11.3 WASTEWATER FLOW MEASUREMENTS

11.3.1 General

The USDI Water Measurement Manual is the standard DEQ reference for details on checking the installation of primary open channel flow devices. Basic guidance for making wastewater flow measurements and a basic description of all common wastewater flow measurement systems are given in the EPA Compliance Inspection Manual. This manual shall also be used as DEQ guidance for such measurements.

11.3.2 Site Selection

It is the field investigator's responsibility to insure that the waste water flow measurement system or technique used measures the total wastewater discharged (described by the DEQ permit, if applicable). All recycled waters must be accounted for so that any reported flows accurately reflect the volume of wastewaters discharged. The actual location of wastewater flow measurement is not important if these criteria are met, and the chosen location is suitable for the technique or flow measurement system used to measure flow.

11.3.3 Flow Measurement Systems

Flow may be measured on an instantaneous or a continuous basis. A typical continuous system consists of a primary flow device, a flow sensor, transmitting equipment, a recorder, and possibly a totalizer. Instantaneous flow measurements can be obtained without using such a system.

The heart of a typical continuous flow measurement system is the primary flow device. This device is constructed to produce predictable hydraulic re sponses related to the flow rate of water or wastewater through it. Examples include weirs and flumes that relate water depth (head) to flow , Venturi and orifice type meters that relate differential pressure to flow, and magnetic flow meters that relate induced electric voltage to flow. Standard primary flow devices have undergone detailed testing and experimenta tion, and their accuracy has been verified.

A flow sensor is required to measure the particular hydraulic responses of the primary flow measurement device and transmit them to the recording system. Typically, sensors include floats, pressure transducers, capacitance probes, differential pressure cells, and electromagnetic cells.

The sensor signal is generally converted using mechanical, electromechani cal, or electronic systems into units of flow recorded directly on a chart or transmitted into a data system. Systems that use a recorder are generally equipped with a flow totalizer that displays the total flow on a real time basis.

Studies that require continuous flow measurements require a complete system. Instantaneous flow measurements do not necessarily dictate the use of any portion of such a system. Techniques that are described later in this section are available for measuring instantaneous flows with portable equipment.

An important consideration during wastewater studies is that the investi gator may want to obtain continuous flow data at a facility where only instan taneous flow data are being measured. If an open channel primary flow device is used for making the instantaneous measurements, only the installation of a portable field sensor and recorder is

necessary. If, on the other hand, the facility being investigated does not use a primary flow device, and a continuous flow record is desired , a portable primary flow device must be installed. This chapter does not cover in detail the installation of primary flow devices, but many of the cited references treat this area quite adequately.

Wastewater flow measurement systems are generally very accurate. The total error inherent in a flow measuring system is the sum of each component of the system. However, any system that cannot measure the wastewater flow within ± 10 percent of the actual flow is considered unacceptable for use in measuring wastewater flow.

11.3.4 Use of Existing Flow Measurement Systems

The installation of systems to measure wastewater flows can be a time-consuming task, particularly if a primary device is not available. Therefore, DEQ Program field personnel shall always use existing facility primary flow devices and flow measurement systems when the accuracy of these devices and the system can be verified. The objective of this section is to outline the responsibilities of DEQ field personnel in verifying the accuracy of existing primary flow devices and systems.

The field investigator must verify that any existing flow measurement system (including the primary flow device) used to measure wastewater flows conforms with recognized design and installation standards, and any deviation from standard conditions shall be thoroughly documented. The accuracy of the primary flow device shall be checked by making an independent "calibration" or flow measurement. If no usable or existing primary flow measuring device is available or if the device has been lost, the investigator shall attempt to install a portable primary flow device.

If the discharger's flow measurement system is accurate within $\pm$ 10 percent of the actual flow, the investigator can use the installed system. The accuracy of flow sensors and recorders can be easily checked for open channel flow devices by making an instantaneous measurement using the primary flow device and comparing this against the recorder reading. The accuracy of the recorder time trace shall be checked by physically marking the times on the flow chart and comparing these with the correct time. It is necessary to make an independent flow measurement when closed conduit systems must be checked.

If the existing equipment cannot be calibrated in a timely manner, the investigator shall install a portable flow sensor and recorder for the duration of the investigation. The installation and use of this equipment are preferred to attempts to correct incorrect flow measurement systems. The investigator shall note the action taken and inform the discharger that the equipment shall be calibrated as soon as possible if flow is required for calculating mass loadings or is itself a permit monitoring requirement. If nonstandard primary flow devices are being used, data supporting the accuracy and precision of the methods being employed shall be provided by the discharger.

11.3.5 Specific Techniques

This section outlines and familiarizes the field investigator with the most commonly used methods for wastewater flow measurements and the primary devices that shall be encountered during field studies. Volumetric and dilution techniques are presented at the beginning of this section, since they are appli cable to both open channel and closed conduit flow situations. The remaining methods are grouped under categories dealing with open channels and closed conduits. The general method of checking individual primary flow devices is given, where applicable. Several estimation techniques are presented. However, it shall be recognized that flow estimates do not satisfy DEQ permit monitor ing requirements unless the permit specifically states that this is permissible. The following methods are included to enable the field investigator to make accurate flow estimates when necessary.

Volumetric Techniques -- Volumetric flow measurement techniques are among the simplest and most accurate methods for measuring flow. Basically, these techniques involve the measurement of volume and/or the measurement of time required to fill a container of known size.

Vessel Volumes -- The measurement of vessel volumes to obtain flow data is particularly applicable to batch wastewater discharges. Accur ate measurements of the vessel volumes and the frequency that they are dumped are all required. An accurate tape to verify vessel dimensions and a stop watch are the only required field equipment. The NPDES Compliance Inspection Manual (2) is a useful reference on the equations for calculating volumes of various containers.

Sump Pumps -- This measurement is made by observing the sump levels at which the pumps cut on and off and calculating the volume contained between these levels. This volume with the number of pump cycles, shall give a good estimate of the daily wastewater flow. The inspector must also account for the quantity of wastewater that flows into the sump during the pumping cycle.

Bucket and Stop Watch -- The bucket and stop watch technique is particularly useful for the measurement of small wastewater flows. Using it is accurate and easy. The only equipment required to make this measurement is a calibrated container (bucket, drum, tank, etc.) and a stop watch. A minimum of 10 seconds to fill the container is recommended. Three consecutive measurements shall be made, and the results shall be averaged.

11.3.6 Dilution Methods

Dilution methods for water and wastewater flow measurements are based on the color, conductivity, fluorescence, or other quantifiable property of an injected tracer. Dilution methods require specialized equipment, special attention to detail by the investigator, and time consuming. However, these techniques offer the investigator:

- a method for making instantaneous flow measurements where other methods are inappropriate or impossible to use;
- a reference procedure of high accuracy to check in-situ those primary flow devices and flow measurement systems that are nonstandard or are improperly installed; and
- a procedure to verify the accuracy of closed conduit flow measuring systems.

The Turner Designs nomograph (3), the NPDES Compliance Inspection Manual (2), and the Geological Survey publication (4) outline the recommended reference procedures. The dilution method utilizing Rhodamine WT dye is the preferred reference procedure to be used by DEQ personnel when verifying the accuracy of flow measurement systems.

11.3.7 Open Channel Flow Measurements

Measurement of wastewater flow in open channels is the most frequently encountered situation in field investigations. An open channel is defined as any open conduit, such as a channel or flume, or any closed conduit, such as a pipe, which is not flowing full. The most commonly encountered methods and primary flow devices used in measuring open channel wastewater flows are described in this section. Several flow estimation techniques are also presented.

The measurement accuracies quoted in this section apply only to the specific method or to the primary flow device being discussed. Total error involved in a continuous flow measurement system, which is the sum of the errors of each component, is beyond the scope of this discussion.

Weirs -- A weir is defined as an overflow structure built according to specific design standards across an open channel to measure the flow of water. The theory of flow measurements using weirs involve the release of potential static energy to kinetic energy. Equations can be derived for weirs of specific geometry that relate static head to water flow (discharge). Weirs are generally classified into two general categories, broad crested and sharp crested.

Broad crested weirs take the following form ; $Q=CLH^{3/2}$. Values for the coefficient C are given in hydraulic handbooks (5, 6). Unless such weirs have been independently calibrated, they are usually not accurate enough for wastewater flow measurements.

Sharp crested weirs are constructed in a variety of shapes. Rectangular, V-notch, and Cipolletti weirs are the most common types. If such weirs are constructed as outlined in the USDI Water Measurement Manual (1), they are considered standard primary flow devices.

All weirs shall be inspected to determine if the weir installation and construction conform to the conditions given in the USDI Water Measurement Manual (1), provide a uniform influent flow distribution, and the weir is placed squarely across the channel perpendicular to the direction of flow. Useful tools for checking weir construction and installation include a carpenter's level, a framing square, a measuring tape, and a staff gage. Any problems observed during the inspection or study shall be noted in the field logbook.

A set of weir tables is necessary for calculating flows. The USDI Water Measurement Manual (1), the Stevens Water Resource Data Book (7), and the ISCO Open Channel Flow Measurement Handbook (8) contain a complete set of tables.

For more procedural information, refer to Paragraph I of this section , Field Analytical Procedure - Wastewater Discharge Flow - Weirs.

Flumes -- The conditions that must be met in a flume are similar to those that occur at a weir or spillway crest; water passing through the throat shall not be impeded by downstream conditions (constrictions, bends in a channel, obstructions). Types of flumes include the Palmer- Bowlus, Cutthroat, H, and Trapezoidal, but the most widely used is the Parshall flume. The Parshall flume is considered a standard pri mary flow device when constructed and installed as outlined in the USDI Water Measurement Manual (1). A complete discussion of other types of flumes is given in references 9, 10, 11, and 12.

All flumes shall be inspected to determine if the entrance conditions provide a uniform influent flow distribution, the flume dimensions conform to those given in the USDI Water Measurement Manual (1), the flume converging throat section is level, and the throat section walls are vertical. Useful tools for checking the construction and installation of Parshall (and other) flumes in clude a carpenter's level, a framing square, and a measuring tape. The flume shall be closely examined to determine if it is discharging freely. If any question about free discharge exists, the downstream head (Hb) shall be measured and compared with the head at the proper location (Ha) in the converging section. A staff gage is useful for making head measurements. Any problems observed during the inspection or study shall be noted in the field log book.

A set of flume tables is necessary for calculating flows. The USDI Water Measurement Manual (1), the Stevens Water Resources Data Book (7), and the ISCO Open Channel Flow Measurement Handbook (8) contain a complete set of tables. The explanatory material accompanying these tables shall be read and understood before they are used. In many cases, tabulated flow values are given for measured heads that are not within the usable measurement range.

Open Flow Nozzles -- Open flow nozzles such as parabolic or Kennison nozzles are factory calibrated and are ordinarily supplied as part of a flow measurement system. Calibration and installation information for each nozzle shall be supplied by or obtained from the manufacturer. The accuracy of these devices is reported to be often better than $\pm$ 5% of the indicated flow (10). A framing square is useful for checking the installation. Volumetric flow measurement may be used to check accuracy of this device if flow volumes are not excessive.

Velocity-Area Method -- The basic principal of this method is that the flow in a channel (cubic feet/second) is equal to the average velocity (feet/second) times the cross sectional area (square feet) of the channel. The velocity of the water or wastewater is determined with a current meter; the area of the channel is either measured or calculated using an approximation technique in conjunction with a series of velocity measure ments. The USGS mid-section method and the stream gaging techniques described in the USGS publication, Discharge Measurements at Gaging Stations (9) shall be the standard practice of the DEQ. This technique shall be used (where appropriate) as an independent flow measurement to verify the accuracy of existing flow measurement systems.

Slope-Area Method -- The slope-area method consists of using the slope of the water surface, in a uniform reach of channel, and the average cross sectional area of that reach, to estimate the flow rate of an open channel. Flow rate is estimated from the Manning formula (5, 6). This method is an estimation technique.

11.3.8 Closed Conduit Flow Measurements

The accuracy of closed conduit flow measuring devices shall be checked when necessary, by making an independent flow measurement, preferably using a dilution technique.

Venturi Meter -- The Venturi meter employs a conversion of static head to velocity head whereby a differential is created that is proportional to flow. The typical accuracy of a Venturi meter is given at 1% to 2% (10, 11, 12, and 13).

Orifice Meter -- The Orifice meter is a pressure differential device that measures flow by the difference in static head. Orifice meters require a 40 to 60 pipe diameters of straight pipe upstream of the installa tion. They can be quite accurate, i.e., within 0.5%, although their usable range is limited (10).

Flow Nozzle -- The basic principle of operation is the same as that of the Venturi meter. The flow nozzle has an entrance section and a throat, but lacks the diverging section of the Venturi. Flow nozzle accuracies can approach those of Venturi meters (10).

Electromagnetic Flow Meter -- The electromagnetic flow meter operates according to Faraday's Law of Induction where the conductor is the liquid stream, and the field is produced by a set of electromagnetic coils. The accuracy of the device is within $\pm$ 1% of full scale (10).

Other Closed Conduct Devices -- References for other closed conduit flow measurement methods such as acoustic flow meters, trajectory methods, pump curves, and water meters can be found in the NPDES Compliance Inspection Manual (2).

11.3.9 Wastewater Discharge Flow - WEIRS

A. EQUIPMENT:

1. Measuring devices (yardstick, calibrated rod or staff, or staff and measuring tape)

2. Blue chalk

3. Discharge table

B. PROCEDURE:

1. A weir is an overflow structure built across an open channel to measure the rate of flow of water or wastewater. It consists of a rectangular or V-notch opening having sharp edges and set vertically so that the flow passes over it and falls away freely. The discharge is a function of the water in the pool upstream from the crest relative to the crest elevation, and the size and shape of the weir (see illustration below).

2. Some weir structures shall have a permanently mounted staff gauge from which the head can be read. Discharge is determined from a table specific to the kind of weir installed (V-notch, Cipolletti, rectangular) or from a discharge equation.

3. If no staff gauge is permanently installed, the head must be measured manually. Depending on the size of the discharge channel, dropbox, or manhole, the measuring device could be a yardstick or a staff or rod several yards long.

4. To measure the head, chalk the portion of the measuring device in the area where the water line shall terminate. Sound the depth of the pool behind the weir, taking the measurement at a point sufficiently upstream to avoid the curve of the water surface over the weir (a distance four times the maximum head on the crest of the weir). Using the wet line on the chalked area to determine the pool depth, the head is calculated by subtracting the crest height from the height of the water surface.

5. Determine discharge from a standard discharge table appropriate for the kind of weir and angle of the V-notch.

C. SPECIAL INSTRUCTIONS:

1. Be sure that tables used to calculate discharge are appropriate for the kind of weir installed.

D. REFERENCES:

USGS (United States Geological Survey). 1980 National Handbook of Recommended Methods for Water Data Acquisition. Chapter 1 - Surface Water. 1980. Reston, Virginia

U.S. EPA (United States Environmental Protection Agency). Handbook for Sampling and Sample Preservation of Water and Wastewater. EPA-600/4-82-089. Environmental Monitoring and Support Laboratory. Cincinnati, Ohio.

E. PROJECTS:

NPDES Compliance Monitoring, Clark Fork Basin Study, Intensive Surveys