BUREAU OF WATER SUPPLY AND WASTEWATER MANAGEMENT

Wastewater Treatment Plant Operator Training

Module 26: Advanced Flowmeters

Topical Outline

Unit 1 – Introduction

I. Introduction
   - A. Definitions

II. Why Use Flowmeters?
   - A. Regulatory Requirements
   - B. Process Control

III. Data Output
   - A. Instantaneous Flowmeters
   - B. Continuous Recording
   - C. Supervisory Control and Data Acquisition (SCADA)
   - D. Variable Rate Data Storage

IV. Flow Hydraulics
   - A. Types of Conditions
   - B. Q = AV
   - C. Manning Equation

Unit 2 – Flowmeter Technologies

I. Open Channel
   - A. Accuracy
   - B. Primary Hydraulic Control Element
   - C. Measuring Devices

II. Closed Pipe
   - A. Flow Measuring Components
   - B. Measuring Devices
   - C. Installation Considerations

Unit 3 – Calibration

I. Introduction

II. Site Conditions
   A. Open Channel
   B. Closed Pipe

III. Location of Sensor
   A. Open Pipe or Channel
   B. Closed Pipe

IV. Calibration Options
   A. Open Channels
   B. Closed Pipes
   C. Measured Volume
   D. Calculated Volume
   E. Air Lift

V. Sensor and Transmitter Verification
   A. 4-20 Milliamp Signal

VI. Accuracy Limits
   A. Weirs
   B. Flumes

Unit 1 – Introduction

Learning Objectives

- Explain why flow is measured.
- List two types of data output.
- Calculate flow when given area and velocity.

This advanced course builds on the basic flowmeter concepts covered in the "Introduction to Flowmeters" course. This course moves beyond the topics needed to understand flowmetering in collection systems and small wastewater treatment plants (WWTP) to cover the concepts needed for complex flowmetering applications and larger facilities.

Definitions

Area is a measure of the surface of a specific two dimensional object. Although the object may be a square, rectangle, or circle, the units are expressed in square units, such as square inches (sq. in.) or square feet (sq. ft.).

Flow is a measure of fluid passing a given point over a given time period. Flow is determined by multiplying area times velocity. This may be expressed as cubic feet per second (cfs), gallons per minute (gpm), millions of gallons per day (MGD), cubic meters per second (m^3/s), etc.

Flowmetering is the task of measuring a quantifiable volume over a defined time, such as million gallons per day, gallons per minute, liters per minute, or cubic meters per day.

Infiltration is the extraneous flow entering the wastewater collection system caused by the percolation of rain water and short-term rise of the groundwater table during and shortly after a storm event. This extraneous flow enters through such sources as defects in manholes, mainline, and lateral sewers.

Inflow is the extraneous flow entering the wastewater collection system during or immediately after a storm event through sources which are directly connected to the system, including, but not limited to, roof leaders/downspouts; basement, yard, and area drains; drains from springs and swampy areas; manhole covers; and cross connections from storm sewers and catch basins.

Surcharging is when the level of water in a sewer is higher than the top of the pipe.

Velocity is the distance traversed (length) by a body divided by the time it took to travel the distance. Therefore, a fluid moving 10 feet in 10 seconds has a velocity of 1 foot per second (fps).

One of two factors dictates flowmetering:

- Regulatory requirements.
- Process control.

If a regulation requires flowmetering, there is no option but to comply. If flowmetering will establish a more stable treatment process, then flowmeters may be installed for process control even though they are not required by a regulation.

Regulatory Requirements

Section 64.8 of the Domestic Wastewater Facilities Manual-10/97

- Devices should be installed in all plants to indicate flow rates of raw wastewater or primary effluent, return sludge, and air to each tank unit.
- Section 64.8 discusses raw wastewater and not WWTP effluent. There are factors which can create differences between raw wastewater and WWTP effluent flows so the regulations are not interchangeable.
- Plants designed for flows of 100,000 gallons per day (gpd) or more should totalize and record flow.

National Pollutant Discharge Elimination System (NPDES) Permit

- The NPDES Permit requires flow-paced composite sampling of Wastewater Treatment Plant (WWTP) effluent.
    - Part A of most NPDES Permits contains the following verbiage under “Composite Sample:” *The composite must be flow-proportional; either the volume of each individual sample is proportional to discharge flow rates, or the sampling interval is proportional to the flow rates over the time period used to produce the composite.*
    - There are two methods to conduct flow-paced composite sampling:
        - A flow-paced sampler requires an electronic interface between the flowmeter, usually on raw wastewater, and the raw wastewater sampler. Such samplers will have this as an option in addition to a time-based composite.
        - Using a discreet sampler with a strip chart. This technique is used to acquire a flow-paced composite sample. The following figure shows the multi bottle holder which is a required component.

Figure 1.1 – Discreet Sampler Multi Bottle Holder[1]

PADEP Chapter 94 Requirements

- Section 94.12. Annual report.

  The report shall include the following:

  (5) A discussion of sewer system monitoring, maintenance, repair and rehabilitation, including routine and special activities, personnel and equipment used, sampling frequency, quality assurance, data analyses, infiltration/inflow monitoring, and, where applicable, maintenance and control of combined sewer regulators during the past year.

  (7) A discussion of the condition of sewage pumping stations, including a comparison of the maximum pumping rate with present maximum flows and the projected 2-year maximum flows for each station.

- Section 94.13. Measuring, indicating, and recording devices.

  Flow measuring, indicating, and recording equipment shall be calibrated **annually**.

- See Appendix A: PADEP Chapter 94 – Municipal Wasteload Management.

Capacity, Management, Operation, and Maintenance (CMOM) Analysis

- Four major documentation requirements of CMOM.
  1. A written summary of the CMOM Program.
  2. An Overflow Emergency Response Plan.
  3. A Program Audit Report.
     - Review of pertinent records and information management systems would include the capacities of pumps and collection systems, as well as flowmeter readings.
  4. A System Evaluation and Capacity Assurance Plan.
     - Collecting and analyzing appropriate information on the management and performance of a wastewater collection system.
     - Development of management performance objectives and goals of the collection system.
     - Clarification of management and performance objectives, developing and evaluating alternatives, and selecting measures.
     - Implementation of measures.
     - Continued monitoring, assessment, and adjustment of implemented measures.
       - A system evaluation could include a flowmetering study to determine and document flow patterns. Typically, diurnal flow patterns will show lower flows during late night hours, usually from midnight until 5:00 AM. If flow is high during this time, from a rainstorm as an example, this is an indication there is I/I. Your response should be to document the affects of precipitation and include that section of the sewer line on a more extensive investigation program.
       - Metering of flow is the basic way to quantify and prioritize system problems. Therefore, after you develop objectives and select measures to address problems, you must come back and determine their impact. If the flows are not reduced, you will need to adjust the measures used to correct the problem.
- See Appendix B: Water Environment Federation CMOM Summary.

Potential Requirements

- PADEP requires a Corrective Action Plan (CAP) be performed if a municipality is experiencing problems such as sanitary sewer overflows (SSO).
  - If a municipality has problems such as sanitary sewer overflows (SSO), it is common for PADEP to require a CAP be performed. One of the items, which may be included in a CAP, is the identification of flows throughout the system. This generally involves the defining of drainage areas and determination of flows in each area.
  - A municipality conducting Infiltration/Inflow (I/I) work must know several parameters for their system.
    - The base flow is attributed only to the domestic flow.
    - A maximum flow rate in a system will be composed of the peak domestic flow and the effects of I/I.

Process Control

With proper flowmetering, it is possible to operate a more stable treatment process. Benefits include:

- The ability to adjust process equipment or ensure that adequate pumping capacity is available.
- The ability to control downstream chemical feed systems.
- The ability to determine when you are reaching the capacity of a system (sewer line, pumping station, or treatment unit).

Billing

- Potable water use is normally measured and billed—wastewater (WW) flows are not normally measured individually and billed.
- Use of potable water flows does not account for I/I.
    - Under ideal circumstances, potable water flows should relate directly to wastewater flows. However, with older pipe materials such as terra-cotta or orange-burg, which are more prone to leaks, the volume of I/I increases.
- A wastewater flowmeter makes sense for larger communities that discharge to other municipalities.
- Billing should be related to flows, not an outdated method such as "number of fixtures."

Intermunicipal Connections

- Maintenance of different collection systems by different bodies will result in:
  - Different levels of maintenance and repair.
  - Different usage and I/I components.
- Municipal Wasteload Management (Chapter 94) reports required by PADEP on March 31 of each year contain tables that show the number of proposed new connections to a wastewater collection system.
  - All municipalities are required to provide annual records and projected connection data.

Example from Two Municipal Connections

The following examples illustrate why flowmetering of collection systems is beneficial.

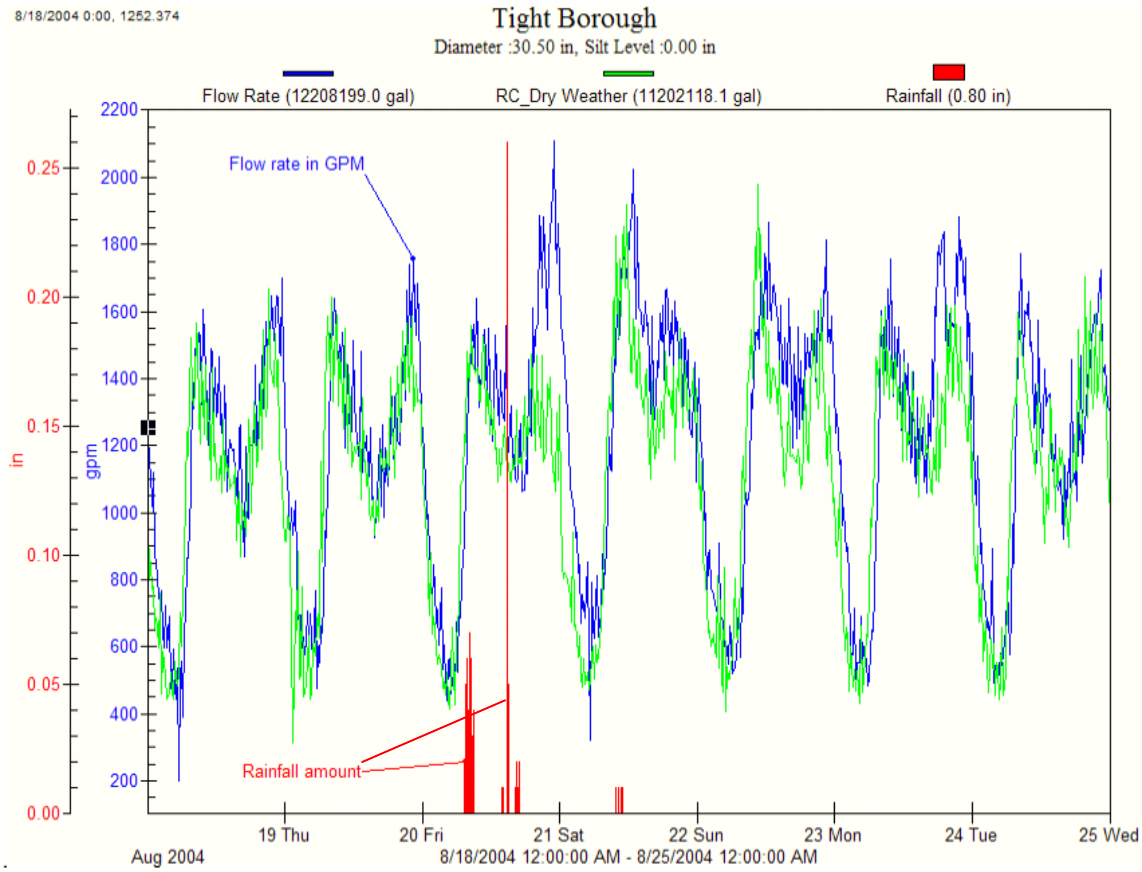


Figure 1.2 – Sample Flow Rates and Rainfall Amounts[2]

Exercise/Activity

1. What is the normal flow for midday, which is about half way between each date stamp?

2. There were 2 rain events when the intensity went above 0.06 inch. What was the affect to the flows?

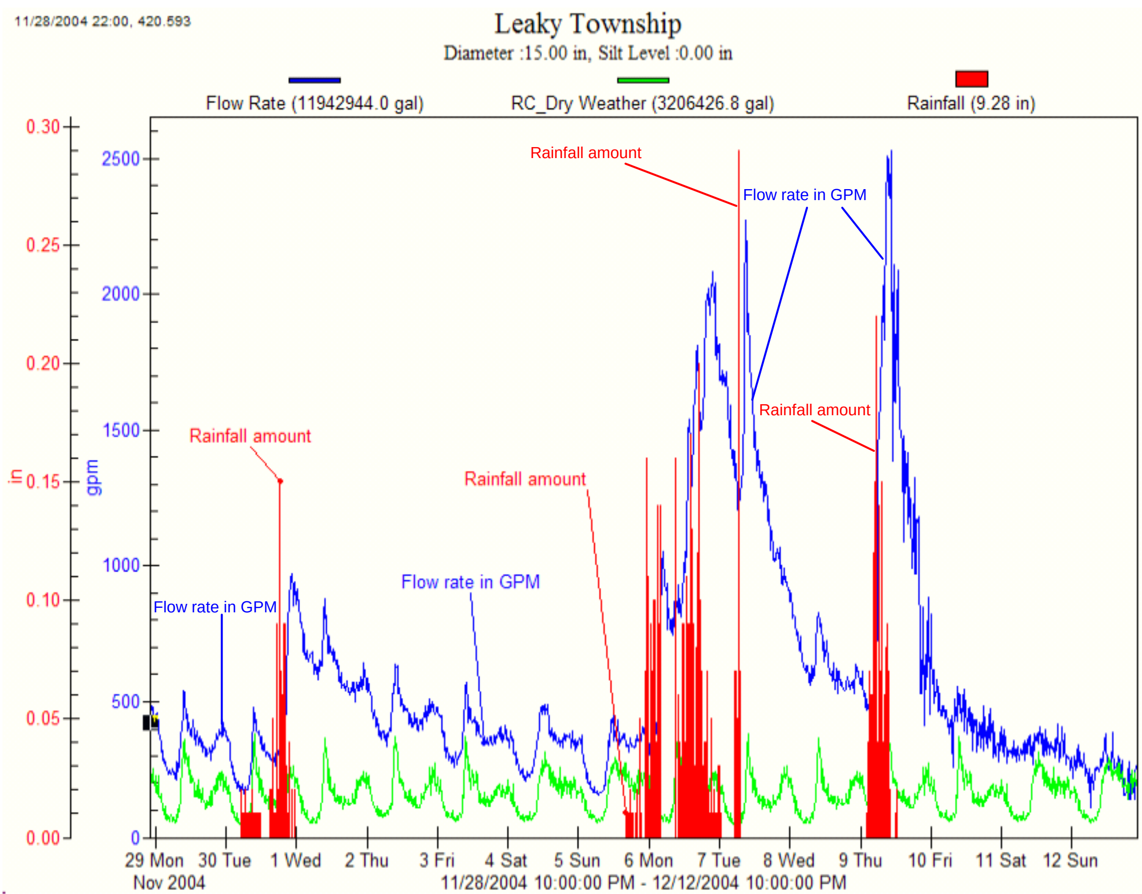


Figure 1.3 – Sample Flow Rates and Rainfall Amounts[3]

☑ Exercise/Activity

1. What is the normal flow for midday (look at the first two days)?

2. What happens during rain events?

Instantaneous Flowmeters

- Can be used for control of flow-paced equipment. However, a volumetric weir such as the picture below would not be used for flow-pacing equipment.
- The portable handheld unit pictured below could be used to evaluate potential flow rates so that a properly sized flow-paced chemical feed system could be installed.
- The permanent mounted flowmeter pictured below shows an instantaneous flowmeter which allows for verification that a feed rate is properly sized. Additionally, the instantaneous readout allows an operator to check the chemical feed system to make sure it is operating at the same time.

Figure 1.4 - Volumetric weir[4]

Figure 1.5 - Portable handheld unit[5]

Figure 1.6 - Permanent mounted flowmeter

Continuous Recording

- Continuous measurement is necessary for flow-paced equipment.
  - A continuous readout is more effective than an instantaneous readout.
  - A continuous readout may be in the form of a strip chart, a circular chart, or an electronic file that can be downloaded to a computer.

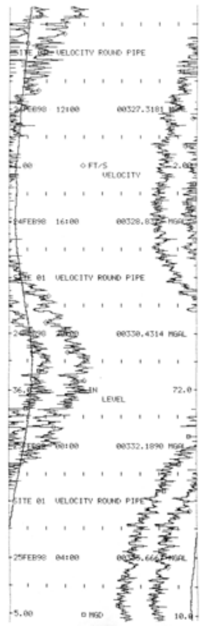


Figure 1.7 - Strip chart

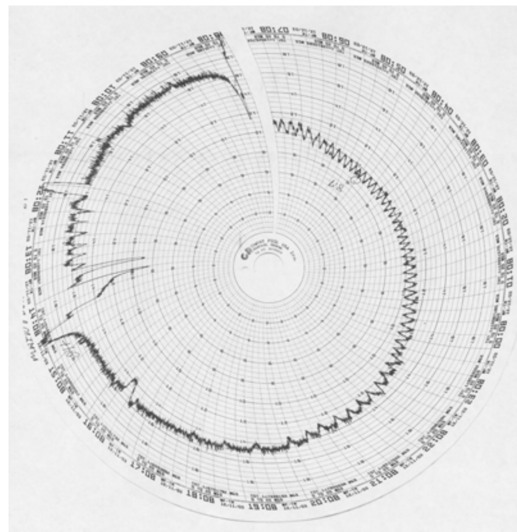


Figure 1.8 - Circular chart

Supervisory Control and Data Acquisition (SCADA)

- A SCADA system does more than just record data. It may monitor data and control various pieces of equipment.
- It generally includes instantaneous and continuous data.
- It can be used for off-site control.
- SCADA normally uses instantaneous flows to control other process equipment in a real-time mode.

Variable Rate Data Storage

- The following diagram is an example of how some flowmeters can be programmed to automatically increase data recording.
- Hash marks show an hourly increment, with a flow reading occurring every 15 minutes.
- A "wake-up" feature was programmed so that when the depth of flow in the pipe increased to about 6 inches, the flowmeter would automatically increase the data recording to about a 1 minute interval. This allows for an accurate evaluation of the flows at their higher rate which may be of a concern. Additionally, it maximizes battery life by only recording additional data at higher flows.

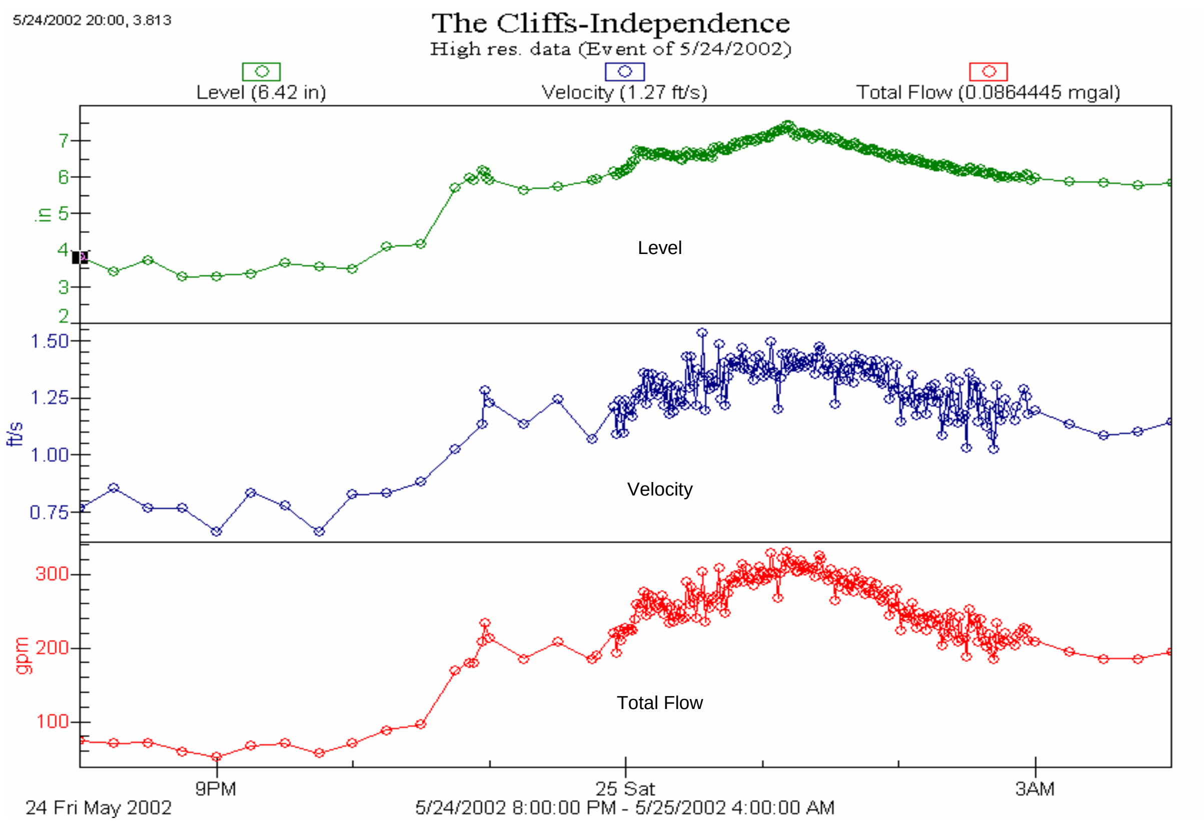


Figure 1.9 – Variable Rate Data[6]

Types of Conditions

- Open Channels/Pipes
  - A channel with the water surface visible.
  - A horizontal pipe if there is a free air space above the liquid. (You can not have an open channel condition if the pipe is vertically inclined.)
  - Any gravity sewer line should be designed as an open channel; otherwise, it implies you are surcharging the pipe.
- Closed Pipes (flowing full)
  - If you have any meter on a force main, it will be considered a closed and full pipe.
  - Closed pipe metering is very common in the following areas in a WWTP:
    - Primary sludge flow.
    - Return activated sludge.
    - Waste sludge.

Q = AV

Q = AV
▶ Q = the volume through a system
▶ A = the area of the system
▶ V = the velocity in the system

- The most fundamental equation to understanding flow in a system—pipe or open channel.
- All units in the equation must be the same.

- Example:

  If the area of a system is 1.5 square feet and the velocity is 2.3 feet per second, what is the volume?

  Q = AV
  Q = 1.5 sq ft x 2.3 fps
  Q = 3.45 cubic feet per second (cfs)

  How much would this be in gallons per second?

  Q = 3.45 cfs x 7.48 gallons per cubic feet
  Q = 25.8 gallons per second.

Calculation

1. If you have an 8 inch diameter pipe and the velocity is 2.5 fps, what is the flow rate? (Hint: $A = \pi r^2$)

2. Given a flow rate of 0.87 cfs conveyed in a 12 inch diameter sewer line, what would be the velocity? (Hint: $A = \pi r^2$). If this is a sewer line, would settling of solids be a concern?

Manning Equation

- The manning equation uses four factors of the coefficient of friction (known as the Manning factor, depth of the water, slope, and shape of the channel) to determine the velocity of water.
- Only used for gravity systems and open channel flow.
- Commonly used equation when other flowmeter devices are not installed.

$$V = \frac{1.486\ R^{2/3}\ S^{1/2}}{n}$$

- V = Velocity
- R = Hydraulic radius, area of water divided by wetted perimeter
- S = Slope of the water
- n = Manning’s factor (from a table)

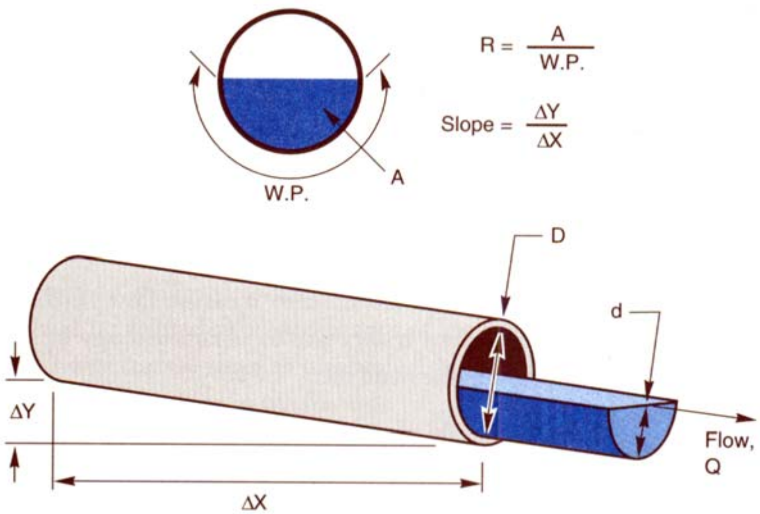


Figure 1.10 – Wetted perimeter in a pipe[7]

Calculation

1. Find the hydraulic radius of a 12 inch diameter pipe if the depth is 9 inches. Use the "Wetted perimeter in a pipe" figure above and Table 6.2 in Appendix C.

2. What is the velocity if the wetted perimeter is 0.3017 ft, the slope is 0.007, and the pipe is a 12 inch diameter sanitary sewer line with a normal amount of internal slime, showing a Manning factor of 0.013?

3. Determine the volume conveyed by the typical sewer line depicted in Problem 2 by using Q=AV and ISCO Table 6.2 in Appendix C.

[1] Courtesy of Isco, Inc.

[2] Courtesy of American Sigma.

[3] Courtesy of American Sigma.

[4] USABlueBook. 6" Volumetric Weir. Retrieved on January 28,2005, from https://usabluebook-onramp.com/cgi-bin/onramp.exe?pgm=itemdet.bbx&id=26411&custnum=&password=.

[5] USABlueBook. Portable Handheld Ultrasonic Flowmeter. Retrieved January 28, 2005, from https://usabluebook-onramp.com/cgi-bin/onramp.exe?pgm=itemdet.bbx&id=71110&custnum=&password=.

[6] Courtesy of Isco, Inc.

[7] Douglas M. Grant and Brian D. Dawson, *ISCO Open Channel Flow Measurement Handbook,* Fifth Edition, (P.O. Box 82531, Lincoln, NE 68501-2531, 2001), p. 131.

Unit 2 – Flowmeter Technologies

Learning Objectives

- Identify two open channel flowmeter components.
- List three primary open channel hydraulic control elements.
- Name four types of open channel measuring devices.
- List three types of closed pipe flowmeters.
- Describe three installation considerations for closed pipe meters.

An open channel implies free air space above a gravity conveyed liquid. Thus, an open channel may be a visible channel, or it may be a closed pipe that is not flowing full.

An open channel flowmeter has two primary components:

- Primary hydraulic control element.
- Measuring device.

Accuracy

Flowmeter instrumentation is normally expressed as plus or minus (±) a certain percentage of actual flow rate.

- The flowmeter reading may be within 2% - 4% of the actual flow, or it may vary from 4% - 8% of the actual flow. It depends on the hydraulic control conditions and the type of meter selected.
  - As the range between the minimum and maximum flow rates increases, the accuracy of the flowmetering decreases.
  - As the presence of suspended solids or debris increases, some meters become less accurate. For example, a V-notch weir does not handle solids or debris well.
  - Even if all variables are controlled, hydraulic limitations prevent an absolute 100% accurate value.

The overall accuracy of a flowmeter cannot be more accurate than the least accurate element.

- For example, if a weir is constructed poorly and its construction is off the proper design by 10%, you cannot get flowmeter readings any more accurate than plus/minus 10%—even if you install a level sensor that is accurate to within 1%.

Table 2.1 – Characteristics of Flowmetering Devices Used in WWTPs[1]

Metering device	Range[b]	Accuracy,[b] percent of actual rate	Repeatability[b] percent of full scale	Straight upstream run in pipe diameters
For open channels				
Head/area				
Flume	10:1–75:1[c]	±5–10[d]	±0.5	
Weir	500:1	±5	±0.5[g]	
Other				
Magnetic (insert type)	10:1	±1–2[e]	±0.5	
Velocity-head				
For closed conduits				
Head/pressure				
Flow tube	4:1	±.3	±0.5	4–10[f]
Orifice	4:1	±1	±1	±5[g]
Pitot tube	3:1	±3	±1[g]	10[g]
Rotameter	10:1	0.5–10	1[g]	5[g]
Venturi meter	4:1	±1	±0.5	4–10[f]
Moving fluid effects				
Magnetic (tube type)	10:1	±1–2[e]	±0.5	5
Magnetic (insert type)	10:1	±1–2[e]	±0.5	5
Target	10:1	±5	1[f]	20
Ultrasonic (Doppler)	10:1	±3	±1	7–10
Ultrasonic (transmission)	10:1	±2	±1	7–10
Vortex shedding	15:1	±1	±0.5	10
Positive displacement				
Propeller	10:1	±2	±0.5	5
Turbine	10:1	±0.25	±0.05	10[h]

[a] Based on industry practice and engineering judgement.

[b] Based on both the primary element and primary conversion device.

[c] Depends on the type of flume.

[d] Parshall flumes ±5%, Palmer-Bowlus flume ±10%.

[e] Of full scale.

[f] Depends on the type of flow-disturbing obstruction.

[g] Estimated.

[h] Assuming that flow straightening is used (25 to 30 pipe diameters, otherwise).

- To select a flowmeter, sizing must be considered. The calculation below provides an example.
  - Appendix D illustrates some of the typical considerations related to the selection of flowmeters.

- Example:

  Let's estimate the flow we should be considering for the selection of a flowmeter. Consider a motel (with kitchen) with 140 rooms and an average of 2 people per room. The first step is to estimate the number of people, which is 280. Use the Average Flow Chart in Appendix D to find the answer.

  Ans: From Appendix D we see an average flow of 60 gpdc. Multiplying 280 by 60 yields 16,800 gpd as the average flow. However, you must have the unit sized for the maximum flow rate. We will use a 4:1 peaking factor. Therefore the average flow of 16,800 gpd may have a peak flow rate of 67,200 gpd rate.

Primary Hydraulic Control Element

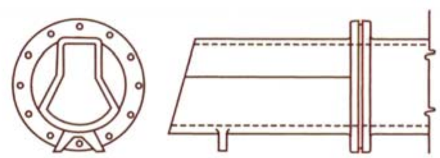
- This is the part of the pipe or flume which controls the hydraulic conditions.
- It may generate a Reynolds number of a magnitude that defines the transition from supercritical flow to subcritical flow.
- There are several types of primary hydraulic control elements (PHCE). Certain ones are used when suspended solids may be of concern.
- The anticipated variability of flow ranges will influence the selection of a PHCE.
- The importance of measuring the flow at the low range, mid range, or highest range will also influence the selection of the PHCE.
- Maintenance requirements of a PCHE can be important in the selection of a PHCE. As an example, if a nozzle is installed properly on a raw wastewater pipe there may be virtually no maintenance on the PHCE.
- Common types of PHCEs are weirs, flumes, and nozzles.

Nozzles

A **Nozzle** is a flow control device that is normally bolted to the end of a pipe. It always requires freefall of at least a foot.

There are various types of nozzles used in open channels. They include Kennison and parabolic nozzles.

Kennison



A. Kennison nozzle (Q proportional to H)

Figure 2.1 – Kennison Nozzle[2]

- Attached to the end of a pipe.
- This primary hydraulic control element has several advantages. One advantage is that it provides accuracy throughout a range of flows, including very low flows.
- Requires a noticeable free fall to avoid any obstruction of flow out of the nozzle.

Parabolic

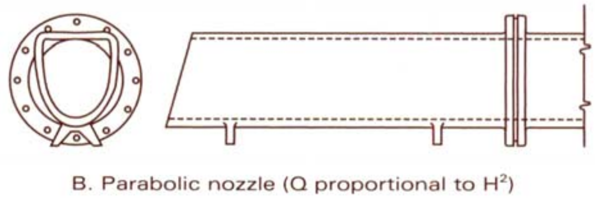


Figure 2.2 – Parabolic Nozzle[3]

- Attached to the end of a pipe.

- As the flow increases, the depth of the flow becomes proportionally less. Provides good measurement at low flows but allows for a wide range of flows.

- Requires a noticeable free fall to avoid any obstruction of flow out of the nozzle.

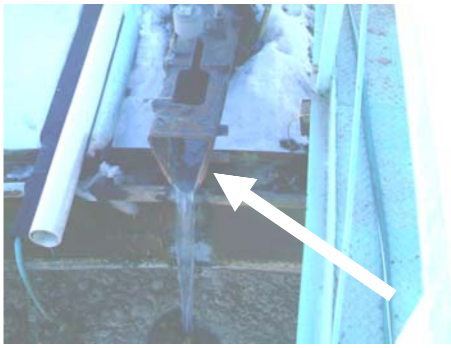


Figure 2.3 – Parabolic nozzle

☑ Exercise/Activity

Compare the maximum flow capacity of a 10 inch Kennison versus a 10 inch Parabolic Nozzle. Look at Appendix C - ISCO Tables 3-8 and 3-9.

Weir

A **Weir** is a controlled obstruction that is usually a sharp-crested, thin plate. Wastewater cascades over the top of the weir and air is present under the nappe.

Sharp-Crested

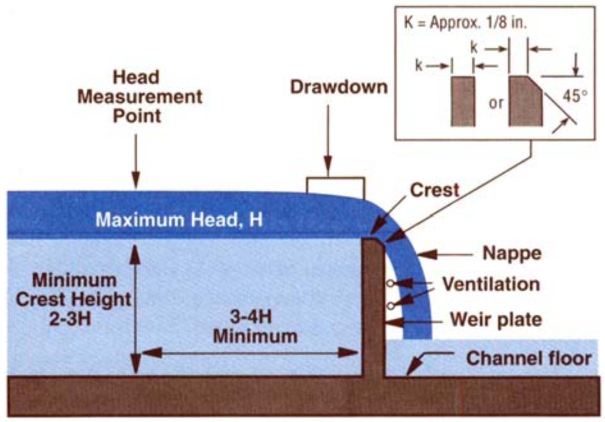


Figure 2.4 – Sharp-Crested Weir[4]

- It cannot be used where solids may collect upstream of the weir.
- Sharp-crested is important. A thick board or piece of rusted steel is **not** acceptable. These will not allow for the proper hydraulic conditions that allow for the accurate determination of flow.
- It must have a nappe.
- A broadcrested weir is almost never found in WWTPs.

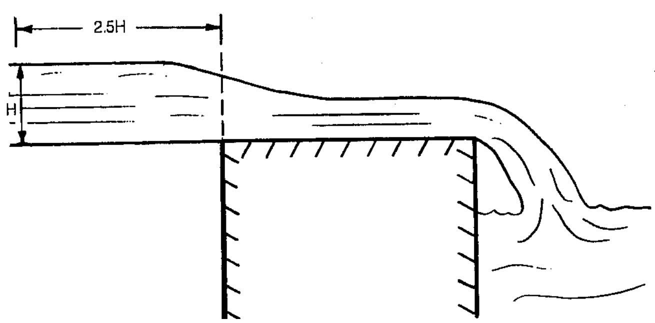


Figure 2.5 – Broad-Crested Weir[5]

V-Notch Weir

- A V-notch weir is used to concentrate flow through a small opening so that a change in the depth of flow is easier to measure.

- Choosing a V-notch requires a compromise between the amount of flow through the V-notch versus the amount of change in flow depth.

☑ Exercise/Activity

A well-operated WWTP has an effluent flow that ranges from 10 gpm to 1,500 gpm. We do not anticipate an unacceptable amount of solids because the weir will be installed as a WWTP effluent flowmeter. What are the possible weir options? Use Appendix C - ISCO Table 5-3A.

Rectangular Weir

- The measuring point is specified and is not at the weir crest. The sharp-crested weir diagram at the bottom of the page shows the head measurement point.

- A disadvantage of a rectangular, sharp-crested weir without end contractions is that since the channel walls affect the flow over the weir, the condition of the wall may alter the flow.

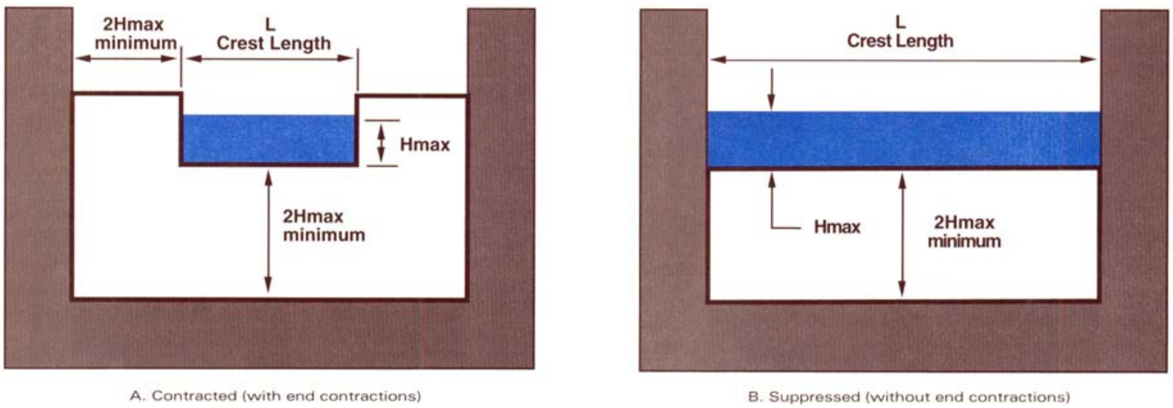


Figure 2.6 – Rectangular Sharp-Crested Weirs With and Without End Contractions[6]

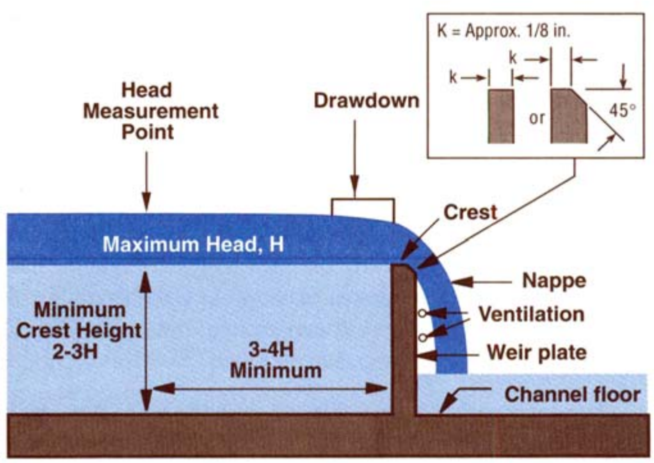


Figure 2.7 – Sharp-Crested Weir[7]

☑ Exercise/Activity

If we have a 2 ft rectangular weir without end contractions and the depth is 0.33 feet, what is the flow? Use Appendix C - ISCO Table 11-3. Using Table 5-3, what is the flow range for this PHCE?

Cipolletti Weir

- This weir is similar to a rectangular weir but has an opening with sloped sides.
- It allows a greater flow range than a rectangular weir.
- As the flow increases and the depth increases, the area of the opening becomes larger.

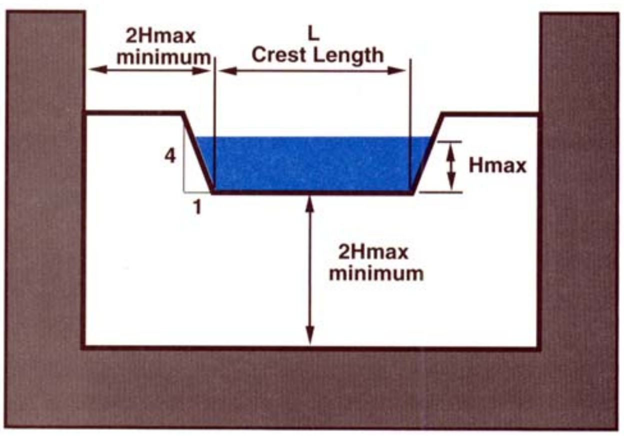


Figure 2.8 – Trapezoidal (Cipolletti) Sharp-Crested Weir[8]

☑ Exercise/Activity

If we have a 2 ft Cipolletti weir and the depth of flow is 0.33 feet, what is the flow? Use Appendix C - ISCO Table 12-3.

Flume

A **Flume** is a *specially shaped open channel* flow section that restricts the channel area and/or changes the channel slope, resulting in an increased velocity and a change in the level of the liquid flowing through the flume.

Parshall Flume

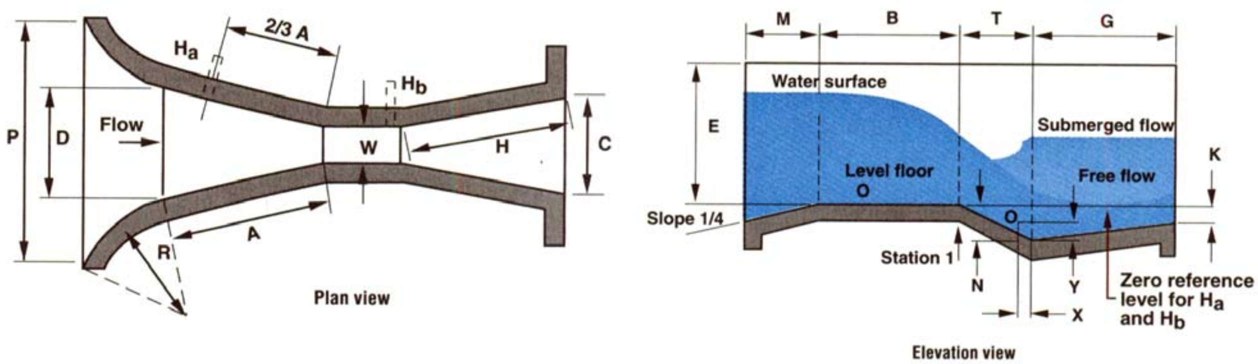


Figure 2.9 – Parshall Flume[9]

- Nomenclature

  Converging section is where wastewater is narrowing down in the channel ("A" in Plan view). The velocity of the wastewater is increasing in this area.

  Throat is where the parallel sides and narrow section of the flume are located ("W" in Plan view). This is the section that creates a hydraulic jump transition from the higher velocity to the slower velocity water.

  Diverging section is where the wastewater returns to the original shape of the channel ("H" in Plan view).

The **measuring point** is identified as "H_a" in the Plan view.

- Parshall flumes have very strict construction dimensions.

- Parshall flumes normally are pre-fabricated units for smaller installations.

- Clogging problems are possible if a small Parshall Flume (less than 3 inches) is used on domestic sanitary flow.

- To obtain the proper hydraulic conditions through the control element, the location of the measuring point is critical.

Figure 2.10 – Parshall Flume with Ultrasonic Sensor

- It is possible to have a nested Parshall flume set. This allows for use of a small flume when flow is low during the initial startup of a system. Then as flow increases, the inside flume is removed to allow for additional capacity.

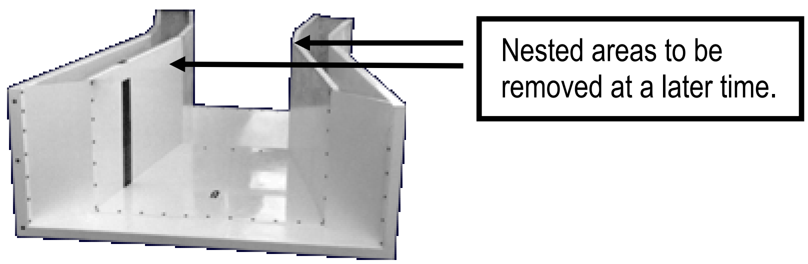


Figure 2.11 – Nested Parshall Flume[10]

- A metering manhole allows for the dual purpose of a manhole and metering. The cost for the primary hydraulic control element (flume) is generally a low additional cost.

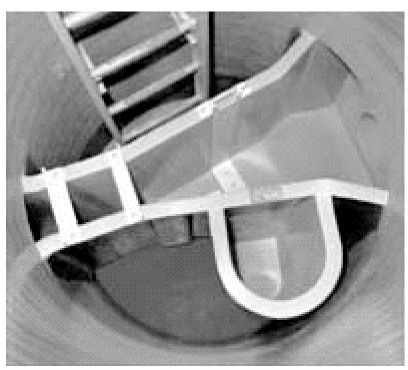


Figure 2.12 – Metering Manhole with Parshall Flume[11]

Exercise/Activity

1. For a 12 inch Parshall flume, where is the measuring point in relationship to the start of the throat? The throat is the size of the flume and is where the sides are parallel. Use Appendix C - ISCO Table 4.1A and the Parshall flume diagrams on the previous pages.

2. If we have a 6 inch Parshall flume and the depth of flow is measured to be 0.42 feet at the head, what is the flow rate in gallons per minute (gpm)? In million gallons per day (mgd)? Use Appendix C - ISCO Table 13-4.

Palmer-Bowlus Flume

- Excellent for measuring flows in sewer systems.
- Easily adapted to a wide variety of sewer diameters.
  - A separate unit is required for each sewer diameter.
  - Commonly used in the retro-fit of a manhole to create a metering manhole.
- The shape is similar to a round pipe but it has either a slightly narrowed channel wall or a slightly raised floor.
- The basic hydraulic principle is the same as that for a Parshall flume.
- Has a range of flow variations of about 10 to 1.

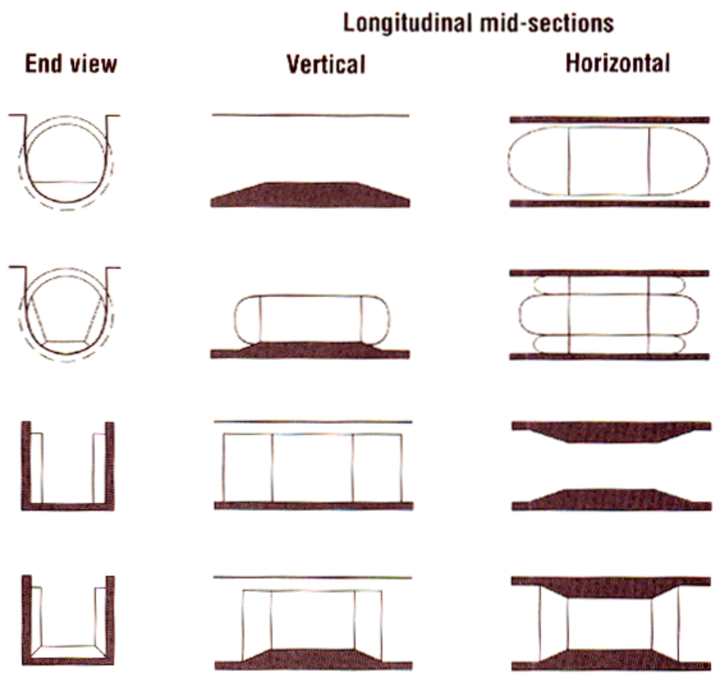


Figure 2.13 – Various Cross-Sectional Shapes of Palmer-Bowlus Flumes[12]

Discussion Question

Look at Appendix C - ISCO Table 14-3 for an 8 inch Palmer-Bowlus Flume and see that at a depth of 0.09 ft at the head, the minimum recorded flow is 13.7 gpm or 0.0198 mgd. If attempting to measure flow in a small residential development, what problems will occur? (Consider an average flow per household of 225 gpd in a development of 75 homes.)

Leopold-Lagco Flume

- This is a modification of a Palmer-Bowlus flume but it is not very common.
- There are other devices that provide better information and are more commonly available.

Trapezoidal Flume

- Very few clogging problems.
- Wide range of capability, especially accurate at low flows.

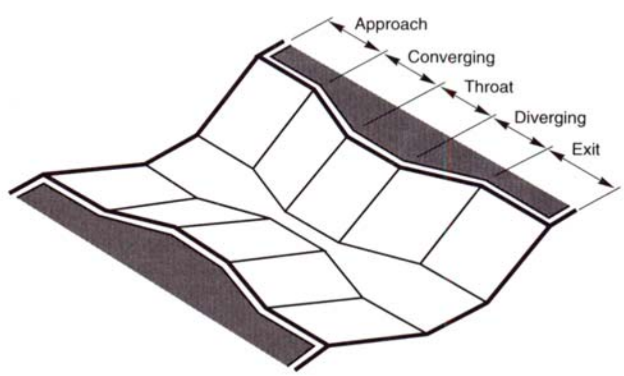


Figure 2.14 – Elements of a Trapezoidal Supercritical Flow Flume[13]

Discussion Question

Look at Appendix C - ISCO Tables 14-3 and 17-2. Compare an 8 inch Palmer-Bowlus with a depth of 0.10 feet to an extra large 60 degree V Trapezoidal Flume. What is the advantage of the Trapezoidal flume vs. a Palmer-Bowlus flume?

HS, H, and HI Flumes

- Infrequently used because they can have clogging problems that are not typical of other flumes.
- See Appendix C, ISCO Figures 4-11A, 4-11B, and 4-11C for additional information.

Figure 2.15 – Typical H-Flume Application[14]

Exercise/Activity

Select a flume that could be used for flows ranging from about 1 gpm up to 900 gpm. The type of material in the flow is normal fecal matter and paper most commonly present in domestic wastewater. Use Appendix C - ISCO Table 5-4.

Measuring Devices

- Measuring devices can be used to determine depth or velocity.

- The flow measurement must also account for how the measuring device influences the flow.

- Contact vs Non-contact types: A submerged area-velocity sensor is within the flow stream but an ultrasonic sensor is above the flow stream and never directly contacts the measured fluid.

- Semi-contact types: The use of a stilling well with a float system such as a Kennsion nozzle.

- A recording system will be associated with the measuring device if the measuring device is providing a continuous signal.

Depth

- Each PHCE has a specific measurement point where the depth must be determined. To obtain accurate readings, it is important to measure the depth of flow at that point.

- Depending on the depth measuring system, the sensor may be placed within the flow stream. However, some PHCEs, such as a Parshall flume, will not be accurate if the sensor interferes with the flow.

Bubbler System

- The typical air flow might be 1 cubic foot per hour.

- A small stream of air bubbles will come out of the bottom of the bubble tube.

- The bubbler system works on backpressure. As the depth of the water increases, it becomes harder to force air out of the bottom of the tube.

- The system requires a dry air supply to avoid condensation problems during the summer when the humidity is high or freezing problems during the winter when the temperatures are below freezing.

- It is rarely used in an exposed location such as an effluent flow meter, unless the tubing line is heat traced.

Ultrasonic

- Sends out an electronic beam that reflects off the water surface and back to a sensor. This checks the water level; it does not measure a change in velocity like a Doppler meter on a closed pipe.
- The beam angle must not be obstructed.
- Because the sensor never touches the water, it can be used where corrosion or damage from chemicals is a concern.

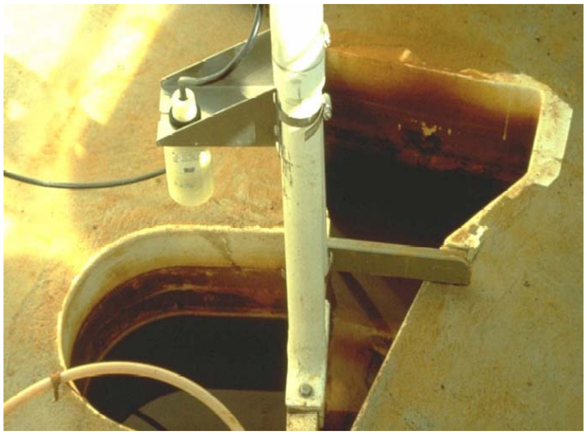


Figure 2.16 – Ultrasonic Sensor, Mounting Bracket, and Stilling Well[15]

- When flow determination is extremely critical, such as billing for wastewater services, redundant sensors can be used.
- In the following picture, a stainless steel band holds a sensor on the bottom of the channel and a sensor is also mounted on the expanding/threaded rod area.
- Generally used on larger sewer lines.

Figure 2.17 – Mount for Dual Redundant Sensors[16]

- A reflector plate may be used on an ultrasonic meter for two different reasons:
  - To keep the sensor above the water level and protect it if the manhole surcharges.
  - To keep the sensor operating properly if high humidity is a problem and moisture could condense on the sensor lens. This is a more common application.

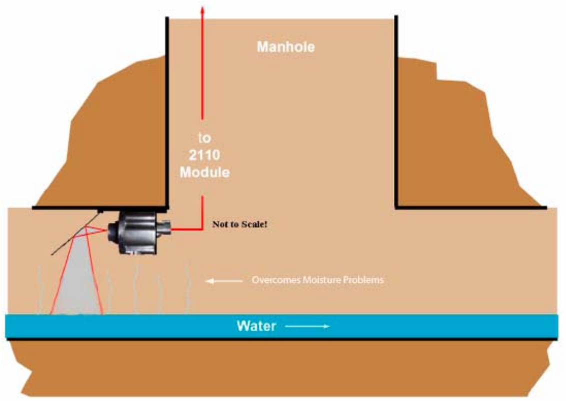


Figure 2.18 – Horizontal Reflector Plate Mount "In Pipe"[17]

Submerged Pressure Transducer

- The pressure exerted on the sensor by a column of water is converted to electrical potential.
- The electrical potential generated is proportional to the liquid level depth.
- Can be used in a stilling well or in a flume if they are manufactured with space for the transducer.
- The sensor may collect solids and need to be cleaned frequently.

Float

- It is highly desirable to keep the float out of the flow stream so that it does not collect rags or affect the flow pattern.
- In the picture below, the stilling well is on the right, with a small cross connection to the nozzle, which is on the left.

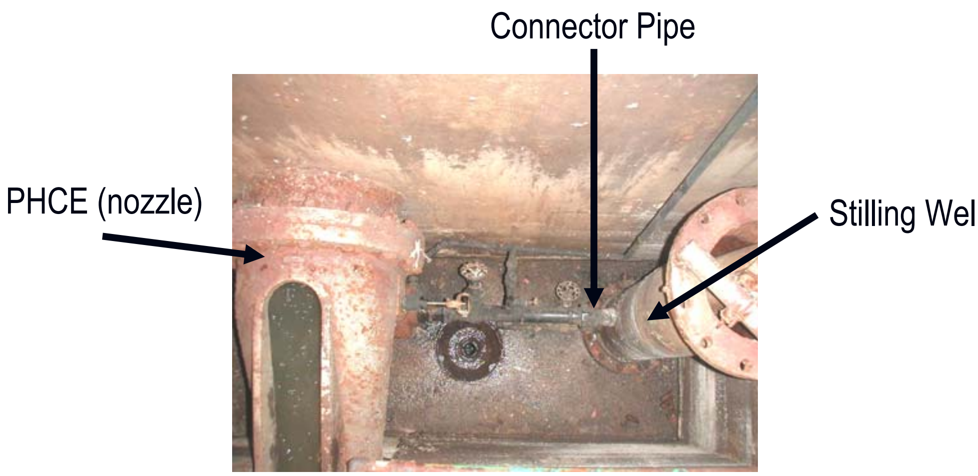


Figure 2.19 – Stilling Well

Portable Meter

- Portable meters are used for checking flows where a permanent meter does not exist.
- Recording and continuous types may consist of a "spring form" stainless steel band with a transducer in the bottom of the channel or an ultrasonic meter mounted above the flow.
- Instantaneous types are often inserted into a pipeline when performing spot-check flowmetering studies.

Figure 2.20 – Insert type weir with threaded rod[18]

Velocity

- In addition to measuring depth, some measuring devices are used to measure flow velocity in an open channel.

Doppler

- The Doppler principle used in an open channel is also used in a closed pipe. The Doppler effect of particles approaching and passing the sensor is used to calculate velocity.

- When a velocity meter is used in conjunction with a built-in sensor that can determine the depth of the flow passing over the sensor, the combined information provides area-velocity.

Area Velocity

- Because it can sense velocity and area, it may be able to detect reverse flow conditions in the pipe.

Figure 2.21 – Area Velocity Meter[19]

Flow Measuring Components

❶ Primary Hydraulic Control Element

- ▶ The pipe controls the hydraulic conditions.
- ▶ The pipe material affects the hydraulic conditions inside the pipe.

❷ Measuring Device

- ▶ Closed pipe flowmeters generally measure full pipe flows. However, some newer ultrasonic flowmeters can be used for partial pipe flows but with reduced accuracy.
  - Closed pipes offer less opportunity for an operator to directly verify a flowmeter reading.
  - A full pipe is generally under some pressure.
  - It is desirable to be able to flush clean water through the meter, especially if it is on a sludge line.
- ▶ There are several types of closed pipe flowmeters. They include:
  - Ultrasonic.
  - Magnetic.
  - Venturi.
  - Pitot.
  - Propeller.

Measuring Devices

Ultrasonic

- There must be a zero air space bond between the sensor and the pipe. Therefore, the thickness of the pipe may limit the use of an ultrasonic meter.
  - May only work on thin-walled pipes.
- Low cost.
- Uses acoustic waves or vibrations to detect fluid flow; therefore, there must be particles in the fluid.
- Requires a clamp-on mount.
- Ultrasonic flowmeters come in two general categories:
  - Transit-Time.
  - Doppler.

Figure 2.22 – Ultrasonic strap on meter

Doppler

- Doppler works at a frequency of 20 kHz or greater.
- Can be either a permanent installation or a portable unit.

Figure 2.23 – Hach Sigma 980 Flowmeter—Permanent Mount[20]

- A Doppler flowmeter works by sensing the Doppler effect from a particle in motion.
  - The transmitted frequency is altered linearly by being reflected from particles and bubbles in the fluid. The net result is a frequency shift between transmitter and receiver frequencies that can be directly related to the flow velocity.
  - Must have a minimum amount of suspended solids or entrained air bubbles in the process flow. Solids provide a better reflection than air bubbles.
  - Must have a sufficient velocity to work. Some manufacturers claim accuracy with velocities of less than 1 ft/sec, but it is better to have at least 3 ft/sec.
  - Some manufacturers use the term "reflective sonar." This type of meter works within an aquatic medium (sonar) and bounces reflective energy off particles approaching a sensor point.

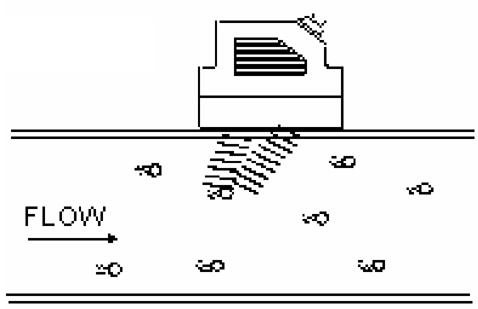


Figure 2.24 – Clamp-on Ultrasonic Doppler Sensor[21]

Transit-Time

- The measurement of flow is based on the principle that sound waves traveling in the direction of the fluid's flow require less time than when traveling in the opposite direction.
- The difference in transit times of the ultrasonic signals is an indication of the flow rate of the fluid.

Magnetic

Figure 2.25 – Magnetic meter

The **turn down ratio** of a magnetic flowmeter measures how wide a flow range the unit can detect.

- The turn down ratio of a magnetic flowmeter is very good. Ranges vary from 4:1 up to 10:1.
- Electromagnetic flowmeters operate on Faraday's law of electromagnetic induction that states that a voltage will be induced when a conductor moves through a magnetic field.
  - The liquid serves as the conductor; the magnetic field is created by energized coils outside the flow tube.
  - Voltage produced is directly proportional to the flow rate. Two electrodes mounted in the pipe wall detect the voltage, which is measured by the secondary element.
- Magnetic flowmeters can measure difficult and corrosive liquids and slurries. They can also measure forward and reverse flows with equal accuracy.

Venturi

- Useful for large volumes of clean water. Used for "clean" wastewater, such as dilution water at a thickener or make up water.
- Uses the Bernoulli effect and equation to calculate the pressure difference between obstructions in the flow through a pipe.
- Works by creating head loss through a piped system.

Figure 2.26 – Set of Four Venturi Flowmeters

Pitot

- Rarely used because it requires very clean water to function properly. More common with air flows.

Propeller

- Consists of a rotating impeller positioned in the flow stream.
- Fluid contacts the impeller causing it to spin.
- The impeller's rotational velocity is directly proportional to the velocity of the flow.
- A very accurate meter that cannot handle suspended solids in the water.
- More commonly used in potable water applications, including your home.

Installation Considerations

Because closed pipes are pressurized, there are more installation options available than there are for open channels which rely solely on gravity.

Vertical Orientation

- An example location is a pumping station force main.
- It is virtually impossible for sedimentation or air bounding problems to occur.
- The pipe may have a reduced diameter section to increase velocity.

Horizontal Orientation

- It is common for a section of the pipe to have a restricted cross section to increase velocity.
- Any loops which can entrap air should be avoided.

Separation Distances

- If valves are near the meter, it is best to have ‘full port’ valves.
- Separation distance is necessary to have proper flow through the meter.

  This means no valves, elbows, or tees near the meter.

- Depends on specific requirements for each meter, but typically requires straight pipe runs of 10 D upstream and 5 D downstream of the meter (D = diameter of pipe).

Calculation

If we have a pipe of 5 inch diameter, using the separation distance guidelines, what is the absolute minimum upstream and also downstream distance of straight pipe that is needed (excluding the width of the meter)?

Pipe Material

Metal

- Pipe should **not** be lined with non-uniform material.
- Pipe can be either ferrous material such as cast iron or ductile iron or it can be stainless steel.

PVC

- Wall thickness may allow use of clamp on meters.
- PVC pipe is constructed very uniformly. It generally does not include any liners or irregular materials.

[1] George Tchobanoglous and Franklin L. Burton, *Wastewater Engineering Treatment, Disposal, and Reuse*, Third Edition, Metcalf & Eddy, Inc., (New York, NY: McGraw-Hill, 1991) p. 199.

[2] Douglas M. Grant and Brian D. Dawson, *ISCO Open Channel Flow Measurement Handbook,* Fifth Edition, (P.O. Box 82531, Lincoln, NE 68501-2531, 2001), p. 53.

[3] Douglas M. Grant, p. 53.

[4] Douglas M. Grant, p. 27.

[5] *Design of Municipal Wastewater Treatment Plants*, Fourth Edition, (Alexandria, VA: ASCE and the Water Environment Federation, 1992), p. 5-15.

[6] Douglas M. Grant, p. 35.

[7] Douglas M. Grant, p. 27.

[8] Douglas M. Grant, p. 41.

[9] Douglas M. Grant, p. 67.

[10] Plasti-Fab. Nested Flume. Retrieved on January 28, 2005, from http://www.plasti-fab.com/flumes/parshall/parshall.html.

[11] Plasti-Fab. 48" Diameter Manhole with 6" Parshall Flume. Retrieved on January 28, 2005, from http://www.plasti-fab.com/manholes/manholes.html.

[12] Douglas M. Grant, page 77.

[13] Douglas M. Grant, page 97.

[14] Courtesy of Isco, Inc.

[15] Courtesy of Isco, Inc.

[16] Courtesy of Isco, Inc.

[17] Courtesy of Isco, Inc.

[18] USABlueBook. 6" Volumetric Weir. Retrieved on January 28,2005, from https://usabluebook-onramp.com/cgi-bin/onramp.exe?pgm=itemdet.bbx&id=26411&custnum=&password=.

[19] AmericanSigma.com. Sigma 910 Area Velocity Flowmeter. Retrieved on February 8,2005, from http://www.americansigma.com/products/910flowmeter.cfm.

[20] AmericanSigma.com. Hach Sigma 980 Flowmeter. Retrieved on March 29,2005, from http://www.americansigma.com/products/980meter.cfm.

[21] Courtesy of Isco, Inc.

Unit 3 – Calibration

Learning Objectives

- List three site conditions that can affect the calibration of a flowmeter on open channels or closed pipes.
- Describe how to identify the correct location for a sensor.
- Outline three calibration techniques.
- Explain how a sensor is verified.
- Calculate known volumes for comparison to meter readings.

- Calibration of a flowmeter ensures that it is providing accurate data. Having a flowmeter that is not calibrated can be worse than not having a flowmeter installed at all. Using incorrect data from a flowmeter can lead to:
    - Incorrect assumptions.
    - More expensive operations.
    - Inaccurate billings.
    - Personal injury.
- Calibration on process control meters should be done at least annually.
- Larger facilities should calibrate their meters at least annually, if not more often.
- Meters used to generate reports for regulatory agencies may be calibrated annually, if not more often, as a requirement.
- For open channels, the depth of flow at the correct location on a primary hydraulic control element can be used to verify a flowmeter by comparing the measurement with a look-up table.

Open Channel

- Clean the area before calibration.
    - Meters are dependent on known hydraulic conditions. Therefore, it is critical to have the site conditions comply with the intended design.
    - Walls should be cleaned of algae.
    - Fats/oils/greases (FOG) should not be accumulating in the pipe or flume.

Closed Pipe

- When calibrating the flowmeter on a closed pipe, it is important to verify that the meter can handle partial pipe flow, or, there must be full pipe flow.
    - Meters that can handle partial pipe flow are available, but not common. The meter will state if it can handle partial pipe flow.
- To ensure an accurate calibration, check for an uneven transition between the inlet and pipe at the meter.
    - Any non-uniform (uneven) transition can lead to inaccuracy.
- A flowmeter typically does not have a “wake up” period. If the meter is always turned on but the reading is zero, the response time of the meter will be less than a second.
    - After turning on the pump, allow a few seconds for the flow rate to reach normal flow.

Open Pipe or Channel

- There must be proper hydraulic conditions.
  - For example, if a flume is designed for a transition from super critical to subcritical flow, operating it in a submerged condition will not allow the meter to be calibrated.
- The measurement of depth must be taken perpendicular to the flow.
- The mounting bracket must be secure.
- The sensor should not be exposed to vibration.

☑ Exercise/Activity

Using Appendix C Table 4-1a, find the sensor location for the following Parshall Flumes:

1 foot wide =

2 foot wide =

Closed Pipe

- Each manufacturer will specify where and how the sensor is to be located.
- Some closed pipe sensors must be oriented in the proper direction.
- Sensors mounted in vertical pipes generally do not have orientation tabs.
- Connectors from the power unit to the sensor should not be painted.
- Do not run electrical cables for other equipment across the sensor.

Open Channels

- Vary the flow through the flowmeter and measure with a device that is more accurate than the flowmeter itself.
- Distribute a known volume of liquid through the channel.
- Have an electronic calibration procedure performed onsite by a qualified instrumentation company.
- Use a ruler to measure the depth of flow at the proper location.
- If you know the range of the flowmeter and then measure the depth of flow at the primary hydraulic control element, you can determine what the output should be.

Closed Pipes

- Vary the flow through the flowmeter and measure with a device that is more accurate than the flowmeter itself.
- Distribute a known volume of liquid through the pipe.
- Have an electronic calibration procedure performed onsite by a qualified instrumentation company.
- In extreme cases, remove the unit and send it to the factory for calibration.
- If you know the range of the flowmeter and then determine the velocity at the primary hydraulic control element, you can determine what the output should be.

Measured Volume

Pumping Station Wet Well Drawdown Test

- If the influent wastewater can be stopped, one method is to determine the volume of wastewater in the wet well and then time how fast a pump can pump it out.

Use of a Pump Station Monitor

- An internal logarithm is used along with pump output information to generate a graph showing pumped flow.
  - The internal programming of a pump station monitoring system uses known information about the actual size of the wet well and information gathered from monitoring the drawdown and refill rates occurring at the pumping station to generate the graph. The internal programming allows for continuous drawdown test data.
  - Some systems may not lend themselves to the use of a flowmeter.
- An alternative is to use a monitoring system, such as ISCO 4501, to generate daily and maximum flows conveyed by the pumping station.
  - This will also allow for cross-checking of the flowmeter.

Calculated Volume

Use of an Elapsed Time Meter and Calibrated Pump Curve to Calculate Daily Flow

- To use the calibrated pump curve, keep the pumps at design capacity by conducting proper preventive maintenance.
- Don't track the elapse time on an hour meter, use minutes instead if possible.
- Should have a simultaneous hour meter that tracks when both pumps are operating at the same time.

Calculation

Determine if a flowmeter needs calibration based on comparing the flowmeter totalizer reading with calculations from the elapsed time meters for a pump station and a calibrated flow curve.

- The pumping station has two pumps. Refer to the pump performance curve from Gorman-Rupp on model S8A in Appendix E. Each pump was tested to provide 1,800 gallons per minute at a total dynamic head of 116 feet.
- The elapsed time meter for pump No 1 is 135 minutes, pump No. 2 is 140 minutes, and the simultaneous elapsed time meter had no run time.
- The discharge pressure on the pumps is normally 50 psi.
- Compare this with the flowmeter reading of 49,500 gallons per day.
- The flowmeter was calibrated by a new company who was not sure if there is a multiplier factor for the meter.

Air Lift

- There are locations where flowmetering is not possible.

- This section provides information on evaluating an airlift, which may be used for air lift systems such as return activated sludge (RAS) at a wastewater treatment plant.

- You cannot insert a flowmeter into the air lift line because it would obstruct flow and adversely affect its conveyance capacity.

- The thickness or density of the liquid being conveyed has a noticeable influence on the flow rate.

1. Determine air flow to the air lift. Use of Figure F.1 in Appendix F enables verification of adequate volume of air through the lift. If the air flow is too low or too high, operational problems may develop (not discussed in this course).

2. Determine how deep the air injection point is in relation to the water surface. This is identified as Submergence “S” in Figure 3.1.

3. Determine how high the RAS flow is lifted from the water surface. This is identified as “H” in Figure 3.1. The two top illustrations with the short horizontal sections are configurations used for RAS and the bottom two illustrations are used for recirculation of liquid within the same tank. The flow out of the RAS pipe must not be restricted; otherwise, flow will be impeded.

4. Calculate the percent submergence, as shown in Figure F.2 of Appendix F. This is 100 times submergence divided by height of lift and submergence to the point of air injection.

5. Observe the pressure gauge reading to verify it is above minimum pressure.

6. Measure the diameter of the airlift.

7. Use Figure F.3 in Appendix F. Find the size of pipe curve and follow it to the percent submergence line on the X-axis.

8. Follow the horizontal line across to the Y axis and read the flow rate. Note that the gpm may vary by as much as 20%, if all components are read properly and functioning as intended.

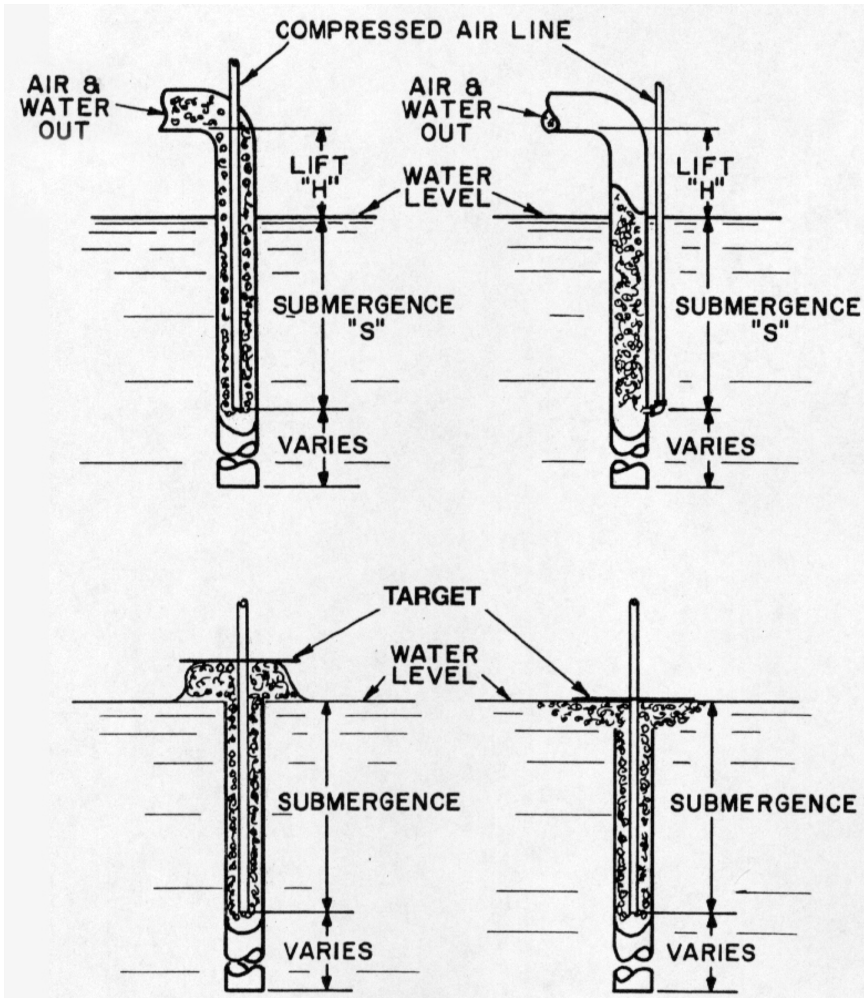


Figure 3.1 – Various Elementary Low Lift Types of Air Lifts[1]

Notes:

- There are points on the airlift curves where the flow rate drops off after a peak rate is provided.
- As the length of the air pipe increases, the pressure and volume of air available for operation of the air lift is adversely affected.
- Take a look at the following picture.
    - The hose with the ball valve (it is red) is the line carrying the air down through the center pipe of the air lift. Note the air throttle valve on the air line.
    - The round handle valve (it is green) is to allow for back flushing of the air lift pipe as well as other functions.
    - The rectangular box houses the discharge from the air lift but the actual discharge is not visible in the picture. Flow out of the rectangular box is by gravity.

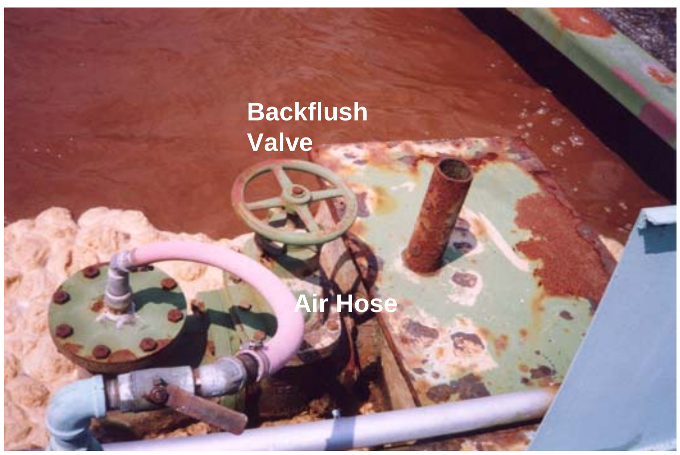


Figure 3.2 – Picture of Air Lift

Example:

1. An operator is attempting to determine if the percentage of RAS flow to raw wastewater flow is within normal guidelines. There is a flowmeter on the raw influent line but the WWTP has airlifts for the RAS system. The raw flow is 0.75 mgd. There are 3 liquid treatment trains at the WWTP, with an air lift for each train.
2. The air lift pipe is 3 inches in diameter and a total of 15 feet long. Two feet of pipe is above the water surface and the rest is below the surface. The air injection point is 10 feet below the water level.
3. Air flow can be adjusted up to a maximum of 10 PSIG, as measured at the point of use for the RAS air lift system in the biological reactor. Air flow can be varied as needed and was determined to be 150 cfm. Note that the recommended range is from about 120 cfm to about 210 cfm for a 3 inch pipe.
4. What is the possible RAS return rate? How does it compare to the raw flow.

Solution:

1. Percent submergence is determined by S = 10, H = 2. From Figure F.2 in Appendix F: (100 x 10) / (10 + 2) = 83%. Figure F.2 in Appendix F shows we are within acceptable pressure.
2. Use Figure F.3 in Appendix F and follow the 83% line until it hits the 3 inch diameter air lift pipe curve.
3. Go horizontal and read 80 gpm. Remember, accuracy is ±20%.

Electronic calibration of a meter can be used to check the transmission of a signal from a flowmeter to a recording location several feet or several miles away. It can also be used to verify that the flow rate through the meter is generating the proper signal.

Zero point calibration involves calibrating the flowmeter with no flow.

One point calibration involves calibrating the flowmeter at one flow rate, anywhere in the flow range. When you spot-check the meter, you are checking just one point.

Two point calibration involves calibrating the flowmeter at two highly different flows, such as 20% and 80% of the flow range. You then assume that the flow range is linear between the two points.

Five point calibration involves checking the flow at both extremes of zero and maximum flow and at three equal distant points in the flow range. This is the best calibration method to use.

4-20 Milliamp Signal

- Use of zero point calibration.
  - This is the easiest to check. When there is no flow, the signal response should be 4 milliamp.
- Use of five point calibration.
  - This method generates a series of signals. The flow at zero flow should equal a 4 milliamp response.
  - At 100% flow, the response should be 20 milliamps.
  - At the intervals of 25%, 50%, and 75%, the flow (and signal) should show a linear scale and be of a uniform slope.
  - Notice that the five points checked were: zero flow, 25%, 50%, 75%, and 100%.

Weirs

- Flowmeter readings from weirs are based on depth of flow.
- The shape and size of the weir is critical to determining accuracy limits.
- The following equations are for V-notch weirs. They can be used if weir tables are not available.
  - Take the measurements at a point upstream before the drawdown effect occurs.
  - You cannot measure at the actual V-notch, except for portable V-notch weirs (used in sewer flow studies), which are designed to allow for direct readings.

Table 3.1 – Rate of Flow Equations for V-Notch Weirs

V-Notch Weir	$Q = 2.48 \tan \frac{1}{2} \theta H^{2.5}$
Rectangular Weir	$Q = 3.33 (L - 0.2 H) H^{1.5}$
Cippoletti Weir	$Q = 3.367 L H^{1.5}$
	Q = rate of flow in cubic feet per second Θ = V-notch angle in degrees H = head in feet of flowing liquid (as measured in the designated point upstream of the drawdown curve effect) L = length of weir crest in feet

Flumes

- The shape and size of a flume is critical to determining accuracy limits.
- The following equations are for single point measurement of a Parshall Flume.
- Two point calibration is possible by qualified instrumentation staff.
  - Possible if the downstream point does not exceed 70% of the level measured near the upstream end of the converging section. If these conditions exist, two point calibration should be avoided—it is probably necessary to upgrade the capacity of the flume.

Table 3.2 – Rate of Flow Equations for Single Point Measurement of a Parshall Flume

For widths less than ½ foot	$Q = 4.12\ H^{1.58}$
For widths less than ¾ foot	$Q = 4.10\ H^{1.53}$
For widths of 1 foot to 8 feet	$Q = 4.0\ L\ H\ (1.522\ L)^{0.026}$
	Q = rate of flow in cubic feet per second
	L = width of throat in feet
	H = head in feet at designated point in flume

Exercise/Activity

1. A 9 inch Parshall Flume on the raw wastewater line was checked by WWTP staff and the depths in inches are shown below, along with the depth converted to feet. Should an instrumentation person be contacted to inspect the flume? Refer to Appendix C - ISCO Table 13-5.

Measured Depth (inches)	Calculated Depth (feet)	Reading (gpm)
1.2	0.10	10
3	0.25	165
4.5	0.38	310
6	0.50	477
7.5	0.62	663

2. A 2 foot Cippoletti Weir is used at the effluent end of a WWTP. What is your opinion of the meter readings? Use Appendix C - ISCO Table 12–3.

Measured Depth (inches)	Calculated Depth (feet)	Reading (gpm)
2.40	0.200	270
2.52	0.210	291
2.76	0.230	333
3.00	0.250	378
3.60	0.300	497
4.32	0.360	653
5.00	0.417	795

3. There is a two-foot wide board that an operator installed trying to fabricate a rectangular weir without end contractions. The operator measured directly above the weir with the following results. Was it measured properly and what are the flows? If measured properly, Appendix C - ISCO Table 11-3 can be used.

Measured Depth (inches)	Calculated Depth (feet)	Reading (gpm)
0.5	0.04	
1.0	0.08	
1.5	0.12	
2.0	0.17	

4. There is a sharp-crested 2 foot long rectangular weir without end contractions at a WWTP. Having taken this course, the operator measured at the proper location upstream of the weir. What are the flows? Use Appendix C - ISCO Table 11-3.

Measured Depth (inches)	Calculated Depth (feet)	Reading (gpm)
2.40	0.200	
2.52	0.210	
2.76	0.230	
3.00	0.250	
3.60	0.300	
4.32	0.360	
4.92	0.410	

5. Determine the amount of error an incorrect depth reading of ½ inch creates in a 120 degree V-notch weir if the perceived depth was 7 inches versus 7.5 inches. Determine its impact for a typical day at that rate. Use Appendix C, Table 9-6.

[1] Revis L. Stephenson and Harold E. Nixon, *Centrifugal Compressor Engineering,* Third Edition, Hoffman Air and Filtration Systems (P.O. Box 548, East Syracuse, NY 13057), pp. 229 - 235.

Unit 4 – Maintenance

Learning Objectives

- Name three considerations for sensor maintenance.
- Identify the advantages of using surge protection.
- Explain how the data acquisition interval affects the ability to monitor flow variations.
- Explain the importance of data backup.
- List four maintenance procedures for portable flowmeters.

To properly maintain sensors, it is important to:

- Avoid excessively abrasive cleaning agents.
  - Don't use woven metal pads (steel wool) on a sensor such as a submerged transducer.
  - Follow the manufacturer's recommendations and procedures for using cleaning pads.
  - Avoid using a strong sodium hypochlorite (12%-15% chlorine by strength) solution.

- Follow the manufacturer's guidelines.
  - Prevent sensor obstructions.
  - Calibrate the sensor annually, if required by the manufacturer. A certified instrumentation company may be necessary.

- Determine if sensor maintenance is needed on closed pipes.
  - Closed pipe meters generally require little maintenance. If a closed pipe meter requires maintenance, it is often removed and sent to the manufacturer.

Power surges can seriously damage electronic equipment. To protect flowmeters from power surges:

- Use Transient Voltage Surge Suppression (TVSS).
  - A TVSS system has a sacrificial component that is destroyed before a voltage surge can reach more sensitive or expensive electrical components downstream.
  - It is important to keep track of which components in your panel have spare parts in inventory.
  - It is possible for a small power fluctuation (i.e. brownout) to damage but not destroy the TVSS. This may affect the voltage levels to the meter. Periodically, check the voltage at the meter during peak electrical demands to ensure the TVSS is working properly.

- Consider the possibility of lightning strikes near the meter.
  - Lightning strikes near a meter can travel through the wastewater or the ground. If the flow sensing element is located in the wastewater, there may be damage to the unit.
  - Portable flowmeters are the most at risk unless a TVSS system is installed. Fortunately, portable flowmeters are less expensive than many other types of units. In addition, portable flowmeters are often placed in low-lying drainage areas which minimizes their exposure to lightning strikes.
  - Check meter components after major electrical storms.

- Avoid running power wires in the same conduit as the signal cables.
  - If the signal cables are not properly shielded, an inductance current may be generated by the power cable and cause interference with the signal from the flowmeter.

There are several site conditions that affect the performance of a flowmeter:

- Humidity
  - Humidity control is critical for bubbler type systems. These systems need the air tank purged on a regular schedule. Purging should be more frequent in the summer because the air has a higher moisture content.
  - High humidity in the air can migrate into a control panel and the panel may need to be protected. For example, portable flowmeters normally have a small vial of desiccant which needs re-charged on a regular basis.
- Solids deposition
  - Solids deposition will alter the hydraulic features of a flume or weir. It is important to clean a V-notch weir on a regular basis to remove algae and debris. It is especially important to clean algae from a narrow V-notch weir in the summer.
  - To keep solids from accumulating in a stilling well or pipe, flush the pipe or well at least every two weeks.
- Foaming problems
  - If the flowmeter is not intended to eliminate incorrect readings due to foam, you may need to switch to a different flow level sensing device.
- Extreme site conditions
  - Extreme hot or cold temperatures may adversely affect the meter.
    - Verify proper ventilation is provided for meters exposed to excessive temperatures or humidity.
  - Extreme pressure changes or vibration will decrease meter service life.
    - Verify that hydraulic surge arresters on force mains are functioning properly.
    - Check that vibration isolators are in good condition.

- Primary hydraulic control element—is it level?
    - It is critical that the weir or flume be level and perpendicular to the flow.
    - Check the primary hydraulic control element of a flume every six months to make sure it is level in both directions (perpendicular to the flow and running with the flow).
- Sensing element—is the elevation correct?
    - Every quarter, check the height of the sensor against the design specifications. For example, if an ultrasonic sensor was designed to be 20 inches above the flume but the bracket was replaced and the sensor is now 22 inches above the flume, the flow reading will be inaccurate.

Batteries play an important role in the operation of portable flowmeters, and in some cases, an internal battery may be a part of a permanent unit.

- When using a portable flowmeter, check the voltage a few hours after charging.
  - Batteries may need a few hours to “settle down” after being charged.
  - Checking the voltage without a load may not properly reveal the condition of the batteries.
- When using a portable flowmeter, check the voltage after usage.
  - Check a battery’s voltage after the flowmeter is brought back from the field. You may not find a weak battery each time, but checking the battery on a frequent basis ensures that you will not lose your power source.
  - If the data being collected is critical, you must check the battery during periodic data downloads (typically weekly) and after any type of metering study has been completed.

- In the following photographs, a digital and analog meter are displayed to illustrate the accuracy and importance of a good digital meter. While the digital meter registers two different readings, there is no discernable difference on the analog meter.
    - In this photo, the digital scale reads 12.44 volt on a partially discharged battery.

Figure 4.1 – Digital and Analog Meters on a Partially Discharged Battery (12.44 volt reading)

- In this photo, the digital scale reads 13.07 volt on a battery being charged.

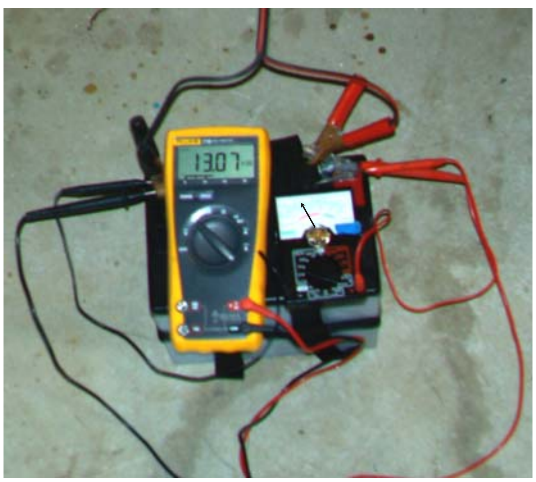


Figure 4.2 – Digital and Analog Meters on a Battery Being Charged (13.07 volt reading)

Data downloading and backup consists of various factors:

- Data acquisition and downloading of data.
  - Data backup is critical to ensure that data is not lost if the primary storage device fails.
- Data acquisition frequency.
  - The more frequently data is collected, the more variations in flow levels you will be able to detect.
  - If a meter has the ability to store data for 30 days, and you acquire data once a week, why not decrease the time interval between flow measurements to obtain more data? For example, if you are checking on a specific industry and they have a batch flow, you could miss part of it if your meter interval is too long.
- Data downloading interval.
  - If the data is critical and may easily become compromised, it may be worthwhile to download it on a frequent basis.
- Data backup.
  - It is better to store data in more than one location and on more than one media. If one location is flooded or if one media becomes unusable, a backup is available.
- Data downloading options.
  - Wireless spread-spectrum will download data from 100’ to 150’ away—even through a closed manhole.
  - Phone modem choices include a landline and CDMA cellular.
  - A text message can be sent to up to five cell phones on alarm.
  - Can decrease time spent at the site and can also save manpower, depending on options.

Figure 4.3 – Importance of Downloading Data Remotely[1]

Portable flowmeters serve a number of purposes in a variety of settings. Below are some portable flowmeter considerations:

- ▶ Portable flowmeters tend to require more maintenance because they are generally installed in less than ideal conditions.

- ▶ On a regular basis, possibly annually, use the portable flowmeter at a location where another method is used to determine the flow. The difference can give you an idea of how well the portable unit is performing.

- ▶ It is important to store portable flowmeters in a clean and dry environment. Storing portable flowmeters in the corner of a dirty garage as an example, will allow dust to enter the control panels and otherwise adversely affect the life of the unit.

- ▶ If equipped with a sampler, make sure the interface connection is working properly. This can be done by ensuring the sample collection bottle contains the correct volume of liquid.

- ▶ General maintenance procedures include:
    - Charge batteries.
    - Recharge desiccant.
    - Download data.
    - Cross-calibrate following the manufacturer’s recommendations.

Portable samplers serve a number of purposes in a variety of settings. Below are some portable sampler considerations:

- Sampler interface requirements.
  - Many portable flowmeters have the ability to interface with a portable sampler. This is a highly desirable feature but requires additional maintenance activities not covered in this course.

- Sampler requirements.
  - Each manufacturer's sampler has specific maintenance requirements. These may include:
    - Replacing the tubing in the pump head.
    - Cleaning the sampler tubing.
    - Lubricating the distribution system.
    - Cleaning the internal containers.
    - Replacing the tubing with the proper type.

[1] Courtesy of Isco, Inc.

Unit 5 – Problems/Troubleshooting

Learning Objectives

- Identify two considerations when selecting a flowmeter.
- Discuss how backwater can affect a flume or weir.
- Define subcritical and supercritical flow.
- Name two ways a sensor becomes fouled.
- List three post-installation problems inside the pipe that create meter inaccuracies.
- Identify the problems caused by placing the signal cable adjacent to a power cable.
- Explain the proper use of a scatter diagram.

Improper Initial Flow Estimates and Applications

Improper Initial Flow Estimates

- When selecting a flowmeter, it is important to consider the estimated minimum, average, and maximum flow rates to ensure the correct meter is utilized.

- Improper initial flow estimates may result in the installation of an improper flowmeter. This may require the primary flow control element or the flowmeter to be replaced.

- Before replacing any items, check the operation and maintenance manual and call the manufacturer about your specific installation.

- Generally it is very easy to determine the average flow rate. However, determining minimum and maximum flow rates may be more difficult.

Exercise/Activity

The average flow through a facility was estimated to be 200 gpm, based on water records. A 120 degree V-notch weir was installed. The staff reported a lack of flow detection sensitivity. The staff needed to interface a chemical feed disinfection system with the flowmeter and were able to determine that the minimum flow might be about 20 gpm and the maximum flow might be about 450 gpm. The metering point is the effluent from the WWTP, with suspended solids always below 30 mg/L, which allows the use of a V-notch weir. Use Appendix C - ISCO Tables 9-3, 9-5, and 9-6 to select a better V-notch weir.

Improper Application

- An ultraviolet (UV) light level control weir is a system that uses a weir to control the depth over UV tubes. Maintaining the proper depth is necessary for the UV system to operate properly.
  - A UV level control weir **cannot** be used to monitor flow because the depth does not vary depending on the flow.

Backwater

- Backwater problems can affect flumes and weirs.
  - **Flume.** In general, it is important to prevent backwater in the throat section of a flume. The flume should have a good discharging section that does not hinder the flow leaving the flume area.
  - **Weir.** If the nappe of a sharp-crested weir does not have air in it, the flow values will be adversely affected.
- When a weir is completely covered by the flow, it is considered a submerged weir. This results from the weir being unable to handle the flow rate.
  - A submerged weir can be used for flow measurements but it requires complex calculations. Therefore, it is recommended that a submerged weir be avoided.

Figure 5.1 – Beginning Stages of a Submerged Condition[1]

Figure 5.2 – Submerged Flume[2]

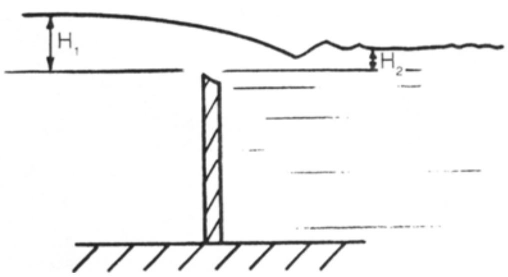


Figure 5.3 – Submerged Weir[3]

Supercritical/Subcritical

Subcritical—flow that is peaceful, calm, and laminar.

Supercritical—flow that is fast and turbulent.

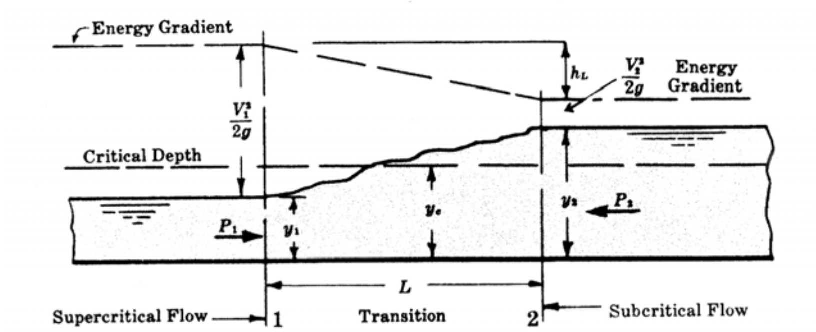


Figure 5.4 – Illustration of Super Critical/Transition/Subcritical Flow[4]
This diagram was reproduced with the permission of the McGraw-Hill Companies. It is from "Ranald V. Giles, *Theory and Problems of Fluid Mechanics & Hydraulics, Second Edition,* McGraw-Hill, 1962."

- A flowmeter must be selected based on the type of flow that is anticipated (supercritical or subcritical).

Sensor Fouling

Sensor fouling can negatively impact the operation of a flowmeter.

- Replacement of failed elements in a closed pipe can be difficult and may require down time for the pipe.
  - Consider periodically flushing the sludge force main and other pipes with clear water to remove internal debris, especially if the pipes are in a horizontal position because debris will accumulate on the bottom of the pipe.
- If you have a float system and the float is not isolated in a stilling well, debris may catch on the float.
- If you have a stilling well but the manufacturer's recommendations are not followed for regular flushing, debris may clog the cross connection pipe and prevent an accurate reading of the level.
- Although not common for flowmetering, if you have a submersible transducer type sensor, make sure that debris has not obstructed a portion of the transducer.
- If using a V-notch weir, remember to clean the V-notch on a regular basis. It may need cleaned once a week in the summer. Typically it will only take a few quick brush strokes to clean the weir.
- If you have a problem with a submerged area-velocity probe, consider a radar area-velocity probe which is not within the flow stream.

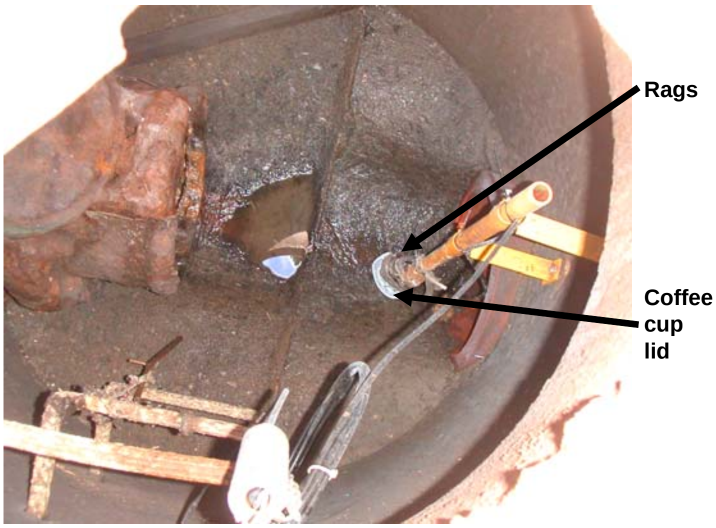


Figure 5.5 – Fouled Sensor[5]

Power Source

All flowmeters require a dependable power source.

- If the power source is unreliable or inconsistent, a flowmeter will not function properly. If power is frequently interrupted, consider an uninterruptible power source (UPS).
- Record the date when new batteries are received. Some facilities will engrave an inventory tracking number on the batteries so the use of each can be recorded.

Security

Some flowmeters are in an area where they might be vandalized or tampered with. If this is the case, consider the following measures:

- If vandalism is a problem, consider other locations that will be more secure.
- If an industry or other entity may want to generate false data or sabotage the flowmeter, consider placing a dummy meter in a conspicuous location to distract attention from the critical meter.
- If a portable flowmeter is used in a manhole, it can be difficult to lock it to prevent theft. The biggest deterrent is that it is under a heavy manhole lid, or the lid may have a bolt down cover.

Other Common Problems

There are various problems that can develop after a flowmeter has been installed.

- Encrustation in a pipe.
  - If encrustation develops inside a pipe, the encrustation should be removed. Encrustation can be removed physically or chemically.
  - When removing encrustation, care must be taken to avoid damaging the flowmeter.

- Sedimentation/silt.
  - If sedimentation or silt develops, flush the line with clear flow.
  - If a v-notch weir is being used, remove the v-notch weir to flush solids out of the channel. Consider a different PHCE, such as a flume which does not collect solids.

- Air bubbles.
  - Air bubbles are only a concern with closed pipes. This is best alleviated with a full pipe or a vertical installation.
  - In an air bubbler type system, you are expelling a specific amount of air and measuring the back pressure. The most common problems involve improper air flow in the system. This could result from freezing or excessive moisture if the system is not purged on a frequent basis. Staff gauges are often used as a backup to the bubbler system.

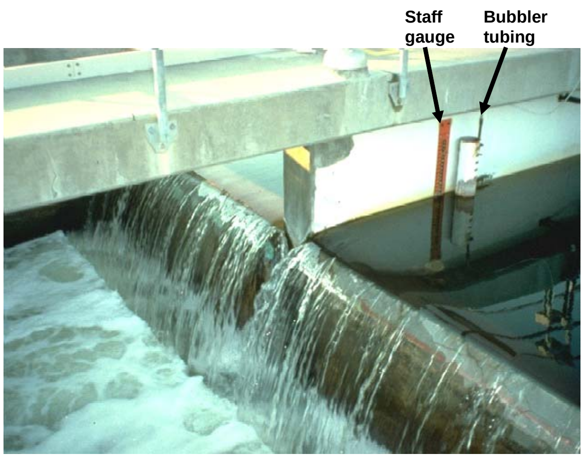


Figure 5.6 – Staff gauge as a backup to a bubbler system[6]

- Severe vibration.
  - Pipe vibration can adversely affect a closed pipe flowmeter. The vibration may damage the meter's electronics, or it may create hydraulic waves that will affect the meter's accuracy.

- Pressure fluctuations.
    - Severe cycling of process pressure may affect a closed pipe meter if it was not designed to handle a sudden increase in pressure.
    - When designing a system, it is important to consider pressure fluctuations and purchase meters that can accommodate them in locations where the fluctuations may occur.
- Temperature fluctuations.
    - If temperature changes are frequent or extreme, it may adversely affect accuracy.
- Poor housekeeping.
    - If the area around the meter is surrounded by trash and debris, it may indicate the meter is not properly maintained.

Figure 5.7 – Evidence of Surcharging by Debris on Top of the Nozzle

- Meter problems or inaccurate readings.
    - In the picture below, note the close proximity of the flowmeter (strap on style) to an air/vacuum release assembly (1-2 feet separation). If there are problems with the meter or readings are inaccurate, consider relocating the meter so that it is further from the air/vacuum release assembly. This is an example were you should work closely with the manufacturer.

Figure 5.8 – Possible Improper Isolation Distance

Exercise/Activity

What is wrong with this picture?

Figure 5.9 – What is wrong?[7]

Portable flowmeters and insertable v-notch weirs are used for spot-checking flows.

- Portable flowmeters and insertable v-notch weirs are useful when implementing a wastewater study to identify where additional infiltration/inflow (I/I) studies should be conducted.
  - As the identification of flows and I/I effects are becoming more important through the continued adoption of Capacity, Management, Operations, and Maintenance (CMOM) procedures, more facilities should obtain a set of insertable v-notch weirs.
  - Insertable V-notch weirs are the only type of weir you will encounter that you read directly at the weir. To use the weir, enter the manhole and place the weir so that the bubble is level. Allow the flow to stabilize for a few minutes before reading the flow value.

To prevent the introduction of false signals:

- Avoid multiple uses of the same conduit.
- Avoid locations close to high voltage power sources.
  - As an example, do not install a meter directly below a high voltage transformer.
  - If there are power cables directly beside signal wires in the same conduit, it is very likely the signal will be compromised.

- Scatter diagrams can be used to determine if data is reliable.

A **scatter diagram** is a visual display of data. It shows the association between two variables acting continuously on the same item. The scatter diagram illustrates the strength of the correlation between the two variables through the slope of a line. It is easy to use, but it should be interpreted with caution as the scale may be too small to adequately show the relationship between the variables.

- Scatter diagrams make the relationship between two continuous variables stand out visually on the page. They can be used in examining a cause-and-effect relationship. They can also show relationships between two effects to see if they might have a common relationship.

- How to create and interpret a scatter diagram. We will use an example of comparing depth of flow to the corresponding flow reading.

  - Creating a scatter diagram can be easily done with a simple spreadsheet in Lotus or Excel.
  - **Step 1.** Collect at least 40 paired data points. "Paired" data points are measures of both the cause being tested and its effect at one point in time.
  - **Step 2.** On linearly uniform diagram paper label the horizontal axis "Depth of Flow" and the vertical axis "Flow Reading." We will assume that depth is the controlling factor in an open channel and the flow reading is obtained from a table for the weir or flume.
  - **Step 3.** Determine the lowest and highest value of each variable and mark the axes accordingly. Determine the scale so that the points cover most of the range of both axes and both axes are about the same length. Make sure you use as much of the graph paper as possible to maximize the accuracy of the analysis.
  - **Step 4.** If you are not using Lotus or Excel, plot the paired points on the graph paper. If there are multiple pairs with the same value, draw as many circles around the point as there are additional pairs with those same values. You should be consistent with the size of the circles. If you feel the accuracy is good, use a tighter circle to illustrate the certainty of the value.
  - **Step 5.** Identify and classify the pattern of association. Use the following graphs as examples.

Scatter Diagram Interpretation

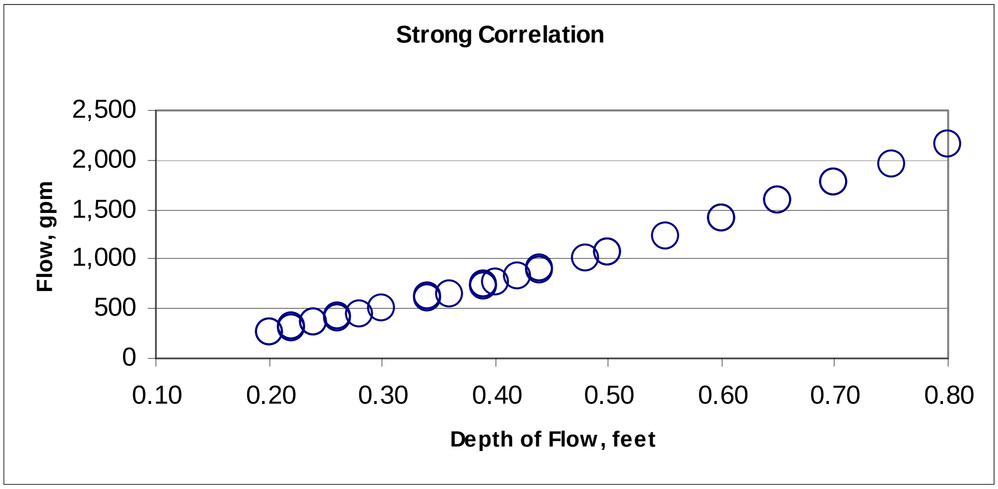


Figure 5.10 – This **strong correlation** shows a strong relationship between the depth of flow and the resultant flowmeter reading.

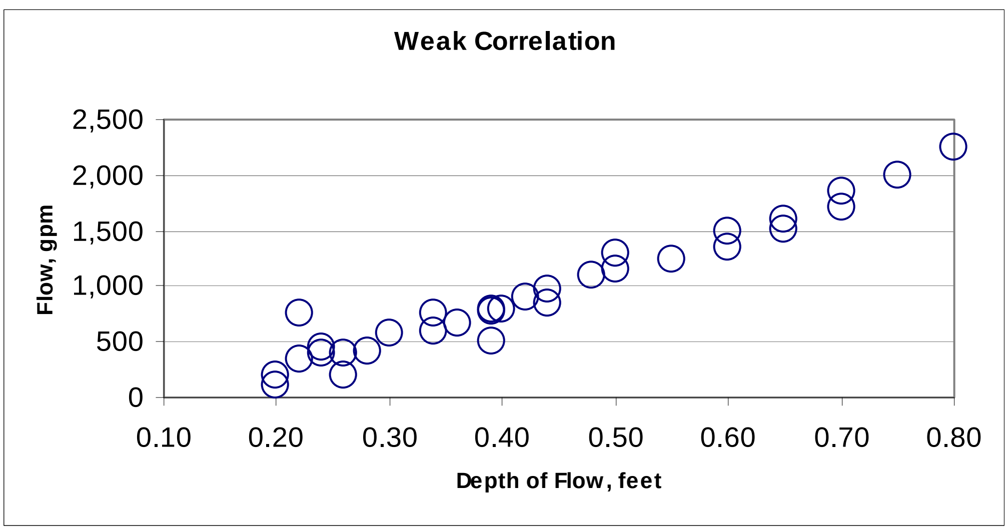


Figure 5.11 – This **weak correlation** shows a poor relationship between the depth of flow and the resultant flowmeter reading. It is most noticeable at lower flows.

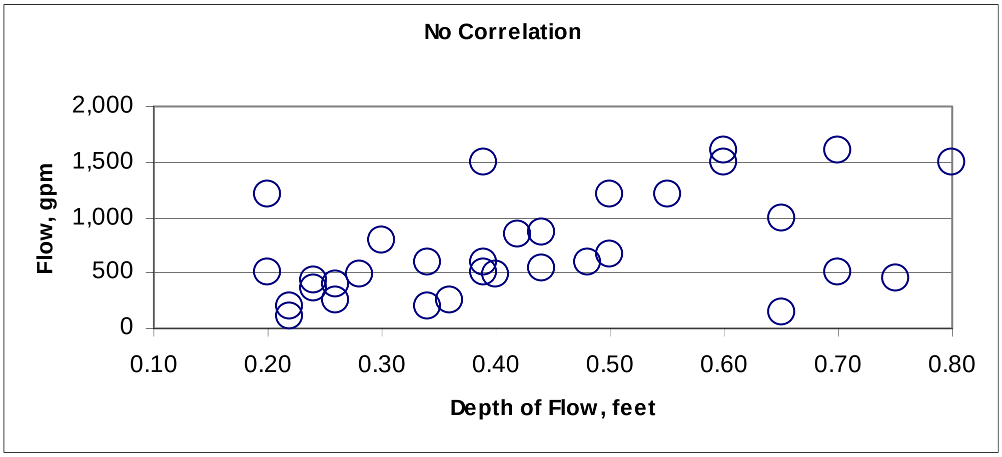


Figure 5.12 – No correlation in this graph shows no relationship between the depth of flow and the resultant flowmeter reading.

- Avoid the temptation to draw a line roughly through the middle of the points. This can be misleading. A true regression line is determined mathematically.
- Scatter diagrams show relationships, but they do not prove that one variable causes the other. The narrower the grouping of data, the better the relationship.
- You can use a scatter diagram for many purposes in the WWTP besides troubleshooting a flowmeter.
  - One example might be flow to a WWTP. You could plot precipitation and flow to evaluate how infiltration/inflow impacts the collection system.

[1] Courtesy of Isco, Inc.

[2] Courtesy of Isco, Inc.

[3] *Design of Municipal Wastewater Treatment Plants*, Fourth Edition, (Alexandria, VA: ASCE and the Water Environment Federation, 1992), p. 5-16.

[4] Ranald V. Giles, *Theory and Problems of Fluid Mechanics & Hydraulics*, Second Edition (New York, NY: McGraw-Hill, 1962), p. 184.

[5] Courtesy of Isco, Inc.

[6] Courtesy of Isco, Inc.

[7] Courtesy of Isco, Inc.

Appendices

Appendix A	PADEP Chapter 94 – Municipal Wasteload Management
Appendix B	Water Environment Federation CMOM Summary
Appendix C	ISCO Figures and Tables
Appendix D	Average Flow Chart
Appendix E	Performance Curve
Appendix F	Air Lift

[PA] [WAT094] 094 - Municipal Wasteload Management

25 - ENVIRONMENTAL PROTECTION

PART I - DEPARTMENT OF ENVIRONMENTAL PROTECTION

SUBPART C - PROTECTION OF NATURAL RESOURCES

ARTICLE II - WATER RESOURCES

CHAPTER 94 - MUNICIPAL WASTELOAD MANAGEMENT

November 21, 1977
Last Amended: Effective September 5, 1998

GENERAL PROVISIONS

Section 94.1. Definitions.

The following words and terms, when used in this chapter, have the following meanings, unless the context clearly indicates otherwise:

Average daily organic load - The arithmetic mean of all samples of 5-day Biochemical Oxygen Demand, expressed in terms of pounds per day, collected over a calendar month.

Ban - A restriction placed by the Department on additional connections to an overloaded sewer system or a sewer system tributary to an overloaded plant and other necessary measures the Department may require to prevent or alleviate an actual organic or hydraulic overload or an increase in an organic or hydraulic overload.

Bypass - The intentional diversion of wastewater either at or after the headworks of the plant.

CAP - Corrective action plan - A plan and schedule developed by the permittee of a sewerage facility which has an existing or projected overload. A CAP establishes actions existing or projected overload. A CAP establishes actions needed and a schedule to reduce the overload and provide needed capacity.

CSO - Combined sewer overflow - An intermittent overflow, or other untreated discharge from a municipal combined sewer system (indicating domestic, industrial and commercial wastewater and stormwater) which results from a flow in excess of the dry weather carrying capacity of the system.

Capacity - The rated ability of the plant to receive and effectively treat a specified load. When the term is used in reference to a pump station or sewer system, the term refers to the rated ability to effectively convey a specified load.

Clean Water Act - 33 U.S.C.A. Sections 1251, 1252, 1254 - 1256, 1259, 1262, 1263, 1281 - 1288, 1291, 1292, 1294 - 1297, 1311, 1314, 1315, 1317 - 1319, 1321 - 1324, 1328, 1341, 1342, 1344, 1345, 1362, 1364, 1375 and 1376.

Combined sewer system - A sewer system which has been designed to serve as both a sanitary sewer and a storm sewer.

Connection - The connection of a structure which generates or could generate hydraulic or organic loads to a sewer system.

Discharge - Wastewater flow which is or would be discharged to a sewer system.

Exception to a ban - An allowable connection to a sewer system even though a ban is in effect.

Extension - An addition to the sewer system to accommodate more than one connection.

Facilities of public need - Hospitals, health clinics, nursing care facilities, primary and secondary education facilities, fire and police stations and correctional institutions.

Headworks - For the purposes of this chapter, the first treatment unit or wetwell within the plant.

Hydraulic design capacity - The maximum monthly design flow, expressed in millions of gallons per day, at which a plant is expected to consistently provide the required treatment or at which a conveyance structure, device or pipe is expected to properly function without creating a backup, surcharge or overflow. This capacity is specified in the water quality management permit (Part II permit issued under Chapter 91) (relating to general provisions).

Hydraulic overload - The condition that occurs when the monthly average flow entering a plant exceeds the hydraulic design capacity for 3-consecutive months out of the preceding 12 months or when the flow in a portion of the sewer system exceeds its hydraulic carrying capacity.

Industrial user - An establishment which discharges or introduces industrial wastes into a sewerage facility.

Interference - A discharge which, alone or in conjunction with a discharge from other sources, does the following:

(i) Inhibits or disrupts the sewerage facility, its treatment processes or operations or its sludge processes, use or disposal.

(ii) Is a cause of a violation of a requirement of the sewerage facility's NPDES permit - including an increase in the magnitude or duration of a violation - or of the prevention of sewage sludge use or disposal in compliance with the following statutory provisions and regulations or permits issued thereunder - or more stringent State or local regulations:

(A) Section 405 of the Clean Water Act (33 U.S.C.A. Section 1345).

(B) The Solid Waste Disposal Act (SWDA) (42 U.S.C.A. Sections 6901 - 6987), including Title II, more commonly referred to as the Resource Conservation and Recovery Act of 1976 (RCRA).

(C) State regulations contained in a State sludge management plan prepared under Subtitle D of the SWDA, the Clean Air Act (42 U.S.C.A. Sections 7401 - 7642, the Toxic Substances Control Act (15 U.S.C.A. Sections 2601 - 2629) and the Marine Protection, Research, and Sanctuaries Act of 1972 (16 U.S.C.A. Sections 1431 - 1434; 33 U.S.C.A. Sections 1401, 1402, 1411 - 1421 and 1441 - 1445).

Load - The rate of flow and organic strength of the wastewater, including infiltration, discharged to a plant, as measured at the influent of the plant or in the sewer system or a portion of it.

Monthly average flow - The total flow received at a sewerage facility or another portion of the sewer system during any 1-calendar month divided by the number of days in that month. This value is always expressed in millions of gallons per day (mgd).

Monthly average organic loading - The total organic load received at a plant during any 1 calendar month divided by the number of days in that month. This value is expressed in pounds per day of biological oxygen demand after 5 days (BOD5).

NPDES permit - A permit or equivalent document or requirements issued by the EPA, or, if appropriate, by the Department, to regulate the discharge of pollutants under section 402 of the Clean Water Act 33 U.S.C.A. Section 1342).

Official plan - A comprehensive plan for the provision of adequate sewage systems adopted by a municipality possessing authority or jurisdiction over the provision of the systems and submitted to and approved by the Department as provided by the Pennsylvania Sewage Facilities Act (35 P.S. Sections 750.1-750.20) and Chapter 71 (relating to administration of sewage facilities planning program).

Organic design capacity - The highest daily organic load at which a sewage treatment facility or a portion thereof is expected to provide a specific predetermined level of treatment. This capacity is normally specified in the water quality management permit (Part II permit issued under Chapter 91).

Organic overload - The condition that occurs when the average daily organic load exceeds the organic design capacity upon which the permit and the plant design are based.

PPP - Pollution Prevention Plan - A written document that guides a discharger in the reduction of pollutants at their source before they reach the wastewater treatment plant. The PPP shall, at a minimum, address the following elements:

(i) An explicit statement of top management support for implementation of the pollution prevention plan.

(ii) A process characterization that identifies and characterizes the input of raw materials, outflow of products and generation of wastes.

(iii) An estimate of the amount of each waste generated.

(iv) Development of pollution prevention alternatives based on an estimate of reductions in the amount and toxicity of waste from each pollution prevention activity.

(v) An identification of pollution prevention opportunities to be implemented and an implementation timetable with interim and final milestones and periodic review of implemented recommendations.

Pass through - A discharge which exits the plant into waters of this Commonwealth in quantities or concentrations which, alone or in conjunction with a discharge from other sources, is a cause of a violation of a requirement of the plant's NPDES permit - including an increase in the magnitude or duration of a violation.

Permit - A permit required by section 202 or 207 of the act (35 P.S. Sections 691.202 and 691.207).

Permittee - A person who possesses or is required to possess a permit.

Plant - Devices, systems or other works installed for the purpose of treating, recycling or disposing of sewage.

Pollution prevention - Source reduction and other practices - for example: direct reuse or in-process recycling - that reduce or eliminate the creation of pollutants through increased efficiency in the use of raw materials, energy, water or other resources, or protection of natural resources by conservation.

Pretreatment - The reduction of the amount of pollutants, the elimination of pollutants or the alteration of the nature of pollutant properties in wastewater prior to or in lieu of discharging or otherwise introducing the pollutants into a sewerage facility.

Pretreatment program - A program administered by a sewerage facility that has been approved by the EPA under 40 CFR 403.11 (relating to approval procedures for pretreatment programs and granting of removal credits).

Prohibition - A restriction placed by a permittee on additional connections to an overloaded sewer system or a sewer system tributary to an overloaded plant.

Sanitary sewer overflow - An intermittent overflow of wastewater, or other untreated discharge from a separate sanitary sewer system (which is not a combined sewer system), which results from a flow in excess of the carrying capacity of the system or from some other cause prior to reaching the headworks of the plant.

Separate sanitary sewer system - A sewer system or part thereof which is specifically designed and intended to carry sanitary sewage separate from stormwater as specified in the permit.

Sewerage facilities - The term used to collectively describe a plant and sewer system owned by or serving a municipality.

Sewer system - The pipelines or conduits, pumping stations and force mains, and other appurtenant constructions, devices and facilities used for conveying sewage to a plant.

(b) A word or phrase which is not defined in this chapter but which is defined in Chapter 92 (relating to National Pollutant Discharge Elimination System) has the meaning as defined therein.

Section 94.2. Purpose.

This chapter is intended to prevent unpermitted and insufficiently treated wastewater from entering waters of this Commonwealth by requiring the owners and operators of sewerage facilities to project, plan and manage future hydraulic, organic and industrial waste loadings to their sewerage facilities. Reductions in wastewater volume and pollutant mass loadings through the application of pollution prevention practices are encouraged to avoid hydraulic, organic and industrial wastewater overloads at sewerage facilities to accomplish the following objectives:

(1) Prevent the occurrence of overloaded sewerage facilities.

(2) Limit additional extensions and connections to an overloaded sewer system or a sewer system tributary to an overloaded plan.

(3) Improve opportunities to prevent or reduce the volume and toxicity of industrial wastes generated and discharged to sewerage facilities and where prevention and reduction opportunities have been maximized, and to recycle and reuse municipal and industrial wastewaters and sludges.

Section 94.3. Scope.

This chapter requires owners of sewerage facilities to properly plan, manage and maintain sewerage facilities in a manner which will do the following:

(1) Anticipate and prevent overloading sewerage facilities.

(2) Limit additional extensions and connections to an overloaded sewer system or a sewer system tributary to an overloaded plant.

(3) Prevent the introduction into sewerage facilities of pollutants which will interfere with the operation of the plant or pass through or otherwise be incompatible with the treatment process or sewerage facility.

(4) Improve opportunities to recycle and reclaim municipal and industrial wastewaters and sludges.

GENERAL REQUIREMENTS

Section 94.11. Sewer extensions.

(a) A sewer extension may not be constructed if the additional flows contributed to the sewerage facilities from the extension will cause the plant, pump stations or other portions of the sewer system to become overloaded or if the flows will add to an existing overload unless the extension is in accordance with an approved CAP submitted under Section 94.21 or Section 94.22 (relating to existing overload; and projected overload) or unless the extension is approved under Section 94.54 (relating to sewer line extension).

(b) The Department may issue a permit for the construction of a capped sewer, which would be tributary to an overloaded sewerage facility where the capped sewer would not be placed into service until adequate conveyance and treatment capacity becomes available under all of the following conditions:

(1) The proposed project is consistent with the approved official plan of the municipality.

(2) The municipality or municipal authority which owns the sewer system to which the capped sewer would connect has an approved program for providing adequate conveyance and treatment capacity within 5 years of the date of issuance of a capped sewer permit by the Department.

(3) Other Department requirements for sewer design and construction are met.

Section 94.12. Annual report.

(a) To provide for annual review of sewerage facilities and ensure that there is sufficient time to address existing operational or maintenance problems or to plan and construct needed additions, plant permittees shall submit a complete and accurate wasteload management annual report, in duplicate, by March 31 of each year to the appropriate regional office of the Department. The report shall be signed by the preparer and by the permittee of the plant and include the following:

(1) A line graph depicting the monthly average flows (expressed in millions of gallons per day) for each month for the past 5 years and projecting the flows for the next 5 years. The graph shall also include a line depicting the hydraulic design flow (also expressed in millions of gallons per day) of the plant included in the water quality management permit (Part II permit issued under Chapter 91 (relating to general provisions)).

(2) A line graph depicting the monthly average organic loading (expressed as pounds per day of BOD5) for each month for the past 5 years and projecting the monthly average organic loading for the next 5 years. The graph shall also include a line depicting the organic loading design (also expressed in pounds per day of BOD5) of the plant included in the water quality management permit (Part II permit issued under Chapter 91).

(3) A brief discussion of the basis for the projections referred to in paragraphs (1) and (2), as well as a description of the time needed to expand the plant to meet the load projections, if necessary. Data used to support those projections should be included in an appendix to the annual report.

(4) A map showing all sewer extensions constructed within the past calendar year, sewer extensions approved or exempted in the past year in accordance with the Pennsylvania Sewage Facilities Act (35 P.S. Sections 750.1 - 750.20) and Chapter 71 (relating to administration of the sewage facilities program), but not yet constructed, and all known proposed projects which require public sewers but are in the preliminary planning stages. The map shall be accompanied by a list summarizing each extension or project and the population to be served by the extension or project. If a sewer extension approval or proposed project includes schedules describing how the project will be completed over time, the listing should include that information and the effect this build-out-rate will have on population served.

(5) A discussion of the permittee's program for sewer system monitoring, maintenance, repair and rehabilitation, including routine and special activities, personnel and equipment used, sampling frequency, quality assurance, data analyses, infiltration/inflow monitoring, and, where applicable, maintenance and control of combined sewer regulators during the past year.

(6) A discussion of the condition of the sewer system including portions of the system where conveyance capacity is being exceeded or will be exceeded in the next 5 years and portions where rehabilitation or cleaning is needed or is underway to maintain the integrity of the system and prevent or eliminate bypassing, combined sewer overflow, sanitary sewer overflow, excessive infiltration and other system problems.

(7) A discussion of the condition of sewage pumping stations, including a comparison of the maximum pumping rate with present maximum flows and the projected 2-year maximum flows for each station.

(8) A report, if applicable, of industrial wastes discharged into the sewer system. This report shall include the following:

(i) A copy of any ordinance or regulation governing industrial waste discharges to the sewer system or a copy of amendments adopted since the initial submission of the ordinance or regulation under this chapter, if it has not previously been submitted. Ordinances, regulations or fee structures may provide incentives to industrial waste dischargers to use pollution prevention techniques to reduce or eliminate the generation of industrial wastewater discharges to the sewer system.

(ii) A discussion of the permittee's or municipality's program for surveillance and monitoring of industrial waste discharges into the sewer system during the past year.

(iii) A discussion of specific problems in the sewer system or at the plant, known or suspected to be caused by industrial waste discharges and a summary of the steps being taken to alleviate or eliminate the problems. The discussion shall include a list of industries known to be discharging wastes which create problems in the plant or in the sewer system and action taken to eliminate the problem or prevent its recurrence. The report may describe pollution prevention techniques in the summary of steps taken to alleviate current problems caused by industrial waste dischargers and in actions taken to eliminate or prevent potential or recurring problems caused by industrial waste dischargers.

(9) A proposed plan to reduce or eliminate present or projected overloaded conditions under Sections 94.21 and 94.22 (relating to existing overload; and projected overload).

(b) Permittees of sewer systems which contribute sewage flows to the plant shall submit information to the permittee of the plant as required to facilitate preparation of the annual report.

Section 94.13. Measuring, indicating and recording devices.

(a) A plant which receives or will receive within the next 5 years, monthly average flows exceeding 100,000 gallons per day shall be equipped to continuously measure, indicate and record the flow. The permittee of the plant shall install equipment necessary for these measurements within 6 months after the date when such a flow becomes evident.

(b) Flow measuring, indicating and recording equipment shall be calibrated annually, and the calibration report shall be included in the annual report submitted under Section 94.12 (relating to annual report).

Section 94.14. Approval of official plans and revisions.

No official plan, official plan revision or supplement will be approved by the Department or delegated agency, nor will an exemption from the planning requirements be granted under Chapter 71 (relating to administration of the sewage facilities planning program) that is inconsistent with this chapter.

Section 94.15. Pretreatment program development.

In cases where pollutants contributed by industrial users result in interference or pass through, and the violation is likely to recur, a permittee shall develop and implement specific local limits for industrial users and other users, as appropriate, that together with appropriate sewerage facility or operational changes, are necessary to ensure renewed or continued compliance with the plant's NPDES permit or sludge use or disposal practices.

ACTION ON OVERLOAD FACILITIES

Section 94.21. Existing overload.

(a) If the annual report establishes or if the Department determines that the sewerage facilities or any portions thereof are either hydraulically or organically overloaded, the permittee of the sewerage facilities shall comply with the following program:

(1) Prohibit new connections to the overloaded sewerage facilities except as approved by the permittee under the standards for granting exceptions contained in Sections 94.55 - 94.57 (relating to building permit issued prior to ban; replacement of a discharge; and other exceptions). No building permit may be issued by a governmental entity which may result in a connection to overloaded sewerage facilities or increase the load to those sewerage facilities from an existing connection. The permittee shall retain records of exceptions granted and make the records available to the Department upon request.

(2) Immediately begin work for the planning, design, financing, construction and operation of the sewerage facilities that may be necessary to provide required capacities to meet anticipated demands for a reasonable time in the future and resulting in a project that is consistent with the applicable official plans approved under the Pennsylvania Sewage Facilities Act (35 P.S. Sections 750.1 - 750.20) and the regulations thereunder in Chapter 71 (relating to administration of the sewage facilities planning program) and consistent with the requirements of the Department and the Federal Government regarding areawide planning and sewerage facilities.

(3) Submit to the Regional Office, for the review and approval of the Department, a written CAP to be submitted with the annual report or within 90 days of notification of the Department's determination of overload, setting forth the actions to be taken to reduce the overload and to provide the needed additional capacity. The written CAP shall include, but not be limited, to limitations on and a program for control of new connections to the overloaded sewerage facilities and a schedule showing the dates each step toward compliance with paragraph (2) shall be completed.

(b) Upon receipt of an acceptable CAP submitted in accordance with subsection (a)(3), the Department may modify or lift the requirement to prohibit new connections and the issuance of building permits contained in subsection (a)(1). In determining whether the requirement to prohibit new connections shall be modified or lifted, the Department will consider the extent to which the permittee plans to limit new connections; the timing for provisions of additional capacity and reduction of the existing overload; and the impact of the overload on treatment plant effluent quality, water quality degradation and public health.

(c) The Department may approve permits for extensions to overloaded sewerage facilities when the following conditions are met:

(1) The proposed extension is consistent with an acceptable CAP submitted under subsection (a)(3).

(2) The proposed extension is consistent with the applicable official plan approved under the Pennsylvania Sewage Facilities Act and the regulations adopted thereunder at Chapter 71.

(3) The additional load from the proposed extension will not have a significant adverse impact on the water quality of the receiving waters.

(4) The proposed extension is in accordance with any other applicable requirement of this title.

(5) The connections to the extension are controlled in accordance with the CAP submitted in accordance with subsection (a)(3); provided that, no connections to extension may be allowed when the approved CAP is not being implemented in accordance with the schedule contained therein.

Section 94.22. Projected overload.

If the annual report shows or if the Department determines that the sewerage facilities or any portion thereof will, within the next 5 years, become hydraulically or organically overloaded, the permittee of the sewerage facilities shall comply with the following:

(1) Submit a report or CAP to the regional office, with the annual report or within 90 days of notification of the Department's determination, setting forth steps to be taken by the permittee to prevent the sewerage facilities from becoming hydraulically or organically overloaded. If the steps to be taken include planning, design, financing, construction and operation of sewerage facilities, the facilities shall be consistent with an official plan approved under the Pennsylvania Sewage Facilities Act (35 P. S. Sections 750.1 - 750.20) and the regulations thereunder in Chapter 71 (relating to administration of the sewage facilities planning program) and consistent with the requirements of the Department and the Federal government regarding areawide planning and sewerage facilities.

(2) Limit new connections to and extensions of the sewerage facilities based upon remaining available capacity under a plan submitted in accordance with this section.

IMPOSITION OF BAN

Section 94.31. Organic or hydraulic overload.

A ban on connections will be imposed by the Department whenever the Department determines that the sewerage facilities or any portion thereof are either hydraulically or organically overloaded or that the discharge from the plant causes actual or potential pollution of the waters of this Commonwealth and, in addition, that one or more of the following conditions prevail:

(1) The Department determines that a ban is necessary to prevent or alleviate endangerment of public health.

(2) The permittee has failed to submit a satisfactory plan or has failed to implement the program as required by Section 94.21 (relating to existing overload).

Section 94.32. Public health hazard or pollution.

A ban may be imposed by the Department whenever the Department finds that such a ban is needed in order to prevent or eliminate public health hazards or pollution resulting from violations of The Clean Streams Law (35 P. S. Sections 691.1 - 691.1001) not otherwise covered by the provisions of this chapter.

Section 94.33. Notice of ban.

(a) A ban imposed by order of the Department will be addressed to the person or municipality who authorizes connection to the sewer system and who operates the sewer system or plant. The ban shall be effective immediately upon receipt of the order imposing the ban.

(b) The Department will publish the order imposing the ban in one newspaper of general circulation in the area affected by the ban beginning no later than 48 hours after the imposition of the ban or as soon thereafter as publication schedules allow. The Department will publish the order imposing the ban, following imposition of the ban, once in the Pennsylvania Bulletin, provided, however, that failure or delay in so publishing by the Department shall not in any way affect the date of imposition or validity of the ban.

(c) The Department, at the time of imposition of the ban, will give notice of the ban to a governmental entity which issues building permits in the area of the ban. No building permit which may result in a connection to the overloaded sewerage facilities or increase the load to those sewerage facilities shall be issued by a governmental entity after the ban is effective; provided, however, that failure or delay in the notification will not, in any way, affect the date of imposition or validity of the ban.

BAN MODIFICATION OR REMOVAL

Section 94.41. Elimination of overload.

A ban may be removed by the Department, in the exercise of its discretion, in accordance with the following conditions:

(1) If the permittee has demonstrated that steps have been taken which have resulted in the reduction of the actual loading to the plant to less than the capacity provided in the permit or, in the case of a sewer system, to eliminate the hydraulic overload, the ban may be removed to allow connections up to capacity.

(2) If it is affirmatively demonstrated, through the submission by the permittee and approval by the Department of an application for an amendment to the permit, that the actual capacity of the plant is in excess of the capacity provided in the existing permit and is sufficient to prevent an overload until additional capacity is made available, the ban may be removed to allow connections up to the new capacity.

Section 94.42. Reduction of overload.

(a) The Department may modify a ban to allow limited approval of connections if the permittee demonstrates that steps have been taken which have resulted in the reduction but not the elimination of the overload, that public health will not be endangered, and that downstream uses will not be adversely affected; provided that the permittee adheres to an acceptable program and schedule for eliminating the overload.

(b) Priority shall be given to connections in the following order:

(1) The elimination of public health hazards.

(2) The elimination of pollution.

(3) The connection of facilities of public need.

Section 94.51. Request for exception.

Exceptions to bans shall be requested in writing from the Regional Office of the Department for the county in which the requested exception is located and shall state with specificity the reasons why such request should be granted. No exception shall be considered granted until the applicant is so advised in writing by the Department.

Section 94.52. Limitations on exception.

The exceptions to a ban described in Sections 94.55 - 94.57 (relating to building permit issued prior to ban; replacement of a discharge; and other exceptions) are to be strictly construed and are the only exceptions the Department will allow.

Section 94.53. Transfer of exception.

The exceptions to a ban described in Sections 94.55 - 94.57 (relating to building permit issued prior to ban; replacement of a discharge; and other exceptions) are not transferable; an owner granted an exception under this title cannot transfer his right to discharge under that exception to another person or to another location, except as such transfer will result from a sale or other transfer of property for which an exception has been granted prior to the sale or other transfer of property.

Section 94.54. Sewer line extension.

Exceptions to a ban are limited to those exceptions which do not require the extension of existing sewer lines, except as needed for the elimination of public health hazards or pollution or for facilities of public need.

Section 94.55. Building permit issued prior to ban.

A discharge which the Department determines will result from a structure for which a valid building permit had been issued within 1 year prior to the date of imposition of the ban shall constitute an exception to the ban.

Section 94.56. Replacement of a discharge.

A new source of discharge which replaces a source of discharge forever eliminated as a result of demolition, destruction, accident, act of God or act of government shall constitute an exception to the ban if the Department determines that the following conditions are met:

(1) The new source of discharge is contained in a structure on the same property as the source of discharge which it has replaced.

(2) The new source of discharge will not generate a greater volume of wastewater flow or organic content than the source of discharge it has replaced.

Section 94.57. Other exceptions.

Connections which are necessary to eliminate a public health hazard or which are necessary for the operation of a facility of public need as the term is defined in Section 94.1 (relating to definitions) shall constitute an exception to a ban.

Sections 94.61 - 94.64. [Reserved]

Capacity, Management, Operation, and Maintenance (CMOM)

Issue Summary

The proposed CMOM regulations are part of the sanitary sewer overflow (SSO) regulations affecting some 19,000 sanitary sewer collection systems in cities, towns, and developments throughout the United States. Owners of all municipal wastewater collection systems would be required by the rules to develop procedures to improve system capacity, perform long-term planning for investments in infrastructure, develop better documentation and asset management procedures and then share all of this information with stakeholders more effectively.

Watershed management approaches are very compatible with CMOM programs.

The CMOM standard permit condition contains the following performance components for municipal sanitary sewer collection systems to help prevent and mitigate sewer overflows:

1. Development of proper management, operation and maintenance procedures and performance measurements for wastewater collection systems;
2. Implementation of asset management and long-term planning geared to provide adequate system capacity for base and peak flows in the collection system;
3. Documentation that all feasible steps to stop and mitigate impacts of sanitary sewer overflows (SSOs) have been taken;
4. Development of procedures to notify parties with reasonable potential of being exposed to pollutants from SSOs;
5. Performance of rigorous self-audits to assess the degree to which the performance measurements are being met;
6. Completion of CMOM program summary reports that are supplied to the regulators and made available to the public

There are four major documentation requirements of the CMOM permit. The frequency with which this documentation will be required will vary based on the size and complexity of the municipal wastewater collection system. Documentation requirements include:

1. A written summary of the CMOM Program
2. An Overflow Emergency Response Plan
3. A Program Audit Report
4. A System Evaluation and Capacity Assurance Plan

The CMOM Program Summary will provide authorities with the information to begin a regulatory evaluation of the permittee's program as well as to provide an overview of the system for the public to review. The CMOM Program Summary should address all elements of a comprehensive CMOM program, which include the following:

- System performance goals and measures
- Detailed organization charts and the assignment of responsibilities within the organization
- Legal authority to implement the program components including:
  >Control of infiltration and inflow
  >Application of proper design and construction methods for wastewater collection systems
  >Address flows from municipal satellite collection systems
  >Implement prohibitions of the national pretreatment program (40 CFR 403.5)
- Implementation of specific measures and activities to meet standards including:
  > Provide adequate maintenance of facilities and equipment

> Maintain accurate collection system maps
> Develop procedures to provide managers with timely relevant information from staff in the field
> Conduct routine, on-going preventive operation and maintenance activities
> Design and implement an ongoing program to access the capacity of the collection system and treatment facility that includes new and existing connections
> Perform ongoing activities to identify structural deficiencies and rehabilitation actions
> Conduct collection system employee training
> Maintain a parts inventory and availability

The Overflow Emergency Response Plan provides a standardized course of action to follow in the event of an SSO. At a minimum the plan will need to address mechanisms to:

- Identify SSOs
- Provide immediate response of appropriate personnel to investigate and mitigate the overflow event to minimize the effect on public health as soon as possible
- Provide immediate notification to all affected including the public, health officials, the NPDES authority, and others
- Ensure personnel are trained to implement the plan

A comprehensive **Program Audit Report** provides for ongoing assessment of the CMOM program and collection system performance and should be conducted at a minimum every five years. Elements of the report include:

- Interviews with facility managers Field inspection of equipment and other resources Interviews with field personnel and first line supervisors, and observation of field crews
- Review of pertinent records and information management systems

The System Evaluation **and Capacity Assurance Plan** is needed to identify, characterize and address hydraulic deficiencies in a wastewater collection system. Generally the plan should address the following:

- Collecting and analyzing appropriate information on the management and performance of a wastewater collection system
- Development of management and performance objectives and goals of the collection system
- Clarification of management and performance objectives, developing and evaluating alternatives, and selecting measures
- Implementation of measures
- Continued monitoring, assessment, and adjustment of implemented measures

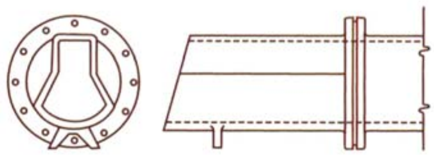
The above CMOM program requirements can reflect watershed considerations in two ways:

1. CMOM activities may be prioritized based on risk.
2. Water quality improvement projects in the permittee's capital improvement plan may be considered when developing schedules for long-term activities.

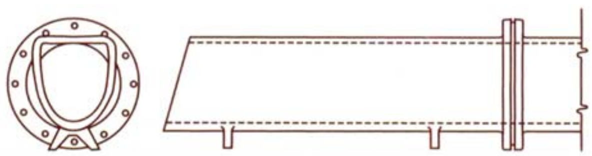
Water Environment Federation
601 Wythe Street, Alexandria, VA, 22314-1994 USA
Tel. 1-800-666-0206 (U.S. and Canada)
Tel. 1-703-684-2452 (Outside the U.S. and Canada)
Fax. 1-703-684-2492

ISCO Figures and Tables

Figures and tables taken with permission from Douglas M. Grant and Brian D. Dawson, *ISCO Open Channel Flow Measurement Handbook,* Fifth Edition, (P.O. Box 82531, Lincoln, NE 68501-2531, 2001).



A. Kennison nozzle (Q proportional to H)



B. Parabolic nozzle (Q proportional to H^2)

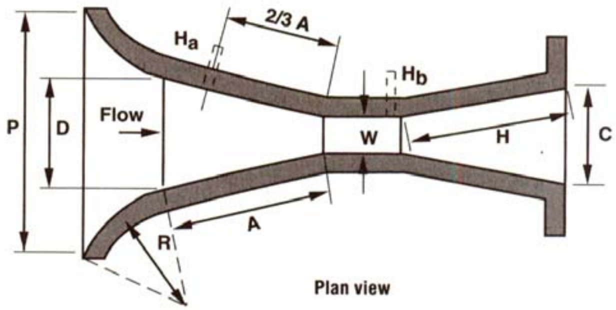
Figure 3-9: Open Flow Nozzles

Table 3-8:
Dimensions and Approximate Capacities for Kennison Nozzles

Nozzle diameter		Nozzle length		Approximate maximum capacity				
inches	mm	inches	mm	CFS	GPM	MGD	l/s	m^3/hr
6	150	12	300	0.45	200	0.29	13	45
8	200	16	410	0.71	320	0.45	20	73
10	250	20	510	1.2	560	0.80	35	130
12	300	24	610	1.9	850	1.2	54	190
16	410	32	810	4.2	1900	2.7	120	430
20	510	40	1020	6.9	3100	4.5	200	700
24	610	48	1220	12	5200	7.5	330	1200
30	760	60	1520	19	8500	12	540	1900
36	910	72	1830	31	14,000	20	880	3200

Table 3-9:
Dimensions and Approximate Capacities for Parabolic Nozzles

Nozzle diameter		Nozzle length		Approximate maximum capacity				
inches	mm	inches	mm	CFS	GPM	MGD	l/s	m^3/hr
6	150	30	760	0.40	180	0.26	11	41
8	200	35	890	0.89	400	0.55	25	91
10	250	40	1020	1.8	800	1.2	50	180
12	300	47	1190	2.5	1100	1.5	69	250
14	360	53	1350	3.6	1600	2.5	100	360
16	410	59	1500	4.7	2100	3.0	130	480
18	460	68	1730	5.8	2600	4.0	160	590
20	510	75	1910	8.3	3700	5.3	230	840
24	610	84	2130	16	7000	10	440	1600



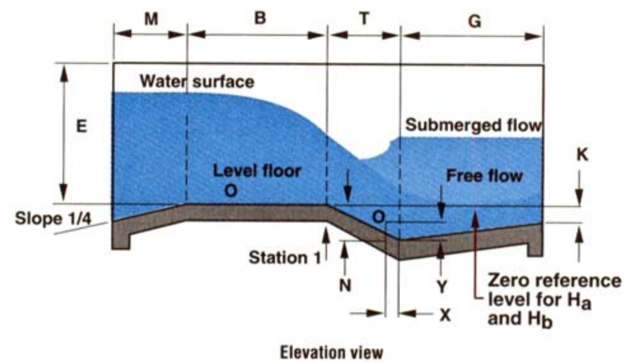


Table 4-1 A: Parshall Flume Dimensions in Inches and Feet for Various Throat Widths, W

W	A	⅔A	B	C	D	E	T	G	H	K	M	N	P	R	X	Y
1"	1' 2-9/32"	9-17/32"	1'2"	3-21/32"	6-19/32"	6" to 9"	3"	8"	8-1/8"	3/4"		1-1/8"			5/16"	1/2"
2"	1' 4-5/16"	10-7/8"	1' 4"	5-5/16"	8-13/32"	6" to 10"	4-1/2"	10"	10-1/8"	7/8"		1-11/16"			5/8"	1"
3"	1' 6-3/8"	1' 1/4"	1' 6"	7"	10-3/16"	1' to 1' 6"	6"	1'	1' 5/32"	1"		2-1/4"			1"	1-1/2"
6"	2' 7/16"	1' 4-5/16"	2'	1' 3-1/2"	1' 3-5/8"	2'	1'	2'		3"	1'	4-1/2"	2' 11-1/2"	1' 4"	2"	3"
9"	2' 10-5/8"	1' 11-1/8"	2' 10"	1' 3"	1' 10-5/8"	2' 6"	1'	1' 6"		3"	1'	4-1/2"	3' 6-1/2"	1' 4"	2"	3"
1'	4' 6"	3'	4' 4-7/8"	2'	2' 9-1/4"	3'	2'	3'		3"	1' 3"	9"	4' 10-3/4"	1' 8"	2"	3"
1' 6"	4' 9"	3' 2"	4' 7-7/8"	2' 6"	3' 4-3/8"	3'	2'	3'		3"	1' 3"	9"	5' 6"	1' 8"	2"	3"
2'	5'	3' 4"	4' 10-7/8"	3'	3' 11-1/2"	3'	2'	3'		3"	1' 3"	9"	6' 1"	1' 8"	2"	3"
3'	5' 6"	3' 8"	5' 4-3/4"	4'	5' 1-7/8"	3'	2'	3'		3"	1' 3"	9"	7' 3-1/2"	1' 8"	2"	3"
4'	6'	4'	5' 10-5/8"	5'	6' 4-1/4"	3'	2'	3'		3"	1' 6"	9"	8' 10-3/4"	2'	2"	3"
5'	6' 6"	4' 4"	6' 4-1/2"	6'	7' 6-5/8"	3'	2'	3'		3"	1' 6"	9"	10' 1-1/4"	2'	2"	3"
6'	7'	4' 8"	6' 10-3/8"	7'	8' 9"	3'	2'	3'		3"	1' 6"	9"	11' 3-1/2"	2'	2"	3"
7'	7' 6"	5'	7' 4-1/4"	8'	9' 11-3/8"	3'	2'	3'		3"	1' 6"	9"	12' 6"	2'	2"	3"
8'	8'	5' 4"	7' 10-1/8"	9'	11' 1-3/4"	3'	2'	3'		3"	1' 6"	9"	13' 8-1/4"	2'	2"	3"
10'		6'	14'	12'	15' 7-1/4"	4'	3'	6'		6"		1' 1-1/2"			1'	9"
12'		6' 8"	16'	14' 8"	18' 4-3/4"	5'	3'	8'		6"		1' 1-1/2"			1'	9"
15'		7' 8"	25'	18' 4"	25'	6'	4'	10'		9"		1' 6"			1'	9"
20'		9' 4"	25'	24'	30'	7'	6'	12'		1'		2' 3"			1'	9"
25'		11'	25'	29' 4"	35'	7'	6'	13'		1'		2' 3"			1'	9"
30'		12' 8"	26'	34' 8"	40' 4-3/4"	7'	6'	14'		1'		2' 3"			1'	9"
40'		16'	27'	45' 4"	50' 9-1/2"	7'	6'	16'		1'		2' 3"			1'	9"
50'		19' 4"	27'	56' 8"	60' 9-1/2"	7'	6'	20'		1'		2' 3"			1'	9"

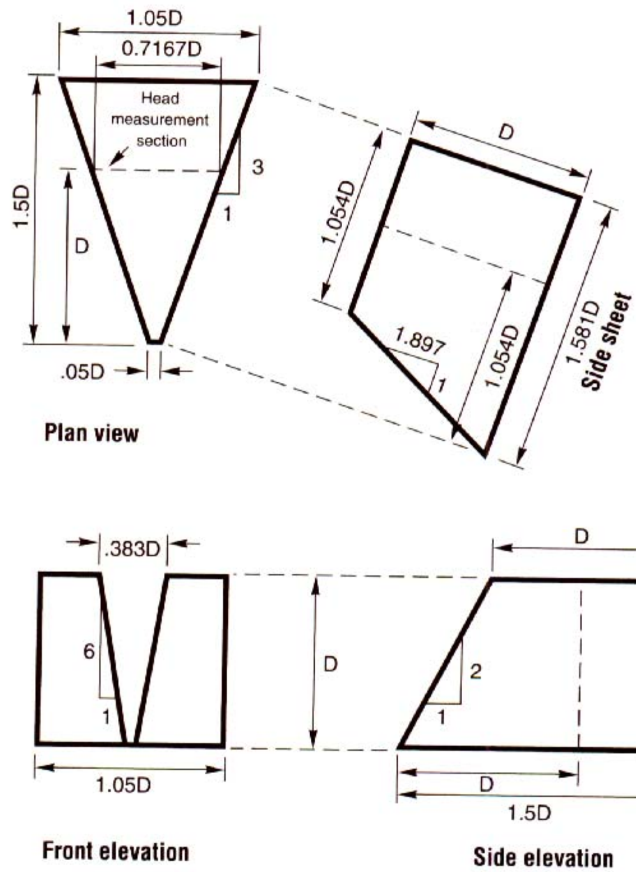
Table 4-2 A:
Minimum and Maximum Recommended Flow Rates for Free Flow through Parshall Flumes with Head in Feet

Throat width, W	Min. head, feet	Minimum flow rate			Max. head, feet	Maximum flow rate		
in./ft.		CFS	GPM	MGD		CFS	GPM	MGD
1 in.	0.10	0.010	4.28	0.006	0.70	0.194	87.3	0.126
2 in.	0.10	0.019	8.55	0.012	0.80	0.478	215	0.309
3 in.	0.10	0.028	12.6	0.018	1.10	1.15	516	0.743
6 in.	0.10	0.054	24.3	0.035	1.50	3.91	1750	2.53
9 in.	0.10	0.091	40.7	0.059	2.00	8.87	3980	5.73
1 ft.	0.10	0.120	54.0	0.078	2.50	16.1	7240	10.4
1½ ft.	0.10	0.174	78.0	0.112	2.50	24.6	11,000	15.9
2 ft.	0.15	0.423	190	0.273	2.50	33.1	14,900	21.4
3 ft.	0.15	0.615	276	0.398	2.50	50.4	22,600	32.6
4 ft.	0.20	1.26	567	0.816	2.50	67.9	30,500	43.9
5 ft.	0.20	1.56	698	1.01	2.50	85.6	38,400	55.4
6 ft.	0.25	2.63	1180	1.70	2.50	103	46,400	66.9
8 ft.	0.25	3.45	1550	2.23	2.50	140	62,600	90.2
10 ft.	0.30	5.74	2570	3.71	2.75	199	89,200	128
12 ft.	0.33	7.93	3560	5.13	3.50	347	156,000	224

Table 4-2 B:
Minimum and Maximum Recommended Flow Rates for Free Flow through Parshall Flumes with Head in Meters

Throat width, W		Min. head, meters	Minimum flow rate		Max. head, meters	Maximum flow rate	
in./ft.	meters		l/s	m^3/hr		l/s	m^3/hr
1 in.	0.0254	0.03	0.263	0.948	0.20	4.98	17.9
2 in.	0.0508	0.03	0.526	1.90	0.25	14.1	50.7
3 in.	0.0762	0.03	0.778	2.80	0.35	34.8	125
6 in.	0.152	0.03	1.50	5.39	0.45	108	389
9 in.	0.229	0.03	2.50	9.01	0.60	245	882
1 ft.	0.305	0.03	3.32	12.0	0.75	446	1610
1½ ft.	0.457	0.03	4.80	17.3	0.75	678	2440
2 ft.	0.610	0.045	11.7	42.0	0.75	915	3290
3 ft.	0.914	0.045	17.0	61.2	0.75	1390	5010
4 ft.	1.22	0.06	34.9	125	0.75	1880	6750
5 ft.	1.52	0.06	42.9	155	0.75	2360	8510
6 ft.	1.83	0.075	72.6	261	0.75	2860	10,300
8 ft.	2.44	0.075	95.2	343	0.75	3850	13,900
10 ft.	3.05	0.09	158	570	0.85	5750	20,700
12 ft.	3.66	0.10	223	801	1.05	9580	34,500

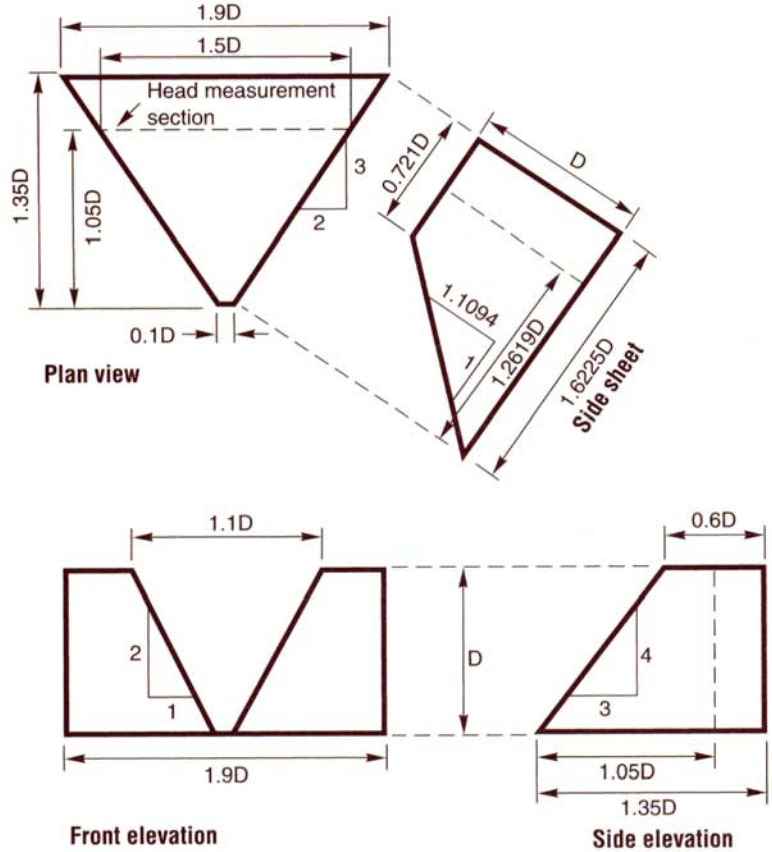
Depth D	
feet	meters
0.4	0.122
0.6	0.183
0.8	0.244
1.0	0.305



HS Flume

Figure 4-11 A: Dimensions of H-type Flumes

Depth D	
feet	meters
0.5	0.152
0.75	0.229
1.0	0.305
1.5	0.457
2.0	0.610
2.5	0.762
3.0	0.914
4.5	1.37

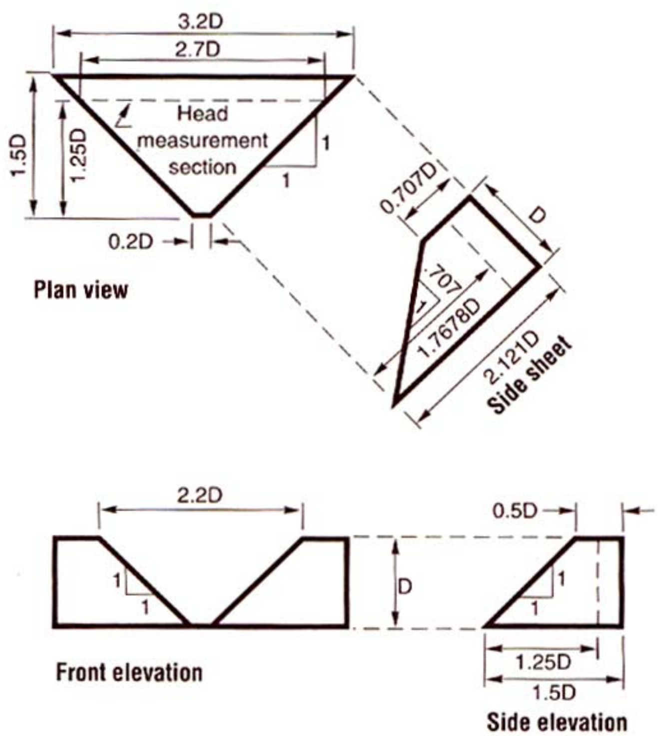


H Flume

Figure 4-11 B: Dimensions of H-type Flumes

Depth D	
feet	meters
2.0	0.610
2.5	0.762
3.0	0.914
3.5	1.07
4.0	1.22

Note: Only the 4.0 foot (1.22 m) HL flume is recommended because smaller flows are measured more accurately with an H flume.



HL Flume

Figure 4-11 C: Dimensions of H-type Flumes

Table 5-3 A: Useful Flow Rate Range of Various Types of Weirs in Feet

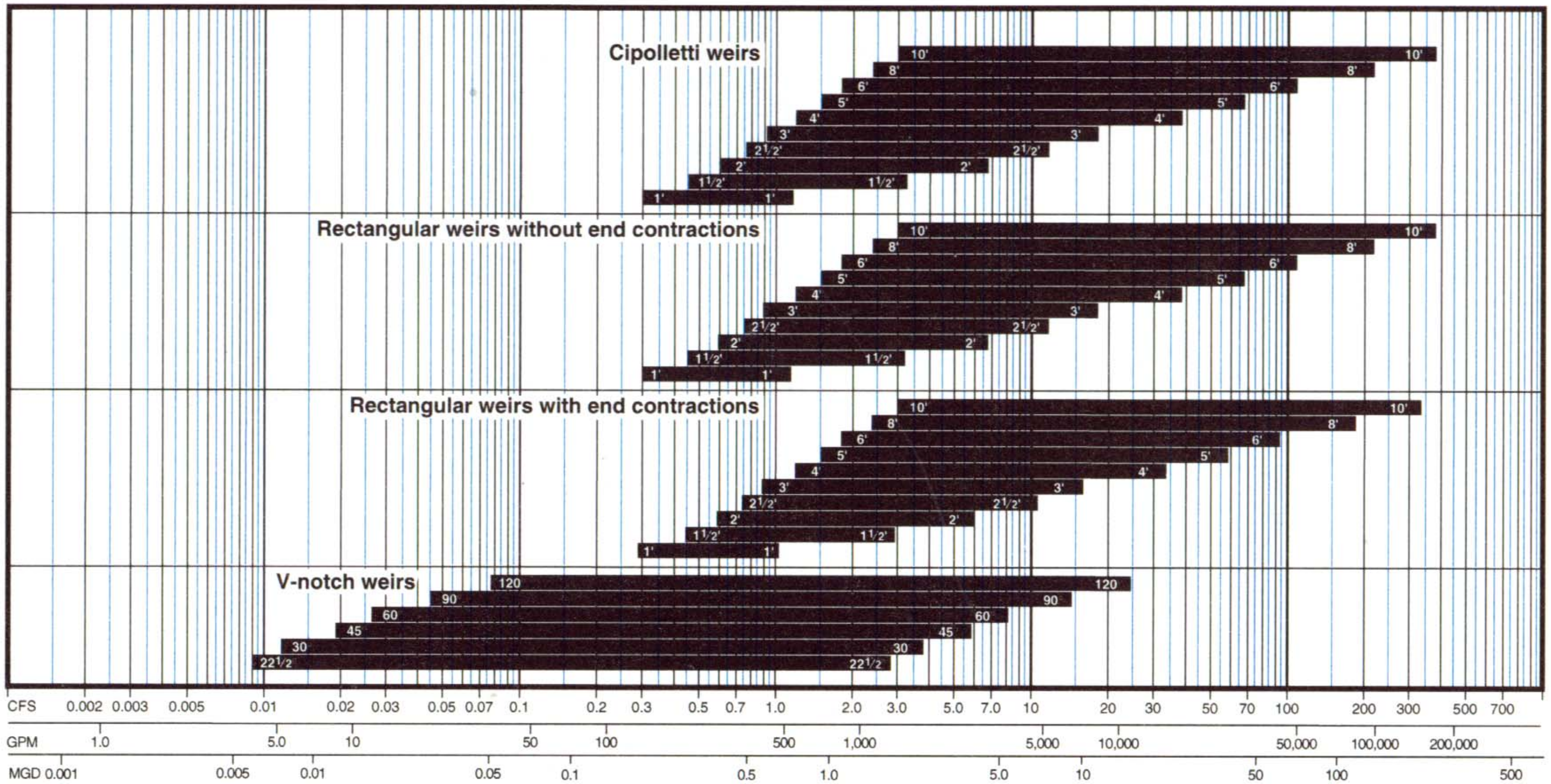


Table 5-3 B: Useful Flow Rate Range of Various Types of Weirs in Meters

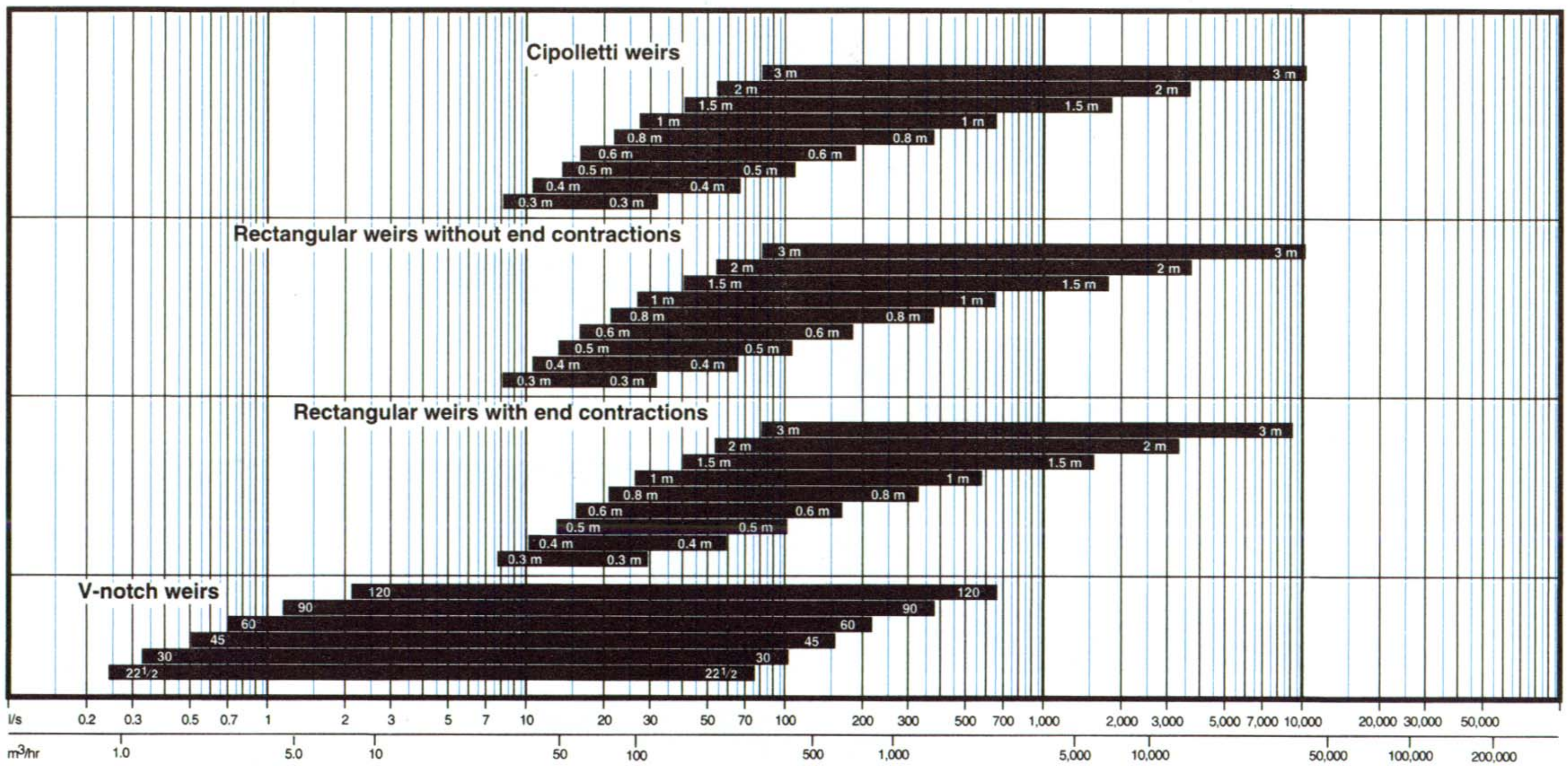


Table 5-4: Useful Flow Rate Range of Various Types of Flumes

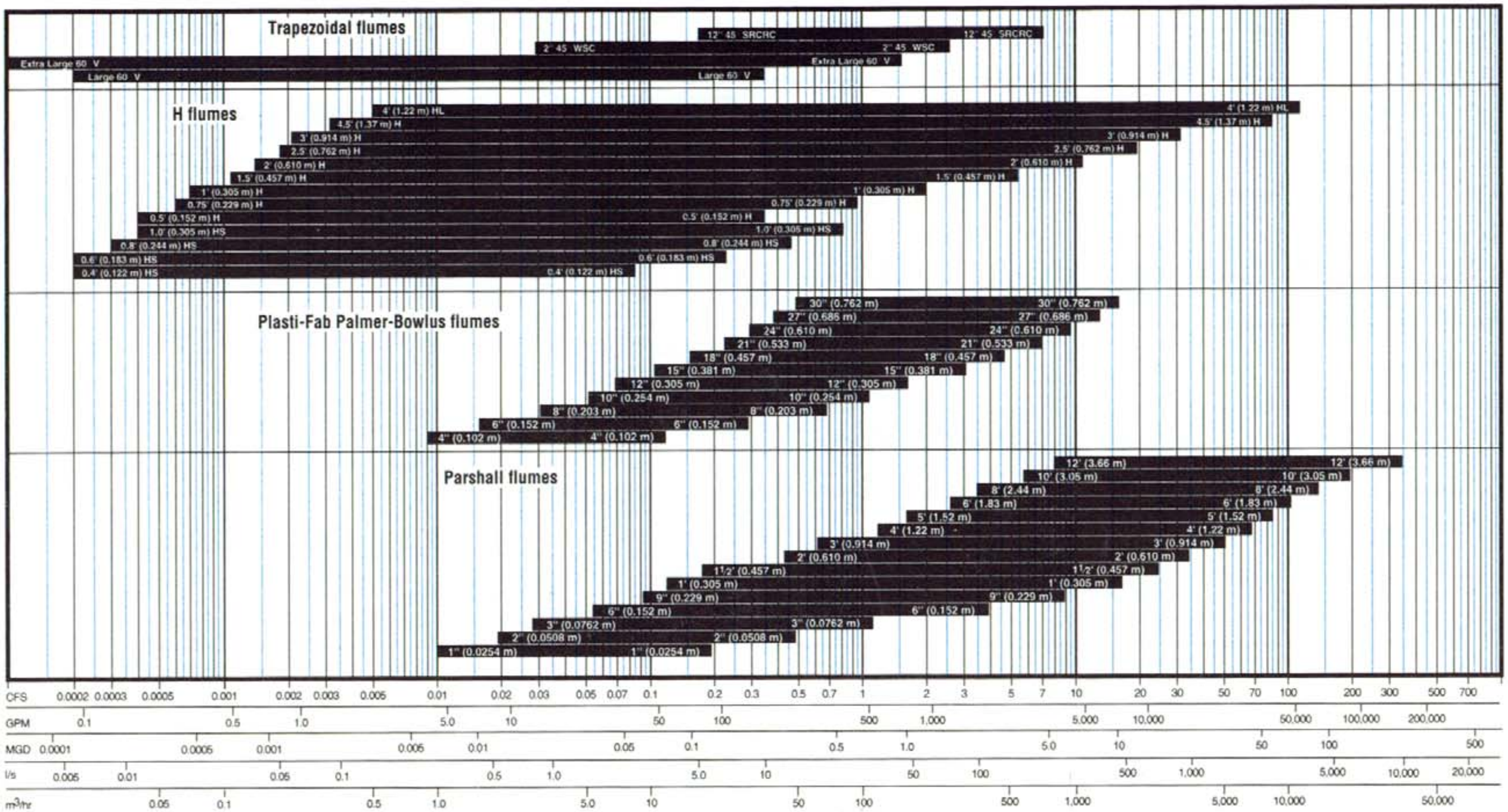


Table 6-1:
Manning Roughness Coefficient "n" for Various Channel Configurations and Conditions

Description of channel	Min.	Norm.	Max.
I. Closed conduit—partly full			
A. Metal			
1. Steel			
a. Lockbar and welded	0.010	0.012	0.014
b. Riveted and spiral	0.013	0.016	0.017
2. Cast Iron			
a. Coated	0.010	0.013	0.014
b. Uncoated	0.011	0.014	0.016
3. Wrought Iron			
a. Black	0.012	0.014	0.015
b. Galvanized	0.013	0.016	0.017
4. Corrugated			
a. Subdrain	0.017	0.019	0.021
b. Storm drain	0.021	0.024	0.030
B. Nonmetal			
1. Acrylic	0.008	0.009	0.010
2. Glass	0.009	0.010	0.013
3. Wood			
a. Stave	0.010	0.012	0.014
b. Laminated, treated	0.015	0.017	0.020
4. Clay			
a. Common drainage tile	0.011	0.013	0.017
b. Vitrified sewer	0.011	0.014	0.017
c. Vitrified sewer with manholes, inlets, etc.	0.013	0.015	0.017
5. Brick			
a. Glazed	0.011	0.013	0.015
b. Lined with cement	0.012	0.015	0.017
6. Concrete			
a. Culvert, straight and free of debris	0.010	0.011	0.013
b. Culvert with bends, connections, and some debris	0.011	0.013	0.014
c. Sewer with manholes, inlet, etc., straight	0.013	0.015	0.017
d. Unfinished, steel form	0.012	0.013	0.014
e. Unfinished, smooth wood form	0.012	0.014	0.016
f. Unfinished, rough wood form	0.015	0.017	0.020
7. Sanitary sewers coated with sewage slimes	0.012	0.013	0.016
8. Paved invert, sewer, smooth bottom	0.016	0.019	0.020
9. Rubble masonry, cemented	0.018	0.025	0.030

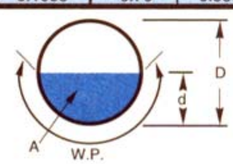
continued on the next page

Table 6-1:
Manning Roughness Coefficient "n" for Various Channel Configurations and Conditions *(continued)*

Description of channel	Min.	Norm.	Max.
II. Lined or built-up channels			
A. Metal			
1. Smooth steel surface			
a. Painted	0.011	0.012	0.014
b. Unpainted	0.012	0.013	0.017
2. Corrugated	0.021	0.025	0.030
B. Nonmetal			
1. Cement			
a. Neat surface	0.010	0.011	0.013
b. Mortar	0.011	0.013	0.015
2. Concrete			
a. Trowel finish	0.011	0.013	0.015
b. Float finish	0.013	0.015	0.016
c. Finished, with gravel on bottom	0.015	0.017	0.020
d. Unfinished	0.014	0.017	0.020
3. Wood			
a. Planed, untreated	0.010	0.012	0.014
b. Planed, creosoted	0.011	0.012	0.015
c. Unplaned	0.011	0.013	0.015
d. Plank with battens	0.012	0.015	0.018
4. Brick			
a. Glazed	0.011	0.013	0.015
b. In cement mortar	0.012	0.015	0.018
5. Masonry			
a. Cemented rubble	0.017	0.025	0.030
b. Dry rubble	0.023	0.032	0.035
6. Asphalt			
a. Smooth	0.013	0.013	—
b. Rough	0.016	0.016	—
7. Vegetal lining	0.030	—	0.500
III. Excavated or dredged			
A. Earth, straight and uniform	0.016	0.022	0.035
B. Earth, winding and sluggish	0.023	0.030	0.040
C. Rock cuts	0.030	0.040	0.050
D. Unmaintained channels	0.040	0.070	0.140
IV. Natural channels (Minor streams, top width at flood 100 ft.)			
A. Fairly regular section	0.030	0.050	0.070
B. Irregular section with pools	0.040	0.070	0.100

Table 6-2: Area and Hydraulic Radius for Various Flow Depths

d / D	A / D²	R / D	d / D	A / D²	R / D	d / D	A / D²	R / D
0.01	0.0013	0.0066	0.36	0.2546	0.1978	0.71	0.5964	0.2973
0.02	0.0037	0.0132	0.37	0.2642	0.2020	0.72	0.6054	0.2984
0.03	0.0069	0.0197	0.38	0.2739	0.2061	0.73	0.6143	0.2995
0.04	0.0105	0.0262	0.39	0.2836	0.2102	0.74	0.6231	0.3006
0.05	0.0147	0.0326	0.40	0.2934	0.2142	0.75	0.6318	0.3017
0.06	0.0192	0.0389	0.41	0.3032	0.2181	0.76	0.6404	0.3025
0.07	0.0242	0.0451	0.42	0.3130	0.2220	0.77	0.6489	0.3032
0.08	0.0294	0.0513	0.43	0.3229	0.2257	0.78	0.6573	0.3037
0.09	0.0350	0.0574	0.44	0.3328	0.2294	0.79	0.6655	0.3040
0.10	0.0409	0.0635	0.45	0.3428	0.2331	0.80	0.6736	0.3042
0.11	0.0470	0.0695	0.46	0.3527	0.2366	0.81	0.6815	0.3044
0.12	0.0534	0.0754	0.47	0.3627	0.2400	0.82	0.6893	0.3043
0.13	0.0600	0.0813	0.48	0.3727	0.2434	0.83	0.6969	0.3041
0.14	0.0668	0.0871	0.49	0.3827	0.2467	0.84	0.7043	0.3038
0.15	0.0739	0.0929	0.50	0.3927	0.2500	0.85	0.7115	0.3033
0.16	0.0811	0.0986	0.51	0.4027	0.2531	0.86	0.7186	0.3026
0.17	0.0885	0.1042	0.52	0.4127	0.2561	0.87	0.7254	0.3017
0.18	0.0961	0.1097	0.53	0.4227	0.2591	0.88	0.7320	0.3008
0.19	0.1039	0.1152	0.54	0.4327	0.2620	0.89	0.7384	0.2996
0.20	0.1118	0.1206	0.55	0.4426	0.2649	0.90	0.7445	0.2980
0.21	0.1199	0.1259	0.56	0.4526	0.2676	0.91	0.7504	0.2963
0.22	0.1281	0.1312	0.57	0.4625	0.2703	0.92	0.7560	0.2944
0.23	0.1365	0.1364	0.58	0.4723	0.2728	0.93	0.7612	0.2922
0.24	0.1449	0.1416	0.59	0.4822	0.2753	0.94	0.7662	0.2896
0.25	0.1535	0.1466	0.60	0.4920	0.2776	0.95	0.7707	0.2864
0.26	0.1623	0.1516	0.61	0.5018	0.2797	0.96	0.7749	0.2830
0.27	0.1711	0.1566	0.62	0.5115	0.2818	0.97	0.7785	0.2787
0.28	0.1800	0.1614	0.63	0.5212	0.2839	0.98	0.7816	0.2735
0.29	0.1890	0.1662	0.64	0.5308	0.2860	0.99	0.7841	0.2665
0.30	0.1982	0.1709	0.65	0.5404	0.2881	1.00	0.7854	0.2500
0.31	0.2074	0.1755	0.66	0.5499	0.2899			
0.32	0.2167	0.1801	0.67	0.5594	0.2917			
0.33	0.2260	0.1848	0.68	0.5687	0.2935			
0.34	0.2355	0.1891	0.69	0.5780	0.2950			
0.35	0.2450	0.1935	0.70	0.5872	0.2962			



A = Area of flow

R = Hydraulic radius

$= \frac{A}{W.P.}$

TABLE 6-4
Characteristics of flow-metering devices used in wastewater treatment facilities[a]

Metering device	Range[b]	Accuracy,[b] percent of actual rate	Repeatability[b] percent of full scale	Straight upstream run in pipe diameters
For open channels				
Head/area				
Flume	10:1–75:1[c]	±5–10[d]	±0.5	
Weir	500:1	±5	±0.5[g]	
Other				
Magnetic (insert type)	10:1	±1–2[e]	±0.5	
Velocity-head				
For closed conduits				
Head/pressure				
Flow tube	4:1	±.3	±0.5	4–10[f]
Orifice	4:1	±1	±1	±5[g]
Pitot tube	3:1	±3	±1[g]	10[g]
Rotameter	10:1	0.5–10	1[g]	5[g]
Venturi meter	4:1	±1	±0.5	4–10[f]
Moving fluid effects				
Magnetic (tube type)	10:1	±1–2[e]	±0.5	5
Magnetic (insert type)	10:1	±1–2[e]	±0.5	5
Target	10:1	±5	1[f]	20
Ultrasonic (Doppler)	10:1	±3	±1	7–10
Ultrasonic (transmission)	10:1	±2	±1	7–10
Vortex shedding	15:1	±1	±0.5	10
Positive displacement				
Propeller	10:1	±2	±0.5	5
Turbine	10:1	±0.25	±0.05	10[h]

[a] Based on industry practice and engineering judgement.

[b] Based on both the primary element and primary conversion device.

[c] Depends on the type of flume.

[d] Parshall flumes ±5%, Palmer-Bowlus flume ±10%.

[e] Of full scale.

[f] Depends on the type of flow-disturbing obstruction.

[g] Estimated.

[h] Assuming that flow straightening is used (25 to 30 pipe diameters, otherwise).

Table 9-3:
45° V-notch Weir Discharge Table with Head in Feet

Formulas: $CFS = 1.035\ H^{2.5}$ $MGD = 0.6689\ H^{2.5}$
$GPM = 464.5\ H^{2.5}$
Where: H = head in feet

Head (feet)	CFS	GPM	MGD	Head (feet)	CFS	GPM	MGD
0.01				0.51	0.1922	86.28	0.1242
0.02				0.52	0.2018	90.57	0.1304
0.03				0.53	0.2117	94.99	0.1368
0.04				0.54	0.2218	99.53	0.1433
0.05				0.55	0.2322	104.2	0.1501
0.06				0.56	0.2429	109.0	0.1570
0.07				0.57	0.2539	113.9	0.1641
0.08				0.58	0.2652	119.0	0.1714
0.09				0.59	0.2767	124.2	0.1789
0.10				0.60	0.2886	129.5	0.1865
0.11				0.61	0.3008	135.0	0.1944
0.12				0.62	0.3133	140.6	0.2025
0.13				0.63	0.3261	146.3	0.2107
0.14				0.64	0.3391	152.2	0.2192
0.15				0.65	0.3526	158.2	0.2278
0.16				0.66	0.3663	164.4	0.2367
0.17				0.67	0.3803	170.7	0.2458
0.18				0.68	0.3947	177.1	0.2551
0.19				0.69	0.4093	183.7	0.2645
0.20	0.0185	8.309	0.0120	0.70	0.4243	190.4	0.2742
0.21	0.0209	9.387	0.0135	0.71	0.4396	197.3	0.2841
0.22	0.0235	10.54	0.0152	0.72	0.4553	204.3	0.2942
0.23	0.0263	11.78	0.0170	0.73	0.4712	211.5	0.3046
0.24	0.0292	13.11	0.0189	0.74	0.4876	218.8	0.3151
0.25	0.0323	14.52	0.0209	0.75	0.5042	226.3	0.3258
0.26	0.0357	16.01	0.0231	0.76	0.5212	233.9	0.3368
0.27	0.0392	17.60	0.0253	0.77	0.5385	241.7	0.3480
0.28	0.0429	19.27	0.0277	0.78	0.5561	249.6	0.3594
0.29	0.0469	21.04	0.0303	0.79	0.5741	257.7	0.3710
0.30	0.0510	22.90	0.0330	0.80	0.5925	265.9	0.3829
0.31	0.0554	24.85	0.0358	0.81	0.6112	274.3	0.3950
0.32	0.0600	26.91	0.0387	0.82	0.6302	282.8	0.4073
0.33	0.0647	29.06	0.0418	0.83	0.6496	291.5	0.4198
0.34	0.0698	31.31	0.0451	0.84	0.6693	300.4	0.4326
0.35	0.0750	33.66	0.0485	0.85	0.6894	309.4	0.4456
0.36	0.0805	36.12	0.0520	0.86	0.7099	318.6	0.4588
0.37	0.0862	38.68	0.0557	0.87	0.7307	327.9	0.4722
0.38	0.0921	41.35	0.0595	0.88	0.7519	337.4	0.4859
0.39	0.0983	44.12	0.0635	0.89	0.7734	347.1	0.4998
0.40	0.1047	47.00	0.0677	0.90	0.7953	356.9	0.5140
0.41	0.1114	50.00	0.0720	0.91	0.8176	366.9	0.5284
0.42	0.1183	53.10	0.0765	0.92	0.8403	377.1	0.5430
0.43	0.1255	56.32	0.0811	0.93	0.8633	387.4	0.5579
0.44	0.1329	59.65	0.0859	0.94	0.8867	397.9	0.5730
0.45	0.1406	63.10	0.0909	0.95	0.9104	408.6	0.5884
0.46	0.1485	66.66	0.0960	0.96	0.9346	419.4	0.6040
0.47	0.1567	70.34	0.1013	0.97	0.9591	430.4	0.6199
0.48	0.1652	74.15	0.1068	0.98	0.9840	441.6	0.6360
0.49	0.1740	78.07	0.1124	0.99	1.009	453.0	0.6523
0.50	0.1830	82.11	0.1182	1.00	1.035	464.5	0.6689

Table 9-4:
60° V-notch Weir Discharge Table with Head in Feet

Formulas: $CFS = 1.443\ H^{2.5}$ $MGD = 0.9326\ H^{2.5}$
$GPM = 647.6\ H^{2.5}$
Where: H = head in feet

Head (feet)	CFS	GPM	MGD	Head (feet)	CFS	GPM	MGD
0.01				0.51	0.2680	120.3	0.1732
0.02				0.52	0.2814	126.3	0.1818
0.03				0.53	0.2951	132.4	0.1907
0.04				0.54	0.3092	138.8	0.1998
0.05				0.55	0.3237	145.3	0.2092
0.06				0.56	0.3386	152.0	0.2189
0.07				0.57	0.3540	158.9	0.2288
0.08				0.58	0.3697	165.9	0.2389
0.09				0.59	0.3858	173.2	0.2494
0.10				0.60	0.4024	180.6	0.2601
0.11				0.61	0.4194	188.2	0.2710
0.12				0.62	0.4368	196.0	0.2823
0.13				0.63	0.4546	204.0	0.2938
0.14				0.64	0.4728	212.2	0.3056
0.15				0.65	0.4915	220.6	0.3177
0.16				0.66	0.5107	229.2	0.3300
0.17				0.67	0.5302	238.0	0.3427
0.18				0.68	0.5502	246.9	0.3556
0.19				0.69	0.5707	256.1	0.3688
0.20	0.0258	11.58	0.0167	0.70	0.5916	265.5	0.3823
0.21	0.0292	13.09	0.0188	0.71	0.6129	275.1	0.3961
0.22	0.0328	14.70	0.0212	0.72	0.6347	284.9	0.4102
0.23	0.0366	16.43	0.0237	0.73	0.6570	294.9	0.4246
0.24	0.0407	18.27	0.0263	0.74	0.6797	305.1	0.4393
0.25	0.0451	20.24	0.0291	0.75	0.7029	315.5	0.4543
0.26	0.0497	22.32	0.0321	0.76	0.7266	326.1	0.4696
0.27	0.0547	24.53	0.0353	0.77	0.7507	336.9	0.4852
0.28	0.0599	26.87	0.0387	0.78	0.7754	348.0	0.5011
0.29	0.0654	29.33	0.0422	0.79	0.8004	359.2	0.5173
0.30	0.0711	31.92	0.0460	0.80	0.8260	370.7	0.5339
0.31	0.0772	34.65	0.0499	0.81	0.8521	382.4	0.5507
0.32	0.0836	37.51	0.0540	0.82	0.8786	394.3	0.5678
0.33	0.0903	40.51	0.0583	0.83	0.9057	406.4	0.5853
0.34	0.0973	43.65	0.0629	0.84	0.9332	418.8	0.6031
0.35	0.1046	46.93	0.0676	0.85	0.9612	431.4	0.6212
0.36	0.1122	50.36	0.0725	0.86	0.9897	444.2	0.6396
0.37	0.1202	53.93	0.0777	0.87	1.019	457.2	0.6584
0.38	0.1284	57.65	0.0830	0.88	1.048	470.5	0.6775
0.39	0.1371	61.51	0.0886	0.89	1.078	483.9	0.6969
0.40	0.1460	65.53	0.0944	0.90	1.109	497.6	0.7166
0.41	0.1553	69.71	0.1004	0.91	1.140	511.6	0.7367
0.42	0.1650	74.03	0.1066	0.92	1.171	525.7	0.7571
0.43	0.1750	78.52	0.1131	0.93	1.204	540.1	0.7779
0.44	0.1853	83.16	0.1198	0.94	1.236	554.8	0.7989
0.45	0.1960	87.97	0.1267	0.95	1.269	569.7	0.8204
0.46	0.2071	92.94	0.1338	0.96	1.303	584.8	0.8421
0.47	0.2185	98.07	0.1412	0.97	1.337	600.1	0.8642
0.48	0.2303	103.4	0.1489	0.98	1.372	615.7	0.8867
0.49	0.2425	108.8	0.1567	0.99	1.407	631.5	0.9095
0.50	0.2551	114.5	0.1649	1.00	1.443	647.6	0.9326

Table 9-4:
60° V-notch Weir Discharge Table with Head in Feet *(continued)*

Formulas: $CFS = 1.443\ H^{2.5}$ $MGD = 0.9326\ H^{2.5}$
$GPM = 647.6\ H^{2.5}$
Where: H = head in feet

Head (feet)	CFS	GPM	MGD	Head (feet)	CFS	GPM	MGD
1.01	1.479	663.9	0.9561	1.51	4.043	1814	2.613
1.02	1.516	680.5	0.9799	1.52	4.110	1845	2.656
1.03	1.554	697.3	1.004	1.53	4.178	1875	2.700
1.04	1.592	714.3	1.029	1.54	4.247	1906	2.745
1.05	1.630	731.6	1.054	1.55	4.316	1937	2.789
1.06	1.669	749.2	1.079	1.56	4.386	1968	2.835
1.07	1.709	766.9	1.104	1.57	4.457	2000	2.880
1.08	1.749	785.0	1.130	1.58	4.528	2032	2.926
1.09	1.790	803.3	1.157	1.59	4.600	2064	2.973
1.10	1.831	821.8	1.184	1.60	4.673	2097	3.020
1.11	1.873	840.6	1.211	1.61	4.746	2130	3.067
1.12	1.916	859.7	1.238	1.62	4.820	2163	3.115
1.13	1.959	879.0	1.266	1.63	4.895	2197	3.163
1.14	2.002	898.6	1.294	1.64	4.970	2231	3.212
1.15	2.046	918.4	1.323	1.65	5.046	2265	3.261
1.16	2.091	938.5	1.352	1.66	5.123	2299	3.311
1.17	2.137	958.9	1.381	1.67	5.201	2334	3.361
1.18	2.183	979.5	1.411	1.68	5.279	2369	3.412
1.19	2.229	1000	1.441	1.69	5.358	2404	3.463
1.20	2.276	1022	1.471	1.70	5.437	2440	3.514
1.21	2.324	1043	1.502	1.71	5.518	2476	3.566
1.22	2.372	1065	1.533	1.72	5.599	2513	3.618
1.23	2.421	1087	1.565	1.73	5.680	2549	3.671
1.24	2.471	1109	1.597	1.74	5.763	2586	3.725
1.25	2.521	1131	1.629	1.75	5.846	2624	3.778
1.26	2.572	1154	1.662	1.76	5.930	2661	3.832
1.27	2.623	1177	1.695	1.77	6.014	2699	3.887
1.28	2.675	1200	1.729	1.78	6.100	2738	3.942
1.29	2.727	1224	1.763	1.79	6.186	2776	3.998
1.30	2.781	1248	1.797	1.80	6.273	2815	4.054
1.31	2.834	1272	1.832	1.81	6.360	2854	4.110
1.32	2.889	1296	1.867	1.82	6.448	2894	4.167
1.33	2.944	1321	1.902	1.83	6.537	2934	4.225
1.34	2.999	1346	1.938	1.84	6.627	2974	4.283
1.35	3.056	1371	1.975	1.85	6.717	3015	4.341
1.36	3.113	1397	2.012	1.86	6.808	3056	4.400
1.37	3.170	1423	2.049	1.87	6.900	3097	4.460
1.38	3.228	1449	2.086	1.88	6.993	3138	4.519
1.39	3.287	1475	2.124	1.89	7.086	3180	4.580
1.40	3.346	1502	2.163	1.90	7.180	3222	4.641
1.41	3.407	1529	2.202	1.91	7.275	3265	4.702
1.42	3.467	1556	2.241	1.92	7.371	3308	4.764
1.43	3.529	1584	2.281	1.93	7.467	3351	4.826
1.44	3.591	1611	2.321	1.94	7.564	3395	4.889
1.45	3.653	1640	2.361	1.95	7.662	3439	4.952
1.46	3.717	1668	2.402	1.96	7.761	3483	5.016
1.47	3.781	1697	2.443	1.97	7.860	3528	5.080
1.48	3.845	1726	2.485	1.98	7.960	3572	5.145
1.49	3.910	1755	2.527	1.99	8.061	3618	5.210
1.50	3.976	1785	2.570	2.00	8.163	3663	5.276

Table 9-5:
90° V-notch Weir Discharge Table with Head in Feet

Formulas: $CFS = 2.500\ H^{2.5}$ $MGD = 1.616\ H^{2.5}$
$GPM = 1122\ H^{2.5}$
Where: H = head in feet

Head (feet)	CFS	GPM	MGD	Head (feet)	CFS	GPM	MGD
0.01				0.51	0.4644	208.4	0.3002
0.02				0.52	0.4875	218.8	0.3151
0.03				0.53	0.5112	229.4	0.3305
0.04				0.54	0.5357	240.4	0.3463
0.05				0.55	0.5609	251.7	0.3625
0.06				0.56	0.5867	263.3	0.3792
0.07				0.57	0.6132	275.2	0.3964
0.08				0.58	0.6405	287.5	0.4140
0.09				0.59	0.6685	300.0	0.4321
0.10				0.60	0.6971	312.9	0.4506
0.11				0.61	0.7265	326.1	0.4696
0.12				0.62	0.7567	339.6	0.4891
0.13				0.63	0.7876	353.5	0.5091
0.14				0.64	0.8192	367.7	0.5295
0.15				0.65	0.8516	382.2	0.5505
0.16				0.66	0.8847	397.1	0.5719
0.17				0.67	0.9186	412.3	0.5938
0.18				0.68	0.9533	427.8	0.6162
0.19				0.69	0.9887	443.7	0.6391
0.20	0.0447	20.07	0.0289	0.70	1.025	460.0	0.6625
0.21	0.0505	22.67	0.0327	0.71	1.062	476.6	0.6864
0.22	0.0568	25.47	0.0367	0.72	1.100	493.5	0.7108
0.23	0.0634	28.47	0.0410	0.73	1.138	510.9	0.7358
0.24	0.0705	31.66	0.0456	0.74	1.178	528.5	0.7612
0.25	0.0781	35.06	0.0505	0.75	1.218	546.6	0.7872
0.26	0.0862	38.67	0.0557	0.76	1.259	565.0	0.8137
0.27	0.0947	42.50	0.0612	0.77	1.301	583.7	0.8408
0.28	0.1037	46.55	0.0670	0.78	1.343	602.9	0.8683
0.29	0.1132	50.81	0.0732	0.79	1.387	622.4	0.8964
0.30	0.1232	55.31	0.0797	0.80	1.431	642.3	0.9251
0.31	0.1338	60.03	0.0865	0.81	1.476	662.5	0.9542
0.32	0.1448	64.99	0.0936	0.82	1.522	683.2	0.9840
0.33	0.1564	70.19	0.1011	0.83	1.569	704.2	1.014
0.34	0.1685	75.63	0.1089	0.84	1.617	725.6	1.045
0.35	0.1812	81.31	0.1171	0.85	1.665	747.4	1.076
0.36	0.1944	87.25	0.1257	0.86	1.715	769.6	1.108
0.37	0.2082	93.43	0.1346	0.87	1.765	792.1	1.141
0.38	0.2225	99.87	0.1438	0.88	1.816	815.1	1.174
0.39	0.2375	106.6	0.1535	0.89	1.868	838.4	1.208
0.40	0.2530	113.5	0.1635	0.90	1.921	862.2	1.242
0.41	0.2691	120.8	0.1739	0.91	1.975	886.3	1.277
0.42	0.2858	128.3	0.1847	0.92	2.030	910.9	1.312
0.43	0.3031	136.0	0.1959	0.93	2.085	935.8	1.348
0.44	0.3210	144.1	0.2075	0.94	2.142	961.2	1.384
0.45	0.3396	152.4	0.2195	0.95	2.199	987.0	1.422
0.46	0.3588	161.0	0.2319	0.96	2.257	1013	1.459
0.47	0.3786	169.9	0.2447	0.97	2.317	1040	1.498
0.48	0.3991	179.1	0.2580	0.98	2.377	1067	1.536
0.49	0.4202	188.6	0.2716	0.99	2.438	1094	1.576
0.50	0.4419	198.3	0.2857	1.00	2.500	1122	1.616

Table 9-6:
120° V-notch Weir Discharge Table with Head in Feet

Formulas: $CFS = 4.330\ H^{2.5}$ $MGD = 2.798\ H^{2.5}$
$GPM = 1943\ H^{2.5}$
Where: H = head in feet

Head (feet)	CFS	GPM	MGD	Head (feet)	CFS	GPM	MGD
0.01				0.51	0.8043	360.9	0.5197
0.02				0.52	0.8443	378.9	0.5456
0.03				0.53	0.8855	397.3	0.5722
0.04				0.54	0.9278	416.3	0.5996
0.05				0.55	0.9714	435.9	0.6277
0.06				0.56	1.016	456.0	0.6566
0.07				0.57	1.062	476.6	0.6863
0.08				0.58	1.109	497.8	0.7168
0.09				0.59	1.158	519.5	0.7481
0.10				0.60	1.207	541.8	0.7802
0.11				0.61	1.258	564.7	0.8132
0.12				0.62	1.311	588.1	0.8469
0.13				0.63	1.364	612.1	0.8815
0.14				0.64	1.419	636.7	0.9168
0.15				0.65	1.475	661.8	0.9531
0.16				0.66	1.532	687.6	0.9902
0.17				0.67	1.591	713.9	1.028
0.18				0.68	1.651	740.9	1.067
0.19				0.69	1.712	768.4	1.107
0.20	0.0775	34.76	0.0501	0.70	1.775	796.6	1.147
0.21	0.0875	39.27	0.0565	0.71	1.839	825.3	1.188
0.22	0.0983	44.11	0.0635	0.72	1.905	854.7	1.231
0.23	0.1099	49.29	0.0710	0.73	1.971	884.7	1.274
0.24	0.1222	54.83	0.0790	0.74	2.040	915.3	1.318
0.25	0.1353	60.72	0.0874	0.75	2.109	946.5	1.363
0.26	0.1493	66.97	0.0964	0.76	2.180	978.4	1.409
0.27	0.1640	73.60	0.1060	0.77	2.253	1011	1.456
0.28	0.1796	80.61	0.1161	0.78	2.327	1044	1.503
0.29	0.1961	88.00	0.1267	0.79	2.402	1078	1.552
0.30	0.2134	95.78	0.1379	0.80	2.479	1112	1.602
0.31	0.2317	104.0	0.1497	0.81	2.557	1147	1.652
0.32	0.2508	112.6	0.1621	0.82	2.636	1183	1.704
0.33	0.2709	121.6	0.1750	0.83	2.718	1219	1.756
0.34	0.2919	131.0	0.1886	0.84	2.800	1257	1.809
0.35	0.3138	140.8	0.2028	0.85	2.884	1294	1.864
0.36	0.3367	151.1	0.2176	0.86	2.970	1333	1.919
0.37	0.3606	161.8	0.2330	0.87	3.057	1372	1.975
0.38	0.3854	173.0	0.2491	0.88	3.146	1411	2.033
0.39	0.4113	184.6	0.2658	0.89	3.236	1452	2.091
0.40	0.4382	196.6	0.2831	0.90	3.327	1493	2.150
0.41	0.4661	209.1	0.3012	0.91	3.421	1535	2.210
0.42	0.4950	222.1	0.3199	0.92	3.515	1577	2.272
0.43	0.5250	235.6	0.3392	0.93	3.612	1621	2.334
0.44	0.5561	249.5	0.3593	0.94	3.709	1665	2.397
0.45	0.5882	263.9	0.3801	0.95	3.809	1709	2.461
0.46	0.6214	278.8	0.4016	0.96	3.910	1754	2.527
0.47	0.6557	294.3	0.4237	0.97	4.013	1801	2.593
0.48	0.6912	310.2	0.4466	0.98	4.117	1847	2.660
0.49	0.7277	326.6	0.4703	0.99	4.223	1895	2.729
0.50	0.7654	343.5	0.4946	1.00	4.330	1943	2.798

Table 11-3:
2 ft. Rectangular Weir without End Contractions
Discharge Table with Head in Feet

Formulas: $CFS = 6.660\ H^{1.5}$ $MGD = 4.304\ H^{1.5}$
$GPM = 2989\ H^{1.5}$

Where: H = head in feet

Head (feet)	CFS	GPM	MGD	Head (feet)	CFS	GPM	MGD
0.01				0.51	2.426	1089	1.568
0.02				0.52	2.497	1121	1.614
0.03				0.53	2.570	1153	1.661
0.04				0.54	2.643	1186	1.708
0.05				0.55	2.717	1219	1.756
0.06				0.56	2.791	1253	1.804
0.07				0.57	2.866	1286	1.852
0.08				0.58	2.942	1320	1.901
0.09				0.59	3.018	1355	1.951
0.10				0.60	3.095	1389	2.000
0.11				0.61	3.173	1424	2.051
0.12				0.62	3.251	1459	2.101
0.13				0.63	3.330	1495	2.152
0.14				0.64	3.410	1530	2.204
0.15				0.65	3.490	1566	2.255
0.16				0.66	3.571	1603	2.308
0.17				0.67	3.652	1639	2.360
0.18				0.68	3.735	1676	2.413
0.19				0.69	3.817	1713	2.467
0.20	0.5957	267.3	0.3850	0.70	3.901	1751	2.521
0.21	0.6409	287.6	0.4142	0.71	3.984	1788	2.575
0.22	0.6872	308.4	0.4441	0.72	4.069	1826	2.629
0.23	0.7346	329.7	0.4747	0.73	4.154	1864	2.684
0.24	0.7831	351.4	0.5060	0.74	4.240	1903	2.740
0.25	0.8325	373.6	0.5380	0.75	4.326	1941	2.796
0.26	0.8829	396.3	0.5706	0.76	4.413	1980	2.852
0.27	0.9344	419.3	0.6038	0.77	4.500	2020	2.908
0.28	0.9868	442.9	0.6377	0.78	4.588	2059	2.965
0.29	1.040	466.8	0.6722	0.79	4.676	2099	3.022
0.30	1.094	491.1	0.7072	0.80	4.766	2139	3.080
0.31	1.150	515.9	0.7429	0.81	4.855	2179	3.138
0.32	1.206	541.1	0.7791	0.82	4.945	2219	3.196
0.33	1.263	566.6	0.8159	0.83	5.036	2260	3.255
0.34	1.320	592.6	0.8533	0.84	5.127	2301	3.314
0.35	1.379	618.9	0.8912	0.85	5.219	2342	3.373
0.36	1.439	645.6	0.9297	0.86	5.312	2384	3.433
0.37	1.499	672.7	0.9687	0.87	5.404	2426	3.493
0.38	1.560	700.2	1.008	0.88	5.498	2467	3.553
0.39	1.622	728.0	1.048	0.89	5.592	2510	3.614
0.40	1.685	756.2	1.089	0.90	5.686	2552	3.675
0.41	1.748	784.7	1.130	0.91	5.781	2595	3.736
0.42	1.813	813.6	1.172	0.92	5.877	2638	3.798
0.43	1.878	842.8	1.214	0.93	5.973	2681	3.860
0.44	1.944	872.4	1.256	0.94	6.070	2724	3.923
0.45	2.010	902.3	1.299	0.95	6.167	2768	3.985
0.46	2.078	932.5	1.343	0.96	6.264	2811	4.048
0.47	2.146	963.1	1.387	0.97	6.363	2856	4.112
0.48	2.215	994.0	1.431	0.98	6.461	2900	4.176
0.49	2.284	1025	1.476	0.99	6.560	2944	4.240
0.50	2.355	1057	1.522	1.00	6.660	2989	4.304

Table 12-3

2 ft. Cipolletti Weir Discharge Table with Head in Feet

Formulas: $CFS = 6.734\ H^{1.5}$ $MGD = 4.352\ H^{1.5}$
$GPM = 3022\ H^{1.5}$

Where: H = head in feet

Head (feet)	CFS	GPM	MGD	Head (feet)	CFS	GPM	MGD
0.01				0.51	2.453	1101	1.585
0.02				0.52	2.525	1133	1.632
0.03				0.53	2.598	1166	1.679
0.04				0.54	2.672	1199	1.727
0.05				0.55	2.747	1233	1.775
0.06				0.56	2.822	1266	1.824
0.07				0.57	2.898	1300	1.873
0.08				0.58	2.975	1335	1.922
0.09				0.59	3.052	1370	1.972
0.10				0.60	3.130	1404	2.023
0.11				0.61	3.208	1440	2.073
0.12				0.62	3.287	1475	2.125
0.13				0.63	3.367	1511	2.176
0.14				0.64	3.448	1547	2.228
0.15				0.65	3.529	1584	2.281
0.16				0.66	3.611	1620	2.333
0.17				0.67	3.693	1657	2.387
0.18				0.68	3.776	1695	2.440
0.19				0.69	3.860	1732	2.494
0.20	0.6023	270.3	0.3893	0.70	3.944	1770	2.549
0.21	0.6480	290.8	0.4188	0.71	4.029	1808	2.604
0.22	0.6949	311.8	0.4491	0.72	4.114	1846	2.659
0.23	0.7428	333.3	0.4800	0.73	4.200	1885	2.714
0.24	0.7918	355.3	0.5117	0.74	4.287	1924	2.770
0.25	0.8418	377.8	0.5440	0.75	4.374	1963	2.827
0.26	0.8928	400.6	0.5770	0.76	4.462	2002	2.883
0.27	0.9448	424.0	0.6106	0.77	4.550	2042	2.941
0.28	0.9977	447.7	0.6448	0.78	4.639	2082	2.998
0.29	1.052	471.9	0.6797	0.79	4.728	2122	3.056
0.30	1.107	496.6	0.7151	0.80	4.818	2162	3.114
0.31	1.162	521.6	0.7512	0.81	4.909	2203	3.173
0.32	1.219	547.0	0.7878	0.82	5.000	2244	3.232
0.33	1.277	572.9	0.8250	0.83	5.092	2285	3.291
0.34	1.335	599.1	0.8628	0.84	5.184	2327	3.350
0.35	1.394	625.7	0.9011	0.85	5.277	2368	3.410
0.36	1.455	652.8	0.9400	0.86	5.371	2410	3.471
0.37	1.516	680.1	0.9795	0.87	5.465	2452	3.532
0.38	1.577	707.9	1.019	0.88	5.559	2495	3.593
0.39	1.640	736.0	1.060	0.89	5.654	2537	3.654
0.40	1.704	764.5	1.101	0.90	5.750	2580	3.716
0.41	1.768	793.4	1.143	0.91	5.846	2623	3.778
0.42	1.833	822.6	1.185	0.92	5.942	2667	3.840
0.43	1.899	852.1	1.227	0.93	6.039	2710	3.903
0.44	1.965	882.0	1.270	0.94	6.137	2754	3.966
0.45	2.033	912.2	1.314	0.95	6.235	2798	4.030
0.46	2.101	942.8	1.358	0.96	6.334	2843	4.094
0.47	2.170	973.7	1.402	0.97	6.433	2887	4.158
0.48	2.239	1005	1.447	0.98	6.533	2932	4.222
0.49	2.310	1037	1.493	0.99	6.633	2977	4.287
0.50	2.381	1068	1.539	1.00	6.734	3022	4.352

Table 13-4:
6 in. Parshall Flume Discharge Table with Head in Feet

Formulas: $CFS = 2.060\ H^{1.580}$ $MGD = 1.331\ H^{1.580}$
$GPM = 924.5\ H^{1.580}$
Where: H = head in feet

Head (feet)	CFS	GPM	MGD	Head (feet)	CFS	GPM	MGD
0.01				0.51	0.7109	319.1	0.4593
0.02				0.52	0.7331	329.0	0.4737
0.03				0.53	0.7555	339.0	0.4881
0.04				0.54	0.7781	349.2	0.5028
0.05				0.55	0.8010	359.5	0.5175
0.06				0.56	0.8241	369.9	0.5325
0.07				0.57	0.8475	380.4	0.5476
0.08				0.58	0.8711	391.0	0.5629
0.09				0.59	0.8950	401.7	0.5783
0.10	0.0542	24.32	0.0350	0.60	0.9191	412.5	0.5938
0.11	0.0630	28.27	0.0407	0.61	0.9434	423.4	0.6095
0.12	0.0723	32.43	0.0467	0.62	0.9679	434.4	0.6254
0.13	0.0820	36.81	0.0530	0.63	0.9927	445.5	0.6414
0.14	0.0922	41.38	0.0596	0.64	1.018	456.7	0.6576
0.15	0.1028	46.15	0.0664	0.65	1.043	468.1	0.6739
0.16	0.1139	51.10	0.0736	0.66	1.068	479.5	0.6903
0.17	0.1253	56.24	0.0810	0.67	1.094	491.0	0.7069
0.18	0.1372	61.55	0.0886	0.68	1.120	502.7	0.7237
0.19	0.1494	67.04	0.0965	0.69	1.146	514.4	0.7406
0.20	0.1620	72.70	0.1047	0.70	1.173	526.2	0.7576
0.21	0.1750	78.53	0.1131	0.71	1.199	538.1	0.7748
0.22	0.1883	84.52	0.1217	0.72	1.226	550.2	0.7921
0.23	0.2020	90.66	0.1305	0.73	1.253	562.3	0.8095
0.24	0.2161	96.97	0.1396	0.74	1.280	574.5	0.8271
0.25	0.2305	103.4	0.1489	0.75	1.308	586.8	0.8448
0.26	0.2452	110.0	0.1584	0.76	1.335	599.2	0.8627
0.27	0.2603	116.8	0.1682	0.77	1.363	611.7	0.8807
0.28	0.2757	123.7	0.1781	0.78	1.391	624.3	0.8989
0.29	0.2914	130.8	0.1883	0.79	1.419	637.0	0.9171
0.30	0.3074	138.0	0.1986	0.80	1.448	649.8	0.9355
0.31	0.3238	145.3	0.2092	0.81	1.477	662.7	0.9541
0.32	0.3404	152.8	0.2199	0.82	1.506	675.7	0.9728
0.33	0.3574	160.4	0.2309	0.83	1.535	688.7	0.9916
0.34	0.3746	168.1	0.2421	0.84	1.564	701.9	1.011
0.35	0.3922	176.0	0.2534	0.85	1.593	715.1	1.030
0.36	0.4100	184.0	0.2649	0.86	1.623	728.5	1.049
0.37	0.4282	192.2	0.2767	0.87	1.653	741.9	1.068
0.38	0.4466	200.4	0.2886	0.88	1.683	755.4	1.088
0.39	0.4653	208.8	0.3006	0.89	1.714	769.0	1.107
0.40	0.4843	217.4	0.3129	0.90	1.744	782.7	1.127
0.41	0.5036	226.0	0.3254	0.91	1.775	796.5	1.147
0.42	0.5231	234.8	0.3380	0.92	1.806	810.4	1.167
0.43	0.5429	243.7	0.3508	0.93	1.837	824.3	1.187
0.44	0.5630	252.7	0.3638	0.94	1.868	838.4	1.207
0.45	0.5834	261.8	0.3769	0.95	1.900	852.5	1.227
0.46	0.6040	271.1	0.3902	0.96	1.931	866.8	1.248
0.47	0.6249	280.4	0.4037	0.97	1.963	881.1	1.268
0.48	0.6460	289.9	0.4174	0.98	1.995	895.5	1.289
0.49	0.6674	299.5	0.4312	0.99	2.028	909.9	1.310
0.50	0.6890	309.2	0.4452	1.00	2.060	924.5	1.331

Table 13-5:
9 in. Parshall Flume Discharge Table with Head in Feet

Formulas: $CFS = 3.070\ H^{1.530}$ $MGD = 1.984\ H^{1.530}$
$GPM = 1378\ H^{1.530}$
Where: H = head in feet

Head (feet)	CFS	GPM	MGD	Head (feet)	CFS	GPM	MGD
0.01				0.51	1.096	491.8	0.7081
0.02				0.52	1.129	506.7	0.7295
0.03				0.53	1.162	521.7	0.7511
0.04				0.54	1.196	536.8	0.7729
0.05				0.55	1.230	552.1	0.7949
0.06				0.56	1.264	567.5	0.8171
0.07				0.57	1.299	583.1	0.8395
0.08				0.58	1.334	598.8	0.8622
0.09				0.59	1.369	614.7	0.8850
0.10	0.0906	40.67	0.0586	0.60	1.405	630.7	0.9081
0.11	0.1048	47.05	0.0677	0.61	1.441	646.9	0.9313
0.12	0.1198	53.75	0.0774	0.62	1.477	663.1	0.9548
0.13	0.1354	60.76	0.0875	0.63	1.514	679.6	0.9784
0.14	0.1516	68.05	0.0980	0.64	1.551	696.2	1.002
0.15	0.1685	75.63	0.1089	0.65	1.588	712.9	1.026
0.16	0.1860	83.47	0.1202	0.66	1.626	729.7	1.051
0.17	0.2040	91.59	0.1319	0.67	1.664	746.7	1.075
0.18	0.2227	99.96	0.1439	0.68	1.702	763.8	1.100
0.19	0.2419	108.6	0.1563	0.69	1.740	781.1	1.125
0.20	0.2616	117.4	0.1691	0.70	1.779	798.5	1.150
0.21	0.2819	126.5	0.1822	0.71	1.818	816.0	1.175
0.22	0.3027	135.9	0.1956	0.72	1.857	833.6	1.200
0.23	0.3240	145.4	0.2094	0.73	1.897	851.4	1.226
0.24	0.3458	155.2	0.2235	0.74	1.937	869.3	1.252
0.25	0.3681	165.2	0.2379	0.75	1.977	887.3	1.278
0.26	0.3909	175.5	0.2526	0.76	2.017	905.5	1.304
0.27	0.4141	185.9	0.2676	0.77	2.058	923.8	1.330
0.28	0.4378	196.5	0.2829	0.78	2.099	942.2	1.357
0.29	0.4620	207.4	0.2985	0.79	2.140	960.8	1.383
0.30	0.4866	218.4	0.3144	0.80	2.182	979.4	1.410
0.31	0.5116	229.6	0.3306	0.81	2.224	998.2	1.437
0.32	0.5371	241.1	0.3471	0.82	2.266	1017	1.464
0.33	0.5629	252.7	0.3638	0.83	2.308	1036	1.492
0.34	0.5893	264.5	0.3808	0.84	2.351	1055	1.519
0.35	0.6160	276.5	0.3981	0.85	2.394	1075	1.547
0.36	0.6431	288.7	0.4156	0.86	2.437	1094	1.575
0.37	0.6706	301.0	0.4334	0.87	2.481	1114	1.603
0.38	0.6986	313.6	0.4515	0.88	2.525	1133	1.632
0.39	0.7269	326.3	0.4698	0.89	2.569	1153	1.660
0.40	0.7556	339.2	0.4883	0.90	2.613	1173	1.689
0.41	0.7847	352.2	0.5071	0.91	2.657	1193	1.717
0.42	0.8142	365.4	0.5262	0.92	2.702	1213	1.746
0.43	0.8440	378.8	0.5454	0.93	2.747	1233	1.775
0.44	0.8742	392.4	0.5650	0.94	2.793	1254	1.805
0.45	0.9048	406.1	0.5847	0.95	2.838	1274	1.834
0.46	0.9357	420.0	0.6047	0.96	2.884	1295	1.864
0.47	0.9670	434.1	0.6250	0.97	2.930	1315	1.894
0.48	0.9987	448.3	0.6454	0.98	2.977	1336	1.924
0.49	1.031	462.6	0.6661	0.99	3.023	1357	1.954
0.50	1.063	477.2	0.6870	1.00	3.070	1378	1.984

Table 14-3:
8 in. Palmer-Bowlus Flume Discharge Table with Head in Feet

Manufactured by Plasti-Fab, Inc. (Data from Plasti-Fab, Inc.)

Head (feet)	CFS	GPM	MGD	Head (feet)	CFS	GPM	MGD
0.01				0.26	0.1942	87.18	0.1255
0.02				0.27	0.2086	93.61	0.1348
0.03				0.28	0.2235	100.3	0.1445
0.04				0.29	0.2391	107.3	0.1545
0.05				0.30	0.2553	114.6	0.1650
0.06				0.31	0.2720	122.1	0.1758
0.07				0.32	0.2895	129.9	0.1871
0.08				0.33	0.3075	138.0	0.1987
0.09	0.0306	13.73	0.0198	0.34	0.3261	146.4	0.2108
0.10	0.0365	16.39	0.0236	0.35	0.3454	155.0	0.2232
0.11	0.0429	19.24	0.0277	0.36	0.3652	163.9	0.2360
0.12	0.0497	22.29	0.0321	0.37	0.3856	173.1	0.2492
0.13	0.0569	25.53	0.0368	0.38	0.4066	182.5	0.2628
0.14	0.0646	28.97	0.0417	0.39	0.4281	192.1	0.2767
0.15	0.0727	32.61	0.0470	0.40	0.4500	202.0	0.2909
0.16	0.0812	36.45	0.0525	0.41	0.4725	212.1	0.3054
0.17	0.0902	40.50	0.0583	0.42	0.4954	222.3	0.3202
0.18	0.0997	44.76	0.0645	0.43	0.5187	232.8	0.3352
0.19	0.1097	49.24	0.0709	0.44	0.5423	243.4	0.3505
0.20	0.1202	53.94	0.0777	0.45	0.5663	254.2	0.3660
0.21	0.1312	58.87	0.0848	0.46	0.5906	265.0	0.3817
0.22	0.1427	64.04	0.0922	0.47	0.6151	276.1	0.3975
0.23	0.1547	69.44	0.1000	0.48	0.6399	287.2	0.4135
0.24	0.1673	75.10	0.1081	0.49	0.6648	298.4	0.4297
0.25	0.1805	81.01	0.1167	0.50	0.6900	309.7	0.4459

Table 17-1:
Large 60° V Trapezoidal Flume Discharge Table with Head in Feet

Manufactured by Plasti-Fab, Inc. (Data from Plasti-Fab, Inc.)

Head (feet)	CFS	GPM	MGD	Head (feet)	CFS	GPM	MGD
0.01				0.29	0.0636	28.53	0.0411
0.02				0.30	0.0694	31.14	0.0449
0.03	0.0002	0.0819	0.0001	0.31	0.0755	33.89	0.0488
0.04	0.0004	0.1721	0.0002	0.32	0.0820	36.78	0.0530
0.05	0.0007	0.3060	0.0004	0.33	0.0887	39.82	0.0574
0.06	0.0011	0.4898	0.0007	0.34	0.0958	43.01	0.0620
0.07	0.0016	0.7290	0.0011	0.35	0.1033	46.35	0.0668
0.08	0.0023	1.029	0.0015	0.36	0.1111	49.84	0.0718
0.09	0.0031	1.394	0.0020	0.37	0.1192	53.50	0.0771
0.10	0.0041	1.830	0.0026	0.38	0.1277	57.31	0.0825
0.11	0.0052	2.340	0.0034	0.39	0.1365	61.28	0.0883
0.12	0.0065	2.929	0.0042	0.40	0.1458	65.41	0.0942
0.13	0.0080	3.600	0.0052	0.41	0.1554	69.72	0.1004
0.14	0.0097	4.359	0.0063	0.42	0.1653	74.19	0.1069
0.15	0.0116	5.208	0.0075	0.43	0.1757	78.83	0.1136
0.16	0.0137	6.152	0.0089	0.44	0.1864	83.65	0.1205
0.17	0.0160	7.193	0.0104	0.45	0.1975	88.64	0.1277
0.18	0.0186	8.336	0.0120	0.46	0.2090	93.82	0.1351
0.19	0.0214	9.584	0.0138	0.47	0.2210	99.17	0.1428
0.20	0.0244	10.94	0.0158	0.48	0.2333	104.7	0.1508
0.21	0.0276	12.41	0.0179	0.49	0.2461	110.4	0.1591
0.22	0.0312	13.99	0.0202	0.50	0.2592	116.3	0.1676
0.23	0.0350	15.69	0.0226	0.51	0.2728	122.4	0.1764
0.24	0.0390	17.51	0.0252	0.52	0.2868	128.7	0.1854
0.25	0.0434	19.46	0.0280	0.53	0.3013	135.2	0.1948
0.26	0.0480	21.53	0.0310	0.54	0.3162	141.9	0.2044
0.27	0.0529	23.73	0.0342	0.55	0.3315	148.8	0.2143
0.28	0.0581	26.06	0.0375	0.56	0.3473	155.8	0.2245

Table 17-2:
Extra Large 60° V Trapezoidal Flume Discharge Table with Head in Feet

Manufactured by Plasti-Fab, Inc. (Data from Plasti-Fab, Inc.)

Head (feet)	CFS	GPM	MGD	Head (feet)	CFS	GPM	MGD
0.01				0.51	0.2623	117.7	0.1695
0.02				0.52	0.2761	123.9	0.1784
0.03	0.0001	0.0671	0.0001	0.53	0.2903	130.3	0.1875
0.04	0.0003	0.1434	0.0002	0.54	0.3050	136.9	0.1970
0.05	0.0006	0.2582	0.0004	0.55	0.3201	143.7	0.2068
0.06	0.0009	0.4175	0.0006	0.56	0.3357	150.6	0.2168
0.07	0.0014	0.6268	0.0009	0.57	0.3517	157.8	0.2272
0.08	0.0020	0.8913	0.0013	0.58	0.3682	165.2	0.2379
0.09	0.0027	1.216	0.0018	0.59	0.3852	172.9	0.2488
0.10	0.0036	1.605	0.0023	0.60	0.4026	180.7	0.2601
0.11	0.0046	2.064	0.0030	0.61	0.4206	188.7	0.2717
0.12	0.0058	2.596	0.0037	0.62	0.4390	197.0	0.2836
0.13	0.0071	3.205	0.0046	0.63	0.4579	205.5	0.2958
0.14	0.0087	3.897	0.0056	0.64	0.4773	214.2	0.3083
0.15	0.0104	4.674	0.0067	0.65	0.4972	223.1	0.3212
0.16	0.0123	5.541	0.0080	0.66	0.5176	232.3	0.3344
0.17	0.0145	6.502	0.0094	0.67	0.5386	241.7	0.3479
0.18	0.0168	7.559	0.0109	0.68	0.5600	251.3	0.3618
0.19	0.0194	8.717	0.0125	0.69	0.5820	261.2	0.3760
0.20	0.0222	9.979	0.0144	0.70	0.6045	271.3	0.3905
0.21	0.0253	11.35	0.0163	0.71	0.6275	281.6	0.4054
0.22	0.0286	12.83	0.0185	0.72	0.6511	292.2	0.4206
0.23	0.0321	14.43	0.0208	0.73	0.6752	303.0	0.4362
0.24	0.0360	16.14	0.0232	0.74	0.6999	314.1	0.4521
0.25	0.0400	17.97	0.0259	0.75	0.7251	325.4	0.4684
0.26	0.0444	19.93	0.0287	0.76	0.7509	337.0	0.4851
0.27	0.0491	22.01	0.0317	0.77	0.7772	348.8	0.5021
0.28	0.0540	24.23	0.0349	0.78	0.8041	360.8	0.5194
0.29	0.0592	26.58	0.0383	0.79	0.8315	373.2	0.5372
0.30	0.0648	29.06	0.0418	0.80	0.8596	385.8	0.5553
0.31	0.0706	31.69	0.0456	0.81	0.8882	398.6	0.5738
0.32	0.0768	34.45	0.0496	0.82	0.9174	411.7	0.5926
0.33	0.0833	37.36	0.0538	0.83	0.9472	425.1	0.6119
0.34	0.0901	40.42	0.0582	0.84	0.9776	438.7	0.6315
0.35	0.0972	43.63	0.0628	0.85	1.009	452.6	0.6515
0.36	0.1047	47.00	0.0677	0.86	1.040	466.8	0.6719
0.37	0.1126	50.52	0.0727	0.87	1.072	481.2	0.6927
0.38	0.1208	54.20	0.0780	0.88	1.105	495.9	0.7139
0.39	0.1293	58.04	0.0835	0.89	1.139	510.9	0.7355
0.40	0.1383	62.05	0.0893	0.90	1.173	526.2	0.7575
0.41	0.1476	66.22	0.0953	0.91	1.207	541.8	0.7799
0.42	0.1572	70.56	0.1016	0.92	1.243	557.6	0.8027
0.43	0.1673	75.08	0.1081	0.93	1.278	573.7	0.8259
0.44	0.1777	79.77	0.1148	0.94	1.315	590.1	0.8495
0.45	0.1886	84.64	0.1218	0.95	1.352	606.8	0.8735
0.46	0.1998	89.69	0.1291	0.96	1.390	623.8	0.8980
0.47	0.2115	94.92	0.1366	0.97	1.429	641.1	0.9228
0.48	0.2236	100.3	0.1444	0.98	1.468	658.7	0.9481
0.49	0.2361	105.9	0.1525	0.99	1.508	676.5	0.9739
0.50	0.2490	111.7	0.1608	1.00	1.548	694.7	1.000

Average Flow Chart

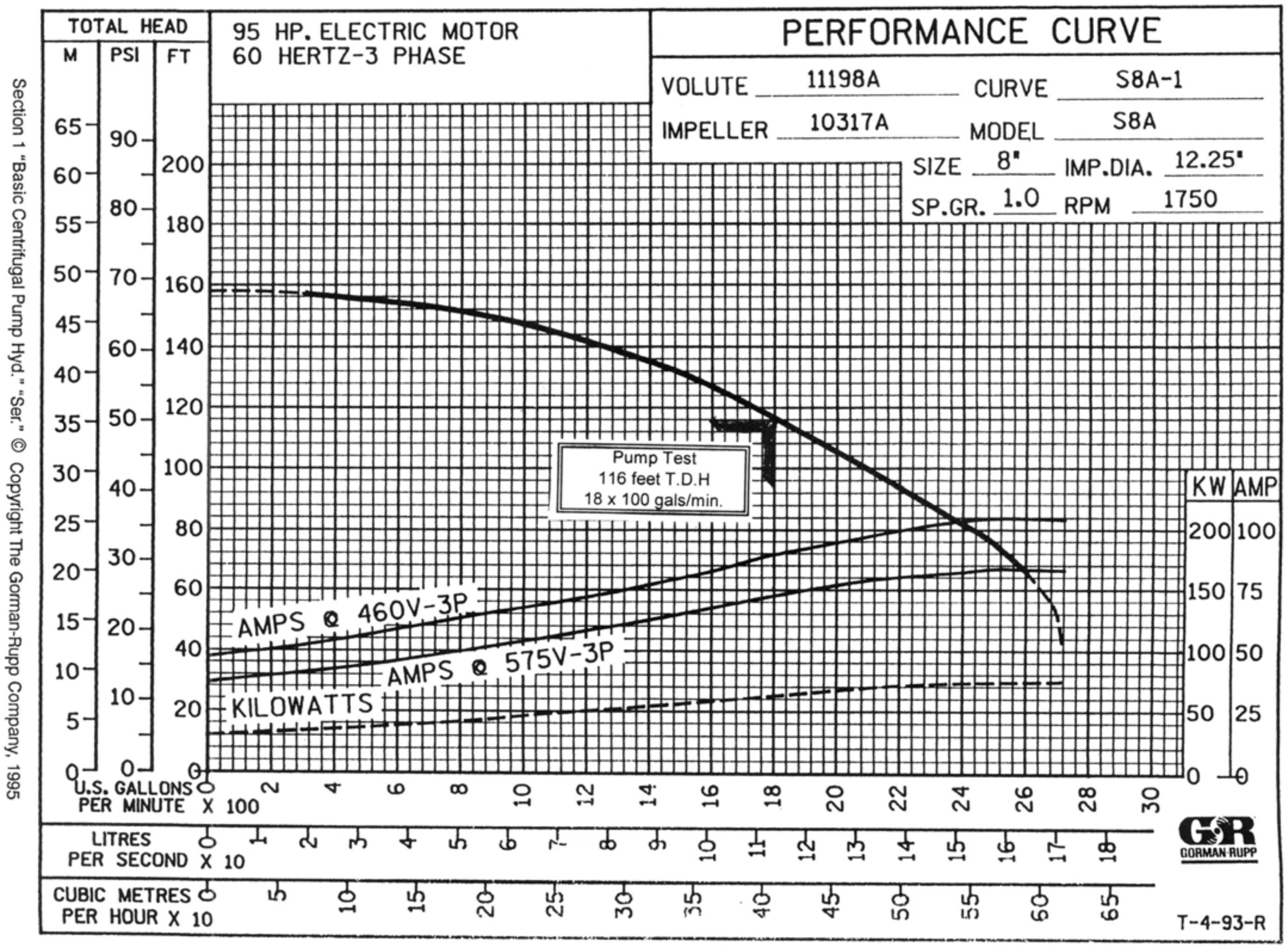
Commercial					
		Flowrate, gal/unit•d		Flowrate, L/unit•d	
Source	**Unit**	**Range**	**Typical**	**Range**	**Typical**
Airport	Passenger	3-5	4	11-19	15
Apartment	Bedroom	100-150	120	380-570	450
Automobile service station	Vehicle served	8-15	10	30-57	40
	Employee	9-15	13	34-57	50
Bar/cocktail lounge	Seat	12-25	20	45-95	80
	Employee	10-16	13	38-60	50
Boarding house	Person	25-65	45	95-250	170
Conference center	Person	6-10	8	40-60	30
Department store	Toilet room	350-600	400	1300-2300	1500
	Employee	8-15	10	30-57	40
Hotel	Guest	65-75	70	150-230	190
	Employee	8-15	10	30-57	40
Industrial building (sanitary waste only)	Employee	15-35	20	57-130	75
Laundry (self-service)	Machine	400-550	450	1500-2100	1700
	Customer	45-55	50	170-210	190
Mobile home park	Unit	125-150	140	470-570	530
Motel (with kitchen)	Guest	55-90	60	210-340	230
Motel (without kitchen)	Guest	50-75	55	190-290	210
Office	Employee	7-16	13	26-60	50
Public lavatory	User	3-5	4	11-19	15
Restaurant:					
Conventional	Customer	7-10	8	26-40	35
With bar/cocktail lounge	Customer	9-12	10	34-45	40
Shopping center	Employee	7-13	10	26-50	40
	Parking space	1-3	2	4-11	8
Theater	Seat	2-4	3	8-15	10

Institutional					
		Flowrate, gal/unit•d		Flowrate, L/unit•d	
Source	**Unit**	**Range**	**Typical**	**Range**	**Typical**
Assembly hall	Guest	3-5	4	11-19	15
Hospital	Bed	175-400	250	660-1500	1000
	Employee	5-15	10	20-60	40
Institutions other than hospitals	Bed	75-125	100	280-470	380
	Employee	5-15	10	20-60	40
Prison	Inmate	80-150	120	300-570	450
	Employee	5-15	10	20-60	40
School, day:					
With cafeteria, gym, and showers	Student	15-30	25	60-120	100
With cafeteria only	Student	10-20	15	40-80	60
School, boarding	Student	75-100	85	280-380	320

Recreational					
		Flowrate, gal/unit•d		Flowrate, L/unit•d	
Facility	**Unit**	**Range**	**Typical**	**Range**	**Typical**
Apartment, resort	Person	50-70	60	190-260	230
Cabin, resort	Person	8-50	40	30-190	150
Cafeteria	Customer	2-4	3	8-15	10
	Employee	8-12	10	30-45	40
Camp:					
With toilets only	Person	15-30	25	55-110	95
With central toilet and bath facilities	Person	35-50	45	130-190	170
Day	Person	15-20	15	55-76	60
Cottages, (seasonal with private bath)	Person	40-60	50	150-230	190
Country club	Member present	20-40	25	75-150	100
	Employee	10-15	13	38-57	50
Dining hall	Meal served	4-10	7	15-40	25
Dormitory, bunkhouse	Person	20-50	40	75-190	150
Fairground	Visitor	1-3	2	4-12	8
Picnic park with flush toilets	Visitor	5-10	5	19-38	19
Recreational vehicle park:					
With individual connection	Vehicle	75-150	100	280-570	380
With comfort station	Vehicle	40-50	45	150-190	170
Roadside rest areas	Person	3-5	4	10-19	15
Swimming pool	Customer	5-12	10	19-45	40
	Employee	8-12	10	30-45	40
Vacation home	Person	25-60	50	90-230	190
Visitor center	Visitor	3-5	4	10-19	15

Adapted from Metcalf & Eddy (1991), Salvato (1992), and Crites and Tchobanoglous (1998).

- This is the pump performance curve for Gorman-Rupp, model S8A.



From *Self-Priming/Submersible Centrifugal Pump Hydraulic, Troubleshooting & Application Technical Seminar*, Issue 1 (Mansfield, OH: The Gorman – Rupp Co., 1995).

All graphics in Appendix F from Revis L. Stephenson and Harold E. Nixon, *Centrifugal Compressor Engineering,* Third Edition, Hoffman Air and Filtration Systems (P.O. Box 548, East Syracuse, NY 13057), pp. 229 - 235.

Friction Lost

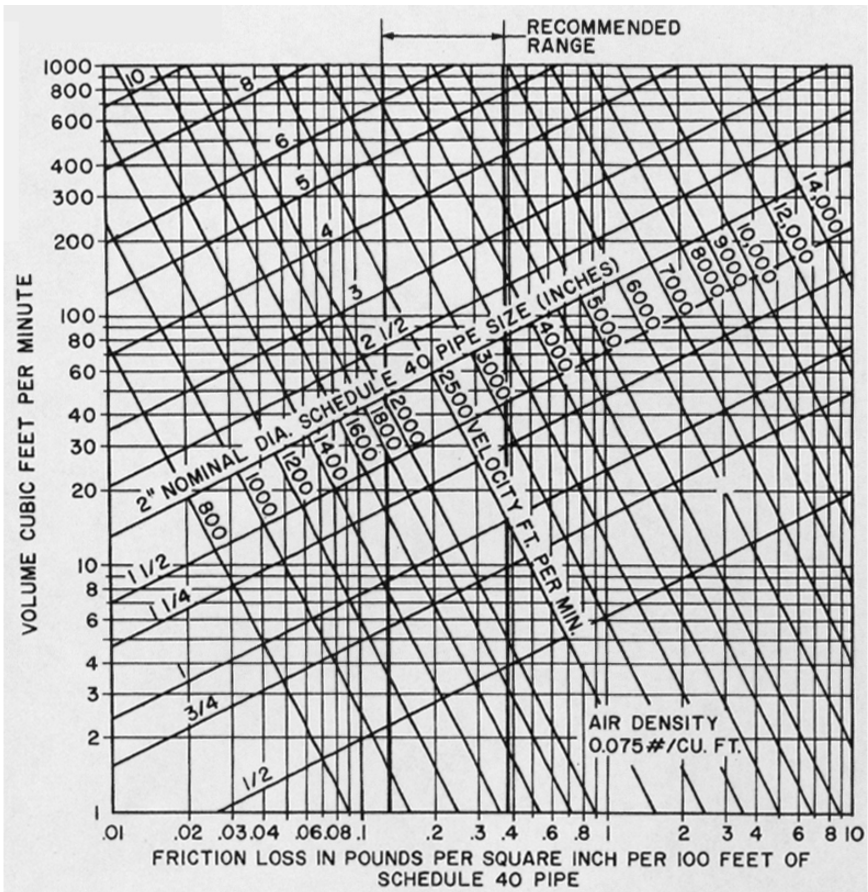


Figure F.1 – Friction Lost in Pounds per Inch^2 per 100 Feet of Schedule 40 Pipe

Lift, Submergence, and Pressure

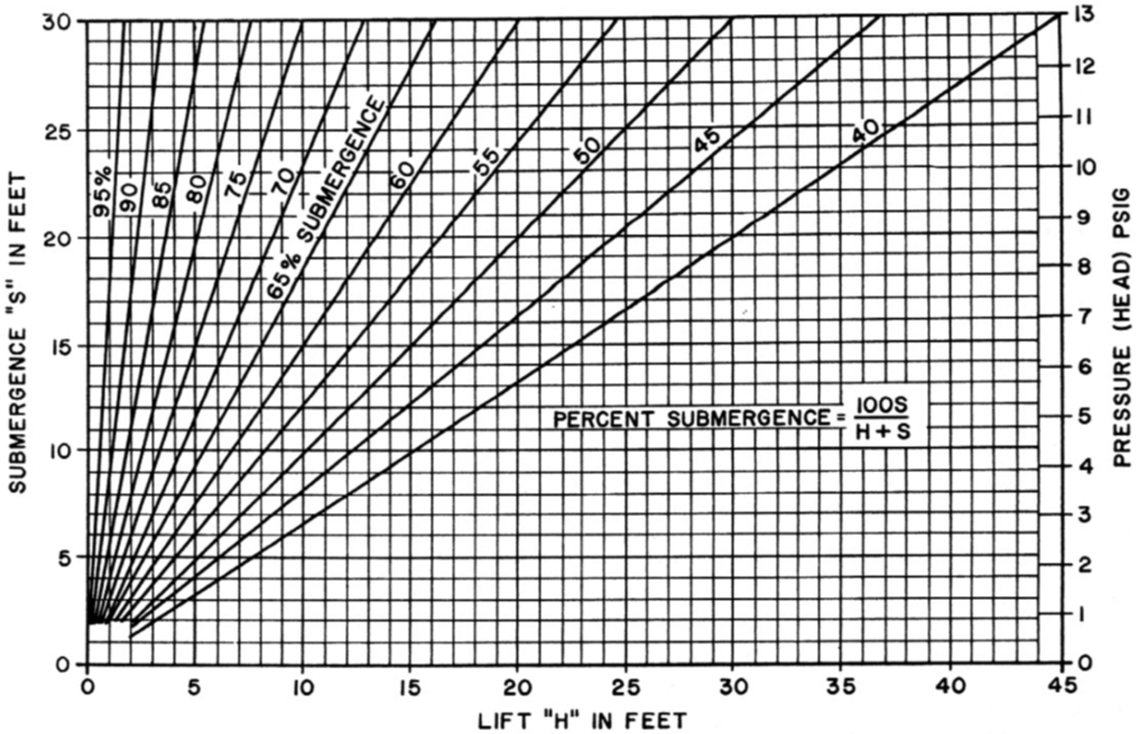


Figure F.2 – Lift, Submergence, and Pressure

Air Lift Capacity

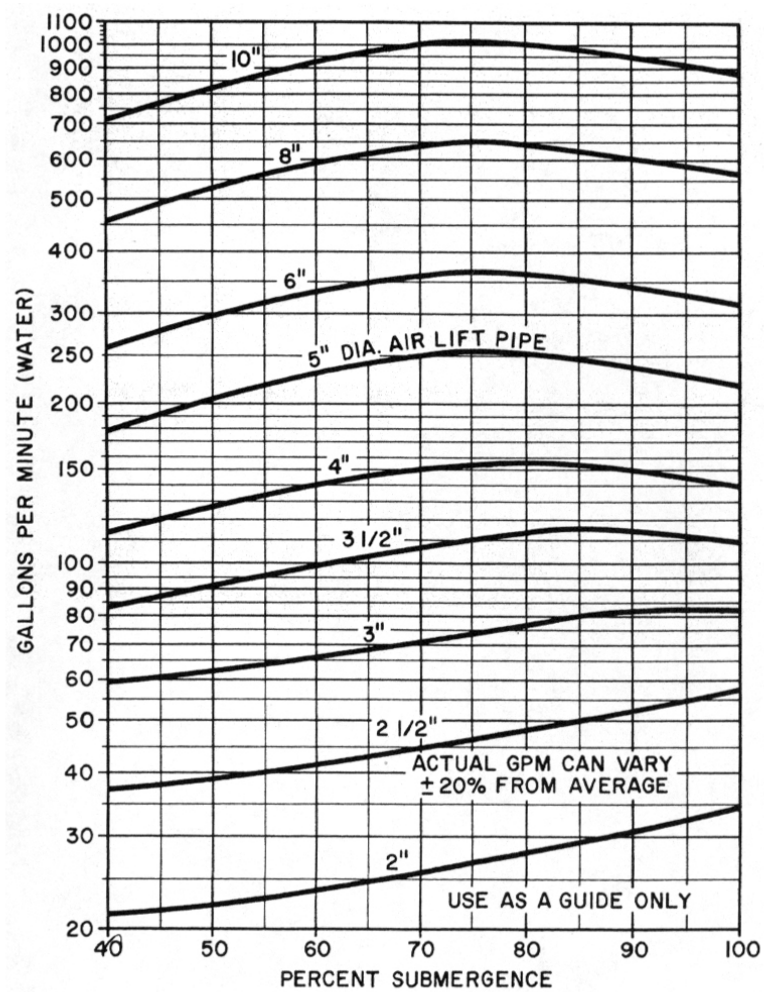


Figure F.3 – Average Capacities Airlift 2–10 Inch

Pipe Loss

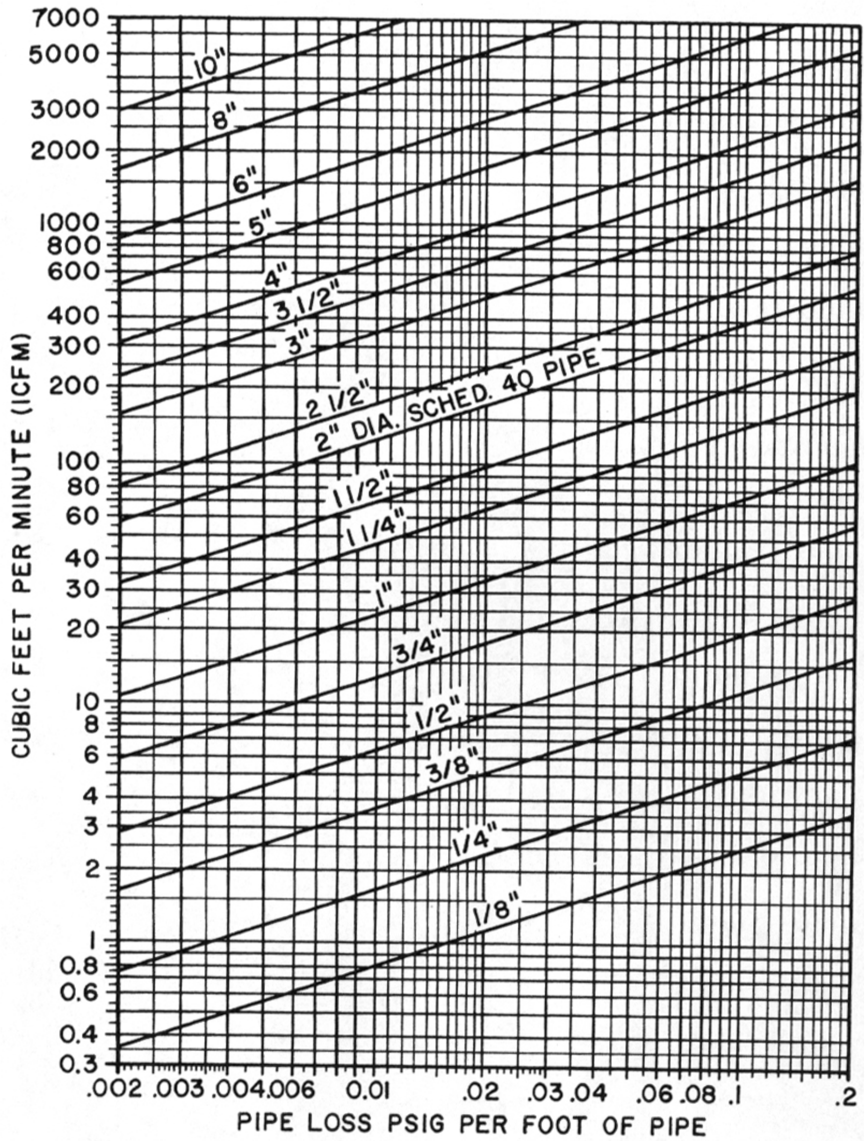


Figure F.4 – Pipe Loss