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NPDES Compliance Inspection Video Workbook: Inspecting a Parshall Flume

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INSPECTING A PARSHALL FLUME

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FOREWORD

PURPOSE OF WORKBOOK

In the fulfillment of their responsibilities, National Pollutant Discharge Elimination System (NPDES) compliance inspectors are often required to evaluate primary and secondary flow measuring devices at wastewater treatment facilities. The Parshall flume is a common primary flow measuring device used to measure wastewater flows at Publicly Owned Treatment Works (POTWs) and industrial facilities. The purpose of the *Inspecting a Parshall Flume* workbook is to provide NPDES compliance inspectors with the proper procedures for evaluating the accuracy of flow measurement systems using a Parshall flume.

This workbook was prepared to be used in conjunction with the video, "Inspecting a Parshall Flume." This workbook will provide training information to augment the information contained in the video and will include questions and answers throughout to test the user's knowledge. Although this workbook is designed to accompany the video, it can also be used as an independent training resource.

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CHAPTER 1
INTRODUCTION

Facilities that discharge to receiving waters of the United States must comply with conditions contained in their NPDES permit. NPDES permit conditions typically include effluent limitations and self-monitoring and reporting requirements. Although flow is usually not identified as a limited parameter in NPDES permits, permits typically contain mass loading limits for certain parameters and requirements to collect flow-proportioned composite samples. Therefore, accurate flow measurements are critical toward verifying compliance with permit mass loading limits [e.g., pounds per day of Total Suspended Solids (TSS)] and in the collection of representative wastewater samples. Flow monitoring also provides useful information for the following:

- A comparison of actual plant flows to design flow rates
- Assessment of inflow and infiltration conditions in the wastewater collection system conveying flow to the POTW
- Development of wasteload allocations and water quality based effluent limits.

The type of flow measuring device selected is dependent on whether the flow passes through an enclosed pipe or an open channel. Open channel flow (i.e., flow in conduits that are not liquid-full) is measured using primary and secondary devices. Primary devices, such as weirs and flumes, are standard, calibrated hydraulic structures that are placed in an open channel. Flow measurement is obtained by measuring the depth of liquid (head) at a specific point in the primary device. Changes in liquid level at the primary device are proportional to variations in flow rates. Secondary devices are used in conjunction with primary devices to automate the flow measurement process. Secondary devices measure the liquid depth in the primary device and convert it to a corresponding flow. The output from the secondary devices is usually transmitted to a recorder and/or totalizer. Examples of the more commonly used secondary devices include floats, ultrasonic transducers, and bubblers.

Parshall flumes and weirs are two types of open channel flow measuring devices commonly used at municipal and industrial dischargers. The advantages of using Parshall flumes instead of weirs include the following:

- Accuracy and reliability over a wide range of flow rates
- Relatively low head loss (unlike weirs which create a dam across the flow channel)

! Solids handling ability (i.e., "self-cleaning" feature).

The simple operation and free-flow design of a properly sized and installed Parshall flume should provide an accurate flow measurement for both small and large discharges that are within the design flow range. The flume design results in a minimal loss of hydraulic head. Increased flow velocities through the open channel result in a flushing or scouring action that allows the flume to handle solids commonly found in raw wastewater without buildup or clogging.

The Parshall flume is a primary flow measuring device that is designed to act as an artificial channel for flow measurement. As seen in Figure 1-1, flumes normally consist of three sections: the converging, throat, and diverging sections. The flow to be measured accelerates as it passes through the converging section. The channel restriction in the throat produces a calibrated change in liquid level (head) and flow velocity as the flow rate varies. The hydraulic head is measured at a point that is two-thirds the length of the converging section upstream from the throat. Flow exits the flume through the diverging section at a level which is less than the level in the converging section, this maintains free-flow conditions.

Flow measurement devices, including flumes and associated secondary devices, must be inspected to ensure that the devices provide accurate flow measurements. A thorough inspection should check for location, design, construction, installation, size, and maintenance problems. To properly evaluate a flow measurement system, it is recommended that the inspector follow these steps:

1. Assess the condition of the primary device and verify that it has been properly installed and maintained;

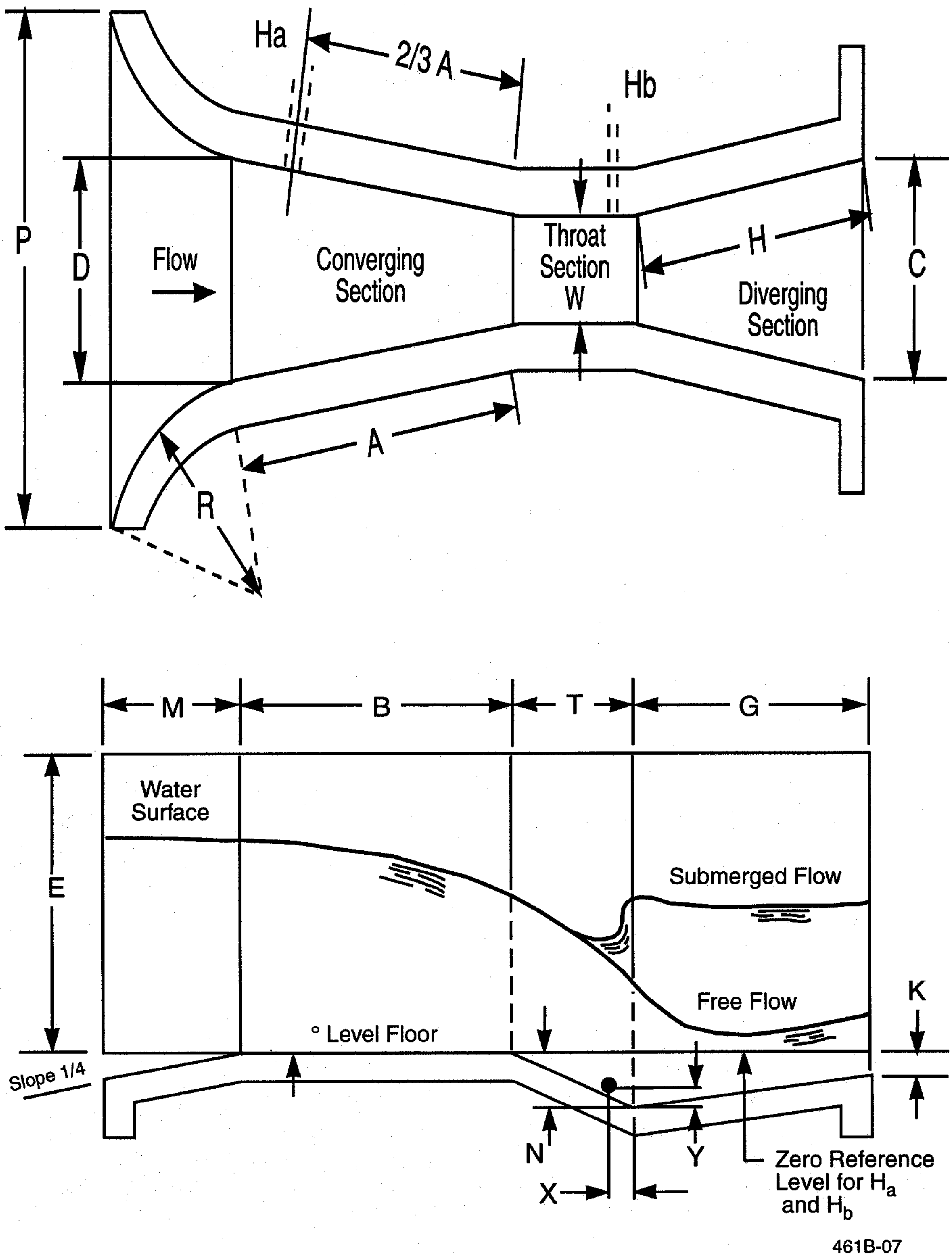
2. Assess the head measurement equipment (secondary device) and verify that it has been installed at the correct location in the convergence section of the flume; and,

3. Verify the accuracy of the flow measurement system as a whole by comparing manual flow measurements to measurements obtained from the facility's flow recorders and totalizers.

Specific points that an inspector should consider while evaluating flow measurement systems are presented in the following sections.

Figure 1-1.

Dimensions and Capacities of Parshall Measuring Flumes for Various Throat Widths (Associated Water and Air Resource Engineers, Inc., 1973)



QUESTIONS

1. A Parshall flume is used to measure wastewater flow that is contained in which of the following?

    A. Open channel
    B. Enclosed pipes
    C. Flow drop
    D. All of the above

2. List the three main sections of a Parshall flume.

    ____
    ____
    ____

3. Which of these factors are not qualities of the Parshall flume?

    A. Accuracy
    B. High head loss
    C. Solids handling ability
    D. All of the above

4. What determines the type of primary flow measuring device selected?

    A. The quantity of flow
    B. Whether the flow is measured in an enclosed completely-filled pipe or open channel
    C. The use of the flow data

CHAPTER 2
INSPECTION OF FLOW MEASUREMENT SYSTEMS

This section will provide guidance to compliance inspectors in identifying flow measurement system deficiencies. The primary device, or the Parshall flume, will be discussed first. The evaluation of secondary devices and flow records will also be addressed in this section.

PARSHALL FLUMES

Errors in Parshall flume flow measurements most commonly result from improper location, construction and installation, sizing, or flow conditions. These topics are discussed below in further detail.

Flume Location

Parshall flumes can be located almost anywhere open channel flow measurement is required. Flumes may be located at the treatment facility influent (i.e., headworks) or at the effluent. There are a few conditions that an inspector should check for to confirm that the location is acceptable for accurate flow measurements:

- Influent flume locations should not include plant recycle flows. The inspector should confirm that all recycle flow streams are introduced downstream of the flume. If recycle flow streams are returned upstream of the flume, some facilities have the capability to measure the recycle flow rate and deduct this from the total flow measurement.

- If the flume location is specified in the NPDES permit, the inspector should verify that the flume is located as specified and that the location is appropriate for compliance monitoring purposes. Effluent flume locations should measure the total wastewater flow discharged to the receiving waters. Therefore, the flume should be installed downstream of any plant water intakes. Also, there should be no discharges to the receiving waters that do not flow through the flume. Some larger treatment plants may have more than one flume to measure the effluent discharge rate. The inspector should thoroughly evaluate all of the flumes present and determine how the individual flume measurements are combined to report the total plant flow.

- The accuracy of flow measurements in flumes can be greatly affected by the flow in the upstream approach channel. The upstream channels should be horizontal, straight, and uniform in cross-sectional area. The channel should be at least as wide as the converging section of the flume and at least ten times the width of the throat. Channel walls should merge into the converging section with a smooth rounded transition to avoid turbulence. Proper upstream channel conditions should result in a flow stream entering the flume which is relatively free from turbulence and waves (i.e., "white water").

- Flumes must have a free flow discharge to the downstream channel throughout the flow range. Downstream channels should be straight for five to twenty times the width of the throat of the flume. The inspector should check the downstream channel for obstructions, constrictions, or turns that may cause the flow to back up into the flume and cause submerged flow conditions. Evaluation of submerged flow conditions will be discussed later.

Construction, Materials, and Installation

Depending on the size of the Parshall flume, the flume may be prefabricated or constructed on-site. Flume construction materials must be corrosion resistant and smooth finished. Materials commonly used are fiberglass, galvanized sheet metal, or concrete. The inspector should evaluate the following areas to verify proper installation and construction:

- Check to ensure the flume structure is in good condition and that the foundation is watertight.
- If possible, a carpenters level should be used to check that the sidewalls are vertical and that the floor of the converging section is level. The converging section may be checked by simply placing the level along the top of the flume.
- The flume should be installed in a straight line with the existing channel, without any bends immediately upstream or downstream.
- The upstream flow should be uniformly distributed across the channel and relatively free of turbulence and waves.

Flume Size

Flume sizing is very important to flow accuracy. Flume sizes are based on the width of the throat. Throat widths can vary from one inch to 50 feet, depending on the quantity of flow which must be measured. The inspector should check historical records to see if flow variations (i.e., average daily and maximum daily flows) are within the accuracy range for the flume size. If the flow is too large (i.e., undersized flume), it may result in submerged flow conditions or "overtopping" of the flume. If the flow is too small (i.e., oversized flume), then adequate level measurement resolution may not be possible. Both circumstances will result in flow measurement errors. Refer to Appendix A for information concerning different Parshall flume throat widths and the corresponding recommended minimum and maximum flow rates for free-flow conditions through flumes.

Submerged Flow Conditions

Parshall flumes provide the most accurate flow measurements under free-flow conditions. Inspectors can visually determine whether flow through the flume is submerged or free-flow by observing the flow pattern in the diverging section. If the hydraulic jump or standing wave is at the end of the diverging section where the flume enters the channel, than the flow is free. However, if the hydraulic jump occurs where the throat enters the diverging section, the flow is submerged. When the submergence exceeds acceptable design criteria, the rate of discharge through flumes will be reduced.

Parshall flumes are able to provide accurate flow measurements at relatively high levels of submergence. The allowable level of submergence varies with the throat width and is illustrated below:

% SUBMERGENCE	THROAT WIDTH
50	1 - 3 inches
60	6 - 9 inches
70	1 - 8 feet
80	8 - 50 feet

The percent submergence can be determined by the inspector if there are concerns about submergence conditions affecting the accuracy of flow measurements at a particular installation. To determine submergence, an additional head measurement must be taken at the outlet of the throat section (refer to Figure 1 and locate Point H_b). The percent submergence is determined by dividing the throat head measurement (Point H_b) by the converging section head measurement (Point H_a) and multiplying by 100. Most flume installations do not include a permanent head measuring device at the throat outlet; therefore, the inspector must obtain this measurement by manual means.

SECONDARY DEVICES

Secondary devices measure the liquid level in the primary device and convert this measurement into an appropriate flow rate. The output of secondary devices is used to totalize the flow over a period of time (usually 24 hours) and may also be transmitted to a circular or strip chart recorder to provide a permanent flow record. Most secondary devices also provide an instantaneous flow readout as either an analog or digital display. A review of flow chart records can provide compliance inspectors with valuable information concerning daily minimum and peak flow variations as well as identifying flow trends related to industrial discharges or Inflow/Infiltration (I&I) conditions.

For Parshall flume installations, secondary devices may be installed directly at the converging section of the flume or at a stilling well in close proximity to the flume. A stilling well is connected by a tap to the converging section of a flume at a point which is two-thirds the distance of the converging section upstream of the throat section (refer to Figure 1 and locate Point H_a). Stilling wells dampen turbulent conditions which may be present in the flume. The level in the stilling well changes as the head in the flume changes. Stilling wells are not required for all flume installations. The most common secondary devices used to measure the head developed by flumes are staff gauges, floats, bubblers, ultrasonic transducers, and electrical sensors (i.e., capacitance strips). Important points to consider during the evaluation of secondary devices are summarized below:

- **Location:** Secondary devices installed in flumes must be located at the converging section point which is two-thirds upstream of the throat inlet. Stilling well taps inside the flume sidewall must also be at the same location. It is not always possible to locate the stilling well tap, especially in large flumes.

- **Flow meter zero setting:** During the initial installation, and at subsequent calibration/service intervals, the flow meter must be "zeroed" with the zero reference point in the flume. An improperly zeroed flow meter will not provide accurate flow measurements. Due to the nonlinear relationship between head and flow rate, the magnitude of the error will increase at higher flow rates. During most inspections, it will not be feasible to stop the flow to check the zero setting. However, zero setting verification may still be accomplished by measuring the actual liquid level in the flume and comparing this measurement to the liquid level reading of the flow meter. A properly zeroed flow meter should have a liquid level reading which is identical to your manually obtained measurement. Checking the zero setting in this manner may not be possible at all installations, since some flow meters do not provide a liquid level readout.

- **Flow meter maintenance:** The inspector should verify that the flow meter is periodically calibrated and serviced to ensure that accurate flow measurements are being recorded. Some NPDES permits specify a minimal maintenance frequency of once per year. Unfortunately, many treatment plant personnel assume the flow meter is working properly as long as it is providing flow measurements and, therefore, do not recognize the need for periodic calibration and servicing. Typically, many larger municipalities or sewerage authorities calibrate flow meters on a more frequent basis if the flow readings are used as a basis to bill customers for wastewater treatment services.

- **Flow meter output:** Many flow meters require the use of a factor to obtain the correctly totalized flow measurement. This factor is usually indicated on the inside cover of the flow meter. The inspector should verify that this factor is being correctly applied to the totalized flow readings by the treatment plant operating staff.

- **Stilling wells:** Inspectors should check stilling wells for the accumulation of any debris (i.e., rags, leaves, solids, or grease) which may interfere with the secondary device measurement of the liquid level in the well. Plant operators should periodically clear any debris which might accumulate in stilling wells. The inspector should be able to verify that changes in head in the flume, produce changes in head in the stilling well. This may be observed by changes in float elevation, cable movement, or actual liquid level measurements.

- **Staff gauges:** If a staff gauge is present, it must be installed at the proper location in the converging section of the flume. Staff gauges provide a reliable means of quickly determining the instantaneous flow rate at a flume. Some NPDES permits require only instantaneous daily or weekly flow measurements which may be obtained from staff gauges. Staff gauges should be cleaned regularly to obtain accurate readings. Staff gauge readings should be verified against manually obtained liquid level measurements.

- **Floats:** These devices float on the water surface (either in the flume or stilling well) and via cables and pulleys rotate a mechanical cam in proportion to the flow rate. Floats are reliable level measuring devices; however, they tend to collect debris and require frequent cleaning to prevent sticking and buoyancy changes. If present, float arm mechanical hinges should be checked for corrosion which can restrict freedom of movement and cause errors. Boat-type floats are attached to a vertically pivoting arm and are located in the flow rather than the stilling well. This type of float should be located on the center line of the flume. Boat-type floats may collect rags and other debris which could affect their level measurement accuracy. Both types of floats are prone to collect ice during periods of cold weather which can also affect their accuracy.

- **Ultrasonic transducers:** The transducer may be installed either at the flume or stilling well. These devices use sound waves to measure the liquid level. Ultrasonic transducers may be affected by excessive turbulence, foam, or floating debris.

- **Bubblers:** A bubbler tube is anchored at the appropriate location in the converging section of the flume. Pressurized air is supplied to the tubing at a constant rate. As the liquid level in the flume varies due to changes in flow rate, the pressure will also vary to maintain the fixed air rate. Therefore, the pressure is proportional to the liquid level in the flume and can be converted to a corresponding flow rate. The end of the bubbler tubing should be checked periodically for accumulations of grease or debris which could produce false pressure readings.

- **Electronic sensors:** These devices may be installed in flumes or stilling wells. Changes in water level result in changes in electrical conductivity which can be converted to flow rates. Grease or solids may coat the probe and interfere with level measurements.

In summary, inspectors should evaluate secondary devices for the following criteria:

- Verify they are properly located at the flume

- Verify that calibration and service are performed at specified intervals and records are maintained

- Verify that the meter has been "zeroed"

- Verify that the treatment plant staff can read the flow meter output correctly

- Check on the condition of the device and verify its ability to properly measure the liquid level in the flume or stilling well.

RECORDS REVIEW

The NPDES permit requires that specific records (i.e., flow, maintenance and calibration) be retained for at least three years. The inspector should verify that flow records and charts are retained as required and are maintained in good condition. The records should be stored onsite and should be easily accessible for inspection. Flow records should contain the flow, date, time of reading, and operators name. Flow charts should contain the flow and date. Maintenance records should note the date the problem was identified and the date of repair. Calibration records should note the date of calibration, equipment calibrated, and calibration problems, if any. The inspector should assess the permittee's flow data and note:

- Flow uniformity - Do flow data indicate equipment malfunction by flow that is too uniform or flows with erratic unexplained variations?
- Flow data - Do flow data have gaps (missing data) as a result of inoperable flow equipment? Are the flow charts changed as appropriate and properly retained?

QUESTIONS

1. Parshall flumes are what type of flow measuring device?

   A. Primary
   B. Secondary
   C. Tertiary

2. The Parshall flume must <u>only</u> be used to measure effluent flows.

   A. True
   B. False

3. What process is used to determine whether the flume is properly sized?

   A. Review flume design information
   B. Compare historical flow data against flume design data
   C. Compare flow data collected during the inspection to the flow range

4. What is submergence?

   A. Flow that has backed up into the divergence section
   B. Flooding of the entire flume
   C. Flow that exceeds the secondary device measurement ability

5. What factor greatly affects flume accuracy?

   A. Turbulence
   B. Upstream channel flow
   C. Submergence
   D. Proper flume sizing
   E. All of the above

6. Upstream channels should have a uniform cross sectional area that is at least _________ times the throat width.

   A. 2
   B. 4
   C. 6
   D. 8
   E. 10

7. Placing the secondary device in a stilling well should eliminate which of the following factors that affect flow measurement?

   A. Turbulence
   B. Clogs
   C. Debris

D. Submergence

8. At what point in the flume should secondary devices be located?

   A. Downstream from the throat one-third of the divergence section length
   B. Upstream from the throat one-third of the convergence section length
   C. Downstream from the throat two-thirds of the divergence section length
   D. Upstream from the throat two-thirds of the convergence section length

CHAPTER 3
OVERALL SYSTEM ACCURACY

Once an inspector has determined that a Parshall flume and its associated secondary device have been installed correctly, the accuracy of the entire installation should be verified. This is accomplished by comparing the inspector's independent measurements at the flume to the flow meter's totalizer or indicator. The flow meter reading should be within ± 10 percent of the inspector's measurements. Due to the non-linear relationship between flow and head measurements, flow comparisons should be made at various flow rates, if conditions allow for this. Additional information concerning verification of the overall system accuracy is presented below.

Depending on the discharge permit requirements, verification of the accuracy of a flow metering system should at the very least include the instantaneous flow readout. If the permit requires the total daily flow to be measured, then the accuracy of the flow meter totalizer should also be verified. Instantaneous flow readouts are verified by simply measuring the flow at the flume and comparing this value to the simultaneous flow meter reading. If the flow meter does not provide a local readout of the flow rate, then two persons will be needed to simultaneously measure and record the flow at the flume and at the plant location (i.e., operations control building, etc.) where the flow rate is indicated. As noted above, the instantaneous flow meter reading should be within ± 10 percent of the manual measurement.

Flow meter totalizers can be checked during periods of relatively stable flow in the following manner. Record the time (or start a stop watch) and the initial totalizer reading just as a new digit appears on the flow meter totalizer. After a period of ten to thirty minutes, the totalizer should be read again, just as a new digit appears. The flow rate in Gallons per Minute (GPM) can be calculated by dividing the difference between the starting and ending totalizer readings by the time period (minutes). The totalized flow rate should be compared to the calculated flow rate determined by manual measurements taken during the same period of time. The total number of manual measurements to be taken will be site-specific; i.e., the more variable the flow, the more frequently manual measurements should be taken. The totalized flow rate should be within $\pm$ 10 percent of the manual flow measurement.

DETERMINATION OF FLOW RATES

Once an inspector has taken manual head measurements at a flume, the measurements must be converted to an equivalent rate of flow. This may be accomplished by any of the following methods: flow curves, formulas, or flow tables. Of the three methods, flow tables are probably the most widely used method.

Flow Curves

A rating curve can be used to determine the flow through a Parshall flume. The appropriate rating curve, flume size (i.e., throat width), and hydraulic head measurement are needed to calculate the flow. An example of a flow curve is presented in Figure 3-1. In the figure, the inches of head measurement are followed horizontally to the point of intersection with the curve. Vertically, from that point a reading of the flume flow is taken at the bottom of the graph. Facilities with prefabricated flumes may have the manufacturer's curve available. Facilities with flumes constructed on-site can develop curves using site-specific data.

Formulas

Flow verification may require the calculation of the primary device flow if a rating curve or flow table are unavailable. Several equations are available to calculate the flow in the flume. The following equation converts the primary device head measurement to flow and is used to calculate free non-submerged flow in a Parshall flume. This equation can be used for flumes having a throat width up to eight feet:

$$Q = 4WH^{1.522W^{0.026}}$$

Where: Q = flow, ft^3/sec
W = throat width, feet
H = liquid head, feet

Flow Tables

Standard flow tables for Parshall flumes and weirs can be found in a variety of references. It is highly recommended that the compliance inspector obtain a copy of one of the following documents prior to performing an inspection of a flow metering system:

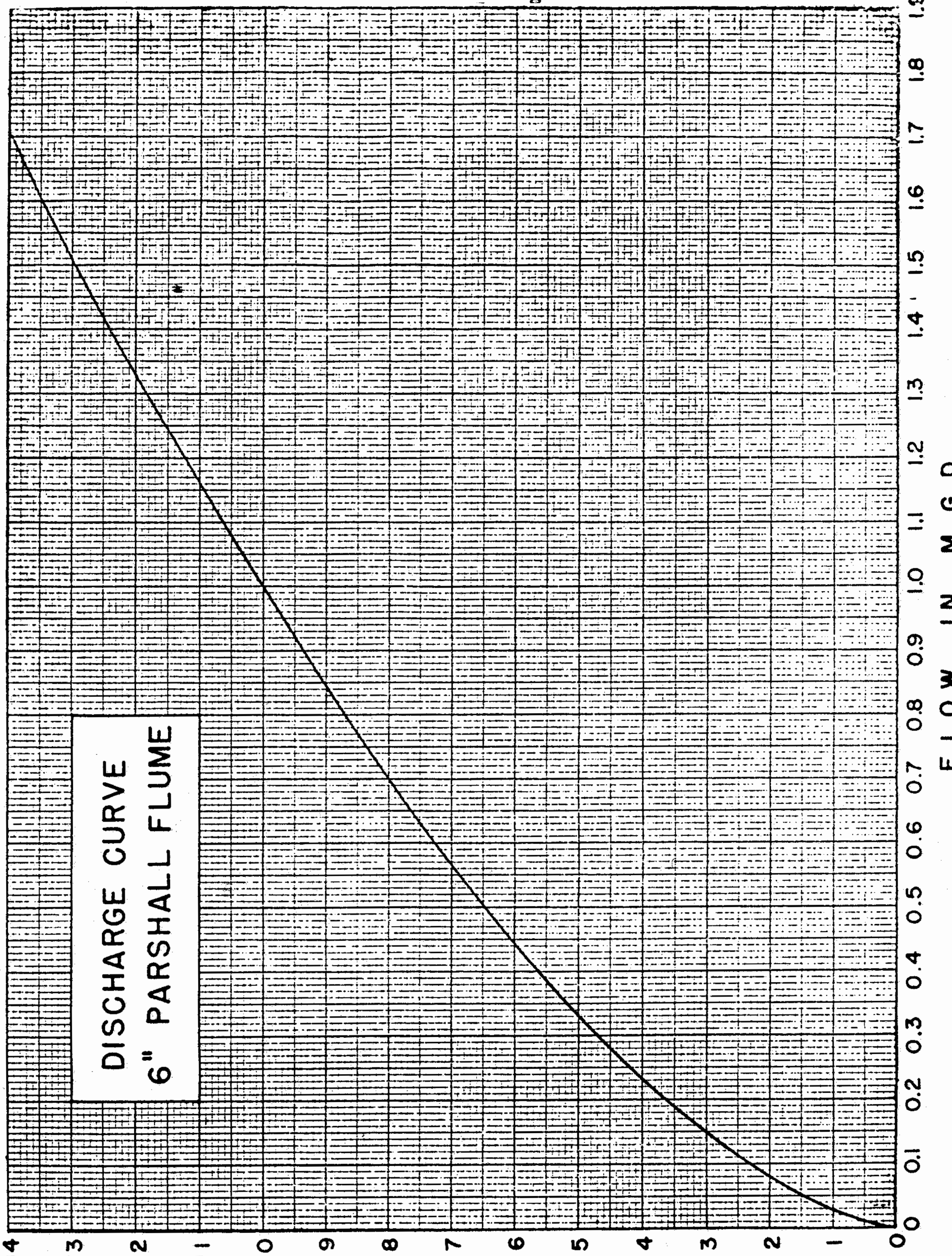
- *ISCO Open Channel Flow Measurement Handbook*, ISCO, Inc., Lincoln, Nebraska, (402) 474-2233, 3rd Ed., 1989.
- *Stevens Water Resources Data Book*, Leupold & Stevens, Inc., Beaverton, Oregon, (503) 646-9171, 4th Ed., 1987.
- *Water Measurement Manual*, U.S. Department of the Interior, Bureau of Reclamation, U.S. Government Printing Office, 2nd Ed., 1967.
- *Handbook of Hydraulics*, King, H.W. and E.F. Brater, McGraw-Hill Book Co., New York, 5th Ed., 1963.

Using the flow tables contained in any of the above references, an inspector can readily determine the flow by turning to the correct table (i.e., correct throat width) and comparing the actual head measurement to a corresponding flow rate. An example of a flow table for 1 inch to 18 inch flumes is presented in Appendix B.

Assessing the accuracy of the entire flow measurement system by performing manual measurements at the time of the inspection can result in the immediate identification of flow measurement deficiencies which may not be evident during the physical inspection or records review phases. However, not all flow measurement facilities will be readily accessible to allow manual measurements. Also, safety concerns should be evaluated before an inspector attempts to gain access to the flume.

Figure 3-1.

Flow Rating Curve



QUESTIONS

1. Primary device flow measurements and recorder readings and/or totalizer flow rates must be within _________ percent of each other to be acceptable for accuracy.

   A. 2%
   B. 5%
   C. 10%
   D. 20%
   E. 25%

2. Which data are required to use a flow rating curve? (circle all that apply)

   A. Flume size
   B. Flow type
   C. Reading time
   D. Hydraulic head measurement

3. How many years must the permittee retain flow records?

   A. 1
   B. 3
   C. 5
   D. 7

4. An initial totalizer reading is 106,490. A second reading taken fifteen minutes later is 106,610. If the totalizer units are thousands, what is the flow rate?

   A. 8,000 gpd
   B. 1,800 gpd
   C. 120,000 gpd
   D. 11,520,000 gpd

APPENDIX A

MINIMUM AND MAXIMUM FLOW RATES FOR FREE FLOW THROUGH PARSHALL FLUMES AT DIFFERENT THROAT WIDTHS

Appendix A

Minimum and Maximum Flow Rates for Free Flow Through Parshall Flumes at Different Throat Widths

Throat Width, W		Minimum Head, ft.	Minimum Flow Rate		Maximum Head, ft.	Maximum Flow Rate	
			MGD	CFS		MGD	CFS
1	in.	0.07	0.003	0.005	0.60	0.099	0.153
2	in.	0.07	0.007	0.011	0.60	0.198	0.306
3	in.	0.10	0.018	0.028	1.5	1.20	1.86
6	in.	0.10	0.035	0.054	1.5	2.53	3.91
9	in.	0.10	0.05	0.091	2.0	5.73	8.87
1	ft.	0.10	0.078	0.120	2.5	10.4	16.1
1.5	ft.	0.10	0.112	0.174	2.5	15.9	24.6
2	ft.	0.15	0.273	0.423	2.5	21.4	33.1
3	ft.	0.15	0.397	0.615	2.5	32.6	50.4
4	ft.	0.20	0.816	1.26	2.5	43.9	67.9
5	ft.	0.20	1.00	1.55	2.5	55.3	85.6
6	ft.	0.25	1.70	2.63	2.5	66.9	103
8	ft.	0.25	2.23	3.45	2.5	90.1	139
10	ft.	0.30	3.71	5.74	3.5	189	292
12	ft.	0.33	5.13	7.93	4.5	335	519

APPENDIX B

EXAMPLE FLOW TABLE FOR PARSHALL FLUMES RANGING IN SIZE FROM 1 INCH TO 18 INCHES

(Source: Stevens Water Resources Data Book, 4th Edition, 1987)

Appendix B

Example Flow Table for Parshall Flumes Ranging in Size from 1 Inch to 18 Inches

Head	1 in.		2 in.		3 in.		6 in.		9 in.		12 in.		18 in.	
Ft.	CFS	MGD	CFS	MGD	CFS	MGD	CFS	MGD	CFS	MGD	CFS	MGD	CFS	MGD
0.05	.0032	.002	.007	.005										
.06	.0043	.003	.009	.006										
.07	.0055	.004	.011	.007										
.08	.0067	.004	.013	.008										
.09	.0081	.005	.016	.010										
.10	.0095	.006	.019	.012	.028	.018	.05	.03	.09	.06				
.11	.0110	.007	.022	.014	.033	.021	.06	.04	.10	.06				
.12	.0126	.008	.025	.016	.037	.024	.07	.05	.12	.08				
.13	.0143	.009	.029	.019	.042	.027	.08	.05	.14	.09				
.14	.0160	.010	.032	.021	.047	.030	.09	.06	.15	.10				
.15	.0179	.012	.036	.023	.053	.034	.10	.06	.17	.11				
.16	.0197	.013	.039	.025	.058	.037	.11	.07	.19	.12				
.17	.0217	.014	.043	.028	.064	.041	.13	.08	.20	.13				
.18	.0237	.015	.047	.030	.070	.045	.14	.09	.22	.14				
.19	.0258	.017	.052	.034	.076	.049	.15	.10	.24	.16				
.20	.028	.018	.056	.036	.082	.053	.16	.10	.26	.17	.35	.23	.50	.32
.21	.030	.019	.060	.039	.089	.058	.17	.11	.28	.18	.37	.24	.54	.35
.22	.032	.021	.065	.042	.095	.061	.19	.12	.30	.19	.40	.26	.58	.37
.23	.035	.023	.069	.045	.102	.066	.20	.13	.32	.21	.43	.28	.63	.41
.24	.037	.024	.074	.048	.109	.070	.22	.14	.35	.23	.46	.30	.67	.43
.25	.039	.025	.079	.051	.116	.075	.23	.15	.37	.24	.48	.31	.71	.46

APPENDIX C

ANSWERS TO QUESTIONS

Appendix C

Answers to Questions

CHAPTER 1

1. A
2. Convergence
   Throat
   Divergence
3. B
4. B

CHAPTER 2

1. B
2. B
3. B
4. A
5. E
6. E
7. A
8. D

CHAPTER 3

1. C
2. A & D
3. B
4. D
   SOLUTION: 106,610
   -106,490
   120 x 1000 = 120,000 gallons in 15 minutes
   120,000 gallons/15 minutes = 1,800 gallons per minute
   1,800 gpm x 1440 minutes/day = 11,520,000 gpd