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## SECTION C

### ***FLOW VERIFICATION (CALIBRATION) METHODS FOR WATER USE ACCOUNTING AND REPORTING OF AGRICULTURAL AND OTHER WATER USE IN SOUTH FLORIDA***

#### **INTRODUCTION**

This section of the handbook is intended to assist all water users with practical flow monitoring procedures that can provide results within the expected +/-10% accuracy level required by the South Florida Water Management District (SFWMD). Its content is based on the draft “Methods for Calibrating, Measuring and Reporting Agricultural Water Use in South Florida”, developed by the Agricultural Coalition of South Florida, Clewiston, Florida 2005. The document lists various methods that are applicable to water use flow verification (calibration), for different withdrawal facilities.

If needed, the user is directed to Section B for more details about the methods mentioned herein. It is recognized that there are other methods discussed in this handbook and elsewhere. Although some of those methods may be more accurate than the ones discussed in this section, they may or may not be practical to use in South Florida.

**While all the flow verification methods listed in this section can provide water use information acceptable to the SFWMD, method accuracy depends on the appropriate use of the method. Therefore, the SFWMD will review for approval the flow verification and resulting water use accounting and reporting information per this section, contingent upon the following conditions:**

#### **Choosing the correct flow verification (calibration) method:**

- The methods should be suitable for the specific facility type and flow conditions to which they apply. For example, “California open pipe discharge method” can be used specifically for open pipes but should not be used for open ditches, while the “volumetric flow meter” method should be used only for small flows.
- **A “Flow Verification (Calibration) Method Selection” document is shown in Appendix ”A”, to aide the user in the selection of the appropriate flow verification method.**



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#### **Having the appropriate training or expertise to conduct the flow verification:**

- The flow verification methods shown in this section can be performed by any user, if they have the necessary level of training or expertise. Other methods, which require a complex flow verification devices or methods, will need to be performed and documented by a Florida registered Professional Engineer.
- **If the flow verification form (shown in Appendix “B”) is not complete, or is incorrectly filled or used by the individual performing the flow verification, he/she will be required to attend a flow verification training class and/or repeat the flow verification appropriately.**

#### **Documenting the conditions during the flow verification:**

- Each flow verification method in this section has a “required conditions” and “test procedure” section, followed by an example for that method. The conditions for the flow verification method chosen are the minimum conditions and should be satisfied prior to conducting the flow verification. A detailed record of these conditions and any other conditions affecting the flow test should be documented and submitted to the SFWMD, along with the flow verification method form. Field notes, pictures, scaled drawings, and/or diagrams are good ways to document all such conditions.
- **A “Flow Verification (Calibration) Method Selection” document is shown in Appendix “A”, to aide the user in the selection of the appropriate flow verification method, for the condition(s) being encountered.**

#### **Submitting the appropriate flow verification form:**

- Flow verification forms are available in Appendix “B” of this Section. Each flow verification method in this section has a corresponding flow verification form. Submittal of such form to the SFWMD is mandatory.
- **If the flow verification form (shown in Appendix “B”) is not complete, incorrectly filled or used by the individual performing the flow verification, he/she will be required to attend a flow verification training class and/or repeat the flow verification appropriately.**

#### **Performing the flow verification during the dry season:**

- Water use information is critical during the dry season; therefore, the flow verification should be done during the dry season. **Such dry season shall be defined as the groundwater elevation or upstream/downstream water levels present between January 1<sup>st</sup> and June 1<sup>st</sup> of any year with normal rainfall.** It is recognized that this dry season flow verification



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produces water use accounting information that should be within the accuracy prescribed in the SFWMD rule, when averaged over a 12-month period.

- There are regional areas where the dry season water stages are highly variable. The level of the groundwater table or the difference in head/tail water might vary up to several feet. In such circumstances, the withdrawal facility should be calibrated for several characteristic water stage conditions and the average of these calibrations will be considered as the representative flow rate.
- The procedures described above are for a typical dry season condition in a typical calendar year. Should the water source be impacted by extreme drought conditions the SFWMD may request the user to perform additional flow verifications that more closely represent these extreme conditions, or the user may elect to do so on his/her own.

It is also recognized that some of the methods described may require modification for specific withdrawal locations and user practices. Further, procedures, calculations and tabulated flow calculation aids can vary since researchers often publish minor adjustments to standard practices and equations. Any modifications to the procedures discussed that are properly referenced should be approved by the SFWMD staff. Other modifications must be justified by the user and reviewed for approval by the SFWMD staff prior to implementation.

Finally, there may be circumstances where a water use structure does not conform to the standards discussed in this document, precluding the use of the methods described in this handbook. In such instances, the user should identify an alternative, reliable, repeatable water use accounting system to monitor water usage from each withdrawal facility in accordance with permit conditions. For these methods, in order to avoid pursuing techniques which do not provide the +/-10% accuracy standard, the user is advised to consult with a Florida registered P.E. and submit a flow verification plan to the SFWMD for approval of the **method**, before starting the measurement or investing in an alternative methodology. The SFWMD will review for approval the alternative flow verification and water use accounting methods plan on a case-by-case basis.



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## ACCEPTABLE FLOW VERIFICATION METHODS:

Typical water use withdrawal facilities from ground water sources are a well and pump system. It is acknowledged some wells are free flowing and may not utilize a pump. Most pumped systems typically utilize either a submersible turbine type pump or a surface-mounted centrifugal or axial flow type pump.

However, it is important here to note that flow wells in Martin and St. Lucie counties will require the verification of flow from these wells **prior to any pump installation**. Failure to provide the SFWMD with this flow verification may require the removal of the pump at the owners expense. The permittee will be authorized to pump the flow well at or below the rate at which the well would freely flow, un-pumped, at land surface.

A surface water pump station typically consists of an axial flow pump discharging into an open canal irrigation system, or a centrifugal pump discharging into a pressurized irrigation system. Some of the larger surface water irrigation systems consist of a combination of a large axial flow pump supplying irrigation water via an open canal that routes this water to internal smaller irrigation pump(s). Verifying the flow of these smaller internal irrigation pumps can sometimes be more cost effective, accurate, and easier than verifying the flow of the single large axial flow pump that supplies them water. Therefore, the user has the option to either verify the flow, account for the water used, and report the total water used from each of the smaller internal irrigation pumps, or verify the flow, account for the water used, and report the total water used from the large axial flow pump. Pump curve relationships are acceptable tools as long as the curves are certified by the manufacturer and the pump has been installed within manufacturer specifications and been in operation for less than five years. It is also acceptable to use pump curves if pumps have been rebuilt to the manufacturers certified specifications, or have had certified flow verifications (recalibrations) conducted according to the SFWMD requirements, within the last five years.

Gravity intake systems are utilized when a surface water source is held at stages higher than the water in the adjacent lands that are to be irrigated. Typically these gravity intake systems utilize a control structure with a flash board riser to control the inflow, and allow the user to open and close the system. The other typical installation is a siphon system through a pump.

Following is an alphabetical listing and explanation of acceptable and practical methods that can be used to verify the flow of the water use withdrawal facilities shown in your water use permit. Each method is followed by an example calculation. The flow verification form for each of these methods is included in Appendix "B" of this section, and will need to be filled and submitted to the SFWMD as part of this flow verification process.



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## CALIFORNIA METHOD

### Required Conditions:

- The pipe must be level (horizontal).
- A straight length of discharge pipe must exist, which is 6 or more times the diameter in length.
- The end of the straight pipe must be cut squarely.
- The pipe must not be flowing full.
- Measurement points must be easily accessed.

### Test Procedure:

- Use a carpenter's level to ensure that pipe is level in the horizontal directions.
- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Allow flow in the pipe to occur for at least 15 minutes, to obtain stable and consistent conditions (may take longer if pumping from groundwater but gap reading fluctuations and flow stream appearance should not be rapidly changing).
- The only measurements needed are the pipe inside diameter (D) and the vertical distance between the inside of the pipe and the water surface (gap) measured from the inside of the top of the pipe. Refer to distance "a" in the figure in the example below.
- Repeat the measurements at least 3 times. Calculate the average of the gap measurements.
- Flow is then calculated using the equation shown below.

### **General Permit Information Required:**

Permit Number/App Number \_\_\_\_\_ / \_\_\_\_\_

Project Name \_\_\_\_\_

Site Contact/Phone Number \_\_\_\_\_ / \_\_\_\_\_

District Facility ID \_\_\_\_\_

*(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)*



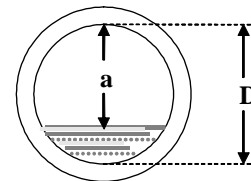
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Withdrawal source: (ex. well, lake, canal name, etc.) \_\_\_\_\_

Withdrawal type (ex. pumped, gravity, flow well, other) \_\_\_\_\_

Facility water use accounting method: \_\_\_\_\_

**Example Flow Verification Information, Data and Calculations:**



Pipe inside diameter (D) = 4 inches

Length of level horizontal discharge pipe tested: \_\_\_\_\_

Gap  
 Readings,      2.5      2.0      1.5      Ave = 2.0  
 (a) inches

Flow (Q) in Pipe (cubic feet per second, cfs):

$$Q = 8.69 \times (1 - a/D)^{1.88} \times D^{2.48}$$

$$a = 2 \text{ inches} / 12 \text{ inches/foot}$$

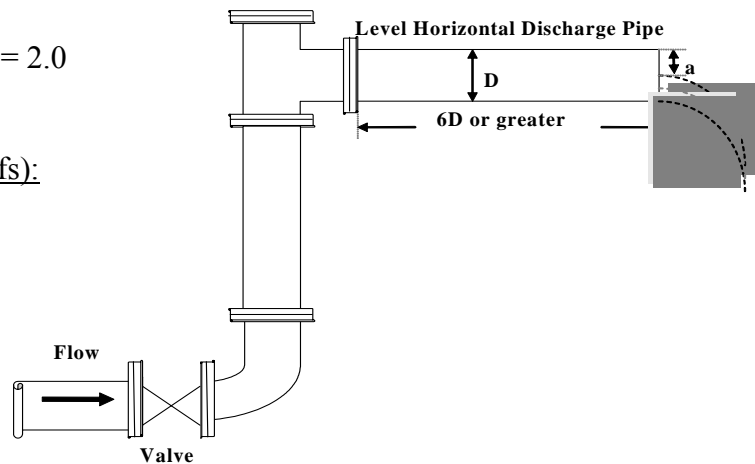
$$a = 0.165 \text{ feet}$$

$$d = 4 \text{ inches} / 12 \text{ inches/foot}$$

$$d = 0.33 \text{ feet}$$

$$Q = 8.69 \times (1 - 0.165/0.33)^{1.88} \times 0.33^{2.48}$$

$$Q = 0.15 \text{ cfs}$$



Convert Flow in Pipe to Gallons per Minute (gpm) if Desired:

$$Q = 0.15 \text{ cfs} \times 448.8 \text{ gpm/cfs}$$

$$Q = 67.3 \text{ gpm}$$

Recommended References:

United States Bureau of Reclamation. 2001. Water Measurement Manual, 3<sup>rd</sup> Edition, Revised.  
 United States Department of the Interior. United States Government Printing Office. Washington, D.C.



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ISCO, Inc. 1992. Open Channel Flow Measurement Handbook, 3<sup>rd</sup> Edition. ISCO, Inc. Lincoln, Nebraska.

Chapter 14 in [www.usbr.gov/pmts/hydraulics\\_lab/pubs/wmm/index.htm](http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm).



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## **DOPPLER AND OTHER EXTERNAL FLOW METERS METHOD**

For these instruments to function properly, pipe vibrations will need to be at a minimum. If vibrations cause undue fluctuations in readings and malfunctioning of the meter, select another method.

### **Required Conditions:**

- Acceptable length of straight pipe away from pump or bends per manufacturer's specifications (generally 6 to 10 pipe diameters).
- Pipe is exposed and accessible.
- Pipe must flow full at point of measurement (the pipes of a pressurized irrigation system have full flow conditions).

### **Test Procedure:**

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Take at least 5 discrete velocity readings.
- Average the 5 velocity measurements.
- If your readings are in feet per second, multiply them by the circular area of the pipe in which you took the readings to calculate flow in cubic feet per second.
- Convert flow to gallons per minute.

### **General Permit Information Required:**

Permit Number/App Number \_\_\_\_\_ / \_\_\_\_\_

Project Name \_\_\_\_\_

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District Facility ID \_\_\_\_\_

*(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)*



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Withdrawal source: (ex. well, lake, canal name, etc.) \_\_\_\_\_

Withdrawal type (ex. pumped, gravity, flow well, other) \_\_\_\_\_

Facility water use accounting method: \_\_\_\_\_

**Example Flow Verification Information, Data and Calculations:**

Instrument Readings:

TIME	VELOCITY READING (ft/s)
1:00 pm	8.56
1:01 pm	8.55
1:02 pm	8.57
1:03 pm	8.57
1:04 pm	8.55

Average Velocity (V) = 8.56 ft/s

Pipe inside diameter (D): 24 inches (2 ft)

Cross-Sectional Area of Pipe, A (ft<sup>2</sup>):

$$A = (\pi \times D^2)/4 \text{ (full pipe)}$$

$$A = (\pi \times 2^2)/4$$

$$A = 3.14 \text{ ft}^2$$

Average Flow in Pipe (ft<sup>3</sup>/s):

$$Q = \text{Average Velocity} \times \text{Cross-Sectional Area of Pipe}$$

$$Q = 8.56 \text{ ft/s} \times 3.14 \text{ ft}^2$$

$$Q = 26.88 \text{ ft}^3/\text{s}$$

Conversion to Gallons per Minute (gpm):

$$Q = 26.88 \text{ ft}^3/\text{s} \times 448.8 \text{ gpm/cfs}$$

$$Q = 12,063 \text{ gpm}$$

Recommended References:

Chapters 11 and 14 in [www.usbr.gov/pmts/hydraulics\\_lab/pubs/wmm/index.htm](http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm).



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## DYE FLUOROMETRY OR CHEMICAL GAUGING METHOD

This method is based on the injection of non-toxic dye or other chemical of a known concentration at a constant rate into a pipe or canal flowing with water. Assuming thorough mixing, the dye or chemical concentration can be assessed and the flow rate in the canal or pipe can be calculated based on the known chemical concentration and velocity.

### Required Conditions:

- This method requires specialized equipment and expertise and will generally require a Professional Engineer (P.E.).
- Contact the SFWMD or the Florida Section of the American Society of Agricultural and Biological Engineers (ASABE) for a listing of P.E.'s available to run this test for you.

### Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- This method requires specialized equipment and expertise and will generally require professional assistance.
- Contact the SFWMD or the Florida Section of the American Society of Agricultural and Biological Engineers, for a listing of professionals available to assist you with this method.
- See Section B for discussion about dye fluorometry methods.

### Recommended References:

Chapter 12 in [www.usbr.gov/pmts/hydraulics\\_lab/pubs/wmm/index.htm](http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm).



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## DYE TRACER OR COLOR METHOD

This method is based on the batch (slug) injection of a small amount of bright non-toxic dye or colorant into a canal or pipe flowing with water. The time required for the dye to travel from one location to another location in the same canal or pipe is measured. The volume of water contained in the canal or pipe between these two locations, divided by the travel time, is used to determine the flow rate in the canal or pipe.

### Required Conditions:

- Flow within the channel or pipe must have known or measurable dimensions (depth, width and length). This will not be a problem in pipes but will require suitably accurate channel measurements for canals or ditches.
- Flow in the canal or pipe must be steady and constant during the calibration measurements (steady flow in open channels is defined as flow occurring with no changes in depth).
- Must have access to the dye injection point.
- Must be able to see the discharge point and observe color change in the flow stream.
- Injection device should deliver the slug of dye perpendicular to the flow stream with little or no initial velocity in the upstream or downstream directions.
- Injection device should deliver the slug of dye near the area of mean velocity within the flow stream. For open channels, injection should occur generally at a point located 6/10 of the total depth of the stream from the water surface. For closed pipes, the injection point location should take place at a distance ranging from 15% to 29% of the pipe diameter in from the pipe wall. For best measurement accuracy, see Sections B, Basic Principles of Flow Monitoring and System Selection, and Section C, Teaching Module 1.
- Injection device should have a positive shutoff at the tip so there will be no leakage of dye after the dye injection has occurred.

### Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.

### Case 1. Canal or Pipe with Uniform Geometry

- Determine the pipe or canal water flow area,  $A$  ( $\text{ft}^2$ ).
- Measure the distance from the injection point to the observation point,  $D$  (ft).
- Instantaneously trigger the injection device and stopwatch.
- Stop the stopwatch when the color change is observed; record the time,  $T$  (seconds).



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Repeat the above two steps at least two more times.

- Average the three measurements.
- Divide  $D$  by  $T$  to obtain the velocity,  $V$  (ft/sec).
- Multiply  $V$  by  $A$  to obtain the flow,  $Q$  (ft<sup>3</sup>/sec).
- Multiply  $Q$  by 448.8 to obtain the flow in gallons per minute (gpm).

## Case 2. Variable Canal or Pipe Geometry

- Determine the pipe or canal cross-sectional area of water flow,  $A_1$ ,  $A_2$ ,  $A_3$ , etc. (ft<sup>2</sup>) for each uniform segment of pipe or channel, between the injection point and the observation point.
- Measure the length of each segment,  $L_1$ ,  $L_2$ ,  $L_3$ , etc. (ft).
- Multiply each segment length by the corresponding segment cross-sectional area to obtain the volume ( $V_1$ ,  $V_2$ ,  $V_3$ ) of each segment.
- Add up all of the segment volumes to obtain the total flow volume,  $V$  (ft<sup>3</sup>).
- Instantaneously trigger the injection device and a stopwatch.
- Stop the stopwatch when the color change is observed and record the time,  $T$  (seconds).
- Repeat the above two steps at least two more times.
- Use the average time from the three measurements.
- Divide  $V$  by average  $T$  to obtain the flow,  $Q$  (ft<sup>3</sup>/sec).
- Multiply  $Q$  by 448.8 to obtain the flow in gallons per minute (gpm).

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Project Name \_\_\_\_\_

Site Contact/Phone Number \_\_\_\_\_ / \_\_\_\_\_

District Facility ID \_\_\_\_\_

*(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)*

Withdrawal source: (ex. well, lake, canal name, etc.) \_\_\_\_\_



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Withdrawal type (ex. pumped, gravity, flow well, other) \_\_\_\_\_

Facility water use accounting method: \_\_\_\_\_

### **Example Flow Verification Information, Data and Calculations:**

Uniform Canal Section Used (assumed trapezoidal shape):

- (a) Bottom width: 5 ft
- (b) Width at water surface: 15 ft
- (c) Water depth: 2.5 ft
- Distance along canal between starting and ending points (D): 85 ft

Stopwatch Readings:

Reading	Travel Time (T) in Seconds
1	85
2	84
3	86
<b>AVERAGE</b>	<b>85</b>

Average Water Velocity in the Canal (V), in Feet per Second:

$V = 85 \text{ ft canal section length} / 85 \text{ seconds average travel time}$

$V = 1 \text{ ft/s}$

Canal Water Flow Area (A) in Square Feet:

$A = (a + b) \times c / 2$

$A = (5 \text{ ft} + 15 \text{ ft}) \times 2.5 \text{ ft} / 2$

$A = 25 \text{ ft}^2$

Average Flow in the Canal (Q), in Cubic Feet per Second:

$Q = \text{Canal Water Flow Area} \times \text{Average Water Velocity in the canal}$

$Q = 25 \text{ ft}^2 \times 1 \text{ ft/s}$

$Q = 25 \text{ cubic feet per second (ft}^3/\text{s or cfs)}$

Average Flow in the Canal (Q), in Gallons per Minute (gpm):

$Q = 25 \text{ ft}^3/\text{s} \times 448.8 \text{ gpm/cfs}$

$Q = 11,220 \text{ gpm}$



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Important Note: Refer to Section A and Section B, Teaching Module 2 for assistance in determining the water flow area in canals that are not easy to identify.

Recommended References:

Chapter 12 in [www.usbr.gov/pmts/hydraulics\\_lab/pubs/wmm/index.htm](http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm).



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## **ELECTROMAGNETIC INSERTION AND NON-INSERTION METERS METHOD**

This method is based on the utilization of a factory calibrated flow meter, which derives flow measurements in pipes or canals from the voltage induced in a specially designed magnetic probe or sensor. The induced voltage is measured and converted to a velocity reading by the flow meter display device. Periodic recalibration of the flow meter by the factory or other qualified personnel is necessary.

### **Required Conditions:**

- Flow within the canal or pipe must have known or measurable dimensions to determine cross-sectional area of flow (diameter, depth, width and length).
- Flow in the canal or pipe must be steady (water surface level must not be changing) and constant during the calibration measurements.
- Must have access to the measurement point.
- Select measurement point based on ease of access, full pipe flow (which is preferred over partial pipe flow) and recommended distance downstream of elbows, pumps, transitions or other flow disturbances (generally 6 to 10 pipe diameters depending on flow characteristics).
- Must be able to hold or fasten the probe perpendicular to the flow direction.
- Probe mounting or rod must be rigid enough to avoid flexing and vibration (becomes important consideration at velocities over 2.5 feet per second).

### **Test Procedure:**

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.

### **Case 1. Full Pipe Flow**

- Determine the pipe inside diameter,  $D$  (ft).
- Calculate the cross-sectional area of flow,  $A$  (ft<sup>2</sup>)
- Determine if the pipe flows full under average dry season conditions.
- Install meter probe according to manufacturer's recommendations.
- Observe velocity readings over a 5 to 10 minute period to ensure stable flow (readings should not vary more than 10%). If there is variation in excess of 10%, continue to run the system until stable flow is established or you have determined the cause of the instability and resolved the cause.



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- Record 10 velocity readings,  $V$  (ft/sec), over a 5 minute period.
- Average the recorded velocity readings,  $V$  (ft/sec).
- Multiply  $V$  by  $A$  to obtain the flow,  $Q$  (ft<sup>3</sup>/sec).
- Multiply  $Q$  by 448.8 to obtain the flow in gallons per minute (gpm).

### Case 2. Closed Pipe Flowing Partially Full

- Determine the cross-sectional area of flow,  $A$  (ft<sup>2</sup>), in the pipe at the measurement point.
- Install meter probe according to manufacturer's specifications.
- Observe velocity readings over 5 to 10 minute period to ensure stable flow (readings should not vary more than 10%). If there is variation in excess of 10%, continue to run the system until stable flow is established or determine the cause of the instability and fix the cause.
- Record 10 velocity readings,  $V$  (ft/sec), over a 5 minute period.
- Average the recorded readings,  $V$  (ft/sec).
- Multiply  $V$  by  $A$  to obtain the flow,  $Q$  (ft<sup>3</sup>/sec).
- Multiply  $Q$  by 448.8 to obtain the flow in gallons per minute (gpm).

### Case 3. Canal or Ditch Flow

- Determine the cross-sectional area of flow,  $A$  (ft<sup>2</sup>), in the ditch or canal at the point of measurement.
- Follow procedure for Case 2.

### **General Permit Information Required:**

Permit Number/App Number \_\_\_\_\_ / \_\_\_\_\_

Project Name \_\_\_\_\_

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District Facility ID \_\_\_\_\_

*(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)*



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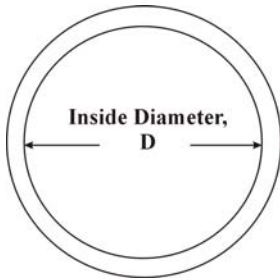
Withdrawal source: (ex. well, lake, canal name, etc.) \_\_\_\_\_

Withdrawal type (ex. pumped, gravity, flow well, other) \_\_\_\_\_

Facility water use accounting method: \_\_\_\_\_

### Example Flow Verification Information, Data and Calculations:

#### Case 1. Full Pipe Flow



36" inside pipe diameter = 3 ft diameter (D)

Pipe is flowing full

Length of level horizontal discharge pipe tested: \_\_\_\_\_

Electromagnetic Meter Readings:

Velocity

Readings,    9.0    9.1    9.2    9.3    9.4    9.5    9.6    9.7    9.8    9.9  
(ft/s)

Average Velocity = 9.45 ft/s

Cross-Sectional Area of Pipe (ft<sup>2</sup>):

$A = (\pi \times D^2)/4$  or  $(\pi \times \text{pipe radius}^2)$  where  $\pi \sim 3.14$

$A = (3.14 \times 3^2)/4 = 7.07 \text{ ft}^2$

Average Flow in Pipe (ft<sup>3</sup>/s):

Q = Velocity in Pipe x Cross-sectional Area of Pipe

Q = 9.45 ft/s x 7.07 ft<sup>2</sup> = 66.81 ft<sup>3</sup>/s



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Conversion to Gallons per Minute (gpm):

$$Q = 66.81 \text{ ft}^3/\text{s} \times 448.8 \text{ gpm/cfs} = 29,985 \text{ gpm}$$

### Case 2. Partial Pipe Flow

36" diameter pipe = 3 ft. diameter (D)

Pipe is flowing half full (depth of water in pipe = 1.5 ft.)

Length of level horizontal discharge pipe tested: \_\_\_\_\_

Electromagnetic Meter Readings:

Velocity

Readings,      9.0    9.1    9.2    9.3    9.4    9.5    9.6    9.7    9.8    9.9  
(ft/s)

Average Velocity = 9.45 ft/s

Cross-Sectional Area of Water Flow in Pipe,  $A_{\text{part}}$  (ft<sup>2</sup>):

$$A = (\pi \times D^2)/4 \text{ (full pipe)}$$

$$A = (\pi \times 3^2)/4$$

$$A = 7.07 \text{ ft}^2$$

$$A_{\text{part}} = A/2$$

$$A_{\text{part}} = 7.07 \text{ ft}^2/2$$

$$A_{\text{part}} = 3.54 \text{ ft}^2$$

Important Note: Refer to Appendix C in this Section or geometry handbooks, for assistance in determining the water flow area in pipes that are not flowing full or half full.

Average Flow in Pipe (ft<sup>3</sup>/s):

Q = Average Velocity x Cross-Sectional Area of Water Flow in Pipe

$$Q = 9.45 \text{ ft/s} \times 3.54 \text{ ft}^2$$

$$Q = 33.40 \text{ ft}^3/\text{s}$$

Conversion to Gallons per Minute (gpm):

$$Q = 33.40 \text{ ft}^3/\text{s} \times 448.8 \text{ gpm/cfs}$$

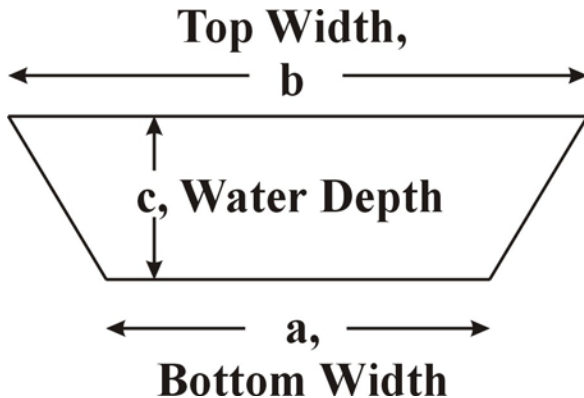
$$Q = 14,990 \text{ gpm}$$



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### Case 3. Canal or Ditch Flow

Canal Section Used (assumed trapezoidal shape):



- (a) Bottom width: 5 ft
- (b) Width at water surface: 15 ft
- (c) Water depth: 2.5 ft

Electromagnetic Meter Readings:

Velocity

Readings,      0.5      0.6      0.7      0.8      0.9      1.0      1.1      1.2      1.3      1.4  
(ft/s)

Average Velocity = 0.95 ft/s

Canal Water Flow Area (A) in Square Feet:

$$A = (a + b) \times c/2$$

$$A = (5 \text{ ft} + 15 \text{ ft}) \times 2.5 \text{ ft}/2$$

$$A = 25 \text{ ft}^2$$

Average Flow in the Canal (Q) in Cubic Feet per Second:

Q = Canal Water Flow Area x Average Water Velocity in the canal

$$Q = 25 \text{ ft}^2 \times 0.95 \text{ ft/s}$$

$$Q = 23.75 \text{ cubic feet per second (ft}^3/\text{s or cfs)}$$

Average Flow in the Canal (Q) in Gallons per Minute (gpm):

$$Q = 23.75 \text{ ft}^3/\text{s} \times 448.8 \text{ gpm/cfs}$$

$$Q = 10,659 \text{ gpm}$$



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Important Note: Refer to Section A or Section B, Teaching Module 2 for assistance in determining the water flow area in open channels (streamgauging methods) that are not easy to identify.

Recommended References:

Chapter 10 in [www.usbr.gov/pmts/hydraulics\\_lab/pubs/wmm/index.htm](http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm).

Chapter 14 in [www.usbr.gov/pmts/hydraulics\\_lab/pubs/wmm/index.htm](http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm).

[www.1728.com/circsect.htm](http://www.1728.com/circsect.htm). Calculator for area of circle segment.



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## FLOAT VELOCITY METHOD

### Required Conditions:

- This method should be selected as a last resort for flow verification. If possible, other methods listed in this Section should be used.
- The section of channel/ditch chosen to do the measurement only carries water from one pump permitted by SFWMD and is located as close to the pump as possible without violating the following conditions.
- There are no other ditches branching out from the ditch chosen, between the irrigation pump being calibrated and the ditch measurement location.
- There is a straight section of ditch at the location where the measurement will be done so that a floating device can travel for at least 20 seconds.
- Ditch has the same dimensions (depth, width, bank slope), throughout the section of ditch chosen for measurement.
- Ditch does not have excessive vegetative growth or debris that will have major impacts on the flow stream below the water surface throughout the section of ditch chosen for measurement (a good rule of thumb is that the vegetation be no taller than 6 inches for a typical ditch flowing at or near capacity).
- Water flow in the ditch is smooth and consistent (not turbulent and no eddies), throughout the section of ditch chosen for measurement.
- The depth of water in the ditch is at least 1 foot, throughout the section of ditch chosen for measurement.
- Floating devices must have a clear and straight pathway
- Taking measurements on excessively windy days, or when winds are in the direction of flow, should be avoided.

### Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Mark starting point and ending point along the ditch, and measure the distance between the two points.
- Measure and record the following ditch information between the starting point and ending point:
  - Water depth
  - Width at the water surface
  - Bottom width.
  - If desired, greater accuracy can be attained through use of area determination methods used in streamgauging techniques.



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- Use similar size and weight floats.
- Select the number of floats to use (see table below) and label or number each float.
- Evenly place the floats across the width of the ditch (at least 5 feet apart), at a location at least 3 feet before the starting point.
- Record the time it takes each float to go from the starting point to the ending point, along the chosen section of ditch.
- Repeat the above two steps at least two more times. Use the average of the measurements.

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*(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)*

Withdrawal source: (ex. well, lake, canal name, etc.) \_\_\_\_\_

Withdrawal type (ex. pumped, gravity, flow well, other) \_\_\_\_\_

Facility water use accounting method: \_\_\_\_\_

**Example Flow Verification Information, Data and Calculations:**

- Ditch Section Used (assumed trapezoidal cross-section):
  - (a) Bottom width: 5 ft
  - (b) Width at water surface: 15 ft
  - (c) Water depth: 2.5 ft
  - (D) Distance along ditch between starting and ending points: 100 ft



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- Number of Floats used (from table below): 2

Ditch Width at Water Surface (ft)	Number of Floats
0 - 10	1
10 - 15	2
15 - 20	3
20 - 25	4

Note: For ditches wider than 15 ft. use the numbers of floats indicated in the table above and add the corresponding numbers of floats and rows for Run 1 through Run 3.

- Float Readings:

Run 1

Float Number	Travel Time (T, Seconds)
1	82
2	88
<b>AVERAGE</b>	<b>85</b>

Run 2

Float Number	Travel Time (T, Seconds)
1	80
2	88
<b>AVERAGE</b>	<b>84</b>

Run 3

Float Number	Travel Time (T, Seconds)
1	85
2	87
<b>AVERAGE</b>	<b>86</b>

Average Travel Time for All Floats and All Runs:

$$T = (85 + 84 + 86)/3 = 85 \text{ seconds}$$

Average Water Velocity in the Ditch (Feet per Second):

$$V = 0.85 \times D \text{ ft}/T \text{ seconds}$$

where 0.85 is a constant that adjusts surface velocity to average channel velocity, D is the test travel distance and T is the time to travel the test distance.

$$V = 0.85 \times 100 \text{ ft}/85 \text{ seconds}$$



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$$V = 1 \text{ ft/s}$$

Cross-Sectional Area of Channel Section Used for Test:

$$A = (a + b) \times c/2$$

$$A = (5 \text{ ft} + 15 \text{ ft}) \times 2.5 \text{ ft}/2$$

$$A = 25 \text{ ft}^2$$

Average Flow in the Ditch (ft<sup>3</sup>/s):

$$Q = V \times A$$

$$Q = 1 \text{ ft/s} \times 25 \text{ ft}^2$$

$$Q = 25 \text{ ft}^3/\text{s}$$

Conversion to Gallons per Minute (gpm):

$$Q = 25 \text{ ft}^3/\text{s} \times 448.8 \text{ gpm}/\text{fps}$$

$$Q = 11,220 \text{ gpm}$$

Important Note: Refer to Section A or Section B, Teaching Module 2 for assistance in determining the water flow area in canals (streamgauging methods) that are not easy to identify.

Recommended References:

Chapter 13 in [www.usbr.gov/pmts/hydraulics\\_lab/pubs/wmm/index.htm](http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm).



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## FLOW PROBE METER METHOD

### Required Conditions:

- Partially full or full pipe flow is occurring from structures such as culverts or surface water pump discharge pipes.
- Flow must not contain excessive debris.
- Must have access to end of discharge pipe.
- Eddies and flow direction changes must not be occurring at the discharge/measuring point.

### Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Determine the inside diameter of the pipe in the same unit of measure as your Flow Probe reads (i.e. use feet if your meter reads feet per second).
- Make sure the water has been flowing long enough to obtain a normal and stabilized condition.
- Position the flow probe at or slightly in the end of the pipe, and measure the velocity at a distance away from the pipe walls that is approximately 29% of the diameter at two different locations (i.e. from the side and from the bottom if flowing full).
- If the pipe is not flowing full, measurements should be taken around the average velocity point for open channel flow (generally about 0.6 times the depth of flowing water down from the water surface in the center of the pipe).
- Repeat the measurement step above once a minute for five minutes to obtain a good average.
- Calculate the flow rate.

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*(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)*

Withdrawal source: (ex. well, lake, canal name, etc.) \_\_\_\_\_

Withdrawal type (ex. pumped, gravity, flow well, other) \_\_\_\_\_

Facility water use accounting method: \_\_\_\_\_

### **Example Flow Verification Information, Data and Calculations:**

#### **Case 1. Full Pipe Flow**

Pipe inside diameter = 35 inches = 2.92 feet

Flow Probe Measurement Locations Away From Pipe Walls:

From the bottom of the pipe = Pipe Diameter x 0.29 = 2.92 ft x 0.29 = 0.85 ft

From the side of the pipe = Pipe Diameter x 0.29 = 2.92 ft x 0.29 = 0.85 ft

Flow Probe Velocity Measurement Results:

From the bottom of the pipe: 6.3 ft per second

From the side of the pipe: 6.7 ft per second

Average Velocity (V):  $(6.3 + 6.7)/2 = 6.5$  ft per second

Cross-Sectional Area of Pipe:

$$A = \pi D^2 / 4$$

$$A = 3.14 \times 2.92^2 / 4$$

$$A = 6.69 \text{ ft}^2$$

Average Flow in Pipe (ft<sup>3</sup>/s):

$$Q = A \text{ (ft}^2\text{)} \times \text{Average Velocity (ft/s)}$$

$$Q = 6.70 \text{ ft}^2 \times 6.5 \text{ ft/s}$$

$$Q = 43.5 \text{ ft}^3/\text{s}$$



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Conversion to Gallons per Minute (gpm):

$$Q = 43.5 \text{ ft}^3/\text{s} \times 448.8 \text{ gpm}/\text{cfs} = 19,523 \text{ gpm}$$

## **Case 2. Pipe Flowing Partially Full**

Important Note: Refer to Appendix C in this Section or a geometry handbook, for assistance in determining the water flow area in pipes that are not flowing full or half full.

Pipe inside diameter measurement = 35 inches = 2.92 feet

Flow Depth in Pipe (half full): 35 inches/2 = 17.5 inches or 1.46 feet

$$\text{Cross-Sectional Area of the Pipe} = \pi r^2 = 3.14 \times (2.92/2)^2 = 6.69 \text{ ft}^2$$

Flow Probe Measurement Locations Away From Pipe Walls:

From the bottom of the pipe = Pipe Diameter  $\times$  0.29 = 2.92 ft  $\times$  0.29 = 0.85 ft

From the side of the pipe = Pipe Diameter  $\times$  0.29 = 2.92 ft  $\times$  0.29 = 0.85 ft

Flow Probe Velocity Measurement Results:

From the bottom of the pipe: 6.3 ft per second

From the side of the pipe: 6.7 ft per second

Average Velocity (V):  $(6.3 + 6.7)/2 = 6.5$  ft per second

Cross-Sectional Area of Pipe Flowing Half Full:

$$A_{\text{part}} = A/2$$

$$A = \pi D^2/4$$

$$A = 3.14 \times 2.92^2/4$$

$$A = 6.69 \text{ ft}^2$$

$$A_{\text{part}} = 6.69 \text{ ft}^2/2$$

$$A_{\text{part}} = 3.35 \text{ ft}^2$$

Average Flow in Pipe (ft<sup>3</sup>/s):

$$Q = V \text{ ft/s} \times A_{\text{part}} \text{ ft}^2$$

$$Q = 6.5 \text{ ft/s} \times 3.35 \text{ ft}^2$$

$$Q = 21.8 \text{ ft}^3/\text{s}$$

Conversion to Gallons per Minute (gpm):

$$Q = 21.8 \text{ ft}^3/\text{s} \times 448.8 \text{ gpm}/\text{cfs}$$

$$Q = 9,784 \text{ gpm}$$



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Recommended References:

[www.globalw.com](http://www.globalw.com)

[www.1728.com/circsect.htm](http://www.1728.com/circsect.htm). Calculator for area of circle segment.



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## ORIFICE MANOMETER METHOD

### Required Conditions:

- The pipe must be flowing full.
- The pipe must be level (horizontal) with a smooth interior.
- The distance between the orifice and any valves or fittings in the approach pipe must be greater than 8 pipe diameters (4 feet is recommended).
- There should be 2 feet between the pressure tap and the orifice.
- The end of the pipe must be cut squarely.
- Measurement points must be easily accessed.
- The orifice must be a true bore, smooth, diameter accurate to  $\pm 0.001$  inches.
- The orifice material should be 1/8 inch thick and rigid.
- Refer to the figure in the example below.

### Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Allow flow in the pipe to occur for at least 15 minutes to obtain stable and consistent conditions.
- When selecting the size of the orifice it is useful to estimate the pipe flow with the California Pipe Method in order to select an orifice that will produce about 20 to 30 inches of water column at the pipe's manometer.
- An air bleeder must be used to let the air out of the top of the pipe at the orifice end before measurements are taken.
- The flow is derived from measuring the orifice diameter, pipe inside diameter and the water level (H) in a standpipe (manometer) measured from the centerline of the discharge pipe located 2 feet upstream of the orifice.
- Repeat the hydraulic head measurements at least 3 times and use the average of the measurements.
- A table or graph is used to select the "C" coefficient, based on the pipe and the orifice diameters. A typical figure for selecting "C" is included in the example below. Tables and figures are available in many hydraulic handbooks.
- The orifice can be left in place if continuous monitoring is necessary.
- This method is one of the most often recommended methods for testing other metering methods for accuracy because of its simplicity and, when accurately constructed, its ability to measure within 2% of exact flow.



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*(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)*

Withdrawal source: (ex. well, lake, canal name, etc.) \_\_\_\_\_

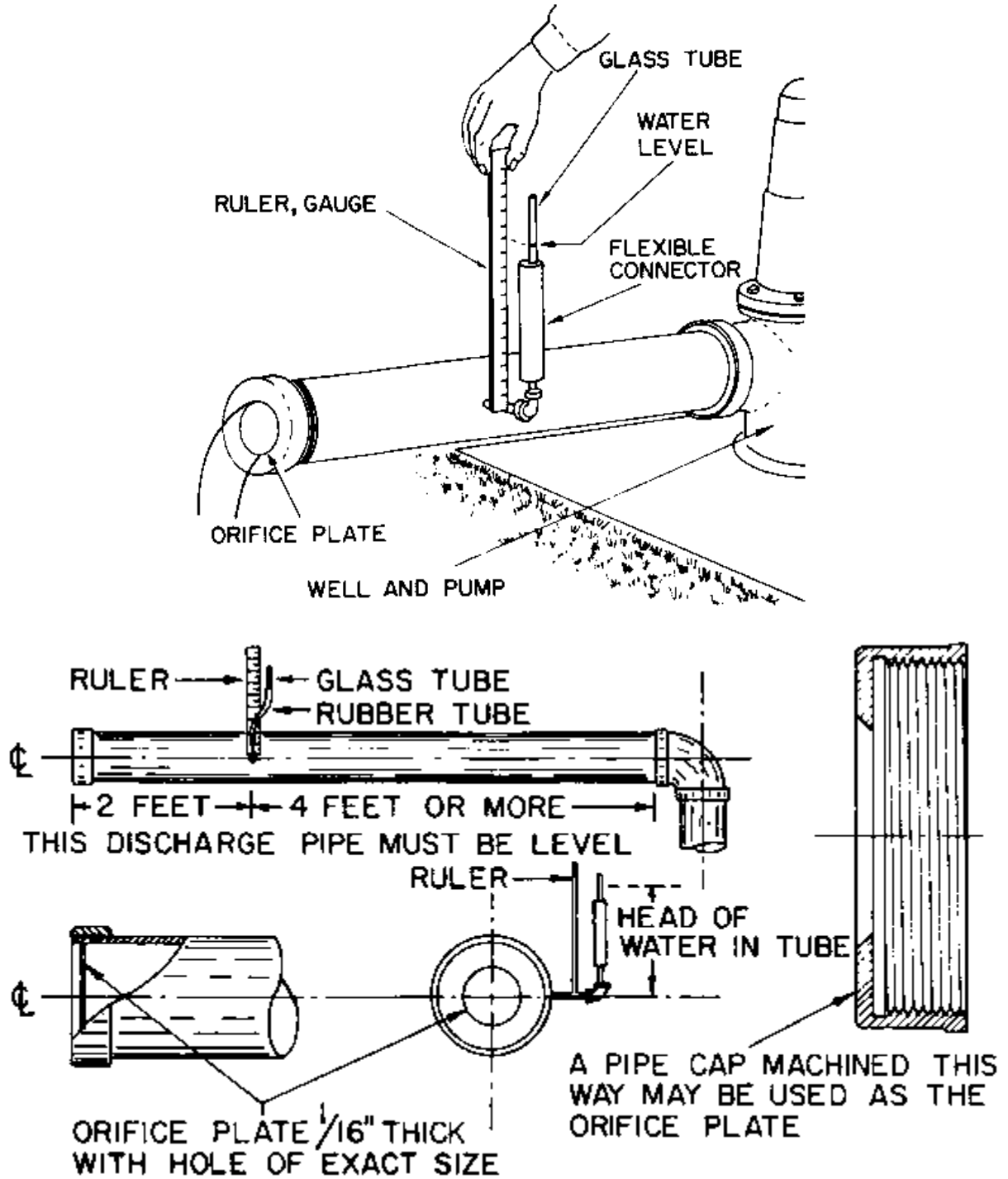
Withdrawal type (ex. pumped, gravity, flow well, other) \_\_\_\_\_

Facility water use accounting method: \_\_\_\_\_



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**Example Flow Verification Information, Data and Calculations:**



Note: Care must be taken to mount the pressure tap flush with the inside of the discharge pipe



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Pipe inside diameter (D) = 4 inches

Orifice diameter (d) = 3 inches

Length of level horizontal discharge pipe tested: \_\_\_\_\_

Manometer Measurements:

Level of Water (H) in Manometer (inches)	5.75	6.0	6.25	Avg.:6.0
---	------	-----	------	----------

Average hydraulic head (H):

$$H = (5.75 + 6.0 + 6.25)/3 = 6.0 \text{ inches}$$

Coefficient (C) from graph below:

Ratio of orifice diameter to pipe diameter = 3 in/4 in = 0.75

From graph below, C = 0.71

Cross-Sectional Area (A) of Orifice (in<sup>2</sup>):

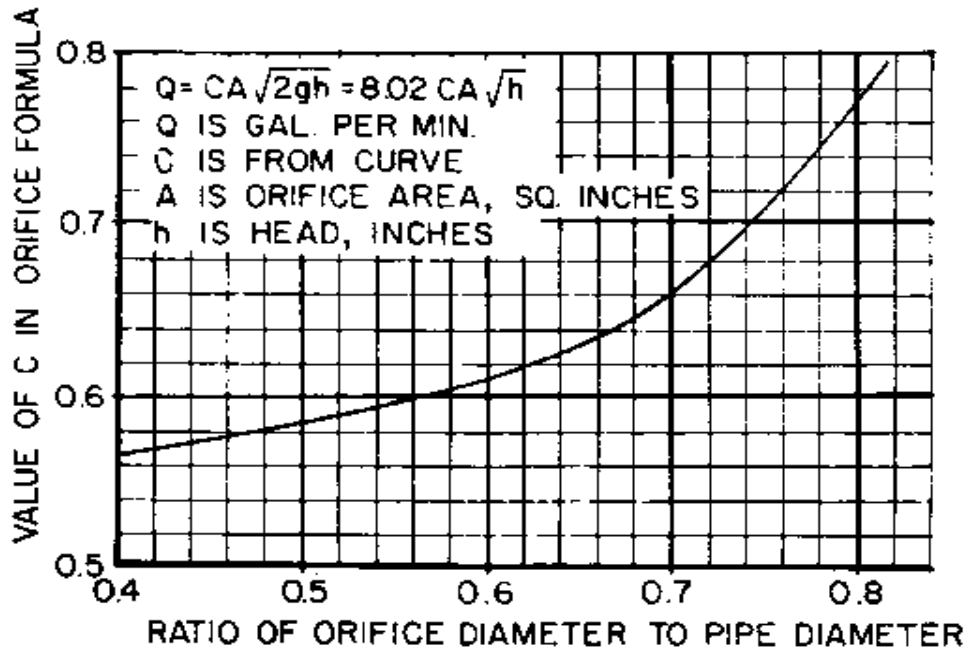
$$A = (\pi \times d^2)/4$$
$$A = (3.14 \times 3^2)/4$$
$$A = 7.07 \text{ in}^2$$

Flow (Q) in Pipe (gpm):

$$Q = 8.02 \times C \times A \times H^{0.5}$$
$$Q = 8.02 \times 0.71 \times 7.07 \times 2.45$$
$$Q = 98.6 \text{ gpm}$$



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Recommended References:

Colt Industries, Inc. 1979. Hydraulic Handbook, 11<sup>th</sup> Edition. Fairbanks Morse Pump Division of Colt Industries. Kansas City, Kansas.

Smajstrla, A.G. and D.S. Haman. 1987. Orifice meters for water flow measurement. IFAS Extension Circular AE22. University of Florida Cooperative Extension Service. Gainesville, Florida.



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## PITOT TUBE MANOMETER METHOD

### Required Conditions:

- Straight length of pipe.
- Flow profiles must be well-developed within the pipe (6 to 20 pipe diameters from pumps or pipe bends).
- Water must be fairly clean to avoid clogging and flow stream disruption.
- Pipe must be exposed and available.
- Can be used for partial or full flowing in pipes.

### Test Procedures:

#### Case 1. Full Pipe Flow

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Take at least 10 manometer readings across the pipe cross-section (recommend use of the 10-point method discussed in Section A; more if flow is expected to be turbulent or the readings are being taken close to pipe obstructions).
- The readings consist of the difference in the height of the two water columns (H) in the manometer (if 2 separate tubes are used, simple calculations will be needed).
- Calculate the average of the readings.
- Determine the water velocity in the pipe, based on that average reading and the formula described below.
- Calculate the cross-sectional area of the pipe.
- Calculate the flow in the pipe by using the cross-sectional area of the pipe and the water velocity in the pipe.

#### Case 2. Partial Pipe Flow

- When conducting your test, use representative dry season conditions, as defined in "Seasonal variations in water stages" located at the beginning of the current section.
- Measure the depth of flow in the pipe. Since the pipe is of known dimensions, an accurate determination of the flow depth in the center of the pipe will allow calculation of the flow area. From the access tap, insert a measuring device and move it side to side after ensuring that it is level in the upstream to downstream direction. The maximum measurement is the vertical depth of the water profile. Repeat several times and average those measurements (chalk on the device will show wetted depth).



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- Take at least 10 manometer readings (across the flow and vertically), which consist of the difference in the height of the two water columns (H) at the manometer. Read the height of the water column at the manometer and adjust for the vertical difference between the bottom of the manometer and the center of water flow in the pipe.
- Calculate the average of the abovementioned readings.
- Determine the water velocity in the pipe based on that average reading and the formula described below.
- Calculate the cross-sectional area of water flow in the pipe. See streamgauging flow area determination techniques in Sections A and B for more information.
- Calculate the flow in the pipe by multiplying the cross-sectional area of water flow in the pipe by the water velocity in the pipe.

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*(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)*

Withdrawal source: (ex. well, lake, canal name, etc.) \_\_\_\_\_

Withdrawal type (ex. pumped, gravity, flow well, other) \_\_\_\_\_

Facility water use accounting method: \_\_\_\_\_

**Example Flow Verification Information, Data and Calculations:**

**Case 1. Full Pipe Flow**

48” diameter pipe = 4 ft.



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<b>Manometer</b>											
<b>Readings,</b>	<b>16.9</b>	<b>17.3</b>	<b>17.0</b>	<b>16.7</b>	<b>17.5</b>	<b>17.7</b>	<b>17.6</b>	<b>17.8</b>	<b>17.9</b>	<b>18.3</b>	<b>Avg.17.47</b>
<b>H (inches)</b>											

Pipe is flowing full

Length of level horizontal discharge pipe tested: \_\_\_\_\_

H in ft = 17.47 in/12 in/ft = 1.46 ft

Velocity (V) in Pipe (ft/s):

$V = (2 \times g \times H)^{0.5}$ ; where g is the acceleration due to gravity (32.2 ft/s<sup>2</sup>)

$V = (2 \times 32.2 \times 1.46)^{0.5}$

V = 9.69 ft/s

Cross-Sectional Area (A) of Pipe (ft<sup>2</sup>):

$A = \pi \times D^2/4$

A = 3.14 x 4<sup>2</sup>/ 4

A = 12.56 ft<sup>2</sup>

Flow (Q) in Pipe (ft<sup>3</sup>/s):

Q = A x V

Q = 12.56 ft<sup>2</sup> x 9.69 ft/s

Q = 121.7 ft<sup>3</sup>/s

Conversion to gpm:

Q = 121.7 ft<sup>3</sup>/s x 448.8 gpm/cfs

Q = 54,618.9 gpm

## Case 2. Partial Pipe Flow

Important Note: Refer to Appendix C in this Section or a geometry handbook, for assistance in determining the water flow area in pipes that are not flowing full or half full.

48" diameter pipe = 4 ft

Pipe flowing half full (depth of water in pipe 2 ft)

Length of level horizontal discharge pipe tested: \_\_\_\_\_



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<b>Manometer Readings H (inches)</b>	<b>16.9</b>	<b>17.3</b>	<b>17.0</b>	<b>16.7</b>	<b>17.5</b>	<b>17.7</b>	<b>17.6</b>	<b>17.8</b>	<b>17.9</b>	<b>18.3</b>	<b>Avg.17.47</b>
--------------------------------------	-------------	-------------	-------------	-------------	-------------	-------------	-------------	-------------	-------------	-------------	------------------

H in ft = 17.47 in/12 in/ft = 1.46 ft

Velocity (V) in Pipe (ft/s):

$V = (2 \times g \times H)^{0.5}$ ; where g is the acceleration due to gravity (32.2 ft/s<sup>2</sup>)

$V = (2 \times 32.2 \times 1.46)^{0.5}$

V = 9.69 ft/s

Cross-Sectional Area (A) of Pipe (ft<sup>2</sup>):

$A_{\text{part}} = A/2$

$A = \pi \times D^2/4$

$A = 3.14 \times 4^2/4$

A = 12.56 ft<sup>2</sup>

$A_{\text{part}} = 12.56 \text{ ft}^2/2$

$A_{\text{part}} = 6.28 \text{ ft}^2$

Flow (Q) in Pipe (ft<sup>3</sup>/s):

$Q = A_{\text{part}} \times V$

$Q = 6.28 \text{ ft}^2 \times 9.69 \text{ ft/s}$

Q = 60.85 ft<sup>3</sup>/s

Conversion to gpm:

$Q = 60.85 \text{ ft}^3/\text{s} \times 448.8 \text{ gpm}/\text{cfs}$

Q = 27,309.4 gpm

Recommended References:

Chapter 13 in [www.usbr.gov/pmts/hydraulics\\_lab/pubs/wmm/index.htm](http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm).

[www.1728.com/circsect.htm](http://www.1728.com/circsect.htm). Calculator for area of circle segment.



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## PROPELLER METER METHOD

### The Following Conditions are Required:

- The measured pipe must be flowing full of water.
- The meter must be new or calibrated for the specific inside diameter (ID) of the pipe to be tested.
- The meter can be installed in a straight section of the pipe.
- Manufacturer's specifications for distance from pumps or pipe bends must be followed.
- This meter may also be used to calibrate a fixed propeller meter that is permanently installed on the pipe (such as a totalizing flow meter).

### Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- The system should be operated until flow in the pipe is stabilized before beginning the test.
- Place and secure the propeller meter at the center of the pipe's circular cross-sectional area
- Record the totalizer reading on the meter at the start of the test.
- Run water through the pipe for 10 minutes, and record the ending totalizer reading.
- Subtract the beginning reading from the ending reading to obtain total gallons for the test.
- Divide the total gallons by 10 to obtain the average flow rate in gallons per minute.
- If the meter does not have a totalizer, record several flow rate (gpm) readings over a 10-minute period after flow stabilizes and simply average the values.

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*(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)*

Withdrawal source: (ex. well, lake, canal name, etc.) \_\_\_\_\_

Withdrawal type (ex. pumped, gravity, flow well, other) \_\_\_\_\_

Facility water use accounting method: \_\_\_\_\_

**Example Flow Verification Information, Data and Calculations:**

Pipe inside diameter (D) = 6 inches

Length of level horizontal discharge pipe tested: \_\_\_\_\_

Test duration (T) = 10 minutes

Totalizer reading beginning = 12,070 gallons

Totalizer reading end = 18,185 gallons

Total flow volume (Vol) for 10-minute event (gal):

Vol = Totalizer reading ending - Totalizer reading beginning

Vol = 18,185 gal – 12,070 gal

Vol = 6,115 gal

Flow (Q) in pipe, gpm:

$Q = \text{Vol}/T$

Q = 6,115 gal/10 min

Q = 611.5 gpm

Recommended References:

Chapter 14 in [www.usbr.gov/pmts/hydraulics\\_lab/pubs/wmm/index.htm](http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm).



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## TRAJECTORY METHOD

### Required Conditions:

- The pipe must be level (horizontal).
- The end of the discharge pipe must be flowing full.
- The straight length of pipe should be 8 to 10 times the diameter in length.
- The end of the pipe must be cut squarely.
- Measurement points must be easily accessed.

### Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Allow flow in the pipe to occur for at least 15 minutes, to obtain stable and consistent conditions.
- The flow rate is derived from a horizontal pipe using the horizontal (X) and vertical (Y) distances to the top of the discharge stream. Refer to the figure in the example below.
- This method typically uses a "Y" distance of 4 or 12 Inches. However, in some cases the "X" direction governs the measurements where "X" is the distance from the end of the pipe to where the water stream impacts the surface of the receiving water body or ground surface.
- Typically, a straight edge and square are use to make the measurement.
- Repeat the measurements at least 3 times. Use the average of the measurements.
- Flow is then calculated using the equation shown in the example below.
- This is also referred to as the Purdue method.

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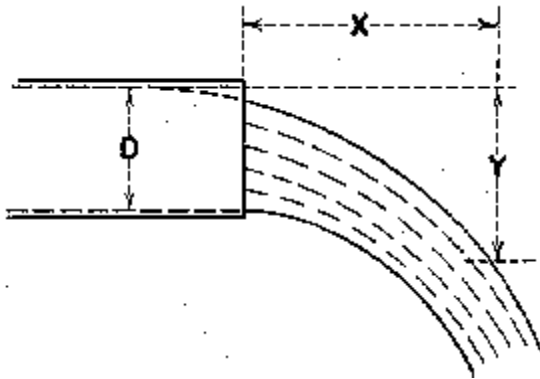
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.) \_\_\_\_\_

Withdrawal type (ex. pumped, gravity, flow well, other) \_\_\_\_\_

Facility water use accounting method: \_\_\_\_\_

**Example Flow Verification Information, Data and Calculations:**



Pipe inside diameter (D) = 4 inches

Length of level horizontal discharge pipe tested: \_\_\_\_\_

Pipe is flowing full

Discharge Stream Measurements:

Horizontal (X) in inches	8	7	6	Avg. 7.0 in
--------------------------	---	---	---	-------------

Vertical (Y) in inches	4.0	4.0	4.0	Avg. 4.0 in
------------------------	-----	-----	-----	-------------

X in ft = 7.0 in/12 in/ft

X, ft = 0.58 ft

Y in ft = 4.0 in/12 in/ft

Y, ft = 0.33 ft



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Velocity (V) in Pipe (ft/s):

$$V = X \times \frac{\sqrt{g}}{\sqrt{2Y}} = \sqrt{g} \times \frac{X}{\sqrt{2Y}} ;$$

where g is the acceleration due to gravity (32.2 ft/s<sup>2</sup>) and X, Y are expressed in ft.

$$V = \sqrt{32.2} \times \frac{X}{\sqrt{2Y}} = 5.67 \times \frac{X}{\sqrt{2Y}}$$

$$V = 5.67 \times \frac{0.58}{\sqrt{2 \times 0.33}} = 4.05 \text{ ft/s}$$

Cross-Sectional Area (A) of Pipe (in<sup>2</sup>):

$$A = \pi \times D^2/4$$

$$A = 3.14 \times 4^2/4$$

$$A = 12.56 \text{ in}^2 = 12.56/144 \text{ ft}^2 = 0.0872 \text{ ft}^2$$

Flow (Q) in Pipe (ft<sup>3</sup>/s):

$Q = A \times V$ ; where A is expressed in ft<sup>2</sup> and V is expressed in ft/s

$$Q = 0.0872 \times 4.05 = 0.3532 \text{ ft}^3/\text{s}$$

Conversion to Gallons per Minute (gpm):

$$Q = 0.3532 \text{ ft}^3/\text{s} \times 448.8 \text{ gpm/cfs} = 158.6 \text{ gpm}$$

Important Note: Flow (Q) can also be read directly from charts or tables given pipe diameter and X and Y readings.

Simplification: If X reading is taken in inches where Y = 12 inches, the equation for Q simplifies to:  $Q, \text{ gpm} = 0.818 \times D^2 \times X$ ; where D and X are in inches.

Recommended References:

Agricultural Coalition of South Florida. 2005. Methods for Calibrating, Measuring and Reporting Agricultural Water Use in South Florida, Draft. Clewiston, Florida.

Colt Industries, Inc. 1979. Hydraulic Handbook, 11<sup>th</sup> Edition. Fairbanks Morse Pump Division of Colt Industries. Kansas City, Kansas.

Karassik, I.J., W.C. Krutzsch, W.H. Fraser and J.P. Messina, eds. 1976. Pump Handbook. McGraw-Hill, Inc., New York.

Chapter 14 in [www.usbr.gov/pmts/hydraulics\\_lab/pubs/wmm/index.htm](http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm).



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## ULTRASONIC AND OTHER EXTERNAL FLOW METERS METHOD

For these instruments to function properly, pipe vibrations will need to be at a minimum. If vibrations cause undue fluctuations in readings and malfunctioning of the meter, select another method.

### Required Conditions:

- Acceptable length of straight pipe away from pump or bends per manufacturer's specifications (generally 6 to 10 pipe diameters).
- Pipe is exposed and accessible.
- Pipe must flow full at point of measurement (the pipes of a pressurized irrigation system have full flow conditions).

### Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Take at least 5 discrete velocity readings.
- Average the 5 velocity measurements.
- If your readings are in feet per second, multiply them by the circular area of the pipe in which you took the readings to calculate flow in cubic feet per second.
- Convert flow to gallons per minute.

### General Permit Information Required:

Permit Number/App Number \_\_\_\_\_ / \_\_\_\_\_

Project Name \_\_\_\_\_

Site Contact/Phone Number \_\_\_\_\_ / \_\_\_\_\_

District Facility ID \_\_\_\_\_

*(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)*



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Withdrawal source: (ex. well, lake, canal name, etc.) \_\_\_\_\_

Withdrawal type (ex. pumped, gravity, flow well, other) \_\_\_\_\_

Facility water use accounting method: \_\_\_\_\_

### **Example Flow Verification Information, Data and Calculations:**

Instrument Readings:

TIME	VELOCITY READING (ft/s)
1:00 pm	8.56
1:01 pm	8.55
1:02 pm	8.57
1:03 pm	8.57
1:04 pm	8.55

Average Velocity (V) = 8.56 ft/s

Pipe inside diameter (D): 24 inches (2 ft)

Cross-Sectional Area of Pipe, A (ft<sup>2</sup>):

$$A = (\pi \times D^2)/4 \text{ (full pipe)}$$

$$A = (\pi \times 2^2)/4$$

$$A = 3.14 \text{ ft}^2$$

Average Flow in Pipe (ft<sup>3</sup>/s):

$$Q = \text{Average Velocity} \times \text{Cross-Sectional Area of Pipe}$$

$$Q = 8.56 \text{ ft/s} \times 3.14 \text{ ft}^2$$

$$Q = 26.88 \text{ ft}^3/\text{s}$$

Conversion to Gallons per Minute (gpm):

$$Q = 26.88 \text{ ft}^3/\text{s} \times 448.8 \text{ gpm/cfs}$$

$$Q = 12,063 \text{ gpm}$$

Recommended References:

Chapters 11 and 14 in [www.usbr.gov/pmts/hydraulics\\_lab/pubs/wmm/index.htm](http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm).



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## VERTICAL PIPE METHOD

### Required Conditions:

- The pipe must discharge to open air
- The pipe must be vertical and not inclined.
- You must have access by foot to the pipe.

### Test Procedures:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Use a carpenter's square or a 90 degree folding scale to measure the vertical rise of the water spout (H) in inches above the edge of the pipe.
- Use a table (see below) or standard equation to determine the flow from your pipe, using H from above and the inside diameter of the pipe in inches.
- Repeat the above two steps at least two more times and report the average result of those H determinations.

### General Permit Information Required:

Permit Number/App Number \_\_\_\_\_ / \_\_\_\_\_

Project Name \_\_\_\_\_

Site Contact/Phone Number \_\_\_\_\_ / \_\_\_\_\_

District Facility ID \_\_\_\_\_

*(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)*

Withdrawal source: (ex. well, lake, canal name, etc.) \_\_\_\_\_

Withdrawal type (ex. pumped, gravity, flow well, other) \_\_\_\_\_



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Facility water use accounting method: \_\_\_\_\_

**Example Flow Verification Information, Data and Calculations:**

- Pipe inside diameter (D): 4 inches
- A level was used to check that the pipe was vertical (side to side and front to back).
- Rise of Water Spout above edge of Pipe:

Measurement Information: Measurement Number	Rise of Water Spout above Edge of Pipe "H" (inches)
1	6
2	5
3	7
<b>AVERAGE</b>	<b>6</b>

Average Flow from Pipe Using Table Below (Gallons per Minute):

- 205 gpm

Flow from Vertical Pipes (gpm)

Pipe Inside Diameter (inches)	Rise of Water Spout Above Edge of Pipe (inches)										
	3	3.5	4	4.5	5	5.5	6	7	8	10	12
2	38	41	44	47	50	53	56	61	65	74	82
3	81	89	96	103	109	114	120	132	141	160	177
4	137	151	163	174	185	195	205	222	240	269	299
6	318	349	378	405	430	455	480	520	560	635	700
8	567	623	684	730	776	821	868	945	1020	1150	1270
10	950	1055	1115	1200	1280	1350	1415	1530	1640	1840	2010

Reference: Colt Industries, 1974



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The flow (Q in gpm) through the pipe is calculated according to the formula:

$$Q = 5.68 \times K \times D^2 \times H^{0.5}$$

where:

K is a coefficient which ranges from 0.87 to 0.97 for pipes with inside diameter between 2 and 6 inches

D = Pipe inside diameter (in)

H = Rise of water spout above edge of pipe (in)

Calculate Coefficient, K:

K = 0.87 for 2 inch diameter pipes and 0.97 for 6 inch diameter pipes, as long as H is within 6 inches to 24 inches. Linear interpolation can be used to adjust K for pipe diameters between 2 and 6 inches.

$$K_{4 \text{ in pipe}} = 0.97 - [(4 - 2)/(6 - 2)] \times (0.97 - 0.87)$$

$$K_{4 \text{ in pipe}} = 0.92$$

Flow (Q) in Pipe (gpm):

$$Q = 5.68 \times 0.92 \times 4^2 \times 6^{0.5}$$

$$Q = 205 \text{ gpm}$$

Important Note: Other pipe configuration flow tables can be found in Chapter 14 of the United States Bureau of Reclamation Water Measurement Manual on line at:

[www.usbr.gov/pmts/hydraulics\\_lab/pubs/index.htm](http://www.usbr.gov/pmts/hydraulics_lab/pubs/index.htm).

Recommended References:

Colt Industries, Inc. 1979. Hydraulic Handbook, 11<sup>th</sup> Edition. Fairbanks Morse Pump Division of Colt Industries. Kansas City, Kansas.

Karassik, I.J., W.C. Krutzsch, W.H. Fraser and J.P. Messina, eds. 1976. Pump Handbook. McGraw-Hill, Inc., New York.

Chapter 14 in [www.usbr.gov/pmts/hydraulics\\_lab/pubs/wmm/index.htm](http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm).



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## VOLUMETRIC FLOW METHOD

### Required Conditions:

- The flow of water in the pipe is low enough that it can fill in a container over a period of no less than 15 seconds; or
- A large enough container is available such that it will take no less than 15 seconds to completely fill it with water from the small pipe being measured.
- A container is available such that you know its weight when empty and when full of water, or you know the total volume of water it can hold when full.
- The small pipe is positioned in such a way that you can temporarily direct its flow to the container chosen for the measurement without the use of flow altering connectors and pipes/hoses.
- A container is available such that you can transport it to the location where the small pipe is.

### Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Place the empty container you chose at the discharge end of the small pipe so that it captures all the flow.
- Use a stop watch or a watch that is capable of reading in seconds, to determine the time it takes to completely fill the container.
- Repeat the above two steps at least two more times.

### General Permit Information Required:

Permit Number/App Number \_\_\_\_\_ / \_\_\_\_\_

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District Facility ID \_\_\_\_\_



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(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.) \_\_\_\_\_

Withdrawal type (ex. pumped, gravity, flow well, other) \_\_\_\_\_

Facility water use accounting method: \_\_\_\_\_

### **Example Flow Verification Information, Data and Calculations:**

- Pipe inside diameter: 4 inches
  - Flow from the pipe was directed to the container via a temporary PVC pipe extension that allowed free flow of water to the container with no addition of hydraulic head to the system.
- Container Information (choose only one below):
  - a) Weight Information:
    - ✓ Weight of Container when Empty: 50 lbs
    - ✓ Weight of Container when Full of Water: 1719 lbs
  - b) Volume Information:
    - ✓ Volume of Container: 200 gallons

Measurement Information:

Measurement Number	Time to Fill Container, T (Seconds)
1	18
2	20
3	22
<b>AVERAGE TIME, T</b>	<b>20</b>



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### Case 1. Weight Information

#### Convert Weight of Water to Volume (gal):

Weight of Water Only in Container: 1719 lbs – 50 lbs = 1669 lbs

Volume of Water in Container ( $\text{Vol}_{\text{water}}$ ): 1669 lbs/62.4 lbs per  $\text{ft}^3$  = 26.75  $\text{ft}^3$

#### Flow (Q) from Pipe ( $\text{ft}^3/\text{s}$ ):

$$Q = \text{Vol}_{\text{water}}, \text{ft}^3/\text{T}, \text{sec}$$

$$Q = 26.75 \text{ft}^3/20 \text{s}$$

$$Q = 1.34 \text{ft}^3/\text{s}$$

#### Conversion to gpm:

$$Q = 1.34 \text{ft}^3/\text{s} \times 448.8 \text{gpm}/\text{cfs}$$

$$Q = 600 \text{gpm}$$

### Case 2. Volume Information

#### Flow (Q) from Pipe (gpm):

T, time to fill container full = 20 seconds

Container size = 200 gallons

$$Q = \text{Vol}_{\text{container}}, \text{gal}/(\text{T}, \text{sec} \times \text{Conversion Factor}, \text{seconds to minutes})$$

$$Q = 200 \text{gal}/(20 \text{s} \times 1/60 \text{min}/\text{s})$$

$$Q = 600 \text{gpm}$$

Important Note: It is important that flow characteristics at the outlet where water is collected are not changed. Additionally, when using the weight method, it is recommended that the weight of a gallon of water that has passed through the system be measured.

#### Recommended References:

Jensen, M.E., ed. 1983. Design and Operation of Farm Irrigation Systems, Chapter 17. American Society of Agricultural Engineers. St. Joseph. Michigan.

Smajstrla, A. G., Harrison, D. S., and Zazueta, F. S. 1985. Agricultural Water Measurement. IFAS Bulletin 207. University of Florida Cooperative Extension Service. Gainesville, Florida.



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## WEIR METHOD

### Required Conditions:

- A typical weir is a flash board riser with boards installed.
- The weir needs to be rectangular in shape and have water moving freely over its top
- The weir needs to be leveled
- The velocity of the water approaching the weir is low.
- The water approaching the weir needs to be free of trash.
- The level of the water approaching the weir needs to be high enough above the top of the weir, to be able to measure that water level.
- The water level downstream of the weir needs to be below the top of the weir.
- For other type of weirs or flow conditions (submerged, v-notch, and others), you will be required to retain a P.E. so that he/she can submit a calibration plan to SFWMD for review and approval.

### Test Procedure:

- When conducting your test, use representative dry season conditions, as defined at the beginning of this Section.
- Measure the height of the upstream water level above the top of the weir, or Head (H). This measurement needs to be taken a distance of at least one weir width, from the weir.
- Measure the width of the weir.
- All measurements should be as accurate as possible, and at worst, to the nearest 1/2 inch.
- Additional Comments:
  - The weir coefficient should be verified if the riser or canal width is less than 3 times the weir width.

### General Permit Information Required:

Permit Number/App Number \_\_\_\_\_ / \_\_\_\_\_

Project Name \_\_\_\_\_

Site Contact/Phone Number \_\_\_\_\_ / \_\_\_\_\_



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District Facility ID \_\_\_\_\_  
(If not known, use site name and GPS coordinates or site map referencing location to known landmarks)

Withdrawal source: (ex. well, lake, canal name, etc.) \_\_\_\_\_

Withdrawal type (ex. pumped, gravity, flow well, other) \_\_\_\_\_

Facility water use accounting method: \_\_\_\_\_

### **Example Flow Verification Information, Data and Calculations:**

Weir dimensions:      Length of Crest, L = 2.50 ft  
                                    Top of Weir Elevation\* = 9.65 ft

Water Surface Elevation (Upstream)\*:      10.95 ft

Head on Weir (H):

H = Water Surface Elevation, ft\* – Top of Weir Elevation, ft\*  
H = 10.95 – 9.65  
H = 1.30 ft

**\* Important Note: Not necessary, if the height of water above the top of the weir can be measured directly.**

Weir Equation:

$$Q, \text{ ft}^3/\text{s} = C \times L, \text{ ft} \times (H, \text{ ft})^{1.5}$$

$$C = \text{Weir Coefficient} = 3.13$$

Flow (Q) in ft<sup>3</sup>/s:

$$Q = 3.13 \times 2.50 \times 1.30^{1.5}$$
$$Q = 11.60 \text{ ft}^3/\text{s}$$



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Conversion to gpm:

$$Q = 11.60 \text{ ft}^3/\text{s} \times 448.8 \text{ gpm/cfs}$$

$$Q = 5205 \text{ gpm}$$

Recommended References:

Colt Industries, Inc. 1979. Hydraulic Handbook, 11<sup>th</sup> Edition. Fairbanks Morse Pump Division of Colt Industries. Kansas City, Kansas.

ISCO, Inc. 1992. Open Channel Flow Measurement Handbook, 3rd Edition. ISCO, Inc. Lincoln Nebraska.

Chapter 7 in [www.usbr.gov/pmts/hydraulics\\_lab/pubs/wmm/index.htm](http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/index.htm).