Chapter 3
Measuring Water Applications

3.1 Introduction

3.1.1 Need for Water Measurement

In Chapter 2, we discussed soil water storage and related this storage to an “equivalent depth” of water on the soil surface. You can envision this “equivalent depth” as the water measured in a rain gauge. In Chapter 4 we will present how this depth relates to plant water needs. In this chapter we discuss how we can determine the depth of water applied with an irrigation system.

Have you ever wondered what it would be like to drive an automobile without a speedometer and an odometer? You might feel somewhat lost. You would not know how fast you were going, nor how far you’ve traveled. Irrigating without water measurement is much the same way. Without knowing the water flow rate, you do not know how fast you are applying water. And, without measured volumes, you cannot determine the depth of application. Good water management begins with accurate water measurement. Unfortunately, because of the regulatory implications, some water users have an unfavorable attitude towards water measurement. Good water managers use water measurement to evaluate how efficiently they are using the water that they apply.

Energy management is another reason to measure water. To evaluate the energy efficiency of pumping systems, you need to know both the energy input and the output from the pumping system. The output includes the water flow rate.

3.1.2 Depth Volume Relationships

Irrigators commonly measure and discuss rainfall depth. Since irrigation is artificial rainfall, it is also useful to express irrigation water application as a depth. Equations 3.1 and 3.2 relate the depth applied and applied volume to the land area irrigated:

\[
V = A \times d
\]

(3.2)

\[
d = \frac{V}{A}
\]

(3.1)

where:
- \(d\) = depth of water applied,
- \(V\) = volume of water applied, and
- \(A\) = area irrigated.

The concepts of Equations 3.1 and 3.2 are shown in Figure 3.1.

Since the volume of water applied is the product of system flow rate and the time of application, Equation 3.2 is often expressed as:

\[
Q \times t = A \times d
\]

(3.3)

where:
- \(Q\) = system flow rate and
- \(t\) = time of water application.

This equation assumes that the flow rate is constant over the application time.
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application time. Use of Equation 3.3 is basic to efficient irrigation management. Although straightforward, Equation 3.3 requires that the user apply the appropriate conversion factors to make the units consistent. When using Equation 3.1 and 3.2, it is most convenient to convert volume units to acre-inch (ac-in) when working in agriculture. Table 3.1 lists common unit conversion factors for volume and flow rate. When using U.S. units, approximately 450 gallons per minute (gpm) equals 1 ac-in/hr. An ac-in is the volume of water that covers 1 acre 1 inch deep. Before using Equation 3.3 for an agricultural application, the system flow rate \( Q \) should be converted to ac-in/hr. One ac-in/hr is also equal to 1 cubic foot per second (cfs), another common flow unit used in agricultural irrigation.

Equation 3.3 can be rearranged to calculate both depth per unit of time \( d/t \) and average application intensity.

\[
\frac{d}{t} = \frac{Q}{A} \tag{3.4}
\]

For sprinkler heads and other water emitters, Equation 3.4 often takes the form:

\[
A_r = \frac{96.3 \cdot q}{A} \tag{3.5}
\]

where: \( A_r = \) application rate, application intensity, or precipitation rate (in/hr),
\( q = \) discharge rate (gpm),
\( A = \) in effect, the area irrigated by the device (ft\(^2\)), and
96.3 = constant for unit conversion.

The area irrigated by an individual sprinkler head equals the spacing between heads on the lateral (ft) multiplied by the spacing between laterals (ft).

The flow rate \( Q \) is a volume per unit of time and can be metered with flow measuring...
devices. For a known flow rate, Equation 3.3 can then be used to determine depth applied.

Using Equation 3.3 to determine depth requires that the flow rate remain constant over the entire application time. Records must be kept of both time of application and flow rate. If the flow measuring device includes a volume totalizer, record keeping is much simpler. Volume totalizers register the total volume that has passed through the device much like an odometer measures total miles traveled in an automobile.

Equation 3.1 would be used to calculate depth as shown in the next example.

Example 3.1
An irrigation system delivers 900 gpm. If 30 acres is irrigated every 24 hr, determine the total depth applied in inches.

Given: \( t = 24 \text{ hr} \)
\( A = 30 \text{ ac} \)

Find: Depth applied in inches

Solution:
Using Equation 3.3: \( Q \times t = A \times d \) or \( d = \frac{Qt}{A} \)

First, convert the flow rate from gpm to acre-inch/hour:
\[
900 \text{ gpm} \times \frac{1 \text{ ac-in/hr}}{450 \text{ gpm}} = 2 \text{ ac-in/hr}
\]

\[
d = \frac{(2 \text{ ac-in/hr})(24 \text{ hr})}{30 \text{ ac}} = 1.6 \text{ in}
\]

Example 3.2
A flow meter has a volume totalizer. If 90 acres were irrigated and the totalizer registered 12,590,900 gallons after an irrigation and 8,925,100 gallons before the irrigation, what was the depth of application in inches?

Given: Volume after = 12,590,900 gal
Volume before = 8,925,100 gal

Find: Depth in inches

Solution:
\[
d = \frac{V}{A}
\]

Volume applied = 12,590,900 gal – 8,925,100 gal = 3,665,800 gal

\[
V = 3,665,800 \text{ gal} \times \frac{1 \text{ ac-in}}{27,154 \text{ gal}} = 135 \text{ ac-in}
\]

\[
d = \frac{135 \text{ ac-in}}{90 \text{ ac}} = 1.5 \text{ in}
\]

3.2 Basic Principles of Flow Measurement

3.2.1 Velocity-Flow-Area Relationship

The flow rate in an irrigation water conduit can be expressed as:
\[ Q = V_m A_f \]  
(3.6)

where: \( V_m \) = mean velocity of flow in the channel or pipeline and
\( A_f \) = cross-sectional area of flow.

The concept of this equation is shown in Figure 3.2. This equation is called the continuity equation and is fundamental to water measurement. Velocity \( V_m \) is the average or mean velocity within the pipeline or channel. The use of this equation is illustrated in Example 3.3.

![Figure 3.2. The continuity principle for flow.](image-url)
3.2.2 Measurement of Mean Velocity

With most water measuring devices, the fundamental measurement is the velocity of the flowing water. Using the continuity principle (Equation 3.6), flow velocity is converted to flow rate. There are many methods used to estimate flow velocity. These include mechanical devices such as impellers, paddle wheels, bucket wheels, vanes, floats, and the measurement of pressure differences within hydraulic structures to infer the flow velocity. Newer devices, e.g., ultrasonic meters, use either the Doppler principle or the time of travel of an ultrasonic wave to estimate the velocity. These devices will be discussed in more detail in Sections 3.3 and 3.4.

3.2.3 Distribution of Velocity

The water velocity in a pipeline or in an open channel is not constant throughout its cross section. Typically, the velocity in a closed circular pipeline is highest in the middle of the pipeline and then gradually goes to zero at the wall of the pipeline. This is illustrated in Figure 3.3. Likewise, open channels also have nonuniform velocities within the flow area. Again, the velocity is zero at the wall of the channel and then gradually increases towards the center. In Figure 3.4 you see the illustration of the nonuniform distribution of velocity in an open channel. The variations of velocity within the flow conduit affect where velocity should be sensed or how to correct the measured velocity to obtain the mean velocity as required to use the continuity equation.

Example 3.3

Determine the flow rate (gpm) in a circular pipeline that has an inside diameter (ID) of 8 in and a mean velocity of flow of 5 ft/s.

Given: \( ID = 8 \text{ in} \)
\( V_m = 5 \text{ ft/s} \)

Find: The flow rate \( (Q) \) in gallons per minute (gpm)

Solution:

\[
A_r = \frac{\pi (ID^2)}{4}
\]

ID = 8 in

\[
A_r = \frac{\pi (8)^2 \text{ in}^2}{4} = \frac{64 \pi \text{ in}^2}{4} = 50.27 \text{ in}^2
\]

\[
A_r = 50.27 \text{ in}^2 \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} = 0.349 \text{ ft}^2
\]

\[
Q = (5 \text{ ft/s})(0.349 \text{ ft}^2) = 1.75 \text{ cfs}
\]

\[
= (1.75 \text{ cfs}) \frac{450 \text{ gpm}}{1 \text{ cfs}} = 785 \text{ gpm}
\]

3.3 Flow Measurement in Pipelines

There are many water measuring devices available for both pressurized pipelines and open channels. We will discuss only a few of them. For more detailed discussions of water measurement, the reader is referred to the following: ASME (1971), Bos et al. (1984), Miller (1996), Replogle et al. (1990), and USBR (1997).

3.3.1 Mechanical Meters

Propeller meters (impeller meters) and turbine meters are common methods for measuring
pipeline flow in agricultural irrigation and in municipal water distribution systems. The force of the flowing water turns the propeller. The propeller is sensing the velocity in the pipeline. A propeller meter is illustrated in Figure 3.5. The rotations of the propeller are converted to flow rate by proper gear ratios in the meter head. The diameter of the propeller is usually slightly smaller than the inside diameter of the pipeline. This gives a good estimate of the mean velocity in the pipeline and allows the meter to operate over a wide range of flows.

The register in the meter head of these devices comes in various configurations. Four common ones are shown in Figure 3.6. The one on the left has the volumetric totalizer combined with a sweep hand, which can be used for timing the rate of flow. Each revolution of the sweep hand corresponds to a known volume of water that has passed through the meter. The second register from the left contains two components: the totalizer and the flow rate indicator. The third register from the left has three components on one meter head: the totalizer, the flow rate indicator, and an index hand or sweep hand for timing. The register on the right represents a digital display which contains both a flow rate indicator display and a volume totalizer. One key advantage of electronic register heads is that they lend themselves to remote monitoring through cellular or satellite communication.

Usually the accuracy of the meter is based upon what is registered on the totalizer. Since the totalizer and the sweep hands are directly connected, the true flow rate is best obtained by either timing the sweep hand or timing the rate that the numbers are changing on the odometer. The least accurate, or the poorest representation of the meter's accuracy, is the flow rate indicator. The flow rate indicator is helpful to observe changes in flow rate and as an indicator of excessive spiraling or disturbed flow. The latter condition is noticed by significant needle movement or bounce.

Proper selection and installation of flow measuring devices are very important. Propeller meters should be located away from pipeline fittings that cause spiraling or disturbance of water flowing in the pipe such as pumps, elbows, valves, etc. A flow disturbance refers to the disruption or distortion of the parabolic velocity distribution an example of flow caused by a pipe elbow is shown in Figure 3.7.
Between any of these devices there should be adequate, straight, and unobstructed pipe ahead of the propeller so that the flow can be straightened before reaching the meter section. It is best to have a distance of at least 10 pipe diameters of straight pipe upstream of the propeller and at least 1 pipe diameter distance downstream between the propeller and a flow disturbance. Sometimes there is not adequate room available to allow for 10 pipe diameters. If not, a shorter distance can be used if straightening vanes are placed in the pipeline ahead of the propeller (Figure 3.5). A typical field installation of a propeller meter is shown in Figure 3.8.

It is also important that the meter section always flow full of water. This is to guarantee that the flow area is equal to the cross-sectional area of the pipeline. If the pipe discharges into the air and the pipeline is not flowing full, an upward turned elbow or a horseshoe-shaped fitting, as shown in Figure 3.9, is useful to guarantee full pipe flow. Another approach to measuring flow in pipelines is paddlewheel meters. These mechanical meters usually have a magnetic pickup to measure the number of revolutions of the paddle wheel. The paddlewheel movement then is converted to flow rate by the velocity area relationships. Like the propeller meters, the paddlewheel should be installed with adequate piping ahead of the meter so that the velocity profile can be established before the water reaches the meter.

3.3.2 Pressure Differential Methods

Differences in pressure between 2 points in a flowing system are often used to measure flow rates. The mean velocity is inferred from the pressure difference. In the simplest case a pitot tube is used (Figure 3.10). With the pitot tube the upstream sensor picks up both the pressure head and the velocity head while the downstream sensor only senses pressure. Thus, there is a difference in head or pressure between the upstream and downstream tubes. Pitot
tubes come in various configurations. It is best to sense velocity at several positions in the pipeline to obtain a good estimate of the average velocity.

In Chapter 8, we will discuss the relationships between the various forms of energy in flowing water: the pressure energy, relative energy due to elevation, and velocity energy. The change of forms of energy from pressure to velocity will be illustrated by using Bernoulli’s Energy Equation. As the velocity increases in a pipeline, the pressure is usually reduced. This principle is used quite often in flow measurement.

A Venturi, such as the one shown in Figure 3.11, can be used to measure flow. The upstream pressure is higher than the pressure in the Venturi throat because of the high velocity in the throat of the Venturi. There is a correlation between the difference in pressure, or head, between the upstream sensing position and the throat of the Venturi. The pressure differential is directly related to the velocity of the fluid in the pipeline.

Another pressure differential device is the orifice meter. The orifice shown in Figure 3.12 discharges to the air. In this case the head is measured upstream. The downstream head is zero (atmospheric pressure). The flow of an orifice follows the following relationship:

\[ Q = KA_0 \sqrt{2g\Delta h} \]  

(3.7)

where: \( K \) = flow coefficient,  
\( A_0 \) = cross-section area of the orifice,  
\( g \) = gravitational constant, 32.2 \( \text{ft/s}^2 \), and  
\( \Delta h \) = head of water upstream of the orifice.

An orifice meter does not have to discharge to the air, but rather it can be imbedded within a pipeline and the difference in pressure head upstream and immediately downstream of the orifice can be measured to determine differential head.

### 3.3.3 Ultrasonic Measurement

Another approach for measuring flow in a pipeline is to use ultrasonic energy. With this method ultrasonic waves are transmitted through the pipe wall and into the flow. One burst of energy is transmitted upstream while another burst is sent downstream. The travel time of the two waves are measured and compared. The difference in wave velocity is directly related to the velocity of the water. Another ultrasonic approach takes advantage of the Doppler principle. A high-frequency signal is transmitted into the liquid. Suspended particles or gas bubbles reflect the wave. The frequency of the reflected wave is measured. The difference in transmitted and reflected frequencies is directly proportional to the liquid's flow velocity.
The ultrasonic methods have a large advantage in that they are nonintrusive; the transducers are simply clamped onto the outside of a pipeline. They can measure velocity inside a pipeline without disassembling the piping system. This makes this approach particularly attractive to water agencies that want to do periodic monitoring of a flow system. A clamp-on ultrasonic meter in operation is shown in Figure 3.13.

The straight pipe spacing requirements between flow disturbances and clamp-on ultrasonic meters are the same as propeller meters, 10 pipe diameters upstream of the meter and 1 pipe diameter downstream. Eisenhauer (2008) presents multipliers that can remove meter bias if the upstream spacing between a flow disturbance and clamp-on meter cannot be met. These multipliers were based on research by Johnson et al. (2001).

3.3.4 Magnetic Flowmeters

Magnetic flowmeters have been used for the measurement of pipeline flows for many years but only recently have gained economic acceptance in agricultural irrigation. Magnetic flowmeters use the principle of Faraday’s Law where the voltage induced across a conductor that is moving at a right angle through a magnetic field is proportional to the average velocity of the conductor. In this case, water with solutes is the conductor. In-line or tube magnetic flow meters are illustrated in Figures 3.14 and 3.15. Battery operated magnetic flow meters have been developed to increase their applicability in irrigation. Research has shown that the in-line magnetic flow meters require less upstream distance from flow disturbances as compared to other meter types. For example, rather than needing 10 pipe diameters upstream and 1 downstream of straight unobstructed pipe between a flow disturbance and the metering section (as is the case for propeller meters), only 2 are needed upstream and 1 downstream for magnetic flow meters. Depending

Figure 3.13. Clamp-on ultrasonic meter installed on a pipeline.

Figure 3.14. In-line magnetic flowmeter. (Modification of diagram provided courtesy of McCrometer Corporation.)

Figure 3.15. Electromagnetic flowmeter installed in the field.
upon the situation, these shorter required distances can be a significant savings in the costs of retrofitting a piping system to accommodate metering.

3.4 Flow Measurement in Open Channels

Open channel flow is distinguished from pipeline flow by the fact that the water surface is at atmospheric pressure. With closed conduit or pipeline flow, the surface of the water is contained by the conduit's wall which causes the water pressure to exceed atmospheric pressure.

3.4.1 Velocity Methods

Probably the most common method for measuring open channel (stream) flow is to use a current meter (Figure 3.16). The current meter that measures the water velocity at predetermined positions in the channel can either be a mechanical device, such as the cup-type meter illustrated in Figure 3.16, or ultrasonic devices that utilize the Doppler principle. In the latter case, the water velocity is assumed equal to the velocity of suspended particles. Water velocity and depth of the measurement are determined at various points across the stream. The flow rate in subsections of the channel is computed using the velocity and flow depth data.

A simpler approach to velocity measurement of an open channel is to use a float on the water surface. The float speed is timed between two positions in the flow, such as shown in Figure 3.17. The float speed is the water velocity at the surface. Since the surface velocity \( V_s \) is not the average velocity \( V_m \), the float velocity has to be corrected. The average velocity can be calculated using Equation 3.8 where \( K_f \) is the velocity correction factor.

\[
V_m = K_f V_s \tag{3.8}
\]

\( K_f \) typically ranges from 0.65 to 0.8. The 0.65 correction factor applies to depths of 1 foot or less and 0.8 for water depths of 20 feet or more. The float method can be used as a quick estimate of flow, but it is normally not sufficiently accurate for good water management.

Figure 3.16. Current meter method for measuring flow rate in an open channel.

Figure 3.17. Float method for determining surface velocity in a channel.
3.4.2 Pressure Differential Methods

Like flow in pipelines, the pressure differential concept can be used to measure with open channel flow. With open channel devices, velocity is usually not computed but is imbedded in the equations of flow. The equations of flow then account for both the shape of the metering section and the implied velocity. There are two general classes of pressure differential devices used in open channels: weirs and flumes. An example of a weir is shown in Figure 3.18. Figures 3.19 and 3.20 are pictures of flumes. With both classes of devices, a head or depth of water is measured upstream of the metering section. Since the metering section causes a contraction of flow, there is a lowering of the water surface elevation through the metering section, much like the decrease in pressure as water flows through a pipeline Venturi. Flow must pass through what is called critical depth for there to be a unique relationship between the upstream head and the flow rate.

The contraction of flow is caused by either positioning the metering section above the channel floor (contraction from the bottom) or by having a narrower metering section than the channel (contraction from the side). Flow measurement flumes typically use a side contraction. Weirs always have a bottom contraction. Often, weirs use both a side and bottom contraction (Figure 3.18) while flumes sometimes have both side and bottom contractions.

Table 3.2 presents various shapes of weirs that are used to measure flow. These weirs have a relatively sharp edge (sharp crested). The edge where flow is measured is usually made out of metal or other rigid materials. The edge must retain its shape and maintain its sharp edge so that the correlation between flow and head will remain constant. Weirs come in various shapes and sizes: rectangular, trapezoidal, or triangular. The flow equations for these three types of weirs are shown in Table 3.2. While weirs are relatively simple devices, they have several disadvantages; a relatively large head loss is required to make them function properly and sediment accumulation upstream of the weir can lead
to a change in the weir's head-flow relationship. The nappe of water leaving the crest of the weir must spring free of the weir for the unique head discharge relationship. If downstream water submerges a weir, the calculated flow may be incorrect. Flumes usually have a much higher tolerance to downstream submergence than weirs.

Like weirs, there are many shapes and designs of flow measuring flumes available for flow measurement. The Parshall flume is common in irrigation; it is illustrated in Figure 3.19. Parshall flumes come in various sizes with throat widths from 1 inch to 50 feet. A big advantage is that sediment flows freely through Parshall flumes.

Another approach to flow measurement is the RBC flume. The RBC flume was designed to utilize a small ramp or bottom contraction within a prismatic channel or flume. This is illustrated in Figure 3.20. One advantage of this flume is that if an irrigator has a trapezoidal irrigation channel with stable sides, such as a concrete-lined ditch, the flow measuring device can be created by installing a ramp and a staff gauge upstream of the ramp section. An important feature of this type of flume is that the calibration is very predictable once the dimensions and materials of the metering section are known. Calibration equations and tables are available for Parshall and RBC flumes of numerous sizes. Example calibrations are given in Tables 3.3 and 3.4.

### Table 3.2. Weir shapes and discharge formulas.

<table>
<thead>
<tr>
<th>Measuring Device (all sharp crested)</th>
<th>Views</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rectangular Weir</strong> &lt;br&gt; (without side contraction)</td>
<td><img src="image" alt="Top view" /> <img src="image" alt="Side view" /></td>
<td>[ Q = 3.33LH^{3/2} ]</td>
</tr>
<tr>
<td><strong>Trapezoidal Weir</strong></td>
<td><img src="image" alt="End view" /> <img src="image" alt="Side view" /></td>
<td>[ Q = 3.37LH^{3/2} ]</td>
</tr>
<tr>
<td><strong>90° Triangular Weir</strong></td>
<td><img src="image" alt="End view" /> <img src="image" alt="Side view" /></td>
<td>[ Q = 2.49H^{3/2} ]</td>
</tr>
</tbody>
</table>

### Table 3.3. Flow rate of 1-foot Parshall flume.

<table>
<thead>
<tr>
<th>Upstream Head (ft)</th>
<th>Flow Rate[a] (cfs)</th>
<th>(gpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>0.46</td>
<td>207</td>
</tr>
<tr>
<td>0.50</td>
<td>1.35</td>
<td>605</td>
</tr>
<tr>
<td>0.75</td>
<td>2.53</td>
<td>1140</td>
</tr>
<tr>
<td>1.00</td>
<td>3.95</td>
<td>1770</td>
</tr>
<tr>
<td>1.25</td>
<td>5.58</td>
<td>2500</td>
</tr>
<tr>
<td>1.50</td>
<td>7.41</td>
<td>3320</td>
</tr>
<tr>
<td>1.75</td>
<td>9.40</td>
<td>4220</td>
</tr>
<tr>
<td>2.00</td>
<td>11.60</td>
<td>5190</td>
</tr>
</tbody>
</table>

\[ Q = 3.95H^{1.55} \]

*Q = flow rate in cfs and H = head in ft* [a] Assumes that free flowing criteria is met.

### Table 3.4. Flow rate of 8-inch fiberglass RBC flume.

<table>
<thead>
<tr>
<th>Upstream Head (ft)</th>
<th>Flow Rate[a] (cfs)</th>
<th>(gpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>0.06</td>
<td>29</td>
</tr>
<tr>
<td>0.20</td>
<td>0.21</td>
<td>93</td>
</tr>
<tr>
<td>0.30</td>
<td>0.42</td>
<td>188</td>
</tr>
<tr>
<td>0.40</td>
<td>0.70</td>
<td>314</td>
</tr>
<tr>
<td>0.50</td>
<td>1.04</td>
<td>469</td>
</tr>
<tr>
<td>0.60</td>
<td>1.45</td>
<td>651</td>
</tr>
<tr>
<td>0.70</td>
<td>1.92</td>
<td>860</td>
</tr>
</tbody>
</table>

\[ Q = 3.575 \left( H + 0.01259 \right)^{1.8419} \]

*Q = flow rate in cfs and H = head in ft* [a] Assumes that free flowing criteria is met.
3.5 Summary

Flow measurement is important in irrigation so that both the rate that water is being applied and the depth of application are known. Without this information it is difficult to be a good water manager.

Flow measurement typically relies on the principle of continuity. Flow rate is related to the velocity of water flow and the cross-sectional area of flow (Equation 3.6).

For both pipeline and open channel flow, mechanical, ultrasonic, or electromagnetic meters are used to sense velocity. Pressure differential methods are also used to estimate velocity. The selection of the proper flow measuring device depends on the desired accuracy, the cost of the measuring device, and the physical characteristics of the site where the flow is to be measured.

With all flow measuring devices, it is important that they be selected and installed properly. Upstream conditions must be considered for all flow measuring devices so that unreasonable flow disturbance and spiraling is not present in the measurement area. The devices should also be selected so that an adequate pressure differential can be measured but not result in a large energy or head loss in the conduit.

Questions

1. List three reasons for measuring water.
2. What would you consider to be an acceptable accuracy for water measurement in irrigation? Explain your answer.
3. What is the fundamental physical law used by most flow measuring devices?
4. Which is more useful for determining depth applied in irrigation, a volume totalizer, or a flow rate indicator? Why?
5. What assumption is made about flow rate when using Equation 3.3 to calculate depth applied?
6. a. Show how Equation 3.3 can be rearranged to determine the depth applied.
   b. Show how Equation 3.3 can be rearranged to determine the time required to apply a desired depth.
   c. Show how Equation 3.3 can be rearranged to determine the flow rate required to apply a desired depth in a given time period.
7. Why are long sections of straight pipe and straight channel, free of obstructions, required of upstream flow measuring devices?
8. Why must the metering section of a propeller meter flow full?
9. How many gallons per minute are required to apply 1 million gallons in a day?
10. Why is it better to time the totalizer or a timing hand (index hand) of a propeller meter than to read the flow rate indicator directly to determine flow rate?
11. A totalizer on a flow meter is timed to determine flow rate. The last digit represents 100 gallons. Ten numbers are allowed to pass during timing. The time was 1 minute, 30 seconds. Determine the flow rate in:
   a. gpm (gallons per minute)
   b. cfs (cubic feet per second)
   c. m$^3$/s (cubic meters per second)
d. L/s (liters per second)
e. ac-in/hr (acre-inch per hour)
f. ha-cm/hr (hectare-cm/hour)

12. A 130-ac field was irrigated. The totalizer on the system’s flow meter read:
   After irrigation: 60,325,100 gallons
   Before irrigation: 57,324,600 gallons
   Calculate the gross depth applied in inches.

13. A 200-ac field was irrigated. The totalizer on the system’s flow meter read:
   After irrigation: 2,425 ac-in
   Before irrigation: 2,121 ac-in
   Calculate the gross depth applied in inches.

14. A 7,000 square foot lawn was watered. The household meter registered 500,300 ft$^3$ before watering and 500,708 ft$^3$ after watering. Calculate the gross depth applied in inches (assume that other uses of water in the house were insignificant during the water application).

15. A golf course irrigation system irrigates 60 ac and the flow rate is 1200 gpm.
   a. How many hours of irrigation will be required to apply 1 inch of water?
   b. If you can only irrigate 8 hours per day, how many days will it take to apply 1 inch of water?
   c. Suppose ET is 0.25 in/d and you want to apply this amount each day (assume you can only irrigate 8 hours per day). How many gpm would be needed?

References