Volumetric Flow Measurement for Irrigation District Turnouts

updated January 2020

Charles M. Burt, Ph.D., P.E., D.W.R.E.
Daniel J. Howes, Ph.D., P.E.,
Stuart Styles, D.E., P.E., D.W.R.E.

Funding Provided by
California Department of Water Resources
Bureau of Indian Affairs, Branch of Irrigation and Power
Bureau of Reclamation, Mid-Pacific Region

Calif. DWR, BIA, and USBR have not officially reviewed or approved the contents of this report

ITRC
moving water in new directions

IRRIGATION TRAINING & RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Office Phone: (805) 756-2434 FAX: (805) 756-2433
www.itrc.org

Table of Contents

Introduction ... **1**
Senate Bill X7-7 Requirements ... 1
Irrigation District Turnouts ... 2

Volumetric Flow Rate Measurement ... **4**
Volumetric Measurement with Totalizers ... 4
Volumetric Measurement – Devices with Instantaneous Flow Rate Only ... 5
Duration Accuracy ... 5
Unsteady (Varying) Turnout Flow Rates ... 6

Farmer Meter or Irrigation District Meter? ... **8**

Pipeline Flow Meters ... **9**
Turbulence and Accuracy ... 9
Full Pipe ... 9
Propeller Meters ... 11
Magnetic Meters ... 12
Other Pipeline Meters – Closed Pipelines ... 13

Other Flow Measurement Options at Canal Turnouts ... **14**
General Types of Canal Turnout Flow Measurement ... 14
Field Calibration of Flow Meters ... 15
Metergates ... 15
Accuracy of Metergates ... 16
Measured Field Accuracy of Metergates ... 16
Details of Metergate Installation and Preparation ... 17
Canal Metergates Gates in Free-Flow Conditions ... 23
Fixed Submerged Rectangular Fully Contracted Orifice Plate ... 24
Sloping Fully Contracted Rectangular Submerged Orifice Plate ... 27
Adjustable Contracted Rectangular Submerged Orifice Plate ... 27
Constant Head Orifice (CHO) ... 28
Acoustic Doppler Velocity Meters ... 33
Acoustic Doppler Velocity Meters on Open Channels ... 33
Acoustic Doppler Meters in Pipes ... 35
Flumes and Weirs ... 36
Weirs ... 38
Flumes ... 40
Pump Kilowatt-Hours ... 42

References ... **43**

Attachment 1 California Code of Regulations Title 23, Division 2, Chapter 5.1, Article 2
Attachment 2 Hanson and Schwankl (1998) "Water Turbulence Disrupts Accuracy of Some Flow Meters"
Attachment 3 Metergate Tables

List of Figures

Figure 1. Field ditch with "bump" visible below the water surface near the head of the canal. This is the first irrigation set, with the area closest to the supply canal being irrigated first. The "bump" barely creates a ripple on the water surface. 7
Figure 2. Same ditch. The irrigated area, and check dam, have been moved downstream in the farm ditch. The "bump" has kept the water level in the first part of the ditch high – helping to ensure that the flow rate into the ditch remains fairly constant. 7
Figure 3. A propeller meter (white arrow) installed downstream of drip system filters, with a long, straight pipe section upstream of the meter (red arrow) 8
Figure 4. Propeller meter with a vertical orientation 9
Figure 5. A loop in a pipe is installed to keep the upstream pipe section full. A continuous acting air vent is needed at the top of the loop. 10
Figure 6. An elbow installed downstream of a propeller meter. In this case, the elbow is much higher than it needs to be. It only needs to be high enough to make the pipe completely full. 10
Figure 7. Weir boards are installed downstream of an open propeller meter. Obviously, these are not high enough to create a full pipe condition. 10
Figure 8. Open propeller meter installed at the discharge end of a large full turnout pipe. Water flows from right to left. 11
Figure 9. Punch plate at the inlet to an irrigation district lateral pipeline. 1 inch holes, 50% open area, to maintain less than 0.5 ft/sec through the holes (0.25 ft/sec approach velocity). 11
Figure 10. Locally fabricated trash screen in Browns Valley ID 12
Figure 11. Automatic screen upstream of a turnout in Merced ID. Note the wall that helps prevent sand from entering the turnout. 12
Figure 12. Example of transit time technology built into a water meter (from Netafim, 2016) 13
Figure 13. USBR/ITRC Irrigation Turnout Calibration Unit 15
Figure 14. Proper metergate dimensions – but lacking precast design. 17
Figure 15. Minimum upstream submergence above the top of the gate 18
Figure 16. Custom-made tool used to measure actual gate opening 19
Figure 17. The "zero" opening mark ground into the threaded rod 19
Figure 18. Example of a stilling well with too small of a diameter. The operators will not be able to see the water surface and severe surging (up and down movement) will occur. 20
Figure 19. Stilling well installed on metergate with proper diameter, position, and height but not precast. 20
Figure 20. Example drawing for a metergate installation with pre-cast forms on both ends of the pipe that crosses a road 21
Figure 21. Field installation of a pre-cast canal metergate (Glenn Colusa ID) 22
Figure 22. Top view of prefabricated canal metergate (Fresno ID, 2019) 22
Figure 23. Side view of prefabricated canal metergate (Fresno ID, 2019) 23
Figure 24. Installed pre-fabricated canal metergate (Fresno ID, 2019) 23
Figure 25. A fixed contracted submerged rectangular orifice at Fresno ID 24
Figure 26. Dimensions for fully contracted submerged rectangular orifice 25
Figure 27. Guidelines for orifice entrance extensions 25
Figure 28. Alta ID rectangular orifice gate (front) provides flow measurement, while sluice gate (rear) provides flow control 27
Figure 29. Schematic of a USBR CHO *(from USBR, 2001)* 29

Figure 30. Sluice gate (CHO) configuration for flow measurement on side sloping canals. Plan view. Not to scale. 30
Figure 31. Side view of CHO on lined canal bank. Not to scale. 30
Figure 32. End view of upstream gate of CHO 31
Figure 33. Plan view of CHO constructed in earthen canal. Not to scale. Rounded entrances are recommended. 31
Figure 34. Doppler shift caused by moving particles in the water 33
Figure 35. Beam angle relative to flow path 34
Figure 36. Water depth beam (center) and velocity beams (left and right) on an upward-looking ADVM *(from SonTek, 2005)* 34
Figure 37. Parabolic velocity distribution without a contraction (left) and theoretical velocity distribution with contraction installed (right) 35
Figure 38. A “Replogle flume” installed on a ditch with high flows in Truckee-Carson ID in Nevada. This is constructed in a trapezoidal section of canal. 36
Figure 39. Flume with expensive monitoring and a slight maintenance problem 37
Figure 40. A flume with an ePaint™ coating to minimize algae growth 37
Figure 41. Example of a staff gauge from Modesto ID, reading directly in CFS. 38
Figure 42. Use of an ITRC weir stick on flashboards 38
Figure 43. Example of a suppressed weir. The upstream channel has the same width as the weir crest. In this particular case, the walls diverge immediately downstream of the weir, so the nappe is aerated. 39
Figure 44. Example of a rectangular contracted weir 39
Figure 45. Example output from WinFlume™ for a typical Replogle flume. This has rectangular side walls. 41
Figure 46. Flat-bottomed (actually, a “Vee” in this case) flume immediately after construction. The sediment will flush out once water flows in the ditch. 41
Figure 47. The discharge pressure of the pump will change over time with this type of direct connection to a standpipe 42

List of Tables

Table 1. Results of 2016 metergate accuracy testing 17
Table 2. Design dimensions and flows for fixed fully contracted submerged rectangular orifice plates... 26
Table 3. CHO rating table for ΔH = 0.2’ 32

Volumetric Flow Measurement for Irrigation District Turnouts

Introduction

Technical assistance related to irrigation district turnout flow/volumetric measurement is provided by ITRC on behalf of California Dept. of Water Resources, USBR, and BIA irrigation projects. Throughout that work, it was apparent there was a need to organize well-established information as well as to provide new insights into irrigation flow measurement. The target audiences are irrigation districts and others who want to improve measurement accuracy for irrigation flow rates and volumetric deliveries to meet regulations, improve the efficiency of ditchriders (system operators), and provide equity and transparency to farmers and managers. The focus of this publication is on turnouts (deliveries) to fields or to relatively small groups of fields, rather than flow measurement on large canals.

Dozens of excellent publications are available on the topic of flow measurement. This publication is not meant to replace those other references. Rather, it supplements those with two important types of information:

1. An overview of irrigation turnout flow measurement devices and situations for the western US.
2. Practical insights on the installation and operation of various devices.

Three important companion resources from the US Bureau of Reclamation are the following:

1. *Water Measurement Manual*. 1997. A Water Resources Technical Publication. Third Edition. Revised Reprint 2001. Available as a PDF download at: www.usbr.gov/tsc/techreferences/mands/wmm.html
2. WinFlume™ software. Updated 2016. The WinFlume™ home page contains downloadable design software and information on weirs and flumes: www.usbr.gov/tsc/techreferences/computer%20software/software/winflume/index.html
3. Water Management Planner Standard Criteria and Planner. 2017. Available as a PDF download at: http://www.usbr.gov/mp/watershare

Senate Bill X7-7 Requirements

Senate Bill X7-7 (SBX7-7) required that the California Department of Water Resources "adopt regulations that provide for a range of options that agricultural water suppliers may use or implement to comply" with various water measurement requirements. The details are found in Article 2 (Agricultural Water Measurement), Chapter 5.1 (Water Conservation Act of 2009), Division 2 (Dept. of Water Resources) and Title 23 (Waters) of the California Code of Regulations. Attachment 1 includes copy of this Article.

Briefly, the regulations specify that water deliveries must be measured volumetrically. The specific requirements depend upon the size of the agricultural water supplier and the history/type of measurement device.

Many conversations have been held as to what devices are suitable for water measurement. This publication provides insight into some common issues, although cost is not specifically addressed. For example, it is well-known that:

1. Not all devices are applicable for all situations. For example, there are installations with high-pressure pipes, low-pressure pipes, and no pipes at all.

2. Some devices are inherently more accurate than others, or may require less maintenance than others, for the same situation. Costs can also vary widely.
3. Proper installation and sizing can be as important for accuracy as the type of device.

Irrigation District Turnouts

In the most basic form, all irrigation turnouts, or delivery points, serve two purposes:

- Starting and stopping the flow of water
- Controlling delivered flow rates, which is typically done with a mechanism such as a valve or gate. In other cases, the turnout mechanism is adjusted wide open, and the turnout flow rate is determined by something such as the number of open alfalfa valves or sprinklers downstream.

SBx7-7 requires that turnouts in California also be capable of:

- Flow measurement – an instantaneous quantification provided by various methods.
    - For some turnouts, a supplementary device measures the flow rate (with various levels of accuracy) and displays the result digitally or with an analog gauge.
    - For canal or low-pressure pipeline deliveries, field measurements of the mechanism's opening, upstream and (sometimes) downstream water levels are sometimes applied to an equation or rating table. In these cases, the turnout structure itself is used as the flow measurement device, without auxiliary equipment.
- Volumetric totalizing – an accumulation of the flow measurement over time. The accumulation can be completed either:
    - Automatically, via mechanical or electronic methods, or
    - Manually, by "averaging" multiple, discrete flow measurements over an irrigation event.

Accurate flow measurement requires, among other things, satisfactory hydraulic conditions both upstream and downstream of the flow measurement location. For this reason, flumes are not recommended immediately downstream of a bend in the canal. Similarly, propeller meters are not recommended for installations immediately downstream of a partially closed butterfly valve. In these examples, it is unlikely that the instantaneous flow measurement would reflect the actual flow rate.

From an engineering perspective, achieving flow measurement and automatic volumetric totalizing within acceptable accuracy stipulations has become relatively straightforward for most pipeline turnouts because:

- The hydraulic conditions upstream and downstream of the flow measurement device can be easily "standardized" with a length of straight pipe. The exact length of straight pipe required by each product is specified by the manufacturer. "Straightening vanes" can be installed to correct swirling problems caused by elbows, and allow a shorter pipe length, but these do not correct problems with skewed velocity profiles.
- The round pipe cross section provides a clean and easily calculated flow area.
- There are numerous commercially available "flow meters" (utilizing various technologies) that provide flow measurement and *automatic* volumetric totalizing with more than acceptable accuracies. Many can also be delivered with factory calibration certificates traceable to the National Institute for Science and Technology (NIST).
- If the piping system is designed properly, the flow meter can be easily removed and recalibrated by the manufacturer or other entities.
- Flow meters can be easily installed with standard, commercially available fittings.

For the reasons listed, meeting flow measurement and volumetric totalizing regulations for new or existing pipeline turnouts has become more of an economic analysis than an engineering topic. A variety of irrigation districts simplify the challenge by requiring that farmers install accessible, properly installed magnetic or propeller meters downstream of their filter systems when the farmers install a drip/micro system.

Conversely, meeting flow measurement mandates for canal turnouts is more complex. Although there are good solutions for new canal turnouts, there are very few new canal turnouts being constructed and it can be prohibitively expensive to replace each non-conforming structure at the district level. As such, this publication will discuss options for utilizing existing structures for flow measurement as well as options for retrofitting existing canal turnout structures to meet flow measurement regulatory obligations.

A major constraint for canal turnout flow measurement is access. In general, most canal turnout structures and accompanying gate/valve mechanisms are installed on the canal side of an access road. The structure discharges into a buried pipe under the canal access road. The buried pipe may or may not daylight on the farm side of the access road. This physical configuration limits flow measurement options to one side of the buried pipe or the other, and many districts have limited (or no) jurisdiction to install devices on the farm side of the turnout.

The size and placement of a flow measurement device is also constrained by other factors. The device cannot obstruct normal canal maintenance operations, or be vulnerable to damage from access road traffic. Flow measurement devices are also susceptible to typical problems experienced in most open channel applications such as sedimentation, trash and biological debris, and vandalism.

Volumetric Flow Rate Measurement

Volume is an accumulation of water deliveries over time. In California agricultural irrigation districts, volumes are typically measured and billed as "acre-feet" (AF). Flow rate is an instantaneous measurement and may be measured as Gallons per Minute (GPM) or Cubic Feet per Second (CFS) – with GPM being used on smaller irrigation deliveries. The usage of the "miner's inch" is disappearing.

Volumetric Measurement with Totalizers

Some flow measurement devices have a totalizer (which reports cumulative volume) built into them. With pipeline flow measurement, this is common. The oldest and most common totalizer unit type is a propeller flow meter, with a display providing a rough estimate of instantaneous flow rate, and a more accurate totalized volume. Previously, the displays were mechanical (a dial for flow rate, and a series of small gears and wheels to provide total volume) that were usually mechanically moved via some type of speedometer cable mechanism driven by the rotating propeller. Now most companies also offer an electronic display option, which is still driven by the rotating propeller.

Other pipeline flow measurement devices such as magnetic meters or double beam ultrasonic meters have no moving/rotating parts and therefore only offer electronic (digital) displays. Within the electronics, instantaneous flow rates are accumulated over time to compute the volume of water delivered.

For water meters that have built-in totalizers, there are several factors that influence the accuracy of the volumetric estimate. These include:

- Inherently, the volumetric estimate cannot be more accurate than the instantaneous flow rate measurements. This will be discussed in more detail later.
- With electronic flow measurement devices such as magnetic meters, acoustic Doppler meters, transit time devices, and double beam ultrasonic meters, there can be a very large amount of signal noise. An accurate estimate of a flow rate may require that the instrumentation average hundreds of measurements. The accuracy of both the flow rate and volumetric estimates will depend upon the frequency of measurement, and how the instantaneous numbers are processed.

Some flow measurement devices require a single or multiple electronic readings that are input to a local datalogger or programmable logic controller. An example could be a water level measurement in a canal upstream of a weir or flume. The datalogger will take a water level reading every minute or so and translate each level into an instantaneous flow rate (Q). The flow rate, multiplied by the time interval between flow rate measurements, equals the volume for that time interval. The basic formula is:

Volume = (Flow rate) × (Time)

If the flow rates are measured every minute, for example, then:

Volume = Sum of all the 1 minute volumes

For example, if the flow rate is measured in CFS, once every minute (60 seconds), then:

$$\text{Total volume (cubic feet)} = \sum\left(\frac{Cubic\ feet}{sec} \times 60\ sec\right)$$

If an instantaneous flow rate was 10 CFS, then every minute, the volume would be:

Volume = 10 CFS × 60 sec = 600 cubic feet

Some conversion factors are:

1 acre-foot (AF) = 43,560 cubic feet
1 CFS × 1 hour = 0.993 Acre-inches = 0.08272 AF
1 CFS × 24 hours = 23.8 Acre-inches = 1.985 AF

Keep in mind that although we can report numbers to numerous decimal places, it would be extremely unusual to find a flow meter that could consistently be accurate within 1%.

Because the flow rate can change over time, the automatic summation of frequently measured (e.g., 1 minute) volumes can provide the same accuracy of volumetric measurement as that of the flow rate measurement.

Volumetric Measurement – Devices with Instantaneous Flow Rate Only

Many districts in California, especially those with turnout deliveries directly from canals, use devices that can be used for flow rate measurement but which have no automatic totalizing equipment. The volume delivered during a specific irrigation event is typically computed as:

Volume = (Flow rate) × (Duration of the Irrigation Event)

For example, an irrigation district operator may record:
10 CFS for 12.5 hours

The volume would be computed as:
10 CFS × 12.5 hours × 0.08272 AF/(CFS-hr) = 10.34 AF

The accuracy of this estimation depends upon three things:

1. Accuracy of flow meter
2. Accuracy of duration value
3. Accuracy of assumption that the flow rate remains constant

The accuracy of flow measurement will be discussed more in later sections on a device-by-device basis. Also, chapter 10 (Flow Measurement Calibration and Measurement) of the USBR Water Management Planner (2017) contains relevant information.

Duration Accuracy

In many irrigation districts, the policy is that only the district employees can open and close turnouts or adjust flow rates. In those cases, if district employees are very diligent and/or have portable electronic devices that automatically timestamp entries (such as observations of flow rate), the measurement of the total irrigation duration is quite accurate.

However, there are almost always occasions in which farmers or irrigators operate the turnouts. In those cases, the district employee must depend upon correct reporting by the farmer/irrigator.

Short of installing sensors and a telemetry (SCADA) system at every turnout, about the only practical option may be to install a simple wet/dry sensor connected to a datalogger. Similar equipment is used by some farmers on drip systems, to verify that hoses are pressurized for the proper duration. ITRC is unaware of any districts that have installed such sensors and dataloggers on irrigation district turnouts.

Unsteady (Varying) Turnout Flow Rates

Turnout flow rates may change with time, without the district operator knowing exactly when and by how much. Typical reasons are:

1. An irrigator may adjust the turnout flow control device without permission. There is very little that can be done about this except to lock the gate in a fixed position. This works in many cases.
2. The incoming pressure on the turnout changes. Canal water levels may fluctuate up or down. As the canal water level increases, the flow out of a turnout will increase. It is very similar in systems with pipeline deliveries; a change in pipeline pressure will give a change in turnout flow rate.
3. The water level on the farmer side of the turnout may change over time. If the flow control device is submerged (the water is backed up against the downstream side of the flow control gate), then this change in water level will change the flow rate. This often occurs in open ditch deliveries, as a farmer/irrigator moves dams and siphons further from the turnout on subsequent irrigation sets.

Solutions for these problems have been developed as follows:

Problem 1: Unauthorized turnout gate adjustment.
Solution: Lock the adjustment handle/wheel. The success depends upon the ability of the district to effectively punish the offender the first time the lock is cut off.

Problem 2: Varying canal water levels.
Solutions:

1. Most districts are modernizing with new canal control equipment to maintain fairly constant water levels. They understand that a fairly constant canal level not only gives more stable and known turnout flow rates – it also helps in moving flow changes safely and quickly along canals.
2. ITRC examined lateral canal water level fluctuations in one district over the course of an irrigation season. In that case, the fluctuations were random. The net result was that over the course of an irrigation season, they did not create a significant error in volumetric estimations. The high flows canceled out the low flows. However, on-farm irrigation management suffers if flows randomly vary over time.

Problem 3: Varying water level on the downstream side of a submerged flow control gate. The problem is often that when the district operator adjusts the turnout for the desired flow, the downstream water level (on the farmer's field) is at its highest level because a farmer will begin irrigating with siphons or spiles on the uphill side of the field. As the farmer/irrigator moves the irrigation down the field, the water level at the head of the ditch will drop. This will increase the flow rate through the turnout – with a net result of the farmer receiving a greater volume than assumed based on the initial flow rate.

Solution: The water level on the downstream side of the flow control gate should be maintained at a constant level over time. This is accomplished by installing a "bump" in the farmer ditch between the turnout gate and the first outlet from the farmer ditch. The action is illustrated in Figure 1 and Figure 2.

Figure 1. Field ditch with "bump" visible below the water surface near the head of the canal. This is the first irrigation set, with the area closest to the supply canal being irrigated first. The "bump" barely creates a ripple on the water surface.

Figure 2. Same ditch. The irrigated area, and check dam, have been moved downstream in the farm ditch. The "bump" has kept the water level in the first part of the ditch high – helping to ensure that the flow rate into the ditch remains fairly constant.

Farmer Meter or Irrigation District Meter?

With several million acres of drip/micro irrigation systems in California, some districts opt to use the farmer's flow meter rather than a standard district installation at the side of the canal. The reasons for doing this include:

1. This is often the most inexpensive option for accurate flow measurement.
2. Many farmers install meters on their own initiative, to keep good water management records.
3. Propeller meters and magnetic meters are most commonly used, and they have totalizers.
4. The meters are installed downstream of the filters (see Figure 3), which typically provides two benefits:
    a. There is usually a long, straight section upstream of the meter.
    b. The water is very clean because it has passed through the filters.

Figure 3. A propeller meter (white arrow) installed downstream of drip system filters, with a long, straight pipe section upstream of the meter (red arrow)

The potential disadvantages of using these farmer meters are:

1. The meter will not record any filter backflushing flows. These may or may not be significant; the importance will depend upon whether the dirty backflush water is returned to the canal or is discharged on the farmer's field, and how often the filter backflushing cycle is initiated.
2. The meter may be difficult to access.
3. The meter may not have been installed properly, or may be an inexpensive and inaccurate model.

It is strongly recommended that irrigation districts establish written policies for such installations that include topics such as installation, acceptable meters, and ease of access.

Pipeline Flow Meters

Turbulence and Accuracy

An excellent study was conducted in 1998 by Drs. Blaine Hanson and Larry Schwankl of the University of California Extension Service. It is provided as Attachment 2, because it provides great detail about turbulence and accuracy of pipeline flow meters. It is clear from the results that paddle-wheel meters (an example of small insert units) were much more impacted by turbulence than were full bore, velocity-integrating propeller meters.

Key points from the UC study include:

- Elbows and partially closed valves upstream of flow meters will create turbulence.
- Pipeline flow meters should be “full bore”, rather than partial pipe “insert” meters. The least expensive pipe flow meters are insert meters, and will have some type of apparatus that is attached to one side of the pipe, and which extends a short distance into the pipeline. As such, they will only measure water velocities in a small area of the pipe. Typically, those are non-representative of the average pipe velocities.
- A single elbow does not create an unreasonable error for a full bore propeller meter, regardless of whether the meter is 2, 5, or 10 diameters downstream of the elbow.
- A partially closed butterfly valve creates a large error for a full bore propeller meter at distances of 2, 5, 10, and 15 diameters downstream of the valve – if the velocities are less than 4 feet/second. At 8 feet/second, the errors were acceptable (less than 4%).

Full Pipe

All pipeline meters require a full pipe. Typical techniques used to obtain a full pipe on low-pressure systems include:

1. The meter may be installed on a vertical pipe, as seen in Figure 4.

Figure 4. Propeller meter with a vertical orientation

2. An elbow is installed in the pipeline downstream of the meter.

Figure 5. A loop in a pipe is installed to keep the upstream pipe section full. A continuous acting air vent is needed at the top of the loop.

Figure 6. An elbow installed downstream of a propeller meter. In this case, the elbow is much higher than it needs to be. It only needs to be high enough to make the pipe completely full.

Figure 7. Weir boards are installed downstream of an open propeller meter. Obviously, these are not high enough to create a full pipe condition.

Figure 8. Open propeller meter installed at the discharge end of a large full turnout pipe. Water flows from right to left

3. Sufficient air vents are installed to remove any air that might accumulate in the pipe section that includes the flow meter.

Propeller Meters

Propeller meters are still the most common pipeline flow measurement device. There are a variety of manufacturers and a wide variety of configurations. They have been successfully used in irrigation districts for many decades.

Key points regarding propeller meters include:

1. Trash in the water can be a huge problem. A typical irrigation district bar grill assembly on a canal bank is usually inadequate because so much trash can pass through. Typical solutions include:
    a. At least one propeller meter manufacturer sells a “reverse propeller” meter that is designed to help shed trash.
    b. Static perforated steel plate screens with a very large open area are widely used in western Colorado by districts with propeller meters. They are very easy to clean with a floor squeegee, although the trash simply moves downstream in the canal.

Figure 9. Punch plate at the inlet to an irrigation district lateral pipeline. 1 inch holes, 50% open area, to maintain less than 0.5 ft/sec through the holes (0.25 ft/sec approach velocity).

    c. Some type of automatic trash rack that removes the trash from water before it enters the turnout is used.

Figure 10. Locally fabricated trash screen in Browns Valley ID

Figure 11. Automatic screen upstream of a turnout in Merced ID. Note the wall that helps prevent sand from entering the turnout.

2. Sand and silt in the water can quickly destroy bearings. Some manufacturers have special bearings that hold up very well with sand; other bearings are very intolerant. Sand barriers in a canal upstream of the turnout can help reduce the sand load in the water, as seen in Figure 11.
3. If a saddle configuration is used, it is absolutely essential to order it for the correct inside diameter of the pipeline, so that the meter will be properly calibrated when it arrives from the factory.
4. Propeller meters operate best (mechanically and accurately) within a certain range of velocities. Usually they are not very accurate at velocities under 1 ft/sec. At high velocities, manufacturers should be consulted because special bearing assemblies may be required.
5. Irrigation districts with long-term successful usage of propeller meters have programs (and sometimes special shops) for rebuilding the propeller meters every few years, and spin-testing them more frequently.

Magnetic Meters

Magnetic meters have become common in some districts over the past decade. Because water is a conductive liquid, it induces a voltage while it travels through the meter's magnetic field. The voltage produced is proportional to the velocity of the water. A microprocessor is able to compute the flow rate. One of the reasons for the increased interest is the availability of battery-operated magnetic meters, as opposed to the historical need for AC power. However, batteries may only last 1-2 years.

ITRC has had highly variable results with magnetic meters in irrigation district turnout applications. While a few brands/models have provided excellent results, others have had fatal errors with accuracy or dependability. The claims by some large manufacturers, of dependability and accuracy, have not always matched the actual performance. That said, the ITRC Water Resources Facility laboratory utilizes magnetic meters rather than propeller meters for most critical installations. Those magnetic meters are tested for accuracy every year, using a large weighing tank and are re-calibrated if necessary.

The major reasons that magnetic meters have been selected in some districts are:

1. Some brands/models only require 2-3 diameters of straight pipe upstream.
2. There are no moving parts or obstructions, so sand and trash are not problems, and there is no gradual wear over time.

Other Pipeline Meters – Closed Pipelines

Magnetic meters and propeller meters are by far the most common meters used in California for closed pipelines. A few other technologies are briefly mentioned here.

1. Venturi meters have typically only been used on large canal turnouts such as found on the Friant-Kern Canal and the Tehama-Colusa Canal. Venturis have large pressure losses, only operate effectively in a relatively narrow range of flows and are a bit complicated with instrumentation.
2. Transit time meters use ultrasonic waves to measure water velocity and operate under the theory that sound waves are accelerated or decelerated by the relative velocity of their medium. For example, if a wave is sent out in the same direction that the water is flowing, the wave will accelerate and travel faster in that direction. Likewise, a wave will decelerate and travel slower if it is directed against the flow. Transit time meters use pairs of transducers oriented diagonally across the diameter of the pipe. As the number of transducer pairs increases, the device will get a better representation of the actual cross section flow rate, and thus get better results.

   At this time, this technology is rarely used on irrigation district turnouts. It is more common on very large diameter (4' and greater) pipelines where there is a cost advantage. If this technology is used, it is highly recommended that the transducers be directly exposed to the water – rather than clamp-on configurations that attach the transducers to the outside of the pipeline.

   A relatively new approach to transit time meters is found in commercial valves that have the technology built in – rather than needing to install transducers separately in a pipe. An example of this technology is shown in Figure 12. The purported battery life expectancy is 10 years.

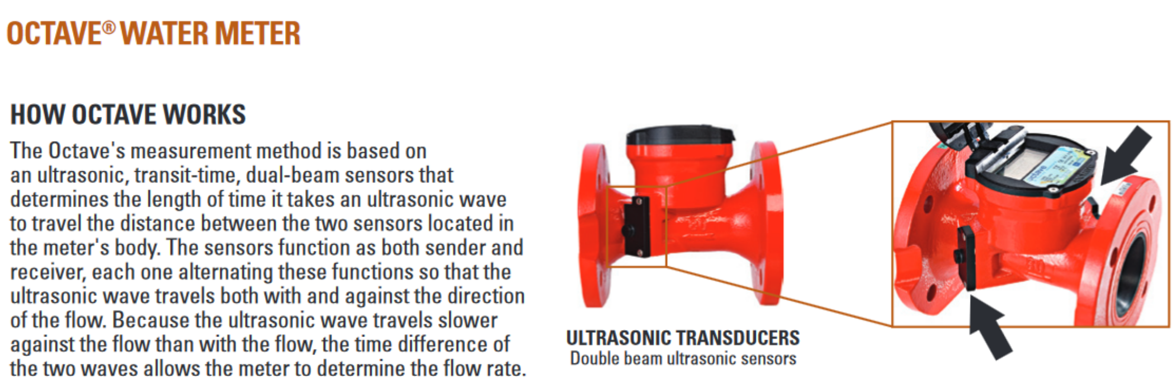


Figure 12. Example of transit time technology built into a water meter (from Netafim, 2016)

Other Flow Measurement Options at Canal Turnouts

There are two special characteristics for most other western USA canal turnout flow meter types (other than propeller or magnetic meters):

1. Most of the flow measurement/control devices used at canal turnouts consist of a variety of parts and pieces that are assembled locally. For example, flumes are locally constructed, and the staff gauges or electronic instrumentation are installed and calibrated locally. While this provides the necessary flexibility to have a flume/weir that matches the specific conditions, errors are often introduced if the device is improperly designed/located, or details are not taken care of.
2. Most of the devices (CHOs, metergates, weirs, etc.) have rating tables that were developed in a laboratory with a relatively small sample of devices, using a relatively small range of hydraulic conditions. These devices all have “empirical” equations, which means that the laboratory data were plotted to develop a “best-fit curve”, or to create a table of flow rates versus measurements. The rating tables or curves were not developed using hydraulic theory. Therefore, if the device installations do not closely match the laboratory installations (velocity, side clearance, bottom clearance, etc.) that were used to develop the empirical calibrations, there will be an error and it is unclear how to correct the formulas/tables.

Even if a district purchases a complete gate assembly for an automated turnout, the accuracy of that device will still depend upon the installation, the flow rate equation calibration that was used for the device in some laboratory, the quality and positioning of the sensors, and their calibration. ITRC has found that some package gates, even when installed by the manufacturers, can experience large inexplicable errors in spite of being advertised as having very accurate results. It is truly “buyer beware”, although in some irrigation districts the accuracy is never questioned.

General Types of Canal Turnout Flow Measurement

Canal turnout measurement devices can generally be grouped into the following types:

1. Submerged holes (orifices). The flow rate depends upon the pressure (head) difference across the orifice, and the orifice open area. Devices of this type that will be discussed in this publication are:
    a. Metergates (by far the most common device of this type in California other than propeller or magnetic meters, though quality of installation and usage varies widely)
    b. Orifice plates
    c. Sluice gates/CHOs
2. Weirs and flumes, over which water flows. The water level above the crest of the weir/flume is somehow measured and then translated into a flow rate. All of these devices require “free flow”, or the creation of a hydraulic critical depth. If they are not designed with a large drop, they generally end up being abandoned because for one reason or another the downstream level will sometimes submerge them, preventing the development of free flow. Downstream channel maintenance is done by the farmer, not by the irrigation districts. These are not common in California, likely because of frequent downstream submergence problems.
3. Acoustic Doppler, transit time, or similar devices that are inserted into short pipeline sections, or in canals. These usually measure velocity of a relatively small sample of the current, which is then combined with canal/pipeline dimensions and water depth to estimate flow rate.

Field Calibration of Flow Meters

In 2016, while working for the USBR, Mid-Pacific Region, ITRC identified a need to provide the hardware and methodology for calibrating flow measurements at existing and new irrigation turnouts supplied by open canals. ITRC designed and built (and used) a portable turnout calibration unit (see Figure 13). The unit pumps water from the downstream side of a turnout and recirculates it (up to 10 CFS) to the source canal. The water passes through two calibrated magnetic meters. Three flow rates are tested: the highest flow for the turnout, the lowest, and an intermediate flow rate. The downstream water level is maintained at a typical depth. The results are then compared against the flow rate estimates that are made by district staff for that turnout. The ITRC magnetic meters used for calibration are within about 1% accuracy.

Figure 13. USBR/ITRC Irrigation Turnout Calibration Unit

Metergates

A metergate is a structure with an adjustable vertical round or rectangular gate controlling the flow into a pipeline. A specially designed stilling well is installed on the pipeline a specific distance downstream of the gate's frame, to measure the downstream head. Once the gate opening and the head loss between the canal and the stilling well are known, a table can be referenced that will give a specific flow rate.

Metergates have been used for over 70 years for turnout flow measurement in the USA. They are different from regular sluice gates and "canal gates" because they have a stilling well just downstream of the gate so that the downstream water level can be measured. Recent studies at ITRC, funded by California DWR, show that the 1950's rating tables for "Armco"-type gates provide good accuracy for flow measurement (Burt and Howes, 2015). The Waterman tables are less accurate and are not recommended. ITRC has produced improved tables and has established a variety of rules for proper installation and operation. Recommended rating tables for metergates are included in Attachment 3.

Accuracy of Metergates

1. A high level of accuracy (+/-5%) was found if all of the following conditions are met:
    a. Gate opening range: 20% < Gate opening < 75%
    b. Upstream submergence > 0.5D (where D is the gate diameter)
    c. The optimum stilling well access hole location is 12” downstream of the face of the gate
2. The distance downstream of the gate at which the stilling well is located (as long as it is within the 4” to 12” range) does not have a significant effect on the flow rate obtained using the tables **unless** the gate is **open** more than 70-75% (percent of fully open). In that case (which would occur if a small head difference is available across a turnout), it is important to install the stilling well access hole at the optimum location 12” downstream.
3. Tangential supply channel flow velocities of up to 1.9 feet/sec do not have a significant impact on the calibration flow through the metergates. Higher velocities could be expected to have an impact, but the magnitude is unknown.
4. Higher uncertainty (error) occurs at smaller gate openings.
5. Optimum range of operation for the highest accuracy was an opening between 20% and 75% under most conditions. Smaller gate openings seem to be more problematic than larger gate openings.
6. The water level in the supply canal above the turnout pipeline should be greater than (0.5 × gate diameter). The USBR standard is (1 × gate diameter).
7. The “zero” opening of the metergate must be closely defined.
8. The stilling well and access hole must be properly designed to stabilize the water level for proper reading.
9. The measurement of differential head is often awkward because many installations have no common, easily-accessed elevation datum for both the upstream and downstream measurements. This can contribute to inaccurate measurements.
10. Operators should be supplied with scales that read in 100ths of feet, rather than in inches. This eliminates fractions and conversions in computations.

Measured Field Accuracy of Metergates

In 2016, ITRC verified the accuracy of a total of 27 metergates from six different irrigation districts. The results are provided in Table 1. The Mechanical Associates gates do not have the same configuration as Waterman and Fresno Valves gates, and therefore it was not surprising that the tables a district received were inaccurate.

The pre-cast Briggs metergates come as a total assembled package. They were designed for Glenn-Colusa ID following ITRC guidelines. The accuracies of the measurements are quite good.

Table 1. Results of 2016 metergate accuracy testing

Flow Measurement Device	Gate Manufacturer/Type	Nominal Gate Size (in)	Typical Min Flow Rate (CFS)	Typical Max Flow Rate (CFS)	Flow Measurement Method	Average Absolute Error (%)
New, pre-cast Briggs **Metergates**	Waterman Round	15	3	6	ITRC Water Measurement Tables	**2**
		15	3	5		**4**
		18	3	8		**3**
		24	3	6		**6**
		18	3	6		**3**
New, field constructed Mech. Assoc. **Metergates**	Mechanical Associates Round and Square	18	1.5	3.5	Mechanical Associates Tables	**15**
		18	1.5	3.5		**18**
		24	2	4		**29**
		18	2.5	5		**28**
Existing, district constructed **Metergates**	Fresno Round	18	3	4	Armco Tables	**9**
		20	4	6		**9**
		18	2.5	4.5		**3**
		18	2.5	4.5		**11**
		24	3	5		**5**
		20	3	6		**8**
		20	3	6		**3**
		20	3	4		**2**
		24	1	3		**13**
		18	3	5		**3**
		18	3.5	5.5		**12**
		24	3.5	11		**8**
		18	5	10		**4**
		18	5	10		**10**
Canal Gate	Fresno Round	18	3	5	Armco Tables	**9**
		24	1	5		**4**

Details of Metergate Installation and Preparation

Figure 14 depicts the proper metergate dimensions as recommended by ITRC. Several practical details that are essential to accurate flow measurement with metergates are discussed. Additional details can be found in Burt and Howes (2015).

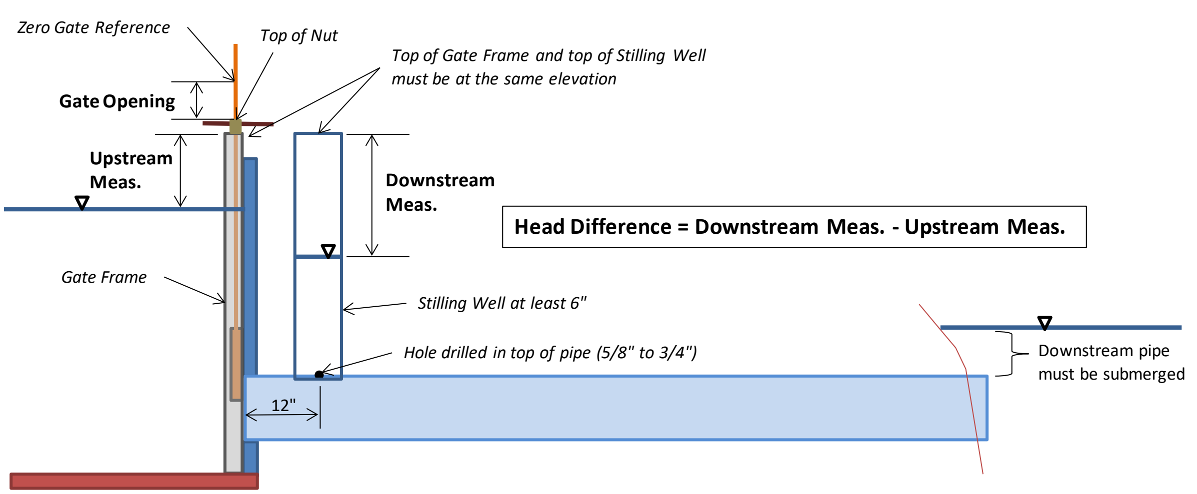


Figure 14. Proper metergate dimensions – but lacking precast design.

Practical Detail #1 – The pipe downstream of the metergate needs to be full. This means that the downstream pool must have a water level higher than the top of the pipe. Also, the water level needs to rise to some measurable level in the downstream stilling well.

Practical Detail #2 – Sufficient upstream submergence is needed (Figure 15). The required water level in the canal, above the top of the pipe at the inlet, must be at least ½ of the gate (or pipe) diameter. In other words, if there is a 12" pipe, the water level in the supply canal needs to be at least 6" above the top of the pipe.

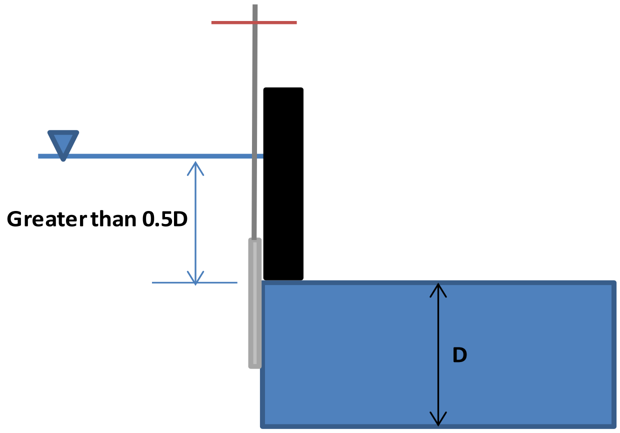


Figure 15. Minimum upstream submergence above the top of the gate

Practical Detail #3 – All of the calibration charts require knowledge of the **gate opening**, as measured by the shaft opening. The "zero" gate opening must be properly determined and marked on the gate shaft. This is not a trivial detail. Specific points are:

- All measurements of gate opening, as well as the initial marking, must be made after the gate stem has been lifted (opened). This is because there is some "slop" or movement between the shaft and the gate itself.
- The gate stem will move up some distance before the gate plate itself reaches the bottom of the pipe. The charts depend on knowing the gate opening, not the movement from the gate seating position. The gate must be closed beyond the bottom of the pipe to seal off completely. That sealed position is not the "zero" position.
- There must be some specific way to measure the shaft position when the bottom of the gate just barely clears the bottom of the pipe – in other words, when there is a "zero opening". This is fairly easy to set and measure if the canal is full. The gate is opened until a narrow strip of paper can be inserted into the crack. Figure 16 shows photos taken at San Luis Canal Company of a customized tool that is used to detect the actual gate opening, but a similar device can be used to detect the initial "cracking (zero) open" position.

Figure 16. Custom-made tool used to measure actual gate opening

- The shaft needs to be marked in a clear manner so that operators know where the “zero” opening is for the gate when they open the gate. Figure 17 shows a properly cut notch. It has a sharp bottom edge that was cut with a grinding wheel so that the bottom of the cut is at the same elevation as the top of the bushing. Notice from the color on the shaft that the shaft can be lowered from this position to properly seal the gate.

  The operator will measure from the bottom of cut to the top of the bushing, when the gate is open, to determine the gate opening. This is always measured after an “uplift” action.

Figure 17. The "zero" opening mark ground into the threaded rod

Practical Detail #4 – The stilling well needs to have sufficient diameter to dampen the turbulence, and so that operators can see into it. It is recommended to have a stilling well of 6"–8" diameter, with an access hole at the top of the pipe of about 5/8" or 3/4" diameter.

Figure 18. Example of a stilling well with too small of a diameter. The operators will not be able to see the water surface and severe surging (up and down movement) will occur.

Practical Detail #5 – The stilling well does not need to be centered over the access hole in the top of the discharge pipe. In general, it is good to have the stilling well close to the gate frame/bulkhead, so that it can be supported.

Practical Detail #6 – Make it easy to measure the difference in head (between the water level in the canal, and the water level in the stilling well). In other words, use the same datum (elevation) for both measurements. Figure 19 shows a stilling well with the top correctly placed at the same elevation as the gate frame, and with a proper diameter. **The top of the stilling well should be at the same elevation as the top of the gate frame (where the bottom of the nut rests), or have the same elevation as another reference point.** Then the upstream measurement should be taken from the top of the gate frame to the water level. The downstream measurement should be taken from the top of the stilling well to the water level. The head difference is the difference between the upstream and downstream water levels.

Figure 19. Stilling well installed on metergate with proper diameter, position, and height but not precast.

Practical Detail #7 – If possible, for new installations purchase a new integrated and properly designed precast unit from a company such as Briggs in Willows. Very importantly, the stilling well is built into the unit. This integration eliminates the very common problems with traditional stilling wells for metergates such as:

1. They are often located at an incorrect distance from the back of the gate.
2. The diameters are typically too small.
3. They are made of easily breakable material such as concrete or plastic pipe.
4. The top of the stilling well is not at the same elevation as the concrete box.
5. The diameter of the entrance hole at the bottom of the stilling well is too large or too small.
6. There is no cap on the top of the stilling well, and as a result they become filled with dirt from regular canal bank/road maintenance.

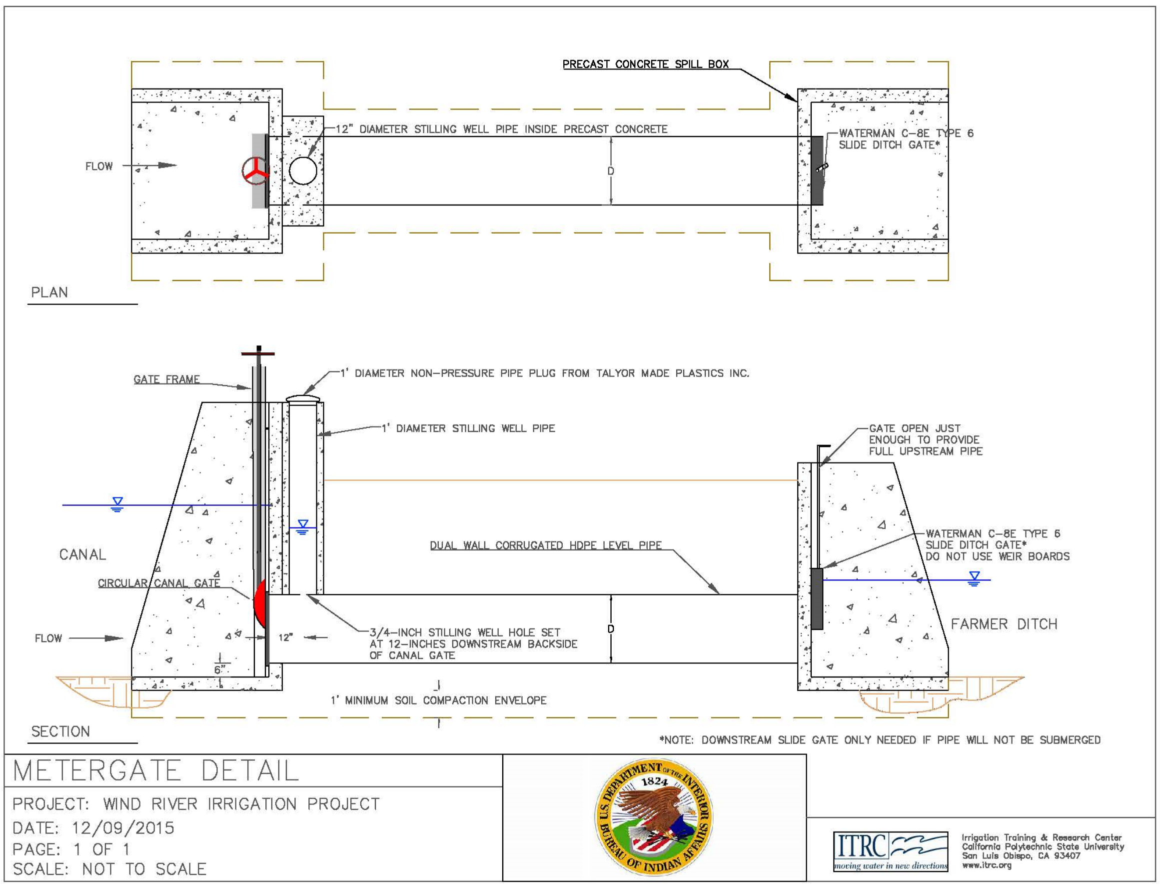


Figure 20. Example drawing for a metergate installation with pre-cast forms on both ends of the pipe that crosses a road

Figure 21. Field installation of a pre-cast canal metergate (Glenn Colusa ID)

Cost is always a challenge, especially with older existing gates. Fresno Irrigation District has recently (2019) experimented with a bolt-on unit that replaces an existing turnout canal gate. Figure 22 through Figure 24 show various views of the experimental unit.

Figure 22. Top view of prefabricated canal metergate (Fresno ID, 2019)

Figure 23. Side view of prefabricated canal metergate (Fresno ID, 2019)

Figure 24. Installed pre-fabricated canal metergate (Fresno ID, 2019)

Canal Metergates Gates in Free-Flow Conditions

It is strongly recommended that metergates be operated under submerged conditions to obtain the highest level of accuracy. However, in some cases this may not be possible until the district can modify the downstream condition. ITRC conducted testing of three sizes (12", 18", and 24") of round canal gates on round turnout pipelines in non-submerged conditions. In these cases, the downstream stilling well does not have a measurable water level because the downstream water level is at or below the top of the turnout pipe. The difficulty with this condition is that the downstream water level could still be high enough to submerge the gate opening or it could be fully free flow (downstream water level at or below the bottom of the gate). The testing examined both of these conditions and found that the flow rate could be measured within a reasonable level of accuracy (within +/-8% flow rate uncertainty) if operated within the recommended *Practical Details* outlined for metergates in this report.

Under free-flow conditions, the upstream head is measured from the top of the turnout gate pipe to the upstream water surface. This may be difficult to accurately measure depending on the gate configuration. During the off-season, a staff gauge or reference mark could be installed to more accurately measure the head above the top of the turnout pipe. There is no need to measure the downstream water level as long as the downstream water surface is at or below the top of the turnout pipe at the exit. Special tables for the free-flow condition are included for the 12”, 18”, and 24” round gates in Attachment 3. For this situation, the normal metergate tables also shown in this attachment should not be used, since those are for submerged conditions only.

Fixed Submerged Rectangular Fully Contracted Orifice Plate

This design option is sometimes used for surface irrigation deliveries at turnouts that always receive the same flow rate. For a target flow rate, the orifice can be sized to have about 0.2’-0.25’ of head loss. A minimum of 0.2’ of head loss (i.e., “difference in head”) is recommended because the accuracy of the head measurement can be unacceptably poor with less head loss. A maximum head loss of 0.25’ is recommended to minimize turbulence in the box that has the orifice plate at its entrance.

Figure 25 illustrates such an installation. The downstream gate is used for on/off and flow rate adjustment. Operators adjust that gate until a target head loss is measured across the orifice plate.

Figure 25. A fixed contracted submerged rectangular orifice at Fresno ID

The equation for determining the flow through a submerged orifice plate is:

$$Q = C_d A \sqrt{2g\Delta h}$$

Where:
Q = Flow rate, CFS
C_d = Coefficient of discharge, 0.63
A = Area of the orifice, ft^2
$A = W \times Y$
W = Orifice opening width, ft
Y = Orifice opening height, ft
g = Acceleration due to gravity, 32.2 ft/s^2
Δh = Difference in head (head loss), ft

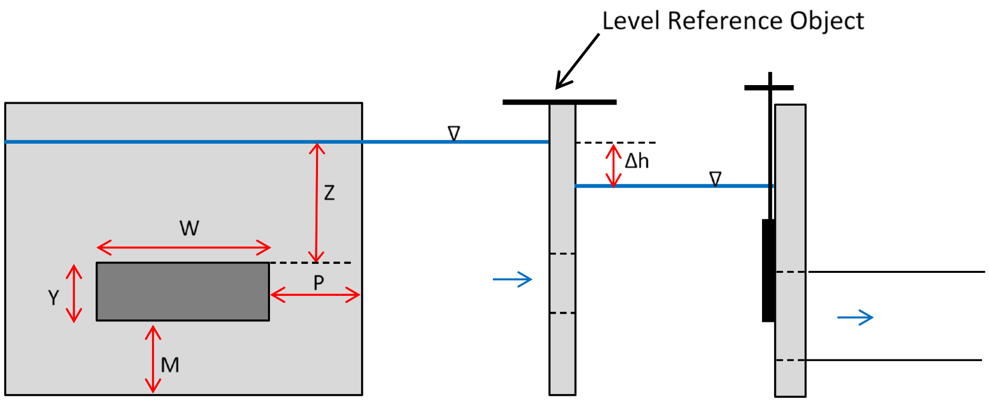


Figure 26. Dimensions for fully contracted submerged rectangular orifice

For a sharp-edged rectangular orifice where full contraction occurs from every side of the orifice, the coefficient of discharge is typically reported to be 0.61. ITRC has found that 0.63 is more accurate for the sizes and configurations found with irrigation district turnouts.

It is recommended that "Y" be considerable smaller than "W", so that a good depth "Z" can be maintained. This helps keep the orifice entrance submerged all the time regardless of upstream water level fluctuations, and also provides for the proper entrance conditions.

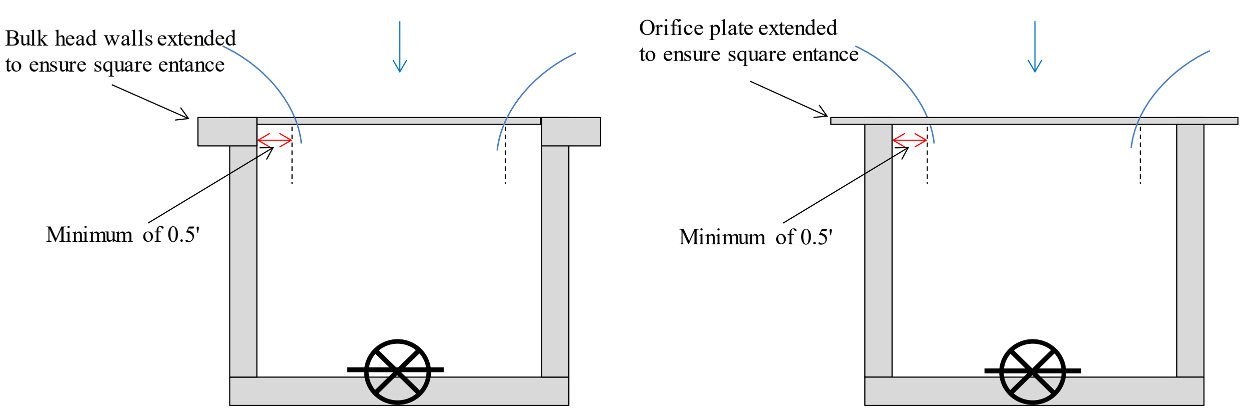


Figure 27. Guidelines for orifice entrance extensions

According to the USBR *Water Measurement Manual*, conditions for achieving accurate flow measurement for a fully contracted submerged rectangular orifice are:

- The upstream edges of the orifice should be straight, sharp, and smooth.
- The upstream face and the sides of the orifice opening need to be vertical.
- The top and bottom edges of the orifice opening need to be level.
- Any fasteners present on the upstream side of the orifice plate and the bulkhead must be countersunk.
- The face of the orifice plate must be clean of grease and oil.
- The thickness of the orifice plate perimeter should be between 0.03 and 0.08 inches. Thicker plates would need to have the downstream side edge chamfered at an angle of at least 45 degrees.
- Flow edges of the plate require machining or filing perpendicular to the upstream face to remove burrs or scratches and should not be smoothed off with abrasives.
- Using the dimensions depicted in Figure 26, P, Z, and M must all be greater than 2Y.

Table 2 provides some guidance for orifice dimensions and target flow rates. The box dimensions are based on a target ratio of about 20 (cubic feet)/CFS, with a depth dimension (B) that provides one 1.5 feet of freeboard in the box at zero flow. Dimensions also account for the requirement that P, Z, and M must all be greater than 2Y.

Table 2. Design dimensions and flows for fixed fully contracted submerged rectangular orifice plates

		Orifice dimensions, ft		Head loss, ft		Min. dimensions for the box, ft		
				0.20	0.25			
Y, in	W, in	Y, height	W, width	CFS		B, depth	E, width	L, length
9	24	0.75	2.00	3.4	3.8	7.5	4.0	3.5
12	24	1.00	2.00	4.5	5.1	7.5	5.0	3.5
15	30	1.25	2.50	7.1	7.9	8.0	6.5	4.0
15	36	1.25	3.00	8.5	9.5	8.0	6.5	4.5
15	48	1.25	4.00	11.3	12.6	8.0	6.5	6.0
18	48	1.50	4.00	13.6	15.2	8.5	7.0	6.0
18	60	1.50	5.00	17.0	19.0	9.0	7.5	6.0

The measurement of the Δh (difference in head, or "head loss") needs special attention. Almost all published drawings show staff gauges installed both upstream and downstream of the orifice plate. ITRC's experiences show that (a) the staff gauges are often placed without having the zeroes on the two gauges at the same elevation, and (b) staff gauges often have short lives because of corrosion. Furthermore, staff gauges often have a poor resolution.

The following recommendations are offered by ITRC to remedy the staff gauge problems:

1. Do not use staff gauges.
2. Equip ditchriders (i.e., "zanjeros" or "DSOs" or "operators") with a rigid ruler that reads either in hundredths of feet (not inches) or in mm. Mm is preferable simply because there is better resolution than with hundredths of feet. Discharge tables will need to be converted for Δh in mm.
3. Install a thick horizontal steel strip on the top of the concrete box wall, at an accessible location, to serve as a reference point to measure down to both the upstream and downstream water levels.
4. If stilling wells are used, they should have access tubes (1.5" diameter) located no deeper than 1' below the lowest water surface. The stilling wells should be at least 12" diameter. The stilling wells should be placed adjacent to each other, be capped, and the tops should have exactly the same elevation.

Sloping Fully Contracted Rectangular Submerged Orifice Plate

USBR recommendations for orifice plates are very clear in requiring vertical orifice plates. However, almost all canal linings have side slopes. It would be very convenient to simply lay a steel plate over the turnout entrance, on an angle, and measure the head difference across it. ITRC has found that there is no difference in the Cd between vertical and sloping orifice plates. The average Cd found with ITRC testing was 0.63.

Adjustable Contracted Rectangular Submerged Orifice Plate

The previously described "fixed" orifice plate has the following limitations:

1. If a turnout needs a high flow sometimes, and a low flow at other times, a fixed orifice is unsatisfactory because each flow will require a very different head loss. High head losses cause turbulence in the box and make accurate head loss readings difficult.
2. The flow rate requirement may vary from turnout to turnout. Therefore, there may not be a constant target flow rate that matches all installations.

The solution is to provide an adjustable orifice plate opening. A sliding plate can be used to vary the "Y" dimension seen in Figure 26. Figure 28 shows a very inexpensive retrofit Alta ID design that provides an adjustable orifice opening. The opening size is normally adjusted once and then fixed in place with a bolt between two vertical strips of metal. It can be noted that all the dimensions do not conform to the dimensions recommended in Table 2. Design dimensions and flows for fixed fully contracted submerged rectangular orifice plates Nevertheless, farmers in the district have accepted the measurements and this is a tremendous improvement over just having a canal gate (seen in the background) to adjust an unknown flow rate.

Figure 28. Alta ID rectangular orifice gate (front) provides flow measurement, while sluice gate (rear) provides flow control

Constant Head Orifice (CHO)

First, there may be some confusion about the name. There is nothing about the CHO structure that will automatically maintain a constant head difference or a constant flow rate. If the supply canal water level goes up, the turnout flow rate will increase because the available head difference increases.

At first glance, a constant head orifice (CHO) may appear to be the same as the adjustable contracted orifice plate described in the previous section. The operation is the same:

1. The most upstream opening is set at a position that will provide the target flow rate with a head loss of 0.20-0.25 feet. Sometimes this upstream gate is a rectangular gate, and sometimes it is just a steel plate with a rectangular orifice. The "head loss" is the difference in water level across this orifice.
2. The downstream gate is used for on/off and flow rate adjustment. It also ensures that the upstream orifice remains submerged – that the water level on the downstream side of the orifice is above the top of the orifice.

The most important differences are:

1. The orifice of a CHO is not a fully contracted rectangular submerged orifice. Rather, it should have a suppressed (smooth, no obstructions jutting into the flow) floor both upstream and downstream, and suppressed sides. The only contraction is at the top of the orifice (hole). The fundamental discharge equation is the same: $Q = C_d A\sqrt{2g\Delta h}$
   However, the C_d value varies significantly depending upon the relations between the elevations of upstream water and the top of the orifice, and with the relative orifice perimeter length that is suppressed versus contracted.
2. The "box chamber" between the flow measurement sluice gate and the flow control gate is typically much smaller than found in a pre-fabricated fully contracted rectangular submerged orifice design. This can result in significant turbulence, which reduces the accuracy of head measurements.

A standard, old USBR design for a CHO is shown in Figure 29. It has been noted by ITRC and much earlier by Kruse (1965) that field installations of CHOs have historically had significant variations in contractions, entrance conditions, and so on. It appears that engineers and districts often install two gates in series and use the same discharge table for all conditions. This is similar to what is seen with canal metergates and is definitely incorrect.

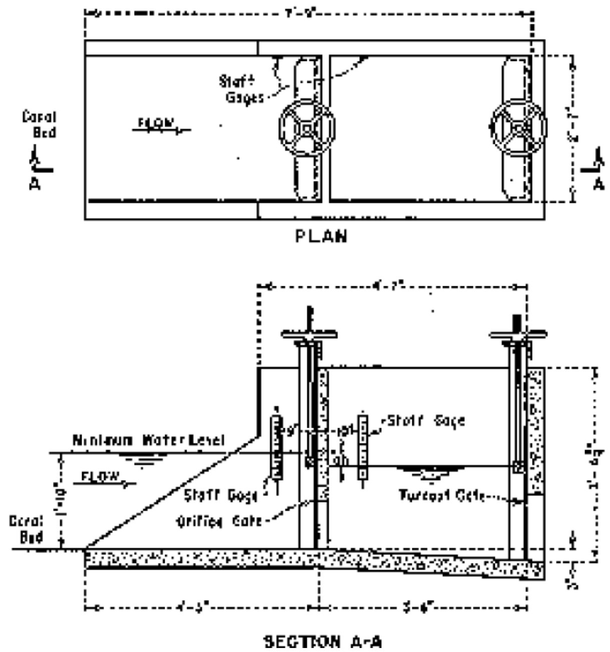


Figure 29. Schematic of a USBR CHO *(from USBR, 2001)*

Recommended designs differ in several ways:

1. Figure 29 shows a gate frame that extends into the flow path on the sides. Those obstructions do not provide suppressed walls. The concrete walls should have a groove into which the gate frame can be placed, so that the flow path never touches the gate frame on the sides or floor. Designs should have straight suppressed walls and floors.
2. The figure shows staff gauges. A previous section stated that (a) the staff gauges are often placed without having the zeroes on the two gauges at the same elevation, and (b) staff gauges often have short lives because of corrosion. Furthermore, staff gauges often have a poor resolution. See the earlier discussion on using rulers to measure depths to water surfaces.
3. The figure shows dimensions for illustrative purposes, but actual dimensions will depend upon the design maximum flow rate.
4. Such figures also often show access holes for stilling wells (sometimes called "piezometers" in CHO literature). Usually those access holes are shown to be below the bottom of the open gate. Because of the dynamic pressure distributions around the gate, that location will give incorrect readings. If stilling wells are used, the access holes should be no more than 1' below the water surface.

Kruse (1965) noted that if the entrance floor sloped downward (to provide sufficient submergence on the gate opening), there was excessive turbulence downstream of the first gate and it was difficult to measure water depths within 0.1'. He was experimenting with relatively shallow water depths.

The following provides a more detailed discussion of the recommended configuration. To repeat, a distinguishing feature of this is that the sluice gate opening is suppressed on three sides: the two vertical sides, and on the bottom both upstream and downstream. This means that no part of the gate frame extends into the opening, and that the floor is absolutely flat before, across, and after the sluice gate. This is important because we have fairly accurate coefficients for the flow rate computation of suppressed sluice gates. If there are side or bottom obstructions, the amount of flow contraction is different and we are unsure of how to adjust the formulas.

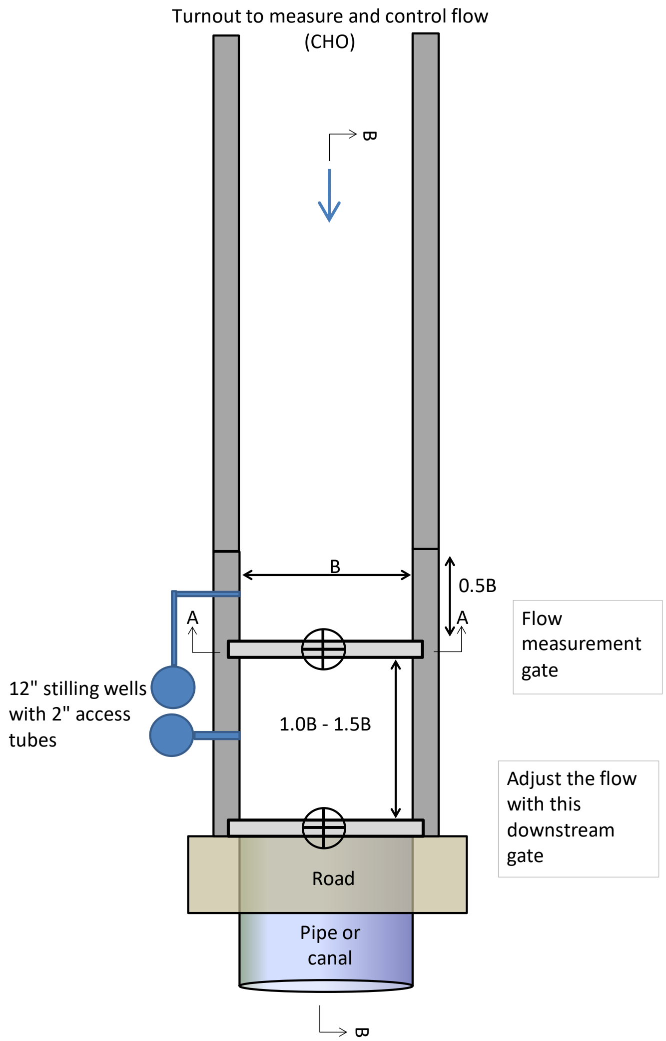


Figure 30. Sluice gate (CHO) configuration for flow measurement on side sloping canals. Plan view. Not to scale.

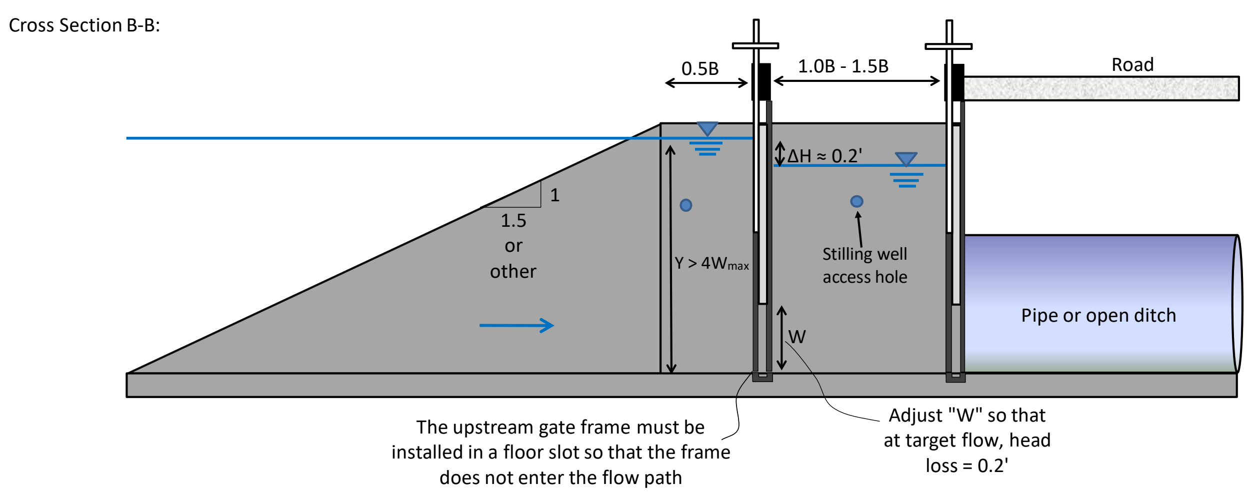


Figure 31. Side view of CHO on lined canal bank. Not to scale.

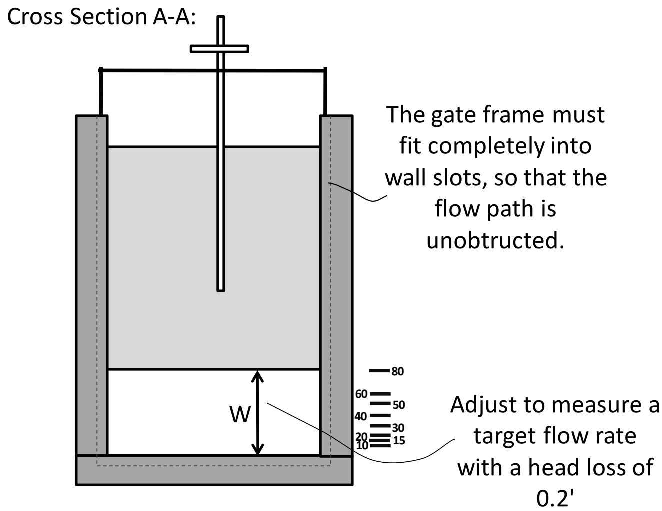


Figure 32. End view of upstream gate of CHO

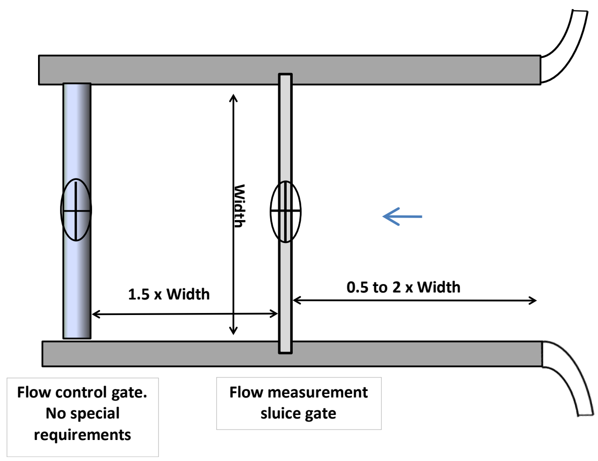


Figure 33. Plan view of CHO constructed in earthen canal. Not to scale. Rounded entrances are recommended.

A major advantage of CHOs over orifice plates is that because there is no side or bottom contraction, the structure can be smaller. A second advantage is that because the floor is flat, there is little/no accumulation of sediment with CHOs. There are also many irrigation district turnouts that have the entrance depicted in Figure 31; they just lack the upstream gate and stilling wells.

Because the structures are relatively small (per unit flow rate) downstream of the flow measurement gate (the upstream gate), the velocity is higher than with contracted submerged orifice plate boxes. Therefore, there is more turbulence in the section between the two gates. For this reason, it is highly recommended to install stilling wells to measure the head difference. As recommended earlier for orifice plates, they should have access tubes (2” diameter) located no deeper than 1’ below the lowest water surface. The stilling wells should be at least 12” in diameter. The stilling wells should be placed adjacent to each other, and the tops should have exactly the same elevation. The tops should be covered when not used (for a lid source see: http://www.thepipeplug.com/NonPressurePlugs.htm), and the stilling well pipes should be constructed from steel pipe so that they do not chip or break easily.

The flow rate is calculated using the following equation with dimensions from the upstream sluice gate (Burt et al, 2019):

$$Q_{Gate} = C_{dcomb} \times W \times B \times \sqrt{64.4 \times \Delta Head}$$

Where: Q = flow rate, CFS
C_{dcomb} = Gate flow coefficient, described below
B = Gate width, ft
W = Gate vertical opening, ft
ΔHead, ft = (Upstream Water Depth – Downstream Water Depth)

C_{dcomb} = (0.7206a^2 - .0867a + .3988) (1+.9B/(B+W))

$$a = \frac{\text{Gate Vertical Opening}}{\text{Upstream Water Depth above floor}}$$

Table 3. CHO rating table for ΔH = 0.2'

	Gate Openings (W) for Various Bottom Widths (B)							
	1 ft.		2 ft.		3 ft.		4 ft.	
CFS	W, ft	Min Y, ft	W, ft	Min Y, ft	W, ft	Min Y, ft	W, ft	Min Y, ft
1	0.41	1.6	0.19	0.8	0.12	0.5	0.09	0.4
1.5	0.63	2.6	0.28	1.1	0.18	0.7	0.13	0.5
2	0.88	3.5	0.38	1.5	0.24	1.0	0.18	0.7
2.5	1.11	4.5	0.48	2.0	0.3	1.2	0.22	0.9
3	1.37	5.5	0.59	2.4	0.37	1.5	0.27	1.1
3.5			0.7	2.8	0.43	1.8	0.31	1.3
4			0.81	3.2	0.5	2.0	0.36	1.5
4.5			0.92	3.7	0.57	2.3	0.42	1.7
5			1.03	4.1	0.64	2.6	0.46	1.8
5.5			1.14	4.6	0.7	2.8	0.51	2.0
6			1.27	5.1	0.78	3.1	0.56	2.2
6.5			1.38	5.6	0.84	3.4	0.61	2.4
7			1.51	6.0	0.92	3.7	0.66	2.6
7.5			1.62	6.5	0.99	4.0	0.71	2.8
8					1.07	4.3	0.75	3.0
8.5					1.13	4.6	0.81	3.2
9					1.21	4.9	0.86	3.4
9.5					1.29	5.2	0.91	3.6
10					1.37	5.5	0.97	3.9
10.5					1.43	5.8	1.02	4.1
11					1.52	6.1	1.07	4.3
11.5					1.59	6.4	1.13	4.5
12					1.68	6.7	1.18	4.7
12.5					1.74	7.0	1.23	4.9
13					1.82	7.3	1.29	5.2
13.5					1.9	7.6	1.33	5.4
14					1.99	8.0	1.39	5.6
14.5							1.44	5.8
15							1.5	6.0
15.5							1.56	6.3
16							1.62	6.5
16.5							1.67	6.7
17							1.73	7.0
17.5							1.78	7.2
18							1.84	7.4
18.5							1.89	7.6
19							1.95	7.8
19.5							2.01	8.1
20							2.07	8.3

Acoustic Doppler Velocity Meters

Acoustic Doppler velocity meters (ADVMs) are non-mechanical devices that can be used in both open channel and pressurized pipe systems. They usually contain two or more ultrasonic transducers that can emit and receive sound waves. The ADVM works by sending out an ultrasonic wave at discrete points along the channel/pipe cross-section; as the wave hits air bubbles or suspended solid particles, a wave is reflected with a Doppler shift (Figure 34). This shift in the wave is proportional to the velocity of the water in the channel or pipe. Using the depth measurement in the canal, or the pipe inside diameter to find the cross-sectional area, the meter can calculate the flow rate, similar to manual current metering devices.

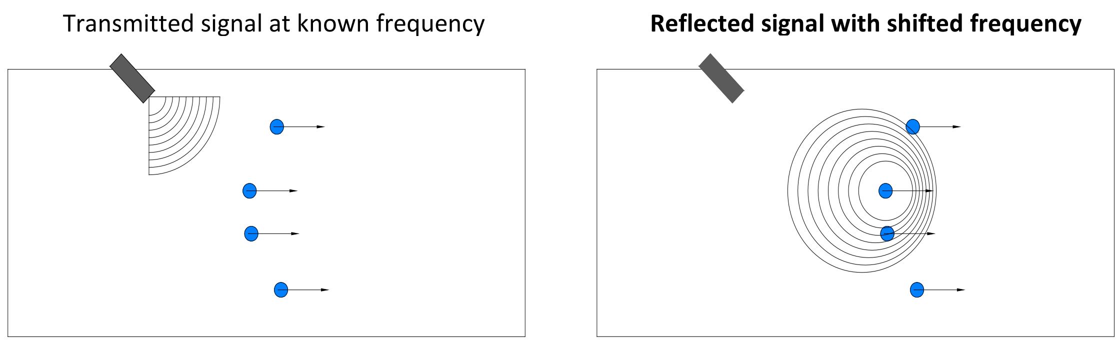


Figure 34. Doppler shift caused by moving particles in the water

There are two different wave transmitting/receiving methods for ADVMs: **continuous** signaling (incoherent) and **pulsed** (coherent) signaling (USBR, 2001). As the name implies, a continuous ADVM sends a continuous sound wave through the water and continuously reads the reflected waves without any pause between readings. The ADVM only averages the velocities along a single beam path, without taking into account the water depth.

On the other hand, a pulsed ADVM sends out short bursts of sound waves and waits a certain length of time before beginning to receive reflected waves. The pulsed ADVM is able to send its pulse to discrete points along the cross-section. The ability to read velocities at certain points gives pulsed ADVMs better velocity resolution, but generally makes them more expensive than their counterpart.

When looking at ADVMs, another important factor to take into consideration is the device's transducer wave output frequency. In general irrigation applications, ADVMs are usually set to frequencies between 1.2 MHz and 5 MHz, although the devices have the capability to go above or below those values. The lower end of the spectrum is usually used in situations where the water is very deep or the channel is very wide, but results in lower resolution. Higher frequencies are better for shorter distances and shallower waters, and have much better resolution.

Acoustic Doppler Velocity Meters on Open Channels

In open channel applications, ADVMs can be mounted on either the canal floor or on the side wall of the canal. Floor mounted units are "upward looking." They contain one transducer that "looks up" and determines the height of the water, and another two transducers that determine the velocity upstream and downstream of the unit, usually at beam angles of 25 or 45 degrees. For open channel systems, the beam angle is measured relative to the vertical beam center line, as seen in Figure 35. Figure 36 shows a 3D rendition of an upward-looking ADVM installation.

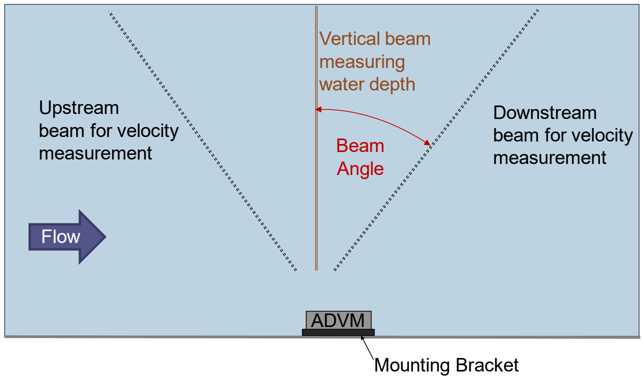


Figure 35. Beam angle relative to flow path

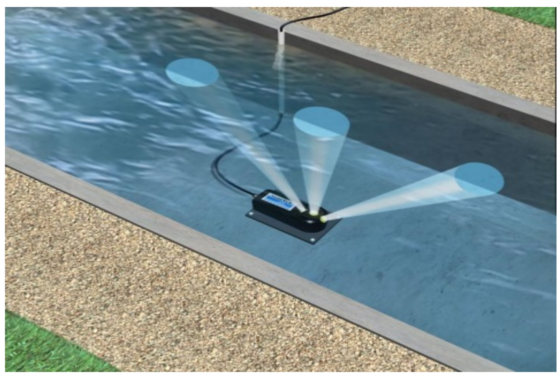


Figure 36. Water depth beam (center) and velocity beams (left and right) on an upward-looking ADVM *(from SonTek, 2005)*

Another configuration option for an ADVM in open channels is a "side looking" installation. The concept is very similar to an upward-looking ADVM, except that the device is mounted on a side wall of the canal instead.

It is very important to understand that all ADVMs only take a sample reading of the velocities in a channel. Those are not the same as the average velocities. Therefore, there must be some type of mathematical adjustment within the electronics to change the sample readings into average readings. The result may be close or quite distant from reality. In large installations, it is typical to spend a fair amount of time using current meters to measure actual flow rates, and then to develop some type of calibration curve. This is impractical for field turnouts.

Choosing an Installation Location

When installing an ADVM in an open channel, it is important to choose a location where there is little to no turbulence and where there is a uniform velocity profile so that the device can get the best readings possible. The USBR *Water Measurement Manual* (2001) recommends having at least 5 to 10 channel widths upstream and 1 to 2 widths downstream of the device in order to reduce turbulence.

ITRC developed a velocity conditioning device for open channels that is meant to create a uniform velocity profile over a variety of different flow rates and depths. The device is known as a subcritical contraction and is meant to cause a sudden change in channel cross section and equalize all the velocities in the profile, as seen in Figure 37. In other words, with a contraction installed, the velocity taken directly at the cross-section centerline should be equal to the actual mean channel velocity. Designs of subcritical contractions vary depending on the actual site characteristics, such as inlet channel width and channel material (i.e., earth or concrete), but will equalize velocities just the same.

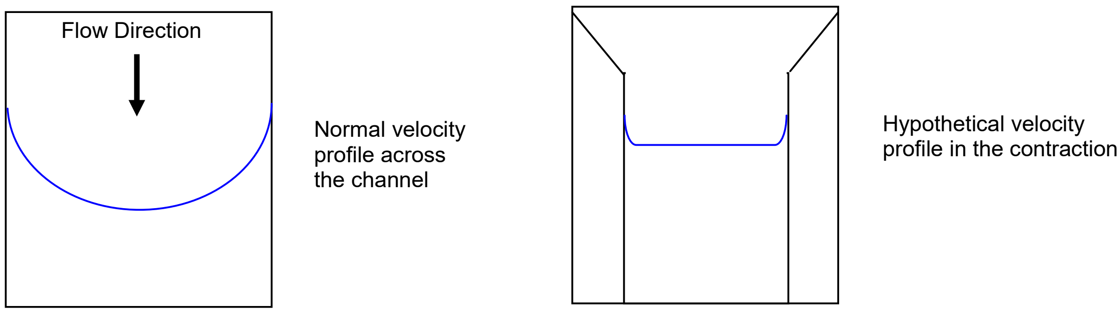


Figure 37. Parabolic velocity distribution without a contraction (left) and theoretical velocity distribution with contraction installed (right)

Additional notes include:

- It is recommended to install a subcritical contraction at every site where an ADVM is to be placed in order to get the most accurate results for volumetric flow rate.
- ADVMs need to be positioned in the proper angle. They also need to be cleaned off occasionally. They should be installed with brackets that make it easy to remove the ADVM and inspect it, and then return it to the exact location and orientation (angle) as before. This is especially important if calibration was done to develop the signal/flow relationship, as any change in location or orientation will change the calibration curve.
- ADVMs have had a varied history of complexity, life expectancy, and accuracy. Some of the more accurate devices do not have good user interfaces (there is no simple display of volume and flow rate).
- ADVMs are typically used when there is not enough head available in a canal to use any other device such as a flume.

Acoustic Doppler Meters in Pipes

ADVMs can also be used on systems where water passes through a pipe section, such as in an intermediate delivery between district canals and farmer-owned ditches. A variety of techniques have been developed that allow the ADVM to be attached to the inside of pipe walls, yet also be easily removable for servicing. Again, there can be challenges with quality control. ITRC worked with 30 units from one large manufacturer and had to discard all of them. There were problems even detecting flow, and obtaining an accurate answer was even less likely.

If the pipe is full, it is generally advised to install the ADVM on the side of the pipe to prevent it being covered with sediment or being hit by floating trash.

Flumes and Weirs

Flumes and weirs are sometimes used downstream of flow control gates (turnout canal gates). Major challenges include:

1. These devices must be far enough downstream of turbulence to have relatively straight approach sections. This usually means they are on the farmer's property.
2. Because the devices are on the farmer's property, the hydraulic conditions (damming up of water, weeds, etc.) downstream of the device may deteriorate and the weir or flume may become submerged, rendering them useless.
3. Flumes and weirs require a fair amount of head loss across them. In theory, flumes can be operated with a very small head loss, but experienced designers know that it is unwise to assume too much about downstream conditions. Therefore, they will typically design them for at least 6"-12" head loss, which is often not available if one also considers the head loss needed for water to flow into the turnout and through the gate and structure, plus ideally leaving about 1' of extra head loss for good flow control.

Weirs are less expensive to construct than flumes, but they are very sensitive to the approach velocity. The equations used by most people assume that where the head is measured upstream of the weir, the velocity is zero. That is rarely the case, so the typical weir equations often underestimate the flow rate. Additionally, turnout weirs are rarely constructed with the appropriate dimensions, clearances, and approach conditions.

In the western US there has been a fair amount of standardization of flume design. The most common is called a "Replogle flume" or a "ramp flume" or a "broad-crested weir" – all names for the same design.

Figure 38. A "Replogle flume" installed on a ditch with high flows in Truckee-Carson ID in Nevada. This is constructed in a trapezoidal section of canal.

The accuracy of both flumes and weirs is very sensitive to silt and sand in the water. Figure 39 illustrates such a problem.

Figure 39. Flume with expensive monitoring and a slight maintenance problem

Flumes also tend to have a large algae growth on the top and entrance concrete, in which case the flow rate is overestimated. This can be minimized by carefully painting the flume with a special paint. Figure 40 shows a flume that has received an ePaint™ non-toxic anti-fouling coating.

Figure 40. A flume with an ePaint™ coating to minimize algae growth

If a weir or flume is used for turnout flow measurement, it is highly recommended that staff gauges be purchased that read out directly in flow rate. This eliminates errors in conversion from feet to CFS. A variety of companies (e.g., Stevens, Oregon Rule, All Star Trophy) provide such staff gauges in a variety of widths and materials. The discharge equation needs to be provided, and if the staff is on a slope that angle also needs to be provided. Interestingly, one of the biggest errors with flume and weir measurement is that the staff gauges are not put in the proper location, and/or the "zero" is not placed at the correct height.

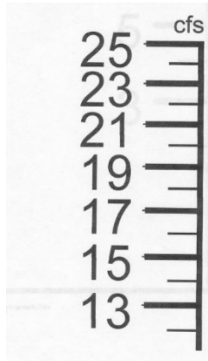


Figure 41. Example of a staff gauge from Modesto ID, reading directly in CFS

Weirs

Key characteristics of weirs were mentioned previously. All weir equations are derived empirically using limited laboratory test results. Therefore, the importance of following the installation rules cannot be over-emphasized. The USBR *Water Measurement Manual* (2001) provides excellent information regarding weir types and weir dimensions.

Besides problems with not considering the entrance velocity and using improper clearances for weirs, the most common problems appear to be:

1. Many weirs are not properly sized for the flow rates that will be encountered. Specifically, many are oversized and therefore only have a shallow depth over the crest.
2. Many weirs are submerged on the downstream side.
3. Staff gauges are not zeroed properly.

ITRC Weir Stick

The ITRC weir stick is used by many districts to measure flow rates in canals. It was intended to provide a relatively quick and reasonably accurate estimate of flow rates over flashboards used in irrigation district canal check structures. Some districts use it at the turnout level.

Figure 42. Use of an ITRC weir stick on flashboards

Ideally, the weir would be suppressed and well-aerated. The nappe (downstream side) of the weir seen in Figure 43 is aerated; air can move under the nappe and prevent a suction from forming.

Figure 43. Example of a suppressed weir. The upstream channel has the same width as the weir crest. In this particular case, the walls diverge immediately downstream of the weir, so the nappe is aerated.

The weir in Figure 44 is not suppressed but is "contracted". In other words, the water flows in from the sides of the weir. As can be seen in Figure 43, a foot of weir length at the sides does not convey as much flow rate as a foot of weir length in the middle.

Figure 44. Example of a rectangular contracted weir

The ITRC weir stick reads directly in CFS/ft of *effective* weir length. The actual weir length usually needs to be reduced to provide the value of "effective weir length" that is used in an equation. In other words, if the boards were 6' wide, perhaps the effective length is 5.5'.

The general equation (assuming zero velocity head where the staff gauge is located) for a sharp-crested *suppressed* weir is:

$$CFS = 3.33 \times L \times H^{1.5}$$

Where: L = length of the weir, feet
H = Head above the weir crest, feet (measured before the water begins to converge downward over the crest.

For a perfectly designed/installed contracted (not suppressed) weir, for which water converges from the sides, bottom, and top to pass over the crest, the equation is:

$$CFS = 3.33 \times (L - 0.2H) \times H^{1.5}$$

Where: L and H are the same values as earlier

The value of (L-0.2H) represents the "effective length" of the weir. As more flow passes over the weir, the head (H) increases, and so does the side convergence – reducing the effective weir length.

Operators that use the ITRC weir stick may not understand the need to use an effective length, rather than an actual length. This is not necessary, of course, if the weir is suppressed on its sides.

The ITRC weir stick does automatically take the velocity head into consideration, because it measures the total head at the crest (the water "runs up" the stick above the actual water surface elevation, by an amount equal to the velocity head).

While the accuracy of the ITRC weir stick is reasonable for flashboards, it has not been verified on weirs that may be used for farm turnouts.

Flumes

For the past 30 years, most irrigation districts in the US have standardized the Replogle flume. The main advantages of this flume are:

1. It can be designed with trapezoidal or vertical side walls.
2. The WinFlume™ program is free from USBR and provides good designers with excellent design and analysis capabilities.
3. The post-construction flume dimensions can be inserted into the WinFlume™ program to obtain flow rate equations that match what is actually in the field.
4. These flumes have minimal head loss.
5. These flumes are very accurate if designed and installed properly.
6. There is no adjustment for the velocity of approach.

The two major errors that are made in design are likely:

1. The entrance velocity is too high (in hydraulic terms, the Froude number is too high). This occurs on steep canals.
2. The downstream conditions are not well defined, and therefore the flume becomes too submerged for accurate readings.

A "standard" Replogle flume configuration is illustrated in Figure 45.

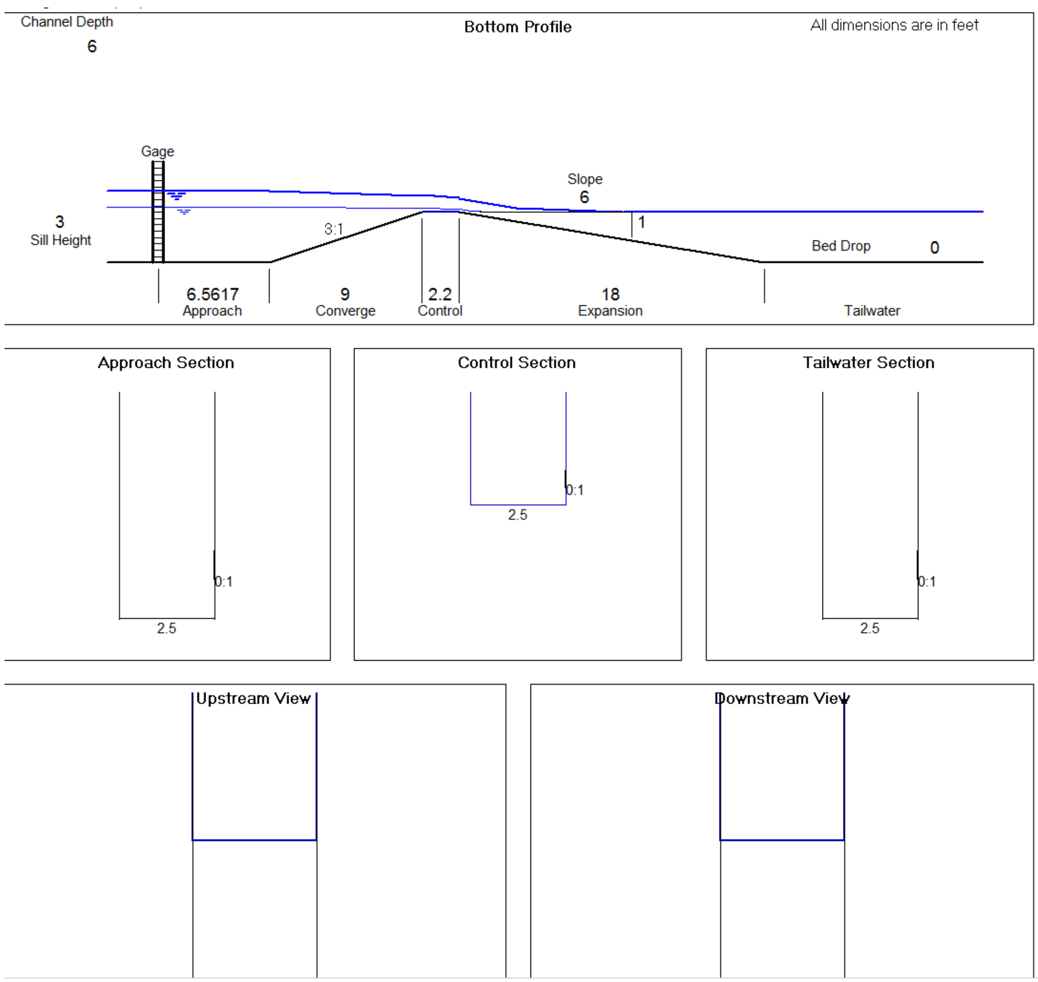


Figure 45. Example output from WinFlume™ for a typical Replogle flume. This has rectangular side walls.

For situations in where there is a heavy silt/sand load, the trend is to use WinFlume™ to design a flat-bottomed flume, with contractions on the sides but not on the bottom. Figure 46 shows an example of such a flume.

Figure 46. Flat-bottomed (actually, a "Vee" in this case) flume immediately after construction. The sediment will flush out once water flows in the ditch.

Pump Kilowatt-Hours

Some districts have pumped turnouts from canals. It is generally not recommended to use the power billing records to estimate the volume that is pumped, because:

1. Pump inlet conditions often change. For example, the pumping depths in wells can change substantially from month to month, which impacts the volume/kwh.
2. Pump parts wear with time, changing the volume/kwh.
3. Pump discharge conditions can change. In Figure 47, the height of water in the concrete stand will be different, depending on where in the field the water is going. This creates different pressure requirements for the pump. For low lift pumps, the flow rate can change substantially with only a foot or two of discharge pressure difference.
4. Pump discharge pressures (and therefore flow rates) also change over time if the pump discharges directly into a pressurized pipe.

Figure 47. The discharge pressure of the pump will change over time with this type of direct connection to a standpipe

Instead, it is recommended to just put a flow meter on the pump discharge with appropriate clearances.

References

Burt, C.M. and D.J. Howes. 2015. Practical Guide for Metergates. Irrigation Training & Research Center, California Polytechnic State University, San Luis Obispo, California, USA.

Burt, C.M., K. Feist, and B. Clemmens (likely authors). 2019. Sluice Gate Discharge Coefficients for Flow Measurement. To be submitted to I&D Journal of ASCE.

Kruse, E.G. The Constant-Head-Orifice Farm Turnout. 1965. USDA/ARS. ARS Report 41-93. 24 p.

Netafim. 2016. Octave® Ultrasonic Water Meters. Online at: http://www.netafimusa.com/agriculture/products/water-meters/octave-ultrasonic-water-meters/ <Accessed 31 August 2017>

SonTek. 2005. Argonaut-SW: Shallow Water Flow, Level and Velocity. Product Informational Datasheet. Online at: https://observator.com/download/datasheet-sontek-argonaut-sw <Accessed 31 August 2017>

USBR. 2001. *Water Measurement Manual*. Water Resources Technical Publication. U.S. Department of the Interior, Bureau of Reclamation. In cooperation with the US Department of Agriculture Agricultural Research Service and Natural Resources Conservation Service. Online at: https://www.usbr.gov/tsc/techreferences/mands/wmm.html <Accessed 31 August 2017>

Attachment 1

California Code of Regulations
Title 23. Waters
Division 2. Department of Water Resources
Chapter 5.1. Water Conservation Act of 2009
Article 2. Agricultural Water Measurement

§597. Agricultural Water Measurement

Under the authority included under California Water Code §10608.48(i)(1), the Department of Water Resources (Department) is required to adopt regulations that provide for a range of options that agricultural water suppliers may use or implement to comply with the measurement requirements in paragraph (1) of subdivision (b) of §10608.48.

For reference, §10608.48(b) of the California Water Code states that:

> *Agricultural water suppliers shall implement all of the following critical efficient management practices:*
>
> *(1) Measure the volume of water delivered to customers with sufficient accuracy to comply with subdivision (a) of Section 531.10 and to implement paragraph (2).*
>
> *(2) Adopt a pricing structure for water customers based at least in part on quantity delivered.*

For further reference, §531.10(a) of the California Water Code requires that:

> *(a) An agricultural water supplier shall submit an annual report to the department that summarizes aggregated farm-gate delivery data, on a monthly or bi-monthly basis, using best professional practices.*

Notes:

(1) Paragraphs (1) and (2) of §10608.48(b) specify agricultural water suppliers' reporting of aggregated farm-gate water delivery and adopting a volumetric water pricing structure as the purposes of water measurement. However, this article only addresses developing a range of options for water measurement.

(2) Agricultural water suppliers reporting agricultural water deliveries measured under this article shall use the "Agricultural Aggregated Farm – Gate Delivery Reporting Format for Article 2" (Rev. 6-20-12), developed for this article and hereby incorporated by reference.

1

(3) The Department shall report on the availability of new commercially available water measurement technologies and impediments to implementation of this article when reporting to the Legislature the status of adopted Agricultural Water Management Plans in plan submittal years 2012, 2015 and every five years thereafter as required by California Water Code §10845. The Department shall also report the findings to the California Water Commission.

Note: Authority cited: Section 10608.48, Water Code. Reference: Sections 531.10, 10608.48 (b), 10608.48 (i), 10608.52 (b) and 10845 Water Code.

§597.1. Applicability

(a) An agricultural water supplier providing water to 25,000 irrigated acres or more, excluding acres that receive only recycled water, is subject to this article.

(b) A wholesale agricultural water supplier providing water to another agricultural water supplier (the receiving water supplier) for ultimate resale to customers is subject to this article at the location at which control of the water is transferred to the receiving water supplier. However, the wholesale agricultural water supplier is not required to measure the receiving agricultural water supplier's deliveries to its customers.

(c) A water supplier providing water to wildlife refuges or habitat lands where (1) the refuges or habitat lands are under a contractual relationship with the water supplier, and (2) the water supplier meets the irrigated acreage criteria of Water Code §10608.12(a), is subject to this article.

(d) An agricultural water supplier providing water to less than 10,000 irrigated acres, excluding acres that receive only recycled water, is not subject to this article.

(e) An agricultural water supplier providing water to 10,000 or more irrigated acres but less than 25,000 irrigated acres, excluding acres that receive only recycled water, is not subject to this article unless sufficient funding is provided specifically for that purpose, as stated under Water Code §10853.

(f) A canal authority or other entity that conveys or delivers water through facilities owned by a federal agency is not subject to this article.

(g) Pursuant to Water Code §10608.8(d), an agricultural water supplier "that is a party to the Quantification Settlement Agreement, as defined in subdivision (a) of Section 1 of Chapter 617 of the Statutes of 2002, during the period within which the Quantification Settlement Agreement remains in effect," is not subject to this article.

(h) Pursuant to Water Code §10608.12(a), the Department is not subject to this article.

2

Note: Authority cited: Section 10608.48, Water Code. Reference: Sections 10608.12 (a), 10608.48 (d), 10608.48 (f), 10828, and 10853 Water Code.

§597.2. Definitions

(a) For purposes of this article, the terms used are defined in this section.

(1) "Accuracy" means the measured volume relative to the actual volume, expressed as a percent. The percent shall be calculated as 100 x (measured value – actual value) / actual value, where "measured value" is the value indicated by the device or determined through calculations using a measured value by the device, such as flow rate, combined with a duration of flow, and "actual value" is the value as determined through laboratory, design or field testing protocols using best professional practices.

(2) "Agricultural water supplier," as defined in Water Code §10608.12(a), means a water supplier, either publicly or privately owned, providing water to 10,000 or more irrigated acres, excluding acres that receive only recycled water. "Agricultural water supplier" includes a supplier or contractor for water, regardless of the basis of right, which distributes or sells water for ultimate resale to customers. "Agricultural water supplier" does not include the Department.

(3) "Approved by an engineer" means a California-registered Professional Engineer has reviewed, signed and stamped the plans, design, testing, inspection, and/or documentation report for a measurement device as described in this article.

(4) "Best professional practices" means practices attaining to and maintaining accuracy of measurement and reporting devices and methods described in this article, such as operation and maintenance procedures and practices recommended by measurement device manufacturers, designers, and industry professionals.

(5) "Customer" means the purchaser of water from an agricultural water supplier who has a contractual arrangement with the agricultural water supplier for the service of conveying water to the customer delivery point.

(6) "Delivery point" means the location at which the agricultural water supplier transfers control of delivered water to a customer or group of customers. In most instances, the transfer of control occurs at the farm-gate, which is therefore, a delivery point.

(7) "Existing measurement device," means a measurement device that was installed in the field prior to the effective date of this article.

(8) "Farm-gate," as defined in Water Code §531(f), means the point at which water is delivered from the agricultural water supplier's distribution system to each of its customers.

3

(9) "Irrigated acres," for purposes of applicability of this article, is calculated as the average of the previous five-year acreage within the agricultural water supplier's service area that has received irrigation water from the agricultural water supplier.

(10) "Manufactured device" means a device that is manufactured by a commercial enterprise, often under exclusive legal rights of the manufacturer, for direct off-the-shelf purchase and installation. Such devices are capable of directly measuring flow rate, velocity, or accumulating the volume of water delivered, without the need for additional components that are built on-site or in-house.

(11) "Measurement device" means a device by which an agricultural water supplier determines the numeric value of flow rate, velocity or volume of the water passing a designated delivery point. A measurement device may be a manufactured device, on-site built device or in-house built device.

(12) "New or replacement measurement device" means a measurement device installed after the effective date of this article.

(13) "Recycled water" is defined in subdivision (n) of §13050 of the Water Code as water that, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that would not otherwise occur, and is therefore considered a valuable resource.

(14) "Type of device" means a measurement device that is manufactured or built to perform similar functions. For example, rectangular, v-notch, and broad crested weirs are one type of device. Similarly, all submerged orifice gates are considered one type of device.

Note: Authority cited: Section 10608.48, Water Code. Reference: Sections 10608.12 (a), 10608.12 (m), 10608.48, and 10813 Water Code.

§597.3 Range of Options for Agricultural Water Measurement

An agricultural water supplier subject to this article shall measure surface water and groundwater that it delivers to its customers pursuant to the accuracy standards in this section. The supplier may choose any applicable single measurement option or combination of options listed in paragraphs (a) or (b) of this section. Measurement device accuracy and operation shall be certified, tested, inspected and/or analyzed as described in §597.4 of this article.

(a) Measurement Options at the Delivery Point or Farm-gate of a Single Customer

An agricultural water supplier shall measure water delivered at the delivery point or farm-gate of a single customer using one of the following measurement options. The stated numerical accuracy for each measurement option is for the volume delivered. If a device measures a value other than volume, for example, flow rate,

4

velocity or water elevation, the accuracy certification must incorporate the measurements or calculations required to convert the measured value to volume as described in §597.4(e).

(1) An existing measurement device shall be certified to be accurate to within ±12% by volume.

and,

(2) A new or replacement measurement device shall be certified to be accurate to within:

(A) ±5% by volume in the laboratory if using a laboratory certification;

(B) ±10% by volume in the field if using a non-laboratory certification.

(b) Measurement Options at a Location Upstream of the Delivery Points or Farm-gates of Multiple Customers

(1) An agricultural water supplier may measure water delivered at a location upstream of the delivery points or farm-gates of multiple customers using one of the measurement options described in §597.3(a) if the downstream individual customer's delivery points meet either of the following conditions:

(A) The agricultural water supplier does not have legal access to the delivery points of individual customers or group of customers needed to install, measure, maintain, operate, and monitor a measurement device.

Or,

(B) An engineer determines that, due to small differentials in water level or large fluctuations in flow rate or velocity that occur during the delivery season at a single farm-gate, accuracy standards of measurement options in §597.3(a) cannot be met by installing a measurement device or devices (manufactured or on-site built or in-house built devices with or without additional components such as gauging rod, water level control structure at the farm-gate, etc.). If conditions change such that the accuracy standards of measurement options in §597.3(a) at the farm-gate can be met, an agricultural water supplier shall include in its Agricultural Water Management Plan, a schedule, budget and finance plan to demonstrate progress to measure water at the farm-gate in compliance with §597.3(a) of this article.

(2) An agricultural water supplier choosing an option under paragraph (b)(1) of this section shall provide the following current documentation in its Agricultural Water Management Plan(s) submitted pursuant to Water Code §10826:

(A) When applicable, to demonstrate lack of legal access at delivery points of individual customers or group of customers downstream of the point of measurement, the agricultural water supplier's legal counsel shall certify to the Department that it does not have legal access to measure water at customers delivery points and that it has sought and been denied access from its customers to measure water at those points.

(B) When applicable, the agricultural water supplier shall document the water measurement device unavailability and that the water level or flow conditions described in §597.3(b)(1)(B) exist at individual customer's delivery points downstream of the point of measurement as approved by an engineer.

(C) The agricultural water supplier shall document all of the following criteria about the methodology it uses to apportion the volume of water delivered to the individual downstream customers:

(i) How it accounts for differences in water use among the individual customers based on but not limited to the duration of water delivery to the individual customers, annual customer water use patterns, irrigated acreage, crops planted, and on-farm irrigation system,

and;

(ii) That it is sufficient for establishing a pricing structure based at least in part on the volume delivered,

and;

(iii) That it was approved by the agricultural water supplier's governing board or body.

Note: Authority cited: Section 10608.48, Water Code. Reference: Sections 531.10, 10608.48 *(i)* (1), and 10826 Water Code.

§597.4 Accuracy Certification, Records Retention, Device Performance, and Reporting

(a) Initial Certification of Device Accuracy

The accuracy of an existing, new or replacement measurement device or type of device, as required in §597.3, shall be initially certified and documented as follows:

(1) For existing measurement devices, the device accuracy required in section 597.3(a) shall be initially certified and documented by either:

(A) Field-testing that is completed on a random and statistically representative sample of the existing measurement devices as described in §597.4(b)(1) and §597.4(b)(2). Field-testing shall be performed by individuals trained in the use of field-testing equipment, and documented in a report approved by an engineer.

6

Or,

(B) Field-inspections and analysis completed for every existing measurement device as described in §597.4(b)(3). Field-inspections and analysis shall be performed by trained individuals in the use of field inspection and analysis, and documented in a report approved by an engineer.

(2) For new or replacement measurement devices, the device accuracy required in sections 597.3 (a)(2) shall be initially certified and documented by either:

(A) Laboratory Certification prior to installation of a measurement device as documented by the manufacturer or an entity, institution or individual that tested the device following industry-established protocols such as the National Institute for Standards and Testing (NIST) traceability standards. Documentation shall include the manufacturer's literature or the results of laboratory testing of an individual device or type of device.

Or,

(B) Non-Laboratory Certification after the installation of a measurement device in the field, as documented by either:

(i) An affidavit approved by an engineer submitted to the agricultural water supplier of either (1) the design and installation of an individual device at a specified location, or (2) the standardized design and installation for a group of measurement devices for each type of device installed at specified locations.

Or,

(ii) A report submitted to the agricultural water supplier and approved by an engineer documenting the field-testing performed on the installed measurement device or type of device, by individuals trained in the use of field testing equipment.

(b) Protocols for Field-Testing and Field-Inspection and Analysis of Existing Devices

(1) Field-testing shall be performed for a sample of existing measurement devices according to manufacturer's recommendations or design specifications and following best professional practices. It is recommended that the sample size be no less than 10% of existing devices, with a minimum of 5, and not to exceed 100 individual devices for any particular device type. Alternatively, the supplier may develop its own sampling plan using an accepted statistical methodology.

(2) If during the field-testing of existing measurement devices, more than one quarter of the samples for any particular device type do not meet the criteria pursuant to §597.3(a), the agricultural water supplier shall provide in its Agricultural Water

7

Management Plan, a plan to test an additional 10% of its existing devices, with a minimum of 5, but not to exceed an additional 100 individual devices for the particular device type. This second round of field-testing and corrective actions shall be completed within three years of the initial field-testing.

(3) Field-inspections and analysis protocols shall be performed and the results shall be approved by an engineer for every existing measurement device to demonstrate that the design and installation standards used for the installation of existing measurement devices meet the accuracy standards of §597.3(a) and operation and maintenance protocols meet best professional practices.

(c) Records Retention

Records documenting compliance with the requirements in §597.3 and §597.4 shall be maintained by the agricultural water supplier for ten years or two Agricultural Water Management Plan cycles.

(d) Performance Requirements

(1) All measurement devices shall be correctly installed, maintained, operated, inspected, and monitored as described by the manufacturer, the laboratory or the registered Professional Engineer that has signed and stamped certification of the device, and pursuant to best professional practices.

(2) If an installed measurement device no longer meets the accuracy requirements of §597.3(a) based on either field-testing or field-inspections and analysis as defined in sections 597.4 (a) and (b) for either the initial accuracy certification or during operations and maintenance, then the agricultural water supplier shall take appropriate corrective action, including but not limited to, repair or replacement to achieve the requirements of this article.

(e) Reporting in Agricultural Water Management Plans

Agricultural water suppliers shall report the following information in their Agricultural Water Management Plan(s):

(1) Documentation as required to demonstrate compliance with §597.3 (b), as outlined in section §597.3(b)(2), and §597.4(b)(2).

(2) A description of best professional practices about, but not limited to, the (1) collection of water measurement data, (2) frequency of measurements, (3) method for determining irrigated acres, and (4) quality control and quality assurance procedures.

(3) If a water measurement device measures flow rate, velocity or water elevation, and does not report the total volume of water delivered, the agricultural water supplier must document in its Agricultural Water Management Plan how it converted the

8

measured value to volume. The protocols must follow best professional practices and include the following methods for determining volumetric deliveries:

(A) For devices that measure flow-rate, documentation shall describe protocols used to measure the duration of water delivery where volume is derived by the following formula: Volume = flow rate x duration of delivery.

(B) For devices that measure velocity only, the documentation shall describe protocols associated with the measurement of the cross-sectional area of flow and duration of water delivery, where volume is derived by the following formula: Volume = velocity x cross-section flow area x duration of delivery.

(C) For devices that measure water elevation at the device (e.g. flow over a weir or differential elevation on either side of a device), the documentation shall describe protocols associated with the measurement of elevation that was used to derive flow rate at the device. The documentation will also describe the method or formula used to derive volume from the measured elevation value(s).

(4) If an existing water measurement device is determined to be out of compliance with §597.3, and the agricultural water supplier is unable to bring it into compliance before submitting its Agricultural Water Management Plan in December 2012, the agricultural water supplier shall provide in its 2012 plan, a schedule, budget and finance plan for taking corrective action in three years or less.

Note: Authority cited: Section 10608.48, Water Code. Reference: Sections 531.10, 10608.48 *(i)* (1), and 10826 Water Code.

State of California | The Natural Resources Agency | Department of Water Resources

Agricultural Aggregated Farm-Gate[1] Delivery Reporting Format for Article 2

Due annually beginning no later than July 31, 2013 from agricultural water suppliers subject to Title 23, Division 2, Chapter 5.1, Article 2 of the CCR - Agricultural Water Measurement

1. Water Supplier Information

Name:

Address:

Phone Number:

Fax:

Total Number of Farm-Gates:

Number of Measured Farm-Gates:

Service Area Acreage:

2. Contact information

Name:

Title:

Address:

Phone Number:

Fax:

E-mail:

Submittal date:

3. Aggregated Farm-Gate Delivery Data[2]: *(provide monthly or bimonthly data, acre-feet)*

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
Monthly Deliveries													

	Jul-Aug	Sep-Oct	Nov-Dec	Jan-Feb	Mar-Apr	May-Jun	Total
Bimonthly Deliveries							

4. Explanations, Comments and Best Professional Practices[3]:

Note: An agricultural water supplier's total water use may be different from Aggregated Farm-Gate deliveries because measurement at these points may not account for other practices (such as groundwater recharge/conjunctive use, water transfers, wheeling to other agencies, urban use, etc).

1. "Farm-gate" means the point at which water is delivered from the agricultural water supplier's distribution system to each of its individual customers as specified in the Agricultural Water Measurement Regulation (Title 23, Division 2, Chapter 5.1, Article 2 of the CCR).
2. "Aggregated farm-gate delivery data" means information reflecting the total volume of water an agricultural water supplier provides to its customers and is calculated by totaling its deliveries to customers.
3. "Best Professional Practices" is defined in Title 23, Division 2, Chapter 5.1, Article 2 of the CCR, Section 597.2.

Article 2 Form - Rev. 6-20-2012

Attachment 2

Jack Kelly Clark

Growers depend on flow meters to measure the amount of irrigation water being applied to crop. If meter readings are inaccurate, some of the precious resource may be wasted.

Water turbulence disrupts accuracy of some flow meters

Blaine R. Hanson ❑ Larry J. Schwankl

Flow meters were tested under a variety of conditions to determine potential errors in flow rate measurements due to excessive turbulence in the water. Results showed that propeller meters, the Hall meter and the Collins meter were not particularly sensitive to turbulence caused by elbows, while paddle-wheel meters and velocity gauges were sensitive to turbulence. Relatively large errors occurred for all meters under turbulence caused by a partially closed butterfly valve. Inserting six straightening vanes greatly reduced the error caused by partially closed valves.

As water resources become more scarce and competition for them increases, using flow meters to measure the amount of irrigation water applied to a crop field is becoming more common. The flow of irrigation water in pipelines is measured with a variety of devices and is often done under less-than-ideal flow conditions, particularly where a flow measurement device is retrofitted into an existing agricultural pumping plant.

Flow meter manufacturers generally suggest installing an 8-to-10-pipe-diameter section of straight pipe (length is always relative to the diameter of the pipe) upstream of the flow meter and a 2-pipe-diameter length of straight pipe downstream. Over time, this rule of thumb has been generally accepted without a clear understanding of its origin or the impact on flow measurement devices of upstream flow conditions. The origin of this rule of thumb is difficult to determine, but the 1935 standards of the Joint American Gas Association–American Society of Mechanical Engineers Committee on Orifice Coefficients and subsequent work seem to form the basis for it.

Pumps used for irrigation systems are rarely installed with sufficient straight pipe upstream of the flow meter. Little information appears to exist on the possible error resulting from a nonideal flow condition. This project was conducted to assess the error in flow rate measurements of flow meters used in agricultural applications under a variety of nonoptimal upstream flow conditions.

Flow rate measurement

Flow rates were measured with eight different flow meters at distances of 2-, 5-, 10- and 15-pipe diameters downstream from a source of excessive turbulence in the water. Measurements were made in an 8-inch Schedule 40 PVC pipe. The flow meter measurement was compared to flow rate measurements obtained with a volumetric tank, where water flowing though the pipe containing the flow meter discharged into the volumetric tank. Each test consisted of making two tank measurements by filling the tank, draining it and then refilling it. The flow meter reading was compared with the average of the two tank measurements. The percent error was calculated as

RE = 100(Meter – Tank)/Tank

where RE = error, Meter = flow meter reading, and Tank = volumetric tank measurement. Flow rates ranged between about 400 gallons per minute (gpm) and nearly 1,300 gpm.

Water velocity profiles across the horizontal pipe diameter were measured with a pitot tube to characterize the turbulence patterns for each condition. Measurements were made every half inch across the diameter.

We used eight flow meters for this experiment. However, in this article, we discuss the results of only four of the meters — a propeller flow meter, a paddlewheel meter, a Collins pitot meter and a Hall pitot meter. The propeller meter was a strap-on saddle meter installed by cutting a hole in the pipe, inserting the propeller into the hole and strapping the meter onto the pipe. The paddle-wheel meter consisted of a paddle wheel mounted at the end of a metal stem and inserted 1.5 inches into the top of the pipe. The Hall and Collins meters measured the flow rate across the horizontal diameter of the pipe.

The propeller meter, Hall meter and Collins meter were classified as velocity-integrating meters because they responded to some type of integration of the water velocity across the pipe cross-sectional area. The paddle-wheel meter was classified as a point-velocity meter because its flow rate readings were based on the water velocity at a point within the pipe cross-sectional area.

There were nine flow conditions studied in this project:

1. Control. Flow rate measurements were made at 9- and 22-pipe-diameter distances downstream from a 90-degree elbow.

2. Check valve. This disk type valve was installed in such a way that the disk was at the top of the pipe during water flow.

3. Partially closed butterfly valve. The stem of the valve deviated about 10 degrees from the vertical. This was necessary because the valve stem extended beyond the bottom of the valve and therefore the test pipe. The test section could not be raised to accommodate this extension.

4. 90-degree elbow. The elbow was installed with the bend in the horizontal plane.

5. Butterfly valve and elbow. The 90-degree elbow was installed immediately upstream from the partially closed valve.

6. Single vane and butterfly valve. A straightening vane was installed immediately downstream from a partially closed butterfly valve.

7. Six vanes and butterfly valve. The straightening vanes were inserted 1-pipe diameter downstream from a partially closed butterfly valve.

8. Six vanes and elbows. The straightening vanes were inserted 1-pipe diameter downstream from a 90-degree elbow.

9. Six vanes, butterfly valve and elbow. The straightening vanes were inserted 1-pipe diameter downstream from a 90-degree elbow and a partially closed butterfly valve.

Tank measurements

The difference between the individual flow rate measurements and the average flow rate (average of the two volumetric tank measurements) was less than 1% for 81% of the volumetric tank measurements and less than 1.25% for 91% of the individual measurements. The maximum difference was 3.6%. The percent difference decreased as the average flow rate increased. The standard error of the mean of the two measurements was 4.7 gallons per minute.

Control condition

Figure 1 shows the water velocity profiles across the pipe diameter at 9-pipe diameters to be uniform until the pipe wall was approached. As would be expected, smaller velocities occurred adjacent to the pipe wall. Similar behavior occurred at 22-pipe diameters.

Average errors under the control condition were 1.6% for the propeller meter, 1.2% for the paddle-wheel

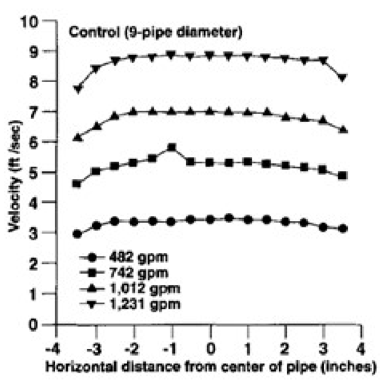


Fig. 1. Water velocity profiles under control conditions.

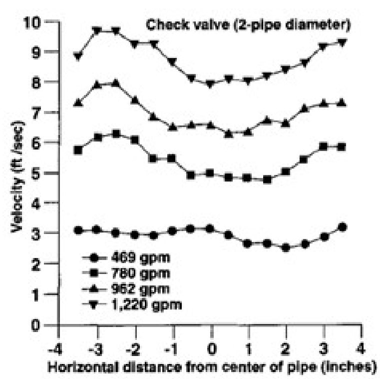


Fig. 2. Water velocity profiles under a check valve.

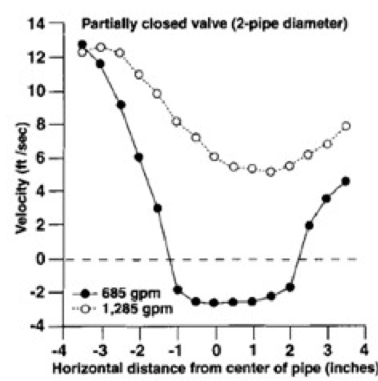


Fig. 3. Water velocity profiles under a partially closed butterfly valve.

meter, -0.9% for the Hall meter and 0.5% for the Collins meter. The average control error for the propeller meter was statistically different from zero at a level of significance of 0.05 because of the small standard deviation. The average control errors of the Hall and Collins meters and the paddle-wheel meter were not statistically different from zero.

We used the control errors to help interpret the results of the tests made under the various conditions. Turbulence was assumed to have little effect on the flow meter reading when the actual error was about equal to the average control error. Where a sufficient number of tests existed for a particular condition, the errors were statistically compared with the control errors.

Check valve

At 2-pipe diameters, larger water velocities occurred near the edges of the pipe for all flow rates except for the smallest (fig. 2). At 5- and 10-pipe diameters (not shown), velocity profiles were similar to the control profiles.

Errors similar to the average control error generally occurred for the propeller and Hall meters (table 1). Little or no trend in error occurred with increasing downstream distance for the propeller meter. For the Collins meter, larger errors occurred at 2-pipe diameters for each flow rate compared with the other downstream distances.

Errors were generally large relative to the control errors for the paddle-wheel meter, with a trend of decreasing error with increasing downstream distance.

Average errors were calculated for each flow meter at each downstream distance since no trend with flow rate appeared to exist in the error data. Differences between these average errors and the control errors were statistically significant at all downstream distances for the paddle-wheel meter. Differences were not statistically significant for the propeller meter, the Hall meter and the Collins meter.

These results indicate that the velocity-integrating meters were not adversely affected by the turbulence caused by the check valve. The point-velocity meter, however, would be affected by the turbulence, depending on the location of the meter's sensor with respect to the water velocity profile.

TABLE 1. Check valve errors

Pipe diameters	Propeller Flow rate	Propeller Error	Paddle-wheel Flow rate	Paddle-wheel Error	Collins Flow rate	Collins Error	Hall Flow rate	Hall Error
	gal/min	%	gal/min	%	gal/min	%	gal/min	%
2	470	−1.1	464	3.7	470	−12.6	478	0.8
5	—	—	485	−13.4	467	−2.6	468	2.9
10	—	—	470	−4.3	486	−4.5	479	1.5
2	734	3.8	762	−28.4	738	5.8	766	1.2
5	—	—	757	−7.6	771	−3.4	779	−2.9
10	—	—	738	−2.6	761	−3.3	776	2.6
2	969	0.9	980	−25.6	969	4.7	997	−2.9
5	—	—	976	−6.9	981	−1.3	961	3.2
10	—	—	969	−3.1	956	0.6	984	−3.2
2	1,224	2	1,244	−28.5	1,155	8.2	1,197	1
5	—	—	1,183	−4.6	1,165	3.4	1,219	2.8
10	—	—	1,155	1	1,179	1.3	1,185	3.6

TABLE 2. Butterfly valve errors

Pipe diameters	Propeller Flow rate	Propeller Error	Paddle-wheel Flow rate	Paddle-wheel Error	Collins Flow rate	Collins Error	Hall Flow rate	Hall Error
	gal/min	%	gal/min	%	gal/min	%	gal/min	%
2	393	14.2	—	—	—	—	—	—
5	395	8.6	—	—	—	—	—	—
10	392	7.9	—	—	—	—	—	—
15	391	7.9	—	—	—	—	—	—
2	677	15.1	541	29.4	558	4.2	554	0.5
5	682	8.1	549	−3.5	540	1.1	542	−1.3
10	684	7.4	539	2.8	545	0.7	553	−1.6
15	647	10.5	558	−8.6	562	−2.1	540	0
2	1,289	2.4	987	33.6	976	8	987	−11.2
5	1,273	2.8	969	3.1	976	−0.6	969	−3.1
10	1,284	2.8	985	−4.7	1,000	0.1	985	−3.8
15	1,281	3.6	971	−1.2	971	0.1	971	3.68

Partially closed butterfly valve

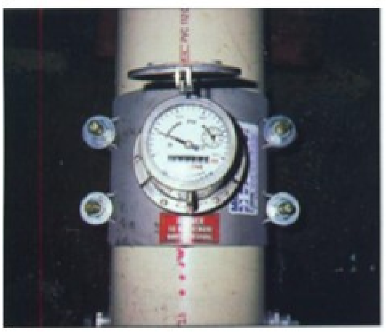
The velocity profiles at 2-pipe diameters (fig. 3) show relatively large velocities near the pipe wall for the smallest flow rate caused by jetting around the valve disk and negative velocities along the middle of the pipe cross section, indicating an eddy. At the larger flow rate, however, there was much less turbulence and no eddy existed. The differences in the velocity profiles at 2-pipe diameters indicate that the flow geometry differed between the two flow rates.

At downstream distances of 5- and 10-pipe diameters (not shown), velocities were relatively uniform and similar across the horizontal pipe diameter. However, the possibility exists that the normalized profile in the vertical cross section may not be uniform.

For the propeller meter, relatively large errors occurred compared with the average control error for all downstream distances except for the largest flow rate (table 2). The largest errors occurred at 2-pipe diameters. Smaller errors relatively constant with distance occurred for the other downstream distances.

At the largest flow rates, small errors occurred for the propeller meter regardless of downstream distance. This behavior is an experimental artifact caused by increasing the valve opening to obtain the larger flow rate, which greatly changed the flow geometry. Thus, at these flow rates, during which the valve was 70% open, the

***Above*, propeller flow meter, the most common flow meter used for irrigation pumping plants. *Below*, flow meter installed in test section used for this study.**



turbulence caused by the valve had little effect on the flow-meter readings.

Large errors also occurred at 2-pipe diameters for the paddle-wheel meter for the middle and largest flow rates. For the other downstream distances, much smaller errors were found, fluctuating between positive and negative values. However, caution should be used in assuming that these small errors indicate that this meter is particularly accurate under this flow condition. These results reflect the point-velocity characteristic of the meter, which depends on the location of the paddle wheel relative to the velocities across the pipe cross-sectional area.

Interestingly, relatively small errors occurred for the Collins and Hall meters, with no apparent trend with downstream distance or flow rate. One would not expect these small errors, given the amount of turbulence for this flow condition. Errors fluctuated between positive and negative values with downstream distance.

The average error of each group of flow rates was determined for each flow meter and then compared with the average control error. For the propeller meter, differences between these errors were statistically significant for the smaller flow rates but not for the largest flow rate. For the Collins and Hall meters, differences were not statistically significant for all flow rates. Mixed results occurred for the paddle-wheel meter.

These results suggest that turbulence from a partially closed valve can substantially affect the flow meter reading, particularly at small downstream distances from the valve such as 2-pipe diameters.

90-degree elbow

Higher water velocities occurred along the right side of the pipe at 2-pipe diameters, reflecting larger water velocities along the outer edge of the elbow (not shown). At 5- and 10-pipe diameters, however, uniform profiles were found across the pipe diameter (not shown).

The results showed that small errors were caused by the turbulence from the elbow. Little or no trend in error with either downstream distance or flow rate occurred for each flow meter.

The average error for each group of flow rates was compared with the average control error. Differences in the average errors were not statistically significant for the propeller meter. Differences in the errors were statistically significant at all flow rates for the paddle-wheel meter, where negative but small errors occurred in contrast with a positive average control error. For the other flow meters, mixed results occurred for the statistical tests, with differences not significant at 2-pipe diameters but significant at 15-pipe diameters.

The results of these data suggest that the elbow did not adversely affect the flow meters' performance. This is particularly true for the velocity-integrating meters. However, a point-velocity meter at 2-pipe diameters positioned on the right-hand side of pipe would read differently from one positioned on the left-hand side because of differences in water velocity.

Butterfly valve and elbow

At 2-pipe diameters, an eddy existed along the right side of the pipe for the smallest flow rate (fig. 4), similar to that of the valve only, while at 5- and 10-pipe diameters (not shown), a trend of increasing velocity occurred from left to right across the pipe. The magnitude of the trend decreased as the downstream distance increased, although the trend was reversed for the middle flow rate at 10-pipe diameters. For the largest flow rates, profiles were very different compared to the smallest flow rate.

Very large errors generally occurred at 2-pipe diameters for all flow meters except at the largest flow rates, for which only the propeller meter was used (table 3). The error relative to length of straight pipe downstream from the flow meter differed among the meters. For the propeller meters, errors of the smallest flow rates were relatively constant regardless of downstream distance. Errors tended to decrease with distance for the middle group of flow rates. The average error of each group of flow rates was statistically different from the average control error for the meter, except for the largest flow rate. As with the valve-

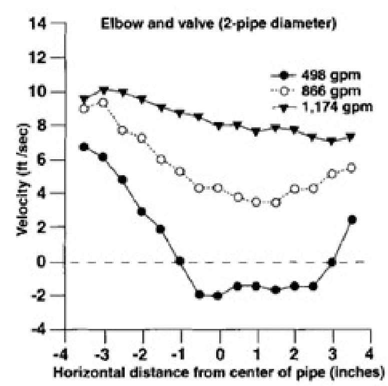


Fig. 4. Water velocity profiles under an elbow and a partially closed butterfly valve.

only condition, the small errors of the largest flow rates reflect opening the valve to obtain the largest flow rates.

The paddle-wheel meter, Collins meter and Hall meter showed a trend of decreasing error with increasing downstream distance for both groups of flow rates. Very large errors occurred at 2-pipe diameters. Some fluctuation between positive and negative errors occurred for the smallest flow rates. The fluctuation of the errors of these meters prevented grouping tests together to obtain a sample size needed to conduct statistical tests on the differences of average values compared with the average control errors.

TABLE 3. Elbow and butterfly valve errors

Pipe diameters	Propeller		Paddle-wheel		Collins		Hall	
	Flow rate	Error	Flow rate	Error	Flow rate	Error	Flow rate	Error
	gal/min	%	gal/min	%	gal/min	%	gal/min	%
2	368	28	434	84.3	393	17.5	412	-37.9
5	383	28.9	432	-20.2	366	12.3	396	14.6
10	419	21.9	366	14.8	432	-0.9	440	-18.4
15	372	20.2	393	6.4	434	-0.9	410	1
2	875	11.6	929	30.1	832	13.6	877	-11.8
5	840	16.3	902	1.9	895	-1.7	937	-7.5
10	899	6.7	895	-4	902	-0.1	931	-1.5
15	869	9.8	932	-4.6	929	-5.1	922	-3.5
2	1,156	0.2	—	—	—	—	—	—
5	1,189	-1.7	—	—	—	—	—	—
10	1,190	-0.4	—	—	—	—	—	—
15	1,159		—	—	—	—	—	—

Straightening vanes

Straightening vanes installed upstream of the flow meter are used to reduce excessive turbulence. We investigated the effects of two commercially available straightening-vane arrangements on the readings of some of the flow meters. One arrangement was a single steel plate, 6 inches wide by 7 inches long, mounted vertically inside the pipe. The other was an arrangement of six vanes installed radially across the pipe cross section. Each of the six vanes was 3 inches long and 3.5 inches wide.

Single vane and butterfly valve. The velocity profile for the smallest flow rate at 2-pipe diameters is considerably different for the single vane and the butterfly valve than that for the butterfly valve only (fig. 5). Velocities were largest in the middle of the pipe where previously an eddy existed. As the flow rate increased, the turbulence lessened, with a relatively uniform profile at the largest flow rate. At 5-pipe diameters (not shown), relatively uniform profiles occurred at all flow rates across the horizontal pipe diameter.

Large errors were found for all flow meters at 2-pipe diameters (table 4). Errors of the propeller meter were larger than the errors for the butterfly valve only, except at the largest flow rate. Thus the single vane increased the error in the flow meter measurements at 2-pipe diameters. Errors were less at 5-pipe diameters, but were still excessive for the propeller flow meter except at the highest flow rates.

TABLE 4. Errors with straightening vanes

Pipe diameters	Propeller		Paddle-wheel		Collins		Hall	
	Flow rate	Error	Flow rate	Error	Flow rate	Error	Flow rate	Error
	gal/min	%	gal/min	%	gal/min	%	gal/min	%
			Butterfly valve and single vane					
2	391	26	368	19.6	360	-19.1	390	8.7
5	384	17.2	360	19.4	368	-4.1	365	-2.5
2	664	8	643	56.6	636	-11	661	7.7
5	640	17.6	636	2.2	643	0	647	6.5
2	1,147	-3.5	1,156	21.6	1,149	5.2	1,140	-9.9
5	1,104	0.9	1,149	-1.7	1,156	-2.6	1,119	2
			Butterfly valve and 6 vanes					
2	436	10.1	362	10.5	355	16.3	446	18.8
5	362	-0.6	417	-11.3	446	-5.6	355	4.8
2	866	4.7	831	37	860	4.8	864	-12.6
5	881	3.2	866	7.3	864	0.8	860	-5.5
2	1,242	2.1	1,216	23.2	1,253	1.6	1,199	-12.7
5	1,232	3	1,270	-5.2	1,199	0	1,253	-12.1
			Butterfly valve, elbow and 6 vanes					
2	490	17.6	423	-7.8	382	13.1	404	29
5	42	8.8	409	-2.2	404	6.9	382	3.4
10	361	10.3		—		—		—
2	915	3.9	924	21.2	880	2.9	949	-12.8
5	840	4.6	902	-60	949	-5.9	880	-2.5
10	843	4.7	—	—	—	—		—
2	1,196	-7.4	1203	-3.8	1,204	-0.8	1,204	-6.4
5	1,078	3.1	1226	-18.5	1,204	5.9	1,204	-7.7
10	1,084	3.1	—	—		—	—	—

For the paddle-wheel meter, large errors occurred at 2-pipe diameters for all flow rates. No trend in decreasing error with increasing flow rate was found at 2-pipe diameters. Errors were smaller at 5-pipe diameters. Errors for the Collins and Hall meters were also larger than those for the valve-only condition.

Six vanes and butterfly valve. Turbulence was much less for the valve and the six-vane arrangement at 2-pipe diameters for all flow rates compared with the single-vane ar-

Attachment 3

Metergate Tables

ITRC Water Measurement Tables for

ROUND (Armco-Type) Gates on Round Pipes

Discharge Values in CFS

Normal submerged metergate operation

ITRC Water Measurement Tables – 12" Armco-Type Gate, Stilling Well Located 12" d/s of Back of Gate [Blue center represents best accuracy range]

ΔH (feet)	Net Gate Opening (feet)																	
	0.042	0.08	0.13	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00
0.08	0.07	0.16	0.25	0.34	0.42	0.48	0.55	0.61	0.67	0.73	0.79	0.85	0.97	1.10	1.20	1.27	1.32	1.34
0.10	0.08	0.18	0.28	0.38	0.47	0.54	0.61	0.68	0.75	0.81	0.89	0.96	1.09	1.23	1.34	1.42	1.47	1.50
0.13	0.09	0.20	0.31	0.42	0.51	0.59	0.67	0.74	0.82	0.89	0.97	1.05	1.19	1.35	1.46	1.56	1.61	1.64
0.15	0.09	0.21	0.33	0.45	0.55	0.64	0.72	0.80	0.88	0.96	1.05	1.13	1.28	1.46	1.58	1.68	1.74	1.77
0.17	0.10	0.23	0.36	0.49	0.59	0.68	0.77	0.86	0.94	1.03	1.12	1.21	1.37	1.56	1.69	1.80	1.86	1.89
0.19	0.10	0.24	0.38	0.52	0.63	0.72	0.82	0.91	1.00	1.09	1.19	1.28	1.46	1.66	1.79	1.91	1.98	2.01
0.21	0.11	0.25	0.40	0.54	0.66	0.76	0.87	0.96	1.06	1.15	1.25	1.35	1.53	1.74	1.89	2.01	2.08	2.12
0.23	0.12	0.26	0.42	0.57	0.69	0.80	0.91	1.00	1.11	1.20	1.31	1.42	1.61	1.83	1.98	2.11	2.19	2.22
0.25	0.12	0.28	0.44	0.60	0.72	0.84	0.95	1.05	1.16	1.26	1.37	1.48	1.68	1.91	2.07	2.21	2.28	2.32
0.27	0.13	0.29	0.45	0.62	0.75	0.87	0.99	1.09	1.20	1.31	1.43	1.54	1.75	1.99	2.16	2.30	2.38	2.41
0.29	0.13	0.30	0.47	0.64	0.78	0.90	1.02	1.13	1.25	1.36	1.48	1.60	1.82	2.06	2.24	2.38	2.47	2.50
0.31	0.14	0.31	0.49	0.67	0.81	0.94	1.06	1.17	1.29	1.41	1.53	1.66	1.88	2.14	2.32	2.47	2.55	2.59
0.33	0.14	0.32	0.50	0.69	0.84	0.97	1.09	1.21	1.34	1.45	1.58	1.71	1.94	2.21	2.39	2.55	2.64	2.68
0.35	0.14	0.33	0.52	0.71	0.86	1.00	1.13	1.25	1.38	1.50	1.63	1.76	2.00	2.27	2.46	2.63	2.72	2.76
0.38	0.15	0.34	0.53	0.73	0.89	1.03	1.16	1.28	1.42	1.54	1.68	1.81	2.06	2.34	2.54	2.70	2.80	2.84
0.40	0.15	0.35	0.55	0.75	0.91	1.05	1.19	1.32	1.46	1.58	1.73	1.86	2.12	2.40	2.61	2.78	2.87	2.92
0.42	0.16	0.36	0.56	0.77	0.93	1.08	1.22	1.35	1.49	1.62	1.77	1.91	2.17	2.47	2.67	2.85	2.95	2.99
0.46	0.16	0.37	0.59	0.81	0.98	1.13	1.28	1.42	1.57	1.70	1.86	2.00	2.28	2.59	2.80	2.99	3.09	3.14
0.50	0.17	0.39	0.62	0.84	1.02	1.18	1.34	1.48	1.64	1.78	1.94	2.09	2.38	2.70	2.93	3.12	3.23	3.28
0.54	0.18	0.41	0.64	0.88	1.06	1.23	1.40	1.54	1.70	1.85	2.02	2.18	2.47	2.81	3.05	3.25	3.36	3.41
0.58	0.19	0.42	0.66	0.91	1.10	1.28	1.45	1.60	1.77	1.92	2.10	2.26	2.57	2.92	3.16	3.37	3.49	3.54
0.63	0.19	0.44	0.69	0.94	1.14	1.32	1.50	1.66	1.83	1.99	2.17	2.34	2.66	3.02	3.27	3.49	3.61	3.67
0.67	0.20	0.45	0.71	0.97	1.18	1.37	1.55	1.71	1.89	2.06	2.24	2.42	2.75	3.12	3.38	3.60	3.73	3.79
0.71	0.20	0.46	0.73	1.00	1.22	1.41	1.60	1.76	1.95	2.12	2.31	2.49	2.83	3.22	3.49	3.71	3.84	3.90
0.75	0.21	0.48	0.75	1.03	1.25	1.45	1.64	1.82	2.00	2.18	2.38	2.56	2.91	3.31	3.59	3.82	3.96	4.02
0.79	0.22	0.49	0.77	1.06	1.29	1.49	1.69	1.87	2.06	2.24	2.44	2.63	2.99	3.40	3.68	3.93	4.06	4.13
0.83	0.22	0.50	0.79	1.09	1.32	1.53	1.73	1.91	2.11	2.30	2.50	2.70	3.07	3.49	3.78	4.03	4.17	4.23
0.92	0.23	0.53	0.83	1.14	1.39	1.60	1.82	2.01	2.22	2.41	2.63	2.83	3.22	3.66	3.97	4.22	4.37	4.44
1.00	0.24	0.55	0.87	1.19	1.45	1.67	1.90	2.10	2.31	2.52	2.74	2.96	3.36	3.82	4.14	4.41	4.57	4.64
1.08	0.25	0.57	0.91	1.24	1.51	1.74	1.97	2.18	2.41	2.62	2.86	3.08	3.50	3.98	4.31	4.59	4.75	4.83
1.17	0.26	0.60	0.94	1.29	1.56	1.81	2.05	2.26	2.50	2.72	2.96	3.20	3.63	4.13	4.47	4.77	4.93	5.01
1.25	0.27	0.62	0.97	1.33	1.62	1.87	2.12	2.34	2.59	2.81	3.07	3.31	3.76	4.27	4.63	4.93	5.11	5.19
1.33	0.28	0.64	1.00	1.37	1.67	1.93	2.19	2.42	2.67	2.91	3.17	3.42	3.88	4.41	4.78	5.09	5.27	5.36
1.42	0.29	0.66	1.04	1.42	1.72	1.99	2.26	2.50	2.75	3.00	3.27	3.52	4.00	4.55	4.93	5.25	5.44	5.52
1.50	0.30	0.68	1.07	1.46	1.77	2.05	2.32	2.57	2.83	3.08	3.36	3.63	4.12	4.68	5.07	5.40	5.59	5.68
1.58	0.30	0.69	1.09	1.50	1.82	2.11	2.39	2.64	2.91	3.17	3.45	3.73	4.23	4.81	5.21	5.55	5.75	5.84
1.67	0.31	0.71	1.12	1.54	1.87	2.16	2.45	2.71	2.99	3.25	3.54	3.82	4.34	4.93	5.35	5.70	5.90	5.99
1.75	0.32	0.73	1.15	1.57	1.91	2.21	2.51	2.77	3.06	3.33	3.63	3.92	4.45	5.06	5.48	5.84	6.04	6.14
1.83	0.33	0.75	1.18	1.61	1.96	2.27	2.57	2.84	3.13	3.41	3.71	4.01	4.55	5.18	5.61	5.97	6.18	6.28
1.92	0.34	0.76	1.20	1.65	2.00	2.32	2.63	2.90	3.20	3.48	3.80	4.10	4.66	5.29	5.73	6.11	6.32	6.42
2.00	0.34	0.78	1.23	1.68	2.05	2.37	2.68	2.96	3.27	3.56	3.88	4.19	4.76	5.41	5.86	6.24	6.46	6.56
2.08	0.35	0.80	1.26	1.72	2.09	2.42	2.74	3.03	3.34	3.63	3.96	4.27	4.85	5.52	5.98	6.37	6.59	6.69
2.17	0.36	0.81	1.28	1.75	2.13	2.46	2.79	3.09	3.41	3.70	4.04	4.36	4.95	5.63	6.10	6.49	6.72	6.83
2.25	0.36	0.83	1.31	1.79	2.17	2.51	2.84	3.14	3.47	3.78	4.11	4.44	5.04	5.73	6.21	6.62	6.85	6.96
2.33	0.37	0.84	1.33	1.82	2.21	2.56	2.90	3.20	3.53	3.84	4.19	4.52	5.14	5.84	6.33	6.74	6.98	7.09
2.42	0.38	0.86	1.35	1.85	2.25	2.60	2.95	3.26	3.60	3.91	4.26	4.60	5.23	5.94	6.44	6.86	7.10	7.21
2.50	0.38	0.87	1.38	1.88	2.29	2.65	3.00	3.31	3.66	3.98	4.34	4.68	5.32	6.04	6.55	6.98	7.22	7.33
2.58	0.39	0.89	1.40	1.91	2.33	2.69	3.05	3.37	3.72	4.05	4.41	4.76	5.40	6.14	6.66	7.09	7.34	7.45
2.67	0.40	0.90	1.42	1.94	2.36	2.73	3.10	3.42	3.78	4.11	4.48	4.84	5.49	6.24	6.76	7.20	7.46	7.57
2.75	0.40	0.91	1.44	1.97	2.40	2.78	3.15	3.48	3.84	4.17	4.55	4.91	5.58	6.34	6.87	7.32	7.57	7.69
2.83	0.41	0.93	1.46	2.00	2.44	2.82	3.19	3.53	3.89	4.24	4.62	4.98	5.66	6.43	6.97	7.43	7.69	7.81

ITRC Water Measurement Tables – 18" Armco-Type Gate, Stilling Well Located 12" d/s of Back of Gate [Blue center represents best accuracy range]

ΔH (feet)	Net Gate Opening (feet)																							
	0.042	0.08	0.13	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33	1.42	1.50
0.04	0.07	0.16	0.25	0.35	0.44	0.52	0.61	0.68	0.75	0.81	0.87	0.93	1.05	1.17	1.29	1.40	1.54	1.67	1.81	1.95	2.05	2.14	2.17	2.17
0.06	0.08	0.20	0.31	0.43	0.54	0.64	0.74	0.84	0.92	1.00	1.07	1.14	1.29	1.43	1.58	1.72	1.88	2.05	2.22	2.39	2.51	2.62	2.66	2.66
0.08	0.10	0.23	0.36	0.50	0.62	0.74	0.86	0.96	1.06	1.15	1.24	1.31	1.49	1.65	1.82	1.98	2.18	2.36	2.57	2.76	2.90	3.02	3.07	3.07
0.10	0.11	0.25	0.40	0.56	0.70	0.83	0.96	1.08	1.19	1.29	1.38	1.47	1.67	1.85	2.04	2.22	2.43	2.64	2.87	3.09	3.24	3.38	3.43	3.43
0.13	0.12	0.28	0.44	0.61	0.76	0.91	1.05	1.18	1.30	1.41	1.51	1.61	1.83	2.03	2.23	2.43	2.66	2.89	3.14	3.38	3.55	3.70	3.76	3.76
0.15	0.13	0.30	0.48	0.66	0.82	0.98	1.13	1.28	1.40	1.52	1.63	1.73	1.97	2.19	2.41	2.62	2.88	3.12	3.39	3.65	3.84	4.00	4.06	4.06
0.17	0.14	0.32	0.51	0.70	0.88	1.05	1.21	1.36	1.50	1.63	1.75	1.85	2.11	2.34	2.58	2.80	3.08	3.34	3.63	3.90	4.10	4.27	4.34	4.34
0.19	0.15	0.34	0.54	0.75	0.93	1.11	1.28	1.45	1.59	1.73	1.85	1.97	2.24	2.48	2.74	2.97	3.26	3.54	3.85	4.14	4.35	4.53	4.60	4.61
0.21	0.15	0.36	0.57	0.79	0.98	1.17	1.35	1.52	1.68	1.82	1.95	2.07	2.36	2.62	2.88	3.13	3.44	3.74	4.06	4.36	4.58	4.78	4.85	4.85
0.23	0.16	0.37	0.60	0.82	1.03	1.23	1.42	1.60	1.76	1.91	2.05	2.17	2.47	2.74	3.02	3.29	3.61	3.92	4.25	4.58	4.81	5.01	5.08	5.09
0.25	0.17	0.39	0.62	0.86	1.08	1.28	1.48	1.67	1.84	2.00	2.14	2.27	2.58	2.87	3.16	3.43	3.77	4.09	4.44	4.78	5.02	5.23	5.31	5.32
0.27	0.17	0.41	0.65	0.90	1.12	1.34	1.54	1.74	1.91	2.08	2.23	2.36	2.69	2.98	3.29	3.57	3.92	4.26	4.62	4.98	5.23	5.44	5.53	5.54
0.29	0.18	0.42	0.67	0.93	1.16	1.39	1.60	1.80	1.99	2.16	2.31	2.45	2.79	3.10	3.41	3.71	4.07	4.42	4.80	5.16	5.42	5.65	5.74	5.74
0.31	0.19	0.44	0.70	0.96	1.20	1.44	1.66	1.87	2.06	2.23	2.39	2.54	2.89	3.20	3.53	3.84	4.21	4.57	4.97	5.35	5.62	5.85	5.94	5.95
0.33	0.19	0.45	0.72	0.99	1.24	1.48	1.71	1.93	2.12	2.30	2.47	2.62	2.98	3.31	3.65	3.96	4.35	4.72	5.13	5.52	5.80	6.04	6.13	6.14
0.35	0.20	0.46	0.74	1.02	1.28	1.53	1.76	1.99	2.19	2.38	2.55	2.70	3.07	3.41	3.76	4.09	4.48	4.87	5.29	5.69	5.98	6.23	6.32	6.33
0.38	0.21	0.48	0.76	1.05	1.32	1.57	1.82	2.05	2.25	2.44	2.62	2.78	3.16	3.51	3.87	4.20	4.61	5.01	5.44	5.86	6.15	6.41	6.50	6.51
0.40	0.21	0.49	0.78	1.08	1.36	1.62	1.87	2.10	2.31	2.51	2.69	2.86	3.25	3.61	3.98	4.32	4.74	5.15	5.59	6.02	6.32	6.58	6.68	6.69
0.42	0.22	0.50	0.81	1.11	1.39	1.66	1.91	2.16	2.37	2.58	2.76	2.93	3.33	3.70	4.08	4.43	4.86	5.28	5.74	6.17	6.48	6.75	6.86	6.87
0.46	0.23	0.53	0.84	1.17	1.46	1.74	2.01	2.26	2.49	2.70	2.90	3.08	3.50	3.88	4.28	4.65	5.10	5.54	6.02	6.47	6.80	7.08	7.19	7.20
0.50	0.24	0.55	0.88	1.22	1.52	1.82	2.10	2.36	2.60	2.82	3.03	3.21	3.65	4.05	4.47	4.85	5.33	5.79	6.28	6.76	7.10	7.40	7.51	7.52
0.54	0.25	0.57	0.92	1.27	1.59	1.89	2.18	2.46	2.71	2.94	3.15	3.34	3.80	4.22	4.65	5.05	5.55	6.02	6.54	7.04	7.39	7.70	7.82	7.83
0.58	0.26	0.60	0.95	1.31	1.65	1.96	2.26	2.55	2.81	3.05	3.27	3.47	3.94	4.38	4.83	5.24	5.75	6.25	6.79	7.30	7.67	7.99	8.11	8.12
0.63	0.26	0.62	0.99	1.36	1.70	2.03	2.34	2.64	2.91	3.16	3.38	3.59	4.08	4.53	5.00	5.43	5.96	6.47	7.02	7.56	7.94	8.27	8.40	8.41
0.67	0.27	0.64	1.02	1.41	1.76	2.10	2.42	2.73	3.00	3.26	3.49	3.71	4.22	4.68	5.16	5.61	6.15	6.68	7.25	7.81	8.20	8.54	8.67	8.68
0.71	0.28	0.66	1.05	1.45	1.81	2.16	2.50	2.81	3.10	3.36	3.60	3.82	4.35	4.82	5.32	5.78	6.34	6.89	7.48	8.05	8.45	8.81	8.94	8.95
0.75	0.29	0.68	1.08	1.49	1.87	2.23	2.57	2.89	3.19	3.46	3.71	3.93	4.47	4.96	5.47	5.95	6.53	7.09	7.70	8.28	8.70	9.06	9.20	9.21
0.79	0.30	0.69	1.11	1.53	1.92	2.29	2.64	2.97	3.27	3.55	3.81	4.04	4.59	5.10	5.62	6.11	6.70	7.28	7.91	8.51	8.94	9.31	9.45	9.46
0.83	0.31	0.71	1.14	1.57	1.97	2.35	2.71	3.05	3.36	3.64	3.91	4.15	4.71	5.23	5.77	6.27	6.88	7.47	8.11	8.73	9.17	9.55	9.70	9.71
0.92	0.32	0.75	1.19	1.65	2.06	2.46	2.84	3.20	3.52	3.82	4.10	4.35	4.94	5.49	6.05	6.57	7.21	7.83	8.51	9.15	9.62	10.02	10.17	10.18
1.00	0.34	0.78	1.25	1.72	2.15	2.57	2.97	3.34	3.68	3.99	4.28	4.54	5.16	5.73	6.32	6.86	7.53	8.18	8.89	9.56	10.04	10.46	10.62	10.64
1.08	0.35	0.81	1.30	1.79	2.24	2.67	3.09	3.48	3.83	4.15	4.45	4.73	5.37	5.96	6.58	7.15	7.84	8.52	9.25	9.95	10.45	10.89	11.05	11.07
1.17	0.36	0.84	1.35	1.86	2.33	2.78	3.20	3.61	3.97	4.31	4.62	4.91	5.58	6.19	6.83	7.41	8.14	8.84	9.60	10.33	10.85	11.30	11.47	11.49
1.25	0.37	0.87	1.39	1.92	2.41	2.87	3.32	3.73	4.11	4.46	4.78	5.08	5.77	6.41	7.06	7.68	8.42	9.15	9.93	10.69	11.23	11.70	11.87	11.89
1.33	0.39	0.90	1.44	1.99	2.49	2.97	3.42	3.86	4.25	4.61	4.94	5.25	5.96	6.62	7.30	7.93	8.70	9.45	10.26	11.04	11.60	12.08	12.26	12.28
1.42	0.40	0.93	1.49	2.05	2.56	3.06	3.53	3.98	4.38	4.75	5.09	5.41	6.15	6.82	7.52	8.17	8.97	9.74	10.58	11.38	11.96	12.45	12.64	12.66
1.50	0.41	0.96	1.53	2.11	2.64	3.15	3.63	4.09	4.51	4.89	5.24	5.56	6.32	7.02	7.74	8.41	9.23	10.02	10.88	11.71	12.30	12.81	13.01	13.03
1.58	0.42	0.98	1.57	2.17	2.71	3.23	3.73	4.20	4.63	5.02	5.39	5.72	6.50	7.21	7.95	8.64	9.48	10.30	11.18	12.03	12.64	13.17	13.36	13.38
1.67	0.43	1.01	1.61	2.22	2.78	3.32	3.83	4.31	4.75	5.15	5.53	5.86	6.67	7.40	8.16	8.86	9.73	10.56	11.47	12.34	12.97	13.51	13.71	13.73
1.75	0.44	1.03	1.65	2.28	2.85	3.40	3.92	4.42	4.87	5.28	5.66	6.01	6.83	7.58	8.36	9.08	9.97	10.83	11.75	12.65	13.29	13.84	14.05	14.07
1.83	0.45	1.06	1.69	2.33	2.92	3.48	4.01	4.52	4.98	5.40	5.79	6.15	6.99	7.76	8.56	9.29	10.20	11.08	12.03	12.95	13.60	14.17	14.38	14.40
1.92	0.46	1.08	1.73	2.38	2.98	3.56	4.11	4.62	5.09	5.53	5.93	6.29	7.15	7.93	8.75	9.50	10.43	11.33	12.30	13.24	13.91	14.48	14.70	14.72
2.00	0.47	1.10	1.76	2.43	3.05	3.63	4.19	4.72	5.20	5.64	6.05	6.42	7.30	8.10	8.94	9.71	10.66	11.57	12.57	13.52	14.20	14.80	15.02	15.04
2.08	0.48	1.13	1.80	2.48	3.11	3.71	4.28	4.82	5.31	5.76	6.18	6.56	7.45	8.27	9.12	9.91	10.88	11.81	12.83	13.80	14.50	15.10	15.33	15.35
2.17	0.49	1.15	1.84	2.53	3.17	3.78	4.36	4.92	5.41	5.88	6.30	6.69	7.60	8.44	9.30	10.10	11.09	12.05	13.08	14.07	14.79	15.40	15.63	15.66
2.25	0.50	1.17	1.87	2.58	3.23	3.85	4.45	5.01	5.52	5.99	6.42	6.81	7.75	8.60	9.48	10.30	11.30	12.27	13.33	14.34	15.07	15.69	15.93	15.95
2.33	0.51	1.19	1.91	2.63	3.29	3.93	4.53	5.10	5.62	6.10	6.54	6.94	7.89	8.75	9.65	10.49	11.51	12.50	13.57	14.61	15.34	15.98	16.22	16.25
2.42	0.52	1.21	1.94	2.68	3.35	3.99	4.61	5.19	5.72	6.21	6.65	7.06	8.03	8.91	9.82	10.67	11.71	12.72	13.81	14.86	15.61	16.26	16.51	16.53
2.50	0.53	1.23	1.97	2.72	3.41	4.06	4.69	5.28	5.82	6.31	6.77	7.18	8.16	9.06	9.99	10.85	11.91	12.94	14.05	15.12	15.88	16.54	16.79	16.82
2.58	0.54	1.26	2.01	2.77	3.46	4.13	4.77	5.37	5.91	6.42	6.88	7.30	8.30	9.21	10.16	11.03	12.11	13.15	14.28	15.37	16.14	16.82	17.07	17.09
2.67	0.55	1.28	2.04	2.81	3.52	4.20	4.84	5.45	6.01	6.52	6.99	7.42	8.43	9.36	10.32	11.21	12.30	13.36	14.51	15.61	16.40	17.09	17.34	17.37
2.75	0.56	1.30	2.07	2.85	3.57	4.26	4.92	5.54	6.10	6.62	7.10	7.53	8.56	9.50	10.48	11.38	12.50	13.57	14.73	15.86	16.66	17.35	17.61	17.64
2.83	0.56	1.31	2.10	2.90	3.63	4.33	4.99	5.62	6.19	6.72	7.20	7.65	8.69	9.65	10.64	11.56	12.68	13.77	14.96	16.09	16.91	17.61	17.88	17.90

ITRC Water Measurement Tables – 24" Armco-Type Gate, Stilling Well Located 12" d/s of Back of Gate [Blue center represents best accuracy range]

Net Gate Opening (feet)

ΔH (feet)	0.042	0.08	0.13	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33	1.42	1.50	1.58	1.67	1.75	1.83	1.92	2.00
0.04	0.10	0.22	0.35	0.49	0.61	0.73	0.84	0.95	1.05	1.14	1.23	1.31	1.49	1.65	1.81	1.96	2.14	2.32	2.45	2.57	2.71	2.85	3.01	3.16	3.30	3.51	3.68	3.71	3.77	3.57
0.06	0.12	0.27	0.43	0.60	0.75	0.89	1.03	1.17	1.29	1.40	1.51	1.61	1.82	2.02	2.22	2.40	2.63	2.84	3.00	3.14	3.32	3.49	3.68	3.87	4.04	4.30	4.51	4.54	4.62	4.37
0.08	0.14	0.31	0.50	0.69	0.86	1.03	1.19	1.35	1.49	1.62	1.74	1.85	2.10	2.33	2.56	2.78	3.03	3.28	3.46	3.63	3.84	4.03	4.25	4.47	4.67	4.97	5.20	5.24	5.34	5.04
0.10	0.15	0.35	0.56	0.77	0.96	1.15	1.33	1.51	1.66	1.81	1.95	2.07	2.35	2.61	2.87	3.10	3.39	3.67	3.87	4.06	4.29	4.51	4.76	4.99	5.22	5.56	5.82	5.86	5.97	5.64
0.13	0.17	0.39	0.61	0.84	1.06	1.26	1.46	1.65	1.82	1.98	2.13	2.27	2.58	2.86	3.14	3.40	3.71	4.02	4.24	4.44	4.70	4.94	5.21	5.47	5.72	6.09	6.37	6.42	6.54	6.18
0.15	0.18	0.42	0.66	0.91	1.14	1.36	1.58	1.78	1.97	2.14	2.30	2.45	2.78	3.09	3.39	3.67	4.01	4.34	4.58	4.80	5.07	5.33	5.63	5.91	6.17	6.57	6.88	6.93	7.06	6.67
0.17	0.19	0.44	0.71	0.97	1.22	1.46	1.69	1.91	2.10	2.29	2.46	2.62	2.98	3.30	3.63	3.93	4.29	4.64	4.90	5.13	5.43	5.70	6.02	6.32	6.60	7.03	7.36	7.41	7.55	7.13
0.19	0.20	0.47	0.75	1.03	1.29	1.55	1.79	2.02	2.23	2.43	2.61	2.78	3.16	3.50	3.85	4.17	4.55	4.92	5.20	5.44	5.75	6.05	6.38	6.70	7.00	7.45	7.81	7.86	8.01	7.56
0.21	0.22	0.50	0.79	1.09	1.36	1.63	1.89	2.13	2.35	2.56	2.75	2.93	3.33	3.69	4.05	4.39	4.80	5.19	5.48	5.74	6.07	6.38	6.73	7.06	7.38	7.86	8.23	8.29	8.44	7.97
0.23	0.23	0.52	0.83	1.14	1.43	1.71	1.98	2.23	2.47	2.68	2.89	3.07	3.49	3.87	4.25	4.61	5.03	5.44	5.74	6.02	6.36	6.69	7.05	7.41	7.74	8.24	8.63	8.69	8.85	8.36
0.25	0.24	0.54	0.87	1.19	1.49	1.78	2.07	2.33	2.58	2.80	3.02	3.21	3.65	4.04	4.44	4.81	5.25	5.68	6.00	6.28	6.64	6.98	7.37	7.74	8.08	8.61	9.01	9.08	9.24	8.74
0.27	0.25	0.57	0.90	1.24	1.55	1.86	2.15	2.43	2.68	2.92	3.14	3.34	3.79	4.21	4.62	5.01	5.47	5.92	6.24	6.54	6.92	7.27	7.67	8.05	8.41	8.96	9.38	9.45	9.62	9.09
0.29	0.26	0.59	0.94	1.29	1.61	1.93	2.23	2.52	2.78	3.03	3.26	3.47	3.94	4.37	4.80	5.20	5.67	6.14	6.48	6.79	7.18	7.54	7.96	8.36	8.73	9.30	9.74	9.80	9.98	9.43
0.31	0.26	0.61	0.97	1.33	1.67	2.00	2.31	2.61	2.88	3.13	3.37	3.59	4.08	4.52	4.96	5.38	5.87	6.36	6.71	7.03	7.43	7.81	8.24	8.65	9.04	9.62	10.08	10.15	10.33	9.77
0.33	0.27	0.63	1.00	1.38	1.72	2.06	2.38	2.69	2.97	3.24	3.48	3.71	4.21	4.67	5.13	5.55	6.07	6.56	6.93	7.26	7.67	8.06	8.51	8.93	9.33	9.94	10.41	10.48	10.67	10.09
0.35	0.28	0.65	1.03	1.42	1.78	2.12	2.46	2.78	3.07	3.34	3.59	3.82	4.34	4.81	5.29	5.72	6.25	6.77	7.14	7.48	7.91	8.31	8.77	9.21	9.62	10.25	10.73	10.80	11.00	10.40
0.38	0.29	0.67	1.06	1.46	1.83	2.19	2.53	2.86	3.16	3.43	3.69	3.93	4.46	4.95	5.44	5.89	6.43	6.96	7.35	7.70	8.14	8.55	9.02	9.47	9.90	10.54	11.04	11.12	11.32	10.70
0.40	0.30	0.69	1.09	1.50	1.88	2.25	2.60	2.94	3.24	3.53	3.79	4.04	4.59	5.09	5.59	6.05	6.61	7.15	7.55	7.91	8.36	8.79	9.27	9.73	10.17	10.83	11.34	11.42	11.63	10.99
0.42	0.31	0.70	1.12	1.54	1.93	2.30	2.67	3.01	3.33	3.62	3.89	4.15	4.71	5.22	5.73	6.21	6.78	7.34	7.75	8.11	8.58	9.02	9.51	9.99	10.44	11.11	11.64	11.72	11.93	11.28
0.46	0.32	0.74	1.17	1.61	2.02	2.42	2.80	3.16	3.49	3.80	4.08	4.35	4.94	5.47	6.01	6.51	7.11	7.70	8.12	8.51	9.00	9.46	9.98	10.47	10.94	11.66	12.20	12.29	12.52	11.83
0.50	0.33	0.77	1.22	1.69	2.11	2.52	2.92	3.30	3.64	3.96	4.26	4.54	5.16	5.72	6.28	6.80	7.43	8.04	8.48	8.89	9.40	9.88	10.42	10.94	11.43	12.17	12.75	12.84	13.07	12.35
0.54	0.35	0.80	1.27	1.75	2.20	2.63	3.04	3.44	3.79	4.13	4.44	4.73	5.37	5.95	6.54	7.08	7.73	8.37	8.83	9.25	9.78	10.28	10.85	11.39	11.90	12.67	13.27	13.36	13.61	12.86
0.58	0.36	0.83	1.32	1.82	2.28	2.73	3.15	3.56	3.94	4.28	4.61	4.91	5.57	6.17	6.78	7.35	8.03	8.68	9.16	9.60	10.15	10.67	11.26	11.82	12.35	13.15	13.77	13.87	14.12	13.34
0.63	0.37	0.86	1.37	1.88	2.36	2.82	3.27	3.69	4.07	4.43	4.77	5.08	5.76	6.39	7.02	7.61	8.31	8.99	9.49	9.94	10.51	11.04	11.65	12.23	12.78	13.61	14.25	14.35	14.62	13.81
0.67	0.39	0.89	1.41	1.95	2.44	2.91	3.37	3.81	4.21	4.58	4.92	5.24	5.95	6.60	7.25	7.85	8.58	9.28	9.80	10.26	10.85	11.41	12.03	12.63	13.20	14.06	14.72	14.82	15.10	14.26
0.71	0.40	0.92	1.46	2.01	2.51	3.00	3.48	3.93	4.34	4.72	5.08	5.41	6.14	6.80	7.47	8.10	8.84	9.57	10.10	10.58	11.18	11.76	12.40	13.02	13.61	14.49	15.17	15.28	15.56	14.70
0.75	0.41	0.94	1.50	2.06	2.59	3.09	3.58	4.04	4.46	4.86	5.22	5.56	6.31	7.00	7.69	8.33	9.10	9.85	10.39	10.89	11.51	12.10	12.76	13.40	14.00	14.91	15.61	15.72	16.01	15.13
0.79	0.42	0.97	1.54	2.12	2.66	3.18	3.67	4.15	4.58	4.99	5.37	5.71	6.49	7.19	7.90	8.56	9.35	10.12	10.68	11.18	11.82	12.43	13.11	13.77	14.38	15.32	16.04	16.15	16.45	15.54
0.83	0.43	0.99	1.58	2.18	2.73	3.26	3.77	4.26	4.70	5.12	5.50	5.86	6.66	7.38	8.11	8.78	9.59	10.38	10.95	11.47	12.13	12.75	13.45	14.12	14.76	15.72	16.46	16.57	16.88	15.95
0.92	0.45	1.04	1.66	2.28	2.86	3.42	3.95	4.47	4.93	5.37	5.77	6.15	6.98	7.74	8.50	9.21	10.06	10.88	11.49	12.03	12.72	13.37	14.11	14.81	15.48	16.48	17.26	17.38	17.70	16.73
1.00	0.47	1.09	1.73	2.38	2.99	3.57	4.13	4.67	5.15	5.61	6.03	6.42	7.29	8.08	8.88	9.62	10.51	11.37	12.00	12.57	13.29	13.97	14.74	15.47	16.17	17.22	18.03	18.15	18.49	17.47
1.08	0.49	1.13	1.80	2.48	3.11	3.72	4.30	4.86	5.36	5.84	6.28	6.69	7.59	8.41	9.24	10.01	10.94	11.83	12.49	13.08	13.83	14.54	15.34	16.10	16.83	17.92	18.76	18.90	19.24	18.18
1.17	0.51	1.18	1.87	2.57	3.23	3.86	4.46	5.04	5.57	6.06	6.51	6.94	7.87	8.73	9.59	10.39	11.35	12.28	12.96	13.58	14.35	15.09	15.92	16.71	17.46	18.60	19.47	19.61	19.97	18.87
1.25	0.53	1.22	1.94	2.66	3.34	3.99	4.62	5.22	5.76	6.27	6.74	7.18	8.15	9.04	9.93	10.76	11.75	12.71	13.41	14.05	14.86	15.62	16.48	17.30	18.07	19.25	20.15	20.30	20.67	19.53
1.33	0.55	1.26	2.00	2.75	3.45	4.12	4.77	5.39	5.95	6.47	6.96	7.42	8.42	9.33	10.26	11.11	12.13	13.13	13.85	14.51	15.34	16.13	17.02	17.87	18.67	19.88	20.81	20.96	21.35	20.17
1.42	0.56	1.30	2.06	2.84	3.56	4.25	4.92	5.56	6.13	6.67	7.18	7.64	8.68	9.62	10.57	11.45	12.51	13.53	14.28	14.96	15.82	16.63	17.54	18.42	19.24	20.49	21.46	21.61	22.00	20.79
1.50	0.58	1.33	2.12	2.92	3.66	4.37	5.06	5.72	6.31	6.87	7.39	7.87	8.93	9.90	10.88	11.78	12.87	13.92	14.70	15.40	16.28	17.11	18.05	18.95	19.80	21.09	22.08	22.24	22.64	21.40
1.58	0.59	1.37	2.18	3.00	3.76	4.49	5.20	5.87	6.48	7.06	7.59	8.08	9.17	10.17	11.18	12.10	13.22	14.31	15.10	15.82	16.72	17.58	18.54	19.47	20.34	21.66	22.68	22.84	23.26	21.98
1.67	0.61	1.41	2.24	3.08	3.86	4.61	5.33	6.03	6.65	7.24	7.79	8.29	9.41	10.44	11.47	12.42	13.56	14.68	15.49	16.23	17.16	18.03	19.03	19.97	20.87	22.23	23.27	23.44	23.87	22.55
1.75	0.63	1.44	2.29	3.15	3.95	4.72	5.46	6.17	6.82	7.42	7.98	8.50	9.64	10.69	11.75	12.73	13.90	15.04	15.87	16.63	17.58	18.48	19.50	20.47	21.39	22.77	23.85	24.02	24.46	23.11
1.83	0.64	1.48	2.35	3.23	4.04	4.83	5.59	6.32	6.98	7.59	8.17	8.70	9.87	10.95	12.03	13.03	14.23	15.39	16.25	17.02	17.99	18.91	19.95	20.95	21.89	23.31	24.41	24.58	25.03	23.65
1.92	0.65	1.51	2.40	3.30	4.14	4.94	5.72	6.46	7.13	7.76	8.35	8.89	10.09	11.19	12.30	13.32	14.55	15.74	16.61	17.40	18.40	19.34	20.40	21.42	22.38	23.83	24.96	25.13	25.60	24.19
2.00	0.67	1.54	2.45	3.37	4.22	5.05	5.84	6.60	7.29	7.93	8.53	9.08	10.31	11.43	12.56	13.60	14.86	16.08	16.97	17.78	18.79	19.75	20.84	21.88	22.86	24.35	25.49	25.67	26.15	24.71
2.08	0.68	1.57	2.50	3.44	4.31	5.15	5.96	6.74	7.44	8.09	8.70	9.27	10.52	11.67	12.82	13.88	15.17	16.41	17.32	18.14	19.18	20.16	21.27	22.33	23.33	24.85	26.02	26.20	26.68	25.22
2.17	0.70	1.60	2.55	3.51	4.40	5.25	6.08	6.87	7.58	8.25	8.88	9.45	10.73	11.90	13.07	14.16	15.47	16.73	17.66	18.50	19.56	20.56	21.69	22.77	23.80	25.34	26.53	26.72	27.21	25.72
2.25	0.71	1.63	2.60	3.58	4.48	5.35	6.20	7.00	7.73	8.41	9.05	9.63	10.94	12.13	13.32	14.43	15.76	17.05	18.00	18.85	19.93	20.95	22.11	23.21	24.25	25.82	27.04	27.23	27.73	26.21
2.33	0.72	1.66	2.65	3.64	4.56	5.45	6.31	7.13	7.87	8.56	9.21	9.81	11.14	12.35	13.57	14.69	16.05	17.37	18.33	19.20	20.30	21.34	22.51	23.63	24.69	26.30	27.54	27.73	28.24	26.69
2.42	0.73	1.69	2.69	3.71	4.64	5.55	6.42	7.26	8.01	8.72	9.37	9.98	11.33	12.57	13.81	14.95	16.33	17.67	18.65	19.54	20.66	21.71	22.91	24.05	25.13	26.76	28.02	28.22	28.74	27.16
2.50	0.75	1.72	2.74	3.77	4.72	5.64	6.53	7.38	8.15	8.87	9.53	10.16	11.53	12.78	14.04	15.21	16.61	17.98	18.97	19.87	21.01	22.09	23.30	24.46	25.56	27.22	28.50	28.71	29.23	27.62
2.58	0.76	1.75	2.78	3.83	4.80	5.74	6.64	7.50	8.28	9.01	9.69	10.32	11.72	12.99	14.28	15.46	16.89	18.27	19.29	20.20	21.36	22.45	23.69	24.87	25.98	27.67	28.97	29.18	29.71	28.08
2.67	0.77	1.78	2.83	3.89	4.88	5.83	6.74	7.62	8.41	9.16	9.85	10.49	11.91	13.20	14.50	15.71	17.16	18.56	19.59	20.53	21.70	22.81	24.07	25.27	26.40	28.11	29.44	29.65	30.19	28.53
2.75	0.78	1.81	2.87	3.95	4.95	5.92	6.85	7.74	8.54	9.30	10.00	10.65	12.09	13.41	14.73	15.95	17.42	18.85	19.90	20.84	22.04	23.16	24.44	25.66	26.81	28.55	29.89	30.11	30.66	28.97
2.83	0.80	1.83	2.92	4.01	5.03	6.01	6.95	7.86	8.67	9.44	10.15	10.81	12.27	13.61	14.95	16.19	17.69	19.14	20.20	21.16	22.37	23.51	24.81	26.04	27.21	28.98	30.34	30.56	31.12	29.41

Preliminary Tables for

Round Gates on Round Pipes

Discharge Values in CFS

Normal submerged metergate operation

These tables are from the original ARMCO Flow Measurement Tables and will be replaced as these gate sizes are tested by ITRC

Armco-Type Metergate Tables - Preliminary

8-inch Round Gate

Head Difference (feet)	Net Gate Opening (feet)												
	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.54	0.58	0.63	0.67
	Discharge (CFS)												
0.08	0.27	0.32	0.38	0.42	0.46	0.51	0.55	0.57	0.59	0.61	0.62	0.63	0.64
0.10	0.30	0.36	0.42	0.46	0.51	0.56	0.60	0.63	0.65	0.68	0.70	0.71	0.71
0.13	0.32	0.39	0.46	0.50	0.56	0.61	0.67	0.69	0.72	0.75	0.77	0.78	0.78
0.15	0.35	0.42	0.49	0.54	0.60	0.66	0.72	0.75	0.78	0.81	0.83	0.84	0.85
0.17	0.37	0.44	0.52	0.58	0.64	0.70	0.76	0.80	0.83	0.86	0.89	0.90	0.91
0.19	0.39	0.46	0.54	0.61	0.67	0.74	0.80	0.84	0.88	0.92	0.94	0.96	0.97
0.21	0.41	0.49	0.57	0.64	0.70	0.77	0.85	0.89	0.93	0.96	1.00	1.01	1.02
0.23	0.42	0.51	0.60	0.66	0.74	0.81	0.88	0.93	0.97	1.01	1.04	1.06	1.07
0.25	0.44	0.53	0.62	0.70	0.76	0.84	0.92	0.97	1.02	1.06	1.09	1.11	1.12
0.27	0.46	0.55	0.64	0.72	0.79	0.87	0.95	1.01	1.06	1.10	1.13	1.15	1.16
0.29	0.47	0.57	0.67	0.74	0.82	0.90	0.99	1.05	1.10	1.14	1.18	1.20	1.21
0.31	0.49	0.59	0.69	0.77	0.85	0.93	1.02	1.08	1.14	1.18	1.22	1.24	1.26
0.33	0.50	0.60	0.71	0.79	0.88	0.96	1.05	1.12	10.18	1.22	1.26	1.28	1.30
0.35	0.52	0.62	0.73	0.82	0.90	0.99	1.08	1.15	1.22	1.26	1.30	1.33	1.34
0.38	0.53	0.64	0.75	0.84	0.92	1.02	1.11	1.19	1.25	1.30	1.34	1.37	1.38
0.40	0.54	0.65	0.76	0.86	0.95	1.04	1.14	1.22	1.29	1.34	1.38	1.41	1.42
0.42	0.56	0.67	0.78	0.88	0.97	1.07	1.17	1.25	1.32	1.37	1.42	1.44	1.46
0.46	0.58	0.70	0.81	0.91	1.01	1.12	1.22	1.31	1.38	1.44	1.49	1.52	1.54
0.50	0.60	0.72	0.84	0.95	1.06	1.17	1.27	1.36	1.44	1.50	1.55	1.58	1.60
0.54	0.62	0.75	0.87	0.99	1.10	1.22	1.32	1.42	1.50	1.56	1.61	1.65	1.67
0.58	0.64	0.77	0.90	1.03	1.15	1.26	1.37	1.47	1.55	1.62	1.67	1.71	1.74
0.63	0.66	0.80	0.94	1.06	1.19	1.31	1.42	1.53	1.61	1.68	1.73	1.77	1.80
0.67	0.68	0.82	0.96	1.10	1.22	1.35	1.47	1.58	1.66	1.73	1.79	1.83	1.86
0.71	0.70	0.85	1.00	1.13	1.26	1.39	1.52	1.62	1.71	1.78	1.84	1.88	1.92
0.75	0.72	0.87	1.02	1.16	1.30	1.43	1.56	14.67	1.76	1.84	1.89	1.94	1.97
0.79	0.74	0.90	1.05	1.19	1.33	1.47	1.60	1.72	1.81	1.89	1.94	1.99	2.02
0.83	0.76	0.92	1.08	1.22	1.37	1.51	1.64	1.76	1.85	1.94	1.99	2.04	2.08
0.92	0.79	0.96	1.13	1.28	1.44	1.58	1.72	1.85	1.94	2.03	2.09	2.14	2.18
1.00	0.83	1.01	1.18	1.34	1.50	1.66	1.80	1.93	2.03	2.12	2.18	2.24	2.27
1.08	0.86	1.05	1.23	1.40	1.56	1.72	1.87	2.01	2.12	2.21	2.29	2.33	2.37
1.17	0.89	1.09	1.28	1.45	1.62	1.79	1.94	2.08	2.20	2.29	2.36	2.42	2.46
1.25	0.92	1.13	1.32	1.50	1.68	1.85	2.01	2.16	2.27	2.37	2.44	2.50	2.54
1.33	0.95	1.16	1.37	1.55	1.73	1.91	2.08	2.23	2.35	2.45	2.52	2.58	2.62
1.42	0.98	1.20	1.41	1.60	1.78	1.97	2.14	2.30	2.42	2.52	2.60	2.66	2.71
1.50	1.01	1.23	1.45	1.64	1.84	2.03	2.20	2.36	2.49	2.60	2.68	2.74	2.79

Armco-Type Metergate Tables - Preliminary

15-inch Round Gate

Head Difference (feet)	**Net Gate Opening (feet)**																	
	0.17	**0.21**	**0.25**	**0.29**	**0.33**	**0.38**	**0.42**	**0.46**	**0.50**	**0.58**	**0.67**	**0.75**	**0.83**	**0.92**	**1.00**	**1.08**	**1.17**	**1.25**
	Discharge (CFS)																	
0.08	0.46	0.57	0.66	0.75	0.83	0.91	0.98	1.07	1.14	1.30	1.43	1.58	1.71	1.84	1.94	2.04	2.13	2.18
0.10	0.51	0.62	0.73	0.83	0.92	1.02	1.09	1.19	1.27	1.44	1.59	1.75	1.90	2.05	2.17	2.29	2.38	2.43
0.13	0.55	0.67	0.79	0.91	1.00	1.11	1.19	1.30	1.38	1.57	1.74	1.91	2.08	2.24	2.38	2.51	2.62	2.67
0.15	0.59	0.72	0.85	0.98	1.08	1.19	1.28	1.39	1.49	1.68	1.87	2.06	2.24	2.41	2.57	2.72	2.83	2.90
0.17	0.63	0.77	0.90	1.04	1.15	1.27	1.37	1.48	1.59	1.79	1.99	2.20	2.39	2.58	2.75	2.90	3.03	3.09
0.19	0.67	0.81	0.95	1.10	1.22	1.34	1.45	1.57	1.48	1.89	2.11	2.33	2.54	2.73	2.91	3.07	3.22	3.28
0.21	0.70	0.85	1.00	1.15	1.28	1.41	1.53	1.65	1.76	1.99	2.22	2.45	2.68	2.87	3.07	3.24	3.40	3.46
0.23	0.73	0.89	1.05	1.20	1.33	1.48	1.60	1.73	1.84	2.09	2.33	2.57	2.81	3.01	3.21	3.40	3.57	6.64
0.25	0.76	3.93	1.09	1.25	1.38	1.54	1.67	1.80	1.92	2.18	2.43	2.69	2.93	3.14	3.35	3.54	3.73	3.81
0.27	0.79	0.97	1.13	1.29	1.43	1.60	1.73	1.87	2.00	2.27	2.53	2.80	3.05	3.27	3.49	3.68	3.88	3.97
0.29	0.82	1.00	1.17	1.33	1.48	1.65	1.79	1.94	2.08	2.36	2.63	2.90	3.17	3.39	3.62	3.82	4.01	4.11
0.31	0.85	1.03	1.21	1.37	1.53	1.70	1.85	2.01	2.15	2.44	2.72	3.00	3.28	3.51	3.75	3.96	4.14	4.25
0.33	0.88	1.06	1.25	1.41	1.58	1.75	1.91	2.07	1.22	2.52	2.81	3.10	3.39	3.63	3.87	4.09	4.27	4.39
0.35	0.91	1.09	1.29	1.45	1.63	1.80	1.97	2.13	2.29	2.60	2.90	3.20	3.49	3.74	3.99	4.21	4.40	4.53
0.38	0.93	1.12	1.32	1.49	1.68	1.85	2.03	2.19	2.36	2.68	2.98	3.29	3.59	3.85	4.10	4.33	4.53	4.67
0.40	0.95	1.15	1.35	1.53	1.73	1.90	2.09	2.25	2.42	2.75	3.06	3.38	3.69	3.96	4.21	4.45	4.65	4.80
0.42	0.97	1.18	1.38	1.57	1.77	1.95	2.14	2.31	2.48	2.82	3.14	3.47	3.79	4.06	2.32	4.57	4.77	4.92
0.46	1.01	1.23	1.44	1.64	1.85	2.05	2.24	2.43	2.60	2.96	3.30	3.63	3.97	4.26	4.54	4.79	5.00	5.14
0.50	1.05	1.28	1.50	1.71	1.93	2.14	2.34	2.54	2.72	3.09	3.44	3.79	4.15	4.44	4.74	5.00	5.22	5.36
0.54	1.09	1.33	1.56	1.78	2.01	2.23	2.44	2.64	2.83	3.22	3.58	3.95	4.32	4.62	4.93	5.20	5.43	5.58
0.58	1.13	1.38	1.62	1.85	2.09	2.31	2.53	2.74	2.93	3.34	3.72	4.10	4.48	4.79	5.11	5.40	5.64	5.79
0.63	1.17	1.42	1.68	1.92	2.16	2.39	2.62	2.84	3.03	3.46	2.85	4.25	4.64	4.96	5.29	5.59	5.84	5.99
0.67	1.21	1.46	1.73	1.98	2.23	2.47	2.71	2.93	3.13	3.57	2.98	4.39	4.79	5.13	5.47	5.78	6.03	6.19
0.71	1.24	1.50	1.78	2.04	2.30	2.55	2.79	3.02	3.23	3.68	4.10	4.52	4.93	5.29	5.64	5.95	6.22	6.38
0.75	1.27	1.54	1.83	2.10	2.37	2.62	2.87	3.11	3.33	3.79	4.22	4.65	5.07	5.44	5.80	6.12	6.40	6.56
0.79	1.30	1.58	1.88	2.16	2.43	2.69	2.95	3.19	3.42	3.89	4.34	4.78	5.21	5.59	5.96	6.29	6.58	6.74
0.83	1.33	1.62	1.93	2.22	2.49	2.76	3.03	3.27	3.51	3.99	4.45	4.91	5.35	5.73	6.11	6.46	6.75	6.92
0.92	1.39	1.70	2.03	2.32	2.61	2.90	3.17	3.43	3.68	4.18	4.66	5.14	5.61	6.01	6.41	6.77	7.07	7.26
1.00	1.45	1.78	2.12	2.42	2.73	3.03	3.31	3.59	3.84	4.37	4.87	5.37	5.86	6.29	6.70	7.07	7.39	7.59
1.08	1.50	1.85	2.21	2.52	2.84	3.15	3.45	3.73	4.00	4.55	5.07	5.59	6.10	6.54	6.97	7.36	7.69	7.89
1.17	1.55	1.92	2.29	2.62	2.95	2.37	3.58	3.87	4.15	4.72	5.26	5.80	6.34	6.79	7.24	7.64	7.98	8.19
1.25	1.60	1.99	2.37	2.71	3.05	3.38	3.70	4.01	4.30	4.88	5.44	6.00	6.56	7.03	7.49	7.91	8.26	8.47
1.33	1.65	2.05	2.45	2.80	3.15	3.49	3.82	4.14	4.44	5.04	5.62	6.20	6.77	7.26	7.73	8.17	8.53	8.75
1.42	1.70	2.11	2.52	2.89	3.25	3.60	3.94	4.27	4.57	5.20	5.80	6.39	6.98	7.48	7.97	8.42	8.80	9.02
1.50	1.75	2.17	2.59	2.97	3.34	3.70	4.05	4.39	4.70	5.35	5.96	6.58	7.18	7.69	8.20	8.66	9.05	9.28

Armco-Type Metergate Tables - Preliminary

16-inch Round Gate

Head	Net Gate Opening (feet)																		
Difference	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33
(feet)	Discharge (CFS)																		
0.08	0.49	0.59	0.70	0.79	0.89	0.97	1.05	1.14	1.22	1.37	1.53	1.68	1.83	1.96	2.10	2.24	2.35	2.43	2.47
0.10	0.55	0.66	0.77	0.88	0.98	1.08	1.16	1.27	1.36	1.52	1.70	1.87	2.04	2.19	2.34	2.50	2.63	2.72	2.78
0.13	0.59	0.72	0.84	0.96	1.07	1.18	1.27	1.39	1.48	1.66	1.86	2.04	2.22	2.39	2.56	2.74	2.89	2.98	3.05
0.15	0.63	0.77	0.90	1.03	1.15	1.27	1.37	1.49	1.59	1.79	1.99	2.20	2.40	2.57	2.76	2.96	3.12	3.23	3.31
0.17	0.67	0.82	0.96	1.10	1.23	1.35	1.46	1.59	1.69	1.91	2.12	2.34	2.56	2.74	2.94	3.16	3.31	3.46	3.54
0.19	0.71	0.86	1.02	1.16	1.30	1.43	1.54	1.68	1.79	2.02	2.25	2.48	2.71	2.91	3.11	3.33	3.50	3.66	3.75
0.21	0.75	0.90	1.07	1.21	1.36	1.50	1.62	1.76	1.89	2.13	2.37	2.61	2.85	3.08	3.28	3.50	3.68	3.85	3.95
0.23	0.78	0.94	1.12	1.26	1.42	1.57	1.69	1.84	1.98	2.23	2.49	2.74	2.99	3.23	3.44	3.67	3.86	4.03	4.14
0.25	0.81	0.98	1.16	1.31	1.48	1.64	1.76	1.92	2.06	2.33	2.60	2.86	3.12	3.37	3.59	3.83	4.04	4.20	4.33
0.27	0.84	1.02	1.20	1.36	1.54	1.70	1.84	2.00	2.14	2.43	2.71	2.98	3.25	3.51	3.74	3.99	4.20	4.37	4.51
0.29	0.87	1.06	1.24	1.41	1.59	1.75	1.91	2.08	2.22	2.52	2.81	3.09	3.37	3.64	3.88	4.14	4.36	4.53	4.69
0.31	0.90	1.09	1.28	1.46	1.64	1.81	1.98	2.15	2.30	2.61	2.91	3.20	3.49	3.77	4.02	4.28	4.52	4.69	4.86
0.33	0.93	1.12	1.32	1.51	1.69	1.87	2.05	2.22	2.38	2.69	3.00	3.31	3.61	3.89	4.15	4.42	4.67	4.85	5.02
0.35	0.96	1.15	1.36	1.56	1.74	1.93	2.11	2.29	2.45	2.77	3.09	3.41	3.72	4.01	4.28	4.56	4.81	5.00	5.18
0.38	0.99	1.18	1.40	1.61	1.79	1.99	2.17	2.36	2.52	2.85	3.18	3.51	3.83	4.13	4.40	4.69	4.95	5.15	5.32
0.40	1.02	1.21	1.44	1.65	1.84	2.04	2.23	2.42	2.59	2.93	3.27	3.61	3.94	4.24	4.52	4.82	5.09	5.29	5.46
0.42	1.04	1.24	1.48	1.69	1.89	2.09	2.29	2.48	2.66	3.01	3.36	3.70	4.04	4.35	4.64	4.95	5.22	5.43	5.59
0.46	1.08	1.30	1.55	1.76	1.98	2.19	2.40	2.60	2.79	3.16	3.52	3.88	4.24	4.56	4.87	5.19	5.47	5.69	5.85
0.50	1.12	1.36	1.61	1.83	2.07	2.28	2.50	2.71	2.91	3.30	3.68	4.05	4.42	4.76	5.08	5.42	5.71	5.94	6.10
0.54	1.16	1.41	1.67	1.90	2.15	2.37	2.60	2.82	3.03	3.43	3.83	4.21	4.60	4.96	5.29	5.64	5.95	6.18	6.35
0.58	1.20	1.46	1.73	1.97	2.23	2.46	2.70	2.93	3.14	3.56	3.97	4.37	4.77	5.15	5.49	5.85	6.18	6.41	6.59
0.63	1.24	1.51	1.79	2.04	2.31	2.55	2.80	3.04	3.25	3.69	4.11	4.53	4.94	5.33	5.68	6.06	6.39	6.64	6.82
0.67	1.28	1.56	1.85	2.11	2.39	2.63	2.89	3.14	3.36	3.81	4.25	4.68	5.11	5.50	5.87	6.26	6.60	6.86	7.05
0.71	1.31	1.60	1.90	2.18	2.46	2.71	2.98	3.24	3.46	3.93	4.38	4.82	5.26	5.67	6.05	6.45	6.81	7.07	7.27
0.75	1.34	1.64	1.95	2.24	2.53	2.79	3.07	3.33	3.56	4.04	4.51	4.96	5.41	5.83	6.23	6.64	7.01	7.27	7.48
0.79	1.37	1.68	2.00	2.30	2.60	2.87	3.15	3.42	3.66	4.15	4.63	5.10	5.56	5.99	6.40	6.83	7.20	7.47	7.68
0.83	1.40	1.72	2.05	2.36	2.67	2.95	3.23	3.51	3.75	4.26	4.75	5.23	5.71	6.15	6.56	7.00	7.39	7.67	7.88
0.92	1.46	1.80	2.15	2.48	2.80	3.09	3.39	3.68	3.93	4.46	4.98	5.48	5.98	6.45	6.88	7.34	7.74	8.04	8.26
1.00	1.52	1.88	2.25	2.59	2.92	3.23	3.54	3.84	4.11	4.66	5.20	5.73	6.25	6.74	7.19	7.66	8.09	8.40	8.63
1.08	1.58	1.96	2.34	2.69	3.04	3.36	3.68	4.00	4.28	4.85	5.41	5.96	6.50	7.01	7.48	7.98	8.41	8.74	8.98
1.17	1.64	2.04	2.43	2.79	3.15	3.49	3.82	4.15	4.44	5.03	5.61	6.19	6.75	7.28	7.76	8.27	8.73	9.07	9.32
1.25	1.70	2.11	2.51	2.89	3.26	3.61	3.96	4.29	4.60	5.21	5.81	6.40	6.99	7.54	8.04	8.56	9.04	9.39	9.65
1.33	1.76	2.18	2.59	2.99	3.37	3.73	4.09	4.43	4.75	5.38	6.00	6.61	7.22	7.79	8.30	8.85	9.34	9.70	9.96
1.42	1.81	2.25	2.67	3.08	3.48	3.84	4.22	4.57	4.90	5.55	6.19	6.82	7.44	8.03	8.56	9.13	9.63	10.00	10.27
1.50	1.86	2.31	2.75	3.16	3.58	3.95	4.34	4.70	5.04	5.71	6.37	7.01	7.65	8.25	8.80	9.39	9.90	10.28	10.56

Armco-Type Metergate Tables - Preliminary

20-inch Round Gate

Head Difference (feet)	Net Gate Opening (feet)																						
	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33	1.42	1.50	1.58	1.67
	Discharge (CFS)																						
0.08	0.58	0.73	0.86	0.96	1.10	1.21	1.32	1.43	1.54	1.75	1.92	2.12	2.29	2.48	2.66	2.84	3.01	3.16	3.31	3.44	3.57	3.68	3.71
0.10	0.66	0.81	0.96	1.09	1.23	1.35	1.42	1.60	1.72	1.95	2.16	2.37	2.56	2.77	2.98	3.18	3.37	3.54	3.71	3.86	4.01	4.14	4.19
0.13	0.72	0.88	1.04	1.18	1.35	1.47	1.61	1.74	1.88	2.12	2.35	2.58	2.79	3.03	3.25	3.47	3.69	3.88	4.06	4.23	4.39	4.52	4.61
0.15	0.77	0.95	1.11	1.27	1.44	1.58	1.72	1.87	2.02	2.27	2.52	2.77	3.00	3.26	3.50	3.73	3.95	4.18	3.36	4.55	4.71	4.86	4.97
0.17	0.82	1.01	1.18	1.36	1.53	1.68	1.83	1.99	2.15	2.42	2.69	2.95	3.21	3.48	3.73	3.97	4.20	4.46	4.66	4.85	5.02	5.20	5.31
0.19	0.87	1.07	1.25	1.44	1.62	1.78	1.94	2.11	2.27	2.56	2.86	3.13	3.42	3.69	3.96	4.21	4.45	4.72	4.95	5.15	5.33	5.53	5.65
0.21	0.91	1.12	1.31	1.51	1.70	1.87	2.04	2.21	2.38	2.70	3.02	3.31	3.62	3.89	4.18	4.45	4.70	4.97	5.21	5.43	5.63	5.83	5.95
0.23	0.95	1.17	1.37	1.58	1.78	1.96	2.13	2.31	2.49	2.84	3.16	3.49	3.80	4.08	4.39	4.66	4.95	5.21	5.46	5.70	5.91	6.13	6.24
0.25	0.99	1.22	1.43	1.65	1.85	2.04	2.22	2.41	2.60	2.96	3.30	3.64	3.96	4.26	4.58	4.86	5.16	5.44	5.70	5.95	6.17	6.41	6.52
0.27	1.03	1.27	1.49	1.71	1.92	2.12	2.31	2.51	2.71	3.08	3.44	3.79	4.12	4.44	4.77	5.06	5.37	5.66	5.94	6.20	6.43	6.68	6.80
0.29	1.07	1.31	1.54	1.77	1.99	2.19	2.40	2.61	2.82	3.20	5.56	3.93	4.28	4.60	4.95	5.25	5.57	5.88	6.16	6.43	6.67	6.92	7.08
0.31	1.10	1.35	1.59	1.83	2.06	2.26	2.49	2.70	2.92	3.31	3.68	4.07	4.43	4.76	5.13	5.44	5.77	6.09	6.38	6.65	6.90	7.15	7.32
0.33	1.13	1.39	1.64	1.88	2.12	2.33	2.57	2.79	3.02	3.42	3.80	4.20	4.57	4.92	5.29	5.62	5.96	6.29	6.58	6.87	7.12	7.38	7.56
0.35	1.16	1.43	1.69	1.93	2.18	2.40	2.65	2.88	3.12	3.52	3.92	4.33	4.71	5.07	5.45	5.79	6.14	6.48	6.78	7.08	7.34	7.61	7.79
0.38	1.19	1.47	1.73	1.98	2.24	2.47	2.73	2.96	3.21	3.62	4.04	4.46	4.85	5.22	5.61	5.96	6.32	6.67	6.98	7.29	7.56	7.84	8.02
0.40	1.22	1.51	1.77	2.03	2.30	2.54	2.80	3.04	3.29	3.72	4.16	4.58	4.99	5.36	6.76	6.13	6.50	6.85	7.18	7.50	7.77	8.05	8.25
0.42	1.25	1.55	1.81	2.08	2.36	2.61	2.87	3.12	3.37	3.82	4.26	4.70	5.12	5.50	5.91	6.29	6.66	7.03	7.36	7.69	7.97	8.26	8.46
0.46	1.31	1.61	1.89	2.18	2.48	2.74	3.02	3.28	3.53	1.01	4.47	4.93	5.36	5.77	6.20	6.59	6.98	7.37	7.72	8.06	8.36	8.66	8.87
0.50	1.37	1.67	1.97	2.28	2.59	2.86	3.15	3.42	3.69	4.19	4.67	5.15	5.60	6.04	6.48	6.89	7.30	7.70	8.06	8.41	8.73	9.05	9.26
0.54	1.42	1.73	2.05	2.38	2.69	2.98	3.28	3.56	3.85	4.36	4.86	5.37	5.84	6.28	6.76	7.17	7.60	8.02	8.40	8.76	9.10	9.44	9.65
0.58	1.47	1.79	2.12	2.47	2.79	3.09	3.40	3.70	3.99	4.53	5.05	5.57	6.06	6.51	7.01	7.45	7.89	8.32	8.72	9.10	9.43	9.78	10.02
0.63	1.52	1.85	2.19	2.56	2.89	3.20	3.52	3.82	4.13	4.68	5.22	5.76	6.26	6.74	7.25	7.70	8.16	8.61	9.02	9.42	9.76	10.12	10.37
0.67	1.57	1.91	2.26	2.65	2.98	3.30	3.63	3.94	4.26	4.83	5.39	5.95	6.46	6.96	7.48	7.95	8.43	8.88	9.31	9.72	10.08	10.44	10.70
0.71	1.61	1.97	2.33	2.73	3.07	3.40	3.74	4.06	4.39	4.98	5.55	6.13	6.66	7.17	7.70	8.19	8.69	9.15	9.60	10.01	10.40	10.76	11.03
0.75	1.65	2.02	2.40	2.80	3.16	3.50	3.85	4.18	4.52	5.13	5.71	6.31	6.86	7.38	7.92	8.43	8.95	9.42	9.88	10.30	10.70	11.08	11.34
0.79	1.69	2.07	2.47	2.87	3.25	3.60	3.96	4.30	4.65	5.27	5.87	6.49	7.06	7.59	8.14	8.67	9.20	9.69	10.15	10.59	11.00	11.40	11.65
0.83	1.73	2.12	2.54	2.94	3.34	3.70	4.07	4.42	4.77	5.41	6.03	6.65	7.25	7.79	8.36	8.90	9.44	9.95	10.41	10.88	11.28	11.69	11.96
0.92	1.81	2.22	2.67	3.08	3.50	3.87	4.28	4.63	5.00	5.67	6.31	6.97	7.60	8.16	8.76	9.32	9.88	10.42	10.91	11.44	11.82	12.24	12.53
1.00	1.88	2.32	2.79	3.22	3.66	4.04	4.47	4.84	5.22	5.92	6.59	7.29	7.93	8.53	9.16	9.74	10.32	10.89	11.41	11.93	12.34	12.79	13.10
1.08	1.95	2.42	2.91	3.36	3.81	4.21	4.64	5.04	5.44	6.17	6.87	7.60	8.26	8.88	9.55	10.13	10.76	11.33	11.88	12.40	12.86	13.32	13.65
1.17	2.02	2.52	3.02	3.49	3.95	4.38	4.81	5.23	5.64	6.40	7.13	7.89	8.57	9.21	9.90	10.52	11.16	11.77	12.32	12.87	13.33	13.82	14.17
1.25	2.08	2.61	3.12	3.61	4.09	4.53	4.97	5.41	5.84	6.62	7.38	8.15	8.86	9.53	10.24	10.88	11.53	12.18	12.74	13.30	13.80	14.30	14.65
1.33	2.14	2.70	3.22	3.73	4.22	4.67	5.13	5.58	6.03	6.84	7.62	8.41	9.15	9.85	10.58	11.23	11.90	12.56	13.16	13.72	14.25	14.78	15.13
1.42	2.20	2.78	3.32	3.84	4.35	4.81	5.29	5.75	6.22	7.05	7.85	8.67	9.43	10.15	10.90	11.58	12.27	12.94	13.58	14.14	14.69	15.24	15.59
1.50	2.26	2.86	3.41	3.95	4.47	4.95	5.45	5.92	6.40	7.25	8.08	8.93	9.70	10.44	11.22	11.92	12.64	13.32	13.98	14.56	15.11	15.68	16.05

Armco-Type Metergate Tables - Preliminary

30-inch Round Gate

Head Difference (feet)	Net Gate Opening (feet)																									
	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33	1.50	1.67	1.83	2.00	2.17	2.33	2.50
	Discharge (CFS)																									
0.08	0.84	1.05	1.25	1.45	1.63	1.84	2.00	2.20	2.34	2.69	3.03	3.35	3.64	3.92	4.20	4.48	4.75	5.03	5.28	5.84	6.34	6.76	7.10	7.46	7.70	7.86
0.10	0.93	1.17	1.39	1.62	1.82	2.04	2.23	2.45	2.61	2.99	3.36	3.71	4.04	4.36	4.67	4.99	5.30	5.61	5.89	6.49	7.04	7.51	7.90	8.31	8.58	8.77
0.13	1.01	1.27	1.52	1.76	1.97	2.22	2.43	2.66	2.85	3.25	3.63	4.05	4.41	4.75	5.11	5.46	5.80	6.12	6.46	7.08	7.67	8.19	8.65	9.07	9.40	9.59
0.15	1.08	1.37	1.63	1.89	2.12	2.39	2.62	2.87	3.06	3.50	3.88	4.37	4.73	5.11	5.49	5.86	6.22	6.57	6.94	7.60	8.25	8.81	9.29	9.72	10.15	10.32
0.17	1.16	1.46	1.74	2.02	2.27	2.54	2.80	3.05	3.27	3.73	4.13	4.64	5.03	5.45	5.86	6.26	6.63	7.02	7.41	8.11	8.78	9.40	9.91	10.34	10.88	11.04
0.19	1.23	1.55	1.85	2.14	2.40	2.69	2.96	3.22	3.46	3.95	4.38	4.90	5.33	5.78	6.21	6.64	7.04	7.45	7.86	8.61	9.31	9.94	10.48	10.94	11.56	11.74
0.21	1.30	1.63	1.94	2.25	2.52	2.84	3.11	3.38	3.63	4.15	4.63	5.15	5.61	6.09	6.55	7.00	7.41	7.85	8.29	9.07	9.81	10.48	11.03	11.52	12.16	12.40
0.23	1.36	1.70	2.03	2.35	2.64	2.98	3.25	3.53	3.80	4.34	4.86	5.40	5.89	6.39	6.87	7.34	7.78	8.23	8.69	9.51	10.28	19.98	11.56	12.08	12.68	13.00
0.25	1.41	1.77	2.11	2.45	2.75	3.11	3.38	3.67	3.95	4.53	5.08	5.64	6.16	6.68	7.17	7.67	8.13	8.60	9.08	9.94	10.75	11.47	12.07	12.62	13.18	13.55
0.27	1.46	1.84	2.19	2.55	2.86	3.22	3.50	3.81	4.10	4.71	5.29	5.87	6.41	6.95	7.46	7.98	8.46	8.95	9.45	10.34	11.20	11.95	12.57	13.15	13.68	14.05
0.29	1.51	1.90	2.27	2.64	2.96	3.33	3.62	3.94	4.25	4.88	5.49	6.09	6.65	7.21	7.75	8.28	8.78	9.29	9.81	10.74	11.62	12.40	13.06	13.65	14.18	14.52
0.31	1.56	1.96	2.35	2.72	3.06	3.43	3.74	4.07	4.40	5.05	5.68	6.30	6.88	7.47	8.02	8.57	9.09	9.62	10.14	11.12	12.03	12.83	13.50	14.12	14.67	14.98
0.33	1.61	2.02	2.42	2.80	3.15	3.53	3.85	4.20	4.54	5.21	5.86	6.51	7.10	7.71	8.28	8.85	9.38	9.93	10.47	11.48	12.42	13.25	13.94	15.58	15.15	15.44
0.35	1.65	2.08	2.49	2.88	3.24	3.63	3.96	4.33	4.68	5.38	6.04	6.71	7.32	7.95	8.54	9.12	9.67	10.23	10.80	11.83	12.80	13.66	14.37	15.03	15.61	15.90
0.38	1.69	2.14	2.56	2.96	3.33	3.73	4.07	4.45	4.82	5.54	6.22	6.91	7.54	8.18	8.79	9.39	9.95	10.53	11.12	12.17	13.17	14.06	14.80	15.47	16.07	16.36
0.40	1.73	2.20	2.62	3.04	3.42	3.82	4.18	4.57	4.95	5.69	6.39	7.10	7.75	8.40	9.03	9.65	13.23	10.82	11.43	12.51	13.54	14.45	15.20	15.90	16.52	16.82
0.42	1.77	2.25	2.68	3.11	3.50	3.91	4.29	4.69	5.08	5.84	6.56	7.29	7.95	8.62	9.26	9.90	10.50	11.11	11.73	12.84	13.90	14.83	15.60	16.32	16.95	17.26
0.46	1.85	2.35	2.80	3.25	3.66	4.09	4.50	4.92	5.33	6.12	6.88	7.64	8.34	9.05	9.72	10.38	11.02	11.65	12.30	13.47	14.57	15.56	16.36	17.10	17.77	18.10
0.50	1.93	2.45	2.92	3.39	3.82	4.27	4.70	5.14	5.56	6.39	7.19	7.98	8.70	9.45	10.14	10.84	11.50	12.16	12.83	14.06	15.20	16.23	17.08	17.85	18.55	18.90
0.54	2.01	2.55	3.04	3.53	3.97	4.44	4.89	5.35	5.79	6.65	7.48	8.31	9.06	9.84	10.56	11.29	11.96	12.66	13.36	14.63	15.83	16.90	17.77	18.58	19.30	19.65
0.58	2.09	2.64	3.15	3.64	4.13	4.61	5.07	5.55	6.01	6.90	7.76	8.62	9.40	10.20	10.96	11.72	12.42	13.14	13.87	15.19	16.43	17.53	18.45	19.30	20.04	20.40
0.63	2.16	2.72	3.25	3.76	4.27	4.77	5.25	5.75	6.21	7.15	8.03	8.92	9.74	10.56	11.35	12.13	12.85	13.60	14.36	15.72	17.00	18.15	19.10	19.97	20.74	21.12
0.67	2.23	2.80	3.34	3.88	4.41	4.92	5.42	5.94	6.42	7.38	8.30	9.21	10.06	10.90	11.72	12.52	13.27	14.04	14.83	16.23	17.56	18.73	19.72	20.62	21.42	21.82
0.71	2.30	2.88	3.43	3.99	4.54	5.07	5.59	6.12	6.61	7.60	8.55	9.49	10.36	11.23	12.08	12.91	13.68	14.47	15.29	16.73	18.10	19.30	20.32	21.26	22.08	22.52
0.75	2.36	2.96	3.52	4.10	4.67	5.22	5.75	6.30	6.81	7.82	8.80	9.76	10.66	11.56	12.44	13.28	14.07	14.90	15.74	17.21	18.62	19.87	20.91	21.87	22.72	23.17
0.79	2.42	3.04	3.61	4.21	4.80	5.36	5.91	6.47	7.00	8.04	9.04	10.03	10.95	11.89	19.79	13.64	14.46	15.30	16.15	17.68	19.14	20.41	21.49	22.47	23.34	23.80
0.83	2.48	3.12	3.70	4.32	4.93	5.50	6.06	6.64	7.18	8.26	9.28	10.30	11.24	12.20	13.12	14.00	14.85	15.70	16.60	18.15	19.65	20.95	22.06	23.06	23.95	24.40
0.92	2.59	3.27	3.88	4.53	5.17	5.78	6.36	6.96	7.53	8.66	9.73	10.80	11.78	12.79	13.74	14.69	15.57	16.47	17.40	19.03	20.50	21.96	23.13	24.20	25.12	25.58
1.00	2.70	3.40	4.05	4.74	5.4	6.04	6.64	7.27	7.86	9.04	10.16	11.28	12.31	13.36	14.35	15.33	16.26	17.20	18.16	19.88	21.50	22.95	24.15	25.25	26.23	26.72
1.08	2.81	3.52	4.21	4.93	5.62	6.28	6.91	7.57	8.19	9.40	10.57	11.74	12.82	13.90	14.94	15.96	16.93	17.90	18.90	20.70	22.40	23.90	25.15	26.28	27.30	27.80
1.17	2.91	3.64	4.37	5.11	5.84	6.51	7.17	7.86	8.49	9.76	10.97	12.18	13.30	14.43	15.50	15.56	17.56	18.57	19.60	21.48	23.23	24.80	26.10	27.28	28.32	28.85
1.25	3.01	3.76	4.52	5.29	6.04	6.74	7.42	8.13	8.79	10.10	11.37	12.62	13.76	14.93	16.04	17.14	18.18	19.23	20.30	22.23	24.05	25.66	27.00	28.23	29.32	29.86
1.33	3.11	3.88	4.67	5.47	6.24	6.96	7.66	8.40	9.08	10.43	11.74	13.03	14.22	15.42	16.57	17.70	18.77	19.86	20.97	22.95	24.84	26.50	27.87	29.15	30.30	30.84
1.42	3.20	3.99	4.81	5.64	6.43	7.18	7.90	8.66	9.36	10.76	12.10	13.43	14.65	15.90	17.08	18.26	19.36	20.48	21.62	23.66	25.60	27.32	28.73	30.06	31.25	31.80
1.50	3.28	4.10	4.95	5.79	6.61	7.39	8.13	8.91	9.63	11.06	12.43	13.81	15.08	16.36	17.57	18.78	19.90	21.05	22.25	24.34	26.34	28.10	29.56	30.92	32.15	32.70

Armco-Type Metergate Tables - Preliminary

36-inch Round Gate

Head Difference (feet)	Net Gate Opening (feet)																												
	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33	1.50	1.67	1.83	2.00	2.17	2.33	2.50	2.67	2.83	3.00
	Discharge (CFS)																												
0.08	0.96	1.22	1.47	1.71	1.94	2.16	2.41	2.61	2.82	3.24	3.67	4.05	4.42	4.77	5.10	5.47	5.83	6.13	6.50	7.12	7.86	8.43	8.92	9.37	9.84	10.10	10.35	10.56	10.74
0.10	1.07	1.35	1.62	1.89	2.15	2.41	2.69	2.90	3.12	3.59	4.05	4.50	4.91	5.31	5.67	6.10	6.49	6.82	7.22	7.87	8.67	9.30	9.88	10.38	10.89	11.20	11.50	11.74	11.92
0.13	1.17	1.47	1.77	2.06	2.34	2.63	2.94	3.16	3.40	3.92	4.43	4.93	5.36	5.79	6.20	6.68	7.08	7.44	7.89	8.59	9.44	10.14	10.81	11.33	11.86	12.24	12.57	12.84	13.02
0.15	1.26	1.59	1.92	2.22	2.53	2.84	3.18	3.42	3.67	4.24	4.77	5.32	4.79	6.25	6.70	7.20	7.63	8.04	8.52	9.28	10.17	10.95	11.65	12.25	12.80	13.24	13.60	13.91	14.09
0.17	1.34	1.70	2.05	2.36	2.69	3.04	3.39	3.66	3.92	4.53	5.08	5.68	6.18	6.66	7.17	7.67	8.13	8.60	9.10	9.95	10.87	11.71	12.43	13.09	13.67	14.16	14.54	14.87	15.05
0.19	1.42	1.80	2.17	2.50	2.85	3.21	3.58	3.87	4.14	4.79	5.38	6.00	6.52	7.04	7.61	8.12	8.62	9.12	9.65	10.57	11.52	12.42	13.18	13.86	14.47	15.00	15.39	15.74	15.95
0.21	1.50	1.89	2.28	2.63	3.00	3.37	3.76	4.07	4.35	5.04	5.65	6.30	6.85	7.42	8.02	8.56	9.09	9.61	10.18	11.13	12.16	13.10	13.88	14.60	15.21	15.76	16.17	16.54	16.78
0.23	1.57	1.98	2.39	2.76	3.14	3.52	3.93	4.26	4.55	5.28	5.91	6.60	7.18	7.79	8.42	8.98	9.54	10.07	10.68	11.68	12.76	13.73	14.55	15.31	15.93	16.50	16.94	17.34	17.60
0.25	1.63	2.06	2.49	2.88	3.28	3.67	4.10	4.45	4.75	5.50	6.17	6.89	7.50	8.13	8.79	9.37	9.95	10.52	11.15	12.20	13.31	14.35	15.20	16.00	16.64	17.23	17.68	18.10	18.38
0.27	1.69	2.14	2.59	3.00	3.41	3.82	4.27	4.63	1.95	5.72	6.42	7.17	7.81	8.46	9.15	9.76	10.35	10.96	11.60	12.70	13.86	14.95	15.83	16.66	17.33	17.94	18.40	18.85	19.14
0.29	1.75	2.21	2.68	3.11	3.53	3.95	4.42	4.79	5.13	5.93	6.66	7.44	8.10	8.78	9.49	10.12	10.74	11.37	12.04	13.18	14.37	15.50	16.42	17.28	17.98	18.61	19.08	19.54	19.85
0.31	1.81	2.28	2.76	3.22	3.65	4.08	4.56	4.95	5.31	6.14	6.90	7.70	8.39	9.09	9.82	10.48	11.11	11.77	12.46	13.63	14.89	16.04	16.99	17.89	18.60	19.27	19.74	20.23	20.55
0.33	1.86	2.35	2.84	3.31	3.76	4.20	4.68	5.11	5.49	6.34	7.13	7.95	8.66	9.38	10.14	10.83	11.48	12.15	12.87	14.08	15.37	169.56	17.55	18.46	19.20	19.90	20.40	20.89	21.25
0.35	1.91	1.42	2.92	3.40	3.86	4.32	4.81	5.27	5.66	6.54	7.35	8.20	8.93	9.67	10.45	11.16	11.83	12.52	13.27	14.51	15.84	17.08	18.10	19.03	19.80	20.50	21.05	21.53	21.90
0.38	1.96	2.49	3.00	3.49	3.96	4.44	4.94	5.42	5.82	6.73	7.56	8.44	9.19	9.95	10.76	11.49	12.18	12.89	13.66	14.94	16.31	17.57	18.61	19.60	20.38	21.10	21.65	22.17	22.55
0.40	2.01	2.56	3.08	3.58	4.06	4.56	5.07	5.57	5.98	6.92	7.77	8.67	9.45	10.22	11.06	11.80	12.52	13.25	14.04	15.35	16.76	18.05	19.13	20.15	20.95	21.68	22.25	22.80	23.20
0.42	2.06	2.62	3.16	3.67	4.16	4.68	5.19	5.72	6.14	7.10	7.97	8.89	9.70	10.49	11.34	12.10	12.85	13.60	14.40	15.75	17.20	18.53	19.64	20.65	21.50	22.25	22.80	23.40	23.80
0.46	2.16	2.74	3.31	3.84	4.36	4.90	5.43	6.00	6.43	7.44	8.36	9.33	10.17	11.00	11.90	12.70	13.47	14.25	15.10	16.52	18.03	19.43	20.60	21.65	22.55	23.35	23.90	24.50	24.90
0.50	2.26	2.86	3.45	4.00	4.55	5.11	5.67	6.26	4.71	7.77	8.73	9.73	10.61	11.50	12.42	13.26	14.07	14.88	15.77	17.25	18.82	20.28	21.50	22.62	23.55	24.39	24.95	25.60	26.00
0.54	2.35	2.98	3.59	4.16	4.72	5.32	5.91	6.52	6.99	8.09	9.09	10.13	11.04	11.97	12.93	13.80	14.64	15.50	16.41	17.97	19.60	21.13	22.40	23.65	24.50	26.39	26.00	26.65	27.10
0.58	2.44	3.09	3.72	4.31	4.89	5.52	6.14	6.76	7.25	8.39	9.43	10.51	11.46	12.41	13.42	14.32	15.20	16.09	17.03	18.64	20.35	21.94	23.25	24.44	25.43	26.33	27.00	27.67	28.15
0.63	2.53	3.19	3.85	4.45	5.06	5.72	6.36	7.00	7.51	8.69	9.76	10.89	11.87	12.85	13.90	14.83	15.74	16.67	17.64	19.30	21.08	22.72	24.08	25.30	26.34	27.25	27.95	28.65	19.15
0.67	2.61	3.29	3.97	4.59	5.23	5.91	6.57	7.23	7.76	8.97	10.09	11.24	12.26	13.28	14.35	15.32	16.25	17.20	18.21	19.92	21.75	23.45	24.84	26.13	27.20	28.13	28.85	29.55	30.10
0.71	2.69	3.38	4.08	4.72	5.39	6.09	6.77	7.45	8.00	9.25	10.40	11.59	12.63	13.68	14.79	15.79	16.74	17.72	18.77	20.54	22.42	24.15	25.60	26.95	28.05	29.00	29.75	3.0.45	31.00
0.75	2.76	3.47	4.19	4.85	5.55	6.27	6.97	7.60	8.23	9.52	10.70	11.93	13.00	14.08	15.21	16.25	17.23	18.23	19.31	21.15	23.07	24.85	26.33	27.73	28.85	29.84	30.62	31.35	31.88
0.79	2.83	3.56	4.30	4.98	5.70	6.44	7.16	7.87	8.45	9.78	11.00	12.26	13.37	14.47	15.63	16.68	17.70	18.73	19.84	21.72	23.70	15.55	27.05	28.47	29.63	30.65	31.45	32.20	32.75
0.83	2.90	3.65	4.41	5.11	5.85	6.61	7.35	8.07	8.67	10.03	11.28	12.58	13.71	14.83	16.03	17.10	18.17	19.21	20.35	22.27	24.30	26.20	27.75	29.20	30.40	31.45	32.25	33.05	33.60
0.92	3.05	3.82	4.60	5.36	6.13	6.92	7.70	8.46	9.10	10.52	11.82	13.18	14.37	15.55	16.81	17.93	19.05	20.14	21.33	23.35	25.47	27.45	29.10	30.60	31.85	32.95	33.80	34.65	35.20
1.00	3.16	3.98	4.79	5.61	6.40	7.23	8.05	8.85	9.51	10.99	12.35	13.78	15.01	16.25	17.58	18.74	19.90	21.05	22.30	24.40	26.62	18.70	30.40	32.00	33.30	34.45	35.35	36.20	36.80
1.08	3.28	4.14	4.98	5.85	6.67	7.52	8.39	9.22	9.89	11.44	12.85	14.35	15.62	16.93	18.30	19.53	20.72	21.92	23.22	25.40	27.75	29.87	31.65	33.32	34.65	35.85	36.80	37.68	38.30
1.17	3.39	4.29	5.16	6.06	6.91	7.81	8.70	9.56	10.26	11.88	13.33	14.88	16.21	17.58	18.99	20.25	21.50	22.75	24.10	26.35	28.80	31.00	32.85	34.60	35.98	37.20	38.18	39.10	39.75
1.25	3.50	4.43	5.34	6.27	7.15	8.08	9.00	9.89	10.62	12.30	13.80	15.40	16.78	18.19	19.64	20.95	22.24	23.54	24.93	27.30	29.80	32.10	34.00	35.80	37.25	28.50	39.50	40.45	41.15
1.33	3.61	4.56	5.51	6.48	7.39	8.34	9.29	10.22	10.98	12.69	14.27	15.90	17.33	18.78	20.29	54.65	22.98	24.30	25.75	28.20	30.75	33.15	35.10	36.95	38.45	29.80	40.80	41.80	42.50
1.42	3.72	4.69	5.68	6.68	7.62	8.60	9.58	10.54	11.32	13.08	14.70	16.39	17.86	19.34	20.92	22.32	23.69	25.05	26.55	29.03	31.70	34.15	36.20	38.10	39.60	41.10	42.05	43.10	43.80
1.50	3.82	4.82	5.85	6.87	7.84	8.85	9.86	10.84	11.64	13.45	15.12	16.88	18.39	19.89	21.54	22.97	24.36	25.78	27.33	29.85	32.63	35.15	37.25	39.20	40.75	42.30	43.25	44.35	45.10

ITRC Water Measurement Tables for
FREE FLOW Armco-Type Gates on Round Pipes
Discharge Values in CFS

Upstream head is measured from the top of the turnout pipe

Upstream Head (feet)	ITRC Water Measurement Tables – 12" Armco-Type Gate, FREE FLOW [Blue center represents best accuracy range] (Flows in CFS) Net Gate Opening (feet)																	
	0.042	0.08	0.13	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00
1.00	0.24	0.55	0.87	1.17	1.47	1.75	2.04	2.31	2.53	2.74	2.89	3.01	3.31	3.58	3.79	3.99	4.11	4.16
1.04	0.25	0.57	0.88	1.20	1.50	1.79	2.08	2.36	2.59	2.79	2.95	3.08	3.38	3.65	3.87	4.07	4.19	4.25
1.08	0.25	0.58	0.90	1.22	1.53	1.82	2.12	2.41	2.64	2.85	3.00	3.14	3.44	3.72	3.94	4.15	4.28	4.33
1.13	0.26	0.59	0.92	1.25	1.56	1.86	2.16	2.45	2.69	2.90	3.06	3.20	3.51	3.79	4.02	4.23	4.36	4.41
1.17	0.26	0.60	0.94	1.27	1.59	1.89	2.20	2.50	2.74	2.95	3.12	3.25	3.57	3.86	4.09	4.31	4.44	4.49
1.21	0.27	0.61	0.95	1.29	1.61	1.92	2.24	2.54	2.79	3.01	3.17	3.31	3.64	3.93	4.17	4.39	4.52	4.57
1.25	0.27	0.62	0.97	1.31	1.64	1.96	2.28	2.59	2.83	3.06	3.23	3.37	3.70	4.00	4.24	4.46	4.59	4.65
1.29	0.28	0.63	0.98	1.33	1.67	1.99	2.31	2.63	2.88	3.11	3.28	3.42	3.76	4.06	4.31	4.54	4.67	4.73
1.33	0.28	0.64	1.00	1.36	1.70	2.02	2.35	2.67	2.93	3.16	3.33	3.48	3.82	4.13	4.38	4.61	4.74	4.80
1.38	0.29	0.65	1.02	1.38	1.72	2.05	2.39	2.71	2.97	3.21	3.39	3.53	3.88	4.19	4.44	4.68	4.82	4.88
1.42	0.29	0.66	1.03	1.40	1.75	2.08	2.42	2.75	3.02	3.26	3.44	3.59	3.94	4.26	4.51	4.75	4.89	4.95
1.46	0.29	0.67	1.05	1.42	1.77	2.11	2.46	2.79	3.06	3.30	3.49	3.64	4.00	4.32	4.58	4.82	4.96	5.02
1.50	0.30	0.68	1.06	1.44	1.80	2.14	2.49	2.83	3.10	3.35	3.54	3.69	4.05	4.38	4.64	4.89	5.03	5.09
1.54	0.30	0.69	1.08	1.46	1.82	2.17	2.53	2.87	3.15	3.40	3.58	3.74	4.11	4.44	4.71	4.96	5.10	5.16
1.58	0.31	0.70	1.09	1.48	1.85	2.20	2.56	2.91	3.19	3.44	3.63	3.79	4.16	4.50	4.77	5.02	5.17	5.23
1.63	0.31	0.71	1.10	1.50	1.87	2.23	2.60	2.95	3.23	3.49	3.68	3.84	4.22	4.56	4.83	5.09	5.24	5.30
1.67	0.31	0.71	1.12	1.52	1.90	2.26	2.63	2.99	3.27	3.53	3.73	3.89	4.27	4.62	4.89	5.15	5.30	5.37
1.71	0.32	0.72	1.13	1.53	1.92	2.29	2.66	3.02	3.31	3.58	3.77	3.94	4.32	4.67	4.95	5.22	5.37	5.44
1.75	0.32	0.73	1.15	1.55	1.94	2.32	2.69	3.06	3.35	3.62	3.82	3.99	4.38	4.73	5.01	5.28	5.44	5.50
1.79	0.33	0.74	1.16	1.57	1.97	2.34	2.73	3.10	3.39	3.66	3.86	4.03	4.43	4.79	5.07	5.34	5.50	5.57
1.83	0.33	0.75	1.17	1.59	1.99	2.37	2.76	3.13	3.43	3.70	3.91	4.08	4.48	4.84	5.13	5.40	5.56	5.63
1.88	0.33	0.76	1.19	1.61	2.01	2.40	2.79	3.17	3.47	3.75	3.95	4.13	4.53	4.90	5.19	5.46	5.63	5.70
1.92	0.34	0.77	1.20	1.63	2.03	2.42	2.82	3.20	3.51	3.79	4.00	4.17	4.58	4.95	5.25	5.53	5.69	5.76
1.96	0.34	0.77	1.21	1.64	2.05	2.45	2.85	3.24	3.55	3.83	4.04	4.22	4.63	5.01	5.30	5.59	5.75	5.82
2.00	0.34	0.78	1.22	1.66	2.08	2.48	2.88	3.27	3.58	3.87	4.08	4.26	4.68	5.06	5.36	5.64	5.81	5.88
2.04	0.35	0.79	1.24	1.68	2.10	2.50	2.91	3.30	3.62	3.91	4.13	4.31	4.73	5.11	5.41	5.70	5.87	5.94
2.08	0.35	0.80	1.25	1.69	2.12	2.53	2.94	3.34	3.66	3.95	4.17	4.35	4.78	5.16	5.47	5.76	5.93	6.00
2.13	0.35	0.81	1.26	1.71	2.14	2.55	2.97	3.37	3.69	3.99	4.21	4.39	4.82	5.21	5.52	5.82	5.99	6.06
2.17	0.36	0.81	1.27	1.73	2.16	2.58	3.00	3.40	3.73	4.03	4.25	4.44	4.87	5.26	5.58	5.87	6.05	6.12
2.21	0.36	0.82	1.29	1.74	2.18	2.60	3.03	3.44	3.77	4.07	4.29	4.48	4.92	5.32	5.63	5.93	6.11	6.18
2.25	0.36	0.83	1.30	1.76	2.20	2.63	3.05	3.47	3.80	4.10	4.33	4.52	4.96	5.37	5.68	5.99	6.16	6.24
2.33	0.37	0.85	1.32	1.79	2.24	2.67	3.11	3.53	3.87	4.18	4.41	4.60	5.05	5.46	5.79	6.10	6.28	6.35
2.42	0.38	0.86	1.35	1.83	2.28	2.72	3.16	3.60	3.94	4.25	4.49	4.68	5.14	5.56	5.89	6.20	6.39	6.47
2.50	0.38	0.88	1.37	1.86	2.32	2.77	3.22	3.66	4.01	4.33	4.56	4.76	5.23	5.66	5.99	6.31	6.50	6.58
2.58	0.39	0.89	1.39	1.89	2.36	2.81	3.27	3.72	4.07	4.40	4.64	4.84	5.32	5.75	6.09	6.41	6.60	6.69
2.67	0.40	0.90	1.41	1.92	2.40	2.86	3.32	3.78	4.14	4.47	4.71	4.92	5.40	5.84	6.19	6.52	6.71	6.79
2.75	0.40	0.92	1.44	1.95	2.43	2.90	3.38	3.84	4.20	4.54	4.79	5.00	5.49	5.93	6.28	6.62	6.81	6.90
2.83	0.41	0.93	1.46	1.98	2.47	2.95	3.43	3.89	4.27	4.60	4.86	5.07	5.57	6.02	6.38	6.72	6.92	7.00
2.92	0.42	0.95	1.48	2.01	2.51	2.99	3.48	3.95	4.33	4.67	4.93	5.15	5.65	6.11	6.47	6.82	7.02	7.10
3.00	0.42	0.96	1.50	2.03	2.54	3.03	3.53	4.01	4.39	4.74	5.00	5.22	5.73	6.20	6.56	6.91	7.12	7.20
3.08	0.43	0.97	1.52	2.06	2.58	3.07	3.57	4.06	4.45	4.80	5.07	5.29	5.81	6.28	6.65	7.01	7.21	7.30
3.17	0.43	0.99	1.54	2.09	2.61	3.12	3.62	4.12	4.51	4.87	5.14	5.36	5.89	6.36	6.74	7.10	7.31	7.40
3.25	0.44	1.00	1.56	2.12	2.65	3.16	3.67	4.17	4.57	4.93	5.20	5.43	5.97	6.45	6.83	7.19	7.41	7.50
3.33	0.44	1.01	1.58	2.14	2.68	3.20	3.72	4.22	4.63	4.99	5.27	5.50	6.04	6.53	6.92	7.29	7.50	7.59
3.42	0.45	1.02	1.60	2.17	2.71	3.24	3.76	4.28	4.68	5.06	5.34	5.57	6.12	6.61	7.00	7.38	7.59	7.69
3.50	0.46	1.04	1.62	2.20	2.75	3.28	3.81	4.33	4.74	5.12	5.40	5.64	6.19	6.69	7.09	7.47	7.69	7.78
3.58	0.46	1.05	1.64	2.22	2.78	3.31	3.85	4.38	4.80	5.18	5.47	5.70	6.26	6.77	7.17	7.55	7.78	7.87
3.67	0.47	1.06	1.66	2.25	2.81	3.35	3.90	4.43	4.85	5.24	5.53	5.77	6.34	6.85	7.26	7.64	7.87	7.96
3.75	0.47	1.07	1.68	2.27	2.84	3.39	3.94	4.48	4.91	5.30	5.59	5.83	6.41	6.93	7.34	7.73	7.96	8.05
3.83	0.48	1.08	1.70	2.30	2.87	3.43	3.99	4.53	4.96	5.36	5.65	5.90	6.48	7.00	7.42	7.81	8.04	8.14
3.92	0.48	1.10	1.71	2.32	2.91	3.46	4.03	4.58	5.01	5.41	5.71	5.96	6.55	7.08	7.50	7.90	8.13	8.23
4.00	0.49	1.11	1.73	2.35	2.94	3.50	4.07	4.63	5.07	5.47	5.77	6.03	6.62	7.15	7.58	7.98	8.22	8.32

ITRC Water Measurement Tables – 18" Armco-Type Gate, FREE FLOW [Blue center represents best accuracy range] (Flows in CFS)

Upstream Head (feet)	Net Gate Opening (feet)																							
	0.042	0.08	0.13	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33	1.42	1.50
1.50	0.42	0.99	1.58	2.18	2.78	3.39	3.99	4.59	5.03	5.43	5.79	6.11	6.89	7.59	8.30	8.95	9.50	9.97	10.44	10.85	11.15	11.36	11.55	11.59
1.54	0.43	1.00	1.60	2.21	2.82	3.44	4.05	4.65	5.10	5.51	5.87	6.20	6.99	7.69	8.42	9.08	9.63	10.11	10.59	11.00	11.30	11.52	11.71	11.75
1.58	0.44	1.02	1.62	2.24	2.86	3.48	4.10	4.72	5.17	5.58	5.95	6.28	7.08	7.79	8.53	9.20	9.76	10.24	10.73	11.14	11.46	11.67	11.87	11.91
1.63	0.44	1.03	1.65	2.27	2.90	3.53	4.15	4.78	5.24	5.65	6.03	6.36	7.17	7.90	8.64	9.32	9.89	10.38	10.87	11.29	11.61	11.83	12.03	12.06
1.67	0.45	1.04	1.67	2.30	2.94	3.57	4.21	4.84	5.30	5.72	6.10	6.44	7.26	8.00	8.75	9.44	10.01	10.51	11.01	11.43	11.75	11.98	12.18	12.22
1.71	0.45	1.06	1.69	2.33	2.97	3.62	4.26	4.90	5.37	5.80	6.18	6.52	7.36	8.10	8.86	9.55	10.14	10.64	11.15	11.57	11.90	12.13	12.33	12.37
1.75	0.46	1.07	1.71	2.36	3.01	3.66	4.31	4.96	5.43	5.87	6.25	6.60	7.44	8.19	8.97	9.67	10.26	10.77	11.28	11.72	12.04	12.27	12.48	12.52
1.79	0.46	1.08	1.73	2.38	3.04	3.70	4.36	5.02	5.50	5.94	6.33	6.68	7.53	8.29	9.07	9.78	10.38	10.89	11.42	11.85	12.19	12.42	12.63	12.67
1.83	0.47	1.09	1.75	2.41	3.08	3.75	4.41	5.07	5.56	6.00	6.40	6.76	7.62	8.39	9.18	9.90	10.50	11.02	11.55	11.99	12.33	12.56	12.77	12.81
1.88	0.47	1.11	1.77	2.44	3.11	3.79	4.46	5.13	5.62	6.07	6.47	6.83	7.71	8.48	9.28	10.01	10.62	11.14	11.68	12.13	12.47	12.70	12.92	12.96
1.92	0.48	1.12	1.79	2.47	3.15	3.83	4.51	5.19	5.69	6.14	6.55	6.91	7.79	8.57	9.39	10.12	10.74	11.27	11.81	12.26	12.60	12.84	13.06	13.10
1.96	0.49	1.13	1.81	2.49	3.18	3.87	4.56	5.24	5.75	6.21	6.62	6.98	7.88	8.67	9.49	10.23	10.85	11.39	11.93	12.39	12.74	12.98	13.20	13.24
2.00	0.49	1.14	1.83	2.52	3.22	3.91	4.61	5.30	5.81	6.27	6.69	7.06	7.96	8.76	9.59	10.34	10.97	11.51	12.06	12.52	12.88	13.12	13.34	13.38
2.04	0.50	1.15	1.84	2.55	3.25	3.95	4.66	5.36	5.87	6.34	6.76	7.13	8.04	8.85	9.69	10.44	11.08	11.63	12.19	12.65	13.01	13.26	13.48	13.52
2.08	0.50	1.17	1.86	2.57	3.28	3.99	4.70	5.41	5.93	6.40	6.82	7.20	8.12	8.94	9.79	10.55	11.20	11.75	12.31	12.78	13.14	13.39	13.62	13.66
2.13	0.51	1.18	1.88	2.60	3.31	4.03	4.75	5.46	5.99	6.46	6.89	7.27	8.20	9.03	9.88	10.65	11.31	11.86	12.43	12.91	13.27	13.52	13.75	13.79
2.17	0.51	1.19	1.90	2.62	3.35	4.07	4.80	5.52	6.05	6.53	6.96	7.34	8.28	9.12	9.98	10.76	11.42	11.98	12.55	13.04	13.40	13.66	13.89	13.93
2.21	0.52	1.20	1.92	2.65	3.38	4.11	4.84	5.57	6.10	6.59	7.03	7.41	8.36	9.20	10.07	10.86	11.53	12.10	12.67	13.16	13.53	13.79	14.02	14.06
2.25	0.52	1.21	1.94	2.67	3.41	4.15	4.89	5.62	6.16	6.65	7.09	7.48	8.44	9.29	10.17	10.96	11.63	12.21	12.79	13.28	13.66	13.92	14.15	14.19
2.33	0.53	1.23	1.97	2.72	3.47	4.23	4.98	5.73	6.27	6.77	7.22	7.62	8.60	9.46	10.36	11.17	11.85	12.43	13.03	13.53	13.91	14.17	14.41	14.45
2.42	0.54	1.26	2.01	2.77	3.53	4.30	5.07	5.83	6.38	6.89	7.35	7.76	8.75	9.63	10.54	11.36	12.06	12.65	13.26	13.77	14.15	14.42	14.67	14.71
2.50	0.55	1.28	2.04	2.82	3.60	4.37	5.15	5.93	6.49	7.01	7.48	7.89	8.90	9.79	10.72	11.56	12.26	12.87	13.48	14.00	14.40	14.67	14.92	14.96
2.58	0.56	1.30	2.08	2.86	3.65	4.45	5.24	6.02	6.60	7.13	7.60	8.02	9.04	9.95	10.90	11.75	12.47	13.08	13.71	14.23	14.63	14.91	15.16	15.21
2.67	0.57	1.32	2.11	2.91	3.71	4.52	5.32	6.12	6.71	7.24	7.72	8.15	9.19	10.11	11.07	11.94	12.67	13.29	13.93	14.46	14.87	15.15	15.41	15.45
2.75	0.57	1.34	2.14	2.95	3.77	4.59	5.40	6.22	6.81	7.35	7.84	8.27	9.33	10.27	11.24	12.12	12.86	13.50	14.14	14.69	15.10	15.39	15.64	15.69
2.83	0.58	1.36	2.17	3.00	3.83	4.66	5.48	6.31	6.91	7.46	7.96	8.40	9.47	10.43	11.41	12.30	13.06	13.70	14.36	14.91	15.33	15.62	15.88	15.93
2.92	0.59	1.38	2.20	3.04	3.88	4.72	5.56	6.40	7.01	7.57	8.07	8.52	9.61	10.58	11.58	12.48	13.25	13.90	14.56	15.12	15.55	15.84	16.11	16.16
3.00	0.60	1.40	2.24	3.09	3.94	4.79	5.64	6.49	7.11	7.68	8.19	8.64	9.75	10.73	11.74	12.66	13.43	14.10	14.77	15.34	15.77	16.07	16.34	16.39
3.08	0.61	1.42	2.27	3.13	3.99	4.86	5.72	6.58	7.21	7.79	8.30	8.76	9.88	10.88	11.90	12.83	13.62	14.29	14.98	15.55	15.99	16.29	16.57	16.62
3.17	0.62	1.44	2.30	3.17	4.05	4.92	5.80	6.67	7.31	7.89	8.41	8.88	10.01	11.02	12.06	13.01	13.80	14.48	15.18	15.76	16.20	16.51	16.79	16.84
3.25	0.63	1.46	2.33	3.21	4.10	4.99	5.87	6.76	7.40	7.99	8.52	8.99	10.14	11.17	12.22	13.18	13.98	14.67	15.37	15.97	16.41	16.73	17.01	17.06
3.33	0.63	1.48	2.36	3.25	4.15	5.05	5.95	6.84	7.50	8.10	8.63	9.11	10.27	11.31	12.38	13.34	14.16	14.86	15.57	16.17	16.62	16.94	17.22	17.28
3.42	0.64	1.49	2.39	3.29	4.20	5.11	6.02	6.93	7.59	8.20	8.74	9.22	10.40	11.45	12.53	13.51	14.34	15.04	15.76	16.37	16.83	17.15	17.44	17.49
3.50	0.65	1.51	2.42	3.33	4.25	5.18	6.10	7.01	7.68	8.30	8.85	9.33	10.53	11.59	12.68	13.67	14.51	15.23	15.95	16.57	17.03	17.36	17.65	17.70
3.58	0.66	1.53	2.44	3.37	4.30	5.24	6.17	7.09	7.77	8.39	8.95	9.44	10.65	11.72	12.83	13.84	14.68	15.41	16.14	16.76	17.23	17.56	17.86	17.91
3.67	0.66	1.55	2.47	3.41	4.35	5.30	6.24	7.18	7.86	8.49	9.05	9.55	10.78	11.86	12.98	14.00	14.85	15.59	16.33	16.96	17.43	17.77	18.06	18.12
3.75	0.67	1.56	2.50	3.45	4.40	5.36	6.31	7.26	7.95	8.59	9.16	9.66	10.90	11.99	13.13	14.15	15.02	15.76	16.51	17.15	17.63	17.97	18.27	18.33
3.83	0.68	1.58	2.53	3.49	4.45	5.42	6.38	7.34	8.04	8.68	9.26	9.77	11.02	12.13	13.27	14.31	15.19	15.94	16.70	17.34	17.83	18.17	18.47	18.53
3.92	0.69	1.60	2.56	3.53	4.50	5.48	6.45	7.42	8.13	8.78	9.36	9.87	11.14	12.26	13.42	14.47	15.35	16.11	16.88	17.53	18.02	18.36	18.67	18.73
4.00	0.69	1.62	2.58	3.56	4.55	5.53	6.52	7.50	8.21	8.87	9.46	9.98	11.25	12.39	13.56	14.62	15.51	16.28	17.06	17.71	18.21	18.56	18.87	18.93
4.08	0.70	1.63	2.61	3.60	4.59	5.59	6.58	7.57	8.30	8.96	9.55	10.08	11.37	12.52	13.70	14.77	15.67	16.45	17.23	17.90	18.40	18.75	19.06	19.12
4.17	0.71	1.65	2.64	3.64	4.64	5.65	6.65	7.65	8.38	9.05	9.65	10.18	11.49	12.64	13.84	14.92	15.83	16.61	17.41	18.08	18.58	18.94	19.26	19.32
4.25	0.71	1.67	2.66	3.67	4.69	5.70	6.72	7.73	8.47	9.14	9.75	10.29	11.60	12.77	13.98	15.07	15.99	16.78	17.58	18.26	18.77	19.13	19.45	19.51
4.33	0.72	1.68	2.69	3.71	4.73	5.76	6.78	7.80	8.55	9.23	9.84	10.39	11.71	12.89	14.11	15.22	16.15	16.94	17.75	18.43	18.95	19.31	19.64	19.70
4.42	0.73	1.70	2.71	3.74	4.78	5.81	6.85	7.88	8.63	9.32	9.94	10.49	11.83	13.02	14.25	15.36	16.30	17.11	17.92	18.61	19.13	19.50	19.83	19.89
4.50	0.74	1.71	2.74	3.78	4.82	5.87	6.91	7.95	8.71	9.41	10.03	10.58	11.94	13.14	14.38	15.51	16.45	17.27	18.09	18.79	19.31	19.68	20.01	20.07
4.58	0.74	1.73	2.76	3.81	4.87	5.92	6.98	8.02	8.79	9.49	10.12	10.68	12.05	13.26	14.51	15.65	16.61	17.42	18.26	18.96	19.49	19.86	20.20	20.26
4.67	0.75	1.75	2.79	3.85	4.91	5.98	7.04	8.10	8.87	9.58	10.21	10.78	12.16	13.38	14.64	15.79	16.76	17.58	18.42	19.13	19.67	20.04	20.38	20.44
4.75	0.76	1.76	2.81	3.88	4.96	6.03	7.10	8.17	8.95	9.66	10.30	10.87	12.26	13.50	14.78	15.93	16.90	17.74	18.59	19.30	19.84	20.22	20.56	20.62
4.83	0.76	1.78	2.84	3.92	5.00	6.08	7.16	8.24	9.03	9.75	10.39	10.97	12.37	13.62	14.90	16.07	17.05	17.89	18.75	19.47	20.02	20.40	20.74	20.80
4.92	0.77	1.79	2.86	3.95	5.04	6.13	7.22	8.31	9.11	9.83	10.48	11.06	12.48	13.73	15.03	16.21	17.20	18.05	18.91	19.64	20.19	20.57	20.92	20.98
5.00	0.78	1.81	2.89	3.98	5.08	6.19	7.29	8.38	9.18	9.91	10.57	11.16	12.58	13.85	15.16	16.34	17.34	18.20	19.07	19.80	20.36	20.75	21.09	21.16

ITRC Water Measurement Tables – 24" Armco-Type Gate, FREE FLOW [Blue center represents best accuracy range] (Flows in CFS)

Upstream Head (feet)	Net Gate Opening (feet)																													
	0.042	0.08	0.13	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33	1.42	1.50	1.58	1.67	1.75	1.83	1.92	2.00
2.00	0.67	1.54	2.45	3.37	4.29	5.20	6.11	7.01	7.82	8.60	9.35	10.1	11.6	13.0	14.2	15.2	16.5	17.8	18.8	19.7	20.5	21.2	21.9	22.6	23.1	23.5	23.8	24.2	24.4	24.5
2.04	0.68	1.56	2.48	3.41	4.33	5.25	6.17	7.09	7.90	8.69	9.45	10.2	11.7	13.2	14.3	15.3	16.7	18.0	19.0	19.9	20.7	21.4	22.2	22.8	23.4	23.8	24.1	24.5	24.6	24.8
2.08	0.68	1.57	2.50	3.44	4.38	5.31	6.24	7.16	7.98	8.78	9.54	10.3	11.8	13.3	14.5	15.5	16.9	18.2	19.2	20.1	20.9	21.7	22.4	23.0	23.6	24.0	24.3	24.7	24.9	25.0
2.13	0.69	1.59	2.53	3.47	4.42	5.36	6.30	7.23	8.06	8.87	9.64	10.4	11.9	13.4	14.6	15.6	17.0	18.4	19.4	20.3	21.1	21.9	22.6	23.3	23.8	24.2	24.6	25.0	25.1	25.3
2.17	0.70	1.60	2.55	3.51	4.46	5.41	6.36	7.30	8.14	8.95	9.73	10.5	12.1	13.6	14.7	15.8	17.2	18.5	19.6	20.5	21.4	22.1	22.8	23.5	24.1	24.5	24.8	25.2	25.4	25.5
2.21	0.70	1.62	2.57	3.54	4.50	5.47	6.42	7.37	8.22	9.04	9.83	10.6	12.2	13.7	14.9	15.9	17.4	18.7	19.8	20.7	21.6	22.3	23.1	23.7	24.3	24.7	25.0	25.5	25.6	25.8
2.25	0.71	1.63	2.60	3.58	4.55	5.52	6.48	7.44	8.30	9.12	9.92	10.7	12.3	13.8	15.0	16.1	17.5	18.9	20.0	20.9	21.8	22.5	23.3	23.9	24.5	25.0	25.3	25.7	25.9	26.0
2.29	0.72	1.65	2.62	3.61	4.59	5.57	6.54	7.51	8.37	9.21	10.01	10.8	12.4	13.9	15.2	16.2	17.7	19.1	20.1	21.1	22.0	22.7	23.5	24.2	24.7	25.2	25.5	25.9	26.1	26.3
2.33	0.72	1.66	2.65	3.64	4.63	5.62	6.60	7.58	8.45	9.29	10.10	10.9	12.5	14.1	15.3	16.4	17.8	19.2	20.3	21.3	22.2	22.9	23.7	24.4	25.0	25.4	25.7	26.2	26.3	26.5
2.38	0.73	1.68	2.67	3.67	4.67	5.67	6.66	7.64	8.52	9.37	10.19	11.0	12.6	14.2	15.4	16.5	18.0	19.4	20.5	21.5	22.4	23.1	23.9	24.6	25.2	25.6	26.0	26.4	26.6	26.7
2.42	0.73	1.69	2.69	3.71	4.71	5.72	6.72	7.71	8.60	9.45	10.28	11.1	12.7	14.3	15.6	16.7	18.2	19.6	20.7	21.7	22.5	23.3	24.1	24.8	25.4	25.9	26.2	26.6	26.8	27.0
2.46	0.74	1.71	2.72	3.74	4.75	5.77	6.77	7.78	8.67	9.54	10.37	11.2	12.8	14.4	15.7	16.8	18.3	19.8	20.9	21.8	22.7	23.5	24.3	25.0	25.6	26.1	26.4	26.9	27.0	27.2
2.50	0.75	1.72	2.74	3.77	4.79	5.81	6.83	7.84	8.74	9.62	10.45	11.3	13.0	14.6	15.8	17.0	18.5	19.9	21.0	22.0	22.9	23.7	24.5	25.2	25.8	26.3	26.6	27.1	27.3	27.4
2.54	0.75	1.74	2.76	3.80	4.83	5.86	6.89	7.91	8.82	9.70	10.54	11.4	13.1	14.7	16.0	17.1	18.6	20.1	21.2	22.2	23.1	23.9	24.7	25.5	26.1	26.5	26.9	27.3	27.5	27.7
2.58	0.76	1.75	2.78	3.83	4.87	5.91	6.94	7.97	8.89	9.77	10.63	11.4	13.2	14.8	16.1	17.2	18.8	20.3	21.4	22.4	23.3	24.1	24.9	25.7	26.3	26.7	27.1	27.5	27.7	27.9
2.63	0.77	1.77	2.81	3.86	4.91	5.96	7.00	8.04	8.96	9.85	10.71	11.5	13.3	14.9	16.2	17.4	18.9	20.4	21.5	22.6	23.5	24.3	25.1	25.9	26.5	27.0	27.3	27.8	27.9	28.1
2.67	0.77	1.78	2.83	3.89	4.95	6.01	7.06	8.10	9.03	9.93	10.80	11.6	13.4	15.0	16.4	17.5	19.1	20.6	21.7	22.8	23.7	24.5	25.3	26.1	26.7	27.2	27.5	28.0	28.2	28.3
2.71	0.78	1.79	2.85	3.92	4.99	6.05	7.11	8.16	9.10	10.01	10.88	11.7	13.5	15.2	16.5	17.6	19.2	20.7	21.9	22.9	23.9	24.7	25.5	26.3	26.9	27.4	27.7	28.2	28.4	28.5
2.75	0.78	1.81	2.87	3.95	5.03	6.10	7.17	8.23	9.17	10.09	10.97	11.8	13.6	15.3	16.6	17.8	19.4	20.9	22.1	23.1	24.1	24.9	25.7	26.5	27.1	27.6	27.9	28.4	28.6	28.8
2.79	0.79	1.82	2.89	3.98	5.06	6.14	7.22	8.29	9.24	10.16	11.05	11.9	13.7	15.4	16.7	17.9	19.5	21.1	22.2	23.3	24.2	25.1	25.9	26.7	27.3	27.8	28.2	28.6	28.8	29.0
2.83	0.80	1.83	2.92	4.01	5.10	6.19	7.27	8.35	9.31	10.24	11.13	12.0	13.8	15.5	16.9	18.0	19.7	21.2	22.4	23.5	24.4	25.3	26.1	26.9	27.5	28.0	28.4	28.8	29.0	29.2
2.88	0.80	1.85	2.94	4.04	5.14	6.24	7.33	8.41	9.38	10.31	11.21	12.1	13.9	15.6	17.0	18.2	19.8	21.4	22.6	23.6	24.6	25.4	26.3	27.1	27.7	28.2	28.6	29.1	29.2	29.4
2.92	0.81	1.86	2.96	4.07	5.18	6.28	7.38	8.47	9.45	10.39	11.29	12.2	14.0	15.7	17.1	18.3	19.9	21.5	22.7	23.8	24.8	25.6	26.5	27.3	27.9	28.4	28.8	29.3	29.4	29.6
2.96	0.81	1.87	2.98	4.10	5.21	6.33	7.43	8.53	9.51	10.46	11.37	12.3	14.1	15.8	17.2	18.4	20.1	21.7	22.9	24.0	24.9	25.8	26.7	27.5	28.1	28.6	29.0	29.5	29.7	29.8
3.00	0.82	1.89	3.00	4.13	5.25	6.37	7.48	8.59	9.58	10.53	11.45	12.3	14.2	16.0	17.3	18.6	20.2	21.8	23.0	24.1	25.1	26.0	26.9	27.7	28.3	28.8	29.2	29.7	29.9	30.0
3.04	0.82	1.90	3.02	4.16	5.29	6.41	7.54	8.65	9.65	10.61	11.53	12.4	14.3	16.1	17.5	18.7	20.4	22.0	23.2	24.3	25.3	26.2	27.1	27.8	28.5	29.0	29.4	29.9	30.1	30.2
3.08	0.83	1.91	3.04	4.19	5.32	6.46	7.59	8.71	9.71	10.68	11.61	12.5	14.4	16.2	17.6	18.8	20.5	22.1	23.4	24.5	25.5	26.3	27.2	28.0	28.7	29.2	29.6	30.1	30.3	30.5
3.13	0.84	1.93	3.06	4.21	5.36	6.50	7.64	8.77	9.78	10.75	11.69	12.6	14.5	16.3	17.7	19.0	20.6	22.3	23.5	24.6	25.6	26.5	27.4	28.2	28.9	29.4	29.8	30.3	30.5	30.7
3.17	0.84	1.94	3.08	4.24	5.39	6.54	7.69	8.83	9.84	10.82	11.77	12.7	14.6	16.4	17.8	19.1	20.8	22.4	23.7	24.8	25.8	26.7	27.6	28.4	29.1	29.6	30.0	30.5	30.7	30.9
3.21	0.85	1.95	3.10	4.27	5.43	6.59	7.74	8.88	9.91	10.89	11.84	12.8	14.7	16.5	17.9	19.2	20.9	22.6	23.8	25.0	26.0	26.9	27.8	28.6	29.3	29.8	30.2	30.7	30.9	31.1
3.25	0.85	1.96	3.12	4.30	5.46	6.63	7.79	8.94	9.97	10.96	11.92	12.8	14.8	16.6	18.1	19.3	21.1	22.7	24.0	25.1	26.1	27.1	28.0	28.8	29.5	30.0	30.4	30.9	31.1	31.3
3.29	0.86	1.98	3.14	4.32	5.50	6.67	7.84	9.00	10.03	11.03	12.00	12.9	14.9	16.7	18.2	19.5	21.2	22.9	24.1	25.3	26.3	27.2	28.2	29.0	29.7	30.2	30.6	31.1	31.3	31.5
3.33	0.86	1.99	3.16	4.35	5.53	6.71	7.89	9.06	10.10	11.10	12.07	13.0	15.0	16.8	18.3	19.6	21.3	23.0	24.3	25.4	26.5	27.4	28.3	29.2	29.8	30.4	30.8	31.3	31.5	31.7
3.38	0.87	2.00	3.18	4.38	5.57	6.76	7.94	9.11	10.16	11.17	12.15	13.1	15.1	16.9	18.4	19.7	21.5	23.1	24.4	25.6	26.6	27.6	28.5	29.3	30.0	30.6	31.0	31.5	31.7	31.9
3.42	0.87	2.01	3.20	4.41	5.60	6.80	7.99	9.17	10.22	11.24	12.22	13.2	15.1	17.0	18.5	19.8	21.6	23.3	24.6	25.8	26.8	27.7	28.7	29.5	30.2	30.7	31.2	31.7	31.9	32.1
3.50	0.88	2.04	3.24	4.46	5.67	6.88	8.08	9.28	10.35	11.38	12.37	13.3	15.3	17.2	18.7	20.1	21.8	23.6	24.9	26.1	27.1	28.1	29.0	29.9	30.6	31.1	31.5	32.1	32.3	32.4
3.58	0.89	2.06	3.28	4.51	5.74	6.96	8.18	9.39	10.47	11.51	12.52	13.5	15.5	17.4	19.0	20.3	22.1	23.9	25.2	26.4	27.5	28.4	29.4	30.2	30.9	31.5	31.9	32.4	32.6	32.8
3.67	0.91	2.09	3.32	4.56	5.80	7.04	8.27	9.50	10.59	11.65	12.66	13.6	15.7	17.6	19.2	20.5	22.4	24.1	25.5	26.7	27.8	28.7	29.7	30.6	31.3	31.9	32.3	32.8	33.0	33.2
3.75	0.92	2.11	3.35	4.62	5.87	7.12	8.37	9.61	10.71	11.78	12.80	13.8	15.9	17.8	19.4	20.8	22.6	24.4	25.8	27.0	28.1	29.1	30.1	30.9	31.7	32.2	32.6	33.2	33.4	33.6
3.83	0.93	2.13	3.39	4.67	5.94	7.20	8.46	9.71	10.83	11.91	12.95	13.9	16.0	18.0	19.6	21.0	22.9	24.7	26.0	27.3	28.4	29.4	30.4	31.3	32.0	32.6	33.0	33.5	33.8	34.0
3.92	0.94	2.16	3.43	4.72	6.00	7.28	8.55	9.82	10.95	12.04	13.09	14.1	16.2	18.2	19.8	21.2	23.1	24.9	26.3	27.6	28.7	29.7	30.7	31.6	32.3	32.9	33.4	33.9	34.1	34.3
4.00	0.95	2.18	3.46	4.77	6.06	7.36	8.64	9.92	11.06	12.16	13.22	14.2	16.4	18.4	20.0	21.4	23.4	25.2	26.6	27.9	29.0	30.0	31.0	31.9	32.7	33.3	33.7	34.3	34.5	34.7
4.08	0.96	2.20	3.50	4.82	6.13	7.43	8.73	10.02	11.18	12.29	13.36	14.4	16.6	18.6	20.2	21.7	23.6	25.5	26.9	28.2	29.3	30.3	31.4	32.3	33.0	33.6	34.1	34.6	34.8	35.0
4.17	0.96	2.22	3.54	4.87	6.19	7.51	8.82	10.12	11.29	12.41	13.50	14.5	16.7	18.8	20.4	21.9	23.8	25.7	27.1	28.4	29.6	30.6	31.7	32.6	33.4	34.0	34.4	35.0	35.2	35.4
4.25	0.97	2.25	3.57	4.91	6.25	7.58	8.91	10.23	11.40	12.54	13.63	14.7	16.9	19.0	20.6	22.1	24.1	26.0	27.4	28.7	29.9	30.9	32.0	32.9	33.7	34.3	34.7	35.3	35.5	35.8
4.33	0.98	2.27	3.61	4.96	6.31	7.66	8.99	10.33	11.51	12.66	13.76	14.8	17.1	19.2	20.8	22.3	24.3	26.2	27.7	29.0	30.2	31.2	32.3	33.2	34.0	34.6	35.1	35.7	35.9	36.1
4.42	0.99	2.29	3.64	5.01	6.37	7.73	9.08	10.42	11.62	12.78	13.90	15.0	17.2	19.4	21.0	22.5	24.5	26.5	28.0	29.3	30.5	31.5	32.6	33.6	34.4	35.0	35.4	36.0	36.2	36.5
4.50	1.00	2.31	3.67	5.06	6.43	7.80	9.17	10.52	11.73	12.90	14.03	15.1	17.4	19.5	21.2	22.7	24.8	26.7	28.2	29.6	30.8	31.8	32.9	33.9	34.7	35.3	35.7	36.3	36.6	36.8
4.58	1.01	2.33	3.71	5.10	6.49	7.87	9.25	10.62	11.84	13.02	14.16	15.2	17.5	19.7	21.4	23.0	25.0	27.0	28.5	29.8	31.1	32.1	33.2	34.2	35.0	35.6	36.1	36.7	36.9	37.1
4.67	1.02	2.35	3.74	5.15	6.55	7.94	9.33	10.72	11.95	13.14	14.28	15.4	17.7	19.9	21.6	23.2	25.2	27.2	28.7	30.1	31.3	32.4	33.5	34.5	35.3	35.9	36.4	37.0	37.2	37.5
4.75	1.03	2.38	3.78	5.19	6.61	8.02	9.42	10.81	12.05	13.25	14.41	15.5	17.9	20.1	21.8	23.4	25.5	27.5	29.0	30.4	31.6	32.7	33.8	34.8	35.6	36.3	36.7	37.3	37.6	37.8
4.83	1.04	2.40	3.81	5.24	6.66	8.09	9.50	10.90	12.16	13.37	14.54	15.7	18.0	20.3	22.0	23.6	25.7	27.7	29.2	30.6	31.9	33.0	34.1	35.1	35.9	36.6	37.1	37.7	37.9	38.1
4.92	1.05	2.42	3.84	5.28	6.72	8.15	9.58	11.00	12.26	13.48	14.66	15.8	18.2	20.4	22.2	23.8	25.9	27.9	29.5	30.9	32.2	33.3	34.4	35.4	36.2	36.9	37.4	38.0	38.2	38.5
5.00	1.06	2.44	3.87	5.33	6.78	8.22	9.66	11.09	12.37	13.60	14.79	15.9	18.3	20.6	22.4	24.0	26.1	28.2	29.7	31.2	32.4	33.6	34.7	35.7	36.6	37.2	37.7	38.3	38.6	38.8

ITRC Water Measurement Tables for
RECTANGULAR Gates on Round Pipes
Discharge Values in CFS

Normal submerged metergate operation

ITRC Water Measurement Tables – 18” Rectangular Gate, Stilling Well Located 12” d/s of Back of Gate [Blue center represents best accuracy range]

ΔH (feet)	Net Gate Opening (feet)																							
	0.042	0.08	0.13	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33	1.42	1.50
	Discharge (CFS)																							
0.04	0.02	0.05	0.09	0.13	0.18	0.23	0.28	0.34	0.40	0.46	0.52	0.58	0.72	0.86	1.01	1.17	1.34	1.51	1.71	1.92	2.07	2.21	2.26	2.28
0.06	0.02	0.06	0.11	0.16	0.22	0.28	0.35	0.42	0.49	0.56	0.64	0.71	0.88	1.05	1.24	1.43	1.64	1.85	2.10	2.36	2.54	2.70	2.77	2.79
0.08	0.02	0.07	0.12	0.19	0.25	0.33	0.40	0.48	0.56	0.65	0.73	0.82	1.01	1.21	1.43	1.65	1.89	2.13	2.43	2.72	2.93	3.12	3.20	3.22
0.10	0.03	0.08	0.14	0.21	0.28	0.37	0.45	0.54	0.63	0.72	0.82	0.92	1.13	1.36	1.60	1.85	2.11	2.39	2.71	3.04	3.28	3.49	3.58	3.60
0.13	0.03	0.08	0.15	0.23	0.31	0.40	0.49	0.59	0.69	0.79	0.90	1.01	1.24	1.49	1.75	2.02	2.32	2.61	2.97	3.33	3.59	3.82	3.92	3.95
0.15	0.03	0.09	0.16	0.25	0.34	0.43	0.53	0.63	0.74	0.86	0.97	1.09	1.34	1.61	1.89	2.19	2.50	2.82	3.21	3.60	3.88	4.13	4.24	4.26
0.17	0.03	0.09	0.17	0.26	0.36	0.46	0.57	0.68	0.80	0.92	1.04	1.16	1.44	1.72	2.02	2.34	2.67	3.02	3.43	3.85	4.15	4.42	4.53	4.56
0.19	0.04	0.10	0.18	0.28	0.38	0.49	0.60	0.72	0.84	0.97	1.10	1.23	1.52	1.82	2.15	2.48	2.84	3.20	3.64	4.08	4.40	4.68	4.80	4.84
0.21	0.04	0.11	0.19	0.29	0.40	0.52	0.64	0.76	0.89	1.02	1.16	1.30	1.60	1.92	2.26	2.61	2.99	3.37	3.83	4.30	4.63	4.94	5.06	5.10
0.23	0.04	0.11	0.20	0.31	0.42	0.54	0.67	0.79	0.93	1.07	1.22	1.36	1.68	2.01	2.37	2.74	3.14	3.54	4.02	4.51	4.86	5.18	5.31	5.35
0.25	0.04	0.12	0.21	0.32	0.44	0.57	0.70	0.83	0.97	1.12	1.27	1.42	1.76	2.10	2.48	2.86	3.28	3.70	4.20	4.71	5.08	5.41	5.55	5.58
0.27	0.04	0.12	0.22	0.34	0.46	0.59	0.72	0.86	1.01	1.17	1.32	1.48	1.83	2.19	2.58	2.98	3.41	3.85	4.37	4.90	5.28	5.63	5.77	5.81
0.29	0.04	0.13	0.23	0.35	0.48	0.61	0.75	0.90	1.05	1.21	1.37	1.54	1.90	2.27	2.68	3.09	3.54	3.99	4.54	5.09	5.48	5.84	5.99	6.03
0.31	0.05	0.13	0.24	0.36	0.49	0.63	0.78	0.93	1.09	1.25	1.42	1.59	1.97	2.35	2.77	3.20	3.66	4.13	4.70	5.27	5.68	6.05	6.20	6.24
0.33	0.05	0.13	0.24	0.37	0.51	0.65	0.80	0.96	1.12	1.30	1.47	1.64	2.03	2.43	2.86	3.30	3.78	4.27	4.85	5.44	5.86	6.24	6.41	6.45
0.35	0.05	0.14	0.25	0.38	0.52	0.67	0.83	0.99	1.16	1.33	1.51	1.69	2.09	2.50	2.95	3.41	3.90	4.40	5.00	5.61	6.04	6.44	6.60	6.65
0.38	0.05	0.14	0.26	0.40	0.54	0.69	0.85	1.02	1.19	1.37	1.56	1.74	2.15	2.57	3.03	3.50	4.01	4.53	5.14	5.77	6.22	6.62	6.79	6.84
0.40	0.05	0.15	0.27	0.41	0.55	0.71	0.88	1.04	1.23	1.41	1.60	1.79	2.21	2.65	3.12	3.60	4.12	4.65	5.29	5.93	6.39	6.81	6.98	7.03
0.42	0.05	0.15	0.27	0.42	0.57	0.73	0.90	1.07	1.26	1.45	1.64	1.84	2.27	2.71	3.20	3.69	4.23	4.77	5.42	6.08	6.55	6.98	7.16	7.21
0.46	0.06	0.16	0.29	0.44	0.60	0.77	0.94	1.12	1.32	1.52	1.72	1.93	2.38	2.85	3.35	3.87	4.44	5.00	5.69	6.38	6.87	7.32	7.51	7.56
0.50	0.06	0.16	0.30	0.46	0.62	0.80	0.98	1.17	1.38	1.59	1.80	2.01	2.49	2.97	3.50	4.05	4.63	5.23	5.94	6.66	7.18	7.65	7.84	7.90
0.54	0.06	0.17	0.31	0.48	0.65	0.83	1.03	1.22	1.43	1.65	1.87	2.10	2.59	3.09	3.65	4.21	4.82	5.44	6.18	6.93	7.47	7.96	8.16	8.22
0.58	0.06	0.18	0.32	0.49	0.67	0.86	1.06	1.27	1.49	1.71	1.94	2.17	2.69	3.21	3.78	4.37	5.00	5.65	6.42	7.20	7.75	8.26	8.47	8.53
0.63	0.07	0.18	0.33	0.51	0.70	0.90	1.10	1.31	1.54	1.77	2.01	2.25	2.78	3.32	3.92	4.52	5.18	5.84	6.64	7.45	8.03	8.55	8.77	8.83
0.67	0.07	0.19	0.35	0.53	0.72	0.92	1.14	1.36	1.59	1.83	2.08	2.32	2.87	3.43	4.05	4.67	5.35	6.04	6.86	7.69	8.29	8.83	9.06	9.12
0.71	0.07	0.20	0.36	0.54	0.74	0.95	1.17	1.40	1.64	1.89	2.14	2.40	2.96	3.54	4.17	4.82	5.51	6.22	7.07	7.93	8.55	9.10	9.34	9.40
0.75	0.07	0.20	0.37	0.56	0.76	0.98	1.21	1.44	1.69	1.94	2.20	2.47	3.04	3.64	4.29	4.96	5.67	6.40	7.28	8.16	8.79	9.37	9.61	9.67
0.79	0.07	0.21	0.38	0.57	0.78	1.01	1.24	1.48	1.73	2.00	2.26	2.53	3.13	3.74	4.41	5.09	5.83	6.58	7.47	8.38	9.03	9.62	9.87	9.94
0.83	0.08	0.21	0.39	0.59	0.81	1.03	1.27	1.52	1.78	2.05	2.32	2.60	3.21	3.84	4.52	5.22	5.98	6.75	7.67	8.60	9.27	9.87	10.13	10.20
0.92	0.08	0.22	0.41	0.62	0.84	1.08	1.33	1.59	1.87	2.15	2.43	2.73	3.37	4.03	4.74	5.48	6.27	7.08	8.04	9.02	9.72	10.36	10.62	10.69
1.00	0.08	0.23	0.42	0.65	0.88	1.13	1.39	1.66	1.95	2.24	2.54	2.85	3.52	4.20	4.96	5.72	6.55	7.39	8.40	9.42	10.15	10.82	11.09	11.17
1.08	0.09	0.24	0.44	0.67	0.92	1.18	1.45	1.73	2.03	2.33	2.65	2.96	3.66	4.38	5.16	5.96	6.82	7.69	8.74	9.81	10.57	11.26	11.55	11.62
1.17	0.09	0.25	0.46	0.70	0.95	1.22	1.50	1.79	2.10	2.42	2.75	3.08	3.80	4.54	5.35	6.18	7.08	7.98	9.07	10.18	10.97	11.68	11.98	12.06
1.25	0.09	0.26	0.47	0.72	0.99	1.27	1.56	1.86	2.18	2.51	2.84	3.18	3.93	4.70	5.54	6.40	7.33	8.26	9.39	10.53	11.35	12.09	12.40	12.49
1.33	0.10	0.27	0.49	0.75	1.02	1.31	1.61	1.92	2.25	2.59	2.94	3.29	4.06	4.86	5.72	6.61	7.57	8.53	9.70	10.88	11.72	12.49	12.81	12.90
1.42	0.10	0.28	0.50	0.77	1.05	1.35	1.66	1.98	2.32	2.67	3.03	3.39	4.18	5.00	5.90	6.81	7.80	8.80	10.00	11.21	12.09	12.87	13.20	13.29
1.50	0.10	0.28	0.52	0.79	1.08	1.39	1.71	2.03	2.39	2.75	3.11	3.49	4.31	5.15	6.07	7.01	8.02	9.05	10.29	11.54	12.44	13.25	13.59	13.68
1.58	0.10	0.29	0.53	0.81	1.11	1.42	1.75	2.09	2.45	2.82	3.20	3.58	4.42	5.29	6.24	7.20	8.24	9.30	10.57	11.86	12.78	13.61	13.96	14.05
1.67	0.11	0.30	0.55	0.83	1.14	1.46	1.80	2.14	2.52	2.90	3.28	3.68	4.54	5.43	6.40	7.39	8.46	9.54	10.85	12.16	13.11	13.96	14.32	14.42
1.75	0.11	0.31	0.56	0.85	1.17	1.50	1.84	2.20	2.58	2.97	3.36	3.77	4.65	5.56	6.56	7.57	8.67	9.78	11.11	12.46	13.43	14.31	14.68	14.77
1.83	0.11	0.31	0.57	0.87	1.19	1.53	1.89	2.25	2.64	3.04	3.44	3.85	4.76	5.69	6.71	7.75	8.87	10.01	11.37	12.76	13.75	14.65	15.02	15.12
1.92	0.11	0.32	0.59	0.89	1.22	1.57	1.93	2.30	2.70	3.11	3.52	3.94	4.87	5.82	6.86	7.92	9.07	10.23	11.63	13.04	14.06	14.97	15.36	15.46
2.00	0.12	0.33	0.60	0.91	1.25	1.60	1.97	2.35	2.76	3.17	3.60	4.03	4.97	5.95	7.01	8.09	9.27	10.45	11.88	13.32	14.36	15.30	15.69	15.79
2.08	0.12	0.34	0.61	0.93	1.27	1.63	2.01	2.40	2.81	3.24	3.67	4.11	5.07	6.07	7.15	8.26	9.46	10.67	12.13	13.60	14.66	15.61	16.01	16.12
2.17	0.12	0.34	0.62	0.95	1.30	1.67	2.05	2.44	2.87	3.30	3.74	4.19	5.18	6.19	7.29	8.42	9.64	10.88	12.37	13.87	14.95	15.92	16.33	16.44
2.25	0.12	0.35	0.64	0.97	1.32	1.70	2.09	2.49	2.92	3.36	3.81	4.27	5.27	6.31	7.43	8.58	9.83	11.09	12.60	14.13	15.23	16.22	16.64	16.75
2.33	0.13	0.36	0.65	0.99	1.35	1.73	2.13	2.54	2.98	3.43	3.88	4.35	5.37	6.42	7.57	8.74	10.01	11.29	12.83	14.39	15.51	16.52	16.95	17.06
2.42	0.13	0.36	0.66	1.00	1.37	1.76	2.17	2.58	3.03	3.49	3.95	4.43	5.47	6.54	7.70	8.90	10.19	11.49	13.06	14.65	15.78	16.81	17.25	17.36
2.50	0.13	0.37	0.67	1.02	1.39	1.79	2.20	2.63	3.08	3.55	4.02	4.50	5.56	6.65	7.84	9.05	10.36	11.69	13.28	14.90	16.05	17.10	17.54	17.66
2.58	0.13	0.37	0.68	1.04	1.42	1.82	2.24	2.67	3.13	3.61	4.09	4.58	5.65	6.76	7.96	9.20	10.53	11.88	13.50	15.14	16.32	17.38	17.83	17.95
2.67	0.14	0.38	0.69	1.05	1.44	1.85	2.27	2.71	3.18	3.66	4.15	4.65	5.74	6.87	8.09	9.34	10.70	12.07	13.72	15.39	16.58	17.66	18.12	18.24
2.75	0.14	0.39	0.70	1.07	1.46	1.88	2.31	2.75	3.23	3.72	4.22	4.72	5.83	6.97	8.22	9.49	10.87	12.26	13.93	15.62	16.84	17.94	18.40	18.52
2.83	0.14	0.39	0.71	1.09	1.48	1.91	2.34	2.80	3.28	3.78	4.28	4.79	5.92	7.08	8.34	9.63	11.03	12.44	14.14	15.86	17.09	18.21	18.67	18.80

ITRC Water Measurement Tables – 24" Rectangular Gate, Stilling Well Located 12" d/s of Back of Gate [Blue center represents best accuracy range]

ΔH (feet)	Net Gate Opening (feet)																													
	0.042	0.08	0.13	0.17	0.21	0.25	0.29	0.33	0.38	0.42	0.46	0.50	0.58	0.67	0.75	0.83	0.92	1.00	1.08	1.17	1.25	1.33	1.42	1.50	1.58	1.67	1.75	1.83	1.92	2.00
	Discharge (CFS)																													
0.04	0.04	0.07	0.12	0.18	0.25	0.31	0.38	0.44	0.52	0.60	0.68	0.76	0.93	1.11	1.30	1.49	1.68	1.86	2.06	2.25	2.45	2.65	2.87	3.08	3.28	3.70	3.89	4.05	4.06	4.07
0.06	0.04	0.08	0.15	0.23	0.30	0.38	0.46	0.54	0.64	0.73	0.83	0.93	1.14	1.36	1.60	1.83	2.06	2.28	2.52	2.75	3.00	3.25	3.51	3.77	4.02	4.54	4.76	4.96	4.97	4.98
0.08	0.05	0.09	0.17	0.26	0.35	0.44	0.54	0.63	0.74	0.85	0.96	1.07	1.32	1.57	1.84	2.11	2.38	2.64	2.91	3.18	3.47	3.75	4.06	4.36	4.64	5.24	5.50	5.73	5.74	5.75
0.10	0.06	0.10	0.19	0.29	0.39	0.50	0.60	0.70	0.82	0.95	1.07	1.20	1.48	1.76	2.06	2.36	2.66	2.95	3.25	3.55	3.88	4.20	4.54	4.87	5.19	5.85	6.15	6.41	6.42	6.43
0.13	0.06	0.11	0.21	0.32	0.43	0.54	0.66	0.77	0.90	1.04	1.18	1.32	1.62	1.93	2.26	2.59	2.91	3.23	3.56	3.89	4.25	4.60	4.97	5.33	5.69	6.41	6.73	7.02	7.03	7.04
0.15	0.07	0.12	0.23	0.34	0.46	0.59	0.71	0.83	0.97	1.12	1.27	1.42	1.75	2.08	2.44	2.80	3.14	3.49	3.85	4.20	4.59	4.96	5.37	5.76	6.14	6.93	7.27	7.58	7.59	7.61
0.17	0.07	0.13	0.24	0.37	0.50	0.63	0.76	0.89	1.04	1.20	1.36	1.52	1.87	2.23	2.60	2.99	3.36	3.73	4.11	4.49	4.90	5.31	5.74	6.16	6.57	7.41	7.77	8.10	8.12	8.13
0.19	0.08	0.14	0.26	0.39	0.53	0.66	0.80	0.94	1.10	1.27	1.44	1.61	1.98	2.36	2.76	3.17	3.56	3.96	4.36	4.77	5.20	5.63	6.09	6.53	6.97	7.86	8.24	8.59	8.61	8.62
0.21	0.08	0.15	0.27	0.41	0.55	0.70	0.85	0.99	1.16	1.34	1.52	1.70	2.09	2.49	2.91	3.34	3.76	4.17	4.60	5.02	5.48	5.93	6.41	6.89	7.34	8.28	8.69	9.06	9.07	9.09
0.23	0.08	0.15	0.28	0.43	0.58	0.73	0.89	1.04	1.22	1.41	1.59	1.78	2.19	2.61	3.05	3.50	3.94	4.37	4.82	5.27	5.75	6.22	6.73	7.22	7.70	8.68	9.11	9.50	9.52	9.53
0.25	0.09	0.16	0.30	0.45	0.61	0.77	0.93	1.09	1.28	1.47	1.66	1.86	2.29	2.73	3.19	3.66	4.12	4.57	5.04	5.50	6.00	6.50	7.03	7.54	8.05	9.07	9.52	9.92	9.94	9.96
0.27	0.09	0.17	0.31	0.47	0.63	0.80	0.97	1.13	1.33	1.53	1.73	1.94	2.38	2.84	3.32	3.81	4.28	4.75	5.24	5.73	6.25	6.77	7.31	7.85	8.37	9.44	9.91	10.33	10.35	10.37
0.29	0.10	0.17	0.32	0.49	0.66	0.83	1.00	1.18	1.38	1.59	1.80	2.01	2.47	2.95	3.45	3.95	4.45	4.93	5.44	5.94	6.49	7.02	7.59	8.15	8.69	9.80	10.28	10.72	10.74	10.76
0.31	0.10	0.18	0.33	0.50	0.68	0.86	1.04	1.22	1.43	1.64	1.86	2.08	2.56	3.05	3.57	4.09	4.60	5.11	5.63	6.15	6.71	7.27	7.86	8.43	8.99	10.14	10.64	11.09	11.11	11.13
0.33	0.10	0.19	0.34	0.52	0.70	0.89	1.07	1.26	1.47	1.70	1.92	2.15	2.64	3.15	3.68	4.23	4.75	5.27	5.82	6.35	6.93	7.51	8.11	8.71	9.29	10.47	10.99	11.46	11.48	11.50
0.35	0.11	0.19	0.35	0.54	0.72	0.91	1.11	1.29	1.52	1.75	1.98	2.22	2.72	3.25	3.80	4.36	4.90	5.44	6.00	6.55	7.15	7.74	8.36	8.98	9.58	10.80	11.33	11.81	11.83	11.85
0.38	0.11	0.20	0.36	0.55	0.74	0.94	1.14	1.33	1.56	1.80	2.04	2.28	2.80	3.34	3.91	4.48	5.04	5.59	6.17	6.74	7.35	7.96	8.61	9.24	9.85	11.11	11.66	12.15	12.17	12.20
0.40	0.11	0.20	0.37	0.57	0.76	0.97	1.17	1.37	1.61	1.85	2.09	2.34	2.88	3.43	4.01	4.61	5.18	5.75	6.34	6.92	7.55	8.18	8.84	9.49	10.12	11.41	11.98	12.49	12.51	12.53
0.42	0.11	0.21	0.38	0.58	0.78	0.99	1.20	1.40	1.65	1.90	2.15	2.40	2.96	3.52	4.12	4.73	5.31	5.90	6.50	7.10	7.75	8.39	9.07	9.74	10.39	11.71	12.29	12.81	12.83	12.86
0.46	0.12	0.22	0.40	0.61	0.82	1.04	1.26	1.47	1.73	1.99	2.25	2.52	3.10	3.69	4.32	4.96	5.57	6.18	6.82	7.45	8.13	8.80	9.51	10.21	10.89	12.28	12.89	13.44	13.46	13.48
0.50	0.13	0.23	0.42	0.64	0.86	1.09	1.31	1.54	1.80	2.08	2.35	2.63	3.24	3.86	4.51	5.18	5.82	6.46	7.12	7.78	8.49	9.19	9.94	10.67	11.38	12.83	13.46	14.03	14.06	14.08
0.54	0.13	0.24	0.43	0.66	0.89	1.13	1.37	1.60	1.88	2.16	2.45	2.74	3.37	4.01	4.70	5.39	6.06	6.72	7.42	8.10	8.84	9.57	10.34	11.10	11.84	13.35	14.01	14.61	14.63	14.66
0.58	0.14	0.25	0.45	0.69	0.93	1.17	1.42	1.66	1.95	2.24	2.54	2.84	3.50	4.17	4.87	5.59	6.29	6.98	7.70	8.40	9.17	9.93	10.73	11.52	12.29	13.85	14.54	15.16	15.18	15.21
0.63	0.14	0.26	0.47	0.71	0.96	1.21	1.47	1.72	2.02	2.32	2.63	2.94	3.62	4.31	5.04	5.79	6.51	7.22	7.97	8.70	9.49	10.28	11.11	11.93	12.72	14.34	15.05	15.69	15.72	15.75
0.67	0.14	0.26	0.48	0.74	0.99	1.25	1.52	1.78	2.08	2.40	2.72	3.04	3.74	4.45	5.21	5.98	6.72	7.46	8.23	8.98	9.80	10.61	11.47	12.32	13.14	14.81	15.55	16.20	16.23	16.26
0.71	0.15	0.27	0.50	0.76	1.02	1.29	1.56	1.83	2.15	2.47	2.80	3.13	3.85	4.59	5.37	6.16	6.93	7.69	8.48	9.26	10.11	10.94	11.83	12.70	13.54	15.27	16.02	16.70	16.73	16.76
0.75	0.15	0.28	0.51	0.78	1.05	1.33	1.61	1.88	2.21	2.54	2.88	3.22	3.97	4.72	5.53	6.34	7.13	7.91	8.73	9.53	10.40	11.26	12.17	13.07	13.93	15.71	16.49	17.19	17.22	17.25
0.79	0.16	0.29	0.53	0.80	1.08	1.37	1.65	1.94	2.27	2.61	2.96	3.31	4.07	4.85	5.68	6.51	7.32	8.13	8.97	9.79	10.68	11.57	12.50	13.42	14.32	16.14	16.94	17.66	17.69	17.72
0.83	0.16	0.30	0.54	0.82	1.11	1.40	1.70	1.99	2.33	2.68	3.04	3.40	4.18	4.98	5.82	6.68	7.52	8.34	9.20	10.05	10.96	11.87	12.83	13.77	14.69	16.56	17.38	18.12	18.15	18.18
0.92	0.17	0.31	0.57	0.86	1.16	1.47	1.78	2.08	2.44	2.81	3.19	3.57	4.38	5.22	6.11	7.01	7.88	8.75	9.65	10.54	11.50	12.45	13.45	14.44	15.41	17.37	18.23	19.00	19.03	19.07
1.00	0.18	0.32	0.59	0.90	1.21	1.53	1.86	2.18	2.55	2.94	3.33	3.72	4.58	5.45	6.38	7.32	8.23	9.14	10.08	11.00	12.01	13.00	14.05	15.09	16.09	18.14	19.04	19.85	19.88	19.92
1.08	0.18	0.34	0.61	0.94	1.26	1.60	1.93	2.26	2.66	3.06	3.46	3.88	4.77	5.68	6.64	7.62	8.57	9.51	10.49	11.45	12.50	13.53	14.63	15.70	16.75	18.88	19.82	20.66	20.69	20.73
1.17	0.19	0.35	0.64	0.98	1.31	1.66	2.01	2.35	2.76	3.17	3.59	4.02	4.95	5.89	6.89	7.91	8.89	9.87	10.88	11.89	12.97	14.04	15.18	16.30	17.38	19.59	20.57	21.44	21.47	21.51
1.25	0.20	0.36	0.66	1.01	1.36	1.72	2.08	2.43	2.85	3.28	3.72	4.16	5.12	6.10	7.13	8.18	9.20	10.21	11.27	12.30	13.43	14.53	15.71	16.87	17.99	20.28	21.29	22.19	22.23	22.27
1.33	0.20	0.37	0.68	1.04	1.40	1.77	2.14	2.51	2.95	3.39	3.84	4.30	5.29	6.30	7.37	8.45	9.51	10.55	11.63	12.71	13.87	15.01	16.23	17.42	18.58	20.95	21.99	22.92	22.95	23.00
1.42	0.21	0.39	0.70	1.07	1.45	1.83	2.21	2.59	3.04	3.49	3.96	4.43	5.45	6.49	7.59	8.71	9.80	10.87	11.99	13.10	14.29	15.47	16.73	17.96	19.15	21.59	22.66	23.62	23.66	23.71
1.50	0.22	0.40	0.72	1.11	1.49	1.88	2.27	2.66	3.13	3.60	4.08	4.56	5.61	6.68	7.81	8.97	10.08	11.19	12.34	13.48	14.71	15.92	17.21	18.48	19.71	22.22	23.32	24.31	24.35	24.39
1.58	0.22	0.41	0.74	1.14	1.53	1.93	2.34	2.74	3.21	3.69	4.19	4.69	5.76	6.86	8.03	9.21	10.36	11.50	12.68	13.85	15.11	16.36	17.68	18.98	20.25	22.83	23.96	24.97	25.01	25.06
1.67	0.23	0.42	0.76	1.17	1.57	1.98	2.40	2.81	3.29	3.79	4.30	4.81	5.91	7.04	8.24	9.45	10.63	11.79	13.01	14.21	15.50	16.78	18.14	19.48	20.77	23.42	24.58	25.62	25.66	25.71
1.75	0.23	0.43	0.78	1.19	1.61	2.03	2.46	2.88	3.38	3.88	4.40	4.93	6.06	7.22	8.44	9.68	10.89	12.08	13.33	14.56	15.89	17.20	18.59	19.96	21.29	24.00	25.19	26.25	26.30	26.35
1.83	0.24	0.44	0.80	1.22	1.64	2.08	2.51	2.95	3.45	3.98	4.51	5.04	6.20	7.38	8.64	9.91	11.15	12.37	13.64	14.90	16.26	17.60	19.03	20.43	21.79	24.56	25.78	26.87	26.92	26.97
1.92	0.24	0.45	0.82	1.25	1.68	2.13	2.57	3.01	3.53	4.07	4.61	5.16	6.34	7.55	8.83	10.14	11.40	12.65	13.95	15.23	16.62	18.00	19.46	20.89	22.28	25.11	26.36	27.48	27.52	27.57
2.00	0.25	0.46	0.84	1.28	1.72	2.17	2.63	3.08	3.61	4.15	4.71	5.27	6.47	7.71	9.02	10.35	11.64	12.92	14.25	15.56	16.98	18.39	19.87	21.34	22.76	25.65	26.93	28.07	28.11	28.17
2.08	0.26	0.47	0.85	1.30	1.75	2.22	2.68	3.14	3.68	4.24	4.80	5.37	6.61	7.87	9.21	10.57	11.88	13.19	14.54	15.88	17.33	18.76	20.28	21.78	23.22	26.18	27.48	28.65	28.69	28.75
2.17	0.26	0.48	0.87	1.33	1.79	2.26	2.73	3.20	3.76	4.32	4.90	5.48	6.74	8.03	9.39	10.78	12.12	13.45	14.83	16.20	17.68	19.14	20.69	22.21	23.68	26.70	28.03	29.21	29.26	29.32
2.25	0.27	0.49	0.89	1.35	1.82	2.30	2.79	3.26	3.83	4.40	4.99	5.59	6.87	8.18	9.57	10.98	12.35	13.70	15.11	16.51	18.01	19.50	21.08	22.63	24.14	27.21	28.56	29.77	29.82	29.88
2.33	0.27	0.49	0.90	1.38	1.86	2.34	2.84	3.32	3.90	4.49	5.08	5.69	6.99	8.33	9.75	11.18	12.58	13.95	15.39	16.81	18.34	19.86	21.47	23.05	24.58	27.71	29.08	30.32	30.37	30.42
2.42	0.27	0.50	0.92	1.40	1.89	2.39	2.89	3.38	3.97	4.56	5.17	5.79	7.12	8.48	9.92	11.38	12.80	14.20	15.66	17.11	18.67	20.21	21.85	23.45	25.01	28.20	29.60	30.85	30.90	30.96
2.50	0.28	0.51	0.93	1.43	1.92	2.43	2.94	3.44	4.03	4.64	5.26	5.89	7.24	8.62	10.09	11.58	13.02	14.44	15.93	17.40	18.99	20.56	22.22	23.85	25.44	28.68	30.11	31.38	31.43	31.49
2.58	0.28	0.52	0.95	1.45	1.95	2.47	2.99	3.50	4.10	4.72	5.35	5.99	7.36	8.77	10.25	11.77	13.23	14.68	16.19	17.69	19.30	20.90	22.59	24.25	25.86	29.16	30.60	31.90	31.95	32.01
2.67	0.29	0.53	0.96	1.47	1.98	2.51	3.03	3.55	4.17	4.80	5.43	6.08	7.48	8.91	10.42	11.95	13.44	14.92	16.45	17.97	19.61	21.23	22.95	24.64	26.28	29.62	31.09	32.41	32.46	32.52
2.75	0.29	0.54	0.98	1.50	2.01	2.55	3.08	3.61	4.23	4.87	5.52	6.18	7.59	9.04	10.58	12.14	13.65	15.15	16.71	18.25	19.91	21.56	23.30	25.02	26.68	30.08	31.57	32.91	32.97	33.03
2.83	0.30	0.54	0.99	1.52	2.04	2.58	3.13	3.66	4.29	4.94	5.60	6.27	7.71	9.18	10.74	12.32	13.86	15.38	16.96	18.52	20.21	21.88	23.65	25.39	27.08	30.53	32.05	33.41	33.46	33.52