ALMOND IRRIGATION IMPROVEMENT CONTINUUM 1.0

california almonds
Almond Board of California

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INTRODUCTION AND OVERVIEW

The efficient use and management of water is one of four key initiatives of the Accelerated Innovation Management (AIM) program adopted by Almond Board of California (ABC). The ABC has long based been a research-based organization, with both traditional research and sustainability initiatives. Through the AIM program, the Almond Board is now placing greater emphasis on innovative almond farming practices to better meet future needs of the California Almond industry as well as the consumer, the community and the environment.

The AIM's Water Management and Efficiency Initiative focuses on accelerating grower adoption of irrigation management and scheduling tools that are based on research, commercially available and increasing water efficiency. To help support growers in this transition ABC has developed the *Almond Irrigation Improvement Continuum*, a comprehensive manual of irrigation management and scheduling practices. Recognizing that growers may be operating at different stages of irrigation efficiency, the *Continuum* provides information at three proficiency levels, each covering the following concepts and how to execute and effectively integrate them:

- Measuring irrigation system performance and efficiency
- Estimating orchard water requirements based on evapotranspiration
- Determining the water applied
- Evaluating soil moisture
- Evaluating plant water status

The *Continuum Level 1.0* (minimum proficiency) outlines irrigation management practices that are within reach for all California Almond growers. The *Continuum Level 2.0* (intermediate proficiency) and *Level 3.0* (advanced proficiency) address practices at more sophisticated levels to attain even more "crop per drop."

The Almond Board's first objective with the *Continuum* is to assist all almond growers in meeting level 1.0 proficiency. Beyond this, the Almond Board will work with growers to progress along the *Continuum* to levels 2.0 and 3.0 proficiency. This effort will be done in partnership with the many trusted and respected technical experts and resources available, such as University of California Division of Agriculture and Natural Resources Cooperative Extension.

As level 2 and 3 manual of the *Almond Irrigation Improvement Continuum* are developed, they will be published as eBooks on almonds.com/irrigation.

ALMOND IRRIGATION IMPROVEMENT CONTINUUM

Use the proficiency levels and guidance below to adopt good irrigation water management practices for almonds. Each level of the *Almond Irrigation Improvement Continuum* will provide the tools necessary to obtain measurements needed to best schedule and manage almond irrigation.

Measurement	1.0 Minimum	2.0 Intermediate	3.0 Advanced
Orchard Water Requirements	Estimate orchard water requirements using "normal year" regional ETc to estimate irrigation demand on a monthly basis.	Estimate orchard water requirements using "normal year" regional ETc—adjusting for current weather and cover crop use on a bi-weekly basis.	Estimate orchard water requirements using "normal year" regional ETc to plan irrigations, then use real-time ETc data to correct the schedule on a weekly basis.
Irrigation System Performance	Evaluate irrigation system for pressure variation and average application rate at least once every 3 years. Correct any diagnosed system performance problems.	Assess distribution uniformity and average application rate by measuring water volume at least every 3 years. Correct any diagnosed system performance problems.	Assess distribution uniformity and average application rate by measuring water volume at least every 2 years. Correct any diagnosed system performance problems.
Applied Water	Use application rate and duration of irrigation to determine water applied.	Use water meters to determine flow rate and water applied.	Use water meters to determine applied water and compare to crop water use (ETc, evapotranspiration) to determine irrigation efficiency.
Soil Moisture	Evaluate soil moisture based upon feel and appearance by augering to at least 3-5 feet. Monitor on a monthly time step.	Use manually operated soil moisture sensors to at least 3-5 feet and monitor on a bi-weekly time step. Use information to ensure calculated water is not over/under irrigating trees.	Use automated moisture sensors that store data over time. Review weekly to ensure calculated water is not over/under irrigating trees.
Plant Water Status	Evaluate orchard water status using visual plant cues just prior to irrigation or on a bi-weekly basis.	Use pressure chamber to measure midday stem water potential just prior to irrigation on a monthly basis. Ensure calculated water applications are not over/under irrigating trees.	Use pressure chamber to measure midday stem water potential prior to irrigation on a weekly basis. Ensure calculated water applications are not over/under irrigating trees. Use it to assess when to start irrigating.
Integrating Irrigation Water Management Practices	Combine irrigation system performance data with "normal year" regional ETc to determine orchard-specific water requirements and schedule irrigations. Check soil moisture with an auger and/or monitor plant water status to verify scheduling.	Use irrigation system performance data with regional estimates of "normal year" ETc to schedule irrigations and adjust based on feedback from monitoring soil moisture or crop water status.	Develop an irrigation schedule based on predicted "normal year" demand, monitor status using soil and plant based methods. Adjust irrigation schedule with real-time ETc as the season progresses.

DETERMINING AND MEETING ORCHARD WATER REQUIREMENTS

1.0 Practice: Estimate orchard water requirements using "normal year" regional crop evapotranspiration and other site-specific factors to determine irrigation applications on a monthly time basis.

An orchard's water requirement is a combination of the crop water use and other beneficial water uses, such as salt leaching (if necessary) and water added to account for irrigation non-uniformity. Crop water use is considered to include losses from the orchard's soil (evaporation) and tree's leaves (transpiration). These losses are combined into the term evapotranspiration (ETc), or, for our purposes, "almond water use." Almond water use can vary with climate, canopy size, existence of a planted cover crop or weeds, or reduced soil moisture.

The orchard water requirement is met by soil moisture stored in the root zone (including frost protection water applications if stored in the root zone), in-season rainfall stored in the soil, and applied irrigation water. In-season rainfall that enters the root zone for orchard use tends to occur in the first few months of the season. Likewise, stored soil moisture is at a maximum at the beginning of the season. It is not uncommon for these two water sources to supply the entire crop water use in the first month and up to 15 to 35% on a seasonal basis.

The amount of water available to the orchard from these sources can vary widely, since the rainfall stored in the root zone and in-season effective rainfall (rain that is ultimately used by the orchard) varies with rainfall duration and frequency, as well as with root zone water-holding capacity. As an example of the variability, rainfall in Bakersfield (ET zone 15) averages 6.45 inches, while northern almond regions such as Red Bluff (ET Zone 14) average 24.5 inches. To determine the irrigation application target in northern almond regions, you must account for the orchard's use of moisture stored in the soil and in-season effective rainfall. The result will be a reduction of applied irrigation water or a delay in irrigation in the spring months, or both. In southern almond regions, effective in-season rainfall is small and soil storage is largely a function of applied irrigation water wetting the root zone.

ESTIMATING MATURE ALMOND ORCHARD WATER REQUIREMENTS

Figure 1. Mature almond orchard with no cover crop. An almond orchard is considered mature when about 80% or more of the orchard floor is shaded at midday during the middle of the growing season. (Photo by T. Prichard)

Orchard water use, or evapotranspiration (ETc), is the sum of the orchard water use through transpiration and water lost through evaporation from the soil surface. Climate factors affecting evapotranspiration include direct solar radiation (sunlight), temperature, wind, and humidity. Tree and soil factors affecting evapotranspiration include canopy size, health of the tree, how tree row middles are managed (i.e., cover crop/weeds) and available soil moisture. Added to the orchard water use are other beneficial water uses that determine the orchard's water requirement, such as water used for salt leaching and for irrigation non-uniformity.

This section reviews calculations to determine the orchard water requirement for mature orchards without cover crops or vegetation in row middles (figure 1). The best way to determine a mature orchard's water requirement is by using climatic data and the orchard's specific characteristics.[1] An almond orchard is considered to be mature when about 80% or more of the orchard floor is shaded at midday during the

1. Allen, R.G., Pereira, L.S., Raes, D & Smith, M. 1998. Crop Water Requirements. FAO Irrigation and Drainage. Papre No. 56, Rome, FAO. http://www.kimberly.uidaho.edu/water/fao56/fao56.pdf

middle of the growing season. More than 80% canopy coverage may result in increased water use; however, that level of coverage is considered to be the practical limit based on necessary cultural activities. If the shaded area of your orchard is less than 80%, refer to the section "Estimating Young Almond Orchard Water Requirements."

DETERMINING THE ORCHARD FLOOR SHADED AREA

The orchard floor shaded area is the percentage of tree spacing that is shaded when measured at midday. For example, a tree spacing of 17 × 24 feet equals 408 square feet per tree. If the shaded area is 326 square feet, 80% of the tree spacing would be shaded.

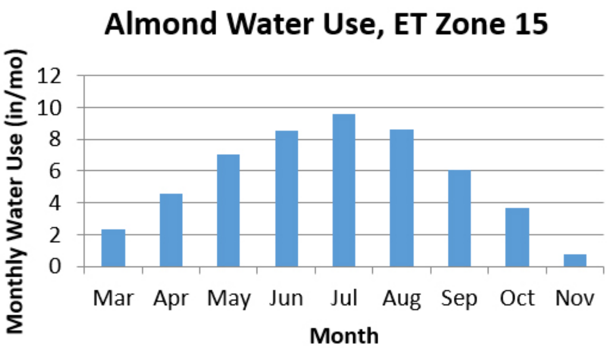


Figure 2. Monthly almond monthly water use by a mature orchard with no cover crop and no significant water stress in climate zone 15 (Bakersfield to Los Banos), one of the four major climactic zones where California almonds are grown.

MATURE ALMOND ORCHARD WATER USE

Each year, almond trees begin using water as the leaves develop and shoot growth begins. As the growing season progresses and concurrent with canopy development, the water needed due to the warming climate increases, driven by longer days, higher temperatures, and lower humidity. Together, these factors cause seasonal orchard water use to start at a low level, peak in mid-season, and fall as the growing season comes to an end (figure 2).

Once an orchard's mature water use has been determined, that amount may need to be modified to account for orchard-specific factors such as soil or water salinity levels and irrigation system non-uniformity.

CALCULATING ORCHARD WATER USE

Calculate almond orchard evapotranspiration ETc by multiplying the weather-based reference crop ETo by a canopy-based crop coefficient (Kc):

Crop water use (ETc) = Reference evaporation (ETo) × Crop coefficient (Kc).

- ETc (almond water use) in inches of water can be based on the day, week, month, or season in order to assess the orchard's water requirements for irrigation scheduling purposes.

- ETo (reference ET) information is available from a variety of sources. The most well-known is the California Department of Water Resources' CIMIS network of nearly 100 California weather stations that provide daily reference evapotranspiration values (www.cimis.water.ca.gov). CIMIS provides real-time current-season values and ETo in inches of water and can be based on the day, week, month, or season (table 1). Another web-based source for this ETo data is the UC Statewide Integrated Pest Management website. Additionally, some newspapers and irrigation districts regularly publish CIMIS ETo data. While some in-orchard weather stations have the necessary inputs to calculate ETo, their accuracy depends on instrument siting. Use caution when using these ETo values. Best practices suggest verifying the values obtained in an orchard with the closest CIMIS station or to those obtained using spatial CIMIS.

Month	Kc[3]	Zone 12[4]		Zone 14[5]		Zone 15[6]		Zone 16[7]	
		ETo	ETc	ETo	ETc	ETo	ETc	ETo	ETc
Jan	0.4	1.24	0.5	1.55	0.62	1.24	0.5	1.55	0.62
Feb	0.41	1.96	0.81	2.24	0.92	2.24	0.92	2.52	1.04
Mar	0.62	3.41	2.11	3.72	2.3	3.72	2.3	4.03	2.49
Apr	0.8	5.1	4.09	5.1	4.09	5.7	4.57	5.7	4.57
May	0.94	6.82	6.44	6.82	6.44	7.44	7.02	7.75	7.31
Jun	1.05	7.8	8.2	7.8	8.2	8.1	8.51	8.7	9.14
Jul	1.11	8.06	8.93	8.68	9.61	8.68	9.61	9.3	10.3
Aug	1.11	7.13	7.9	7.75	8.59	7.75	8.59	8.37	9.28
Sep	1.06	5.4	5.73	5.7	6.05	5.7	6.05	6.3	6.68
Oct	0.92	3.72	3.41	4.03	3.69	4.03	3.69	4.34	3.97
Nov	0.69	1.8	1.23	2.1	1.44	2.1	1.44	2.4	1.64
Dec	0.43	0.93	0.4	1.55	0.66	1.24	0.53	1.55	0.66
Totals (in.)									
Yearly			49.75		52.61		53.73		57.70
Crop season[8]			47.43		49.69		51.06		54.56
Non-crop season[9]			2.32		2.92		2.67		3.14

NOTES:

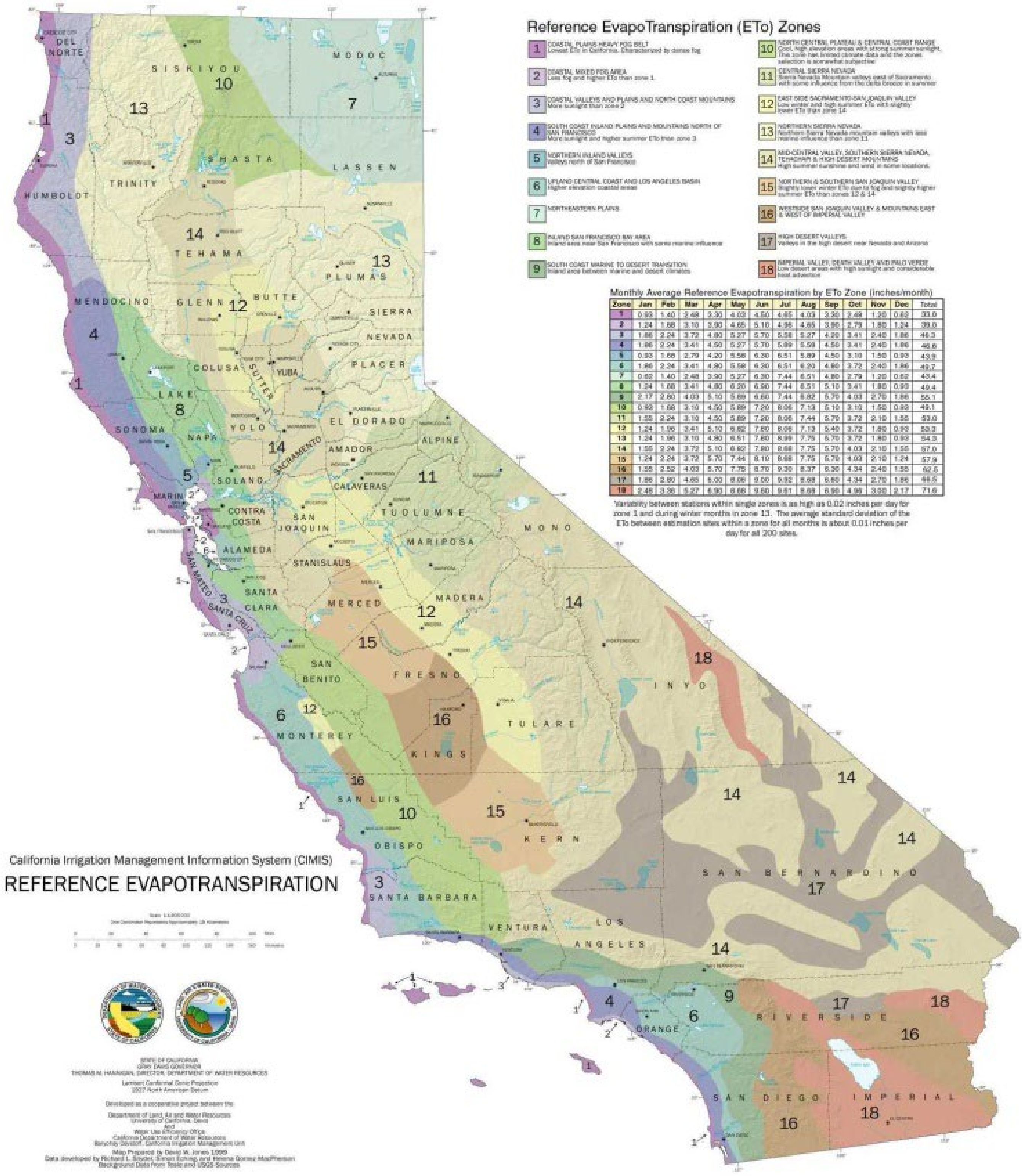
1. Normal year evapotranspiration of unstressed grass (reference crop, ET0) 30-year CIMIS average for the respective zone.
2. Evapotranspiration rates for almonds were calculated by multiplying ETo by the crop coefficient.
3. Almond crop coefficient.
4. Zone 12 ETo rates from Chico, Fresno, Madera, Merced, Modesto, and Visalia.
3. Zone 14 ETo rates from Newman, Red Bluff, and Woodland.
6. Zone 15 ETo rates from Bakersfield, Los Banos, and westside San Joaquin Valley
7. Zone 16 ETo rates from Coalinga and Hanford.
8. Crop season ETc rates for March to November 15.
9. Non-crop season ETc rates for January, February, November 16–30, and December (Source: Adapted from Doll and Shackel 2015)

Table 1. Thirty-year average evapotranspiration reference rates (ETo)[1] and almond (ETc)[2] for selected CIMIS zones in almond-producing areas of California

- Kc (crop coefficient) for almond has been experimentally determined for various times throughout the growing season. A crop coefficient is necessary to convert ETo or reference ET to an almond specific number, as ETo represents the reference crop (grass pasture) used at CIMIS stations. Kc is the ratio at which the almond crop uses water compared with the ETo of the grass pasture. The Kc is developed under conditions where soil moisture is not limited and the crop is not under any water stress.

Historical “normal year,” or long-term average ETo, can be more convenient than real-time ETo information because it is easier to access. It can also be used to prepare an irrigation plan for an entire irrigation season. The California climate zones from which regional ETo information is derived are shown in table 1. If more accuracy is desired, click here to download a Google Earth file that includes CIMIS ETo Zones for the California almond growing region.

Table 1 lists historical monthly ETo values and ETc almond crop water use derived from K_c values for the four climatic zones where almonds are grown in California (see figure 3). These monthly almond crop water use values are applicable to a mature almond orchard that has 80% or more of the orchard floor shaded at midday during the middle of the growing season, no middle cover, and no water stress.



Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	0.93	1.40	2.48	3.30	4.03	4.50	4.65	4.03	3.30	2.48	1.20	0.62	33.0
2	1.24	1.68	3.10	3.90	4.65	5.10	4.96	4.65	3.90	2.79	1.80	1.24	39.0
3	1.86	2.24	3.72	4.80	5.27	5.70	5.58	5.27	4.20	3.41	2.40	1.86	46.3
4	1.86	2.24	3.41	4.50	5.27	5.70	5.89	5.58	4.50	3.41	2.40	1.86	46.6
5	0.93	1.68	2.79	4.20	5.58	6.30	6.51	5.89	4.50	3.10	1.50	0.93	43.9
6	1.86	2.24	3.41	4.80	5.58	6.30	6.51	6.20	4.80	3.72	2.40	1.86	49.7
7	0.62	1.40	2.48	3.90	5.27	6.30	7.44	6.51	4.80	2.79	1.20	0.62	43.4
8	1.24	1.68	3.41	4.80	6.20	6.90	7.44	6.51	5.10	3.41	1.80	0.93	49.4
9	2.17	2.80	4.03	5.10	5.89	6.60	7.44	6.82	5.70	4.03	2.70	1.86	55.1
10	0.93	1.68	3.10	4.50	5.89	7.20	8.06	7.13	5.10	3.10	1.50	0.93	49.1
11	1.55	2.24	3.10	4.50	5.89	7.20	8.06	7.44	5.70	3.72	2.10	1.55	53.0
12	1.24	1.96	3.41	5.10	6.82	7.80	8.06	7.13	5.40	3.72	1.80	0.93	53.3
13	1.24	1.96	3.10	4.80	6.51	7.80	8.99	7.75	5.70	3.72	1.80	0.93	54.3
14	1.55	2.24	3.72	5.10	6.82	7.80	8.68	7.75	5.70	4.03	2.10	1.55	57.0
15	1.24	2.24	3.72	5.70	7.44	8.10	8.68	7.75	5.70	4.03	2.10	1.24	57.9
16	1.55	2.52	4.03	5.70	7.75	8.70	9.30	8.37	6.30	4.34	2.40	1.55	62.5
17	1.86	2.80	4.65	6.00	8.06	9.00	9.92	8.68	6.60	4.34	2.70	1.86	66.5
18	2.48	3.36	5.27	6.90	8.68	9.60	9.61	8.68	6.90	4.96	3.00	2.17	71.6

Figure 3. Reference evapotranspiration (ETo) zones in California. Most almonds are grown commercially in zones 12, 14, 15, and 16. (Source: http://www.cimis.water.ca.gov/App_Themes/images/etozonemap.jpg)

ACCOUNTING FOR COVER CROP WATER USE

A cover crop is a non-economic crop that is grown in the tree row middles. Cover crops are classified based on the season of growth or species. Resident vegetation, or weeds, that are simply allowed to grow in the tree row middles can be managed like a cover crop. The water used by cover crops must be accounted for in determining the orchard water use. Orchards with cover crops in the row middles have higher evapotranspiration rates than orchards without them.[2]

Orchard middles are managed periodically by mowing, cultivation, or herbicide application. Orchard managers may allow cover to grow in row middles at the beginning of the growing season, then remove it as harvest approaches. The orchard water requirement at the beginning of the irrigation season could be calculated using the following approach, but once the cover crops are removed, orchard managers should disregard this calculation.

Figure 4. Almond orchard with fairly dense cover crop (top); almond orchard with fairly sparse cover crop (bottom). (Photo by T. Prichard)

The water-use rate of cover crops in orchards is difficult to measure and has not been thoroughly investigated. Water use by cover crops depends on the mowing or cultivation frequency, plant density, degree of shading by the tree canopies, and whether the cover crop has sufficient water available (whether it is fully wetted by irrigation applications). Estimates of increased water use due to the presence of cover crops are site specific.

Approximating the orchard water use increase due to cover crops depends mostly on the fraction of orchard ground surface occupied by the cover crop and the density of the cover crop (figures 4 and 5). When a cover crop has water available and is green and growing, the increased water use varies from 10 to 30 percent. The approach to account for this increase during the time the cover exists is as follows[3]:

Almond water use with middles cover =
Monthly water use (ETc) x (1+% water use increase)

EXAMPLE

Zone 12: May ETc = 6.44 inches
Full-coverage irrigation system
Cover crop density is fairly sparse
Tree row spacing = 22 ft
Cover crop in middles = 15 ft wide
Fraction of orchard ground surface with middles cover =
15 ft ÷ 22 ft = 0.68, or 68%
Water use increase (from figure 5) = 0.20, or 20%

2. Prichard, T., W Sillis, W. Asai, L. Hendreicks, and C. Elmore. 1989. Orchard water use and soil characteristics. California Agriculture 43(4): 23–25.
3. Fereres, E., D. Goldhamer, and V. Sadras. 2012. Yield Response to Water of Fruit Trees and Vines: Guidlines. In P. Steduto, T. Hsiao, E. Fereres, and D. Raes, eds., Crop yield response to water. FAO Irrigation and Drainage Paper 66:246-295. FAO website, www.fao.org/nr/water/docs/irrigationdrainage66.pdf.

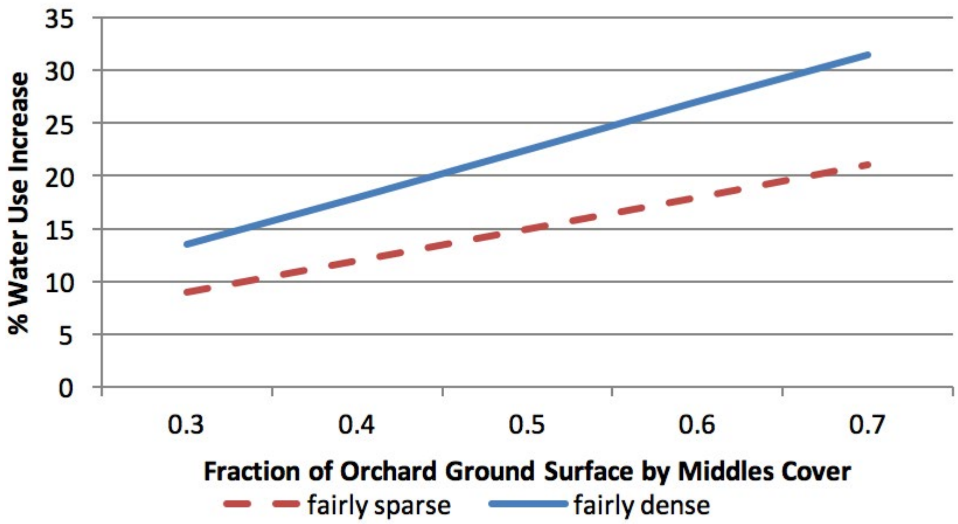


Figure 5. Fraction of orchard row covered by vegetation and the percentage of water use increase. Growers can use this chart to determine the additional water use of their orchard attributed to cover crops. (Source: Fereres et al 2012.)

It would be necessary to provide 6.44 in x (1 + 0.20) = 7.72 inches of water for that month to adequately provide water for the trees and the cover crop.

For irrigation systems that are not full coverage, use only the green growing area to determine the fraction of the orchard that has cover.

For young orchards or orchards with less than 30% canopy shaded area and cover crops in the middles, the best approach is frequent soil moisture monitoring in the root zone to ensure adequate moisture.

ADJUSTING FOR SMALL CANOPY OR YOUNG ORCHARDS

Figure 6. Because young orchards do not have a full canopy, they use less water than mature orchards, and the irrigation amount must be adjusted to account for this.(Photo by T. Prichard)

The smaller canopy of a young orchard (figure 6) uses less water than orchards with mature trees (canopy at or near 80% shaded ground surface at midday). The evapotranspiration of young trees can be estimated by adjusting the mature tree evapotranspiration determined in the previous section based on the percentage of ground shading provided by the young trees (see figure 7).[4]

The percentage of ground shading can be estimated by visually examining the extent of the orchard floor shaded at midday. Since the shaded area in young orchards increases over the season, the shaded area should be evaluated monthly.

The shaded area is the percentage of the tree spacing that is shaded when measured at midday. For example, a tree spacing of 17 by 24 feet yields 408 square feet of growing area per tree. If the shaded area is measured at 163 square feet, the shaded floor area would be 40% of the tree spacing.

4. Fereres, E., Martinich, D.A., Aldrich, T.M., Castel, J.R., Holzapfel, E. & Schulbach, H.1982. Drip irrigation saves money in young almond orchards. California Agriculture 36:12–13. Bruce Lampinen (personal communication)

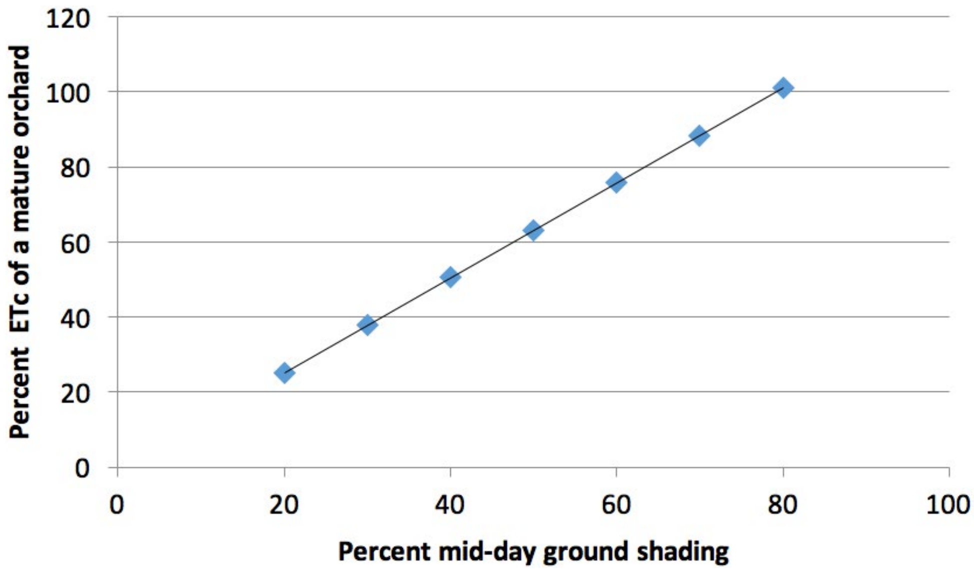


Figure 7. Relationship between the percentage of ground shading and mature ET.

% Shaded area	% Mature orchard ETc
20	25
30	38
40	50
55	63
60	76
70	88
80	101

Table 2. Growers can use this table to determine from the percent of midday ground shading in their orchard the percent of ET that orchard will require.

The relationship between mature orchard use and shaded area has been measured using various methods to determine water use and the shaded area. The most recent consensus relationship is shown in table 2. The evapotranspiration increases at a rate approximately 1.26 times the percent ground shading. Current research is underway in almond to measure shaded area and water use in a weighing lysimeter, which is much more accurate than previously used methods. When results are available this relationship—if different—will be updated.

This method of using the percent of shading to determine water use is not recommended until the canopy reaches at least 30% shaded area, by which time the roots will have expanded to most of the area where the irrigation water is applied.

EXAMPLE A

Irrigation systems such as drip, which directs all of the irrigation water to the root zone, can work well for the orchards with lower amounts of shaded area.

If water is applied to the entire orchard surface (e.g., by solid-set sprinklers) and the tree roots occupy only a small portion of the area, most of the applied water will not be accessible by the orchard, and the orchard will be under-irrigated. Frequent soil moisture monitoring will be required in the young trees' root zone to ensure adequate irrigation.

Use the following formula to adjust mature crop water use to that of a young orchard:

Young orchard water use (ETc) = Monthly mature orchard water use (ETc) x percent of mature orchard ETc (figure 7)

EXAMPLE B

Zone 12 May ETc = 6.44 inches without middles cover
Young orchard ground surface shading at midday = 40% or 0.40
Percentage ETc of a mature orchard = 50% or 0.50 (see figure 7)
6.44 in. x 0.050 = 3.22 inches for the 40% coverage orchard

ADJUSTING WATER USE FOR OTHER ORCHARD WATER REQUIREMENTS

In addition to the orchard water covered in the previous sections, a variety of factors can impact the actual water requirement of an orchard. These include the additional water needed to address factors such as salinity and irrigation system nonuniformity or reductions in water use due to factors such as disease management and inadequate water supplies.

IRRIGATION SYSTEM NON-UNIFORMITY

In addition to orchard water use described and calculated in the previous sections, other factors can impact the actual water requirement of an orchard. One of these is increasing the orchard water irrigation to overcome irrigation system non-uniformity. System uniformity is determined by measuring the distribution uniformity (DU) of the orchard irrigation system. This discussion focuses on three issues:

- how the distribution of water throughout the orchard is related through the measurement of DU
- whether the measured distribution should be used as a modifier to increase the average irrigation application to ensure that less of the orchard is under-irrigated while over-irrigating a greater portion of the orchard
- the effect of under- or over-irrigation on orchard production and longevity.

DISTRIBUTION UNIFORMITY

The amount of over- or under-irrigation in an orchard depends on the distribution uniformity of the irrigation application, which is affected by pressure variations in the system, emitter clogging, slope, and other factors. As described in the section "Irrigation System Performance" in *Continuum Level 1.0*, it is essential to evaluate your irrigation system for pressure differential and estimate the distribution uniformity. If your system has low distribution uniformity, determine the causes and solutions to prevent over- and under-irrigation.

- **High DU Example:** Using the example of an average irrigation application of 1.0 inch and a measured DU of 90% (figure 8), the average area of the orchard (the 1/2 point on the graph) receives 1.0 inch (100%) of the target application. At the 1/8 points of the graph, the area of the orchard receiving the least water gets about 12% less water than the average, and the area receiving the most water gets about 12% more than the average.

- **Low DU Example:** Using the example of an average irrigation application of 1.0 inch and a measured DU of 75% (see figure 8), the average area of the orchard receives 1.0 (100%) of the target application. At the 1/8 points on the graph, the orchard receiving the least water is gets 30% less than the average, and the area receiving the most water gets about 30% more than the average.

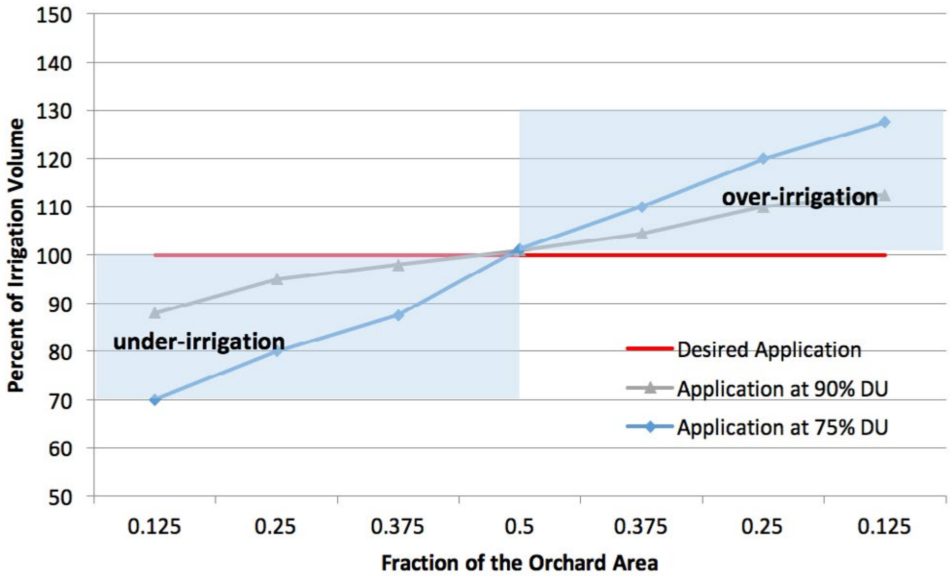


Figure 8. Irrigation distribution across an orchard measured 90 and 75% DU.

USING DISTRIBUTION UNIFORMITY AS A MODIFIER

It is possible to use distribution uniformity to adjust the water application by applying more water to ensure that most of the orchard receives the planned amount of water. The procedure is as follows.

$$\frac{\textit{Orchard Irrigation Water Application}}{\textit{Distribution Uniformity (DU)}} = \textit{Applied Water Application considering DU}$$

- **High DU Example:** An average irrigation application of 1.0 inch at a distribution uniformity of 90% yields 1.11 inches of applied water. This is an 11% increase over the 1.0 inch of water applied if the DU were not a factor (figure 9). However, that 11% is an increase in the average applied, since the distribution of the water is not changed. The 1/8 area of the orchard receiving the least water gets about 3% less than the 1.0 inch target. On the other end of the spectrum, the 1/8th area receiving the most water gets about 24% more than the 1.0 inch target.

- **Low DU Example:** A 1.0 inch average irrigation application at a DU of 75% yields 1.33 inches of water. This is a 33% increase over the 1.0 inch if DU were not a factor (see figure 10). However, that 33% is an increase in the average since the distribution of the water is not changed. The 1/8 area of the orchard receiving the least water gets about 7% less than the 1.0 inch target. On the other end of the spectrum, the 1/8 area receiving the most water gets about 69% more than the 1.0 inch target.

It is a simple fact that increasing the amount of water applied to overcome poor distribution uniformity to assure that less of the orchard is under-irrigated comes at the expense of overwatering the remainder.

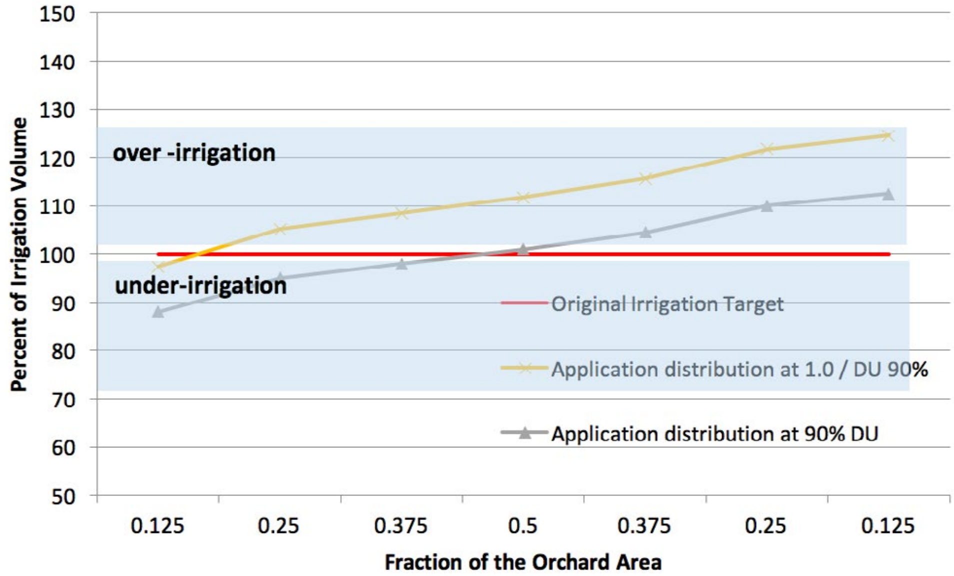


Figure 9. Irrigation distribution across the orchard measured at 90% DU and DU a 1.0 inch application divided by 90% DU.

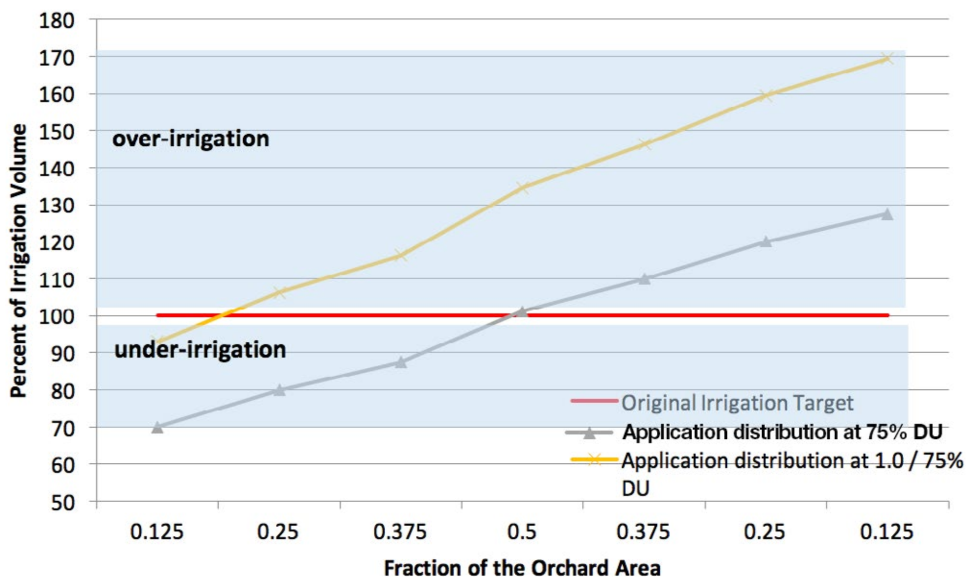


Figure 10. Irrigation distribution across the orchard measured at 75% DU and DU a 1.0 inch application divided by 75% DU.

EFFECT ON ORCHARD PRODUCTION AND LONGEVITY

When using the DU as a modifier, the amount of water going to the lowest-application areas of the orchard approaches the target average application, but the water applied in over-irrigated areas increases—in the case of 75% DU, up to 69% more water than desired (figure 10).

This over-irrigation can cause production losses and reduce orchard longevity. In contrast, if more water is not added to compensate for poor DU, some of the orchard will be under-irrigated. The solution lies in improving DU to a point where there is minimal difference in the over- and under-irrigation levels in the orchard. A DU of about 90% is probably optimal, as research has shown that trees are able to produce optimally with about 90% of full irrigation. Orchards with lower DU should be analyzed to determine the problem and solutions implemented to improve DU.

IRRIGATION WATER AND SOIL SALINITY

All irrigation water contains dissolved mineral salts, but the concentration and composition of the salts depend on the specific water source. Over time, salts can build up in the root zone and can reduce orchard production if not removed by leaching. Salt buildup poses two distinct hazards to almond orchards: the total salt content and the toxic effect of specific salts such as sodium, chloride, and boron.

Excess total salinity creates an osmotic stress, which reduces crop growth by the concentration of dissolved salts in the crop's root zone. The most common positively charged ions, or cations, are calcium, magnesium, and sodium, while the most common negatively charged particles, or anions, are chloride, sulfate, and bicarbonate. To overcome this osmotic stress, plants must expend more energy to absorb water from the saline soil, leaving less energy for plant growth. The more saline the irrigation water, the faster salts build up in the soil, potentially reaching a level which reduces production.

Higher irrigation water salinity requires applying more water than required by normal orchard growth to leach salts below the root zone and maintain production. In areas where irrigation water salinity levels are low or rainfall is high, rainfall may be all that is needed to maintain an acceptable level of salts in the root zone. When salts in irrigation water are higher and coupled with lower rainfall, the irrigation amounts may need to be increased to ensure adequate salt leaching. Additionally, in orchards with poor irrigation distribution uniformity, some areas of the orchard may receive enough water to leach salts, while a greater portion of the orchard gets less than the average amount of water, causing less or no leaching.

The salinity of the water used for irrigation and the salinity of the saturated soil extract is reported as electrical conductivity (EC) in units of decisiemens per meter (dS/m) (which is the same as the older unit, millimho per centimeter, or mmho/cm). The maximum soil salinity that does not reduce yield below that obtained under non-saline conditions is known as the salinity threshold. For almond, this is an average root zone salinity1.5 dS/m. Irrigation water salinity concentrates over time by a factor of 1.5 in the soil when about 15% of the applied water passes through the root zone as deep percolation. Therefore, a water salinity of 1.0 dS/m concentrates to 1.5 dS/m as the average root zone salinity.

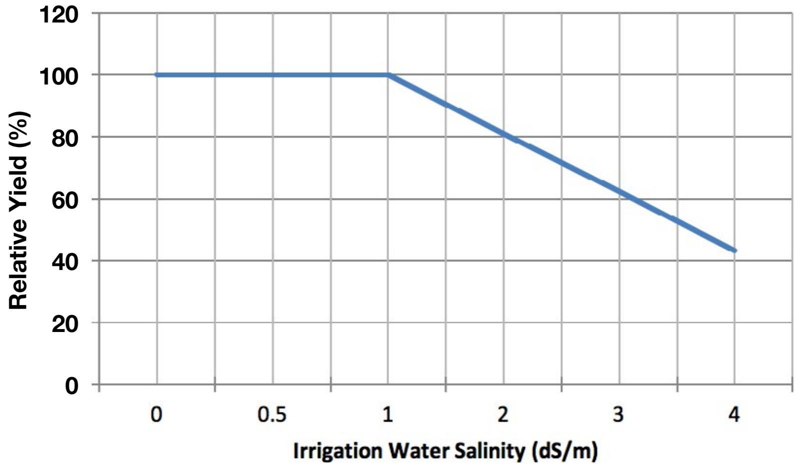


Figure 11. Relative almond yield (percent) as a function of irrigation water salinity (dS/m) assuming a 15% leaching fraction, as defined in Maas and Hoffman 1977.

Figure 11 illustrates the yield response of almond to increasing salinity of the irrigation water using this 1.5 concentration factor.[5] Note that yield is not reduced until the threshold salinity is reached.

To maintain a favorable salt balance, deep percolation of water is needed to transport the salt introduced by the irrigation water out of the root zone. The amount of deep percolation required is referred to as the leaching requirement (LR), and it depends on irrigation water quality as well as the crop sensitivity to salinity, which can vary by rootstock and variety. LR is expressed as a percentage of the applied irrigation water[5]. The leaching requirement is the minimum leaching to prevent yield loss; another common term, "leaching fraction," is the fraction or percentage of water applied to the orchard that actually drains below the root zone.

As the concentration of the salts in the water increases, more salinity is transported into the orchard, and more leaching is required to leach salts below the root zone.

Irrigation water electrical conductivity (dS/m)	Leaching requirement % to maintain root zone salinity at 1.5dS/m
0.25	3
0.50	7
0.75	11
1.00	15
1.20	19
1.50	30

Table 3. Leaching fraction required to maintain average root zone salinity at the threshold with increasing salinity in the irrigation water.

Table 3 gives the leaching requirement expressed as the percentage of crop water use necessary to maintain the average salt concentration in the root zone at the salinity threshold at various irrigation water salinities.

In addition to the effect of salinity on the orchard, elements such as sodium (Na), chloride (Cl), and boron (B) can build up in the root zone and be taken up by the tree to a toxic level, burning the leaves and reducing photosynthesis. Because there are differences in tolerance to these elements among rootstocks and varieties, tissue analysis is the best indicator of the toxic element hazard. Boron and sodium can be leached—just as with total salts—but are more difficult to remove than the other salts.

5. Ayers, R.S. & Westcot, D.W. 1985. Water quality for agriculture. FAO Irrigation and Drainage. Paper No. 29 rev 1., Rome, FAO. http://www.calwater.ca.gov/Admin_Record/C-110101.pdf

LEACHING MANAGEMENT CONSIDERATIONS

- Salinity leaching may not be needed every season.
  - Soil and irrigation water testing will help determine when leaching is necessary or how much is needed.

- Rainfall may adequately reduce salts when it fills the root zone to field capacity and then provides the leaching water requirement.
  - In areas of lower rainfall, early-fall dormant irrigation can recharge the root zone and reduce the rainfall amount required to meet the leaching requirement.

- To the extent possible, time irrigations to leach salinity during fallow or dormant periods. This will avoid critical periods of crop growth and development when nitrogen uptake and fertilization should not be occurring.

- If the root zone starts the season at the salinity threshold, in-season leaching will be necessary to prevent yield loss.

- Poor irrigation distribution uniformity, if used to increase the average application of irrigation water, may achieve the leaching requirement in some parts of the orchard.
  - If a DU of 75% is used, 63% of the orchard would meet or exceed the leaching requirement, while 37% of the orchard would not.
  - If a DU of 90% is used, about half of the orchard would meet or exceed the leaching requirement, while the other half would not.

- The use of partial-coverage irrigation systems—drip and microirrigation—results in nontraditional salt buildup patterns. Typically, the salts build up on the edge of the wetted zone. Leaching with the irrigation system is not as effective as with traditional surface-applied full-coverage systems. Irrigate to fill the root zone near the end of season to leverage effective rainfall. This practice tends to keep accumulated salts moving away from rather than into the root zone.

Determine the applied water required to leach salts from orchards without adequate rainfall using the formula and required information below:

$$\textit{Applied Water} = \frac{ETc}{(1 - LR)}$$

1. Determine the crop water use (ETc) for the orchard with information in the section **"Calculating Orchard Water Use."**

2. Select the leaching fraction (LR) from table 3 based on the irrigation water salinity.

3. Using the following example or your own data, calculate the amount of water required to adequately irrigate the orchard and leach salts.

   EXAMPLE

   ETc = 47.5 in
   EC irrigation water = 1.0 dS/m
   LR = 15% or 0.15 (from table 3)

$$\textit{Applied Water} = \frac{47.5}{(1 - 0.15)} = 55.9 \text{ in}$$

IRRIGATION AND INADEQUATE WATER SUPPLIES

Deficit irrigation is the practice of supplying less water to the orchard than what is required to meet full crop (ETc) water use. Recently, this practice has been employed by growers during the drought, when not enough water was available to meet the needs of the orchard.

Water deficits occur when a tree's water demand exceeds the amount of water available in the soil. These deficits increase water tension within the plant; when this stress is high enough, it negatively affects many plant processes. Unless severe water supply issues are present, deficit irrigation should not be practiced on young orchards.

Deficit irrigation can be done at a proportional deficit at some percentage of full water across the entire season or at specific growth or nut development stages.[6] The method and or timing are usually directed at solving a water supply problem or a specific disease issue, as described in the section "Irrigation and Hull Rot Disease Management," below.

Since deficit irrigation programs are designed to provide a percentage of full water use, accounting for the deficit is straightforward. For example, if conditions dictate that a grower will receive 30% less water than they normally receive (70% of full irrigation), the following formula would apply:

ETc under deficit irrigation = ETc under full irrigation x 0.7

For specific deficit irrigation strategies and their impact on almond growth and yield, see **UC ANR Publication 8515, *Drought Management for California Almonds*.**[7]

IRRIGATION AND HULL ROT DISEASE MANAGEMENT

Hull rot is an infection of almond hulls caused by *Rhizopus stolinifer* or *Monilinia fructicola*. Upon infection, pathogens release toxins that are translocated into the fruiting wood, which kills the wood and causes crop loss. Research conducted in 1990–2000 has shown that incidence of this disease can be reduced with balanced nitrogen applications and hull split deficit irrigation from post–kernel fill through 90% hull split.[8] Properly timed and applied irrigation deficit can reduce hull rot by 80 to 90%. Throughout the duration of the study, the application of this practice did not affect yield or kernel size.

Typically, a 10 to 20% reduction in applied water will be needed, but because this depends on the orchard's soil and irrigation system, it must be determined on an orchard-by-orchard basis[9].

More information on implementing hull split deficit irrigation can be found in the **UC ANR publication 8515, *"Drought Management for California Almonds*,[9]"** which discusses implementation, considerations, and trade-offs associated with deficit irrigation in almonds.

6. Goldhamer, D., and J. Girona. 2012. Almond. In P. Steduto, T. Hsiao, E. Fereres, and D. Raes, eds., Crop yield response to water. FAO Irrigation and Drainage Paper 66:358-373. FAO website, www.fao.org/nr/water/docs/irrigationdrainage66.pdf.
7. Doll, D. and K. Shackel. 2015. Drought Tips, drought Management for California Almonds UCANR publication 8515. http://anrcatalog.ucanr.edu/Details.aspx?itemNo=8515
8. Teviotdale, B, D. Goldhamer, and M. Viveros. 2001. The effects of deficit irrigation on hull rot of almond trees caused by Monilinia fructicola and Rhizopus stolonifer. Plant Disease 85(4): 399-403. ASP Journals website, http://apsjournals.apsnet.org/doi/abs/10.1094/PDIS.2001.85.4.399
9. Doll, D. and K. Shackel. 2015. Drought Tips, drought Management for California Almonds UCANR publication 8515. http://anrcatalog.ucanr.edu/Details.aspx?itemNo=8515

MEETING THE ORCHARD WATER REQUIREMENT

The orchard water requirement is met by the available soil moisture stored in the root zone at the beginning of the season plus in-season rainfall stored in the soil (including frost protection water applications if stored in the root zone), and applied irrigation water.

Rainfall that enters the root zone for orchard use tends to occur in the first few months of the season, and stored soil moisture is at a maximum at the beginning of the season. It is not uncommon for rainfall and stored soil moisture to meet the entire crop water use in the first month and from 15 to 35% on a seasonal basis. The remainder of the orchard water requirement must come from irrigation.

ACCOUNTING FOR IN-SEASON RAINFALL AND SOIL STORED MOISTURE IN THE IRRIGATION SCHEDULE

Rainfall can be an important source of water for almond orchards in California. Depending on location, rain provides from very little to a significant amount of the water available to the orchard. The amount of rain actually used by orchard, called effective rainfall or effective precipitation, is largely influenced by climate and root zone soil characteristics.

ESTIMATING IN-SEASON EFFECTIVE RAINFALL

For areas likely to experience significant rainfall during the season the following method is suggested to estimate the effective rainfall in a given rainfall event. A rainfall event can be a single day or multiple sequential days of rainfall. CIMIS data can be obtained from the **California Irrigation Management Information System (CIMIS) website.**

Effective Rainfall (in) = (Rainfall (in) from event—3 days of ETo (in) after the event) x 0.75

EXAMPLE 1

Merced CIMIS Station 148, April 8–10, 2016: 2.65 inches of rain

EXAMPLE 2

Shafter CIMIS Station 5, April 7–10, 2016: 1.01 inches of rain

ESTIMATING SOIL-STORED WINTER RAINFALL

Winter rain can help meet part of the water use of orchards, because rainwater can infiltrate the soil and remain there as stored soil-water until the following growing season. Relatively involved techniques have been developed to account for winter rains stored in the soil when determining crop evapotranspiration (ETc).[10] However, a field measurement program was conducted by the California Department of Water Resources to validate the techniques of estimating the effectiveness of winter rains.[11] The study was designed to determine the broad relationships between monthly amounts of winter rain and the portion stored in the soil and available for crop use during the following growing season. Total monthly rainfall and the corresponding change in soil water content were measured during the winter at about 10 sites in the Central Valley of California. The 4-year study, started in 1983, drew several important conclusions.

First, the relationship between total rainfall and change in soil water content is remarkably similar for November, December, January, and February. The relationship is

Change in stored soil water = –0.54 + 0.94 x (rainfall amount).

The second conclusion was that the soil water content increases linearly with increased monthly rainfall for each of the four months.

Third, soil surface evaporation is relatively constant, at 0.6 to 0.8 inches per month. The DWR report also concluded that in October, when the soil is initially dry, both the amount of stored soil water and the amount of evaporation from the soil surface increase with increasing amounts of total monthly rain. The relationship for October is

Change in stored soil water = –0.06 + 0.635 x (rainfall amount).

In contrast, for March and April, when the initial soil water content is generally high and evaporative demand is also high, surface evaporation rates are twice those for the four winter months, and the amount of rain going to stored soil water is correspondingly low. The relationship for March is

Change in stored soil water = –1.07 + 0.837 x (rainfall amount).

10. Allen, R. G., J.L. Wright, W. O. Pruitt, L. S. Pereira, and M. E. Jensen. 2007. Chapter 8. Water Requirements. In: Hoffman, G. J., R. G. Evans, M. E. Jensen, D. L. Martin, and R. L. Elliot (eds.) 2nd Edition, Design and Operation of Farm Irrigation Systems. Amer.Soc. Biol. Agric. Eng., St. Joseph, Michigan, 863 p.
11. N.A. MacGillivray, Milton D. Jones. Department of Water Resources, Central District, San Joaquin District. Effective precipitation: a field study to assess consumptive use of winter rains by spring and summer crops. Sacramento, CA: The Dept., [1989].

	Oct	Nov-Feb	Mar-April
Rainfall	Effective Rainfall		
in	in	in	in
1	0.6	0.4	-0.2
2	1.2	1.3	0.6
3	1.8	2.3	1.4
4	2.5	3.2	2.3
5	3.1	4.2	3.1
6	3.8	5.1	4.0

Table 4. The estimated effective rainfall by month for each inch of rainfall.

Using these relationships effective rainfall was calculated for each inch of rainfall and each month (table 4.)

Effective rainfall was calculated based on these relationships and average rainfall data for seven valley locations (table 5). This table provides a good starting point for planning an irrigation schedule; however, actual winter data will provide the data needed to implement the schedule.

An additional complication with stored water relates to the capacity of the root zone to retain the rainfall. Controlling factors of root zone water-holding capacity include soil texture and structure, root extensiveness, and root zone depth.

	Arbuckle		Bakersfield		Chico		Dixon		Fresno		Merced	
	Rain	Effective Rainfall	Rain	Effective Rainfall	Rain	Effective Rainfall	Rain	Effective Rainfall	Rain	Effective Rainfall	Rain	Effective Rainfall
	Inches											
Oct	0.97	0.56	0.31	0.14	1.42	0.84	1.20	0.70	0.67	0.37	0.83	0.47
Nov	2.13	1.46	0.63	0.05	3.27	2.53	2.94	2.22	1.18	0.57	1.34	0.72
Dec	2.99	2.27	1.02	0.42	4.61	3.79	4.75	3.93	2.01	1.35	2.09	1.42
Jan	3.91	3.14	1.14	0.53	4.84	4.01	4.82	3.99	2.28	1.60	2.60	1.90
Feb	3.00	2.28	1.22	0.61	4.41	3.61	4.76	3.93	2.01	1.35	2.36	1.68
Mar	2.47	1.00	1.22	0.00	4.29	2.52	3.30	1.69	2.48	1.01	2.09	.068
		10.70		1.75		17.30		16.47		6.24		6.87

Table 5. Average rainfall and effective rainfall for seven Central Valley locations. (Source: usclimatedata.com)

Determining the soil moisture stored in the tree's root zone is important information for good irrigation water management. Stored soil moisture serves as a bank account of water available for the orchard. As the trees "withdraw" water from the stored soil moisture bank account, irrigation "deposits" must be made throughout the growing season to maintain available water in the account. Maintaining available water in the root zone provides the orchard with a cushion in case of under-irrigation due to management miscalculations, equipment failure, or other factors that affect the availability of water.

Growers should evaluate soil moisture based on feel and appearance of the soil and monitoring on a monthly basis to inform irrigation management decisions. Stored soil moisture is accessed by the trees' roots and is withdrawn to satisfy the tree water needs; this should be accounted for in irrigation decision-making.

Soil texture	Plant-available water-holding capacity (in. of water per ft. of soil)	
Very coarse sand	0.4	–0.75
Coarse sand, fine sand, loamy sand	0.75	–1.25
Sandy loam, fine sandy loam	1.25	–1.75
Very fine sandy loam, loam, silt loam	1.50	–2.30
Clay loam, silty clay loam, sandy clay loam	1.75	–2.50
Sandy clay, silty clay, clay	1.60	–2.50

Table 6. Plant-available water holding capacities of various textured soil. (Source: Adapted from: Schwankl and Prichard. 2009.)

Use the information presented in the section **"Soil Moisture"** to determine the extent of the root zone and its estimated water-holding capacity. Then compare the effective rainfall with the root zone capacity. The amount of stored moisture must not exceed the maximum root zone capacity, regardless of the amount of effective rainfall.

Table 7 shows the plant-available water held by soils of different texture when fully wet. Plant-available water is the amount of water stored in the soil that plants can take up. Technically, it is the difference in soil water content between field capacity and the permanent wilting point. Since some water is held so tightly by the soil that plants cannot take it up, available water content is less than the total amount of water held in soil.

ESTIMATING SOIL STORED WINTER RAINFALL EXAMPLE

LOCATION AND CONDITIONS

- Merced, CA: Mature trees; loam soil; solid-set sprinkler irrigation; root zone depth 4 feet
- Water holding capacity = 2.0 inches of water per foot (from table 6)
- Root zone water holding capacity:
- Root zone depth = 4 ft x 2.0 inches water = 8.0 inches plant-available water
- Effective rainfall: Merced, average year 6.9 inches (from table 5)
- Estimating Root Zone Water-Holding Amount

Since the average effective rainfall does not exceed the estimated root zone water-holding capacity, use 6.9 inches as the estimated root zone water-holding amount.

If a postharvest irrigation was applied, the unused portion can be added to the effective rainfall. Additionally, irrigation water applied in the off season and water applied for frost protection can also be a source of stored soil moisture and can be added to the root zone water amount if the root zone's capacity is not exceeded.

USING EFFECTIVE RAINFALL AND SOIL STORAGE IN AN IRRIGATION SCHEDULE

Effective rainfall and stored soil moisture can be a significant source of water that should be accounted for in an irrigation schedule. In almond-growing regions of the northern San Joaquin Valley and the Sacramento Valley, where rainfall is relatively higher, effective rainfall can commonly contribute from 10 to 35% of the seasonal crop water use, depending on orchard soil and root characteristics. Simple steps to account for the effectiveness of rainfall and soil storage to partially supply the crop water use are outlined below.

The procedure begins with calculating the orchard water use as modified by the distribution uniformity and any necessary leaching fraction, as discussed in the above sections.

Once the orchard water requirement is determined, account for the contribution from in-season effective rainfall and stored moisture, both of which reduce the irrigation amount.

ACCOUNT FOR IN-SEASON EFFECTIVE RAINFALL

Subtract the effective in-season rainfall from the estimated orchard water requirement (see the sections above) for each irrigation calculation period—for example, monthly.

ACCOUNT FOR STORED SOIL MOISTURE FROM WINTER RAINFALL

About 50% of the plant-available water stored in the root zone can be used before tree stress begins. It is good practice to maintain the soil moisture no lower than that level to avoid plant water stress, especially early and in midseason, during tree growth and nut sizing. If water stress is desired for hull split and disease management later in the season, the soil moisture level must be kept below this level. In the case above, the 6.9 inches would be reduced by half, to 3.45 inches. If used over a three-month period, the amount would be about 1.2 inches per month. Table 7 shows the accounting for effective rainfall (in 2016) and soil-stored moisture based on our example conditions above in determining the irrigation schedule.

Zone 12	Merced	2016		
	OWR* (in)	Effective rainfall (in)	Stored moisture (in)	Irrigation application (in)
March	2.1	3.0	0.0	0.0
April	4.1	1.9	1.2	1.1
May	6.4	0.0	1.2	5.3
June	8.2	0.0	1.2	7.1
July	8.9			
August	7.9			
September	5.7			
October	3.4			
Half Nov	0.6			
Season	47.4			
Mar–June	20.8	4.9	3.5	13.4
Note: *Orchard water requirement.				

Table 7. Accounting for in-season rainfall and stored moisture using 2016 Merced conditions and zone 12 monthly orchard water requirements.

In our Merced example, the irrigation water application was reduced by 40% from March through June, or by 17.6% on a seasonal basis. Rainfall varies between different almond-growing regions of the Central Valley, and the amount of the rainfall contribution can be more or less than this example.

Determine the difference between the estimated crop water use and the effective rainfall and available soil storage:

Estimated orchard water requirement—Effective rainfall—Available moisture = Irrigation application

This is the estimated amount of water that will need to be allocated throughout the growing season using timely, efficient irrigation.

NEXT STEPS

Once the estimated orchard water requirements of a specific orchard have been determined, use the irrigation system application rate to determine the appropriate irrigation system operation time. **"Irrigation System Performance"** section provides guidance to measure the system application rate and distribution performance.

MOVING UP THE CONTINUUM

1.0 Orchard Water Requirements practices rely on monthly estimates of orchard water use to develop an irrigation schedule. To improve upon that, 2.0 practices use a biweekly time that allows for anticipation of lower ET in the first 2 weeks on the month of water use in contrast to the last 2 weeks (from leaf out to midseason). The opposite is found from midseason to leaf drop. "Orchard Water Requirements" in *Continuum Level 3.0* moves the time to weekly and accounts for over- and under-estimation of ET and irrigation applications, as well as for any application errors in subsequent irrigations.

IRRIGATION SYSTEM PERFORMANCE

1.0 Practice: Evaluate irrigation system for pressure variation and average application rate at least once every 3 years. Correct any diagnosed system performance problems.

INTRODUCTION

Up-to-date irrigation system performance information is essential in irrigation water management. An orchard's irrigation system should be evaluated at a minimum of every 3 years. The two important steps required for good irrigation water management are knowing how much water needs to be applied and operating the irrigation system to apply that desired amount.

Before you take steps to personally evaluate your irrigation system, check to see if there is a mobile irrigation lab in your area. These mobile labs are sponsored by a local agency (county, resource conservation district, water district, etc.) in partnership with the California Department of Water Resources. They are experts in irrigation system evaluation and will do the evaluation for minimal or no charge. Currently there are 12 to 15 mobile labs working in California, 5 in the Central Valley. Commercial companies in your area may also do irrigation system evaluations for a fee.

To operate a given irrigation system for the correct amount of time, two important irrigation system performance criteria are needed:

1. application rate, measured in inches/hour
2. a measure of how evenly or uniformly water is applied

For more information on determining the irrigation system application rate and uniformity, refer to the system-specific information on the following pages: surface (flood or furrow) irrigation systems, **page 23**; sprinkler irrigation systems, **page 25**; microirrigation (drip/microsprinkler) systems, **page 32**.

SURFACE IRRIGATION SYSTEMS

INTRODUCTION

Surface irrigation systems include furrow and border strip systems. Border strip systems that flood the area between tree rows (middles) are more common in almonds, but irrigation is also done using a number of furrows paralleling the tree rows.

Determining the application rate and especially the application uniformity of surface irrigation systems is very difficult and is almost always done by a professional irrigation system evaluator. A grower can determine how much water is applied during an irrigation set, an important piece of water management information.

INFORMATION TO GATHER

Determining the amount of applied water during an irrigation set requires knowing:

- flow rate to the orchard
- orchard area irrigated during the set
- irrigation set time (duration)

DETERMINING THE VOLUME OF WATER APPLIED

With the above information, use one of the following formulas to determine the applied water (inches; abbreviated as 'in') during the irrigation set.

$$\frac{\left(\begin{matrix}\text{Flow Rate to}\\ \text{Orchard (gpm)}\end{matrix}\right) \times \left(\begin{matrix}\text{Irrigation Set}\\ \text{Time (min)}\end{matrix}\right)}{\text{Orchard Area Irrigated (ft}^2\text{)}} = \text{Applied Water (in)}$$

$$\frac{\left(\begin{matrix}\text{Flow Rate to}\\ \text{Orchard (gpm)}\end{matrix}\right) \times \left(\begin{matrix}\text{Irrigation Set}\\ \text{Time (min)}\end{matrix}\right)}{\text{Orchard Area Irrigated (acres)}} \div 27{,}152 = \text{Applied Water (in)}$$

Water may also be applied to the orchard measured in acre-inches (ac-in). To determine the inches of water applied, use the following formula:

$$\frac{\text{Water Applied (ac – in)}}{\text{Orchard Area Irrigated (ft}^2\text{)}} = \text{Applied Water (in)}$$

Note that the following conversions may be helpful in working through the formulas above:

- 1 acre = 43,560 ft^2
- 1 cubic foot per second (cfs) = 449 gallon per minute (gpm)

In addition to water applied, if runoff from the orchard is reused somewhere else on the property, the runoff volume should be removed from the total water applied during the irrigation. It is often extremely difficult to measure the runoff volume, so an estimate may need to be made. Previous studies have shown that a reasonable estimate of the runoff volume is 15-20% of the applied water (see **Reducing Runoff from Irrigated Lands: Tailwater Return Systems, by L. Schwankl, et al., UC ANR Publication 8225, 2007**).

NEXT STEPS

Compare the amount of irrigation water applied with the estimated orchard water use as described in the **"Orchard Water Requirements"** section. This can be done after each irrigation event or on an annual basis. If you find that you are applying significantly more irrigation water than is needed to meet the orchard's water needs, strongly consider a professional system evaluation to improve your irrigation practices.

MOVING UP THE CONTINUUM

Moving up to the intermediate practices described in "Irrigation System Performance" in *Continuum Level 2.0* involves estimating the irrigation distribution uniformity in addition to measuring the applied water.

For surface irrigation systems, measuring the distribution uniformity is complicated and will require the assistance of an irrigation system evaluation professional. In some areas, a mobile lab team may be available to provide assistance. If you have access to a mobile lab, take advantage of their services.

SPRINKLER IRRIGATION SYSTEMS

Figure 1. Impact sprinkler. (Photo by L. Schwankl)

Figure 2. Rotator-type sprinkler. (Photo by T. Prichard)

Two types of sprinkler irrigation systems are used in almond orchards: impact sprinklers (figure 1) and rotator-type sprinklers (figure 2). These types of sprinklers will be discussed separately, as pressure measurement techniques vary between the two. Please consult the sections below that apply to your system(s).

Pressure measurements can be taken relatively quickly and easily in sprinkler irrigation systems. These measurements allow you to determine the irrigation application rate (most often measured in inches/hour) and give you an indication of the application uniformity.

IMPACT SPRINKLERS

INFORMATION TO GATHER

The following information should be gathered and recorded for orchards irrigated with impact sprinklers.

1. Spacing between sprinklers in a tree row and spacing between sprinklers across the tree row.
2. At each sprinkler sampled, the nozzle orifice size should be determined and the operating pressure measured.

WHEN TO TAKE MEASUREMENTS

It is recommended that the sprinkler system be evaluated at a minimum every 3 years. The evaluation can be done at any time during the irrigation season.

Before any measurements are taken in the orchard, the filters (if any), mainlines, and submains should be flushed to ensure that the sprinkler system is working optimally. If sprinklers need to be cleaned, this should be done at this time.

The objective in gathering the pressure measurements is to characterize the pressure for the orchard or irrigation set as a whole. Pressure measurements should be taken at (figure 3):

- The head (pump or highest point in the system), middle, and tail end of the orchard or irrigation set.
- The head, middle and tail end of sprinkler lateral lines.
- If there are high- or low-elevation areas in the orchard or irrigation set, extra measurements may be needed in those locations. Equally distribute these additional measurements between high and low elevation locations so that the measurements are not biased.

Since the sprinkler system mainlines, submains, and lateral lines are most often below ground, having an irrigation system layout plan or map is extremely useful in planning where to take measurements and for recording where measurements were taken. If it is known that some sprinkler lateral lines are longer than others, measure the pressure on the longer lines, since the pressure loss will be greater in these laterals.

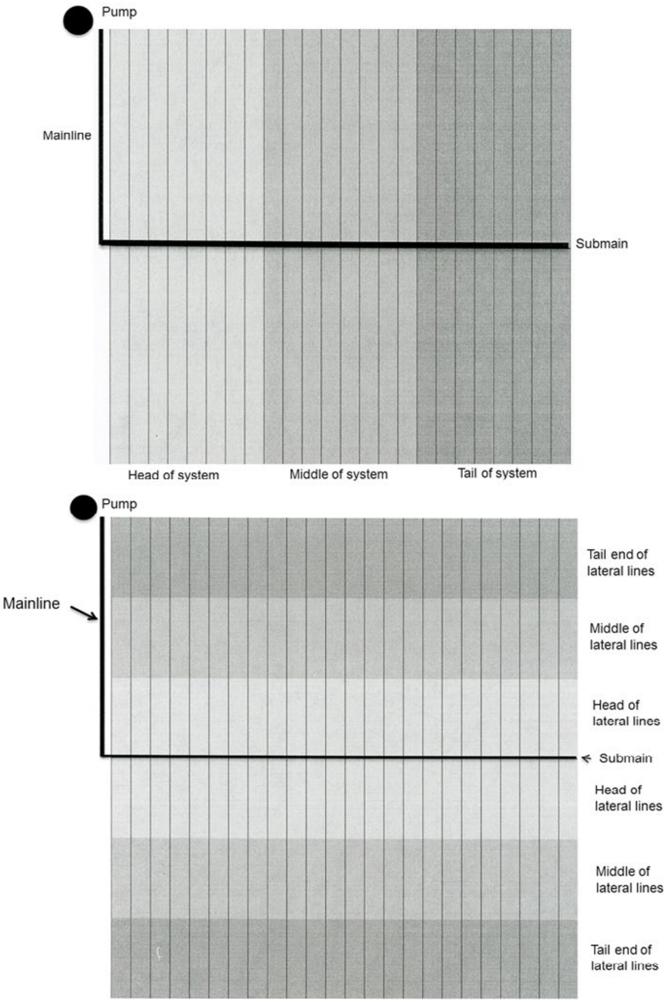


Figure 3. Irrigation system pressure measurements should be taken at a variety of locations within the system. Use the descriptions above to understand how these relate to your setup. (Source: L. Schwankl)

When the pressure is measured at a sprinkler head, the record of its location should be good enough that the same sprinkler could be located and remeasured at a later date. Spray painting the sprinkler riser can assist in locating the sprinkler in the future.

HOW MANY SPRINKLERS TO SAMPLE?

As with all sampling, the answer to how many samples should be collected is that more is always better. At a minimum, 30 to 40 sprinklers should be sampled, even on a small-acreage orchard. As the acreage increases, use the guideline of two or more sprinklers sampled per acre.

If when sampling it becomes evident that there is significant variability between sprinkler pressures, consider increasing the number of sprinklers sampled. Additional sampling increases the probability of diagnosing the cause of the variability. If the sprinkler pressure variability seems to be associated with high- or low-elevation areas of the orchard, additional sampling of sprinkler pressure in those areas is warranted.

SPRINKLER NOZZLE ORIFICE SIZE

Orchards are most often designed to have the same sprinkler nozzle size throughout. However, do not simply assume that this is true for your orchard. For older sprinkler systems, it is not uncommon for sprinklers to have been replaced during maintenance and substituted with nozzle sizes other than the design size.

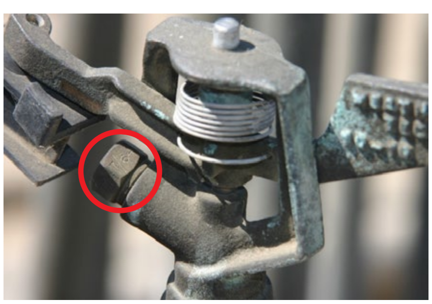


Figure 4. Impact sprinkler nozzle size is often stamped onto the size of the nozzle. On this sprinkler it is noted as "7/64" and circled in red. (Photo by L. Schwankl)

The size of brass nozzles is often stamped on the side of the nozzles (figure 4). This can be very difficult to see, especially in the field, so using a set of drill bits to determine the orifice size is often easier. The correct size bit should just fit into the orifice; keep that drill bit handy, as it can be used to quickly check each sprinkler sampled.

Figure 5. A pitot tube fitted with a pressure gauge works well for taking sprinkler pressure measurements. (Photo by L. Schwankl)

Figure 6. Water pressure is read by positioning the pitot tube directly in the sprinkler's water stream. (Photo by L. Schwankl)

MEASURING SPRINKLER OPERATING PRESSURE

The easiest way to measure the operating pressure of an impact sprinkler is to use a pressure gauge fitted with a pitot tube (figure 5). The pitot tube is a small, curved, hollow brass tube that should be available for purchase from your local irrigation equipment supplier. A 0–60 psi or a 0–100 psi liquid-filled pressure gauge works well for taking the measurements.

It is recommended that the same new pressure gauge be used to measure all the pressures when sampling. A new pressure gauge is advantageous because pressure gauges often become less accurate with use. If multiple pressure gauges are to be used, confirm that they all read the same pressure by measuring a single location with each gauge.

Once fitted with a pressure gauge, hold the pitot tube in the water stream just outside the sprinkler nozzle and read the pressure on the gauge (figure 6). Move the pitot tube around in the water stream until the maximum pressure is noted. With practice, the pressure can be measured at a sprinkler head in only a few seconds. When the measurement is taken, record its location within the orchard on an orchard plot map or write a good description of its location.

USING PRESSURE MEASUREMENTS AS A UNIFORMITY INDICATOR

The variability of the pressure measurements is an indicator of the uniformity of sprinkler discharge in the orchard. High variability between sprinkler pressures leads to over-application of water in areas of higher pressure and under-irrigation in areas of lower pressure. While this guide provides recommendations for 1.0 minimum practices, growers can further improve their practices by consulting the "Irrigation System Performance" section in *Continuum Level 2.0* and *Level 3.0* recommendations, which require increased frequency and detail in monitoring and improvement.

If there is more than a 20% difference between pressure readings, it is likely that the application uniformity is not as good as desired; consult an irrigation professional who may be able to make recommendations to improve the pressure uniformity.

DETERMINING THE AVERAGE APPLICATION RATE

A sprinkler system's average application rate is critical information for applying the correct amount of water. The sprinkler application rate is measured in inches per hour (in/hr), so it can be easily calculated with almond orchard water use estimates that are usually provided in inches. With the sprinkler nozzle orifice size and the operating pressure collected using the guidance above, use the figure below (figure 7) to determine the sprinkler discharge rate (gpm) for each sprinkler measured.

Nozzle size (in)	Pressure (psi)							
	30	35	40	45	50	55	60	65
	Discharge rate (gpm)							
3⁄32	1.7	1.5	1.6	1.7	1.8	1.9	2.0	2.1
7⁄64	1.9	2.0	2.2	2.3	2.4	2.6	2.7	2.8
1⁄8	2.5	2.7	2.9	3.1	3.2	3.4	3.6	3.7
9⁄64	3.1	3.4	3.6	3.8	4.1	4.2	4.4	4.6
5⁄32	3.9	4.2	4.5	4.7	5.0	5.2	5.5	5.8
11⁄64	4.7	5.1	5.4	5.7	6.1	6.3	6.6	6.9
3⁄16	5.6	6.0	6.4	6.8	7.2	7.6	7.9	8.2
13⁄64	6.5	7.1	7.6	8.1	8.5	9.2	9.2	9.5

Figure 7. Sprinkler discharge rates can be determined with measured nozzle orifice size and operating pressure. (Source: UC ANR Publication 3527)

If colored plastic sprinkler nozzles (e.g., from Nelson Rotator sprinklers) are used instead of brass nozzles, visit the manufacturer's website to get the nozzle discharge rate for the field-measured operating pressure.

Note that as the pressure goes up, the sprinkler discharge also goes up. The reverse also holds true. If sprinklers in an area of the orchard consistently have lower pressures, and therefore lower sprinkler discharges, that section of the orchard will be underirrigated compared with orchard areas with higher pressures.

Use the following steps to determine the average application rate (in/hr) for orchards irrigated with impact sprinklers.

1. Average the sprinkler discharge rates (gpm) of all the sprinklers sampled.
2. With the tree spacing information collected at the beginning of this section, use the following formula to determine the average application rate for the orchard.

$$\left(\begin{array}{c}\text{Average Sprinkler}\\ \text{Application}\\ \text{Rate (in/ft)}\end{array}\right) = \frac{96.3 \text{ x (Sprinkler discharge – gym)}}{\left(\begin{array}{c}\text{Sprinkler spacing}\\ \text{in the tree row (ft)}\end{array}\right) \text{ x } \left(\begin{array}{c}\text{Sprinkler spacing}\\ \text{across the tree row (ft)}\end{array}\right)}$$

NEXT STEPS

1. The average application rate is a very important piece of information regarding your sprinkler system. Keep it handy, since it will be used extensively when scheduling irrigations. It should not change significantly unless the pressure in the system changes. If you have filters in the system, be sure to keep them flushed and clean, since they are a frequent source of pressure loss.

2. Variability in measured pressures in the orchard greater than 20% can cause significant irrigation application nonuniformity. Consider calling in an irrigation professional to see what is causing the differences and what can be done to improve it.

3. Recheck your sprinklers every 3 years. It is recommended that you recheck the same sprinklers originally evaluated. This will provide an excellent measure of any changes that may have occurred. Consider measuring additional sprinklers to provide even better information.

MOVING UP THE CONTINUUM

Moving up to the intermediate practices described in the section "Irrigation System Performance" in *Continuum Level 2.0* involves a closer look at evaluating the sprinkler information collected and addresses how to account for the sprinkler discharge rate variability.

ROTATOR SPRINKLERS

INFORMATION TO BE GATHERED

The following information should be gathered and recorded for orchards irrigated with rotator sprinklers.

1. Spacing between sprinklers in a tree row and spacing between sprinkler lines across the tree row.
2. At each sprinkler sampled, note the model of the Rotator sprinkler (e.g., R5, R10), the color of the top plate deflector, the color of the nozzle in the sprinkler, and the operating pressure measured.

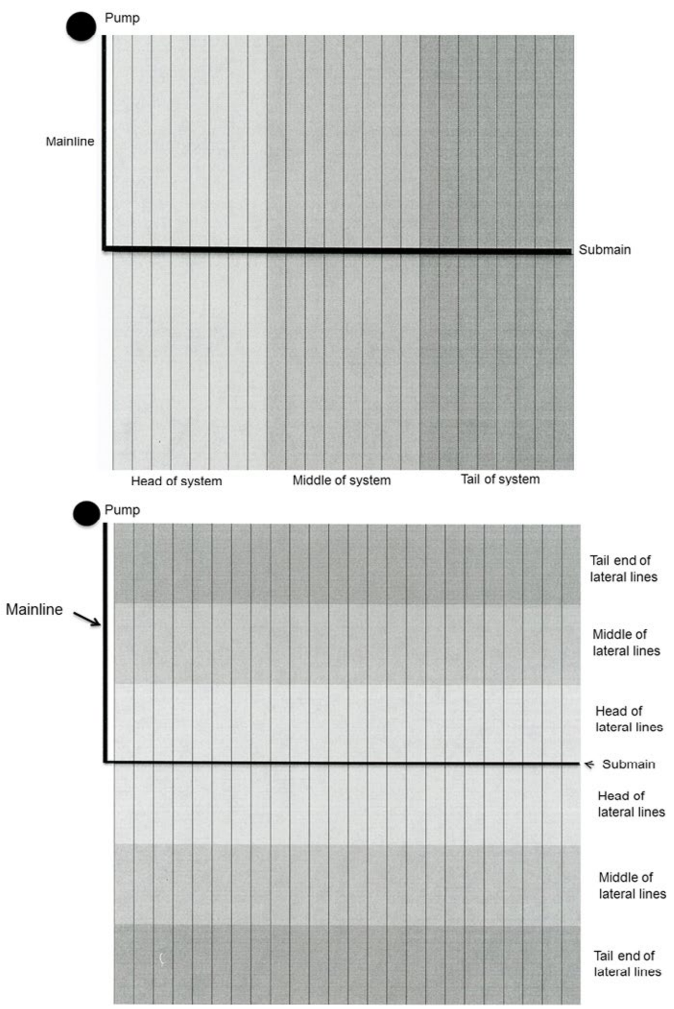


Figure 8. Irrigation system pressure measurements should be taken at a variety of locations within the system. Use the descriptions above to understand where these are relative to your setup. (Source: L. Schwankl)

WHEN TO TAKE MEASUREMENTS

It is recommended that the sprinkler system be evaluated at a minimum every 3 years. The evaluation can be done at any time during the irrigation season. Before any measurements are taken in the orchard, the filters (if any), mainlines, and submains should be flushed to ensure that the sprinkler system is working optimally. If sprinklers need to be cleaned, this should be done.

The objective in gathering the pressure measurements is to characterize the pressure for the orchard or irrigation set as a whole. Pressure measurements should be taken at (figure 8):

- The head, middle, and tail end (from the pump or head of the system) of the orchard or irrigation set.
- The head, middle, and tail end of sprinkler lateral lines.
- If there are high or low elevation areas in the orchard, extra measurements may be needed in those locations. Distribute these additional measurements equally between high- and low-elevation locations so that the measurements are not biased.

Since the sprinkler system mainlines, submains, and lateral lines are most often below ground, having an irrigation system layout map is extremely useful in planning where to take measurements and for recording where measurements were taken. If it is known that some sprinkler lateral lines are longer than others, measure the pressures on the longer lines, since the pressure loss will be greater in these laterals.

When the pressure is measured at a sprinkler head, the record of its location should be good enough that the same sprinkler could be located and remeasured at a later date. Spray painting the sprinkler riser can assist in locating the sprinkler in the future.

HOW MANY SPRINKLERS TO SAMPLE?

As with all sampling, the answer to how many samples should be collected is that more is always better. At a minimum, 30 to 40 sprinklers should be sampled, even on a small-acreage orchard. As the acreage increases, sample two or more sprinklers per acre.

If it becomes evident that there is significant variability between sprinkler pressures, consider increasing the number of sprinklers sampled. Additional sampling increases the probability of diagnosing the cause of the variability. If the sprinkler pressure variability seems to be associated with high- or low-elevation areas of the orchard, additional sampling of sprinkler pressure in those areas is warranted.

MEASURING SPRINKLER OPERATING PRESSURE

Because of the rotator sprinkler design, pressure cannot be measured using the simple method described for impact sprinklers. Instead, remove the rotator sprinkler head and install a pressure gauge fitted with the same thread configuration as a sprinkler head to determine the operating pressure. A 0–60 psi or 0–100 psi liquid-filled pressure gauge works well for taking the measurements. Many rotator sprinklers have Acme threads, which allow for rapid installation and removal; in that case, use and adaptor on the pressure gauge.

Use the same, new pressure gauge to measure all the pressures when sampling. A new pressure gauge is advantageous because pressure gauges often become less accurate with use. If multiple pressure gauges are to be used, confirm that they all read the same by measuring a single location with each gauge.

USING PRESSURE MEASUREMENTS AS A UNIFORMITY INDICATOR

The variability of the pressure measurements is an indicator of the uniformity of sprinkler discharge in the orchard. High variability among sprinkler pressures leads to overapplication of water in areas of higher pressure and underirrigation in areas of lower pressure. While this guide provides recommendations for 1.0 minimum practices, growers can further improve their practices by consulting “Irrigation System Performance” in *Continuum Level 2.0* and *Level 3.0* recommendations which require increased frequency and detail in monitoring and improvement.

If there is more than a 20% difference between pressure readings, it is likely that the application uniformity is not as good as desired. Pressure variability greater than 20% can result in significant irrigation application nonuniformity and is cause to consult an irrigation professional who may be able to make recommendations to improve the pressure uniformity.

DETERMINING THE AVERAGE APPLICATION RATE

With the sprinkler nozzle color and the operating pressure, [visit the Nelson Irrigation online Rotator Technology Pocket Guide] to get the nozzle color, pressure, and flow rate for the sprinkler model being evaluated. For example, the figure below is for the R2000 model sprinkler (figure 9). The tables available from Nelson Irrigation are provided in pressure increments of 5 psi, so interpolation will be required to determine the sprinkler discharge rate.

Plate/Nozzle Options and Flow Performance in GPM and LPH

Plate Series	Plate Options	Recommended Nozzles	PSI 30	35	40	45	50	55	60	BAR 2.0	2.5	3.0	3.5	4.0
K1	K1 6° Cream Radius: 21-25' (6.4-7.6 m) Stream Ht.: 15-25" (38-64 cm)	Gray #8.3	.67	.72	.77	.82	.86	.90	.94	150	166	183	197	210
		.85 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the .85 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of .85 GPM (193 LPH).											
K2	K2 6° Light Blue Radius: 22-26' (6.7-7.9 m) Stream Ht.: 15-32" (38-81 cm)	White #9	.77	.83	.89	.94	1.00	1.05	1.10	172	192	210	229	245
		Dark Blue #10	.97	1.05	1.12	1.19	1.25	1.31	1.37	217	242	266	286	306
		1.0 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 1.0 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 1.0 GPM (227 LPH).											
	K2 9° Green Radius: 23-27' (7.0-8.2 m) Stream Ht.: 18-37" (46-94cm)	Gray #8.3	.67	.72	.77	.82	.86	.90	.94	150	166	183	197	210
		White #9	.77	.83	.89	.94	1.00	1.05	1.10	172	192	210	229	245
	K2 15° Yellow Radius: 27-30' (8.2-9.1 m) Stream Ht.: 31-55" (79-140 cm)	Dark Blue #10	.97	1.05	1.12	1.19	1.25	1.31	1.37	217	242	266	286	306
		.85 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the .85 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of .85 GPM (193 LPH).											
		1.0 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 1.0 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 1.0 GPM (227 LPH).											
K3	K3 9° Brown Radius: 25-28' (7.6-8.5 m) Stream Ht.: 19-33" (48-84 cm)	Orange #11	1.17	1.27	1.36	1.45	1.53	1.61	1.68	261	294	323	350	375
		Purple #12	1.39	1.50	1.61	1.70	1.80	1.89	1.98	311	347	380	412	442
	K3 15° Red Radius: 27-31' (8.2-9.4 m) Stream Ht.: 38-63" (97-160 cm)	1.25 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 1.25 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 1.25 GPM (284 LPH).											
	K3 24° Gray Radius: 29-35' (8.8-10.7 m) Stream Ht.: 68-103" (173-262 cm)	1.5 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 1.5 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 1.5 GPM (341 LPH).											
K4	K4 6° Turquoise Radius: 21-25' (6.1-7.6 m) Stream Ht.: 10-24" (25-61 cm)	Yellow #13	1.64	1.78	1.90	2.02	2.13	2.23	2.34	366	411	451	487	521
		Green #14	1.85	2.00	2.15	2.28	2.40	2.53	2.64	413	463	509	550	590
	K4 9° Purple Radius: 26-32' (7.9-9.4 m) Stream Ht.: 28-42" (71-107 cm)	1.5 2000 FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 1.5 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 1.5 GPM (341 LPH).											
		2.0 2000 FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 2.0 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 2.0 GPM (454 LPH).											
	K4 12° Wine Radius: 27-31' (8.2-9.4 m) Stream Ht.: 32-51" (81-130 cm)													
	K4 15° Gold Radius: 27-33' (8.2-10.1 m) Stream Ht.: 40-60" (102-152 cm)													
	K4 24° Black Radius: 28-36' (8.5-11.0 m) Stream Ht.: 65-100" (165-254 cm)													
K5	K5 9° Orange Radius: 27-31' (8.2-9.4 m) Stream Ht.: 25-42" (54-107 cm)	Tan #15	2.17	2.35	2.53	2.67	2.82	2.97	3.11	485	544	597	647	695
		Dark Red #16	2.50	2.70	2.89	3.07	3.23	3.40	3.54	559	624	685	739	792
	K5 15° Tan Radius: 31-36' (9.4-11.0 m) Stream Ht.: 36-49" (91-124 cm)	2.5 2000FC	Within the recommended pressure range of 30-60 PSI (2.0-4.0 BAR), the 2.5 2000 FC flow control nozzle is flow regulating within a flow range of no more than 3.5% greater and 8% less than the nominal flow of 2.5 GPM (568 LPH).											
	K5 24° Blue Radius: 32-37' (9.8-11.3 m) Stream Ht.: 76-104" (193-264 cm)													

Figure 9. Sample model information for Nelson rotator sprinklers (R2000) which indicates what a given model's nozzle color, pressure, and flow rate should be. (Source: Nelson Irrigation)

Note that as the pressure goes up, the sprinkler discharge also goes up. The reverse holds true. If sprinklers in an area of the orchard consistently have lower pressures and therefore lower sprinkler discharges, that section of the orchard will be underirrigated as compared with other orchard areas with higher pressures.

Use the following steps to determine the average application rate (in/hr) of orchards irrigated with impact sprinklers.

1. Average the sprinkler discharge rates (gpm) of all the sprinklers sampled.
2. With the tree spacing information collected at the beginning of this section, use the following formula to determine the average application rate for the orchard.

NEXT STEPS

1. The average application rate is a very important piece of information regarding your sprinkler system. Keep it handy since it will be used extensively when scheduling your irrigations. It should not change significantly unless the pressure in the system changes. If you have filters in the system, be sure to keep them flushed and clean since they are frequently a source of pressure loss.

2. Variability in measured pressures in the orchard of more than 20% can cause significant irrigation application non-uniformity. Consider calling in an irrigation professional to the cause and what can be done to improve it. Using flow control (FC) nozzles may improve irrigation uniformity on some rotator-type sprinkler systems, as they discharge at a more uniform rate across a range of operating pressures. Flow control nozzles are not available for all rotator sprinklers.

3. Recheck your sprinklers in 3 years. It is recommended that you recheck the same sprinklers originally evaluated. This will give an excellent measure of changes that may have occurred. Consider measuring additional sprinklers to provide even better information.

Figure 10. Microsprinkler irrigation system. (Photo by L. Schwankl)

Figure 11. Drip irrigation system. (Photo by ANR Communications Advisory Board)

MOVING UP THE CONTINUUM

Moving up to the intermediate practices described in the section "Irrigation System Performance" in *Continuum Level 2.0* involves a closer look at evaluating sprinkler information collected and addresses how to account for the sprinkler discharge rate variability.

MICROIRRIGATION SYSTEMS

Microirrigation systems come in the form of microsprinklers or drip (figs. 10 and 11). Pressure measurements for these systems are useful since the discharge from non-pressure-compensating drippers and microsprinklers is significantly impacted by the operating pressure. The discharge from pressure-compensating (PC) drippers and microsprinklers is not as affected by differences in system pressure.

Pressure measurements will allow you to determine the application rate, most often measured in inches per hour (in/hr), and also give you an indication of the application uniformity.

INFORMATION TO BE GATHERED

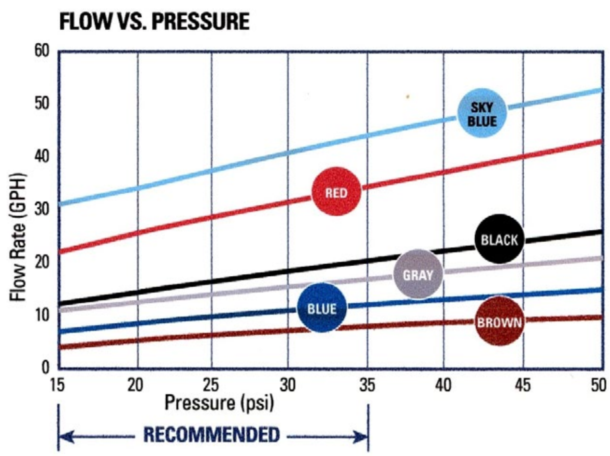
The following information should be gathered and recorded for orchards irrigated with microirrigation systems.

1. Spacing between trees in the row and spacing between tree rows.

2. Spacing between drip emitters or microsprinklers along the row. Note whether there is double-line drip (two lines of drip tubing and emitters per tree row). The objective of gathering this information is to determine the amount of applied water (gallons per hour) per tree.

3. If the orchard is irrigated in sets (sections or blocks of the orchard that are irrigated separately) monitor and evaluate the sets individually. The sets may not be the same hydraulically: they may differ in size, pressure, and flow rate.

4. Record the make and model of the microirrigation emitters used in the orchard. Use a camera or a smartphone to get a good close-up of the dripper or microsprinkler being used. Of particular importance is whether the emitters or microsprinklers are pressure compensating (PC). The discharge rate from non-pressure compensating drippers or microsprinklers is significantly affected by pressure (figure 12). Pressure-compensating drippers or microsprinklers discharge at a constant rate even as operating pressure changes (figure 13). If you are unsure whether your emitters are pressure compensating, take a sample emitter to your local irrigation equipment supplier for identification.



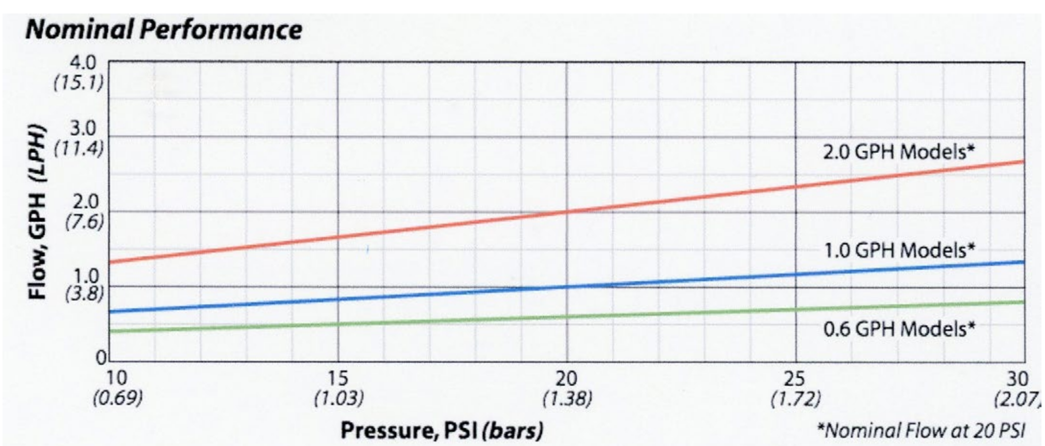
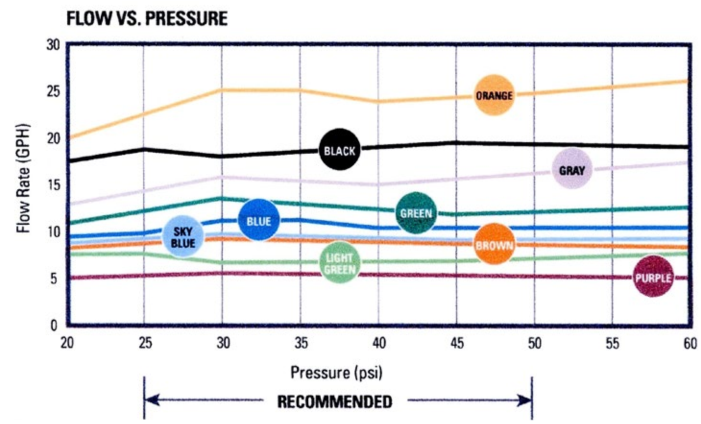


Figure 12. The discharge rate for non-pressure compensating microsprinklers (top) or drippers (bottom) varies with operating pressure. The pressure-discharge rate relationship will vary by manufacturer. (Source: Bowsmith)

Pressure-compensating (PC) microsprinkler



Pressure-compensating (PC) drip emitter

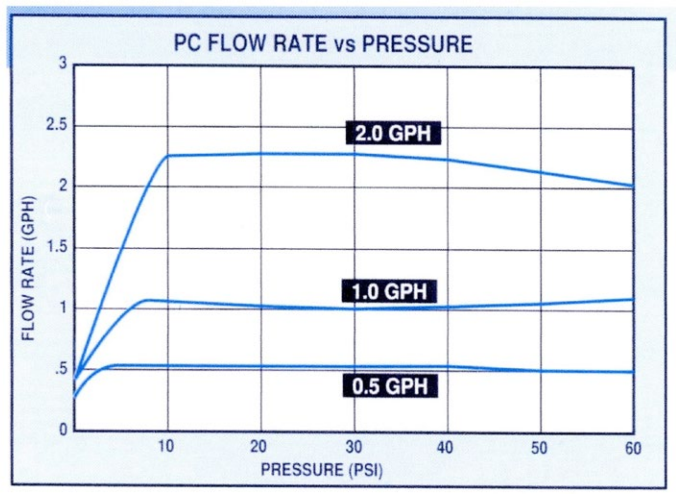


Figure 13. Pressure-compensating microsprinklers (top) and drippers (bottom) adjust to discharge at a constant rate even as operating pressure changes. (Source: Bowsmith and Netafim Irrigation)

WHEN TO TAKE MEASUREMENTS

Microirrigation systems should be evaluated every 3 years to achieve good irrigation water management. An evaluation every 3 years will be adequate to diagnose any problems associated with pressure variability, but evaluations should be done even more frequently, even yearly, if there is clogging in the system.

Figure 14. In-field pressure regulator used to regulate the pressure to a block of the orchard. (Photo by B. Sanden)

For new microirrigation systems, an excellent strategy is to do a system evaluation shortly after installation. This provides a baseline with which future evaluations can be compared. Do not simply rely on design criteria or “as planned” performance.

Before taking any measurements in the orchard, flush the filters, mainlines, submains, and lateral lines to ensure that the system is working optimally. Also check pressure-regulating devices to make sure they are operating at the correct pressure. This includes adjustable pressure-regulating valve(s) at the head of the system and/or pressure regulators on the separate blocks (figure 14).

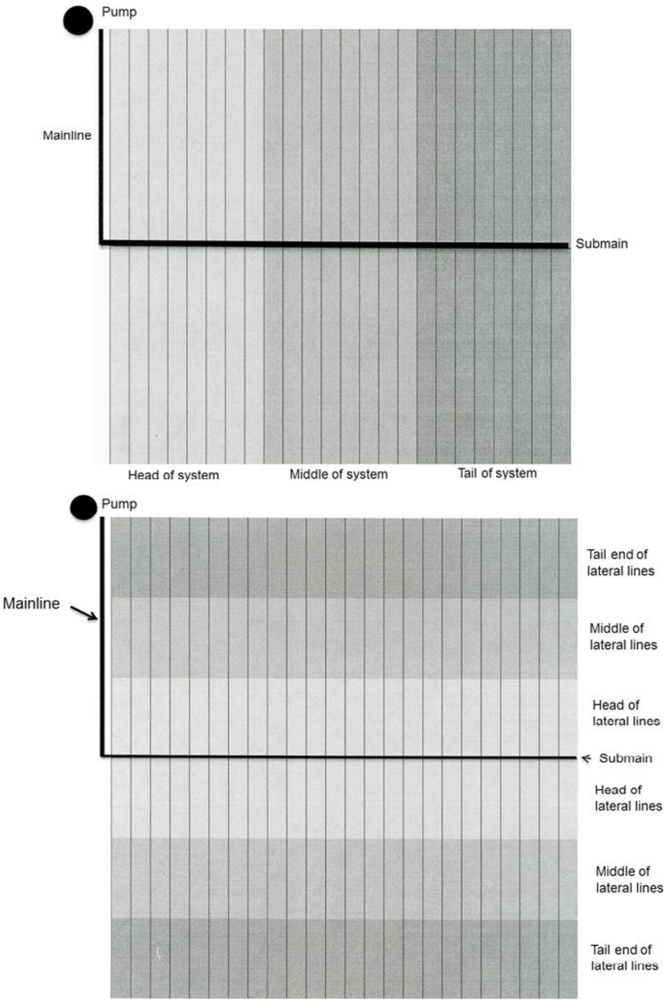


Figure 15. Irrigation system pressure measurements should be taken at a variety of locations within the system. Use the descriptions above to understand where these are relative to your setup. (Source: L. Schwankl)

A 0–30 psi or 0–60 psi liquid-filled pressure gauge works well for taking the measurements. Use the same, new pressure gauge to measure all the pressures. Using a new pressure gauge is advantageous because pressure gauges often become less accurate with use. If multiple pressure gauges are to be used, confirm that they all read the same pressure by measuring a single location with each gauge.

The objective in gathering the pressure measurements is to characterize the pressure for the orchard as a whole. Pressure measurements should be taken at (figure 15):

- The head, middle, and tail end (from the pump or head of the system) of the orchard.
- The head, middle, and tail end of the drip or microsprinkler lateral lines.
- Extra measurements may be needed in areas of high or low elevation in the orchard. Equally distribute these additional measurements between high- and low-elevation locations so that the measurements are not biased.

Since the microirrigation system mainlines and submains are most often below ground, having an irrigation system layout plan map is extremely useful in planning where to take measurements and for recording where measurements were taken.

When the pressure is measured at a dripper or microsprinkler, the record of its location should be good enough that the same emitter could be located and remeasured at a later date. Spray painting the drip hose on either side of the sampled emitter can be helpful in locating the sampled emitter in the future.

HOW MANY EMITTERS TO SAMPLE?

As with all sampling, the answer to how many samples should be collected is that more is always better. At a minimum, 30 to 40 pressure locations should be sampled, even on a small-acreage orchard. As the acreage increases, use the guideline of two or more pressure locations sampled per acre.

If it becomes evident during sampling that there is significant variability in pressures, consider increasing the number of locations sampled. Additional sampling increases the probability of diagnosing the cause of the pressure variability. If the pressure variability seems to be associated with areas of high or low elevation in the orchard, additional sampling of pressures in those areas is warranted.

MEASURING OPERATION PRESSURE

Pressure measurements can be readily taken throughout a microirrigation system. The following are typical and recommended pressure monitoring locations.

Figure 16. Pressure gauge adapted for measurement at tail end of lateral line microirrigation system tubing. Photo by L. Schwankl)

1. At the tail end of lateral lines. There is either an end cap fitting (3/4-inch female hose thread) or the tubing is simply folded over and held closed by a figure-8 fitting or by a 1-inch PVC pipe "ring." Use a pressure gauge that is adapted to the appropriately-sized drip fitting and can be temporarily slid over the end of the tubing while the pressure measurement is taken (figure 16).

   Measurements at the end of a lateral line account for frictional pressure losses through mainlines, submains, and lateral lines. For orchards with little elevation variability, the end of lateral line pressure measurements will be the lowest pressure levels in the system.

2. At the head of the lateral lines. It is very common for there to be an accessible connection where each lateral line connects to the submain system. Often, there is a fitting on the head of the lateral line similar to the female end of a garden hose. These connections should be the same throughout the system, so once you have the pressure gauge adapted to fit it should work throughout the system.

   There is often a hose-end ball valve at this connection that allows the water to be temporarily shut off while the lateral line is disconnected and the adapted pressure gauges installed. Turn the valve back on to take the pressure reading, and turn it off while the lateral line is reinstalled. If no shut off valve is present, install a temporary pressure gauge. This will be a wet process, so it is best done on a warm day.

   As an alternative, measuring the pressure at the first dripper or microsprinkler at the head of a lateral line will give an accurate measure of the pressure at the head of the lateral line.

Figure 17. A pitot tube fitted with a pressure gauge adapted for measurement within micro-irrigation tubing system. (Photo by L. Schwankl)

3. Through the tubing system. The pressure can be taken anywhere in the tubing system by punching a hole in the tubing with a drip punch and measuring the pressure using a pressure gauge fitted with a pitot tube (figure 17) that fits into the punched hole.

   The pitot tube is a small, curved, hollow brass tube that should be available for purchase from your local irrigation equipment supplier. A 0–30 psi or 0–60 psi liquid-filled pressure gauge works well for taking the measurements.

   Once the pressure measurement is taken, close the punched hole using a "goof plug." This method of pressure measurement is preferred by many evaluators because it can be done quickly and allows access to measure the pressure anywhere in the tubing system.

In microsprinkler systems, an alternative to punching a hole in the drip lateral line is to disconnect the tubing (often 1/4-inch tubing) leading to the microsprinkler and temporarily attaching the pressure gauge, fitted with a pitot tube, to the open end of the tubing. Replace the microsprinkler tubing once the measurement is complete.

LIMITATIONS OF PRESSURE MEASUREMENTS IN MICROIRRIGATION SYSTEMS

Whereas pressure measurements provide a great deal of system performance information in sprinkler systems, they are not as informative in microirrigation systems for the following reasons.

- Microirrigation emitter clogging is not generally detected through pressure measurements. Certainly clogged emitters may be observed while collecting pressure measurements, but the pressure measurements themselves do not provide evidence of clogging. To gather information on clogging, emitter discharge measurements (gph per emitter) must be gathered. This is as easily done as collecting pressure measurements and is addressed in Almond Irrigation Improvement *Continuum Level 2.0* and *Level 3.0* recommendations.

- Numerous pressure-compensating (PC) drip emitters and microsprinklers are used in almond irrigation that yield a greater acceptable pressure variability in a PC emitter system design than would be acceptable in a non-PC emitter system design.

One caution when evaluating systems with pressure-compensating drippers or microsprinklers is that the devices have a minimum operating pressure below which the pressure-compensating feature does not work. This minimum pressure will be evident in the manufacturer's pressure versus discharge rate charts for their devices (see figure 13 for an example) or the manufacturer will specify a minimum recommended operating pressure. If during the field evaluation you find system operating pressures below this minimum recommended operating pressure, be aware that the emitters in those low pressure areas are no longer operating as pressure-compensating and their discharge rates will be lower.

WHAT TO DO WITH PRESSURE READINGS

Pressure differences in a microirrigation system are the result of elevation differences and friction from water flowing through the pipeline or tubing. An elevation change of 2.3 feet is equivalent to 1 psi of pressure: lifting water 2.3 feet in elevation requires 1 psi of pressure (a loss of 1 psi) while water falling 2.3 feet in elevation results in a 1 psi gain in pressure.

For the drip emitter or microsprinkler product evaluated in the orchard, go to the manufacturer's website to find a chart or graph of the discharge rate versus pressure relationship for the emitter or microsprinkler. If you are unsure what drip emitter or microsprinkler you have in your orchard or unable to access it online, take a sample emitter to your local irrigation equipment supplier to have them identify it for you. As examples, see the associated graphs (see figs. 12 and 13) for different microirrigation products.

For a pressure measured in the orchard, consult the appropriate graph from your manufacturer for the expected emitter discharge rate.

DETERMINING THE AVERAGE APPLICATION RATE

Estimate the average application rate in the orchard using the field-measured pressure measurements and the manufacturer-provided pressure versus emitter discharge rate information for the emission devices used in the orchard. This is only an estimate, since it assumes minimal emitter clogging. In the section "Irrigation System Performance" in *Continuum Level 2.0* and *Level 3.0*, field measurements will be gathered which account for clogging, if any.

Follow these steps to estimate the average application rate.

1. Determine the average emitter discharge rate from the average operating pressure measured in the field and the manufacturer's pressure versus emitter discharge information for the orchard's emission device.

   DRIP EMITTER EXAMPLE:
   A drip-irrigated orchard with the non-PC drip emitter (DNK04) illustrated in Figure 16 had an average field-measured operating pressure of 16 psi.

   From the emitter discharge rate versus pressure (figure 18), the estimated emitter discharge rate would be 1.1 gph.

   MICROSPRINKLER EXAMPLE:
   A microsprinkler-irrigated orchard with the non-PC "Blue" microsprinkler illustrated in Figure 19 had an average operating pressure of 30 psi.

   From the manufacturers microsprinkler (Blue) discharge rate versus pressure graph (see figure 18), the estimated microsprinkler discharge rate would be 8.0 gph.

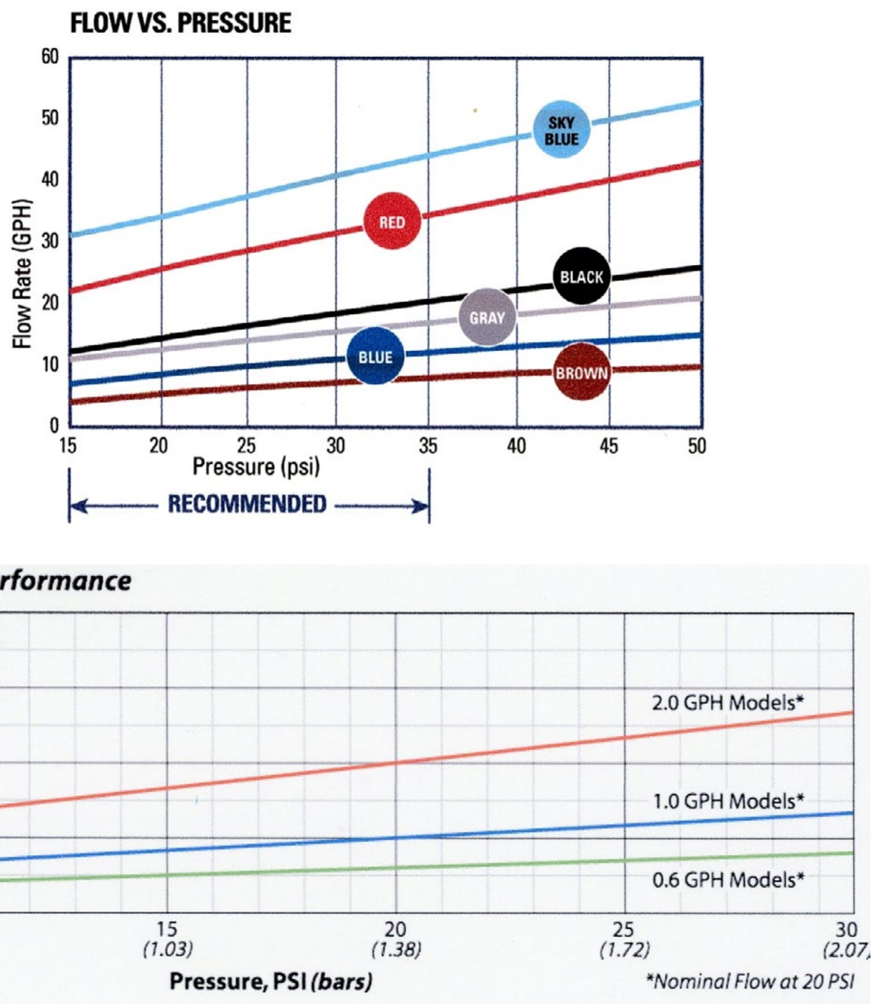


Figure 12. The discharge rate for non-pressure compensating microsprinklers (top) or drippers (bottom) varies with operating pressure. The pressure-discharge rate relationship will vary by manufacturer. (Source: Bowsmith)

2. Using the average emitter discharge rate (gph) and the number of emitters per tree, determine the average tree discharge rate (gph).

DRIP EMITTER EXAMPLE:
The emitter average discharge rate for a drip emitter system was 1.1 gph (from above) and there were 5 drip emitters per tree, the average tree discharge rate (gph) would be 5.5 gph (5 drippers/tree x 1.1 gph/dripper = 5.5 gph).

MICROSPRINKLER EXAMPLE:
If the emitter average application rate was 8.0 gph (from above) for the microsprinkler system, and there was a single microsprinkler per tree, the average tree discharge rate would be 8.0 gph (1 microsprinkler/tree x 8.0 gph/microsprinkler = 8.0 gph).

3. Calculate the microirrigation system average application rate (in/hr) using the following formula:

$$\begin{array}{c}\textit{Microirrigation system average}\\ \textit{Application rate (in/hr)}\end{array} = \frac{\textit{Average tree discharge rate (gph)}}{\textit{Tree spacing (ft}^2\textit{)}} \times 1.6$$

DRIP EMITTER EXAMPLE:
For an almond orchard with a tree spacing of 16 x 22 feet and a drip system with an average tree discharge rate of 5.5 gph (from above), the average application rate would be:
Tree spacing = 16' x 22' = 352 ft^2

$$\begin{array}{c}\textit{Microirrigation system average}\\ \textit{Application rate (in/hr)}\end{array} = \frac{5.5 \text{ gph}}{352 \text{ ft}^2} \times 1.6 = 0.025 \text{ in/hr}$$

MICROSPRINKLER EXAMPLE:
For an almond orchard with a tree spacing of 16 x 22 feet and a microsprinkler system with a tree average discharge rate of 8.0 gph, the average application rate would be:

Tree spacing = 16' x 22' = 352 ft^2

$$\begin{array}{c}\textit{Microirrigation system average}\\ \textit{Application fate (in/hr)}\end{array} = \frac{8.0 \text{ gph}}{352 \text{ ft}^2} \times 1.6 = 0.04 \text{ in/hr}$$

EQUATING PRESSURE DIFFERENCES TO DISTRIBUTION UNIFORMITY

The uniformity of a microirrigation system, a measure of how evenly or uniformly water is applied to the almond orchard, is quantified by distribution uniformity. A non-uniform irrigation system will over-irrigate some trees and under irrigating others.

Using *Irrigation* System Performance minimum 1.0 practices where only pressure measurements are field-collected, distribution uniformity can at best be estimated. In the section “Irrigation System Performance” in *Continuum Level 2.0* and *Level 3.0*, distribution uniformity will be determined from actual emitter discharge rates.

When only pressure measurements are collected, distribution uniformity can be estimated as follows.

1. Non-PC drippers and microsprinklers with minimal emission device clogging:

FIELD PRESSURE DIFFERENCES (%)	ESTIMATED DISTRIBUTION UNIFORMITY (%)
10 or less	85–90
10–20	80–85
Greater than 20	80 or less

2. PC drippers and microsprinklers with minimal emission device clogging and operating within the manufacturer's recommended operation pressure range:

   Assume distribution uniformity of 85–90%

NEXT STEPS

1. The average application rate is a very important piece of information regarding your microirrigation system. Keep it handy since it will be used extensively when scheduling your irrigations. It should not change significantly unless the pressure in the system changes.
2. Variability in measured pressures in the orchard a greater than 20% can cause significant irrigation application non-uniformity. Consider calling in an irrigation professional to see what is causing the differences and what can be done to improve it.
3. Recheck your microirrigation system in 3 years. At a minimum, recheck the same locations originally evaluated. This will give an excellent measure of any changes that may have occurred. Consider measuring some additional locations to provide even better information.

MOVING UP THE CONTINUUM

Moving up to the intermediate practices described in "Irrigation System Performance" in *Continuum Level 2.0* involves a closer look at the microirrigation system information collected here and addresses how to account for microsprinkler or drip emitter discharge rate variability.

APPLIED WATER

1.0 Practice: Use application rate and duration of irrigation to determine water applied.

Keeping good records of the amount of irrigation water applied may be one of the most important elements of good irrigation water management. The amount of irrigation water applied is critical to determining whether irrigation practices are keeping up with orchard water demands and determining the irrigation efficiency.

The following steps use the average application rate determined in the previous section, **"Irrigation System Performance"**; minimum practices; and the irrigation duration to determine the amount of water applied per irrigation event.

INFORMATION TO GATHER

1. Refer to the calculations completed in the *Continuum* section "Irrigation System Performance Level 1.0" that describe minimum practices to obtain the application rate (in/hr) for your irrigation system.

Figure 1: RainBird LXME Pump and Valve Controller (Photo curtesy of Spencer Cooper)

2. Keep careful records of irrigation times or durations for each irrigation set or block, each orchard, or however your irrigation system(s) are operated. The following techniques used by water managers may prove useful.

    a. Keep a paper or electronic record of on/off times on a calendar. This calendar may be also be used to record pest control treatments, fertilizer application, and other cultural practices in the orchard. Keeping these records on an electronic spreadsheet is a good option.

    b. Be diligent in recordkeeping. It is easy to get behind, and remembering specific details after time has passed can prove difficult.

    c. If irrigation events are operated by a controller using electric or hydraulic solenoid valves (figure 1), make sure they are operating correctly and record any changes to the controller. Any operation of the system on the manual setting should be recorded as well.

    d. If irrigation events are controlled manually, write down the times when the system is started and stopped on each block or set.

    e. If issues arise with losing records or in getting them from the field to the individual responsible for maintaining the records, consider using text messages to share information. The text message should indicate which orchard, block, or set the information refers to and also serves as a semipermanent record of when irrigation events were started and stopped.

DETERMINING APPLIED WATER

For each irrigation block or irrigation management zone and each irrigation event, use the formula below to calculate the applied water (in inches) by multiplying the block or set's irrigation application rate (in/hr) by the irrigation time (hr) (Hanson and Schwankl 2009).

$$\textit{Applied Water (inches)} = \left(\begin{array}{c}\textit{Irrigation Application}\\ \textit{Rate (in/hrs)}\end{array}\right) x \left(\begin{array}{c}\textit{Irrigation Set}\\ \textit{Time (hrs)}\end{array}\right)$$

The determined amount of applied water per irrigation event should be recorded in a consistant manner that works best for your operation (calendar, spreadsheet, etc.).

NEXT STEPS

Total the applied irrigation water for the season and compare it with the seasonal almond water use estimates (ET) from the section "Orchard Water Requirements Level 1.0" minimum practices or from the Almond Board's Irrigation Calculator. The values of the applied irrigation water and seasonal almond evapotranspiration (ET) should be close. Remember that some of the almond ET will also be supplied by the stored soil moisture at the beginning of the growing season.

Figure 2. Flow meter register (readout) of a propeller saddle-mount flow meter. Flow meters allow for more accurate and more easily obtainable measures of applied water. (Photo by L. Schwankl)

MOVING UP THE CONTINUUM

Strongly consider installing a flow meter (figure 2) to better and more easily measure applied water. This will allow you to move to the Almond Irrigation Improvement *Continuum Level 2.0* intermediate and the *Level 3.0* advanced levels with regard to applied water, further improving your good irrigation water management practices.

SOIL MOISTURE

1.0 Practice: Evaluate soil moisture based upon feel and appearance by augering to at least 3 to 5 feet. Monitor on a monthly time step.

Determining the amount of moisture stored in the trees' root zone is important information for good irrigation water management. Stored soil moisture serves as a bank account of water available for the orchard. As the trees "withdraw" water from the stored soil moisture bank account, irrigation "deposits" must be made throughout the growing season to maintain available water in the account. Maintaining available water in the root zone provides the orchard with a cushion in case of underirrigation due to management miscalculations, equipment failure, or other factors that affect the availability of water.

Growers should evaluate soil moisture based on feel and appearance of the soil, as well as by soil monitoring on a monthly basis to inform irrigation management decisions. Stored soil moisture is accessed by tree roots and withdrawn to satisfy tree water needs and must be accounted for in irrigation decision making.

INFORMATION TO GATHER

Many sophisticated soil moisture monitoring tools are available, some of which will be described in the Almond Irrigation Improvement *Continuum Level 2.0* and *3.0* standards, but using a simple and inexpensive method for determining soil moisture, known as the feel and appearance method, can be effective. An excellent resource for guidelines on using this method is the Natural Resources Conservation Service's (NRCS) publication **Estimating Soil Moisture by Feel and Appearance**.[12] This publication provides guidelines for the feel and appearance of soils of various textures and moisture content and beyond is available online at the NRCS website and at your local NRCS office.[13]

To use the feel and appearance method, perform the following steps.

Figure 1. Various types of augers that can be used to sample the soil moisture content. (Photo by B. Sanden)

1. Soil samples should be gathered at every foot to a depth from 3 to 5 feet using an auger (figure 1) or other sampling tool. A good selection of augers and other sampling tools are available from retailers including Ben Meadows, Forestry Suppliers, and AMS, Inc. Check online for other suppliers.

2. Determine the soil texture at the site being sampled. The soil texture can be identified by locating the sample site on USDA-NRCS online soils maps or by visiting your local NRCS office.

Increasingly applications are available for smartphones and tablets that can identify the soil texture of the site you are standing on, including work done by UC Davis California Soil Resource Lab. However, note that some of these applications require Google Earth, a free software program, to be installed on your computer, tablet, or smartphone.

12. United States Department of Agriculture, Natural Resources Conservation Service. Estimating Soil Moisture by Feel and Appearance. Apr.1998. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_051845.pdf
13. To locate your local NRCS office, visit Almonds.com/Growers/Resources and filter by the 'NRCS' category

ALMOND TREE ROOT ZONE

What is the root zone of an almond tree? This would seem like an easy question to answer, but it is not. An almond tree's root zone depends on the soil conditions the roots are growing in and the area to which irrigation water is applied. In areas of the almond growing region where winter rainfall is adequate to fill the root zone, the entire area that the tree roots can explore may be the root zone. Later in the season, after the soil moisture has been depleted, only the area where irrigation water is supplied is considered to be the root zone.

In terms of root zone depth, measurements have shown that almond trees withdraw water from as deep as 6 to 7 feet if the soil conditions allow root penetration.[14] More often, almond tree root depth is limited by soil conditions. Layers such as hardpans may restrict root growth, as can changes in soil texture between soil layers. Further complicating the issue is that orchard soil is by no means uniform. Some areas of an orchard may have breaks in restricting layers, and the soil texture may vary widely within an orchard.

Figure 2. Root concentration around a subsurface drip line. (Photo by L. Schwankl)

Water is not taken up evenly throughout a tree's root zone, primarily because roots are not distributed evenly throughout the rooting volume (the soil volume explored by the roots). Greater concentrations of roots generally occur at shallower depths and closer to the tree's trunk, but this pattern may be modified by water availability resulting from irrigation practices.

Soil moisture uptake under localized irrigation techniques such as drip irrigation can differ significantly from that observed in surface and sprinkler irrigation systems. In addition, by mid-to-late season, the rooting volume will be concentrated in the tree root zone (figure 2) where water is applied, as the roots proliferate where water is available and die in dry areas.

WHERE TO COLLECT SOIL MOISTURE SAMPLES

Collect and evaluate samples in a number of locations throughout the orchard, avoiding outside rows. Soil samples should be collected and evaluated at each foot while augering to 3 to 5 feet deep. If there are no restricting layers in the soil, assume the rooting depth is 3 to 5 feet. If there appears to be a consistent restricting layer in the orchard, use its depth as the bottom of the root zone, augering and collecting samples only to that depth.

If you know that there are various soil textures in the orchard, use a minimum of one sampling location in each of the soil textural areas. More sites provide better information, but it is better to sample the selected sites regularly rather than sampling many sites on an irregular basis.

Select sampling sites that have healthy trees and are representative of that section of the orchard. Do not choose a sample site with a missing adjacent tree, as the missing tree will have local implications on soil moisture. Of course, if you are soil sampling to diagnose a problem with a tree or orchard location, you would choose areas to sample based on your best chance of solving the problem.

Sample approximately 6 feet from a tree, taking into account the soil volume wetted by the irrigation system. Sample in the wetted volume, since this is where the roots are active. This is particularly important for microirrigated trees. For example, under drip irrigation, the sampling should be done in the wetted volume but not right next to a drip emitter.

14. Drought Survival Strategies for Established Almonds Orchards—Shackel et al for CAB

WHEN TO COLLECT SOIL MOISTURE MEASUREMENTS

With experience, gathering soil moisture information using the feel and appearance can be done almost as quickly as simply auguring.

The *Level 1.0* minimum practice for measuring soil moisture recommends that soil moisture be monitored on a monthly basis. However, beyond each month there are times when having soil moisture information is of particularly importance.

1. The stored soil moisture, as determined by the feel and appearance method, is particularly useful for determining the amount of water available to the trees prior to the first irrigation of the season.

   Most orchard managers would prefer to go into the irrigation season with the root zone full of water (a full soil profile). Measurements have shown that it is difficult to get deep water penetration with microsprinklers during periods of high water use in the summer, and drip systems wet only a portion of the soil volume.

   Taking feel and appearance method measurements at this time also provides valuable insight into the actual feel of the soil when it is full of water, often referred to as field capacity. Table 1 gives the available water at field capacity for various soil textures. Also given is the length of a ribbon of soil you can squeeze out between your thumb and forefinger when the soil is at field capacity.

Soil Category	Soil Texture	Available Water-holding Capacity (in. per ft. of soil)	"Ribbon" Length at Field Capacity (in.)
Course	Sand /Loamy Sa nd	0.6-1.2	none; ball only
Sandy	Loamy Sand / Sandy Loam / Loam	1.2–1.8	0.4–1
Medium	Loam / Sandy Clay Loam	1.4–2.2	1–2
Fine	Silty Loam / Silty Clay Loam / Clay / Silty Clay	1.7–2.4	>2

Table 1. Soil moisture at field capacity for soils of various textures. A ribbon of soil is formed by holding a ball of soil between your thumb and forefinger and sliding your thumb across the soil in a shearing motion to extrude a continuous ribbon of soil about 1/16 inch to 1/8 inch thick.

2. For surface and sprinkler irrigation systems, to take a set of feel and appearance method soil moisture measurements just prior to an irrigation event and then another set of measurements 2 to 4 days following the irrigation. Comparing these measurements provides valuable information on the depth of water penetration and how well the irrigation refilled the root zone.

3. Prior to irrigation cutbacks that may be planned prior to harvest, determine how much stored soil moisture is available. If the soil profile has little stored soil moisture, cutting back on irrigations may induce more water stress than desired and potentially harm yield the following year. The same holds true for cutting off irrigations during harvest.

DETERMINING STORED SOIL MOISTURE

1. Collect soil samples at 1-foot intervals to a depth of 3 to 5 feet or to the depth where any restricting layers limit root growth. Select sampling locations that are representative of the orchard. If you are aware of different soil textures in the orchard, investigate each of these areas. Tree growth and health can also provide guidance as to where soil samples should be taken. Checking the soil conditions, including soil moisture, can often help explain tree performance problems.

2. For each sample, use the NRCS feel and appearance method to estimate the soil moisture content. As you get to “know” your soil, you will be more sensitive to the soil moisture content. Table 1 also provides a quick estimate of the available water-holding moisture.

3. Keep good records each time the soil moisture is sampled, including soil moisture content and orchard location, as well as where the samples were taken relative to the tree and irrigation system (especially important when drip or microsprinkler irrigation is used). Also note the date and the point in the irrigation cycle the samples were taken.

NEXT STEPS

Determining soil moisture is not an end in itself. Use the information to adjust your irrigation practices. When using evapotranspiration (ET) scheduling, soil moisture sampling is an excellent check to make sure the recommended irrigation amounts are correct. For example, following an irrigation, if you expect the soil profile to be full of water, check the soil moisture to confirm this. Even better would be to have also checked the soil moisture just prior to the irrigation. This would provide you valuable information on where and how deep the irrigation water penetrated.

MOVING UP THE CONTINUUM

To move up the practices described in *Levels 2.0* and *3.0*, consider installing soil moisture monitoring tools that provide information on soil moisture at various depths without having to gather an augered soil sample. Experience from using the feel and appearance method will provide you with guidance on where these monitoring tools are best installed, though cost may limit the number of locations where they can be installed.

Further information and guidance on this approach can be found in *Almond Irrigation Improvement Continuum Levels 2.0* and *3.0*.

PLANT WATER STATUS

Figure 1. Tree water stress in late June expressed through visible defoliation. (Photo by K. Shackel)

1.0 Practice: Evaluate orchard water status using visual plant cues just prior to irrigation or on a biweekly basis.

The most basic observations of plant water status that growers can use in managing irrigation are visual cues. Although monitoring plant water status using visual cues is a poor substitute for quantifiable measurements through stem water potential, they can be valuable in indicating relatively large deviations from the optimal level of irrigation, which would indicate over- and under-irrigation (figure 1). Using this approach, growers should evaluate visual cues as described below just prior to irrigation or on a bi-weekly basis.

INFORMATION TO GATHER

Growers should try to spot the early symptoms of plant water stress and respond before more-severe symptoms appear. Often, by the time the more-severe symptoms are seen, the damage to yield and quality are irreversible.

Early-season symptoms of under-irrigation water stress that growers should watch for are the lack of new shoots and short shoots or early cessation of growth.

Visual symptoms of under-irrigation during the growing season begin as a change in leaf color from bright green to green with a bluish tint. More-severe stress symptoms include leaf droop. If significant water stress due to under-irrigation is experienced prior to hull split, delayed or poor hull split will result.[15] Symptoms of more-severe water stress also include premature leaf drop and shriveled kernels. Although relying on visual symptoms may not be the best method to manage irrigation, recognizing under-watering and taking action is reasonable at this level of management and technology. The early symptoms, if acted upon, can prevent the more severe symptoms.

Figure 2. Almond potassium deficiency symptoms are similar to those that can be observed as visual signs of water stress. Photo: IPNI.

Often associated with water stress due to under-irrigation is the increased incidence of spider mites[16] as well as potassium deficiency symptoms (figure 2) such as reduced leaf and shoot growth followed by leaf margins becoming necrotic with a folded leaf and curled tip.

Visual symptoms of over-irrigation during the growing season are poor tree vigor, evidence of standing water on the soil surface, and the shift of weed species toward water-preferring weeds. Nutsedge and other sedges, as well as common purslane and spurges, tend to prosper in wetter areas. According to UC weed specialists, a sign of over-watering is the reduced longevity of herbicide performance rather than a shift

15. Prichard, T., W. Asai, P. Verdegaal, W. Micke, and B. Teviotdale. 1994. Effects of water supply and irrigation strategies on almonds. Modesto: Almond Board of California. Comprehensive project report 1993-94.
16. Youngman, R., and M. Barnes. 1986. Interaction of spider mites (Acari: Tetranychidae) and water stress on gas exchange rates and water potential of almond leaves. Environmental Entomology 15:594-600.

to a specific suite of weeds. In these cases, summer annual species (pigweeds, lambsquarter, junglerice, spurge, purslane, and similar weeds) are the most common because they are primed to germinate in the late spring and summer. For assistance in visually identifying weed species, visit the **UC IPM weed photo gallery.**

However, it should be noted that in an orchard with poor water infiltration, standing water may not be an indication of over-watering. Over-irrigation should be confirmed by soil augering to evaluate soil moisture, as described in the *Continuum 1.0* section **"Soil Moisture."**

WHEN TO MAKE OBSERVATIONS

Visual evaluation of the orchard should be done during the growing season, just prior to a planned irrigation. This is when water stress is at its highest level for that irrigation period.

OTHER CONSIDERATIONS

During the first years of the orchard, canopy expansion is the most important process that leads to high productivity. As the orchard reaches maturity, the significance of water deficits that affect vegetative growth are reduced. Vegetative growth in almond is very sensitive to water deficits. Avoiding water deficits throughout the season in young trees is critical to reaching full production in the shortest time.

In mature orchards, responses to water deficits depend on the timing of the stress. Since most almond-growing regions typically start the season with adequate soil moisture from rainfall or irrigation, vegetative growth in mature almond orchards is rarely impacted. However, this is not the case during drought and deficient water supply in the soil profile during the spring growth phase. For more information on the impact of water stress from under irrigation due to inadequate water supplies, see **UC ANR Publication 8515, Drought Management for California Almonds.**[17]

NEXT STEPS

Use these visual cues to just prior to irrigation to verify the irrigation schedule based on the orchard water requirement determined in the *Continuum Level 1.0* sections "Orchard Water Requirements" and "Integrating IWM Practices."

MOVING UP THE CONTINUUM

The *Almond Irrigation Improvement Continuum Level 2.0* section "Practices for Plant Water Status," recommends using a pressure chamber to measure stem water potential (SWP) just prior to irrigation on a monthly time basis to ensure calculated water applications are not over- or under-irrigating trees.

SWP measurements taken just before irrigation indicate the orchard water status when soil moisture levels are the driest and orchard stress is potentially the highest. SWP measured at this time can be used to confirm the accuracy of other scheduling methodologies: orchard water demand estimation or soil moisture monitoring.

17. Doll, D., and K. Shackel. 2015. Drought Tips: Drought Management for California Almonds. Oakland: University of California Agriculture and Natural Resources Publication 8515. ANR CS website, http://anrcatalog.ucanr.edu/Details.aspx?itemNo=8515.

INTEGRATING IRRIGATION WATER MANAGEMENT PRACTICES

1.0 Practice: Combine irrigation system performance data with "normal year" regional crop evapotranspiration estimates to determine the orchard-specific water requirements and schedule irrigations. Check soil moisture with an auger and/or visually monitor plant water status to verify scheduling.

The goal of irrigation scheduling is to determine how to supply the orchard with the correct amount of water at the appropriate time. Most growers make irrigation decisions based on their experience and the practical limitations of their systems. However, research has developed good irrigation water management practices to optimize orchard water management that should be included in grower decision making.

There are compelling reasons to adopt technical water management procedures. First, more precise water management can increase revenues. Conserving water reduces grower inputs, which increases revenue by a magnitude dependent on the water cost. Second, reducing the amount of water applied also conserves a natural resource vital to all Californians. Demonstrating good stewardship of water resources will serve growers well in the ever-increasing competition for limited water supplies.

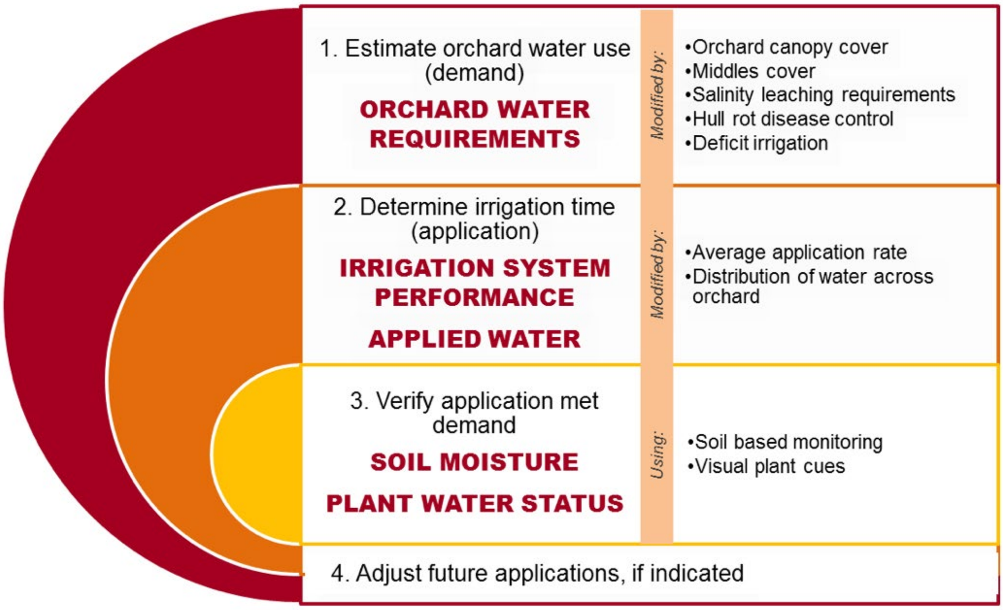
INTEGRATING 1.0 PRACTICES

Supplying irrigation in the correct amount and at the correct time to meet the trees' needs is the goal of irrigation scheduling. This goal is best served by using estimates of crop water use (evapotranspiration, or ETc) considering the specific orchard water requirements and irrigation water conditions. These site-specific factors such as canopy size, the presence of middles cover (cover crops/weeds), soil and water salt levels, and the use of deficit irrigation, are discussed in the *Curriculum Level 1.0* section **"Orchard Water Requirements."** Additionally, delivering the correct amount of water to the majority of the orchard requires knowledge of application rate and the distribution of water across the orchard as discussed in the Level 1.0 section "Irrigation System Performance." Verifying the appropriate amount of applied water is described in the Level 1.0 section "Applied Water."

Although the above method of estimating orchard water requirement and ultimately system operating or set time are good, they are only a best estimate. The adequacy of the irrigation schedule generated using the approach above should be verified by soil- and/or plant-based monitoring methods as discussed in the *Level 1.0* sections **"Soil Moisture"** and **"Plant Water Status."**

To help address the errors inherent in the estimation of the orchard water requirements, growers rely on the soil to act as a buffer to small amounts of over- or under-irrigation by virtue of its water-holding capacity. However, if errors are large, either over-irrigation, causing soil saturation, or under-irrigation, causing water deficits, can occur. Both can be detrimental to the orchard and the crop. If monitoring indicates the existence of either condition, adjustments in the schedule should be made.

Almond irrigation scheduling, water application, and verifying the effectiveness of the process is a four-step process. The following graphic illustrates how the 1.0 measures work together to shape overall good irrigation scheduling and management of California almonds.



1.0 IRRIGATION SCHEDULING SAMPLE CALCULATION

GOOD IRRIGATION WATER MANAGEMENT PRACTICES FOR CALIFORNIA ALMONDS

Four steps for good irrigation water management practices should be employed to schedule almond irrigations. They are:

1. Meet the orchard's estimated orchard requirement by developing an irrigation schedule using ETc estimates based on specific orchard conditions.

2. Determine the irrigation system operation time using the average application rate determined by evaluating the irrigation system performance.

3. After the schedule has been implemented, monitor soil water status and/or plant water status to verify the schedule.

4. If soil- or plant-based monitoring indicate too much or too little irrigation, adjust the schedule for the next irrigation period.

The steps above indicate practices and considerations that should be made for any good irrigation water management system. The sample calculation below uses that as a guide and provides an example of how to tie together the measurements derived from the *Level 1.0* sections of the *Continuum*. Together they provide the pieces to develop a good irrigation water management strategy for your operation.

In this example we will first estimate the orchard water use (ETc) with the given orchard conditions, then determine the orchard water requirements needed at each irrigation and time of irrigation by adding the salt leaching requirements to determine irrigation volumes; confirming the applied water volume through water measurement; and using soil monitoring and/or visual plant cues of water status to verify the estimates of crop water use and irrigation delivery. If monitoring suggests the schedule is in error, corrections to the schedule should be made.

Given orchard conditions:

- Orchard maturity: Mature orchard, canopy shaded area greater than 80%
- Middles cover: None
- Location: Fresno, ET Zone 15
- Scheduling period: June 1–30
- Irrigation water salinity: 1.0 dS/m
- Irrigation system type: Sprinkler irrigation

1. Determine the orchard water requirement.
    - Data collected via instruction from Level 1.0 section “Orchard Water Requirement”:
        - — ETc estimate for Zone 15 in June: 8.51 inches
        - — Leaching requirement: 15%
    - Calculations:
        - — Orchard water requirement (OWR) = ETc / application rate x (1+ leaching requirement)
        - — OWR = 8.51 x 1.15 = 9.79 in

2. Determine the irrigation system application rate and set run time.
    - Data collected via instruction from Level 1.0 section “Irrigation System Performance”:
        - — Average application rate: 0.10 inches per hour
    - Calculations:
        - — Irrigation system run time = OWR / application rate
        - — Irrigaiton System run time = $\frac{9.79}{0.10}$ = 98 hrs

3. Verify schedule prior to the next calculation period.
    - Data collected via instruction from *Level 1.0* section “Soil Moisture” and/or *Level 1.0* section “Plant Water Status”:
    - — Use visual plant water status cues or soil moisture evaluation to confirm the schedule is adequate

4. Adjust future irrigations if the verification described above in step 3 indicates over- or under-irrigation.

MOVING UP THE CONTINUUM

Integrating Irrigation Water Management Practices in the *Almond Irrigation Improvement Continuum Level 2.0* provides for more frequent estimates of water use to align water applications with the seasonally changing orchard water requirements. Improved irrigation system performance procedures and water measurement devices are used. Additionally, soil and plant water status is more accurately measured, providing better information to verify irrigation scheduling.