ARIZONA COOPERATIVE EXTENSION
THE UNIVERSITY OF ARIZONA
College of Agriculture and Life Sciences
College of Agriculture and Life Sciences
AZ1329
Revised 12/11

Measuring Water Flow in Surface Irrigation Ditches and Gated Pipe

Edward C. Martin

Arizona Water Series No.31

Measuring water in surface irrigation systems is critical for peak efficiency management. Without knowing the amount of water being applied, it is difficult to make decisions on when to stop irrigating or when to irrigate next. A good irrigation manager should know the flow rate of the irrigation water, the total time of the irrigation event and the acreage irrigated. From this, the total amount of water applied can be determined, which will help determine whether the irrigation was adequate and when the next irrigation should be. Irrigation management decisions should be made based on the amount of water applied and how this relates to the consumptive use demands of the plants and the soil water holding capacity.

Units of Measuring Water

There are many ways to express water volume and flow. The volume of water applied is usually expressed in acre-inches or acre-feet for row crops or gallons per tree in orchards. Flow rate terminology is even more varied. Flow rate is expressed as cfs (cubic feet per second), gpm (gallons per minute) and in some areas, miner's-inches. Below is a description of each.

Acre-inch (ac-in.): An acre-inch is the volume of water required to cover an acre of land with one inch of water. One acre-inch equals about 3,630 cubic feet or 27,154 gallons.

Acre-foot (ac-ft): An acre-foot is the volume of water required to cover an acre of land with 1 foot of water. One acre-foot equals about 43,560 cubic feet, 325,848 gallons or 12 acre-inches.

Cubic feet per second (cfs): One cubic foot per second is equivalent to a stream of water in a ditch 1- foot wide and 1-foot deep flowing at a velocity of 1 foot per second. It is also equal to 450 gallons per minute, or 40 miner's-inches.

Gallons per minute (gpm): Gallons per minute is a measurement of the amount of water being pumped, or flowing within a ditch or coming out of a pipeline in one minute.

Miner's inches: Miner's-inches was a term founded in the old mining days. It is just another way of expressing flow. Some areas in the West still use this measurement unit. Caution needs to be taken because there are Arizona miner's-inches, California miner's-inches and probably some that are locally used. Approximately 40 Arizona miner's- inches equals 1 cfs or 450 gpm.

Pressure or Head (H): People often use the phrase "head of water." A foot of head usually implies that the water level is one foot above some measuring point. However, head can also mean pressure. For example, as the level of water rises in a barrel, the pressure at the bottom of the barrel increases. One foot of water exerts 0.43 pounds per square inch (psi) at the bottom of the barrel. Approximately 2.31 feet of water equals 1 psi. Thus, if a tank of water were to be raised 23.1 feet (2.31 x 10) in the air with a hose connected to it, the pressure in the hose at the ground would be about 10 psi.

Area: The cross sectional area of a ditch is often required to calculate flow. Some ditches are trapezoids and others or more like ellipses. To find the area of a trapezoid (Fig. 1a), measure the width of the bottom (b) and the width of the ditch at the water surface (s) and add them together. Divide that number by 2 and then multiply by the height (h) of the water. If the ditch is more elliptical in shape (Fig. 1b), take the depth of the water (h), multiply it by the width of the ditch at the surface (s), divide by 4 and then multiply by PI (3.14). To calculate the cross-sectional area of a pipe, the formula is PI x r2, where PI is 3.14 and "r" is the radius of the pipe. **NOTE: All measurements should be in feet.**

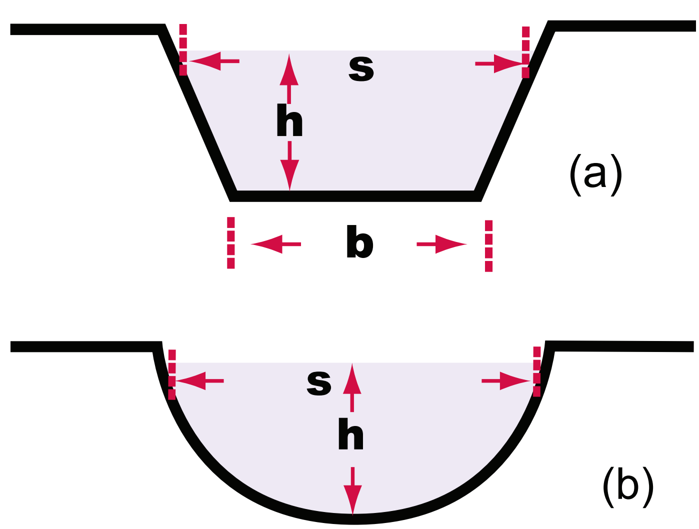

Figure 1. Cross-sectional dimensions for trapezoidal (a) and elliptical (b) ditches. (Diagram by J.S. Jones, 2003)

Table 1. Coefficients to correct surface float velocities to mean channel velocities. (from "Water Management Manual, USDI/BOR, 1997).

Average Depth (ft)	Coefficient
1	0.66
2	0.68
3	0.70
4	0.72
5	0.74
6	0.76
9	0.77
12	0.78
15	0.79
20	0.80

Measuring Water Flow in Ditches

The Float Method: This method is useful to get a rough estimate of flow. First, choose a 100-foot section of ditch that is fairly uniform in depth and width. Mark the zero point and the 100 ft point with a flag or stick. The 100 ft mark should be downstream from the zero point. For most people, one good, long stride equals three feet. If there is no tape measure available, step off about 33 paces. Next, calculate the ditch cross sectional area (see "**Area**" above for details). Use an average of several measurements along the ditch.

Now, take a float (tennis balls, apples, oranges, etc.) and place it a few feet up stream from the zero point, in the center of ditch. Once the float hits the zero point, mark the time (probably to the nearest second). Then, mark the time the float passes the 100 ft mark. Record the time. Do this several times. Try to place the float in the center of the ditch flow so that it won't bounce off the sides or get caught up in any weeds. After 5-10 tries, average the recorded times.

The flow rate is determined by calculating the velocity of the water and multiplying it by the cross sectional area of the ditch. First, take the length of the ditch (100 ft) and divide it by the time (in seconds). This will give the *surface velocity* (speed) in feet per second. However, water at the surface flows faster than water in the center of the flow and it is the average flow or center flow that is needed. Therefore, a conversion factor must be used to determine the *mean channel velocity.* The factor by which the surface velocity should be multiplied by is a function of the depth of the water in the ditch. Table 1 gives the coefficients to be used. Find the depth measured on the left and the corresponding coefficient on the right. Then multiply the surface float velocity by the coefficient to obtain the mean channel velocity.

Finally, take the cross sectional area of the ditch (ft^2) and multiply it by the corrected velocity (ft/sec) and this will compute the flow rate in cubic feet per second (cfs). To convert to gallons per minute, multiply the cfs by 450.

Tracer Method: This method is very similar to the float method but with one exception, a colored dye or salt is used instead of a float. Estimates of the ditch area are still required. Pour the dye upstream of the zero point, and record how long it takes the dye to travel from the zero point to the 100 ft mark. Then the calculations are exactly the same as the float method. This method often works well if the float keeps getting caught on the sides of the ditch. However, in many cases the dye is difficult to see because of the color of the water itself. Test the dye first to make sure it can be seen. The correction factors used with the float method (Table 1) are not required for the tracer method.

Velocity Head Rod: The velocity head rod is used to measure the velocity of water in a ditch and is relatively inexpensive and fairly accurate. The rod is in actuality a ruler used to measure the depth of the water. The water height is first measured with the sharp edge of the ruler parallel with the flow and the again with the ruler turned 90 degrees (Fig. 2). The difference in the height of water is the head differential and using Table 2, an estimate of the velocity (feet per second) can be made. From there, follow the same formula as with the float or tracer method, i.e., multiply the velocity by the cross sectional area of the ditch to get cubic feet per second. The velocity head rod method works only for velocities greater than 1.5 ft/sec and less than about 10 ft/sec.
The procedure is:

- Place the rod with the sharp edge upstream. Record the depth of the water (normal depth).
- Place the rod sideways. This will cause some turbulence and the water level will "jump" causing the water level to rise. Record the level again (turbulent depth).
- Subtract the normal depth from the turbulent depth and this will be the jump height.
- Find the corresponding velocity from Table 2.
- Multiply the velocity by the cross sectional area of the ditch to get the flow rate (cfs).

Weirs: There are several different types of weirs that can be constructed and used to determine the flow rate in a ditch or stream. The three most common weirs are: (1) V-Notch or Triangular (2) Rectangular and (3) Cipolletti.

The simplest design is to make the weir out of a sheet of plywood or sheet metal. Cut the wood or metal to fit ditch with the particular shape notch cut out of the top. Make sure

Table 2. Conversion chart for velocity head rod measurements from inches to ft/sec.

Jump (inches)	½	1	2	3	4	5	6	7	8	9	10	11	12	15	18
Velocity (ft/sec)	1.6	2.3	3.3	4.0	4.6	5.2	5.7	6.1	6.5	6.9	7.3	7.7	8.0	9.0	9.8

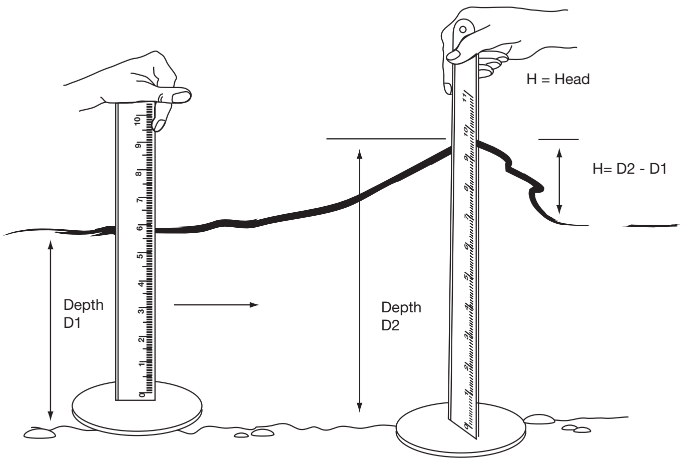

Figure 2. Using a velocity Rod. (Waterwatch, 2002).

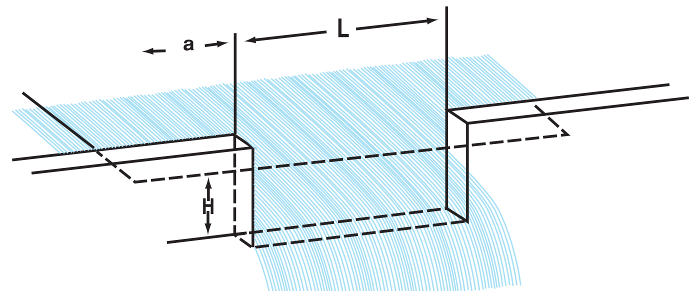

Figure 4. Diagram of a rectangular weir where L = width of weir opening (4 to 8 times H), H = head of weir (measured 6 ft upstream of weir) and a = at least 3*H.

the weir is sturdy enough to hold up against the flow of the water. Figure 3 shows an example of the three different types. The top two are rectangular weirs. The first is a rectangular contracted weir and is one of the most commonly used. The second is another rectangular weir but since the sides of the weir are actually the sides of the ditch, it is called a suppressed rectangular weir. The third type shown in Figure 3 is the Cipolletti weir. This type of weir has a trapezoidal shaped notch. The last type shown is a triangular or V-notched type. With proper installation, all of these weirs can be accurate.

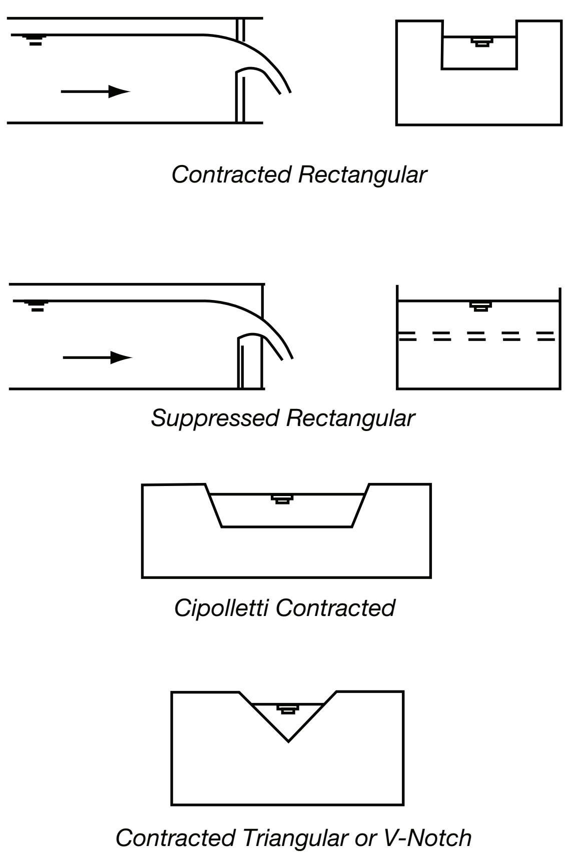

Figure 3. Diagrams of various types of weirs used to measure flow rate in an open ditch. (USDI-BOR, 1997).

The dimensions for a contracted rectangular weir are given in Figure 4. An estimate of the actual flow rate must be made before construction of the weir in order to make sure the notch size is correct. For the V-notch, the dimension requirements are the same and for the Cipolletti, the requirements are also the same but with a 25% slope rising outward at the sides of the notch. To measure the head or height of the water for these weirs, pound in a stake about 6 feet upstream so that the top of the stake is even with the bottom of the notch in the weir. Once in place, the water will rise behind the weir. Measure the depth of water above the stake. Then, use charts like the ones in Tables 3-5 to estimate the flow rate. The length (L) refers to the width of the opening at the base of the weir notch.

CAUTION: Installing a weir in a ditch will cause the water behind the weir to rise. Make sure there is enough freeboard or the water in the ditch will overflow.

Other Methods: There are several other methods available and many devices that can be purchased "off the shelf." One is a current meter, which is a propeller meter that is lowered into the stream of water and records velocity. The flow rate (cfs) is calculated by multiplying the velocity (ft/sec) by the area (ft^2). There are flumes, submerged orifices and even acoustic ultrasonic meters that use ultrasonic pulses to measure the velocity of the flow stream. All of these methods have limits to their use. For more information, refer to the Arizona Cooperative Extension publication "Measuring Water Flow and Rate on the Farm", publication AZ1130, Arizona Water Series No. 24 (Martin, 2009).

Counting Tubes: If siphon tubes are used to irrigate out of an open ditch, an estimate of the flow rate can be obtained by counting the number of tubes. The size of the siphon tube and the distance from the water level in the ditch to the water level in the field (the drop) is needed to estimate the flow rate. Figure 5 shows two possible conditions. In Condition I (free flowing) the drop is the distance from the water level in the ditch to the end of the tube on the field side (usually level with the field). In Condition II (submerged), the drop is the distance from the water level in the ditch to the water level in the field. The larger the tube size or the greater the drop, the higher the flow rate. Table 6 shows some typical sizes and drops used for irrigation.

Table 3. Approximate flow over rectangular weirs. (Peterson and Cromwell, 1993).

Head (inches) (H)	Crest length (L)							
	(L): 1 foot		(L): 2 feet		(L): 3 feet		(L): 2 feet	
	gpm	ac-in/hr	gpm	ac-in/hr	gpm	ac-in/hr	gpm	ac-in/hr
2	98	0.22	198	0.44	298	0.66	398	0.88
3	181	0.40	366	0.81	552	1.22	738	1.63
4	278	0.62	560	1.24	852	1.88	1140	2.52
5			772	1.70	1164	2.58	1560	3.54
6			1010	2.22	1535	3.40	2055	4.54
7			1270	2.80	1980	4.27	2590	5.75
8			1540	3.40	2330	5.18	3120	6.90

Table 4. Approximate flow over 90-degree triangular weirs. (Peterson and Cromwell, 1993).

Head in inches (H)	Gallons per minute (gpm)	Acre-inches per hour (ac-in/hr)
3	36	0.08
4	74	0.16
5	126	0.28
6	200	0.44
7	294	0.65
8	405	0.89
9	548	1.21
10	714	1.58
11	895	1.98
12	1118	2.48
13	1365	3.05
13.5	1495	3.34
14	1630	3.63

Table 5. Approximate flow over trapezoidal weirs. The length "L" refers to the length of the bottom of the trapezoid. (Peterson and Cromwell, 1993).

Head (inches) (H)	Crest length (L)							
	(L): 1 foot		(L): 2 feet		(L): 3 feet		(L): 2 feet	
	gpm	ac-in/hr	gpm	ac-in/hr	gpm	ac-in/hr	gpm	ac-in/hr
2	101	0.22	202	0.45	302	0.67	404	0.89
3	190	0.42	376	0.83	560	1.24	750	1.66
4	296	0.65	580	1.28	864	1.91	1160	2.56
5			802	1.77	1196	2.66	1500	3.52
6			1062	2.34	1530	3.50	2100	4.64
7			1350	2.98	2000	4.42	2660	5.88
8			1638	3.62	2430	5.38	3220	7.14

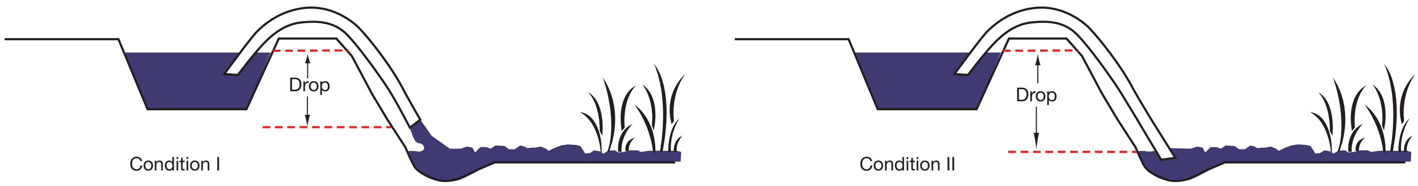

Figure 5. Diagrams where to measure the drop distance for siphon tubes. (Diagram by J.S. Jones, 2003).

Table 6. Approximate flow rate in gallons per minutes for siphon tubes.

Pipe Size (in.)	Flow Rate (gallons per minute)				
	Drop (in.)	4"	6"	8"	10"
¾"		3.6	4.4	5.0	5.6
1"		6.4	7.9	9.0	10.0
1 ¼"		10.4	12.7	14.6	16.2
1 ½"		14.3	17.5	20.2	22.5
2"		25.6	31.8	35.9	40.0
3"		57.2	70.0	80.8	90.0

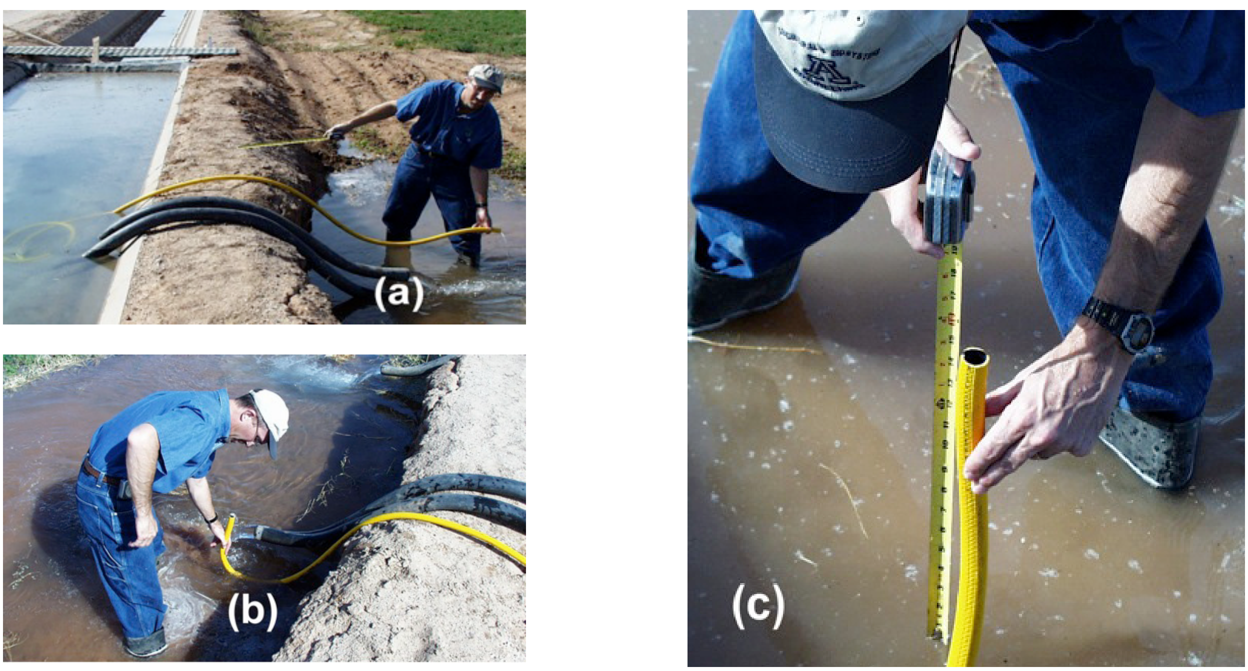

Figure 6. Three photos demonstrating how to measure the "drop" in a surface system. The drop is the distance from the level of the water in the ditch to the water level in the field. (a) Use the hose to siphon water out of the ditch; (b) Raise the hose up until water stops flowing out of the hose end; (c) Measure the distance between the end of the hose and the water level in the field.

It is often difficult to measure the difference in water levels between the ditch and the field. One easy way is to do this is to get a piece of hose and a tape measure. Put the hose in the ditch and use it to siphon water into the field (Fig. 6a). Next, slowly raise the hose in the field until the water stops coming out (Fig. 6b). Now, use your measuring tape to measure the distance between the end of the hose and the water level in the field or the outlet of an irrigation siphon tube (Fig 6c). Make sure to keep the end up just at the level where the water stops coming out. This distance is your drop!

Measuring Flow in Gated Pipe

Measuring water flow in gated pipe can be accomplished many different ways. Probably the most commonly used method is the propeller meter. These meters are normally installed inside a section of pipe at the distributor's shop. The buyer then simply buys a meter section for whatever diameter pipe used. There are some other methods that can be used but for convenience and ease of measurement, the propeller is a simple and accurate method.

Table 7. Typical range of flows for different size propeller meters.

Meter size (inches)	Minimum flow (gpm)	Maximun flow (gpm)
4	50	400
6	90	900
8	100	1200
10	125	1500
12	150	2000

Figure 7. A Mc® Propeller from McCrometer, Inc. This propeller meter is installed inside a pipe section.

Figure 8. Two photos showing how to measure the head (ft) in a gated pipe system. The head is the distance between the water level in the tube and the center of the pipe. These are Rite-Flow™ gates and there is about 3 ft of head. According to Table 8, the flow is approximately 39 gpm per gate.

Table 8. Approximate flow capacities in gallons per minute (gpm) for some commercially available gates. Gates are wide open. (Burt, 1995).

Head (ft)	Flow Capacities (gpm)			
	Rite-Flow™	Epp™ Snap-Top Boot Gate	Epp™ Fly Gate	Tex-Flow™ Yellow Top
0.25 (4")	11	12	15	22
0.50 (6")	16	17	21	32
1.00	22	24	30	46
2.00	32	35	42	67
3.00	39	42	52	82

Propeller meters are permanent pipeline devices that measure and record the volume and flow of water moving through a pipe. The pipe must be running at full flow for the meters to operate properly. Also, there must be a straight length of pipe upstream from the meter at least 10 times the diameter of the pipe. This is to reduce the turbulence in the water as it enters the meter section. Thus, a 6-inch pipe would require 60 inches of straight pipe upstream from the meter. Table 7 gives the range of flows for various size meters and Fig. 7 shows a cross-sectional view of a typical meter.

The meters are usually placed inside a length of aluminum pipe that is inserted into the gated pipe system. If poly-type plastic pipe is being used, there are connectors that will allow a meter section to be put in place. If you don't want to pay the expense for the meter, you can use a piece of tubing, similar to the tube method for ditches. Find a piece of tubing (preferably clear) that either fits tight inside a gate or even better, can be attached tightly to the outside of the gate. Raise the tubing into the air until the water stops flowing out. Measure the distance from the water level in the tubing to the center of the gated pipe. If clear tubing is used, then you can raise the tube well above the point when the water stops coming out and it makes for an easier measurement (Fig. 8). Table 8 gives some estimate of flow rates for various manufacturers gates. Most manufacturers should be able to supply this information.

Summary

There are many methods that can be used to measure flow rate and only the most common have been covered in this paper. In addition, there are meters that use ultrasound waves to measure flow in pipes, flumes, gates and even a Doppler-type acoustic meter. Although these are relatively expensive, the price has come down in recent years and the technology is being applied throughout the agricultural sector. Measuring flow is the first step in determining how much water is being applied to a field. With the flow rate, the area irrigated and the time of irrigation, you can calculate the amount of water applied. For information on calculating how much water was applied, read the University Arizona Cooperative Extension publication Determining the Amount of Water Applied to a Field, Pub. No. AZ1157, Arizona Water Series No. 29 (Martin, 2011).

References

Burt, Charles M. 1995. The Surface Irrigation Manual. Waterman Industries, Inc. Exeter, CA. First edition.

Martin, E.C. 2011. Determining the Amount of Water Applied to a Field. Cooperative Extension Pub. No. AZ1157, Arizona Water Series No. 29. University of Arizona, Tucson, AZ.

Martin, E.C. 2009. Measuring Water Flow and Rate on the Farm. Cooperative Extension Pub. No. AZ1130, Arizona Water Series No. 24. University of Arizona, Tucson, AZ.

Peterson, M and C.F. Cromwell, Jr. 1993. Measuring Irrigation Water in a Ditch, Stream or Reservoir. Ag. Pub. G01681. University of Missouri, Columbia.

Water Measurement Manual. 1997. A Water Resources Technical Publication. U.S. Dep. of the Interior, Bureau of Reclamation. Third edition.

Waterwatch Australia National Technical Manual, 2002. Module 4 - Physical and Chemical Parameters, Waterwatch Australia Steering Committee Environment Australia.

ARIZONA COOPERATIVE EXTENSION
THE UNIVERSITY OF ARIZONA • COLLEGE OF AGRICULTURE AND LIFE SCIENCES

The University of Arizona
College of Agriculture and Life Sciences
Tucson, Arizona 85721

Dr. Edward C. Martin
Professor and Irrigation Specialist, Ag & Biosystems Engineering

Contact:
Edward C.Martin
edmartin@cals.arizona.edu

This information has been reviewed by university faculty.
cals.arizona.edu/pubs/water/az1329.pdf

Originally published: 2006

Other titles from Arizona Cooperative Extension can be found at:

cals.arizona.edu/pubs