Chapter 4

Gauging and Flow Measurement

Abdul Shabbir and Muhammad Yasin*

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Irrigation water provides primary support to the irrigated agriculture, particularly under arid and semiarid conditions as prevailing in most of the cultivated areas of Pakistan. Under constrained and limited water supplies, application of measured quantities of water is quite desirable for efficient irrigation. Further, it helps in overcoming both the under or over irrigation opportunities as both tend to reduce crop yields. Seasonal variations of flow during Kharif and Rabi seasons and equitable distribution of water among the shareholders also demand a consistently measured records of irrigation deliveries at various levels. Flow measurement permits the farmers to plan their cropping schedules in a better way. Correct measurements give a feeling of satisfaction to all concerned parties (both the farmers of a command and irrigation managers), and promote more efficient utilization of limited resources. Therefore, flow measurement and gauging at all levels of the canal irrigation, groundwater pumping and other water supply systems are a basic requirement of successful agriculture. At each control point, it becomes very important to keep the record of releases to various channels and finally to the fields. Therefore, it is important that all the stakeholders of Irrigation and drainage systems (including managers, policy makers, farmers and other water users) may understand not only the availability of water resources but also their efficient use to achieve the goals of potential crop production. They should further learn about the benefits of measured quantities of water delivered for protection of their water rights and its efficient use.

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Correct measurement of water deliveries minimizes the chances of disputes among the shareholders. This chapter of the book has been designed to explain the importance of water measurement, various techniques for flow measurement, in the laboratory as well as in the field, such as volumetric, weighing, velocity area and trajectory methods. The flow measuring devices such as weirs, flumes, venture meter, orifice meter, flow meters, etc. have also been discussed in detail.

Keywords: Water Measurement, Measuring Devices, Watercourse, Pipe Flow, Telemetry System and Gauging

Learning Objectives

Flow measurement and gauging are important elements of an irrigation system to keep the record of releases to various channels and finally to the fields. Therefore, following are the objectives of the chapter on Gauging and Flow Measurements:

- The major objective of the chapter on gauging and flow measurement is to facilitate all the stakeholders of Irrigation System (system managers, policy makers, farmers and other water users) to understand the methodology of measurement and keep a record of the delivered and received amounts of water to safeguard their water rights and its efficient use.
- To understand the seasonal variations of flow during kharif and Rabi seasons, which may help the farmers to plan their cropping schedules.
- The reader may update his knowledge about assuring the correct deliveries to his farm.

4.1 Introduction

Increasing competition exists between multiple users, including irrigation, municipal, industrial, environmental, recreation, aesthetic, fish farming and wildlife uses. Therefore, optimal use of this scarce commodity would be required to satisfy the needs of competing users in terms of quantities and time of use. Good management measures and practices leading to conservation of water will always require accurate measurement of this commodity at all levels.

4.1.1 Types of Flow

Fluid flow may be classified as: (i) Open channel flow (ii) Pipe flow or Closed Conduit flow. Open channel flow conditions exist when the surface of flowing stream is free and open to the atmosphere. The driving force here is gravity creating a gravitational head of water. Flow in canals, watercourses or in vented pipelines, which are not flowing full are typical examples of open channel flow. The presence of the free water surface prevents transmission of pressure from one end of the conveyance channel to another. In case of fully flowing pipelines, the applied pressure dominates the gravitational forces, and therefore, the flow occurs under pressure.

In hydraulics, a pipe is any closed conduit that carries fluid under pressure. Regardless of the cross-sectional shape of the conduit, the pressure in the pipe is equally distributed along the cross section. If flow is occurring in a conduit that does not completely fill it, the flow is not considered as conduit flow, but is classified as open channel flow. The head loss due to friction takes place in the conduit as well as in the open channel. However, different factors are responsible to cause the head loss. Therefore, head loss measurement and consequently, the discharge measurement is carried out using different devices. In most of the cases, the flow considerations in canal irrigation are the open channel flow that will be the focus of this chapter.

4.1.2 Flow Measurement

Determination of the quantity of fluid flowing per unit time across any section of the channel (spillway, under sluice, "mogha", "nakka" or flume etc.) is called Flow Measurement and is usually expressed as flow rate i.e. volume or weight or mass of fluid moving per unit time. The units of measurement may include cubic meter per second (m^3/s), cubic feet per second (ft^3/s), etc. or in terms of weight flow rate such as kilo newton per second (kN/s), or mass flow rate such as kilograms per second (kg/s). In dealing with incompressible fluids (liquids) such as water, oil, etc., volume flow rate is used, whereas the weight flow rate or mass flow rate is more convenient for compressible fluids such as gases. As the irrigation system utilizes water as a fluid, the flow rate is measured in terms of volume of water per unit time.

4.1.3 Importance and Need

For efficient use of irrigation water supplies and potential crop production, water should be applied in measured quantities, which otherwise may cause under irrigation or over irrigation to crops. The under irrigation will cause loss in yield due to water stress and salt accumulation, while over irrigation will cause dual damage i.e. losses of water and reduction in crop yield. The over irrigation further leads to water logging that would ultimately reduce the crop yield. The over irrigation also causes loss of soil nutrients, which ultimately affect soil health and ground water quality. Thus, to get maximum benefit out of limited water resources. Required amount of water should be applied, which is only possible by measuring it. Various uses and benefits of water measurement in irrigation include:

- Application of measured water to crops requires accurate water measurement
- Provision of equitable shares of water between competing uses.
- Water measurement facilitates accurate and equitable distribution of water within farms.
- Employing accurate and convenient water measurement methods improves the evaluation of seepage losses in lined and unlined channels
- Delivery of measured amounts of water to the farms allows the farmers to plan and execute farming activities with better confidence and management options. It also develops a better working relationship with Government functionaries

- Correct measurement of water deliveries minimizes the disputes among the shareholders.
- Correct measurements give a feeling of satisfaction to all concerned parties (farmers of a command, provincial Governments or and promote more efficient utilization

4.1.4 Units of Measurement

Water is found in two states on the earth's surface, at rest or in motion. Water at rest means water in reservoirs, lakes, ponds, tanks and containers, etc., and it is measured in volumetric units like hectare-meter, acre-feet, acre-inches, cubic meters, cubic feet, liters, gallons, etc. When water is in the state of motion, such as in water channels, rivers, canals and in watercourses, etc., it is measured in volume per unit time, units that include cubic meter per second, cubic foot per second, liter per second, cubic meter per hour, cubic foot per hour, etc. Definitions for some of the commonly used units for water measurement have been given in Table 4.1.

Table 4.1 Some Examples of the Units of Water Measurement in the Field

Volume Units			
S.	Unit	Definition	Symbol
1	Hectare-meter	Volume of water required to cover an area of one hectare up to a depth of one meter, which may be mathematically presented as : 1 hectare-meter = 10,000 m^2 X 1m = 10,000 m^3	ha-m
2	Acre-foot	Volume of water required to cover an area of one acre up to a depth of one foot.1 Acre-foot: 43,560 ft^2 X 1 ft = 43,560 ft^3	Ac-ft
3	Acre-inch	It is a volume of water required to cover an area of one acre up to a depth of one inch. It is most widely used unit for irrigation application to crops locally. 1 Acre-inch: 43,560 ft^2 X 1/12 ft = 3630 ft^3	Ac-in
Flow Rate Units			
1	Cubic meter per second	If a volume of one cubic meter of water passes across a control section ("mogha", "nakka", weir, etc.) per second, the discharge is measured as one cubic meter per second (m^3/s).	m^3/s
2	Cubic foot per second	If a volume of one cubic foot of water passes across a control section (mogha, nakka, Weir etc.) per second, the discharge is measured as one cubic foot per second	ft^3/s
3	Liter per second	If a volume of one liter of water passes across a control section (mogha, nakka, weir, etc.) per second, the discharge is measured as one liter per second	l/s

4.2 Methods of Flow Measurement

There are several methods available for flow measurement suitable for various situations as discussed below:

4.2.1 Volumetric Method

The simplest method to estimate small discharges is by direct measurement of the time to fill a container of known capacity. The flow is diverted into a channel or a pipe, which discharges into a suitable container, and the time to fill is determined by stopwatch. The time to fill must be noted accurately, especially when it is only a few seconds. The variation between several measurements taken in succession will give an indication of the accuracy of results. For a given volume and time, the flow rate can be determined as:

Discharge Q = Tank Volume (V)/Filling Time (T)

i.e. $Q = V/T$

Where;

Q = Discharge (m^3/s)

V = Volume of tank (m^3)

T = Filling Time (s)

4.2.2 Weighing Method

Another method of determining the flow rate accurately, is to find the time to collect a known weight of the fluid. The weight of water is divided by time to calculate the weight flow rate, which is then divided by a unit weight of water to get the volumetric flow rate as summarized below.

Weight flow rate = Weight /Time i.e. $G = W/T$ and

If $G = \gamma Q$

Thus, $Q = (W / \gamma) / T$

Where;

G = Weight flow rate (Kilo Newton per second or kN/s)

W = Weight collected (kN)

T = Collection time (s)

Q = Volumetric flow rate (m^3/s)

γ = Unit weight or Specific weight of water (9.81 kN/m^3)

4.2.3 Velocity-Area Method

In flow measurement, the rate of flow is assessed by determining the velocity of fluid passing through a given cross-sectional area using the continuity equation:

i.e. $Q = AV$

Where

Q = Flow Rate - Cubic meter per second

A= Cross Sectional Area – Square meters

V= Velocity of fluid – Meter per second

T= Time- Seconds

The units of flow measurement (volume per unit time) include: gallon per minute (gpm), cubic feet per second (cfs), liter per second (L/s), or cubic meters per second (m^3/s) etc. (Michael 2009).

4.2.3.1 Measurement of Area

Generally, channels are of two types lined (regular section) and unlined (irregular section). The

areas of the regular channel section area are determined using the equations given below:

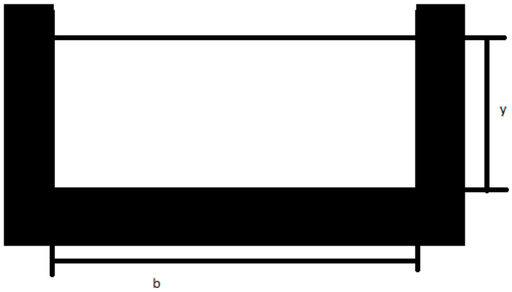
i) Regular Cross Section:

The regular cross sections of a channel include rectangular, trapezoidal and triangular (Fig. 4.1), which can be defined as:

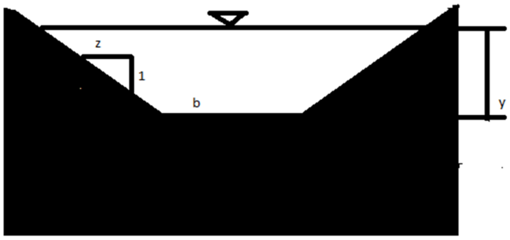
ii) Irregular Cross Section

The area of irregular section is determined by dividing the total width of the channel into several smaller widths and then multiplying each width with respective average depth and finally summing all the smaller areas thus determined as shown in the blue shaded cross section of the channel in Fig. 4.2. The number and widths of the subdivisions depend upon the accuracy needed. The smaller the width, the more accurate is the area.

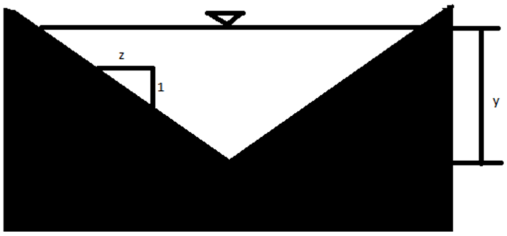
Rectangular section:
A = b .y



Trapezoidal section:
A = (b + z. y) y



Triangular section:
$A = z \times y^2$



Where: A= Cross sectional area
b = Width of channel
y = Depth of water in the channel
z = Side slope i.e. Horizontal/vertical

Fig. 4.1 Cross sectional areas of various channel shapes

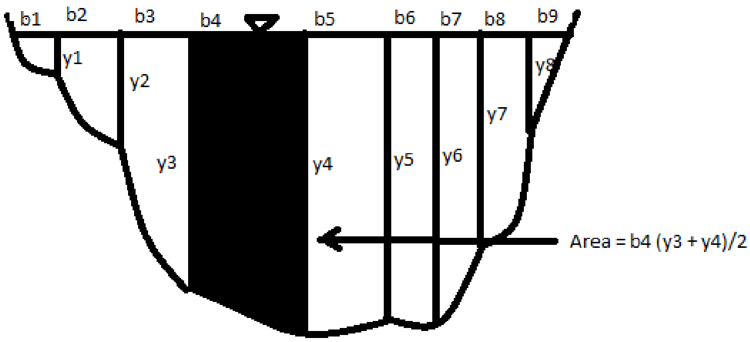


Fig. 4.2 Cross Sectional Area of a Large Unlined Channel with Irregular Cross Section

4.2.3.2 Velocity Measurement

Various methods are in use for velocity measurement out of which only two are given below:

i) Float Method

The float method of flow measurement comprises the use of a float, which may be a piece of wood, a ball or any other object that is dipped in water by 2/3 of its length so that it moves along the water currents (Martin, 2011). The velocity can be determined by noting the time of travel for a predetermined distance and then dividing the distance traversed by the object by the time. Thus, velocity can be measured in units of ft/s, m/s etc. as given below:

Velocity = distance travelled / elapsed time of travel

In an open channel, Volume flow rate is determined by the product of the average flow velocity and the average cross-sectional area of the stream as given below:

$$Q = AV$$

In an open channel, the velocity of flow varies from zero at the bottom surface of the channel to the maximum just below the surface of water in the channel. A well dipped float allows average measurement of velocity. However, more than one measurement would allow to find the average velocity, which is needed the accuracy of flow measurement. For flows in canals and reasonably smooth streams, the measured surface float velocities should be multiplied by the correction factor of 0.85. The corrected velocities should then be multiplied by the cross-sectional area of the corresponding stream sub section to obtain the sub section discharges. The summation of the segment discharges will be the gross discharge.

ii) Current Meter

The Current Meter measures the velocity of fluid currents and thereby the velocity of fluid flow. The velocity of water flowing in an open channel is not the same throughout the cross-section. It approaches zero at the bottom as well as along the sides of the channel and maximum in the mid cross sectional area. To find the mean flow rate, mean current velocity and accurate cross-sectional area of the stream are needed. For determining mean velocity, the top width of the cross-sectional area of the channel is divided into several sections. The average velocity is estimated by the average of the current meter observations taken at 0.2D (20 % of depth) and 0.8D (80 % of the Depth) of channel in the rectangular sub sections. In the triangular subsections near the sides of the channel, the average velocity of flow is determined by taking only one observation at 0.6D (i.e. 60% of the depth) as shown below in Fig. 4.3.

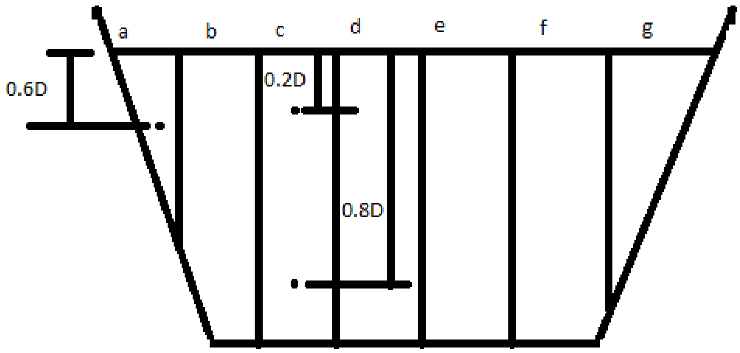


Fig. 4.3 Measuring Points in Channel Cross Section

The flow for each subsection is calculated by the product cross-sectional area of the subsection and the average flow velocity within the subsection. The flow rate through this channel, for example, would be:

Flow = (AaVa) +(AbVb) +(AcVc) +(AdVd) +(AeVe) +(AfVf) +(AgVg) +(AhVh)

Where: Aa, Ab, ... Ah = cross-sectional areas of subdivisions a, b, ...h
Va, Vb, ...Vh = average flow velocities of subdivisions a, b, ...h

Aa, Ab, … are the areas of subsections (average depth multiplied by the subsection width or width multiplied by the depth as the shape may be)

Va = V0.6D (as it is a shallow section)

Vb = (V0.2D + V0.8D) / 2 (as it is as deep section) and so on

4.2.4 Trajectory Method of Tube well Flow Measurement

Trajectory method consists of measuring the horizontal and vertical coordinates of a point in the jet issuing from the end of a pipe (Stock, 1955) as shown in Fig 4.4. The pipe may be positioned either vertically or horizontally. The main difficulty with this technique is the accuracy in measuring the coordinates of the flowing stream.

$$Q = A. X/ (2Y/g)^{0.5}$$

Where;

Q = Flow rate (m^3/s)

X = Horizontal component of water jet (m)

Y = Vertical component of water jet (m)

g = Acceleration due to gravity (m/s^2)

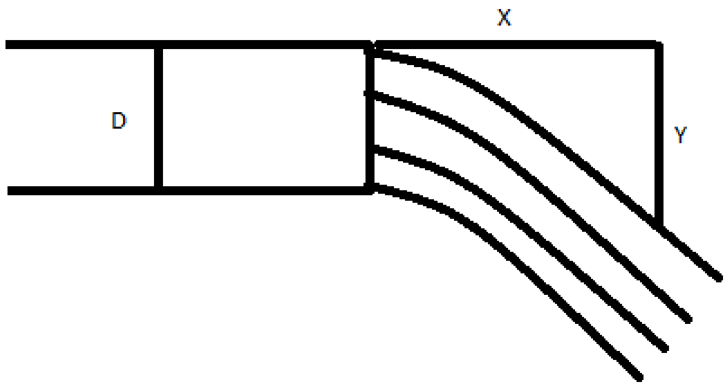


Fig. 4.4 Trajectory Method of Flow Measurement

4.2.5 Telemetry System

Telemetry System has been devised through Supervisory Control and Data Acquisition (SCADA) to observe the flow rate with the help of gate openings and water levels using Sensors equipped with the system. The telemetry system is attached to the gauging points of the entire network and may be connected to other locations through electronic systems. Data loggers can be used to collect data regarding the depth and velocity of flow. Thus, it assists the system managers to properly regulate and distribute irrigation water to various users. This system has been widely used in the developed as well as in many developing countries. Telemetry System has been recently used by WAPDA and IRSA to monitor the canal irrigation system of Pakistan. The telemetry system is working very well and has opened new scenario; however, it requires willingness and participation on the part of the engineers and farmers.

4.2.5.1 Components of Telemetry System

The major components of a telemetry system include:

- Field instrumentation and control equipment
- Remote station
- Communication network, and
- Central monitoring station

Field instrumentation and control equipment collect data from the field. The instruments include sensors, meters and actuators that are directly attached to the canal gates at flow regulators. The telemetry system may utilize telephone, radio and cable or satellite to effectively transfer the collected data to other locations equipped with a computer system. The computer output consists of real time water levels and canal discharge. At the central communication station, the data are processed automatically by computers and gives the flow distribution to various canal systems feeding the provincial irrigation systems.

4.2.5.2 Benefits of Telemetry Systems

The benefits of Telemetry System include:

1. Improve operational and service capability of the system.
2. Standardize operating procedures to run the system more efficiently and to better utilize staff.
3. Reduced operational costs and risks.
4. Better ability to negotiate with water managers and stakeholders.
5. Opportunity to manage the system with equitable distribution among the stakeholders, such as provincial Irrigation Departments.
6. Improved ability to collect data regarding flow rates and sharing status of the stakeholders.

4.3 Gauging

In case of flow over a weir, the flow can be measured by relating flow rate with the flowing depth. Such a control section on a channel is considered as a gauging station. Recording of flow depth through a vertical scale at that section is called stream gauging. The scale is installed in a stilling well provided in the bank of the channel at the measuring point, so that the surface of water becomes still to facilitate accurate recording the depth data.

4.4 Devices for Flow Measurement

Commonly used devices for flow measurement are discussed below:

4.4.1 Weirs

Weirs are devices which can be used to measure the discharge rate in the open channels. As water flows over the weir crest, the depth or head of the water is measured over the weir crest, which acts as a flow control section. The flow equation utilizes the depth information to find the discharge. However, different cross sectional shapes of weirs use different flow equations as shown in Fig 4.5.

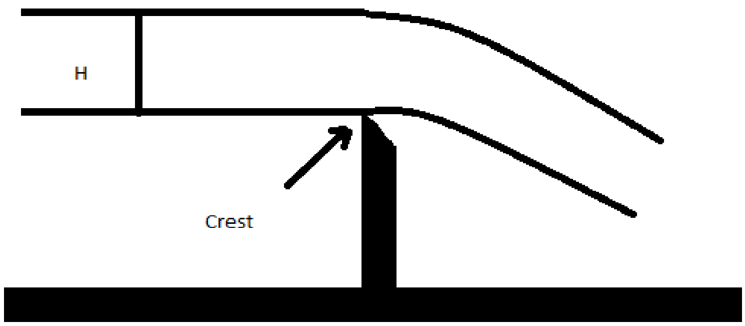


Fig. 4.5 Water Flowing Over a Sharp Crested Weir

Some general terms pertaining to weirs are:

Notch: It is the opening which water flows through

Crest: It is the edge which water flows over

Nappe: It is the free-flowing jet over a weir. There is aeration zone below the nappe

Head: Depth of water above the edge, denoted by (H) and should be measured at 4H from edge.

Length: Distance of V Notch across the width section of the weir notch formulae for different weirs cross sections are given below:

4.4.2 Flumes

Flumes include various specially shaped and stabilized channel sections that are used to measure flow. Use of flumes is similar to the use of weirs in that flow is related to flow depths at specific points along the flume. Various types of flumes are in practice but the most usually used flume is cutthroat as discussed below:

The Cut-Throat Flume was developed by Ralph Parshall. It is suited to flat gradient applications in open-channels. The Cut-Throat Flume has a rectangular constriction with a flat surface floor and throat length reduced to zero that named it as Cut-Throat Flume.

These flumes are available in standard length of 3 feet and standard throat widths of 4, 8, 12 and 16 inches for which discharge rating tables are available. It allows these flumes to be applicable to a wide range of discharge measurement. The advantages of using Cut-Throat Flumes include the following:

- It is less costly to construct than other types of flumes due to its simplicity.
- Easy to install due to flat floor.
- Usable at lower gradient channels due to less head loss.
- Angles of convergence / divergence are the same for all sizes of Cut-Throat Flumes, which allows these flumes to be developed by simply moving the sidewalls in and out as necessary.

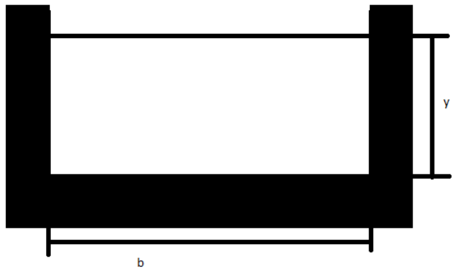
A dimensioned sketch of Cut-Throat Flume is shown in Fig 4.7.

4.4.2.1 Submergence

Cut-Throat Flumes need a minimum head loss to make sure that free-flow conditions exist. Under free flow condition, only one value of upstream head measurement (ha) is needed to determine the discharge rate. When the water surface in the downstream part of the flume rises above a critical point, the resistance to flow of the channel becomes sufficient to reduce the upstream velocity, which causes to increase the flow depth at the upstream component of the flume because of the backwater effect in the flume.

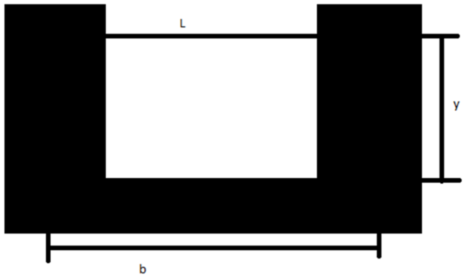
Rectangular weir

$Q = \frac{2}{3} Cd \sqrt{2g}\, L\, H^{3/2}$



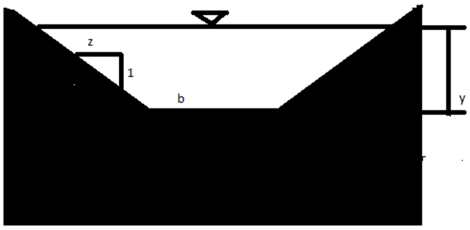
Rectangular contracted weir

$Q = \frac{2}{3} Cd \sqrt{2g} (L - 0.1nH) H^{3/2}$



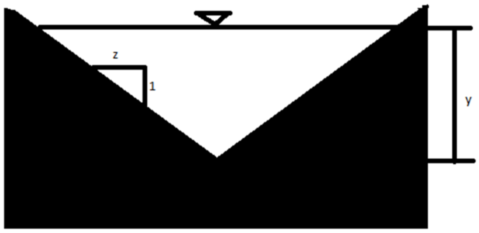
Cipolletti weir

$Q = 1.86\, L\, H^{3/2}$



V-notch weir

$Q = \frac{8}{15} Cd \sqrt{2g} \tan\frac{\theta}{2}\, H^{5/2}$



Q = flow rate (m^3/s)
H = head on the weir (m)
L = width of the weir (m)
g = 9.81 (m/s^2) - gravity
θ = v-notch angle
n = number of end contractions (n = 2 in Fig 4.7 (b))
Cd= discharge constant for the weir - must be determined

Fig. 4.6 Types of Weirs

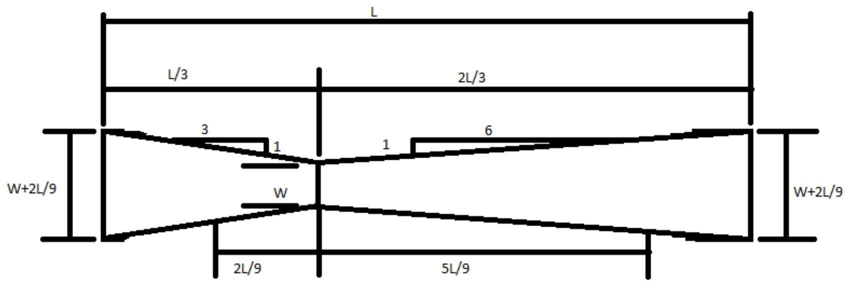


Fig. 4.7 Sketch of Cutthroat Flume (Top View)

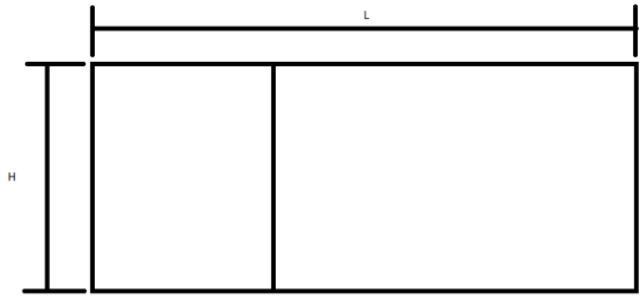


Fig. 4.8 Sketch of Cut-Throat Flume (Side View)

Submerged flow conditions in the flume occur when the resistance to flow at downstream controls the flow upstream. Under submerged flow condition, the flow velocities reduce and the flow depth increases as compared to that achieved under free-flow conditions.

The submergence ratio can be defined as the ratio of the downstream depth of the flume (Hb) to the upstream depth (Ha). Thus, the Submergence Ratio (Hb/Ha) can be is expressed mathematically either as a ratio or as a percentage.

4.4.2.2 Flume Installation

It is advised to follow the following steps to ensure a successful Cut-Throat Flume installation:

- Install the flume at a straight section of the channel, which should be free of bends, dips, elbows, or flow junctions.
- The approaching flow should be sub-critical and uniformly distributed across the channel. Avoid any turbulent, surging, unbalanced flow situation at the channel section where flume is installed. In addition, a poorly distributed velocity pattern should also be avoided.
- The flume should be centered in the channel / flow stream
- The floor of the flume should be set high enough to ensure a free flow condition.

- The floor of the flume must be installed at Zero level, both in the parallel and transverse directions with the flow of water.
- The dimensions of the flume must be checked before installation.
- Check for leakage on the outer sides as well as below the flume during flow measurements by the proper filling of soil.
- Open channel flow conditions must exist at all times

4.4.3 Venturimeter

Venturimeter is used in pipes to find out the flow rate. The Venturi effect is the reduction in fluid pressure that results when a fluid flows through a constricted section of pipe (Doughtery et al, 1985). The Venturi effect is a jet effect; as with a funnel the velocity of the fluid increases as the cross-sectional area decreases, with the static pressure correspondingly decreasing as shown in Fig 4.9. According to the laws governing fluid dynamics, a fluid's velocity must increase as it passes through a constriction to satisfy the principle of continuity, while its pressure must decrease to satisfy the principle of conservation of mechanical energy. Thus, any gain in kinetic energy a fluid may accrue due to its increased velocity through a constriction is negated by a drop in pressure.

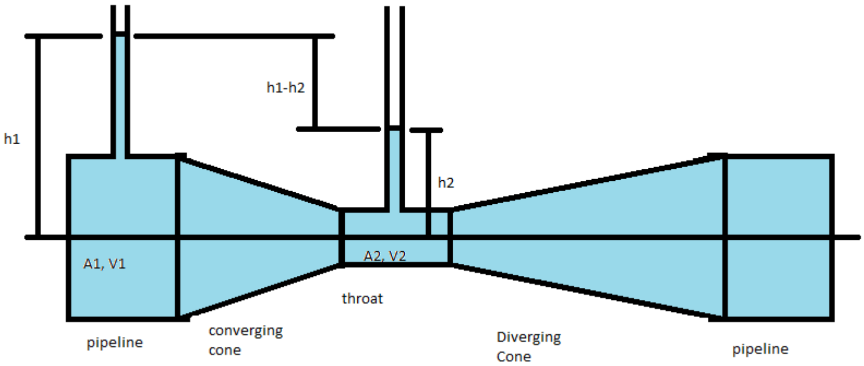


Fig. 4.9 Venturimeter

A venturi can be used to measure the volumetric flow rate, Q.

$$Q = A_2V_2 = \frac{CA_2}{\{1 - (D_2/D_1)\text{-}^{4}\}^{0.5}}\{2g\{(\frac{p_1}{\gamma} + Z_1) - (\frac{p_2}{\gamma} + Z_2)\}\}^{0.5}$$

Where

Q = Flow rate, m^3/s

C = Coefficient of discharge, -

D_1 = Diameter of pipe, m

D_2 = Diameter of throat, m

Z_1 and Z_2 = respective elevations, m

P_1/γ and P_2/γ are respective pressure heads (h_1 and h_2), m

4.4.4 Orifice Meter (Orifice Plate)

An orifice plate is a device used for measuring the flow rate in pipelines. It also uses the Bernoulli's principle which states that there is a relationship between the pressure of the fluid and the velocity of the fluid. When the velocity increases, the pressure decreases and vice versa (Doughtery et al., 1985).

An orifice plate is a thin plate with a hole in the middle. It is placed in a pipe where a fluid is flowing. When the fluid reaches the orifice plate, the fluid is forced to converge through the hole where maximum convergence takes place at the vena contracta point (Fig. 4.10).

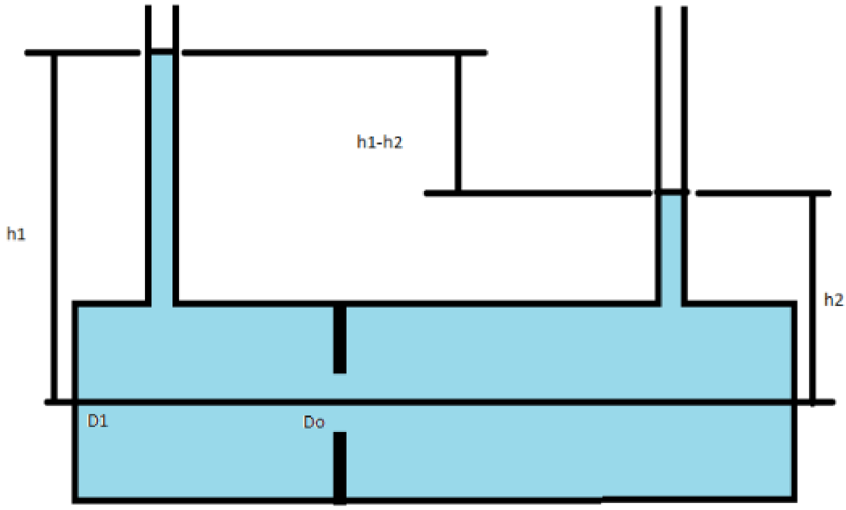


Fig 4.10 Orifice Plate

Orifice plates are used for continuous measurement of fluid flow in pipes. They are also used in some small river systems to measure flow rates at locations where the river passes through a culvert or drain. Only a small number of rivers are appropriate for the use of the technology since the plate must remain completely immersed i.e. the approach pipe must be full, and the river must be substantially free of debris.

$$Q = A_o V_2 = \frac{CA_o}{\{1 - (D_o/D_1)^{-4}\}^{0.5}} \{2g\{\left(\frac{p_1}{\gamma} + Z_1\right) - \left(\frac{p_2}{\gamma} + Z_2\right)\}\}^{0.5}$$

Q = Flow rate, m^3/s

C = Coefficient of discharge, -

D_1 = Diameter of pipe, m

D_o = Diameter of orifice, m

Z_1 and Z_2 = respective elevations, m

P_1/γ and P_2/γ are respective pressure heads (h_1 and h_2), m

4.4.5 Water Meter

Water meters are used to measure the volume of water flowing through a pipe system. Some water meters show the flow in addition to total volume delivered. Several types of water meters are installed on sprinkler as well as on drip irrigation systems to manage the correct application of water to the crop.

4.4.6 Siphon Tube

If siphon tubes (Fig. 4.11) allow application of irrigation to the crop from an open ditch without cutting through the bank of the channel, the difference in head between the channel and the field is utilized to determine the flow rate as well as the total amount of water applied to the field. The siphon may operate under free flow as well as submerged flow conditions. The larger the tube size or the greater the head, the higher will be the flow rate (Gertrudys, 2006).

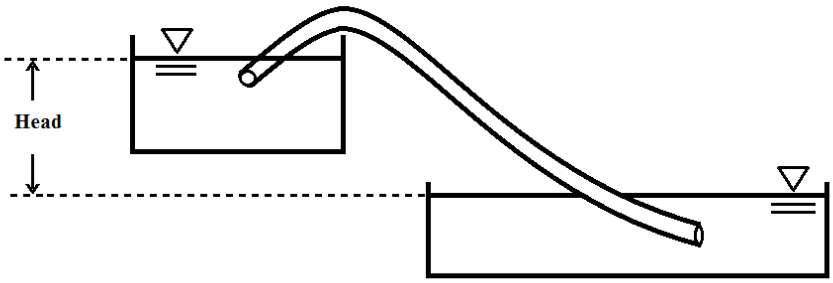


Fig. 4.11 Measurement of Head for Siphon Tube

4.5 Selection of Water Measuring Devices

The following factors should be considered while selecting a suitable measuring device:

- Accuracy
- Cost
- Legal constraints
- Range of flow rates
- Head loss
- Adaptability to site conditions
- Adaptability to operating conditions

- Type of measurements and records needed
- Operating requirements
- Ability to pass sediment and debris
- Suitability to environment
- Maintenance requirements
- Construction and installation requirements
- Minimum troubleshooting opportunities
- Vandalism potential

4.6 Solved Examples

Example 4.1: Calculate the flow rate in a regularly maintained irrigation channel by float method. A 60 m length of channel (Fig. 4.12) is marked at 3 points as A, B and C with the section of channel starting at point A and ending at C. The interval between two points is 30 m each. The mean width of the channel at the bottom and surface of water at three points (A, B and C) are 100, 101 and 102 cm, respectively, with depth of water at those points are 30, 30 and 31 cm, respectively. The time taken by float to cross points B and C are 90 and 186 s respectively after it runs from the point A.

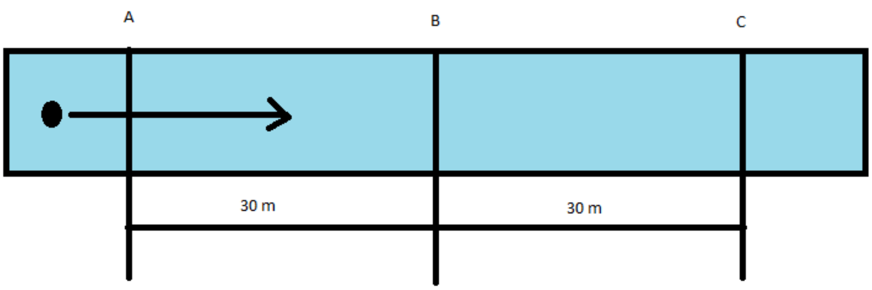


Fig. 4.12 Top View of an Irrigation Channel

Solution

Average depth = (30+30+31)/3 = 30.33 cm

Average width = (100+101+102)/3 = 101 cm

Average area = 0.3033 X 1.01 = 0.3063 m^2

Average velocity = (30/90 + 30/96) x 1/2 x 0.85 = 0.2745 m/s

Discharge = average area x average velocity

= 0.3063 x 0.2745

= 0.0841 m^3/s

Example 4.2: Water flows into a cylindrical tank at a rate of 0.4 m^3/s and is to be discharged from the tank at the same rate over a sharpe-crested, suppressed rectangular weir. Due to the geometry of the tank and the potential for overflow, the maximum head on the weir is 45 cm. Determine the minimum required length of the weir. Take Cd = 0.62.

Solution

$Q = \frac{2}{3} Cd \sqrt{2g}\, L\, H^{3/2}$

$0.4 = \frac{2}{3} 0.62 \sqrt{2 * 9.81}\, L\, 0.45^{3/2}$

L= 0.73 m

Example 4.3: Solve problem of example 4.2 using a sharp-crested, contacted weir

Solution

$Q = \frac{2}{3} Cd \sqrt{2g}(L - 0.1nH)H^{3/2}$

$0.4 = \frac{2}{3} * 0.62\sqrt{2 * 9.81}(L - 0.1 * 2 * 0.45) * 0.45^{3/2}$

L = 0.82 m

Example 4.4: Discharge (Q) through a channel is controlled using a 90° v-notch. For a measured head of 0.3 m, evaluate the flow rate. How does the value of Q if the opening angle is instead 45°? Assume Cd = 0.60

Solution

For $\theta = 90^o$ $\quad Q = \frac{8}{15} Cd \sqrt{2g} \tan\frac{\theta}{2}\, H^{5/2}$

$Q = \frac{8}{15} * 0.60\sqrt{2 * 9.81} \tan\frac{90}{2} * 0.3^{5/2}$

Q = 0.07 m^3/s

For $\theta = 45^o$ $\quad$ Q = 0.029 m^3/s

References

Dougherty, R.L., J.B. Franzini, and E.J. Finnemore (1985). Fluid Mechanics with Engineering Applications, SI Metric Edition. McGraw-Hill Publishers, Columbus, OH, USA.

Federal Water Management Cell (1996). Field Manual of Water Measurement Volume III. Ministry of Food, Agriculture & Livestock. Government of Pakistan, Islamabad.

Gertrudys, B.A. (2006). Flow MeasurementDevices. Division of Water Rights, Utah, USA.

Martin, C.E. (2011). Measuring Water Flow in Surface Irrigation Ditches and Gated pipes. Arizona Water Series No. 31. Arizona, USA.

Michael, A.M. (2009). Irrigation: Theory and Practice. 2nd Edition, Vikas Publishing House Pvt Limited, Ram Nagar, New Delhi, India.

4.8 Appendix

Flow Measuring Table for Different Sizes of Cut-Throat Flumes

4.10.1 Appendix– Flow Measuring Table for Cut Throat Flumes

1.5 Foot Flume				
Hu ft	2in cfs	4in cfs	6in cfs	8in cfs
0.30	0.089	0.184	0.283	0.387
0.32	0.101	0.209	0.321	0.439
0.34	0.114	0.235	0.362	0.494
0.36	0.128	0.263	0.405	0.552
0.38	0.142	0.293	0.450	0.613
0.40	0.157	0.324	0.497	0.677
0.42	0.173	0.356	0.547	0.744
0.44	0.190	0.391	0.599	0.814
0.46	0.207	0.426	0.653	0.887
0.48	0.226	0.463	0.710	0.964
0.50	0.245	0.502	0.769	1.043

3.0 Foot Flume				
Hu ft	4in cfs	8in cfs	12in cfs	16in cfs
0.30	0.153	0.317	0.489	0.668
0.32	0.173	0.357	0.550	0.750
0.34	0.193	0.399	0.614	0.837
0.36	0.214	0.442	0.681	0.927
0.38	0.237	0.488	0.751	1.022
0.40	0.260	0.536	0.824	1.121
0.42	0.285	0.586	0.900	1.223
0.44	0.310	0.638	0.979	1.330
0.46	0.336	0.692	1.061	1.441
0.48	0.364	0.748	1.146	1.555
0.50	0.392	0.806	1.234	1.673
0.52	0.422	0.866	1.325	1.796
0.54	0.452	0.928	1.419	1.922
0.56	0.483	0.991	1.515	2.051
0.58	0.515	1.057	1.615	2.185
0.60	0.548	1.125	1.717	2.322
0.62	0.583	1.194	1.822	2.463
0.64	0.618	1.265	1.930	2.608
0.66	0.654	1.338	2.040	2.756
0.68	0.691	1.413	2.154	2.908
0.70	0.728	1.490	2.270	3.063
0.72	0.767	1.569	2.388	3.222
0.74	0.807	1.649	2.510	3.385
0.76	0.847	1.732	2.634	3.551
0.78	0.889	1.816	2.761	3.721
0.80	0.931	1.902	2.891	3.894
0.82	0.975	1.989	3.023	4.071
0.84	1.019	2.079	3.158	4.251
0.86	1.064	2.170	3.295	4.434
0.88	1.110	2.263	3.435	4.622
0.90	1.157	2.358	3.578	4.812
0.92	1.204	2.454	3.723	5.006
0.94	1.253	2.553	3.871	5.203
0.96	1.302	2.653	4.021	5.404
0.98	1.353	2.754	4.174	5.608
1.00	1.404	2.858	4.330	5.815

4.5 Foot Flume				
Hu ft	6in cfs	12in cfs	18in cfs	24in cfs
0.30	0.237	0.491	0.757	1.034
0.32	0.265	0.548	0.844	1.152
0.34	0.294	0.607	0.935	1.275
0.36	0.324	0.670	1.030	1.404
0.38	0.356	0.734	1.129	1.537
0.40	0.389	0.802	1.231	1.675
0.42	0.423	0.871	1.337	1.818
0.44	0.458	0.943	1.447	1.966
0.46	0.495	1.017	1.560	2.118
0.48	0.532	1.094	1.676	2.274
0.50	0.571	1.173	1.796	2.436
0.52	0.611	1.254	1.920	2.601
0.54	0.652	1.338	2.046	2.772
0.56	0.694	1.423	2.176	2.946
0.58	0.737	1.511	2.309	3.125
0.60	0.781	1.601	2.445	3.307
0.62	0.827	1.694	2.585	3.495
0.64	0.873	1.788	2.728	3.686
0.66	0.921	1.884	2.873	3.881
0.68	0.969	1.983	3.022	4.080
0.70	1.019	2.083	3.174	4.284
0.72	1.069	2.186	3.329	4.491
0.74	1.121	2.291	3.487	4.703
0.76	1.174	2.397	3.648	4.918
0.78	1.227	2.506	3.812	5.137
0.80	1.282	2.617	3.979	5.360
0.82	1.337	2.729	4.149	5.587
0.84	1.394	2.844	4.321	5.817
0.86	1.452	2.961	4.497	6.051
0.88	1.510	3.079	4.675	6.289
0.90	1.570	3.200	4.856	6.531
0.92	1.630	3.322	5.040	6.776
0.94	1.692	3.446	5.227	7.025
0.96	1.754	3.572	5.417	7.278
0.98	1.818	3.700	5.609	7.534
1.00	1.882	3.830	5.804	7.794
1.05	2.047	4.163	6.303	8.459
1.10	2.217	4.507	6.820	9.146
1.15	2.394	4.862	7.352	9.854
1.20	2.576	5.228	7.901	10.583
1.25	2.763	5.606	8.466	11.334
1.30	2.956	5.994	9.047	12.105
1.35	3.154	6.393	9.644	12.896
1.40	3.358	6.802	10.256	13.708
1.45	3.567	7.222	10.883	14.539
1.50	3.782	7.652	11.526	15.390

Source: Federal Water Management Cell, 1996

4.10.2 Appendix (continued) – Flow Measuring Table for Cut-Throat Flumes

1.5 Foot Flume				
S	2in Qs/Qf	4in Qs/Qf	6in Qs/Qf	8in Qs/Qf
0.610	0.993			
0.620	0.990			
0.630	0.987			
0.640	0.983			
0.650	0.979			
0.660	0.974			
0.670	0.968	0.999		
0.680	0.962	0.998		
0.690	0.956	0.996		
0.700	0.949	0.994		
0.710	0.941	0.991		
0.720	0.932	0.988		
0.730	0.923	0.984		
0.740	0.914	0.980		
0.750	0.903	0.974	0.999	
0.760	0.892	0.969	0.998	
0.770	0.880	0.962	0.996	
0.780	0.867	0.955	0.994	
0.790	0.854	0.946	0.991	
0.800	0.839	0.937	0.987	
0.810	0.824	0.927	0.982	
0.820	0.808	0.916	0.977	0.998
0.830	0.790	0.905	0.971	0.997
0.840	0.772	0.891	0.963	0.994
0.850	0.752	0.877	0.955	0.990
0.855	0.742	0.869	0.950	0.988
0.860	0.731	0.861	0.945	0.985
0.865	0.720	0.853	0.940	0.983
0.870	0.709	0.844	0.934	0.980
0.875	0.697	0.835	0.928	0.976
0.880	0.685	0.825	0.921	0.973
0.885	0.673	0.815	0.914	0.969
0.890	0.660	0.805	0.907	0.964
0.895	0.646	0.793	0.899	0.959
0.900	0.632	0.782	0.891	0.954
0.905	0.618	0.770	0.882	0.948
0.910	0.603	0.757	0.872	0.942
0.915	0.587	0.743	0.862	0.935
0.920	0.571	0.729	0.851	0.927
0.925	0.554	0.713	0.839	0.919

3.0 Foot Flume				
S	4in Qs/Qf	8in Qs/Qf	12in Qs/Qf	16in Qs/Qf
0.610	0.998			
0.620	0.996			
0.630	0.994			
0.640	0.992			
0.650	0.989			
0.660	0.986			
0.670	0.982			
0.680	0.978			
0.690	0.973	0.999		
0.700	0.967	0.998		
0.710	0.961	0.997		
0.720	0.955	0.995		
0.730	0.948	0.992		
0.740	0.940	0.989		
0.750	0.931	0.986		
0.760	0.922	0.981		
0.770	0.912	0.976	0.999	
0.780	0.902	0.971	0.998	
0.790	0.890	0.964	0.996	
0.800	0.878	0.957	0.994	
0.810	0.865	0.949	0.991	
0.820	0.851	0.940	0.987	
0.830	0.835	0.931	0.982	0.999
0.840	0.819	0.920	0.977	0.998
0.850	0.802	0.908	0.970	0.996
0.855	0.793	0.901	0.966	0.994
0.860	0.783	0.894	0.963	0.993
0.865	0.773	0.887	0.958	0.991
0.870	0.763	0.880	0.954	0.989
0.875	0.752	0.872	0.949	0.986
0.880	0.741	0.863	0.943	0.984
0.885	0.730	0.855	0.938	0.981
0.890	0.718	0.845	0.932	0.977
0.895	0.706	0.836	0.925	0.973
0.900	0.693	0.825	0.918	0.969
0.905	0.679	0.814	0.911	0.965
0.910	0.665	0.803	0.902	0.960
0.915	0.651	0.791	0.894	0.954
0.920	0.635	0.778	0.884	0.948
0.925	0.619	0.764	0.874	0.941

4.5 Foot Flume				
S	6in Qs/Qf	12in Qs/Qf	18in Qs/Qf	24in Qs/Qf
0.610				
0.620				
0.630				
0.640	0.999			
0.650	0.997			
0.660	0.996			
0.670	0.994			
0.680	0.991			
0.690	0.988			
0.700	0.984			
0.710	0.980			
0.720	0.976			
0.730	0.970	0.999		
0.740	0.965	0.998		
0.750	0.958	0.996		
0.760	0.951	0.993		
0.770	0.944	0.991		
0.780	0.935	0.987		
0.790	0.926	0.983		
0.800	0.916	0.978		
0.810	0.905	0.973	0.999	
0.820	0.894	0.966	0.997	
0.830	0.881	0.959	0.995	
0.840	0.868	0.951	0.992	
0.850	0.853	0.942	0.988	
0.855	0.845	0.937	0.986	
0.860	0.837	0.931	0.983	
0.865	0.828	0.926	0.980	0.999
0.870	0.819	0.920	0.977	0.998
0.875	0.810	0.913	0.974	0.997
0.880	0.800	0.907	0.970	0.996
0.885	0.790	0.900	0.966	0.995
0.890	0.780	0.892	0.962	0.993
0.895	0.768	0.884	0.957	0.991
0.900	0.757	0.876	0.952	0.989
0.905	0.745	0.867	0.947	0.986
0.910	0.732	0.857	0.941	0.983
0.915	0.719	0.847	0.934	0.980
0.920	0.705	0.836	0.927	0.976
0.925	0.690	0.824	0.919	0.972

Source: Federal Water Management Cell, 1996