Designation: D5716/D5716M – 15

# Standard Test Method for
# Measuring the Rate of Well Discharge by Circular Orifice Weir[1]

This standard is issued under the fixed designation D5716/D5716M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope*

1.1 This test method covers construction and operation of a circular orifice weir for measuring the discharge from a well. This test method is a part of a series of standards prepared on the in situ determination of hydraulic properties of aquifer systems by single- or multiple-well tests. Selection of a well discharge measurement test method is described in Guide D5737.

1.2 The discharge rate determined by this test method is commonly used for a number of aquifer test methods and to provide information for the evaluation of well and pump performance.

1.3 *Limitations*—This test method is limited to the description of a method common to hydraulic engineering for the purpose of groundwater discharge measurement in temporary or test conditions.

1.4 Much of the information presented in this test method is based on work performed by the Civil Engineering Department of Purdue University during the late 1940s. The essentials of that work have been presented in a pamphlet prepared by Layne-Bowler, Inc.[2] and updated by Layne Western Company, Inc.[3]

1.5 All observed and calculated values shall be conform to the guidelines for significant digits and rounding established in Practice D6026.

1.5.1 The procedures used to specify how data are collected/recorded and calculated in this standard are regarded as the industry standard. In addition they are representative of the significant digits that should generally be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this document to consider significant digits sused analysis methods for engineering design.

1.6 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*[4]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D5737 Guide for Methods for Measuring Well Discharge

D6026 Practice for Using Significant Digits in Geotechnical Data

2.2 *Other Documents:*

GWPD 10 Estimating discharge from a pumping well by use of a circular orifice weir, United States Geological Survey

## 3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms used in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Groundwater and Vadose Zone Investigations.

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[2] *Measurement of Water Flow Through Pipe Orifice With Free Discharge*, Bulletin 501, Layne-Bowler, Inc., Mission, KS, 1958.

[3] *Measurement of Water Flow Through Pipe Orifice With Free Discharge*, Layne-Western Company, Inc., Mission, KS, 1988.

[4] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

3.2.1 *circular orifice weir*—a circular restriction in a pipe that causes back pressure that can be measured in a piezometer tube.

3.2.1.1 *Discussion*—Also called *orifice tube* and *orifice meter*.

3.3 *Symbols and Dimensions Used in this Standard:*

3.3.1 *A*—orifice plate open area [ $L^2$].

3.3.2 *C*—coefficient of discharge for the orifice [*nd*].

3.3.3 *g*—acceleration due to gravity [ $LT^{-2}$].

3.3.4 *h*—head in manometer [ *L*].

3.3.5 *Q*—control well discharge [ $L^3T^{-1}$].

3.3.6 *o*—orifice diameter [ *L*].

3.3.7 *d*—pipe inside diameter [ *L*].

## 4. Summary of Test Method

4.1 This test method involves pumping a control well at a constant or variable rate through a circular orifice weir for a given period of time. Discharge is through an orifice weir that allows determination of the discharge rate.

4.2

## 5. Significance and Use

5.1 This test method provides design information for construction of an orifice weir. It also describes setup, operation, inspection, calculation of discharge, and reporting. The accuracy of a circular weir decreases at low flows. The use of a circular orifice weir requires a constant flow velocity over the period of measurement. The results may be affected by the piezometers distance from the orifice plate. This equipment may not be appropriate for measuring flows on small wells, or wells with limited recharge.

5.2 Aquifer testing has been conducted for the purposes of production and pressure relief well design and water resource assessment. Production wells are used for public and industrial water supplies, hydraulic controls, and groundwater capture. Pressure relief wells are for hydraulic controls. Test wells are for the purpose of water resource assessment.

5.3 Discharge must also be known for certain methods to evaluate well and pump performance.

NOTE 1—Practice D3740 provides evaluation factors for the activities in this standard. The quality of the result produced by this standard is dependent on the competence of the personnel performing it and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

## 6. Apparatus

6.1 *Construction of a Circular Orifice Weir*—A construction diagram of a circular orifice weir is presented in Fig. 1.[5] The circular orifice is a hole located in the center of a plate attached to a straight horizontal length of discharge pipe. The pipe is at least 1.8 m [6 ft] in length. Approximately 600 mm [24 in.] from the end plate and at least 1.2 m [4 ft] from the other end of the discharge pipe, a piezometer is attached to the discharge pipe so that the head in the discharge pipe can be measured.

[5] Driscoll, F. G., *Ground Water and Wells*, Johnson Division, St. Paul, MN, 1986, pp. 537–541.

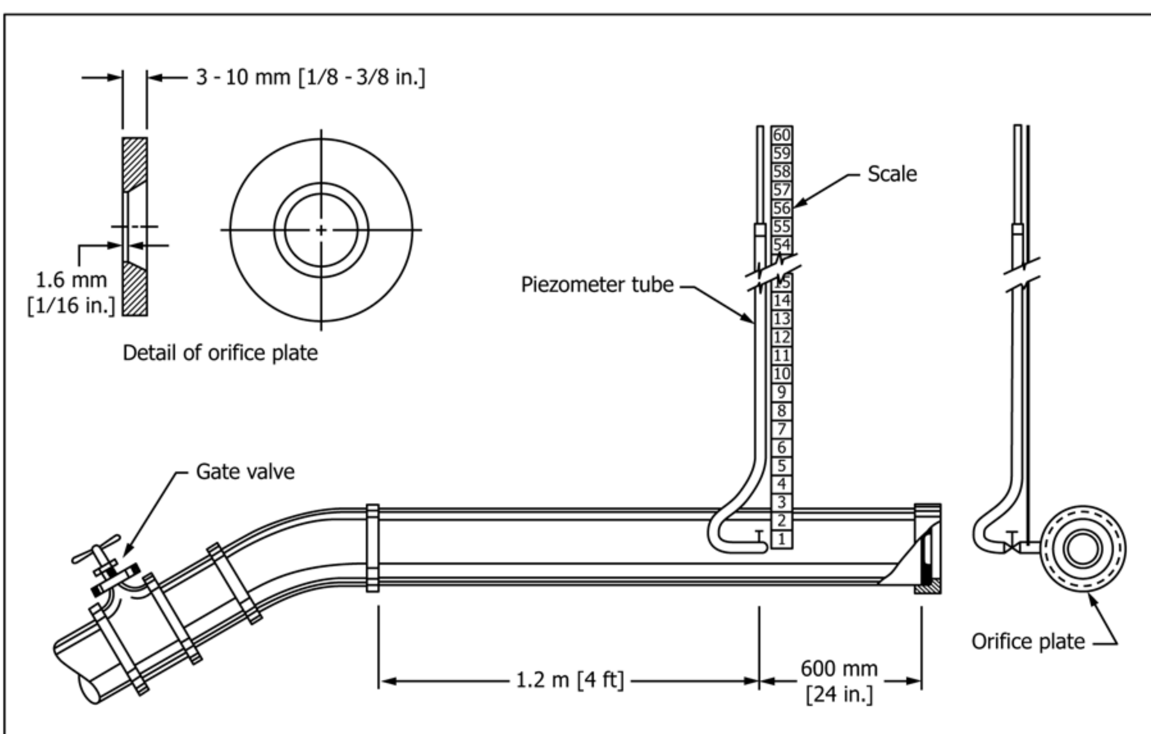


**FIG. 1 Construction of a Circular Orifice Weir[5]**

6.1.1 *Orifice Plate*—The orifice is a round hole with clean, square edges in the center of a circular steel plate. The plate must be a minimum of 1.6 mm [1⁄16 in.] thick around the circumference of the hole. The remaining thickness of the orifice should be chamfered to 45° and with the chamfered edge down stream.

6.1.2 *Discharge Pipe*—The discharge pipe must be straight and level for a distance of at least 1.8 m [6 ft] before the water reaches the orifice plate. This approach channel should be longer if possible. The end of the pipe must be cut squarely so the plate will be vertical. The bore of the pipe should be smooth and free of any obstruction that might cause abnormal turbulence.

6.1.3 *Piezometer*—The discharge pipe wall is tapped midway between the top and bottom with a 3 mm [1⁄8-in.] or 6 mm [1⁄4-in.] hole exactly 600 mm [24 in.] from the orifice plate. The manometer should be a distance of at least ten discharge pipe diameters from the gate valve used to control pipe flow. Any burrs inside the pipe resulting from the drilling or tapping of the hole should be filed off. A nipple is screwed into the tapped hole. The nipple must not protrude inside the discharge pipe. A clear plastic tube 1.2 to 1.5 m [4 or 5 ft] long is connected at one end to the nipple. A scale is fastened to a support so that the vertical distance from the center of the discharge pipe up to the water level in the manometer can be measured. Alternately, a u-tube manometer or pressure transducer may be used. During a test the manometer must be free of air bubbles.

6.2 The diameter of the orifice should be less than 80 % of the inside diameter of the approach channel pipe.

## 7. Procedure

7.1 Set up the apparatus as shown in Fig. 1 and Fig. 2. The apparatus should be set up so that the orifice pipe is horizontal and the discharge is unimpeded. Use a combination of pipe and orifice diameter so that the anticipated head will be at least three times the diameter of the orifice. The orifice plate must be vertical and centered in the discharge pipe.

7.2 Equipment should be inspected to minimize the potential of wear, damage or misuse causing increased head loss that will bias results.

7.3 Initiate flow through the discharge pipe. Check that the manometer is free of air bubbles. Record the manometer level. Using Table 1 and Table 2 for the appropriate pipe and orifice size, read the discharge.

## 8. Calculation

8.1 Calculate the flow through the orifice using the basic equation:

$$Q = AVC \tag{1}$$

where:

$Q$ = the flow per unit time,
$A$ = the area of the orifice,
$V$ = the velocity of flow through the orifice, and
$C$ = the coefficient of discharge for the orifice.

The velocity of the water at the orifice consists of its velocity in the approach channel plus the additional velocity head created by the pressure drop that occurs between the connection for the manometer and the orifice. Because the water discharges at atmospheric pressure, the pressure head indicated by the manometer can be converted to the velocity if friction in the pipe is neglected.

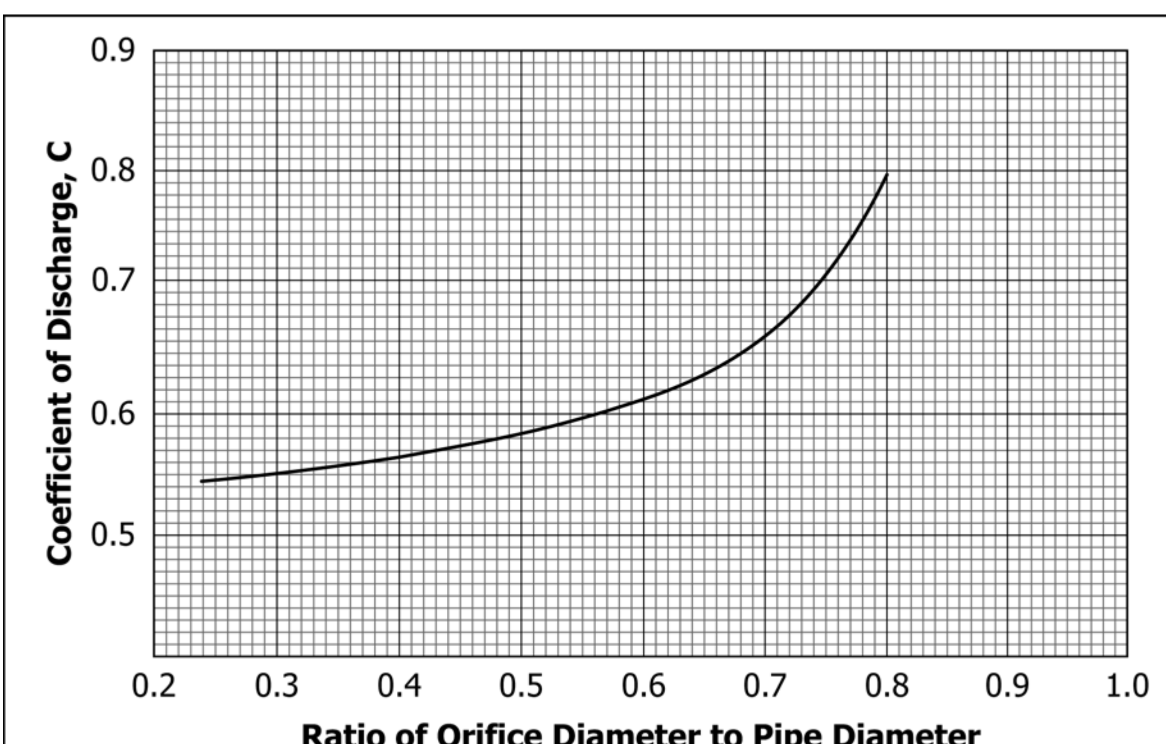


FIG. 2 The Coefficient of Discharge, *C*, in the Orifice-Weir Equation[3]

### TABLE 1 Flow Rates through Circular Orifice Weirs[5] (SI)

NOTE 1—Flow rates indicated below the line are more exact than those above the line because the head developed in the piezometer tube for particular pipe and orifice diameters is large enough to ensure the accuracy of results obtained from Eq 5.

| Head of Water mm | 100 mm Pipe | | 150 mm Pipe | | 200 mm Pipe | | | 250 mm Pipe | | | 300 mm Pipe | | 400 mm Pipe | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 64 mm Orifice Lpm | 76 mm Orifice Lpm | 76 mm Orifice Lpm | 102 mm Orifice Lpm | 102 mm Orifice Lpm | 127 mm Orifice Lpm | 150 mm Orifice Lpm | 150 mm Orifice Lpm | 178 mm Orifice Lpm | 200 mm Orifice Lpm | 150 mm Orifice Lpm | 200 mm Orifice Lpm | 200 mm Orifice Lpm | 250 mm Orifice Lpm | 300 mm Orifice Lpm |
| 127 | 210 | 340 | 290 | 550 | 500 | 830 | 1340 | 1170 | 1740 | 2570 | 1170 | 2200 | 2010 | 3330 | 5380 |
| 150 | 230 | 370 | 310 | 600 | 550 | 910 | 1480 | 1290 | 1890 | 2800 | 1230 | 2420 | 2200 | 3630 | 5900 |
| 175 | 250 | 400 | 330 | 650 | 590 | 980 | 1590 | 1400 | 2040 | 3140 | 1330 | 2610 | 2350 | 3940 | 6360 |
| 200 | 260 | 420 | 360 | 690 | 630 | 1040 | 1700 | 1490 | 2200 | 3330 | 1420 | 2760 | 2540 | 4200 | 6810 |
| 230 | 280 | 450 | 380 | 730 | 670 | 1120 | 1780 | 1590 | 2310 | 3560 | 1510 | 2950 | 2690 | 4470 | 7230 |
| 250 | 290 | 480 | 400 | 770 | 700 | 1170 | 1890 | 1670 | 2420 | 3750 | 1590 | 3100 | 2840 | 4690 | 7610 |
| 300 | 320 | 520 | 430 | 840 | 770 | 1290 | 2080 | 1820 | 2650 | 4090 | 1740 | 3410 | 3100 | 5150 | 8330 |
| 350 | 350 | 560 | 475 | 910 | 830 | 1380 | 2250 | 1970 | 2880 | 4430 | 1890 | 3670 | 3330 | 5570 | 9010 |
| 400 | 370 | 600 | 500 | 980 | 890 | 1480 | 2400 | 2100 | 3070 | 4730 | 2010 | 3940 | 3560 | 5940 | 9620 |
| 450 | 390 | 640 | 530 | 1030 | 950 | 1570 | 2560 | 2230 | 3260 | 5040 | 2120 | 4160 | 3780 | 6320 | 10180 |
| 500 | 420 | 670 | 570 | 1090 | 1000 | 1670 | 2690 | 2350 | 3450 | 5300 | 2230 | 4390 | 3980 | 6660 | 10750 |
| 560 | 440 | 700 | 600 | 1140 | 1040 | 1740 | 2820 | 2460 | 3600 | 5570 | 2350 | 4620 | 4200 | 6970 | 11280 |
| 635 | 460 | 750 | 640 | 1220 | 1120 | 1860 | 3010 | 2610 | 3860 | 5900 | 2500 | 4920 | 4470 | 7420 | 12040 |
| 760 | 510 | 820 | 690 | 1340 | 1230 | 2040 | 3290 | 2880 | 4240 | 6730 | 2760 | 5380 | 4880 | 8140 | 13170 |
| 890 | 550 | 890 | 750 | 1440 | 1340 | 2200 | 3560 | 3100 | 4580 | 7000 | 2990 | 5790 | 5300 | 8780 | 14230 |
| 1020 | 590 | 950 | 800 | 1530 | 1400 | 2350 | 3780 | 3330 | 4880 | 7500 | 3180 | 6210 | 5640 | 9390 | 15220 |
| 1140 | 620 | 1010 | 840 | 1630 | 1500 | 2500 | 4010 | 3520 | 5190 | 7680 | 3370 | 6590 | 5980 | 9960 | 16130 |
| 1270 | 660 | 1060 | 890 | 1720 | 1570 | 2610 | 4240 | 3710 | 5450 | 8110 | 3560 | 6930 | 6320 | 10520 | 17000 |
| 1525 | 720 | 1770 | 980 | 1890 | 1720 | 2880 | 4660 | 4090 | 5980 | 8860 | 3900 | 7610 | 6930 | 11500 | 18620 |
| 1780 | 780 | 1320 | 1060 | 1990 | 1850 | 3070 | 4850 | 4320 | 6470 | 9580 | 4200 | 8210 | 7460 | 12420 | 20100 |

### TABLE 2 Flow Rates through Circular Orifice Weirs[5]

NOTE 1—Flow rates indicated below the line are more exact than those above the line because the head developed in the piezometer tube for particular pipe and orifice diameters is large enough to ensure the accuracy of results obtained from Eq 5.

| Head of Water in. | 4-in. Pipe | | 6-in. Pipe | | 8-in. Pipe | | | 10-in. Pipe | | | 12-in. Pipe | | 16-in. Pipe | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2½-in. Orifice gpm | 3-in. Orifice gpm | 3-in. Orifice gpm | 4-in. Orifice gpm | 4-in. Orifice gpm | 5-in. Orifice gpm | 6-in. Orifice gpm | 6-in. Orifice gpm | 7-in. Orifice gpm | 8-in. Orifice gpm | 6-in. Orifice gpm | 8-in. Orifice gpm | 8-in. Orifice gpm | 10-in. Orifice gpm | 12-in. Orifice gpm |
| 5 | 55 | 89 | 76 | 145 | 131 | 220 | 355 | 310 | 460 | 680 | 300 | 580 | 530 | 880 | 1420 |
| 6 | 60 | 97 | 82 | 158 | 144 | 240 | 390 | 340 | 500 | 740 | 325 | 640 | 580 | 960 | 1560 |
| 7 | 65 | 105 | 88 | 171 | 156 | 260 | 420 | 370 | 540 | 830 | 350 | 690 | 620 | 1040 | 1680 |
| 8 | 69 | 112 | 94 | 182 | 166 | 275 | 450 | 395 | 580 | 880 | 375 | 730 | 670 | 1110 | 1800 |
| 9 | 73 | 119 | 100 | 193 | 176 | 295 | 475 | 420 | 610 | 940 | 400 | 780 | 710 | 1180 | 1910 |
| 10 | 77 | 126 | 106 | 204 | 186 | 310 | 500 | 440 | 640 | 990 | 420 | 820 | 750 | 1240 | 2010 |
| 12 | 85 | 138 | 115 | 223 | 205 | 340 | 550 | 480 | 700 | 1080 | 460 | 900 | 820 | 1360 | 2200 |
| 14 | 92 | 149 | 125 | 241 | 220 | 365 | 595 | 520 | 760 | 1170 | 500 | 970 | 880 | 1470 | 2380 |
| 16 | 98 | 159 | 132 | 258 | 235 | 390 | 635 | 555 | 810 | 1250 | 530 | 1040 | 940 | 1570 | 2540 |
| 18 | 104 | 168 | 140 | 273 | 250 | 415 | 675 | 590 | 860 | 1330 | 560 | 1100 | 1000 | 1670 | 2690 |
| 20 | 110 | 178 | 150 | 288 | 265 | 440 | 710 | 620 | 910 | 1400 | 590 | 1160 | 1050 | 1760 | 2840 |
| 22 | 115 | 186 | 158 | 302 | 275 | 460 | 745 | 650 | 950 | 1470 | 620 | 1220 | 1110 | 1840 | 2980 |
| 25 | 122 | 198 | 168 | 322 | 295 | 490 | 795 | 690 | 1020 | 1560 | 660 | 1300 | 1180 | 1960 | 3180 |
| 30 | 134 | 217 | 182 | 353 | 325 | 540 | 870 | 760 | 1120 | 1710 | 730 | 1420 | 1290 | 2150 | 3480 |
| 35 | 145 | 235 | 198 | 380 | 355 | 580 | 940 | 820 | 1210 | 1850 | 790 | 1530 | 1400 | 2320 | 3760 |
| 40 | 155 | 251 | 210 | 405 | 370 | 620 | 1000 | 880 | 1290 | 1980 | 840 | 1640 | 1490 | 2480 | 4020 |
| 45 | 164 | 267 | 223 | 430 | 395 | 660 | 1060 | 930 | 1370 | 2030 | 890 | 1740 | 1580 | 2630 | 4260 |
| 50 | 173 | 280 | 235 | 455 | 415 | 690 | 1120 | 980 | 1440 | 2140 | 940 | 1830 | 1670 | 2780 | 4490 |
| 60 | 190 | 310 | 260 | 500 | 455 | 760 | 1230 | 1080 | 1580 | 2340 | 1030 | 2010 | 1830 | 3040 | 4920 |
| 70 | 205 | 350 | 280 | 525 | 490 | 810 | 1280 | 1140 | 1710 | 2530 | 1110 | 2170 | 1970 | 3280 | 5310 |

8.2 Relate the velocity to the head in the manometer by the equation:

$$V = \sqrt{2gh} \tag{2}$$

where:

$V$ = velocity,
$g$ = acceleration due to gravity, and
$h$ = the height of water in the manometer.

To compute the actual velocity through the orifice, the value of $V$ from Eq 2 must be added to the velocity in the discharge pipe approach, and the sum of these must be corrected by two factors. One correction is for the contraction of the jet stream just outside of the orifice, and the other is for the sudden change in cross-sectional area of flow, which is controlled by the size of the orifice relative to the size of the approach channel. The approach velocity and the two correction factors are combined into a single factor, $C$, whose value varies with the ratio of the orifice inside diameter to the approach-pipe inside diameter as presented in Fig. 2.

8.3 The equation for flow through the orifice is:

$$Q = CA\sqrt{2gh} = 8.025CA\sqrt{h} \quad (3)$$

Values of $C$ may be obtained from Fig. 2, and Eq 3 may be used to calculate the pumping rate for any combination of orifice diameter, approach-pipe diameter, and water height in the piezometer tube. The pumping rate, $Q$, will be in the units of litres [gallons] per minute when the orifice area, $A$, is in square millimetres [inches] and the water level in the piezometer, $h$, is in millimetres [inches].

8.4 The water level in the manometer indicates the pressure head in the approach pipe when water is being pumped through the orifice. For any given size of orifice discharge pipe, the rate of flow through the orifice varies with the pressure head as measured in this manner. Table 1 and Table 2 present the flow in litres per minute (Lpm) [gallons per minute (gpm)] for various combinations of orifice and pipe diameters.

8.5 Extensive calibrations of circular orifice weirs indicated that they will measure the flow through the orifice within 3 % of the true value when properly constructed and used.[2, 3]

## 9. Report: Test Data Sheet(s)/Form(s)

9.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.5 and in Practice D6026.

9.2 Record, as a minimum, the following general information, including orifice and pipe sizes and manometer reading, time of reading, and well discharge rate.

9.3 Describe the physical features of the apparatus and any unusual aspect of the measurements.

## 10. Precision and Bias

10.1 *Precision*—Test data on precision is not presented due to the nature of the materials tested by this test method. It is either not feasible or too costly at this time to have ten or more agencies participate in an in situ testing program at a given site. Subcommittee D18.21 is seeking any data from the users of this test method that might be used to make a limited statement on precision.

10.2 *Bias*—There is no accepted reference value for this test method, therefore, bias cannot be determined.

## 11. Keywords

11.1 aquifers; aquifer test methods; discharge rate; groundwater; orifice weir

## SUMMARY OF CHANGES

In accordance with Committee D18 policy, this section identifies the location of changes to this standard since the last edition (1995(2006)) that may impact the use of this standard. (November 1, 2015)

*(1)* Corrected the spelling of groundwater.
*(2)* Converted the standard to a SI/Inch pound standard caveat and revised dimensional values throughout.
*(3)* Added D3740 to the referenced standards and added a note to the significance and Use Section.
*(4)* Revised Precision and Bias section wording to comply with current D18 procedures.
*(5)* Added new table 1 for SI units, retitled existing table for inch pound units.
*(6)* Added Caveat in Scope section on D6026 and added D6026 to references.
*(7)* Revised title of Section 9 to Reports, Data & Forms.
*(8)* Added reference to USGS Publication.
*(9)* Removed definitions that are already contained in D653.