6. FLOW MEASUREMENT

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6. A. Evaluation of Permittee's Flow Measurement

Objectives and Requirements

To comply with the permit requirements established under the National Pollutant Discharge Elimination System (NPDES), the permittee must accurately determine the quantity of wastewater being discharged. Discharge flow an measurement is an integral part of the NPDES program, it is important that the inspector evaluate the accuracy of the measurement.

In addition to providing usable information for enforcement purposes, flow measurement serves to:

- Provide data for pollutant mass loading calculations
- Provide operating and performance data on the wastewater treatment plant
- Compute treatment costs, based on wastewater volume
- Obtain data for long-term planning of plant capacity, versus capacity used
- Provide information on Infiltration and Inflow (I/I) conditions, and the need for cost-effective I/I correction

A Flow Measurement Inspection Checklist for the inspector's use appears at the end of this chapter.

Evaluation of Facility-Installed Flow Devices and Data

There are two types of wastewater flow: closed channel flow and open channel flow. Closed channel flow occurs under pressure in a liquid-full conduit (usually a pipe). The facility will usually have a metering device inserted into the conduit which measure flow. Examples of closed channel flow measuring devices are the Venturi meter, the Pitot tube, the paddle wheel, the electromagnetic flowmeter, Doppler, and the transit-time flowmeter. In practice, closed channel flow is normally encountered between treatment units in a wastewater treatment plant, where liquids and/or sludges are pumped under pressure.

Open channel flow occurs in conduits that are not liquid-full. Open channel flow are partially full pipes not under pressure. Open channel flow is the most prevalent type of flow at NPDES-regulated discharge points.

Measure open channel flow using primary and secondary devices. Primary devices are standard hydraulic structures, such as flumes and weirs, that are inserted in the open channel. Inspectors can obtain accurate flow measurements merely by measuring the depth of liquid (head) at the specific point in the primary device. In a weir application, for example, the flow rate is a function of the head of liquid above the weir crest.

Facilities use secondary devices in conjunction with primary devices to automate the flow measuring process. Typically, secondary devices measure the liquid depth in the primary device and convert the depth measurement to a corresponding flow, using established mathematical relationships. Examples of secondary devices are floats, ultrasonic transducers, bubblers, and transit-time flowmeters. A recorder generally measures the output of the secondary device transmitted to a recorder and/or totalizer to provide instantaneous and historical flow data to the operator. Outputs may also be transmitted to sampling systems to facilitate flow proportioning. Appendix O contains further information on flow measurement devices.

The inspector must assure the permittee obtains accurate wastewater flow data to calculate mass loading (quantity) from measured concentrations of pollutants discharged as required by many NPDES permits. The permittee must produce data that meet requirements in terms of precision and accuracy. Precision refers to data reproducibility or the ability to obtain consistent data from repeated measurements of the same quantity. Accuracy refers to the agreement between the amount of a component measured by the test and the amount actually present.

The accuracy of flow measurement (including both primary and secondary devices) varies widely with the device, its location, environmental conditions, and other factors such as maintenance and calibration. Faulty fabrication, construction, and installation of primary devices are common sources of errors. Improper calibration, misreading, and variation in the speed of totalizer drive motors are major errors related to secondary devices. See Appendix O - "Supplement Flow Measurement Information." When evaluating facility installed devices, the inspector should do the following:

- Verify that the facility has installed primary and secondary devices according to manufacturer's manual instructions.

- Inspect the primary device for evidence of corrosion, scale formation, or solids accumulation that may bias the flow measurement.

- Verify that weirs are level, plumb, and perpendicular to the flow direction.

- Verify that flumes are level, the throat walls (narrowed section of flume) are plumb, and the throat width is the standard size intended.

- Inspect historical records (i.e., strip charts and logs) for evidence of continuous flow measurements. Compare periods of missing data with maintenance logs for explanations of measuring system problems.

- Observe the flow patterns near the primary device for excessive turbulence or velocity. The flow lines should be straight.

- Ensure that the flow measurement system or technique being used measures the entire wastewater discharge as required by the NPDES permit. Inspect carefully the piping to determine whether there are any wastewater diversions, return lines, or bypasses around the system. Make sure the system meets the permit requirement, such as instantaneous or continuous, daily, or other time interval measures. Noted anomalies in the inspection report.

- Verify that the site chosen for flow measurement by the facility is appropriate and is in accordance with permit requirements.

- Verify that the site chosen by the facility for flow measurement is suitable for type of discharge, flow range, suspended solids concentration, and other relevant factors.
- Verify that the facility has closed channel flow measuring devices where the pipe is always full. If these devices are used, then there must be also a means for the permittee and regulatory agencies/inspector to verify the accuracy of these meters. Primary flow measuring devices such as weirs and flumes are ideal for this purpose.
- Verify that the facility uses appropriate tables, curves, and formulas to calculate flow rates.
- Review and evaluate calibration and maintenance programs for the discharger's flow measurement system. The permit normally requires the facility to check the calibration regularly by the permittee. The facility must ensure that their flow measurement systems are calibrated by a qualified source at least once a year to ensure their accuracy. Lack of such a program is considered unacceptable for NPDES compliance purposes.
- Verify that the facility calibrates flowmeters across the full range of expected flow.
- Verify that primary and secondary devices are adequate for normal flow as well as maximum expected flow. Note whether the flow measurement system can measure the expected range of flow.
- Collect accurate flow data during inspection to validate self monitoring data collected by the permittee.
- The facility must install a flow measuring system that has the capability of routine flow verification by the permittee or appropriate regulatory personnel.

Evaluation of Permittee Data Handling and Reporting

The permittee or facility must keep flow measurement records for a minimum period of three years as the permit requires. Many flow measuring devices produce a continuous flowchart for plant records. Flow records should contain date, flow, time of reading, and operator's name, if applicable the facility must also record. The facility should record maintenance, inspection dates, and calibration data.

The inspector should review the permittee's records and note the presence or absence of data such as:

- Frequency of routine operational inspections
- Frequency of maintenance inspections

- Frequency of flowmeter calibration (should be as specified in permit, generally at least once per year)

- Irregularity or uniformity of flow.

Evaluation of Permittee Quality Control

The inspection should evaluate following quality control issues during a compliance inspection to ensure:

- Proper operation and maintenance of equipment
- Accurate records
- Sufficient inventory of spare parts
- Valid flow measurement techniques
- Precise flow data
- Adequate frequency of calibration checks.

Evaluate precision of float driven flow meters when flows are stable. Push the float gently downward, hold for 30 seconds, then allowed to return normally. The recorded flow rate should be the same before and after the float was moved. Evaluate accuracy by measuring the instantaneous flow rate at the primary device used at the facility and comparing the value against the value on the meter, graph, integrator, or company record. The difference between two stable totalizer readings (flow is steady for 10 minutes or more) should not exceed ±10 percent of the instantaneous flow measured at the primary device. Note that most flow measurement systems have both an instantaneous meter readout as well as a totalizer. Both of these devices should be in agreement but that is not always the case due to electrical and other various malfunctions in the flow measuring system. In most cases, the totalizer reading will be what is reported by the permittee. If this is the case, then that device should be checked for accuracy and the permittee's flow measuring system rated accordingly.

In addition, the inspector can evaluate accuracy by installing a second flow measurement system, sometimes referred to as a reference system. Agreement in measured flow rates between the two systems should be within ±10 percent of the reference rate if all conditions are as recommended for the systems.

6. B. Flow Measurement Compliance

Objectives

The current NPDES program depends heavily on the permittee's submittal of self-monitoring data. The flow discharge measured during the NPDES compliance inspection should verify the flow measurement data collected by the permittee, support any enforcement action that may be necessary, and provide a basis for reissuing or revising the NPDES permit.

Flow Measurement System Evaluation

The responsibility of the inspector includes collecting accurate flow data during the inspection and validating data collected during the permittee's self-monitoring.

The NPDES inspector must check both the permittee's flow data and the flow measurement system to verify the permittee's compliance with NPDES permit requirements. When evaluating a flow measurement system, the inspector should consider and record findings on the following:

- Whether the system measures the entire discharge flow.
- The system's accuracy and good working order. This will include a thorough physical inspection of the system and comparison of system readings to actual flow or those obtained with calibrated portable instruments.
- The need for new system equipment.
- The existence or absence of a routine calibration and maintenance program for flow measurement equipment.

If the permittee's flow measurement system is accurate within ±10 percent, the inspector should use the installed system. If the flow sensor or recorder is found to be inaccurate, the inspector should determine whether the equipment can be corrected in time for use during the inspection. If the equipment cannot be repaired in a timely manner, use the portable flow sensor and recorder used to assess the accuracy of the permittee's system for the duration of the inspection. If nonstandard primary flow devices are being used, request the permittee to supply data on the accuracy and precision of the method being employed.

For flow measurement in pipelines, the inspector may use a portable flowmeter. The inspector should select a flowmeter with an operating range wide enough to cover the anticipated flow to be measured. The inspector should test and calibrate the selected flowmeter before use. The inspector should select the site for flow measurement according to permit requirements and install the selected flowmeter according to the manufacturer's specifications. The inspector should use the proper tables, charts, and formulas as specified by the manufacturer to calculate flow rates.

Four basic steps are involved in evaluating the permittee's flow measurement system:

- Physical inspection of the primary device
- Physical inspection of the secondary device and ancillary equipment
- Flow measurement using the primary/secondary device combination of the permittee
- Certification of the system using a calibrated, portable instrument.

The following sections present, procedures for inspecting the more common types of primary and secondary devices, for measuring flow using common permanent and portable systems, and for evaluating flow data. Please note that the number of primary/secondary device permutations is limitless; therefore, it is not feasible to provide procedures for all systems. When encountering systems other than those discussed here the inspector should consult the manufacturers manual/personnel for advice before preparing a written inspection procedure.

Primary Device Inspection Procedures

The two most common open channel primary devices are sharp-crested weirs and Parshall flumes. Common sources of error when using them include the following:

- Faulty fabrication—weirs may be too narrow or not "sharp" enough. Flume surfaces may be rough, critical dimensions may exceed tolerances, or throat walls may not be vertical.

- Improper installation—the facility may install weirs and flumes too near pipe elbows, valves, or other sources of turbulence. The devices may be out of level or plumb.

- Sizing errors—the primary device's recommended applications may not include the actual flow range.

- Poor maintenance—primary devices corrode and deteriorate. Debris and solids may accumulate in them.

Specific inspection procedures for the sharp-crested weir, the Parshall flume, and the Palmer-Bowlus flume devices follow.

Sharp-Crested Weir Inspection Procedures

- Inspect the upstream approach to the weir.

  - Verify that the weir is perpendicular to the flow direction.

  - Verify that the approach is a straight section of conduit with a length at least 20 times the maximum expected head of liquid above the weir crest.

  - Observe the flow pattern in the approach channel. The flow should occur in smooth stream lines without velocity gradients and turbulence.

  - Check the approach, particularly in the vicinity of the weir, for accumulated solids, debris, or oil and grease. The approach must have no accumulated matter.

- Inspect the sharp-crested weir.

  - Verify that the crest of the weir is level across the entire conduit traverse.

  - Measure the width of the weir crest. The edge of the weir crest should be no more than 1/8-inch thick.

  - Make certain the weir crest corresponds to zero gauge elevation (zero output on the secondary device).

  - Measure the angle formed by the top of the crest and the upstream face of the weir. This angle must be 90 degrees.

  - Measure the chamfer (beveled edge) on the downstream side of the crest. The chamfer should be approximately 45 degrees.

  - Visually survey the weir-bulkhead connection for evidence of leaks or cracks which permit bypass.

  - Measure the height of the weir crests above the channel floor. The height should be at least twice the maximum expected head (2H) of liquid above the crest.

  - Measure the width of the end contraction. The width should be at least twice the maximum expected head (2H) of the liquid above the crest.

  - Inspect the weir for evidence of corrosion, scale formation, or clinging matter. The weir must be clean and smooth.

  - Observe flow patterns on the downstream side of the weir. Check for the existence of an air gap (ventilation) immediately adjacent to the downstream face of the weir. Ventilation is necessary to prevent a vacuum that can induce errors in head measurements. Also ensure that the crest is higher than the maximum downstream level of water in the conduit.

  - Verify that the nappe is not submerged and that it springs free of the weir plate.

  - If the weir contains a V-notch, measure the apex angle. The apex should range from 22.5 degrees to 90 degrees. Verify that the head is between 0.2 and 2.0 feet. The weir should not be operated with a head of less than 0.2 feet since the nappe may not spring clear of the crest.

King's *Handbook of Hydraulics*, 1963, frequently referenced throughout this chapter, provides a detailed discussion on weirs.

Parshall Flume Inspection Procedures

- Inspect the flume approach.
  - The flow pattern should be smooth with straight stream lines, be free of turbulence, and have a uniform velocity across the channel.
  - The upstream channel should be free of accumulated matter.
- Inspect the flume.
  - The flume should be located in a straight section of the conduit.
  - Flow at the entrance should be free of "white" water.
  - The flume should be level in the transverse and translational directions.
  - Measure the dimensions of the flume. Dimensions are strictly prescribed as a function of throat width (see Figure I-5 in Appendix O for critical dimensions).
  - Measure the head of liquid in the flume and compare with the acceptable ranges in Table I-4 in Appendix O.
- Inspect the flume discharge.
  - Verify that the head of water in the discharge is not restricting flow through the flume. The existence of a "standard wave" is good evidence of free flow and verifies that there is no submergence present.
  - Verify whether submergence occurs at near maximum flow (e.g., look for water marks on the wall).

Palmer-Bowlus Flume Inspection Procedures

- Inspect the flume approach as outlined above (these flumes are seldom used for effluent flow measurement).
- Inspect the flume.
  - The flume should be located in a straight section of the conduit.
  - Flow at the entrance should be free of "white" water.
  - Observe the flow in the flume. The profile should approximate that depicted in Figure I-8 in Appendix O.
  - The flume should be level in the transverse direction and should not exceed the translational slope in Table I-6 in Appendix O.

  - Measure the head of water in the flume. Head should be within the ranges specified in Table I-6 in Appendix O.

- Inspect the flume discharge.

  - Verify that free flow exists. Look for the characteristic "standing wave" in the divergent section of the flume.

Venturi Meter Inspection Procedures

- Verify that the facility installed the Venturi meter according to manufacturer's instructions.

- Verify that the facility installed the Venturi meter downstream from a straight and uniform section of pipe, at least 5 to 20 diameters, depending on the ratio of pipe to throat diameter and whether straightening vanes are installed upstream. (Installation of straightening vanes upstream will reduce the upstream piping requirements.)

- Verify that the pressure measuring taps are free of debris and are not plugged.

- Calibrate the Venturi meter in place by either the volumetric method or the comparative dye dilution method to check the manufacturer's calibration curve or to develop a new calibration curve.

Secondary Device Inspection Procedures

The following are common sources of error in the use of secondary devices:

- Improper location—gauge is located in the wrong position relative to the primary device.
- Inadequate maintenance—gauge is not serviced regularly.
- Incorrect zero setting—zero setting of gauge is not the zero point of the primary device.
- Operator error—human error exists in the reading.

Specific inspection procedures follow.

Flow Measurement in Weir Applications

- Determine that the head measurement device is positioned 3 to 4 head lengths upstream of a weir.

- Verify that the zero or other point of the gauge is equal to that of the primary device.

The inspector should use an independent method of measuring head, such as with a yardstick or carpenter's rule (be sure to take your measurement at least four times the maximum head upstream and from the weir and convert to nearest hundredth of a foot). To determine flow rate, use the appropriate head discharge relationship formula (see Table I-1 in Appendix O).

Flow Measurement in Parshall Flume Applications

Flow Measurement—Free-Flow Conditions.

- Determine upstream head (H_a) using staff gauge.
  - Verify that staff gauge is set to zero head. Use either a yardstick or carpenter's rule.
  - Verify that staff gauge is at proper location (two-thirds the length of the converging section back from the beginning of the throat).
  - Read to nearest division the gauge division at which liquid surface intersects gauge.
  - Read H_a in feet from staff gauge.
- To determine flow rate, use Figure I-6 in Appendix O in the unit desired, use tables published in flow measurement standard references, or calculate using the coefficients in Table I-5 in Appendix O.

Flow Measurement—Submerged-Flow Condition.

Generally it is difficult to make field measurements with submerged-flow conditions. In cases when measurements can be obtained (using a staff or float gauge), the procedures listed below should be followed:

- Determine upstream head using staff or float gauge.
  - Read to nearest division and, at the same time as for H_b, the gauge division at which liquid surface intersects gauge.
  - Calculate H_a from gauge reading.
- Determine downstream head (H_b) using staff or float gauge.
  - H_b refers to a measurement at the crest.
  - Read to nearest division, and at the same time as for H_a, the gauge division at which liquid surface intersects gauge.
  - Calculate H_b from staff reading.

- Determine flow rate.

  - Calculate percent submergence:

$$\left[\frac{H_b}{H_a}\right] \times 100.$$

  - Consult Table I-6 in Appendix O.

  - When a correction factor is obtained, use H_a and find free-flow from Figure I-6.

  - Multiply this free-flow value by the correction factor to obtain the submerged flow.

The inspector may use an independent method of measuring head, such as a yardstick or carpenter's rule at the proper head measurement point. Because of the sloping water surface in the converging section of a flume, it is essential that the proper head measurement point be used.

Flow Measurement in Palmer-Bowlus Flume Applications

- Obtain head measurements as in the Parshall Flume application, using the secondary device. The head is the height of water above the step. The total depth upstream of the step is not the head.

- Refer to manufacturer-supplied discharge tables to convert head measurements to flow data. Palmer-Bowlus flumes, unlike Parshall flumes, are not constructed to standard dimensional standards. The inspector must not use discharge tables supplied by other manufacturers.

Verification

Most flow measurement errors result from inadequate calibration of the flow totalizer, and recorder. If the inspector has determined that the primary device has been installed properly, verification of the permittee's system is relatively simple. Compare the flow determined from the inspector's independent measurement to the flow of the permittee's totalizer or recorder. The inspector's flow measurements should be within 10 percent of the permittee's measurements to certify accurate flow measurement. Optimally, flow comparisons should be made at various flow rates to check system accuracy.

When the permit requires that the daily average flow be measured by a totalizing meter, the inspector should verify that the totalizer is accurate, i.e., properly calibrated. This can be done during a period of steady flow by reading the totalizer and at the same time starting a stopwatch. Start the stopwatch just as a new digit starts to appear on the totalizer. After 10 to 30 minutes, the totalizer should be read again; just as a new digit begins to appear, the stop watch is read. Subtract the two totalizer readings to determine, the total flow over the measured time period. Calculate the flow rate in gallons per minute by using the time from the stop watch. Compare this flow rate to the flow determined by actual measurement of the head made at the primary device at the time interval. Consider the calibration of the totalizer satisfactory if the two flows are within 10 percent of each other, when the actual measured flow is used as the known value, or divisor, in the percent calculation.

6. C. References and Flow Measurement Inspection Checklist

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FLOW MEASUREMENT INSPECTION CHECKLIST

A. GENERAL

Yes	No	N/A	1.	a.	Primary flow measuring device properly installed and maintained.
Yes	No	N/A		b.	Flow measured at each outfall? ___________ Number of outfalls? ___________
Yes	No	N/A		c.	Is there a straight length of pipe or channel before and after the flowmeter of at least 5 to 20 diameters?
Yes	No	N/A		d.	If a magnetic flowmeter is used, are there sources of electric noise in the near vicinity?
Yes	No	N/A		e.	Is the magnetic flowmeter properly grounded?
Yes	No	N/A		f.	Is the full pipe requirement met?
Yes	No	N/A	2.	a.	Flow records properly kept.
Yes	No	N/A		b.	All charts maintained in a file.
Yes	No	N/A		c.	All calibration data entered into a log book.
Yes	No	N/A	3.		Actual discharged flow measured.
Yes	No	N/A	4.		Effluent flow measured after all return lines.
Yes	No	N/A	5.		Secondary instruments (totalizers, recorders, etc.) properly operated and maintained.
Yes	No	N/A	6.		Spare parts stocked.
Yes	No	N/A	7.		Effluent loadings calculated using effluent flow.

B. FLUMES

Yes	No	N/A	1.	Flow entering flume reasonably well-distributed across the channel and free of turbulence, boils, or other disturbances.
Yes	No	N/A	2.	Cross-sectional velocities at entrance relatively uniform.
Yes	No	N/A	3.	Flume clean and free of debris and deposits.
Yes	No	N/A	4.	All dimensions of flume accurate and level.
Yes	No	N/A	5.	Side walls of flume vertical and smooth.
Yes	No	N/A	6.	Sides of flume throat vertical and parallel.
Yes	No	N/A	7.	Flume head being measured at proper location.
Yes	No	N/A	8.	Measurement of flume head zeroed to flume crest.
Yes	No	N/A	9.	Flume properly sized to measure range of existing flow.
Yes	No	N/A	10.	Flume operating under free-flow conditions over existing range of flows.
Yes	No	N/A	11.	Flume submerged under certain flow conditions.
Yes	No	N/A	12.	Flume operation invariably free-flow.

FLOW MEASUREMENT INSPECTION CHECKLIST
(Continued)

C. WEIRS

Yes	No	N/A	1. What type of weir does the facility use?
Yes	No	N/A	2. Weir exactly level.
Yes	No	N/A	3. Weir plate plumb and its top and edges sharp and clean.
Yes	No	N/A	4. Downstream edge of weir is chamfered at 45°.
Yes	No	N/A	5. Free access for air below the nappe of the weir.
Yes	No	N/A	6. Upstream channel of weir straight for at least four times the depth of water level and free from disturbances.
Yes	No	N/A	7. Distance from sides of weir to side of channel at least 2H.
Yes	No	N/A	8. Area of approach channel at least (8 × nappe area) for upstream distance of 15H.
Yes	No	N/A	9. If not, is velocity of approach too high?
Yes	No	N/A	10. Head measurements properly made by facility personnel.
Yes	No	N/A	11. Leakage does not occur around weir.
Yes	No	N/A	12. Use of proper flow tables by facility personnel.

D. OTHER FLOW DEVICES

	1. Type of flowmeter used:
	2. What are the most common problems that the operator has had with the flowmeter?
	3. Measured wastewater flow: ________ mgd; Recorded flow: ________; Error ________%

E. CALIBRATION AND MAINTENANCE

Yes	No	N/A	1. Flow totalizer properly calibrated.
			2. Frequency of routine inspection by proper operator: ________/day.
			3. Frequency of maintenance inspections by plant personnel: ________/year.
Yes	No	N/A	4. Flowmeter calibration records kept. Frequency of flowmeter calibration: ________/month.
Yes	No	N/A	5. Flow measurement equipment adequate to handle expected ranges of flow rates.
Yes	No	N/A	6. Calibration frequency adequate.