measuring devices in open channels since almost two centuries and are probably the most extensively used devices for measurement of the rate of flow of water in open channels. Weirs may be divided in to sharp and broad crested types. The broad crested weirs are commonly incorporated in irrigation structures but are not usually used to determine flow. The types of sharp crested weirs commonly used for measuring irrigation water are the following:

Weirs have the following applications:Serving as emergency spillways for regulating high-return event flows overtopping dams and detention pondsregulating the flow in channelsMeasuring flowapproximating the flow over roadways acting as broad-crested weirs when flow exceeds a culvert's capacity Approximating the interception capacity of unsubmerged drainage inlets in swales

Approximating the flow allowed through an unsubmerged culvert operating under inlet control

A weir is basically an obstruction in an open channel flow path. Weirs are commonly used for measurement of open channel flow rate. A weir functions by causing water to rise above the obstruction in order to flow over it. The height of water above the obstruction correlates with the flow rate, so that measurement of the height of the flowing water above the top of the weir can be used to determine the flow rate by the use of an equation, graph or table. The top of the weir, which is used as the reference level for the height of water flowing over it, is called the crest of the weir.

v- notch : The name for a v notch weir is very descriptive, as you can see in the picture and diagrams in the next couple of sections. A v notch weir is simply a 'v notch' in a plate that is placed so that it obstructs an open channel flow, causing the water to flow over the v notch. It is used to meter flow of water in the channel, by measuring the head of water over the v notch crest. The v notch weir is especially good for measuring a low flow rate, because the flow area decreases rapidly as the head over the v notch gets small.

Orifices and the orifice equations have the following applications:

Regulating the flow out of detention ponds

Regulating the flow through channels in the form of radial and sluice gates

Approximating the interception capacity of submerged drainage inlets in sag

Approximating the flow allowed through a submerged culvert operating under inlet control

Measuring flow

3.5 Assessing the hydraulic principles

Principles of Flow Measurements in Open Channels

To understand flow measurement it is necessary to understand how water flows. Water flow is based on principle of energy. Two types of energy govern flow in open channels, global and specific energy. According to the principle of specific energy, minimum energy occurs when the Froude number (Fr) is equal to 1.

Flow Conveyance :Water travels downhill from points of higher energy to points of lower energy (unless forced to do otherwise) until it reaches a point of equilibrium, such as an ocean. This tendency is facilitated by the presence of natural conveyance channels such as brooks, streams, and rivers. The water's journey may also be aided by man-made structures such as drainage swales, pipes, culverts, and canals. Hydraulic concepts can be applied equally to both man-made structures and natural features.

Area, Wetted Perimeter, and Hydraulic Radius

The term area refers to the cross-sectional area of flow within a channel. When a channel has a consistent cross-sectional shape, slope, and roughness, it is called a prismatic channel.

If the flow in a conveyance section is open to the atmosphere, such as in a culvert flowing partially full or in a river, it is said to be open-channel flow or free-surface flow. If a channel is flowing completely full, as with a water distribution pipe, it is said to be operating under full-flow conditions. Pressure flow is a special type of full flow in which forces on the fluid cause it to push against the top of the channel as well as the bottom and sides. These forces may result from, for example, the weight of a column of water in a backed-up sewer manhole or elevated storage tank.

A section's wetted perimeter is defined as the portion of the channel in contact with the flowing fluid. This definition is illustrated in

The **hydraulic radius** of a section is not a directly measurable characteristic, but it is used frequently during calculations. It is defined as the area divided by the wetted perimeter, and therefore has units of length.

Velocity **:**thevelocity **of a section is not constant throughout the cross-sectional area. Instead, it varies with location. The velocity is zero where the fluid is in contact with the conduit wall.**

The hydraulic radius can often be related directly to the geometric properties of the channel. For example, the hydraulic radius of a full circular pipe (such as a pressure pipe)

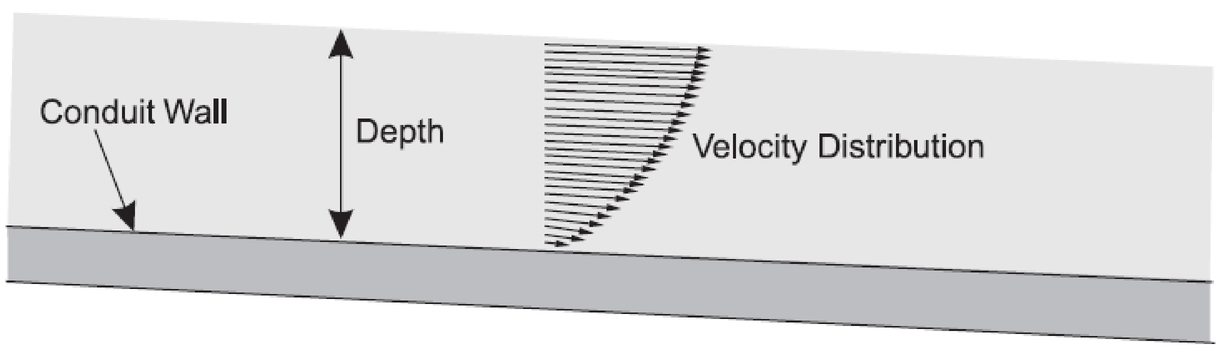


Fig 3.3

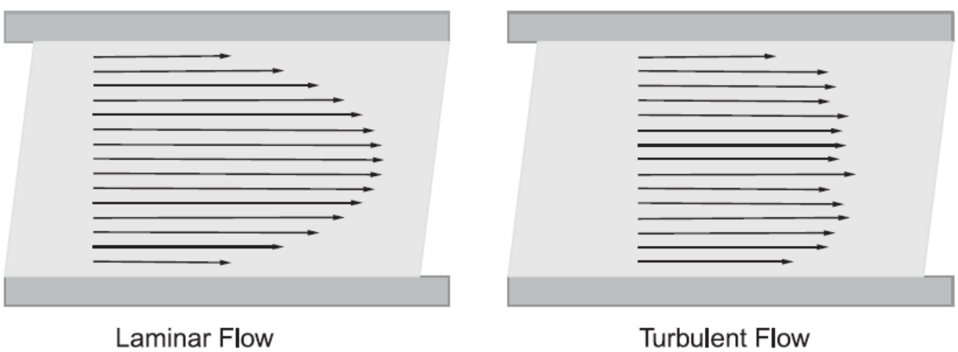
The variation of flow velocity within a cross-section complicates the hydraulic analysis, so the engineer usually simplifies the situation by looking at the average (mean) velocity of the section for analysis purposes. This average velocity is defined as the total flow rate divided by the cross-sectional area, and is in units of length per time.

Steady Flow: Speaking in terms of flow, the word steady indicates that a constant flow rate is assumed throughout an analysis. In other words, the flow velocity does not change with respect to time at a given location. For most hydraulic calculations, this assumption is reasonable. A minimal increase in model accuracy does not warrant the time and effort that would be required to perform an analysis with changing (unsteady) flows over time.

When analyzing tributary and river networks, storm sewers, and other collection systems in which it is desirable to vary the flow rate at different locations throughout the system, the network can often be broken into segments that can be analyzed separately under steady flow conditions.

Laminar Flow, Turbulent Flow, and Reynolds Number

Laminar flow is characterized by smooth, predictable **streamlines** (the paths of single fluid particles). An example of this type of flow is maple syrup being poured. In **turbulent** flow, the streamlines are erratic and unpredictable. Turbulent flow is characterized by the formation of eddies within the flow, resulting in continuous mixing throughout the section



The Energy Principle

The first law of thermodynamics states that for any given system, the change in energy (ΔE) is equal to the difference between the heat transferred to the system (Q) and the work done by the system on its surroundings (W) during a given time interval.

The energy referred to in this principle represents the total energy of the system, which is the sum of the potential energy, kinetic energy, and internal (molecular) forms of energy such as electrical and chemical energy. Although internal energy may be significant for thermodynamic analyses, it is commonly neglected in hydraulic analyses because of its relatively small magnitude.

In hydraulic applications, energy values are often converted into units of energy per unit weight, resulting in units of length. Using these length equivalents gives engineers a better "feel" for the resulting behavior of the system. When using these length equivalents, the engineer is expressing the energy of the system in terms of "head." The energy at any point within a hydraulic system is often expressed in three parts, as shown in Figure 1-4:

- ✓ Pressure head
- ✓ Elevation head
- ✓ Velocity head

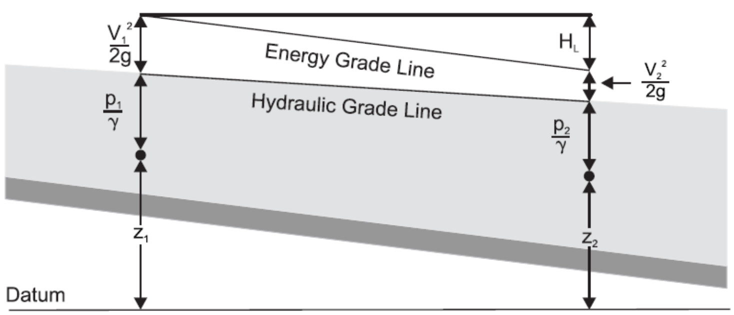


Fig 3.4 energy principles

3.6. Advantage and limitation of weir and notch

Advantages

a. Capable of accurately measuring a wide range of flows

b. Tends to provide more accurate discharge ratings than flumes and orifices
c. Easy to construct
d. Can be used in combination with turnout and division structures
e. Can be both portable and adjustable
f. Most floating debris tends to pass over the structure

Disadvantages

a. Relatively large head required, particularly for free flow conditions. This precludes the practical use of weirs for flow measurement in flat areas.
b. The upstream pool must be maintained clean of sediment and kept free of weeds and trash, otherwise the calibration will shift and the measurement accuracy will be compromised.

Self-Check 3	Written Test

Name: ___________________________Date: ________________

Directions: Answer all the questions listed below. Illustrations may be necessary to aid some explanations/answers.

1. List type of weir?
2. What are the characteristics of v-notch, rectangular weir and copiloted weir?
3. What are the advantage and disadvantage of weir?

Note: Satisfactory rating - 6 points and above Unsatisfactory - below 6 points

You can ask you teacher for the copy of the correct answers.

Operation sheet 3	Measure discharge of overflow weir

Objective: Conduct measurement of discharge of overflow weir

Procedure: -

Step 1

Estimate the maximum discharge that is likely in the canal to be measured. This defines the Corresponding maximum head of water over the weir crest for the structure concerned.

The maximum discharge to be measured is estimated at 200 l/s.

Step 2

Check the level of the weir crest. The level of the crest above the canal bed should be at least 2times the maximum head, 2H.

Step 3

Check the distance between the gauge and the weir. The distance between the gauge and the weir should be at least 4times the maximum head, 4H.

Step 4

Check the elevation of the 0 (zero mark) on the gauge. The 0 on the gauge, which indicates a discharge of 0 l/s - i.e., no flow - should have the same Elevation as the weir crest. This can be checked using a carpenter's level or by the water level when there is no flow over the weir.

LAP Test 3	Practical Demonstration

Name: ______________________________ Date: ________________

Time started: ________________________ Time finished: ________________

Instructions:

1. You are required to perform any of the following:

   1.1 Request your teacher to arrange for you to visit the nearby discharge measurement activities. You should identify type of weir.

1.2 perform the following tasks in front of your teacher

1. Identify the type of type of weir
2. Read the water level on the gauge and estimate (calculate) discharge.

1.3 Request your teacher for evaluation and feedback

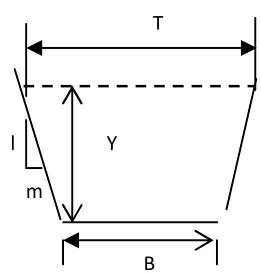
Information Sheet 4	**Calculate proportions for an economic section.**

4.1. Calculating the proportions of rectangular, trapezoidal and circular channels

Geometry of Open Channels

Open channels can be natural (rivers, streams, estuaries) or artificial (canals, flumes, chutes, culverts, drops, open-flow tunnels). The channel geometry can be ***prismatic*** (constant S_o and constant A) or ***non-prismatic***. The geometry is defined by its cross-section and water depth (y).

Some conventions for naming of canal geometric parameters are given underneath:



D = total depth of channel

y = depth of water

l = wetted side of the channel

Ø = angle between the slopping side and the horizontal

f = free board

Figure 4.1 Geometry of an open channel

Where;B = bottom width of channel

T = top width of channel

t = top width of water surface

Water depth (y) :	Vertical distance bottom to surface (measured on a vertical plane)
Section depth (d) :	Normal distance from bottom to surface, depth perpendicular to the bottom (measured on a plane perpendicular to the canal bottom)
Area (A) :	area normal to flow direction
Wetted perimeter (P) :	length of line of wetted intersection
Hydraulic radius (R) :	$R = A/P$
Hydraulicdepth (D) :	$D = A/B_S$ = Area A/top width B_S
Total energy (E) :	$E= z + y + \alpha v^2/2g$ (for small slopes θ with y = d)
Specific energy (E_S) :	E_S energy in relation to lowest point in a section $E_S = y + \alpha v^2/2g$
Velocity (V) :	$v = Q/A$
Velocity head :	$\alpha v^2/2g = \alpha Q^2/2gA^2$
Froude	$Fr^2 = \alpha Q^2 B_S/gA^3$

number

:

Friction $S_f = Q^2n^2/A^2R^{4/3}$ (Manning)

Slope

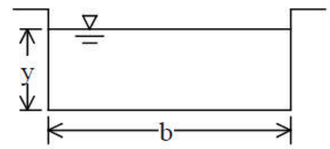
:

Friction $S_f = Q^2/C^2A^2R$ (Chezy)

Slope

: **Rectangularchannel**

- $B = b$
- $A = b*y$
- $P = b+2*y$
- $R = \frac{b*y}{b+2*y}$
- $y_{ave} = y$



Trapezoidal channel

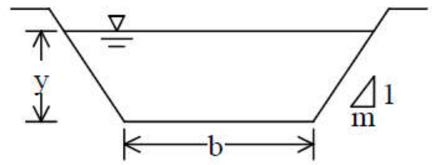
– $B = b + 2*m*y$

– $A = y*(b+m*y)$

– $P = b+2*y*\sqrt{1+m^2}$

– $R = \dfrac{y*(b+m*y)}{b+2*y*\sqrt{1+m^2}}$

– $y_{ave} = \dfrac{y*(b+m*y)}{b+2*m*y}$



Triangular channel

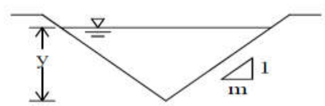
– $B = 2*m*y$

– $A = m*y^2$

– $P = 2*y*\sqrt{1+m^2}$

– $R = \dfrac{m*y}{2*\sqrt{1+m^2}}$

– $y_{ave} = \dfrac{y}{2}$



Circular channel

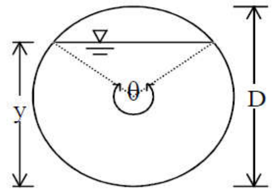
– B $= 2 * \sqrt{y * (D - y)}$

– A $= \dfrac{D^2 * (\theta - \sin\theta)}{8}$

– P $= \dfrac{\theta * D}{2}$

– R $= \dfrac{D}{4}\left(1 - \dfrac{\sin\theta}{\theta}\right)$

– y_{ave} $= \dfrac{D * (\theta - \sin\theta)}{8 * \sin \theta/2}$



(θ in radian)

4.2Identifying the depth of flow using a partial flow chart

The pipe-flow charts in this standard are based on the Manning formula, the Hazen and Williams formula, or the Colebrook-White formula. These three formulas were chosen as they represent those most commonly used for pipeline design in Australia. Designers will need to make their own choice as to which formula they wish to adopt.

The three formulas are as follows:

(a) *Manning:* $V = \frac{1}{n} R^{0.67} S^{0.5}$

(b) *Hazen and Williams:*

V = 0.849 *C R*0.63*S*0.54

(c) *Colebrook-White:* $V = -\sqrt{32gRS}\,\log\left[\frac{k}{14.8R} + \frac{1.255\,v}{R\sqrt{32gRS}}\right]$

where

n = Manning roughness coefficient

C = Hazen and Williams roughness coefficient

k = Colebrook-White roughness coefficient, in metres

V = velocity

R = hydraulic radius, in metres

S = slope, in metres per metre

g = gravitational acceleration, in metres per second squared

n = kinematic viscosity of water, in square metres per second.

It is intended that the charts will give designers a reasonably accurate basis for design of pipe systems. However, it must be realized that the formulas on which they are based may have limitations on the range of velocities, diameters and roughness coefficients to be used. They may be inaccurate where the parameters used are outside the conditions upon which the formulas were originally based. A guide to roughness coefficients for various pipe materials is given in Table 1.

Some hydraulic text books report that the Hazen and Williams's formula may not be entirely suitable for diameters less than 50 mm or velocities greater than 3 m/s. It is also stated that the formula is not entirely accurate for values of *C* substantially less than 100.

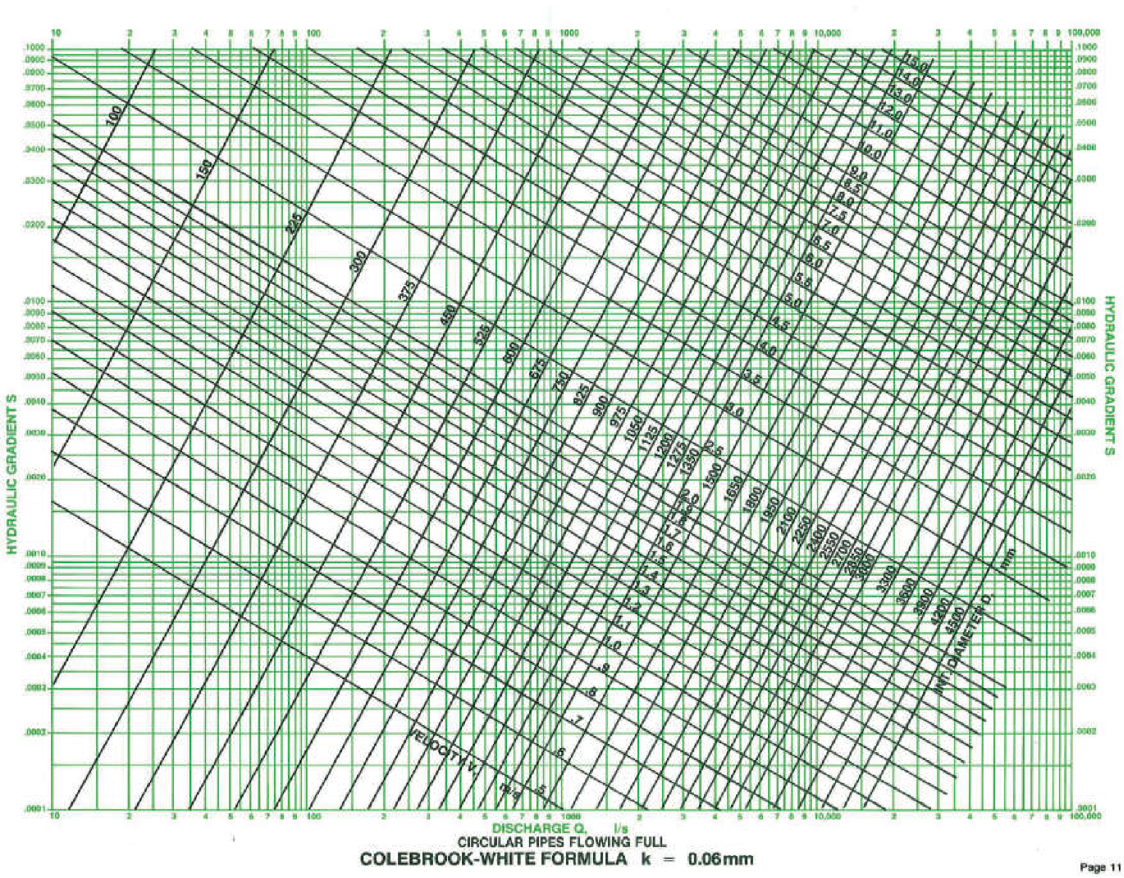
The Manning formula applies to about the same flow range as the Hazen and Williams formula. It may be more useful than the Hazen and Williams formula in cases where the value of *C* is well below 100.

However, its use is now diminishing in favour of the more reliable Hazen and Williams and Colebrook-White formulas.

The most recent formula to be devised is that by Colebrook-White which has only lately been presented in graphical form. It is regarded by many hydraulicians throughout the world as the most accurate basis for hydraulic design. It has had ample experimentation confirmation over wide conditions of flow.

The Colebrook-White charts have been drawn for a water temperature of 20°C. Although the temperature of water and sewage varies between seasons and also between localities, 20°C is considered to be a suitable mean value for Australian conditions. A temperature correction table has not been included because the increase or decrease in discharge due to temperature variations is small. In fact an increase or decrease in temperature of 10°C will vary the discharge by only about 3 percent. Diameters given on the various charts represent internal diameters of pipes. Designers should therefore ensure that, when using the charts, actual internal diameters are applied, and not the ‘nominal size’ from the various Australian standards for pipes.

Examples in the use of the Colebrook-White formula charts are given in Appendix A, and an example in the use of Chart 19, Guide to Resistance Coefficients of Valves and Fittings



Self-Check 3	Written Test

Name: _________________________Date: _______________

Directions: Answer all the questions listed below. Illustrations may be necessary to aid some explanations/answers.

1. List type of channels shape?(6pt)
2. What are the characteristics of **G**eometry of an open channel?(6pt)
3. What are the advantage and disadvantage of using charts?(6pt)

Note: Satisfactory rating - 9 points and above Unsatisfactory - below 9 points

You can ask you teacher for the copy of the correct answers.

Reference

- ✓ Chow, V. T. (1959/2008). Open-Channel Hydraulics. Caldwell, New Jersey: Blackburn Press. ISBN 9780070859067.
- ✓ Battjes, J. A.; Labeur, R. J. (2017). Unsteady flow in open channels. Cambridge University Press. doi:10.1017/9781316576878. ISBN 978-1-107-15029-4.
- ✓ Avila, K.; D. Moxey; A. de Lozar; M. Avila; D. Barkley; B. Hof (July 2011). "The Onset of Turbulence in Pipe Flow". Science. 333 (6039): 192–196.