Measuring Applied Water in Surface-Irrigated Orchards

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The California State Water Code requires anyone discharging waste that could affect the waters of the state to obtain a permit or coverage under a waiver. Agricultural runoff, whether from irrigation or rainfall, that leaves a property has been determined likely to contain waste (sediment, nutrients, chemicals, etc.). Compliance under the Irrigation Lands Conditional Waiver is available to agricultural landowners who have runoff from their property caused by irrigation practices or winter rainfall. If no runoff from any source leaves a property, the California Water Code does not impact the property owner.

A major contributor to irrigation runoff can be water applied in excess of that required to refill the crop's root zone. Excess applied irrigation water may directly run off, or it may contribute to deep percolation losses below the crop's root zone. Deep percolation losses can degrade surface water quality under special hydrologic conditions where shallow groundwater is connected to surface waters.

Minimizing the application of excess water requires good irrigation scheduling (knowing when and how much water to apply) and knowing how much water is being applied by the irrigation system. For additional information on determining how much water to apply by estimating tree crop water use, see the companion publication *Understanding Your Orchard's Water Requirements* (ANR Publication 8212).

It is often difficult to measure the amount of water applied in surface irrigation systems. If water is delivered to the orchard in a pipeline, that pipeline is the easiest and most accurate location to make measurements. For additional information on how to measure pipeline flow rates, see *Measuring Irrigation Flows in a Pipeline* (ANR Publication 8213). It is more difficult and often less accurate to take flow measurements in an open ditch or canal system.

SURFACE IRRIGATION SYSTEMS IN PERMANENT CROPS

Among the many surface irrigation systems used in orchards are ditch and siphon systems (fig. 1), orchard "pot" systems (fig. 2), and alfalfa valve systems. In these systems, irrigation water is applied either by using furrows or by flooding the entire area between tree rows (border check flow system). Measuring the water flow once it is in the furrows or borders is difficult and is not recommended. The best opportunity for measurement is at the inflow point to the orchard.

This publication describes the following surface irrigation flow conditions and measurement techniques:

Ditch and siphon systems
- float-area method
- pipe trajectory
- siphon discharge rate

Orchard pot systems
- flow meter
- hand measurement

Alfalfa valve
- Temporary hydrant

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Figure 1. Orchard ditch and siphon system. *Photo:* Lawrence J. Schwankl.

Each section below details how to determine the volume of applied irrigation water in acre-inches (ac-in). Another useful way of expressing applied water is in terms of the depth of water, inches in English units and millimeters or centimeters in metric units (for converting English units to metric units, see the table at the end of this publication). Expressing irrigation applications as a depth (inches) agrees well with rainfall information and crop water use (evapotranspiration) information, both of which are provided in inches.

To convert acre-inches of applied water to inches of applied water, use the following formula:

_____ applied water (ac-in) ÷ _____ irrigation set area (ac) = _____ applied water (in)

If the irrigation set area is not known, it can be determined by multiplying the field length by the irrigation set width and noting that 1 acre equals 43,560 square feet (ft^2).

Figure 2. Orchard riser, or "pot," system. *Photo:* Lawrence J. Schwankl.

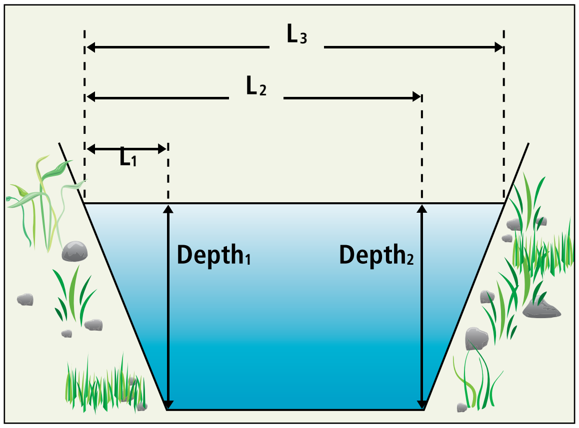

Figure 3. Measurement of channel cross-section.

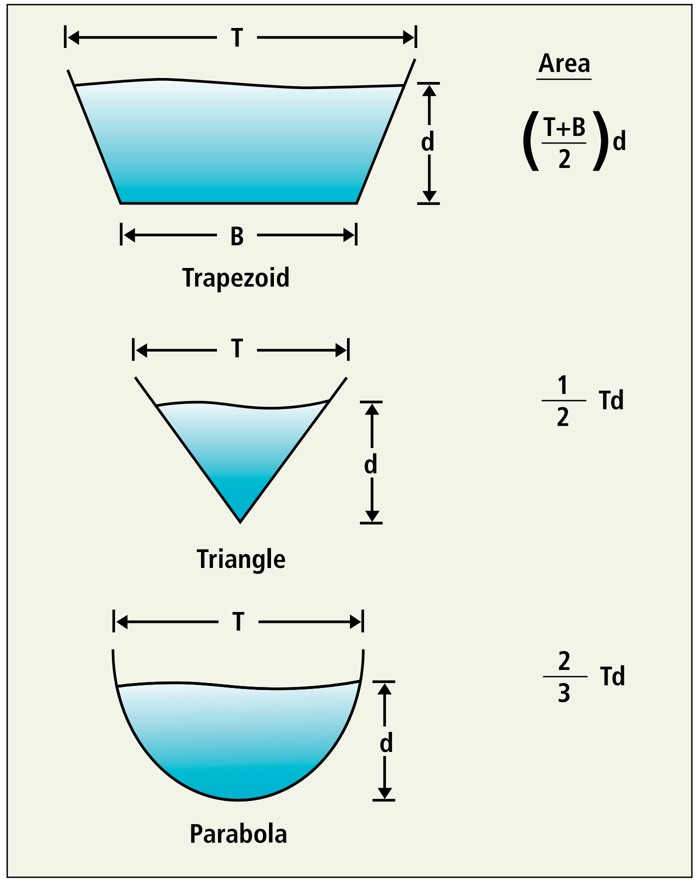

Figure 4. Cross-sectional area of common channel shapes.

DITCH AND SIPHON SYSTEMS

If the flow rate in the ditch is unknown, estimate either the ditch flow rate (float-area method), the pump discharge rate, or the siphon discharge rate.

Float-area Method

The float-area method requires measuring the cross-sectional area of the ditch and the amount of time it takes for a floating object to travel between two points in the ditch. This method provides only an estimate of the ditch flow rate, but it can be useful when other more accurate techniques are not available or practical. An example would be estimating the flow rate in a temporary head ditch that is used for only a few irrigations.

Select a straight section of ditch about 100 feet long where the width and depth are fairly uniform. Measure (in feet) and stake the distance between two locations. Determine the cross-sectional dimensions of the ditch at these points. The dimensions of the upstream and downstream cross-sections will be averaged and used later. If the ditch is very uniform, it will be necessary to determine the area of only one cross-section between the stakes.

A strong fiberglass extension ladder with a board fixed on top can be used as a bridge across the ditch. The top width of the channel can be measured by stretching a tape across the ditch. Most stream cross-sections are roughly triangular or trapezoidal in shape. The bottom and sides of the channel can be delineated by measuring the water depth at key locations from a measuring tape stretched across the top of the channel (fig. 3). These channel measurements can be used to determine the channel cross-sectional area in square feet. Figure 4 shows the formulas for determining the area of a number of common channel shapes.

Table 1. Coefficients for converting float velocity to water velocity

Average water 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 and above	0.80

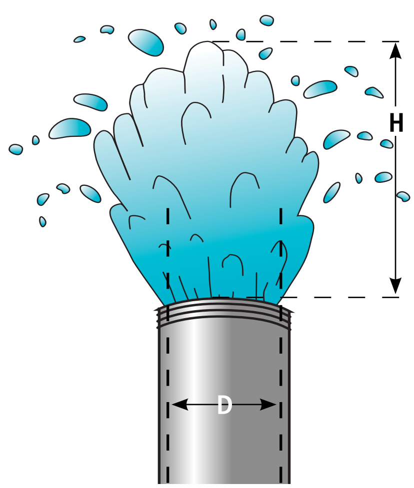

Figure 5. Vertical pipe trajectory flow measurement.

Place a float such as a stick or tennis ball in the channel well upstream of the first stake. This allows the float to reach flow velocity before it reaches the upstream stake. Record the time (in seconds) it takes for the float to move from the first stake to the second. The float should stay in the center of the channel and not touch the channel sides. Repeat the float test a number of times and average the travel times if needed.

Determine the float velocity in feet per second (ft/sec) by dividing the distance between the measurement stakes by the time it took the float to pass between the two stakes. Since the average water velocity is less than the float velocity, a correction coefficient (table 1) must be applied to the measured float velocity.

Finally, determine the channel flow rate in cubic feet per second (cfs) by multiplying the average water velocity (ft/sec) by the average of the channel cross-sectional areas (ft^2) determined at the two stake locations. Note that 1 cfs = 449 gpm.

To determine the irrigation volume in acre-inches (ac-in) applied to the irrigation set from a given ditch, use the applicable formula below:

$$\underline{\qquad}\ \text{cfs} \times \underline{\qquad}\ \begin{matrix}\text{irrigation set}\\ \text{time (min)}\end{matrix} \times 0.0165 = \underline{\qquad}\ \text{ac-in}$$

$$\underline{\qquad}\ \text{gpm} \times \underline{\qquad}\ \begin{matrix}\text{irrigation set}\\ \text{time (min)}\end{matrix} \times 0.000037 = \underline{\qquad}\ \text{ac-in}$$

Pipe Trajectory Method

The pipe trajectory method can be used to estimate the flow rate from a pump discharge. For vertical pipes, measure the pipe's inside diameter (D) and the height water rises above the end of the pipe (H) (fig. 5). Use table 2 to determine the flow rate from a vertical pipe (gpm). For horizontal pipes, measure the pipe's inside diameter (D) and the distance of the trajectory (X) of the discharge water (fig. 6). Use table 3 to determine the pipe discharge in gallons per minute (gpm).

To determine the water applied in acre-inches (ac-in) to the irrigation set from a given pipe, use the following formula:

$$\underline{\qquad}\ \begin{matrix}\text{pipe discharge rate}\\ \text{(gpm)}\end{matrix} \times \underline{\qquad}\ \begin{matrix}\text{irrigation set time}\\ \text{(min)}\end{matrix} \times 0.000037 = \underline{\qquad}\ \begin{matrix}\text{applied water}\\ \text{(ac-in)}\end{matrix}$$

Siphon Discharge Rate

The discharge rate from an individual siphon can also be estimated by measuring the difference in water surface heights between the water in the ditch and the water in the field just downstream of the siphon. This difference in water levels is often called the "head" (fig. 7). Use figure 8 to determine the siphon pipe discharge (gpm).

To determine the water applied in acre-inches (ac-in) to the irrigation set, use the following formula:

$$\underline{\qquad}\ \begin{matrix}\text{siphon flow}\\ \text{rate (gpm)}\end{matrix} \times \underline{\qquad}\ \begin{matrix}\text{no. of}\\ \text{siphons}\\ \text{per set}\end{matrix} \times \underline{\qquad}\ \begin{matrix}\text{irrigation}\\ \text{set}\\ \text{time (min)}\end{matrix} \times 0.000037 = \underline{\qquad}\ \text{ac-in}$$

Table 2. Flow from vertical pipe (gpm)

Jet height, H (in)	Inside diameter of pipe (in)							
	2	3	4	5	6	8	10	12
2	28	57	86	115	150	215	285	355
2.5	31	69	108	150	205	290	385	480
3	34	78	128	182	250	367	490	610
3.5	37	86	145	210	293	440	610	755
4	40	92	160	235	330	510	725	910
4.5	42	98	173	257	365	570	845	1,060
5	45	104	184	275	395	630	940	1,200
6	50	115	205	306	445	730	1,125	1,500
7	54	125	223	336	485	820	1,275	1,730
8	58	134	239	360	521	890	1,420	1,950
9	62	143	254	383	550	955	1,550	2,140
10	66	152	268	405	585	1,015	1,650	2,280
12	72	167	295	450	650	1,120	1,830	2,550
14	78	182	320	485	705	1,220	2,000	2,800
16	83	195	345	520	755	1,300	2,140	3,000
18	89	208	367	555	800	1,400	2,280	
20	94	220	388	590	850	1,480	2,420	
25	107	248	440	665	960	1,670	2,720	
30	117	275	485	740	1,050	1,870	3,000	
35	127	300	525	800	1,150	2,020		
40	137	320	565	865	1,230	2,160		

Note: For pipe inside diameters other than those shown in the table, interpolate values between the closest given values.

Table 3. Discharge rate (gpm) for a horizontal pipe with a vertical water trajectory of 4 inches

Horizontal distance, X (in)	Nominal pipe diameter (in)							
	3	4	5	6	8	10	12	Average velocity (ft/sec)
4	48.5	83.5						2.1
5	61.0	104.0	163					2.6
6	73.0	125.0	195	285				3.1
7	85.0	146.0	228	334	580			3.7
8	97.5	166.0	260	380	665	1,060		4.2
9	110.0	187.0	293	430	750	1,190	1,660	4.7
10	122.0	208.0	326	476	830	1,330	1,850	5.3
11	134.0	229.0	360	525	915	1,460	2,200	5.8
12	146.0	250.0	390	570	1,000	1,600	2,200	6.2
13	158.0	270.0	425	620	1,080	1,730	2,400	6.9
14	170.0	292.0	456	670	1,160	1,860	2,590	7.4
15	183.0	312.0	490	710	1,250	2,000	2,780	7.9
16	196.0	334.0	520	760	1,330	2,120	2,960	8.4
17	207.0	355.0	550	810	1,410	2,260	3,140	9.1
18	220.0	375.0	590	860	1,500	2,390	3,330	9.7
19	232.0	395.0	620	910	1,580	2,520	3,500	10.4
20	244.0	415.0	650	950	1,660	2,660	3,700	10.6
21	256.0	435.0	685	1,000	1,750	2,800		11.4
22		460.0	720	1,050	1,830	2,920		11.8
23			750	1,100	1,910	3,060		12.4
24				1,400	2,000	3,200		13.0

ORCHARD POT SYSTEMS

Concrete risers, or "pots," connected to an underground pipeline are often used to irrigate orchards and vineyards. The riser contains an adjustable valve, and it may also have slide gates that can also be adjusted (fig. 2). Two methods of flow measurement can be used under these conditions: either a flow meter can be installed in the pipeline or water can be measured manually as it discharges from the risers.

Using a Flow Meter

The easiest flow measurement method is to install a flow meter in the pipeline upstream of the field. A propeller meter works very well. Installing a flow meter in the low-head concrete or plastic pipeline can be expensive if the pipeline has a large diameter. For plastic pipeline it may be possible to measure the flow rate using a portable Doppler flow meter temporarily strapped to the pipe's outer wall.

Having a flow meter at the water source may also be an option, especially if the water source is pumped from groundwater or an irrigation canal. The diameter of the pump discharge pipe is usually well suited for a flow meter. A complication to this method is where multiple water sources are used (e.g., multiple wells), and a number of fields are being irrigated simultaneously. In this instance, it may be difficult to determine the flow to an individual field.

If the flow meter indicates both instantaneous flow rate (i.e., gallons per minute, gpm) and totalized flow (i.e., gallons, acre-feet, or acre-inches), use totalized flow readings taken at the beginning and end of the irrigation set to determine the applied water. Using totalized flows is more accurate than using instantaneous flow rates. Use the appropriate formula below to fit your condition.

If your totalized flow is already in acre-inches, leave it in that form. For totalized flow measurements:

$$\_\_\_\_\_\ \text{gal} \times 0.000037 = \_\_\_\_\_\ \text{ac-in}$$

$$\_\_\_\_\_\ \text{ac-ft} \times 12 = \_\_\_\_\_\ \text{ac-in}$$

If only instantaneous flow rates are available, use the appropriate formula below:

$$\_\_\_\_\_\ \text{gpm} \times \_\_\_\_\_\ \begin{matrix}\text{irrigation set}\\ \text{time (min)}\end{matrix} \times 0.000037 = \_\_\_\_\_\ \text{ac-in}$$

$$\_\_\_\_\_\ \text{cfs} \times \_\_\_\_\_\ \begin{matrix}\text{irrigation set}\\ \text{time (min)}\end{matrix} \times 0.0165 = \_\_\_\_\_\ \text{ac-in}$$

Hand-measurement of Discharge

If you do not have a flow meter in the pipeline, your remaining flow measurement option is to manually collect water coming out of the side of the riser. This is done using a bucket and stopwatch to determine the flow rate from the jet being monitored. The following formula can be used to make this calculation:

$$\_\_\_\_\_\ \begin{matrix}\text{water collected}\\ \text{(gal)}\end{matrix} \div \_\_\_\_\_\ \begin{matrix}\text{collection time}\\ \text{(sec)}\end{matrix} \times 60\ \text{sec/min} = \_\_\_\_\_\ \begin{matrix}\text{discharge}\\ \text{rate}\\ \text{(gpm)}\end{matrix}$$

For example, if it took 20 seconds to fill a 5-gallon pail, the discharge rate (gpm) would be

5 gallons ÷ 20 seconds x 60 = 15 gpm

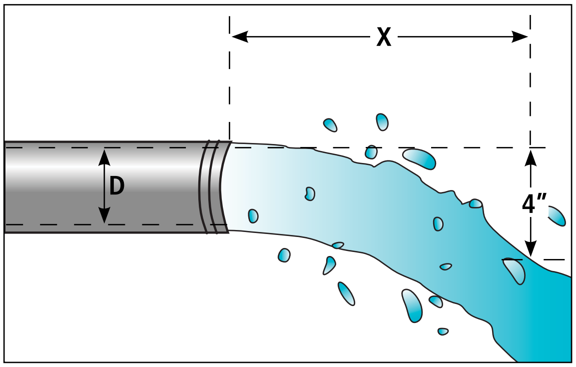

Figure 6. Horizontal pipe trajectory flow measurement.

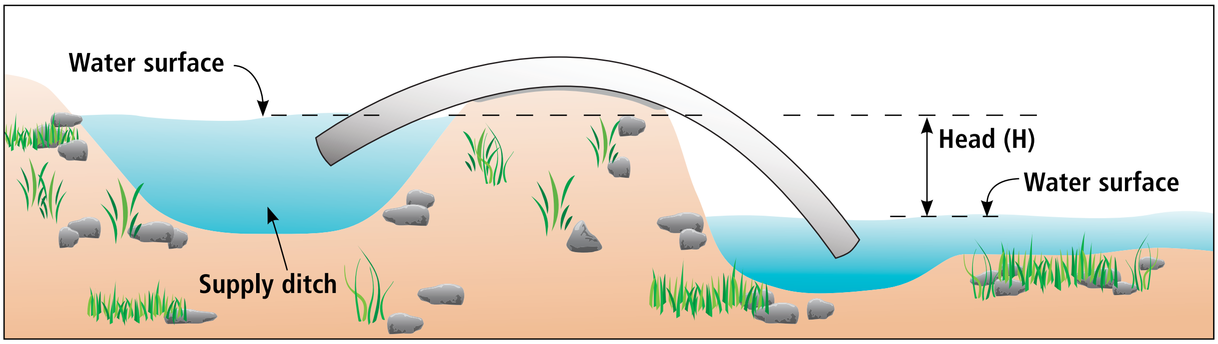

Figure 7. Determining the head (H) difference in siphon pipe irrigation.

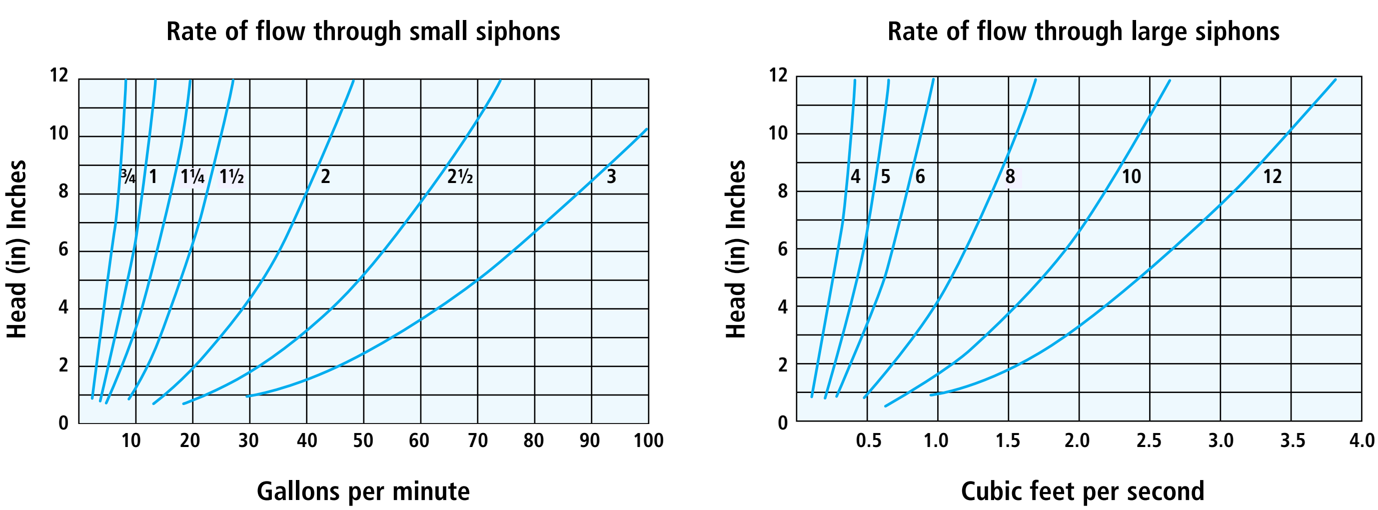

Figure 8. Discharge rate from siphon pipes. Note that 1 cfs = 448 gpm. *Source:* V. H. Scott and C. E. Houston, *Measuring Irrigation Water* (Oakland: University of California Division of Agriculture and Natural Resources Leaflet 2956, 1981), p. 21.

The discharge rate should be measured from as many risers as possible. You will soon determine whether there is a significant difference between riser discharge rates and all risers must be measured, or whether there is consistency between riser discharge rates and only a sampling is needed.

Determine the flow rate to the irrigation set using the following formula:

_____ gate discharge rate (gpm) × _____ no. of gates in irrigation set = _____ applied water (gpm)

Determine the total applied water (ac-in) using the following formula:

_____ applied water (gpm) × _____ irrigation set time (min) × 0.000037 = _____ ac-in

ALFALFA VALVE SYSTEMS

As with orchard pot systems, alfalfa valve systems use a concrete or PVC pipeline to deliver the water to the orchard. If a propeller meter can be installed in the pipeline, it is the best way to measure the flow. Measuring the discharge from an alfalfa valve is difficult but can be done using the following technique.

Temporary Hydrant

A temporary hydrant with a flow meter installed over an alfalfa valve can be used to measure the applied water. See figure 9 for a schematic of this technique.

The flow meter is installed in the section of pipe extending out of the side of the hydrant. This flow meter can be a propeller meter or a Doppler meter temporarily mounted to the side of the horizontal pipe. For details on calculations, see the section "Orchard Pot Systems—Using a Flow Meter," above.

WHAT IF IRRIGATION RUNOFF IS A PROBLEM?

Once the amount of applied water for an irrigation is measured, it is often found that the amount is greater than what is needed to replace the water used by the trees since the last irrigation. The excess water will either percolate deep below the tree root zone or run off from the orchard.

Currently, the emphasis of the Irrigated Lands Discharge Waiver Program is focused on irrigation runoff to surface waters and its impact on water quality. If tailwater is being generated and it is running off the property, there are a number of steps which can be taken. First, determine whether the irrigation set can be managed to decrease the tailwater amount. Could the irrigation water be turned off sooner to minimize tailwater while still adequately irrigating the tail end of the orchard?

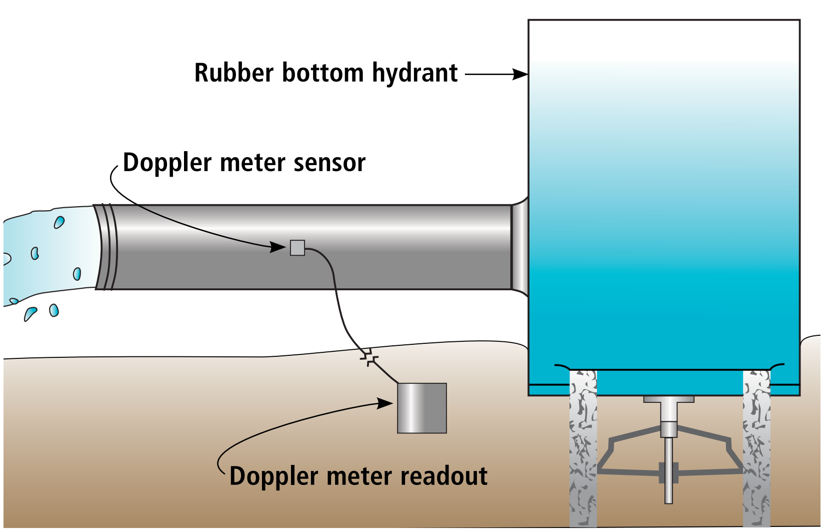

Figure 9. Temporary hydrant installed over an alfalfa valve to measure the flow rate.

Second, consider installing a tailwater return system. This system, often used with surface irrigation in row and field crops, collects runoff at the end of a field and reuses it for irrigation. It eliminates irrigation runoff and is an excellent management practice. For more information on tailwater return systems, see the companion publication *Tailwater Return Systems* (ANR Publication 8225). Additional information on handling irrigation runoff from the orchard can be found in the publication *Causes and Management of Runoff from Surface Irrigation in Orchards* (ANR Publication 8214).

METRIC CONVERSIONS

English	Conversion factor for English to Metric	Conversion factor for Metric to English	Metric
foot (ft)	0.3048	3.28	meter (m)
square foot (ft^2)	0.0929	10.764	square meter (m^2)
cubic foot (ft^3)	28.317	0.353	liter (l)
acre (ac)	0.4047	2.471	hectare (ha)
acre-inch (ac-in)	102.8	0.00973	cubic meter (m^3)
acre-foot (ac-ft)	1,233.0	0.000811	cubic meter (m^3)
pounds per square inch (psi)	6.894	0.145	kilopascal (kPa)
gallon (gal)	3.785	0.264	liter (l)

FOR FURTHER INFORMATION

Storing Runoff from Winter Rains (ANR Publication 8211), 2007.

Understanding Your Orchard's Water Requirements (ANR Publication 8212), 2007.

Measuring Irrigation Flows in a Pipeline (ANR Publication 8213), 2007.

Causes and Management of Runoff from Surface Irrigation in Orchards (ANR Publication 8214), 2007.

Managing Existing Sprinkler Irrigation Systems (ANR Publication 8215), 2007.

Soil Intake Rates and Sprinkler Application Rates in Sprinkler-Irrigated Orchards (ANR Publication 8216), 2007.

Tailwater Return Systems (ANR Publication 8225), 2007.

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