ATTACHMENT A

Case Study – Methods for Determining Irrigation Timing and Application Duration in Pilot Orchards

Methods for Determining Irrigation Timing and Application Duration in Pilot Orchards

INTRODUCTION

A wide range of tools and approaches were used by growers in the Precision Irrigation pilot study to inform decisions on irrigation timing and duration. These methods ranged from relatively simple techniques, such as tracking weekly crop evapotranspiration (ETc) estimates provided jointly by University of California Agricultural and Nature Resources (UC ANR) and California Department of Water Resources (DWR) and making field-level orchard observations, to more advanced approaches that integrated ET data, pressure chamber measurements, and multiple soil and plant-based sensing technologies (Figure 1).

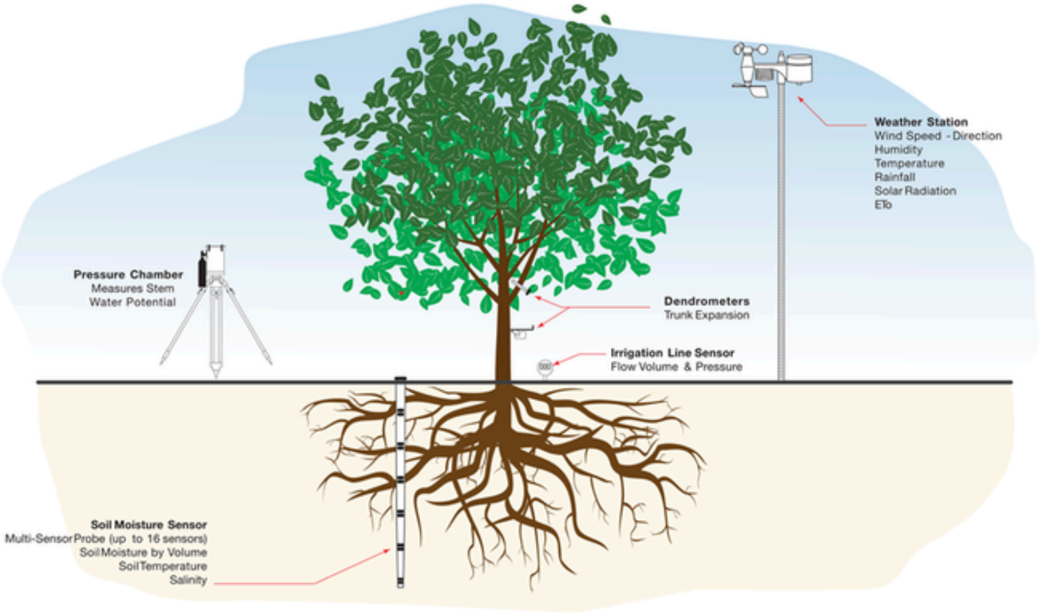


Figure 1. Example of sampling tools used to determine irrigation timings and duration.

Methods Used by Pilot Study Growers:

- Calendar and Experience Based Scheduling
- Crop Evapotranspiration (ETc)
- Soil Moisture Sensors
- Stem Water Potential Measurements
- Dendrometers
- Combination of Methods
- Consultants

DISTRIBUTION OF MULTIPLE DATA SOURCES USED FOR IRRIGATION DECISIONS

A clear trend emerged among pilot study growers, with many leveraging multiple sources of information to guide irrigation decisions. The most common approach included the use of stem water potential (SWP) measurements collected with a pressure chamber. The combination observed most frequently was the use of SWP readings taken with a pressure chamber together with ETc data obtained weekly from UCANR/DWR online reports, California Irrigation Management Information System (CIMIS) reports accessed online, or from in-field weather stations (Figures 2 and 3).

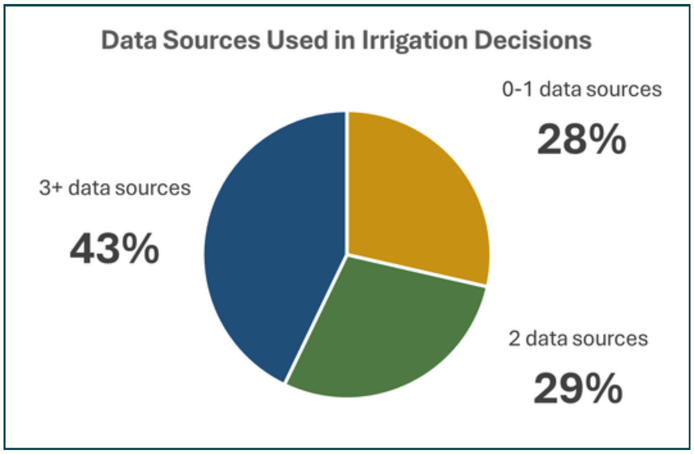


Figure 2. Distribution of pilot orchards by number of data sources used to guide irrigation decisions.

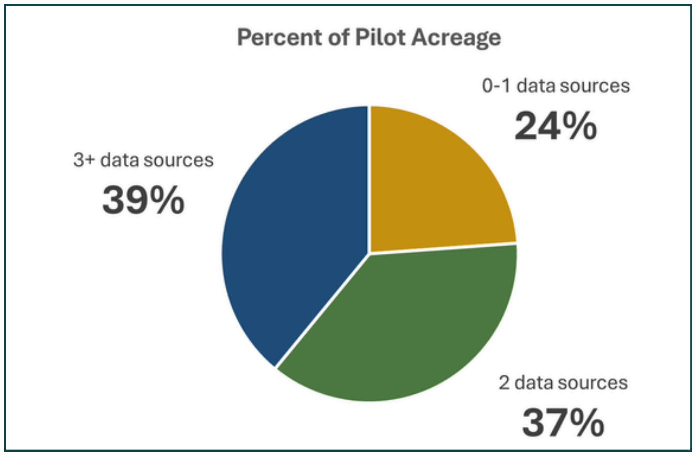


Figure 3. Acreage distribution by number of data sources used to support irrigation decisions.

72% of pilot orchards used two or more data sources to guide irrigation timing, with 43% using three or more sources, 29% using two sources, and 28% relying on a single source or no data sources as with calendar-based scheduling.

When evaluated by acreage, 76% of pilot acres were managed using two or more data sources, with 39% using three or more sources, 37% using two sources, and 24% relying on a single source or no data sources as with calendar-based scheduling.

CALENDAR AND EXPERIENCE-BASED IRRIGATION SCHEDULING

Calendar-based irrigation scheduling involves applying water based upon judgement of current conditions and relating it to previous experience. It usually results in predetermined irrigation start dates and intervals (e.g., applying the first crop irrigation about the same time every year, then applying subsequent irrigations every 7–10 days) rather than adjusting timing and duration based on real-time measurements of crop water use, soil moisture, or plant stress.

Calendar and experience-based irrigation scheduling is common until a grower considers science-based irrigation scheduling tools and information. The latter approach is simple to implement and relies largely on experience to recognize and react to unusual weather or other growing conditions.

In many operations, calendar-based scheduling serves as a baseline approach that can be adjusted. As the season progresses, adjustments may be made based on factors such as:

- Extended heat events that are hotter than seasonal averages
- Cooler-than-normal periods that are expected to reduce crop water demand
- Visual symptoms of crop stress such as lack of shoot growth and early signs of leaf wilting
- Hull split timing and harvest preparation
- Observations of soil moisture conditions with hand feel method

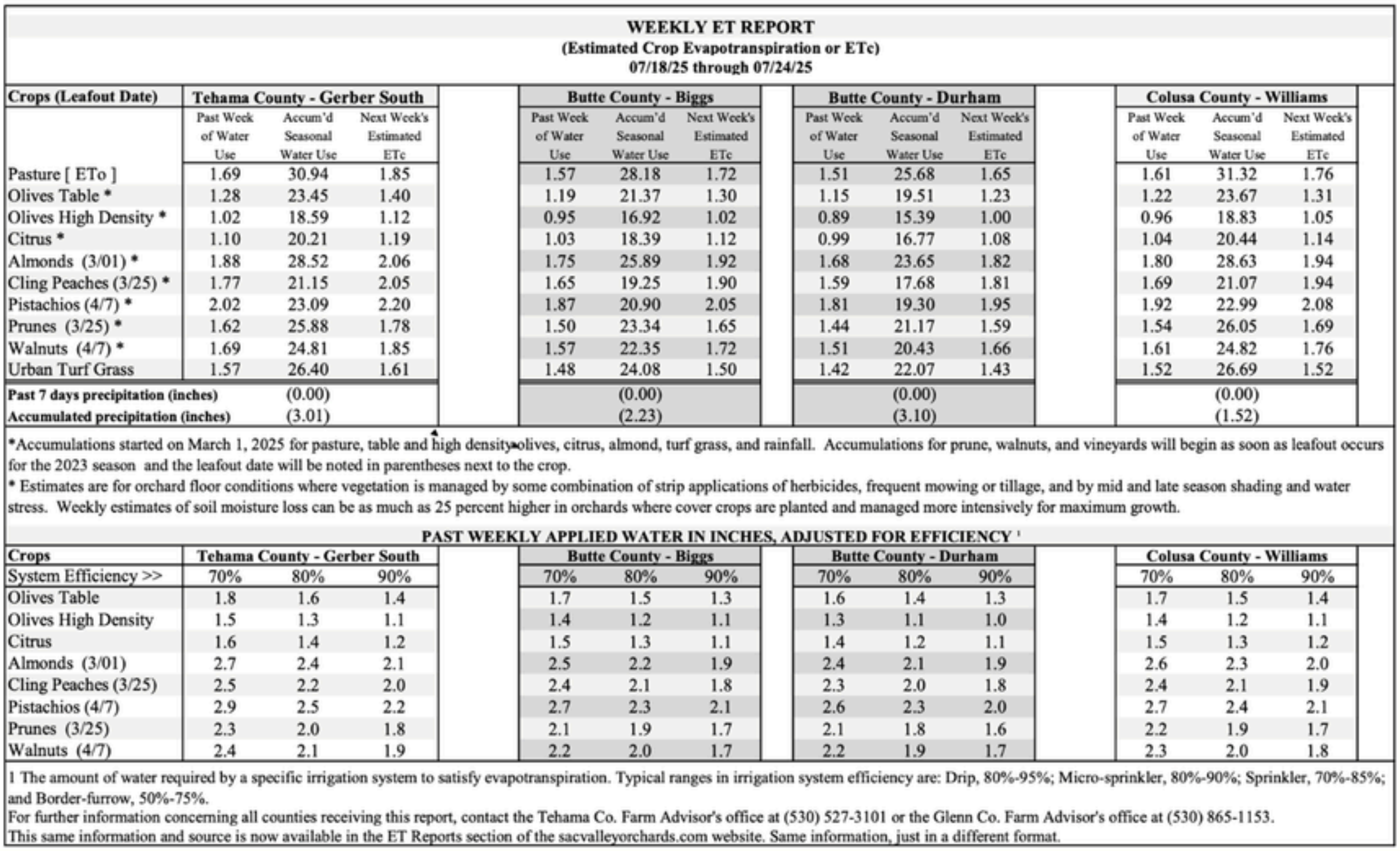
Among the pilot sites using a calendar- or experience-based irrigation approach, results were mixed. Less than 10% of participants and acreage in the pilot study relied primarily on this method. Of that acreage, approximately half achieved productivity and water efficiency comparable to orchards using more science-based irrigation scheduling tools, while the remaining half demonstrated lower yield and water productivity.

Given the limited scale of the pilot study, it is not possible to establish a definitive trend or determine whether these results are representative across the broader Vina Subbasin. However, the findings suggest that while calendar- and experience-based approaches can achieve strong crop performance under certain conditions, outcomes may be more variable.

In contrast, results from the pilot study indicate that integrating multiple, science-based sources of information may contribute to more effective irrigation decisions, water use efficiency and crop performance. The relatively small proportion of growers and acreage relying solely on calendar-based scheduling also suggests that adoption of data-informed irrigation practices is both feasible and ongoing within the region.

CROP EVAPOTRANSPIRATION (ETC)

Crop evapotranspiration (ETc) represents the combined water loss from soil evaporation and plant transpiration and is commonly used to estimate irrigation. ETc is calculated by multiplying reference evapotranspiration (ETo), derived from weather data, by a crop coefficient (Kc) that accounts for crop-specific water use. Irrigation scheduling based on ETc involves replacing estimated crop water use over a defined time or period between irrigations. Soil moisture storage and effective rainfall may supply some of the ETa to lessen the amount of irrigation needed. Also, irrigation may be withheld on purpose as part of a regulated deficit irrigation strategy that reduces applied water but benefits the crop. An example is reduced irrigation during hull split in almonds. Knowledge of the hourly water application rate and irrigation distribution uniformity also needs to be considered when converting ETc estimates into irrigation run times.



WEEKLY ET REPORT
(Estimated Crop Evapotranspiration or ETc)
07/18/25 through 07/24/25

Crops (Leafout Date)	Tehama County - Gerber South			Butte County - Biggs			Butte County - Durham			Colusa County - Williams		
	Past Week of Water Use	Accum'd Seasonal Water Use	Next Week's Estimated ETc	Past Week of Water Use	Accum'd Seasonal Water Use	Next Week's Estimated ETc	Past Week of Water Use	Accum'd Seasonal Water Use	Next Week's Estimated ETc	Past Week of Water Use	Accum'd Seasonal Water Use	Next Week's Estimated ETc
Pasture [ETo]	1.69	30.94	1.85	1.57	28.18	1.72	1.51	25.68	1.65	1.61	31.32	1.76
Olives Table *	1.28	23.45	1.40	1.19	21.37	1.30	1.15	19.51	1.23	1.22	23.67	1.31
Olives High Density *	1.02	18.59	1.12	0.95	16.92	1.02	0.89	15.39	1.00	0.96	18.83	1.05
Citrus *	1.10	20.21	1.19	1.03	18.39	1.12	0.99	16.77	1.08	1.04	20.44	1.14
Almonds (3/01) *	1.88	28.52	2.06	1.75	25.89	1.92	1.68	23.65	1.82	1.80	28.63	1.94
Cling Peaches (3/25) *	1.77	21.15	2.05	1.65	19.25	1.90	1.59	17.68	1.81	1.69	21.07	1.94
Pistachios (4/7) *	2.02	23.09	2.20	1.87	20.90	2.05	1.81	19.30	1.95	1.92	22.99	2.08
Prunes (3/25) *	1.62	25.88	1.78	1.50	23.34	1.65	1.44	21.17	1.59	1.54	26.05	1.69
Walnuts (4/7) *	1.69	24.81	1.85	1.57	22.35	1.72	1.51	20.43	1.66	1.61	24.82	1.76
Urban Turf Grass	1.57	26.40	1.61	1.48	24.08	1.50	1.42	22.07	1.43	1.52	26.69	1.52
Past 7 days precipitation (inches)		(0.00)			(0.00)			(0.00)			(0.00)	
Accumulated precipitation (inches)		(3.01)			(2.23)			(3.10)			(1.52)	

*Accumulations started on March 1, 2025 for pasture, table and high density olives, citrus, almond, turf grass, and rainfall. Accumulations for prune, walnuts, and vineyards will begin as soon as leafout occurs for the 2023 season and the leafout date will be noted in parentheses next to the crop.

* Estimates are for orchard floor conditions where vegetation is managed by some combination of strip applications of herbicides, frequent mowing or tillage, and by mid and late season shading and water stress. Weekly estimates of soil moisture loss can be as much as 25 percent higher in orchards where cover crops are planted and managed more intensively for maximum growth.

PAST WEEKLY APPLIED WATER IN INCHES, ADJUSTED FOR EFFICIENCY [1]

Crops	Tehama County - Gerber South			Butte County - Biggs			Butte County - Durham			Colusa County - Williams		
System Efficiency >>	70%	80%	90%	70%	80%	90%	70%	80%	90%	70%	80%	90%
Olives Table	1.8	1.6	1.4	1.7	1.5	1.3	1.6	1.4	1.3	1.7	1.5	1.4
Olives High Density	1.5	1.3	1.1	1.4	1.2	1.1	1.3	1.1	1.0	1.4	1.2	1.1
Citrus	1.6	1.4	1.2	1.5	1.3	1.1	1.4	1.2	1.1	1.5	1.3	1.2
Almonds (3/01)	2.7	2.4	2.1	2.5	2.2	1.9	2.4	2.1	1.9	2.6	2.3	2.0
Cling Peaches (3/25)	2.5	2.2	2.0	2.4	2.1	1.8	2.3	2.0	1.8	2.4	2.1	1.9
Pistachios (4/7)	2.9	2.5	2.2	2.7	2.3	2.1	2.6	2.3	2.0	2.7	2.4	2.1
Prunes (3/25)	2.3	2.0	1.8	2.1	1.9	1.7	2.1	1.8	1.6	2.2	1.9	1.7
Walnuts (4/7)	2.4	2.1	1.9	2.2	2.0	1.7	2.2	1.9	1.7	2.3	2.0	1.8

1 The amount of water required by a specific irrigation system to satisfy evapotranspiration. Typical ranges in irrigation system efficiency are: Drip, 80%-95%; Micro-sprinkler, 80%-90%; Sprinkler, 70%-85%; and Border-furrow, 50%-75%.

For further information concerning all counties receiving this report, contact the Tehama Co. Farm Advisor's office at (530) 527-3101 or the Glenn Co. Farm Advisor's office at (530) 865-1153.

This same information and source is now available in the ET Reports section of the sacvalleyorchards.com website. Same information, just in a different format.

Figure 4. Weekly ET Report for Butte and surrounding counties, image provided jointly by UC ANR and DWR Northern Region.

Growers in the pilot study mostly utilized weekly ETc reports provided jointly by UC DWR, Northern Region. The resolution of this data is limited with only two CIMIS stations presently operating in Biggs and South Gerber and neither station is in the Vina Subbasin. A third more representative CIMIS station was in operation near Durham in the Vina Subbasin through July 30, 2025, but has been discontinued (Figure 4).

ETc estimates are most effective when combined with soil moisture and plant-based measurements to confirm that irrigation timing and amounts are meeting orchard water needs.

SOIL MOISTURE SENSORS

Soil moisture sensors measure volumetric water content or soil water tension at specific depths, providing information on when and where water is being depleted by the crop.

Soil moisture probes provide a series of sensors at multiple depths within the active root zone. The soil moisture data help growers determine timing of irrigation, the effectiveness of irrigation events in replenishing soil moisture within the rootzone. It also offered insight into infiltration patterns, the rate at which water moved through the soil profile, and whether soil moisture was approaching levels that could result in deep percolation beyond the desired rooting depth (Figure 5).

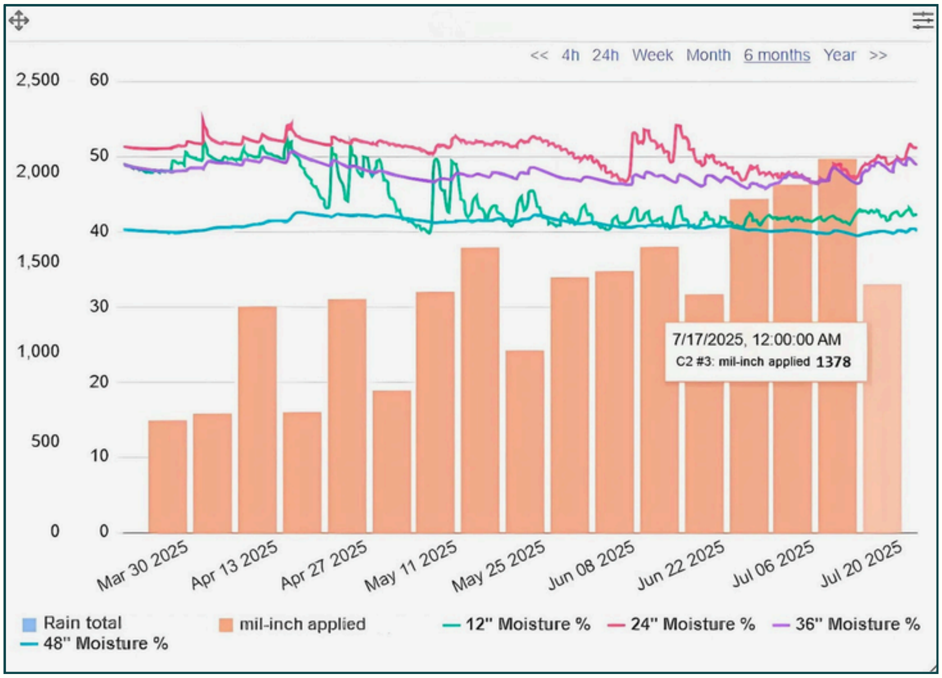


Figure 5. Soil Moisture, image provided by HotspotAG.

Growers and advisors interpret soil moisture trends relative to established thresholds. When soil moisture declines below a target range, often defined as a percentage of available water or a level of soil water tension, irrigation is initiated to avoid excessive crop water stress.

In many cases in this pilot study where soil moisture monitoring was used, it was most often integrated with SWP measurements collected using a pressure chamber, with SWP serving as the primary driver for irrigation timing decisions. These growers and/or consultants preferred the direct measure of crop stress to guide timing decisions over estimations based on soil moisture conditions.

STEM WATER POTENTIAL MEASUREMENTS

Manual Stem Water Potential Measurements – Pressure Chambers

Stem water potential (SWP) is a measure of the water status of a plant (tree), expressed as the negative pressure required to extract water from the xylem tissue of the stem. It reflects the balance between soil water availability, atmospheric demand, and plant water use, and is commonly measured at midday using a pressure chamber on a shaded, bagged leaf that has equilibrated.

Figure 6. Pressure chamber in use.

Pressure Chambers (also known as pressure bombs) were used by multiple growers in the pilot study to collect SWP readings. Growers collected measurements midday, generally between approximately 12:00 and 4:00 p.m., when tree water stress is most pronounced and comparable across dates (Figure 7).

When interpreted relative to established baseline values and prevailing evaporative demand, SWP provides an integrated assessment of soil moisture availability, atmospheric conditions, and tree physiological response. This data can be used to guide irrigation timing and duration and detect developing water stress before visual symptoms are observed.

While pressure chamber measurements provide high-quality, decision-relevant information, their use requires trained personnel and field time. Data collection is labor-intensive, particularly in large orchards or when frequent measurements are needed. As a result, pressure chamber measurements are often used in combination with ET-based scheduling and soil moisture sensors to balance data quality with labor efficiency.

All Star Farms - Arbuckle Ranch - Almonds - South

Commodity: Almonds

Display Data From 09/02/2020 Through 10/29/2020

October 11th, 2020

-0.4 Bars Off Baseline

Figure 7. Charted Trends in Pressure Chamber Data - image provided by Pressure Bomb Express.

Automated Stem Water Potential Sensors

Micro-tensiometers

Micro-tensiometers measure stem water potential (SWP) like what is measured with a pressure chamber. The device is installed into the trunk or tree limbs directly into the tree's xylem (water-conducting tissue) and delivers real-time SWP data that can support irrigation decision-making (Figure 8).

During grower interviews, two pilot study growers described previous field experiences using micro-tensiometers at an experimental level. The readiness and feasibility of using micro-tensiometers in walnuts lags almonds. Standard installation procedures used in almonds does not work as well in walnuts. During installation, a hole is drilled into the almond trunk or a tree limb to insert the instrument. However, in walnuts when the tree

Figure 8. FloraPulse Micro-tensiometer. Photo by Pressure Bomb Express

attempts to heal around the wound and the micro-tensiometer after installation, it interferes with the instruments contact with the water conducting tissue inside the tree and prevents it from functioning reliably.

This is mentioned because pressure chambers were a frequently used tool by growers in this pilot study. While it is a helpful tool and a relatively high rate of adoption was observed, it is labor intensive which can discourage its adoption by other growers. Investment in further development of micro-tensiometers could potentially elevate the use of plant stress indicators in water management and help growers in the Vina Subbasin achieve higher productivity and water efficiency.

DENDROMETERS

Dendrometers were used in a small fraction of the orchards and irrigated acres in this pilot study. They are plant-based sensors used to continuously measure small changes in trunk or branch diameter. In almond and walnut orchards, these measurements provide insight into tree water status by capturing diurnal patterns of shrinkage and expansion associated with transpiration and water uptake. These measurements have been calibrated with SWP measurements to help interpret them (Figure 9).

Figure 9. Dendrometer

During daylight hours, trees typically exhibit trunk shrinkage as transpiration demand increases and water is withdrawn from elastic tissues. At night, trunk diameter generally increases as transpiration declines and tissues rehydrate. Under adequate soil moisture conditions trees show full overnight recovery. When water availability is limited, nighttime rehydration may be incomplete, indicating developing water stress.

Dendrometer data can be summarized into Maximum Daily Shrinkage (MDS) reflecting the difference between daily maximum and minimum trunk diameter and tends to increase as water stress intensifies. Trunk Growth Rate (TGR) reflects longer-term growth trends and may decline or become negative under prolonged water deficits. These indicators allow growers and advisors to detect water stress earlier than visual symptoms and, in some cases, earlier than soil-based measurements (Figure 10).

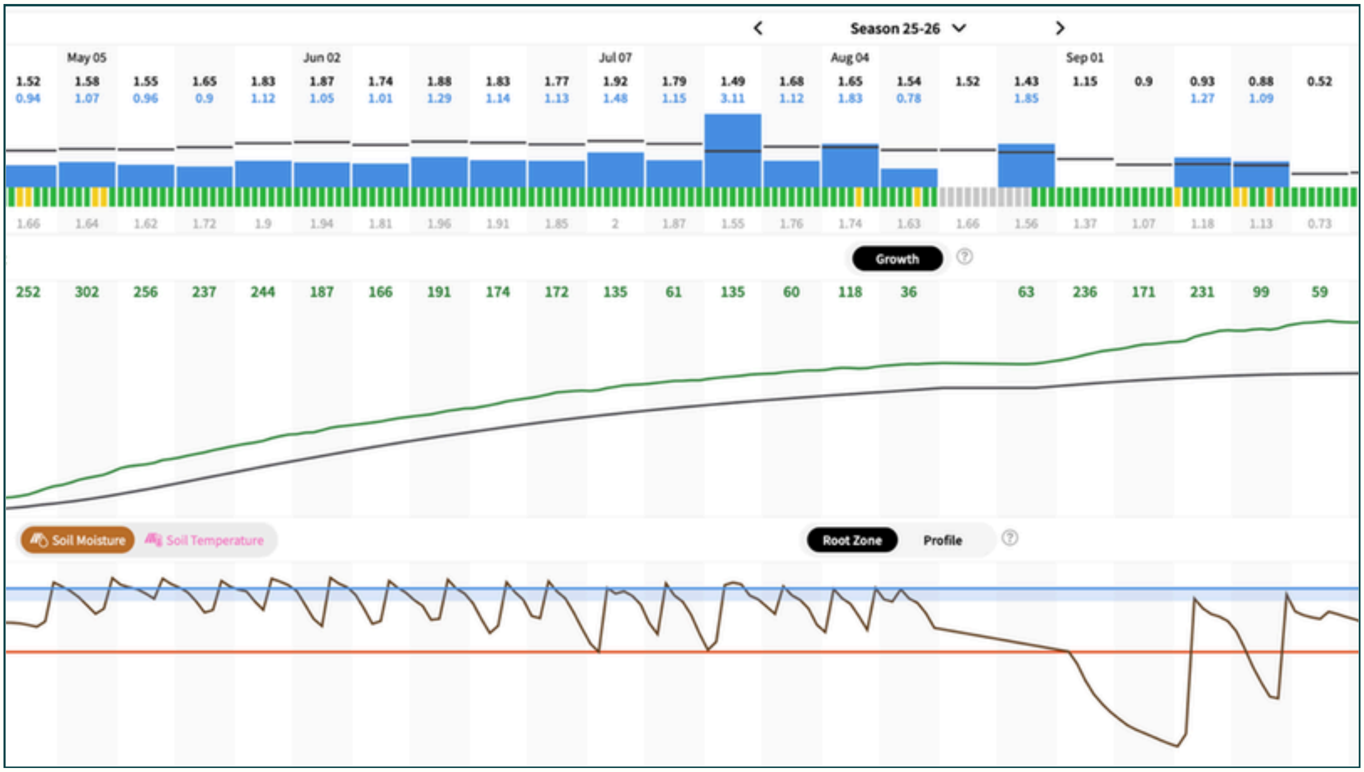


Figure 10. Dendrometer data from Phytech.

In almond and walnut production systems, dendrometers are often used in combination with soil moisture sensors, reference evapotranspiration (ETo), and crop coefficients. This integrated approach supports irrigation scheduling decisions, including adjustments to irrigation timing, duration, and implementation of regulated deficit irrigation during less water-sensitive crop growth stages.

COMBINATION OF METHODS

One-third of the orchards in the pilot project were irrigated using a combination of three irrigation scheduling tools and techniques to guide irrigation timing and duration. While two-thirds of the orchards were irrigated using two or less irrigation scheduling tools. Stem water potential measurements collected using a pressure chamber was the most commonly used tool across the different combinations of methods. It was used along with ETc estimates or with soil moisture information obtained from in-field sensors or verified through hand-feel soil moisture assessments.

The orchards where three tools were used to determine irrigation timing and duration used a complementary set of data inputs: crop evapotranspiration (ET) estimates to quantify crop water use and estimate irrigation run time, plant-based measurements to assess tree water status, and soil moisture information to evaluate the depth and effectiveness of soil moisture replenishment (Figure 11).

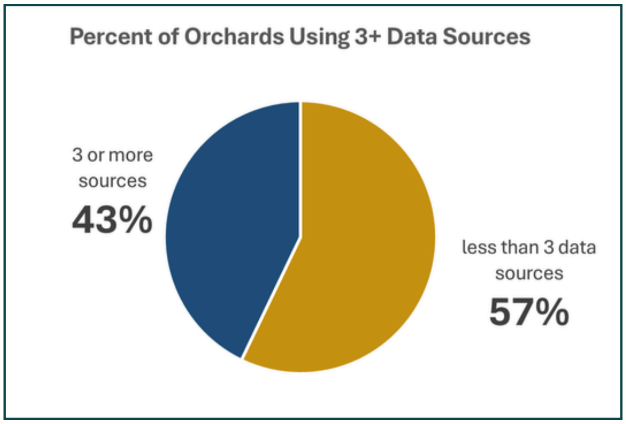
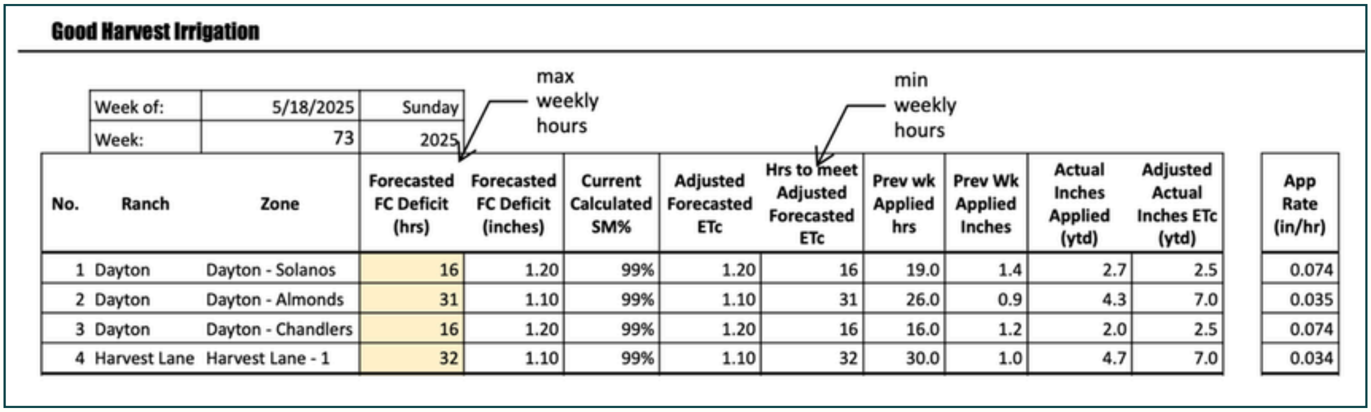


Figure 11. Percent of Orchards Using Three Plus Data Sources.

CONSULTANTS AND THE ROLE THEY CAN PLAY

An alternative approach used by two pilot study growers involved working with an external consultant to provide irrigation recommendations. In one case, the consultant assessed soil moisture using the USDA "estimate of soil moisture by feel and appearance" method and incorporated ETc estimates from UC ANR/DWR reports to develop weekly recommendations for irrigation initiation and run time (Figure 12).



Good Harvest Irrigation

Week of:	5/18/2025	Sunday
Week:	73	2025

No.	Ranch	Zone	Forecasted FC Deficit (hrs)	Forecasted FC Deficit (inches)	Current Calculated SM%	Adjusted Forecasted ETc	Hrs to meet Adjusted Forecasted ETc	Prev wk Applied hrs	Prev Wk Applied Inches	Actual Inches Applied (ytd)	Adjusted Actual Inches ETc (ytd)	App Rate (in/hr)
1	Dayton	Dayton - Solanos	16	1.20	99%	1.20	16	19.0	1.4	2.7	2.5	0.074
2	Dayton	Dayton - Almonds	31	1.10	99%	1.10	31	26.0	0.9	4.3	7.0	0.035
3	Dayton	Dayton - Chandlers	16	1.20	99%	1.20	16	16.0	1.2	2.0	2.5	0.074
4	Harvest Lane	Harvest Lane - 1	32	1.10	99%	1.10	32	30.0	1.0	4.7	7.0	0.034

Figure 12 . Weekly Consultant Provided Recommendation – image provided by Good Harvest Irrigation.

In another case, consultants employed a more intensive, sensor and data-driven approach that included reviewing soil moisture data from in-field sensors, collecting pressure chamber (stem water potential) measurements. These inputs were integrated into a proprietary software platform that estimated soil moisture depletion and generated weekly irrigation scheduling recommendations.

Figure 13. Consultant checking soil moisture content.

CONCLUSIONS AND OBSERVATIONS

While the pilot study included a diverse range of irrigation management approaches and a limited sample size, the findings nonetheless offer useful insight into current technology adoption and irrigation decision-making practices.

The use of scientific data sources - About three quarters of participating orchards and pilot acreage relied on two or more scientific data sources to guide irrigation decisions using the best technologies currently available. Some of the growers demonstrated concern and vision for the future by actively working with technology companies to refine and improve on tools to better meet the need of the tree crops grown in the region (i.e. dendrometers and automated step water potential sensors).

The use of pressure chambers - Almost half of growers incorporated SWP measurements either as a primary decision tool or in combination with other data sources. On average, orchards not using pressure chamber data applied water equal to approximately 75% of estimated crop evapotranspiration (ETc), while orchards using pressure chamber measurements applied approximately 69% of ET. This represents a six percent reduction in

CONCLUSIONS AND OBSERVATIONS

applied water and pumping groundwater as well as better utilization of stored soil moisture and effective rainfall to supply crop ET. In the case of almonds, when irrigation is purposely reduced to enhance hull split during a two-to-three-week period prior to crop maturation, it may represent a regulated deficit irrigation practice that reduces ETc.

In the case of walnuts, the reduction in applied water was greatest, averaging 21.7 percent. With seasonal ETc of approximately 3.62 acre-feet, this reduction corresponds to a potential water savings of about 7.8 inches per acre. This equates to approximately 0.65 acre-feet of reduced applied water per irrigated acre over the season, or about 650 acre-feet of reduced groundwater pumping per 1,000 acres irrigated (Figure 14).

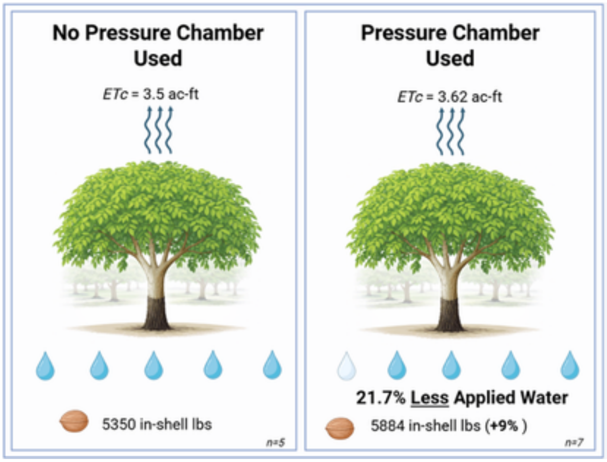


Figure 14.Average percent of ET over applied water in walnuts.

When evaluating water productivity (unit production per unit applied water) in both almonds and walnuts, the orchards with some of the highest water efficiency incorporated pressure chamber SWP measurements as part of their irrigation decision-support approach.

Overall, 48% of pilot orchards used a pressure chamber to collect SWP measurements. Use was more prevalent in walnuts, where 58% of growers incorporated a pressure chamber, either as a primary tool or in combination with other data sources, to guide irrigation decisions. In contrast, adoption in almonds was lower, with 33% of growers using pressure chamber measurements as part of their irrigation decision-support approach (Figure 15).

CONCLUSIONS AND OBSERVATIONS

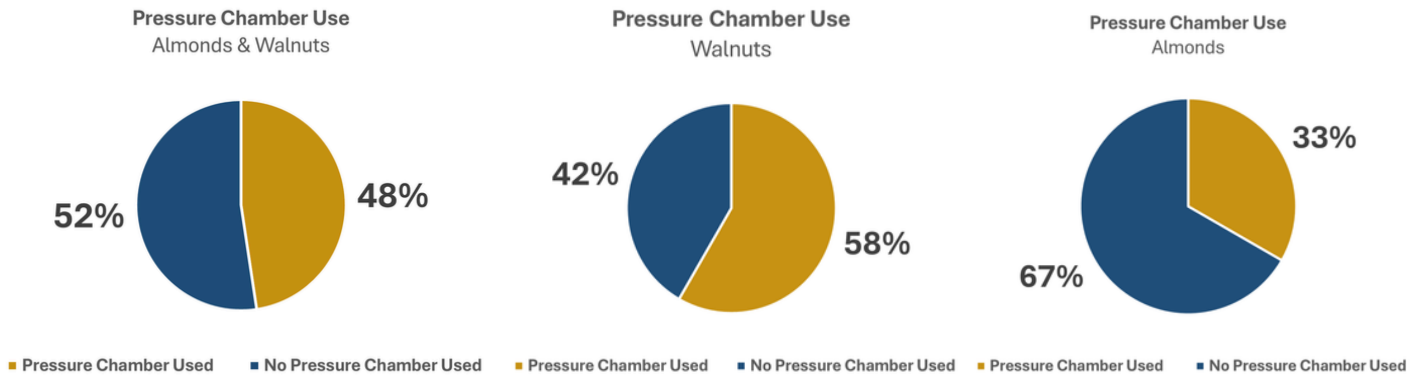


Figure 15. Percent pressure chamber use of pilot orchards

The difference in adoption rates of the pressure chamber and SWP in walnut and almond may be attributed to factors such as ease of use and crop responsiveness. Walnuts have larger leaves and stems which make measurements of SWP with a pressure chamber easier and quicker than almonds. Many walnut rootstocks may respond favorably to improved irrigation scheduling. They tend to be more sensitive to overly saturated soils which damage roots and soil-borne walnut diseases may thrive in overly wet orchards.

ONLINE RESOURCES FOR TECHNOLOGIES ENCOUNTERED IN THIS PILOT STUDY

- UC ANR/DWR joint weekly crop ET reports - https://www.sacvalleyorchards.com/irrigation-mgmt/using-et-reports/
- Wiseconn soil moisture monitoring and other remote monitoring - https://wiseconn.com/
- Stem water potential measurement - https://www.sacvalleyorchards.com/manuals/stem-water-potential/
- Plant Moisture Stress Instruments - https://www.pmsinstrument.com/
- Pressure Bomb Express - https://pressurebombexpress.com/
- Dendrometers - https://www.phytech.com/
- Automated stem water potential sensors - https://florapulse.com/
- Soil augers for soil moisture evaluation – https://www.ams-samplers.com

ATTACHMENT B

Technical Bulletin – Integrating Field Technologies into Irrigation Decision Support

Integrating Field Technologies into Irrigation Decision Support

INTRODUCTION

As described in the section, Growers participating in the pilot project used a range of tools and approaches to address the questions of when to irrigate and how long to apply water (see **PI Case Study:** Methods for Determining Irrigation Timing and Application Duration). Selecting appropriate tools and techniques is an important decision for both small and large operations.

Each operation faces a unique combination of constraints and opportunities, including staff expertise, financial resources, existing irrigation infrastructure, and orchard layout. As a result, no single approach is appropriate for all situations. Developing a plan prior to selecting specific tools or technologies helps ensure that the chosen approach meets current operational needs while remaining adaptable to future conditions.

Developing a Framework for Success

Four key steps can help ensure that irrigation scheduling tools deliver meaningful value and support irrigation decision-making:

1. Develop an **irrigation management plan**.
2. Choose a lead person or **"champion"**.
3. Select **appropriate tools**.
4. **Validate results** with field observations.

STEP 1: DEVELOP AN IRRIGATION MANAGEMENT PLAN

With the wide range of irrigation and monitoring technologies currently available, it is increasingly important for operations to begin with a **clear irrigation management plan** before selecting and installing new tools. Bringing the full management team together to discuss goals, expectations, and constraints is strongly encouraged prior to implementation.

Although this planning step is sometimes overlooked, a well-defined irrigation management plan can lead to a more effective monitoring strategy, improved communication among staff and advisors, and more consistent use of collected data in irrigation decisions.

Time invested upfront helps ensure that decisions made today align with current operational needs while maintaining flexibility for future expansion or changes in management. As with many aspects of farm management, thoughtful planning improves efficiency, reduces unnecessary costs, and increases the likelihood of long-term success.

Defining Goals: The "Why"

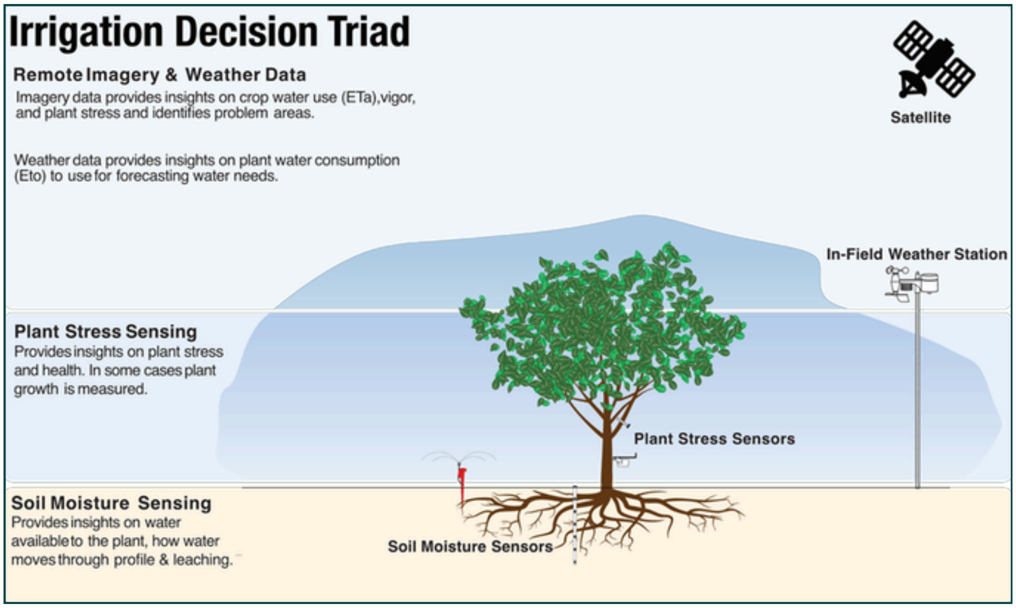
While irrigation management goals vary by operation, common objectives for adopting field monitoring tools include:

- Ensuring irrigation applications meet crop water demand while minimizing over-irrigation.
- Supporting nutrient management by improving fertilizer timing and placement.
- Improving understanding of water movement and storage within the soil profile.
- Enhancing record keeping, supporting future-year planning and document water use.
- Increasing crop production and quality and/or water efficiency to justify return on investment.

Clearly defining these goals provides the foundation for selecting appropriate tools and integrating them into day-to-day irrigation management.

The Irrigation Decision Triad

Early agricultural technology efforts focused primarily on soil moisture monitoring. Today, growers have access to a broader suite of tools that estimate crop water use through evapotranspiration (ET) modeling and remotely sensed imagery, assess plant water status using pressure chambers and plant-based sensors, and measure soil moisture using multiple technologies.



Remote Imagery & Weather Data

Imagery data provides insights on crop water use (ETa),vigor, and plant stress and identifies problem areas.

Weather data provides insights on plant water consumption (Eto) to use for forecasting water needs.

Plant Stress Sensing

Provides insights on plant stress and health. In some cases plant growth is measured.

Soil Moisture Sensing

Provides insights on water available to the plant, how water moves through profile & leaching.

Figure 1- Irrigation Decision Triad

Each of these approaches provides a different perspective on orchard water status. When used together, they form an Irrigation Decision Triad, integrating soil-based measurements, plant-based indicators, and atmospheric or ET-based estimate to provide a more complete and reliable framework for irrigation decision-making.

The Role of Software Platforms in Irrigation Data Management

In discussions of irrigation technology, attention is often placed on sensors, controllers, and telemetry hardware, while the software platforms used to view, organize, and interpret data receive less consideration. In practice, software applications are the primary interface between users and field monitoring systems.

Once hardware is installed and functioning as intended, it typically operates in the background. Software platforms, however, are accessed frequently and play a central role in day-to-day irrigation decision-making. Effective irrigation management depends not only on reliable field measurements, but also on software that presents data in a clear, intuitive, and actionable manner.

Operations are encouraged to evaluate software platforms as a management team, with consideration for how field data will be reviewed, shared, and used to support irrigation decisions across roles and locations.

Key Considerations

Ease of Use	Is the platform intuitive, with clear and efficient access to field data?
Field Accessibility	Does the platform offer a mobile or tablet-friendly interface suitable for use by field staff?
Decision Support	Does the software provide tools that translate measurements into actionable information, or does it only display raw sensor data?
Reporting Capabilities	Are reports available to support internal communication, documentation, or regulatory and program reporting needs?
Scalability & Integration	Can the platform accommodate future expansion, such as additional field stations, automation, or integration with other data sources?
Data Management at Scale	How well does the platform organize and summarize data across large numbers of monitoring locations?
Spatial Visualization	Is a map view available, and does it use visual indicators (e.g., color-coded water status) to improve efficiency in data review?

Considerations for Selecting a Technology Provider

In addition to selecting appropriate tools, choosing a technology provider is an important component of irrigation management planning. Understanding a provider's experience, long-term viability, and support structure can help reduce operational risk and improve the likelihood of successful adoption.

Some operations may be comfortable adopting newer or emerging technologies, while others may prefer systems with an established track record of field use. Aligning the maturity of a product and the stability of the provider with the operation's risk tolerance, staffing capacity, and management goals is an important planning step.

Key Considerations

Product Maturity	Do the products have a demonstrated history of use under commercial field conditions, or are they newer technologies still undergoing refinement?
Company Experience	How long has the provider been operating in the agricultural technology space?
Field Support	Is local or regional technical support available for installation, troubleshooting, and training?
Service Structure	How are field service, technical support, and travel costs charged?
Warranty & Documentation	Is there a clearly documented product warranty and defined expectations for maintenance and replacement?

The Role of Consultants in Irrigation Technology Implementation

In some operations, working with an external consultant may be an effective way to support the adoption and use of irrigation monitoring technologies. Consultants can work alongside internal staff to provide guidance on system selection, installation, data interpretation, and integration of information into irrigation decision-making.

In other cases, consultants may provide full-service support using consultant-installed systems or contracted services, such as collecting pressure chamber measurements or conducting soil moisture monitoring. This approach can be particularly useful when internal staffing, time, or technical expertise is limited.

When considering the use of consultants, it is important to clearly define roles, responsibilities, and expectations to ensure that collected data supports management objectives and is communicated effectively to the irrigation team.

STEP 2: IDENTIFY A CHAMPION

A critical step in developing an irrigation management plan is identifying a **Champion**, the individual responsible for leading implementation and ongoing use of irrigation technologies. Successful adoption depends not only on selecting appropriate tools, but also on clearly assigning responsibility for system oversight, data review, and communication.

In some cases, technologies are purchased and installed without first designating a Champion. When roles and expectations are unclear, adoption may be limited by factors such as insufficient training, lack of clarity around management goals, limited time availability, or skepticism toward new tools. Under these conditions, even well-designed systems may be underutilized or abandoned.

The Champion serves as the primary point of contact for training, troubleshooting, and coordination among management, field staff, and technical advisors. This role helps ensure accountability, promotes consistent use of the technology, and supports integration of field data into routine irrigation decision-making.

Characteristics of an Effective Champion

- Has sufficient time and authority to support implementation
- Understands orchard operations and irrigation practices
- Is willing to engage with software platforms and data tools
- Serves as a communication link between irrigation technology field support staff and other farm management and irrigation field staff

Potential Champions

The Champion may vary by operation and management structure. Depending on available expertise, time, and decision-making authority, this role may be filled by:

- Grower or farm owner
- Ranch manager or irrigation manager
- Crop consultant or irrigation advisor
- Pest Control Advisor (PCA) or Certified Crop Advisor (CCA)

Regardless of who fills this role, it is important that the Champion has clearly defined responsibilities, adequate training in technology field support, and support from farm ownership or upper level management to ensure consistent use of irrigation data in decision-making. It's important the irrigation field staff are also on board to trust and carry out the irrigation decisions.

STEP 3: SELECTING MONITORING AND CONTROL TOOLS

Once an irrigation management plan has been developed, the process of selecting appropriate tools becomes more efficient and effective. Clearly defined goals help narrow options, reduce unnecessary complexity, and ensure that selected technologies align with operational needs.

Tool selection should focus on matching technologies to the cropping system, irrigation infrastructure, staffing capacity, and management objectives, while maintaining flexibility for future changes.

Key Considerations

System Capability	Are sensors and tools appropriate for the crop, soil type, and irrigation system in use?
Budget Considerations	How do initial costs, ongoing service fees, and maintenance requirements align with available resources? What is the likelihood of a positive return on investment?
Integrating Decision Making	Will a single measurement approach meet management needs, or is there value in using multiple inputs (e.g., soil-, plant-, and ET-based information as part of the Irrigation Decision Triad)?
Communication Constraints	Are there site-specific limitations, such as cellular coverage, terrain, or distance between field locations?
Telemetry Options	What communication systems are available and appropriate (e.g., cellular, radio, or LoRa-based networks)?
Scalability	If beginning with a limited number of tools, can the system expand as familiarity increases and operational needs evolve?
Future Functionality	If the initial focus is monitoring to decide when and how much water to apply, does the platform allow for future integration of irrigation system automation or control to help execute these decisions?
Leveraging a Consultant	Is there a role for outsourcing installation, data management, or interpretation through a consulting firm working in coordination with the internal irrigation team?

DECISION MATRIX: SELECTING IRRIGATION DECISION SUPPRORT TOOLS

Consideration	Key Questions	Notes / Tradeoffs
Crop & Soil Fit	Are sensors appropriate for the crop, soil texture, and rooting depth?	Soil variability may require multiple sensor locations
Irrigation System	Is the technology compatible with drip, micro-sprinkler, or flood systems?	Some tools perform better under pressurized systems
Management Objective	Is the goal monitoring, decision support, and/or automation?	Monitoring-only systems may limit future options
Budget	What are upfront, subscription, and maintenance costs?	Lower-cost systems may require more manual interpretation
Data Inputs	Will a single measurement suffice, or are multiple inputs desired?	Multiple inputs improve confidence but increase complexity
Communication	Is reliable cellular service available at the site?	Radio or LoRa may be better in remote locations
Telemetry Type	Cellular, radio, or LoRa?	Tradeoffs between range, cost, and data frequency
Scalability	Can the system expand to additional blocks or sensors?	Important for phased adoption
Automation Potential	Can monitoring later integrate with valves or controls?	Envisioning future needs reduces reinvestment
Support Structure	Will installation and interpretation be handled in-house or outsourced?	Consultants may reduce learning curve

STEP 4: VALIDATING RESULTS

Validating field data is a critical step in successfully using agricultural technologies. Data that is not trusted, even if technically accurate, is unlikely to be used in management decisions. Validation builds confidence, improves acceptance across the management team, and ensures that monitoring tools provide meaningful information.

Key Practices for Field Data Validation

Soil Moisture Verification	Use a soil auger to check moisture conditions throughout the monitored soil profile. Comparing observations to sensor readings helps establish wet and dry reference points that guide irrigation decisions. Frequent checks during the first season are strongly recommended.
Plant Stress Sensor Validation	For pressure chambers, seek training from an experienced pressure chamber operator, acquire and use field validated procedures and interpretive guidelines for best results. For devices such as micro-tensiometers or dendrometers, confirm readings by taking stem water potential (SWP) measurements with a pressure chamber. Spot checks throughout the season help ensure sensor reliability.
Water Budgeting	A water budget, similar to balancing a checkbook, can be used to validate soil moisture and plant stress conditions.Comparing crop evapotranspiration (ETc) to available soil moisture storage, effective rainfall, and applied water can help determine whether irrigation events may have under- or over-supplied crop water demand. Accurate use of this approach requires a working knowledge of the irrigation system application rate and distribution uniformity along with effective rootzone, and soil water holding capacity.
Troubleshooting Unexpected Monitering Results	Unexpected or unusual data does not always indicate faulty sensors or measurements. Investigate field conditions directly before making conclusions or dismissing results.
Field Follow-Up	When results are unclear, return to the orchard to observe soil and plant conditions firsthand. Direct verification supports better interpretation of data and improves confidence in management decisions.

THREE GUIDELINES FOR USING FIELD TECHNOLOGY

When implementing any irrigation technology, following a few simple guidelines can help ensure success and reduce frustration:

Sensors provide information—they do not control conditions.
Sensors measure soil, plant, or environmental conditions, but they do not change them. Management decisions must be made based on the data they provide.

Measured conditions may differ from expectations.
Variability in soil properties, crop characteristics, or weather conditions can result in sensor readings that differ from initial assumptions. For example, assumptions about rootzone depth or plant-available soil water may not accurately reflect field conditions. If the effective rootzone is shallower or deeper than expected, or if plant-available soil moisture is greater or less than assumed, sensor measurements may indicate crop conditions that differ from expectations.

Recognizing this variability is important for properly locating sensors, interpreting data, and adapting management decisions accordingly.

Similarly, following periods of heavy rainfall, there may be an expectation that soil moisture levels at deeper depths will increase. However, in fine-textured or poorly structured soils, water movement to lower depths may be delayed. In some cases, restrictive soil layers may limit downward movement altogether, preventing measurable changes at deeper sensor locations. Understanding this helps accept new findings and interpret data correctly.

Verify uncertain results in the field.
When sensor readings appear unexpected or unclear, conditions should be verified directly in the field using independent measurements such as a soil auger or pressure chamber before making irrigation decisions. Field verification helps determine whether the sensor is functioning properly or whether site conditions explain the readings.

When reviewing soil moisture data, confusion can arise if sensor values do not change over time. Two common scenarios may explain this. First, if soil at the sensor depth is already saturated, readings may not increase because soil water content is not changing. Second, in soils with infiltration limitations, applied irrigation water may not reach the depth of the sensor. In this case, the sensor will show little or no change even though an irrigation event occurred.

Understanding these conditions can prevent misinterpretation of data and support more informed irrigation decisions. Field validation not only helps resolve uncertainty but also builds confidence in using the data.

RECOMMENDED RESOURCES

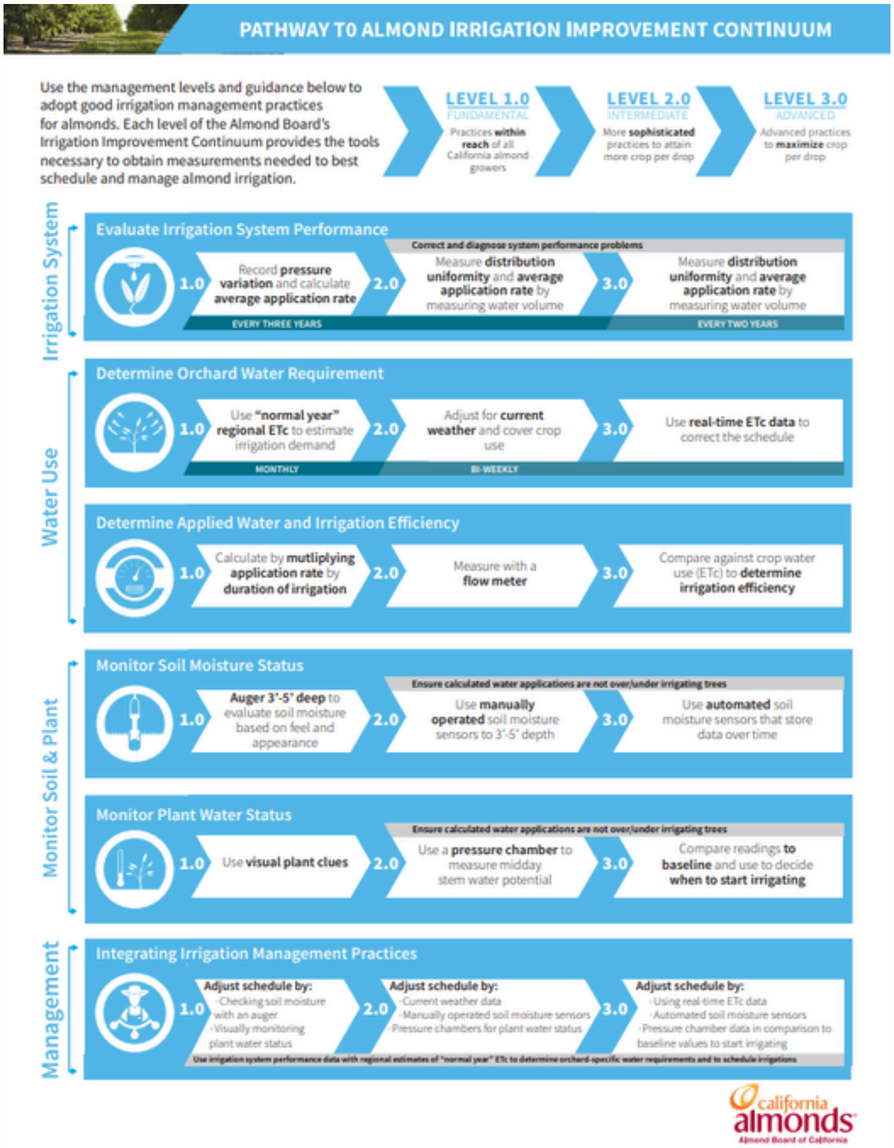
Almond Irrigation Improvement Continuum

The Almond Board of California has developed a practical resource to help growers improve water-use efficiency by tracking performance across four key areas: irrigation system, water use, monitoring, and management.

The resource outlines a three-level pathway for improving irrigation management:

1. **Basic Management Steps**
   Foundational practices to optimize current irrigation operations.
2. **Advanced Monitoring and Tools**
   Integrating technologies to measure soil and plant water status, track water use, and support data-driven decisions.
3. **Enhanced Irrigation and Plant Health**
   Applying insights from monitoring and technology to improve water efficiency while supporting crop growth and health.

Following this structured approach, growers can evaluate current practices, adopt new tools as appropriate, and track improvements over time, supporting both sustainable water use and orchard performance. Although designed for almond production, the resource is equally applicable to walnut orchards.



PATHWAY TO ALMOND IRRIGATION IMPROVEMENT CONTINUUM

Use the management levels and guidance below to adopt good irrigation management practices for almonds. Each level of the Almond Board's Irrigation Improvement Continuum provides the tools necessary to obtain measurements needed to best schedule and manage almond irrigation.

LEVEL 1.0 FUNDAMENTAL: Practices **within reach** of all California almond growers

LEVEL 2.0 INTERMEDIATE: More **sophisticated** practices to attain more crop per drop

LEVEL 3.0 ADVANCED: Advanced practices to **maximize** crop per drop

Irrigation System

Evaluate Irrigation System Performance

1.0 Record **pressure variation** and calculate **average application rate**

2.0 Measure **distribution uniformity** and **average application rate** by measuring water volume

3.0 Measure **distribution uniformity** and **average application rate** by measuring water volume

Correct and diagnose system performance problems

EVERY THREE YEARS

EVERY TWO YEARS

Water Use

Determine Orchard Water Requirement

1.0 Use **"normal year" regional ETc** to estimate irrigation demand

2.0 Adjust for **current weather** and cover crop use

3.0 Use **real-time ETc data** to correct the schedule

MONTHLY

BI-WEEKLY

Determine Applied Water and Irrigation Efficiency

1.0 Calculate by **mutliplying application rate** by **duration of irrigation**

2.0 Measure with a **flow meter**

3.0 Compare against crop water use (ETc) to **determine irrigation efficiency**

Monitor Soil & Plant

Monitor Soil Moisture Status

Ensure calculated water applications are not over/under irrigating trees

1.0 **Auger 3'-5' deep** to evaluate soil moisture based on feel and appearance

2.0 Use **manually operated** soil moisture sensors to 3'-5' depth

3.0 Use **automated** soil moisture sensors that store data over time

Monitor Plant Water Status

Ensure calculated water applications are not over/under irrigating trees

1.0 Use **visual plant clues**

2.0 Use a **pressure chamber** to measure midday stem water potential

3.0 Compare readings **to baseline** and use to decide **when to start irrigating**

Management

Integrating Irrigation Management Practices

1.0 **Adjust schedule by:**
- Checking soil moisture with an auger
- Visually monitoring plant water status

2.0 **Adjust schedule by:**
- Current weather data
- Manually operated soil moisture sensors
- Pressure chambers for plant water status

3.0 **Adjust schedule by:**
- Using real-time ETc data
- Automated soil moisture sensors
- Pressure chamber data in comparison to baseline values to start irrigating

Use irrigation system performance data with regional estimates of "normal year" ETc to determine orchard-specific water requirements and to schedule irrigations

california almonds
Almond Board of California

Figure 2. Irrigation Imporvement Continuum, Almond Board of California. Download a copy of the Continuum.

ATTACHMENT C

Technical Bulletin – Minimizing Midday Irrigation to Reduce Evaporative Losses from Tree Crops in the Vina Subbasin

Minimizing Midday Irrigation to Reduce Evaporative Losses from Tree Crops in the Vina Subbasin

INTRODUCTION

Evapotranspiration (ET) is the water that is consumed to grow tree crops. Crops lose water from soil evaporation (E) and transpiration (T). Water is absorbed from the soil through roots, moves up a tree's vascular system and is vaporized out specialized cells on the underside of leaves, called stomata. Transpiration cools the crop as water exits through stomata while carbon enters the plant for photosynthesis. Solar radiation and wind drive ET, which usually increases with more sunlight, higher temperatures, and more wind.

Since seasonal ET for mature almonds and walnuts has the potential to approach or exceed 42 and 48 inches, respectively, practices that effectively reduce ET without harming the crop could help water users in the Vina Subbasin reduce annual groundwater pumping.

MINIMIZING MIDDAY IRRIGATION

One management strategy is to implement irrigation practices that reduce soil evaporation. This means more nighttime and early-morning irrigation with micro irrigation systems and less late morning and afternoon irrigation. This practice is the focus of this bulletin.

HOW MUCH ET IS SOIL EVAPORATION (E) VERSUS TRANSPIRATION (T)?

Soil evaporation has been studied for many decades across a range of landscapes, climates, and management practices.

Table 1 summarizes six agricultural field studies where evaporative losses were evaluated in almonds, pistachios, and olives in semi-arid conditions like the Vina Subbasin. The orchards were irrigated with drip or micro sprinklers, like those in the Vina Subbasin. Various ages of trees with different percentages of canopy shading and variations in middle vegetation were evaluated in these studies.

Table 1. Description of six nut or olive orchards grown in semi-arid climates, irrigated approximately weekly at peak ET rates using various micro irrigation systems. Seasonal ET and fractions of evaporative losses and transpiration were measured using similar methods in each orchard.

Trial #	Location	Soils	Average Rainfall (Mar-Oct) (in)	Average High July Temp (F)	Crop	Irrigation Method	Orchard Age (yrs)	Size (ac)	Canopy Shading (%)	Middle Vegetation
1	Madera, CA	Sandy loam	11	97	Almonds	Fan-Jet micro sprinkler	18	40	80	Grassy middles
2	Madera, CA	Sandy loam	11	97	Pistachios	Double line drip	14	40	50 to 60	Bare soil
3	Cordoba, Spain	Sandy loam	26	99	Olives	Single line drip, 4 x 1gph	20	NA	36	Bare soil
4	Cordoba, Spain	Sandy loam	26	99	Olives	Single line drip, 2 x 2 gph	6	NA	5	Bare Soil
5	Madera, CA	Sandy laom	12	97	Pistachios Full ET	Full coverage microsprinkler	14	80	57	Bare soil
6	Madera, CA	Sandy loam	12	97	Pistachios RDI	Full Coverage microsprinkler	14	80	57	Bare soil

Table 2 shows evaporative losses ranged from 4 to 43 percent of seasonal ET across all six trials. In the four trials featuring nut crops, the fraction ranged from 13.1 to 36.6 percent. In trial #1, where growing conditions were most like the Vina Subbasin, mature almonds irrigated with grassy middles and irrigated with micro sprinklers, the fraction of evaporation was 16.1 percent of the seasonal ET, which translates to 7.6 inches of seasonal evaporation per acre. This is equivalent to 0.63 ac-ft of groundwater pumping per irrigated acre or 630 ac-ft groundwater pumping per 1000 irrigated acres lost to evaporation. This volume of evaporative highlights why implementing more nighttime and early morning irrigation and minimizing late morning and afternoon irrigation has been identified as a potentially viable practice to help reduce groundwater pumping in the Vina Subbasin.

Table 2. Seasonal ET and fractions of seasonal evaporation (E) and crop transpiration (T) in six nut and olive orchards. ET was determined either with lysimeters or eddy covariance methods while fraction of E and T was determined using microlysimeters and/or calibrated predictive soil moisture loss models.

Trial #	Location	Crop	Irrigation Method	Seasonal ET (in)	Fraction of Seasonal ET			
					E (%)	T (%)	E (in)	T (in)
1	Madera, CA	Almonds	Fan-Jet micro sprinkler	47	16.1	83.9	7.6	39.4
2	Madera, CA	Pistachios	Double line drip	40.2	13.1	86.9	5.3	34.9
3	Cordoba, Spain	Olives	Single line drip, 4 x 1gph	19.7 to 21.3	4 to 12	88.0 to 96.0	1.6 to 1.8	18.1 to 19.5
4	Cordoba, Spain	Olives	Single line drip, 2 x 2 gph	6.4 to 8.9	18 to 43	57 to 82	1.2 to 3.8	5.2 to 6.1
5	Madera, CA	Pistachios Full ET	Full coverage microsprinkler	40.3	30	70	12.1	28.2
6	Madera, CA	Pistachios RDI	Full Coverage microsprinkler	30.9	36.6	63.4	11.3	19.6

Trial #4 was on young olive trees with single line drip and only 5 percent canopy shading. This scenario is not common in the Vina Subbasin but illustrates some important points. The soil was exposed to more sun and wind. Evaporative losses were as high as 43 percent of ET. However, low canopy shading had less seasonal ET (6.4 to 8.9 inches) and less irrigation water was applied to evaporate, which offsets the higher percentages of soil evaporation. Seasonal evaporation ranged from 1.2 to 3.8 inches per acre under these conditions, which equates to only 0.10 to 0.31 ac-ft per acre, or 100 to 310 ac-ft per 1000 acres.

NOT ALL SOIL EVAPORATION CAN BE PREVENTED

Additional research associated with Trial #1 showed that soil evaporation was highest during irrigation at about 0.08 in/day. Evaporation declined by about 20 percent each day after irrigation. By the end of the fifth day, soil evaporation had stabilized at a low rate of about 0.02 in/day until the next irrigation.

Additional research associated with Trial #3 approximated that up to 80 percent of the evaporative losses could be prevented by converting to subsurface drip irrigation, which represents a major change in irrigation methods and comes with other pros and cons. Other field studies with sprinkler irrigation comparing nighttime to daytime solid set sprinkler irrigation showed that evaporative losses still occur at night. Evaporation during nighttime sprinkling was 55 percent of daytime.

Because not all soil evaporation can be prevented, a more realistic estimate of reduced groundwater pumping by minimizing midday irrigation with drip or micro sprinklers in almonds and walnuts for the Vina Subbasin may be in the range of 300 to 350 ac-ft per 1000 acres and not 630 ac-ft per 1000 acres. This approximation would need local field validation. Remotely measured ETa would be a useful tool to validate seasonal reductions of ET with more nighttime irrigation and less midday irrigation.

PRACTICAL CONSIDERATIONS

A key conclusion of one field study stated “Management that emphasizes more nighttime sprinkler irrigation will result in minimizing evaporation. However, such management requires an adequate design of the water delivery network, which must be able to convey irrigation water in a reduced operation time, focusing on night and low-wind periods”.

Growers in the Vina Subbasin who may be interested in nighttime and early morning irrigation and less late-morning and afternoon irrigation need to be prepared to irrigate at most 15 to 18 hours per day and more days to compensate. Automation may be needed to turn the irrigation system on and off more often if it is inconvenient to do manually. To accommodate this, they need to ensure they have sufficient pumping capacity to supply the total orchard acreage given more restricted hours of operation. The irrigation system water application rate needs to also be high enough to supply maximum daily ET demands on extremely hot and windy days. Growers will also need to ensure there is sufficient time with dry orchard floor conditions to enable entry with tractors, heavy air blast sprayers for disease and insect control, and other farm equipment.

Other field studies showed how irrigation system and management types impact how much water is lost to evaporation. Solid set sprinkler systems were observed to have high daytime evaporation, indicating a substantial benefit to nighttime irrigation. Microsprinkler irrigation generally had higher daytime evaporation than drip irrigation due to larger wetting patterns. However, evaporation in drip irrigated orchards was at times observed to be higher than expected, especially when drip systems were operated using long irrigation run times. While the wetted area were smaller, the localized evaporation was high because the soil was almost continuously saturated and the surrounding dry soil contributed to a microclimate with extraordinarily high transfer of heat across the wet soil.

RECOMMENDATIONS

If growers in the Vina Subbasin choose to pursue less late morning and afternoon irrigation to reduce evaporative losses and help reduce groundwater pumping, a logical starting point might target orchards with micro or mini sprinkler irrigation methods and with 20 to 60 percent canopy cover. These orchards are most likely about 3 to 8 years old. These orchards should have:

1. Irrigation systems that wet larger areas of the orchard floor;
2. More barren soil and less middle vegetation between tree rows;
3. Less canopy shading than mature orchards allowing more sunlight penetration and wind to increase soil evaporation;
4. Increasing season totals of ET, resulting in more opportunity to reduce seasonal evaporation each additional year;
5. Lower weekly water requirements than mature orchards with canopy shading of 60 to 90 percent, lessening concerns about sufficient pumping capacity, long enough irrigation set times to supply maximum daily ET, and sufficient time between irrigations with dry soils to allow entry with tractors, sprayers , and other farm equipment.

Remote sensing satellite images and soils maps could help identify orchards with these conditions across the Vina Subbasin. Remotely sensed ET_a measurements could validate reduced ET and groundwater pumping.

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ATTACHMENT D

Technical Bulletin – Field Level Measurements of Applied Water and Opportunities for Improvement

Precision Irrigation Technical Bulletin

Field Level Measurements of Applied Water and Opportunities for Improvement

INTRODUCTION

Accurate and reliable applied water data is a fundamental component of effective irrigation management. Quantifying applied water enables managers to determine whether irrigation events are delivering the intended volume of water to the orchard, both on an event basis and over the course of the season.
Applied water records also help verify that irrigation systems are operating as designed. Comparing applied water to estimated crop evapotranspiration, ETc, provides insight into whether irrigation applications are adequately replacing crop water use.

When combined with soil moisture measurements and plant-based indicators, such as stem water potential, SWP, collected with a pressure chamber or data from tree-based sensors, applied water information helps confirm that irrigation events are aligned with management objectives and supporting overall irrigation plan performance.

Two methods for calculating applied water are addressed in this section. The most used approach is installation of a flow meter at the pumping station. An alternative method involves a monitoring station equipped with either a pressure switch or pressure transducer.This station may also be equipped with other types of sensors such as soil moisture and weather instruments.

FLOW METERS

Eighty-eight percent of growers participating in the pilot had flow meters installed at their pumping stations. Among those, there was an even split between meters that were manually read and meters that transmitted data remotely through software platforms.

Both types of meters can monitor real-time flow, typically displayed as gallons per minute (GPM), and record cumulative flow totals expressed in gallons or acre-feet. However, differences between manually read and remotely monitored meters can significantly affect the accuracy, timeliness, and usefulness of flow records.

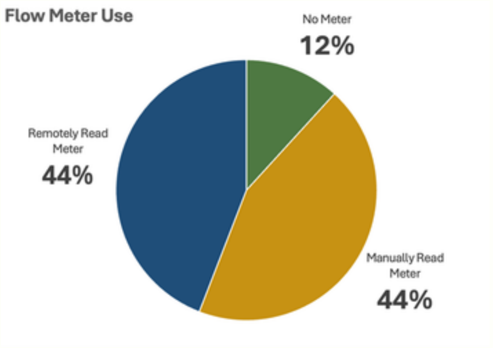

Figure 1. Flow Meter Use

With manually read meters, a person must travel to the field to record readings, either at the start and end of the season or before and after individual irrigation events. If readings are missed, it can be difficult to accurately reconstruct seasonal totals or event-specific flow volumes. Manually retrieving flow meter readings also can disrupt field staff work routines and impact labor both regarding costs and flexibility.

In contrast, remotely monitored meters automatically capture and store flow data within a software platform, allowing information to be retrieved as needed. This approach improves record accuracy, reduces labor requirements, and provides more timely access to applied water data for irrigation decision-making.

Given that the price difference between a manually read propeller meter and a remotely monitored electromagnetic meter can be several thousand dollars, excluding installation costs, it is not surprising that 44 percent of growers relied on simpler, manually read models. Flow meters are often installed when a pumping station is constructed and can remain reliable for many years.

Upgrading to a more advanced, remotely monitored meter can involve substantial additional expense and may be viewed as unnecessary if the existing manually read meter is functioning properly. However, remotely monitored systems can provide long-term benefits, including improved data accuracy, automated record keeping, and easier integration with irrigation management platforms.

Some growers have concerns regarding data privacy, vandalism, and theft associated with flow meters and other components of the pumping station. In many cases, pumping stations are located along roadways, where flow readouts may be visible and accessible to anyone passing by. To limit public visibility and improve security, some operations have installed fencing or enclosures around pump stations. While this can address privacy concerns, it also adds cost and may reduce ease of access for routine operation and maintenance.

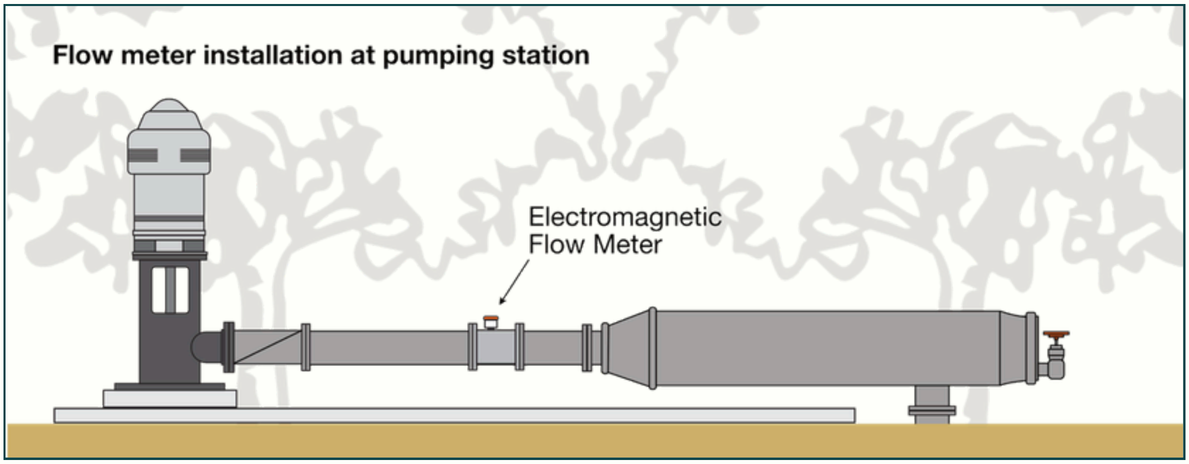

Figure 2. Flow Meter Installation

Comparison of Flow Meter Style

Category	Manually Read Propeller Meter	Remotely Monitored Electromagnetic Meter
Initial Cost	Lower equipment cost	Higher equipment cost
Installation Requirements	Requires longer upstream and downstream distances of straight pipe for installation. (typically, 10 pipe diameters upstream and 5 pipe diameters downstream)	Often shorter straight pipe requirements, depending on manufacturer (typically, 2 pipe diameters upstream, 1 pipe diameter downstream)
Power Requirements	Mechanical register, no external power required	Requires power supply or battery system
Data Access	Manual reading required at pump site	Real-time remote access through software platform
Labor Requirements	Requires field visits for readings	Minimal field visits once installed
Data Resolution	Limited to recorded manual intervals	Continuous data logging at set intervals
Leak Detection	Limited ability to detect small or off-cycle flows	Strong capability to detect abnormal flow patterns
Record Keeping	Manual entry into logs or spreadsheets	Automatic data storage and reporting
Accuracy Over Time	Moving parts subject to wear and debris	No moving parts, less mechanical wear
Maintenance	May require periodic inspection and mechanical servicing	Lower mechanical maintenance, may require sensor or electronics servicing and battery replacement
Longevity	Proven durability in agricultural settings	Durable, but electronics may require updates or replacement over time
Integration with Irrigation Platforms	Manual integration	Seamless integration with ET, soil moisture, and automation platforms
Privacy Considerations	No automatic data transmission but data is viewable at meter location	Data stored electronically and available through software platform, often on smartphone.

IN-FIELD PRESSURE SENSING STATIONS

Another method for estimating applied water involves the use of an **in-line pressure switch or pressure transducer** (Figure 3). Installed on a sprinkler riser or within a drip or micro-sprinkler line, these devices detect when system pressure is present, allowing identification of irrigation start and stop times. Installation location is important and should be placed where pressure reflects typical operating conditions for the block, not immediately adjacent to the pump discharge where pressure may be artificially high. The pressure data is collected by an in-field data logger and transmitted to a web-based software platform, where irrigation runtimes and irrigation system in-line pressures are recorded and stored for review.

Irrigation runtime is combined with the system application rate to calculate the depth of water applied for each irrigation. When irrigation systems are new, the hourly water application rate can be determined from irrigation system design specifications. However, as the system ages and encounter wear, tear, and repair it is very important that the hourly water application be re-measured every few years during a distribution uniformity evaluation. The updated hourly application rate can then be used to estimate the volume of water applied during each irrigation event. The addition of soil moisture probes or tree-based sensors can further improve confidence in irrigation scheduling decisions by providing field-level feedback on crop and soil conditions.

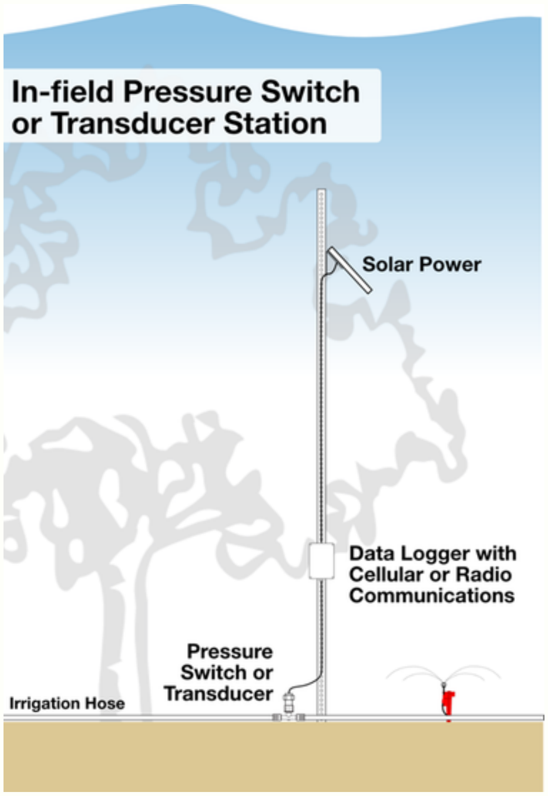

Figure 3. Pressure sensing station.

The simplest and lowest-cost option is a **pressure switch**, which activates when system pressure rises above or falls below a preset threshold, commonly around 10 psi. A **pressure transducer** is a more advanced alternative that continuously measures line pressure in pounds per square inch, allowing verification that the system is operating within the intended pressure range to maintain proper sprinkler distribution patterns or drip emitter flow rates. Software platforms may also generate alerts when irrigation events begin or end, or when line pressure falls outside established operating thresholds.

Unlike a flow meter, pressure-based systems do not display gallons per minute or totalized flow at the orchard location, which may provide greater data privacy. However, applied water values must be calculated within the software platform based on recorded runtime and a validated application rate. Most software platforms provide these calculations automatically and include reporting functions that summarize seasonal applied water.

While pressure-based runtime methods can provide a practical and cost-effective estimate of applied water, their accuracy depends on having a reliable and validated application rate. In contrast, a properly installed and maintained flow meter directly measures total system flow and generally provides greater precision for seasonal water accounting. Pressure-based approaches may also offer insight into system performance and can represent a lower-cost alternative when installation of a flow meter is not feasible.

In the Precision Irrigation pilot study, benefits and challenges were observed for both pressure type and flow meter measurement systems.

Pressure Transducers:

- A pressure transducer was useful to understand when the system turned on and confirmed the irrigation system pressure was sufficient to operate as expected. Every irrigation event throughout the season was tracked and it was possible to reconstruct how much water was applied throughout the season. However, it required computer time and skills to download files and familiarity with Excel software to assess the data.
- Based upon the experience gained from this pilot study, it appeared that water measurement using an accurate hourly water application rate and pressure sensors that track run times better supported field level irrigation management.

Flow Meters:

- With flow meters, it was observed that maintenance along with retrieval and utilization of data was more routine when supported by an irrigation consultant who was familiar with the meter and software platform. It was probably more costly too because of the added technical support.
- In some cases, growers preferred to estimate and record applied water based upon manual records of irrigation dates, set times, and hourly water application rates even with water meter data available. In these instances, there were concerns about meter maintenance, accuracy and availability to record meter data frequently enough.
- For flow meters to assist irrigation management they require proper installation, setup, maintenance, and either remote or timely manual data acquisition and evaluation.
- Water measurement using flow meters appeared more likely to benefit a GSA with broader water resource management responsibilities and perhaps capacity to afford sufficient technical support to assure maintenance, timely readings, and data evaluation.

OPPORTUNITIES FOR IMPROVEMENT

Although accurate measurement of applied water is an important component of irrigation management, two additional areas represent significant opportunities for improvement within the basin. First, limited CIMIS station coverage reduces the availability of localized and representative evapotranspiration, ET, data needed to estimate crop water demand with confidence. Second, irrigation system distribution uniformity remains a critical factor in water use efficiency. Even when applied water is measured accurately, poor uniformity can result in over-irrigation in some areas of an orchard and under-irrigation in others. Improvements in both localized ET data availability and irrigation system performance present opportunities for growers to improve irrigation efficiency and crop performance across the basin.

CIMIS Weather Stations

Most growers in the region rely on grass reference evapotranspiration (ETo) data from regional CIMIS weather stations coupled with specific crop coefficients (Kc) to estimate crop specific water use and determine irrigation replacement needs. However, station coverage within the region is limited. Historically, three CIMIS stations provided ETo data across the area, but as of August 2025, the Durham station became inactive. The remaining stations are located north of the region at Gerber South and south at Biggs (Figure 4).

This reduction in station availability has created a gap in central coverage across the Vina subbasin, resulting in some orchards relying ET estimates that are based on weather data from stations more than 20 miles away. Increased distance from a CIMIS station may reduce the representativeness of ET estimates for local field conditions, particularly during periods of variable weather.

To support accurate irrigation decision-making, additional sources of localized weather data may be needed. This could include expanded CIMIS coverage, stations maintained by other public agencies, or the installation of privately operated weather stations within the region.

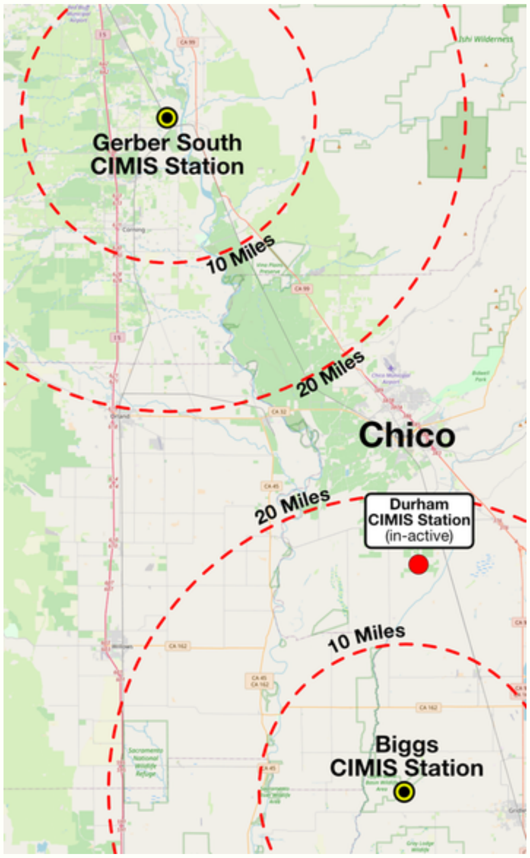

Figure 4. CIMIS station map.

Mobile Irrigation Labs - Evaluating Uniformity Distribution

Poor distribution uniformity, DU, can reduce yield in both almonds and walnuts by creating uneven soil moisture conditions within the orchard. When irrigation water is not applied evenly, some trees experience water stress while others receive excess water. Under-irrigated trees may have reduced nut size, lower kernel weight, or reduced flowering in the subsequent year, while over-irrigated areas may experience nutrient leaching, reduced soil oxygen, and increased disease risk.

Low DU often forces growers to apply additional water to ensure the driest areas receive adequate moisture, resulting in over-irrigation elsewhere. This reduces overall water use efficiency and contributes to variability in tree vigor and yield across the block. Improving distribution uniformity supports more consistent crop performance and better water productivity in both almond and walnut orchards.

Mobile Irrigation Labs can provide irrigation system uniformity distribution test to evaluate irrigation systems to identify hidden challenges such as worn sprinkler nozzles, clogging in irrigation lines, leaks, damaged pressure regulators, and other factors that have an impact on the system performance. At the end of the test the lab will calculate the impact this has on the uniformity of how water is delivered to all areas of the irrigation system. Systems with low uniformity are either under-delivering water (Figure 6), over-delivering water (Figure 7), or both to the orchard. This has a direct impact on water use and crop performance with some trees receiving more water while others may be under irrigated.

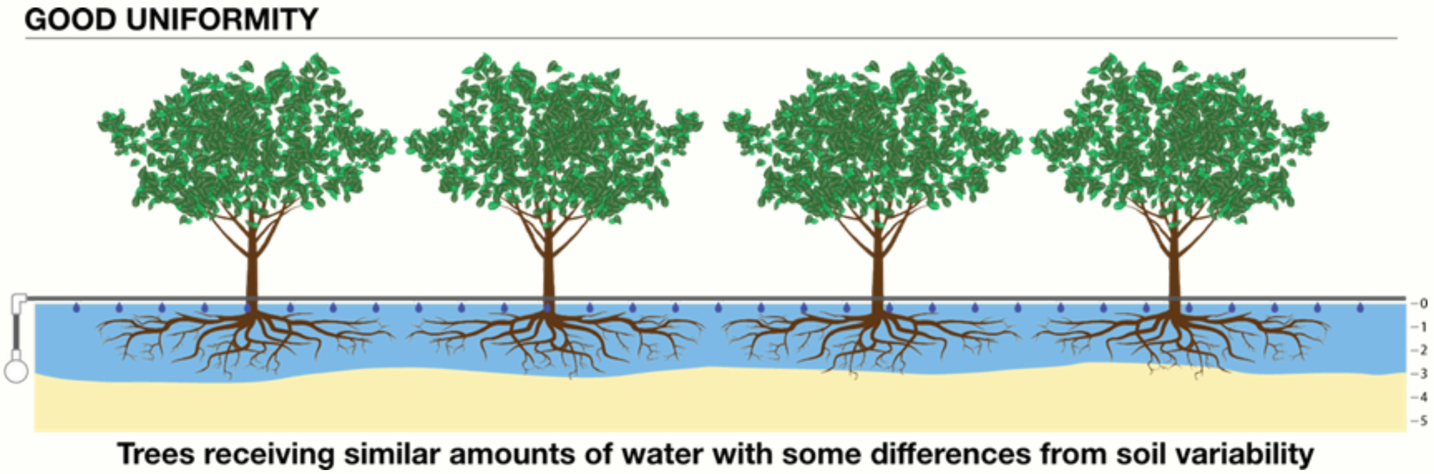

Figure 5. Good distribution uniformity with adequate depth of applied water throughout the orchard.

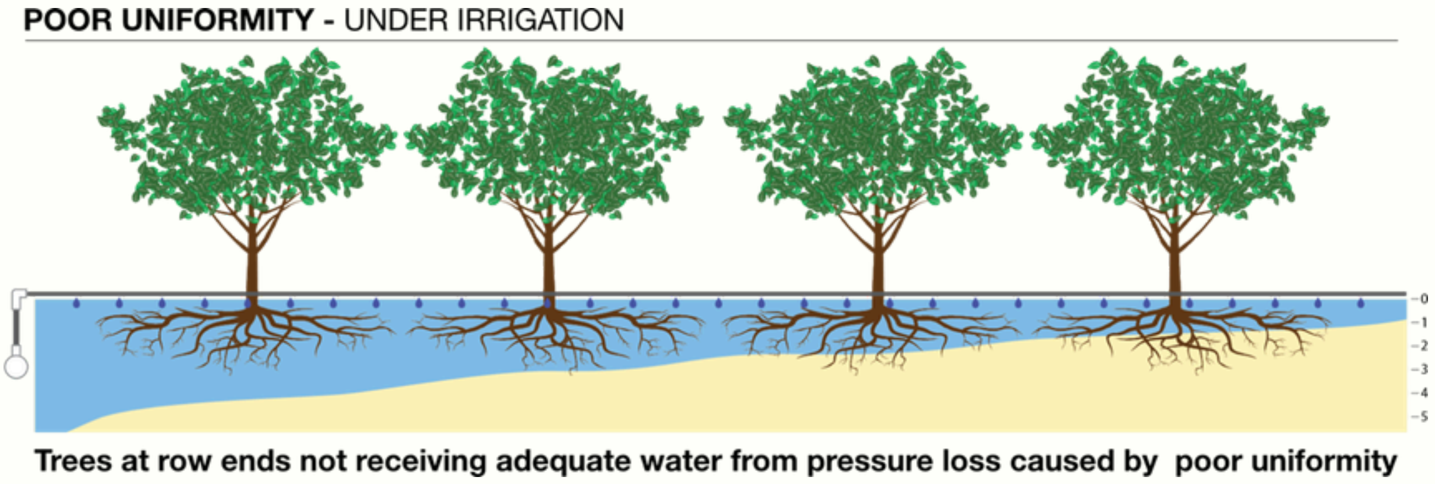

Figure 6. Poor distribution uniformity - under irrigation.

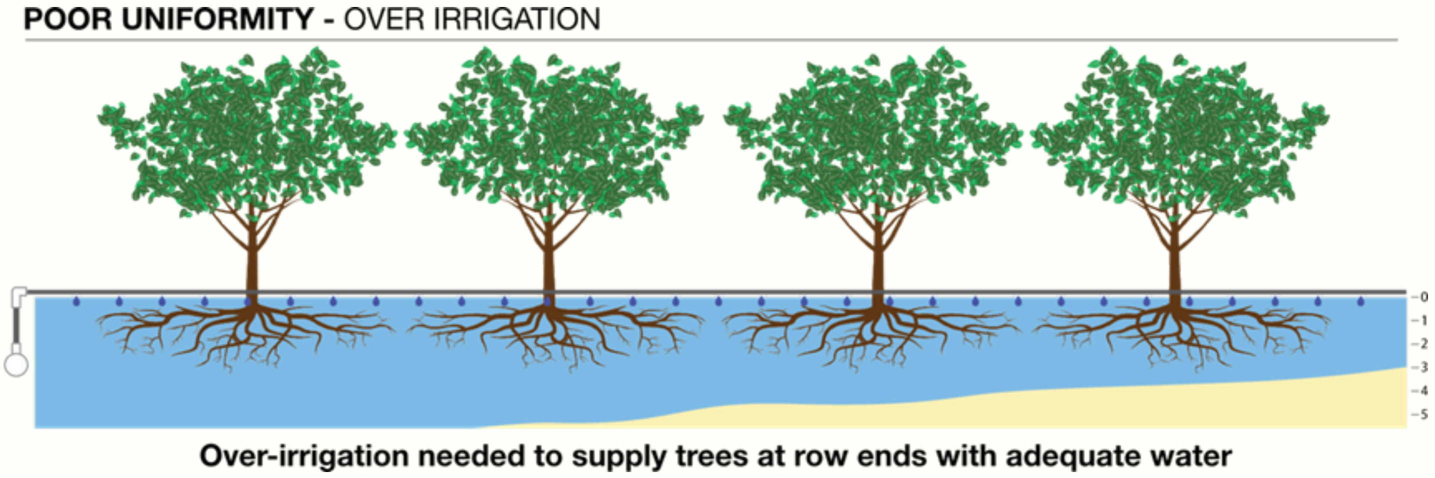

Figure 7. Poor distribution uniformity - over irrigation.

Distribution Uniformity Testing Process

DU testing provides growers with actionable information to support irrigation scheduling adjustments, improve application efficiency, and better align applied water with crop evapotranspiration (ETc). By identifying and addressing system performance limitations, mobile irrigation lab evaluations can help reduce water waste, promote more uniform crop development, and enhance overall irrigation system effectiveness.

Distribution uniformity (DU) evaluations conducted by mobile irrigation labs provide an objective assessment of irrigation system performance under field conditions. During a DU test, discharge measurements are collected from drip emitters, micro-sprinklers, or rotator sprinklers at multiple locations throughout an irrigation block. These data are used to calculate distribution uniformity, which reflects how evenly water is applied across the orchard.

The evaluation also includes pressure measurements at the pump, submains, and laterals, as well as at emitters or sprinklers. Flow regulators, riser screens, and valves are inspected for clogging or other potential sources of variability. An important component of the evaluation is identifying and quantifying water losses resulting from leaks or system deficiencies, including leaks at pump stations, submain-to-lateral connections, faulty air vents, or damaged irrigation lines. Results may identify plugged emitters, worn nozzles, pressure imbalances, leaks, or system design limitations.

Figure 8. DU test results map.

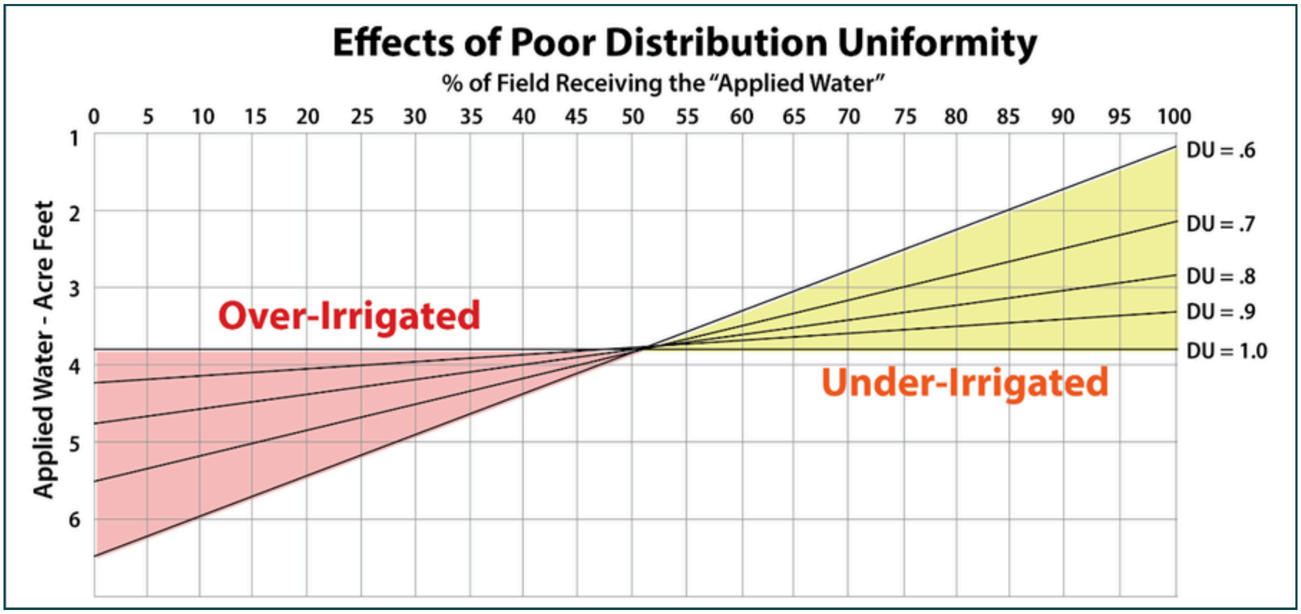

Figure 9. Impacts of poor DU on applied water

As shown in Figure 9, lower DU requires greater total applied water to achieve uniform crop performance.

The x-axis represents yield relative to potential yield ("% Yield Receiving the Applied Water"), while the y-axis represents applied water (acre-feet). The diagonal center line reflects the ideal condition where applied water matches crop water demand uniformly across the field.

As DU decreases (e.g., DU = 1.0 down to DU = 0.6), the shaded wedge widens, demonstrating increasing variability in water application across the orchard.

- The **red shaded area ("Over-Irrigated")** shows portions of the field receiving excess water. To ensure that under-irrigated areas receive enough water, the overall applied water must increase, resulting in deep percolation losses in other parts of the orchard.
- The **yellow shaded area ("Under-Irrigated")** represents areas receiving insufficient water due to poor uniformity, potentially leading to plant stress and reduced yield.

This visually demonstrates that **lower distribution uniformity requires greater total applied water to maintain target yield**, which increases the risk of over-irrigation, water waste, nutrient leaching, and reduced irrigation efficiency. In contrast, higher DU systems allow growers to apply less water overall while maintaining more consistent crop performance.

ATTACHMENT E

Off Peak Irrigation for Precision Irrigation Program

Off-Peak Irrigation for Precision Irrigation Program

Land IQ is additionally working with the Vina Subbasin to develop the PI program. The Vina Subbasin PI program evaluates the potential for reducing groundwater pumping through improved irrigation scheduling, monitoring, and on-farm water management, focusing on permanent crops. This includes evaluating tools such as soil moisture sensors, ET-based irrigation scheduling, and grower technical assistance to better align applied water with crop demand, thereby reducing incidental losses. Results from the Land IQ analysis of selected pilot sites are expected to inform the design of PI as a broader demand-management strategy that could complement other projects and programs (e.g., EOR).

A component of the PI program is changing the timing of irrigation to reduce evaporative losses. ERA Economics was asked to prepare an analysis of potential cost savings by changing irrigation scheduling. Changing irrigation timing offers potential savings through reducing incidental ET by irrigating at night and direct savings in electricity costs by taking advantage of small differences in cents per kilowatt hour (kWh) between peak and off-peak use for time-of-use rates. This additional analysis was developed to explore the potential cost savings in new and existing orchards from shifting electricity use for irrigation to off-peak hours based on representative agricultural time-of-use rates plans. ERA has not been provided with water savings (ET) estimates, but the analysis can be updated in the future when this data is available.

Pacific Gas and Electric (PG&E) rate plans for agricultural operations were reviewed and a sample of representative plans for agricultural operations in Butte County were selected. These plans reflect an operation with low to moderate operating hours and more than 35 kilowatts (kW) of annual electrical use. Each of these rates distinguish between peak and off-peak hours during the summer and winter seasons. The time-of-use plans include:

- **AG-4: Time-of-Use Agricultural Power.** This rate plan is a time-of-use rate with peak window from noon to 6 pm on weekdays in summer and partial-peak from 8:30 am to 9:30 pm on weekdays in winter. Summer is from May to October, and winter is from November to April. Designed for smaller operations, the specific rates for AG-4A and AG-4D2 are used in this analysis.
- **AG-5: Large Time-of-Use Agricultural Power.** This rate plan is a time-of-use rate with benefits for operations with higher annual operating hours. The current peak window is from noon to 6 pm on weekdays in summer, with partial-peak from 8:30 am to 9:30 pm on weekdays in winter. Summer is from May to October, and winter is from November to April. The rates for AG-5B and AG-5E2 are used in this analysis.
- **AG-B (TOU): Large Time-of-Use Agricultural Power.** This rate plan is a time-of-use rate. The peak window is 5 pm to 8 pm every day, all year. Summer is from June to September and winter is from October to May.

The selected plans were applied by season and irrigation timing, and adjusted to account for additional fees. Partial-peak rates are treated as peak rates for winter seasons under AG-4 and AG-5 plans. These rates are current for the period from October 2025 to December 2025. A summary of the adjusted rates per kWh is presented in Table 1.

Table 1: Adjusted Electricity Rates per kWh

Scenario	Summer Rates		Winter Rates	
	Peak	Off-Peak	Peak	Off-Peak
AG-4: Time-of-Use Agricultural Power	$0.548	$0.546	$0.493	$0.492
AG-5: Large Time-of-Use Agricultural Power	$0.395	$0.394	$0.378	$0.377
AG-B (TOU): Large Time-of-Use Agricultural Power	$0.623	$0.550	$0.546	$0.517

The analysis estimated acre-inches of water applied and electrical use per acre each month. The estimated monthly electrical use was then matched to the appropriate adjusted rates based on season. Pumping costs were then calculated for peak or off-peak hours. The difference in these two values represents the maximum difference in cost, or the annual cost savings per acre, by switching irrigation from peak to off-peak times. This does not include any savings from incidental ET savings. The savings are shown per acre and discounted over the 25-year lifetime of the orchard to show the lifetime savings value for each rate plan.

Table 2 summarizes the results for the off-peak pumping scenarios, showing annual and lifetime savings per acre. The AG-B rate provides the greatest cost savings between peak and off-peak use at nearly $70 per acre per year.

Table 2: Off-Peak Cost Savings for Selected PG&E Rates

Scenario	Estimated Peak Cost *Annual* *$/ac*	Estimated Off-Peak Cost *Annual* *$/ac*	Difference *Annual* *$/ac*	Orchard Life Total Savings *Present Value* *$/ac*
AG-4:(Small) Time-of-Use Agricultural Power	$611.70	$609.85	$1.85	$29
AG-5: Large Time-of-Use Agricultural Power	$443.35	$442.50	$0.85	$13
AG-B (TOU): Large Time-of-Use Agricultural Power	$675.30	$608.66	$66.64	$1,041

AG-B has a significantly smaller peak window, making it easier to avoid peak rates, but the differences in peak and off-peak rates for AG-4 and AG-5 are so minimal that changing pumping schedules makes little difference. In addition, it is also the most expensive of the selected rate plans. In comparison to AG-5, an operation would spend another $175 per acre for AG-B using electricity during off-peak hours, which exceeds any cost savings that could be realized by changing irrigation timing.

The preliminary analysis presented above quantifies the cost savings by switching from peak to off-peak irrigation scheduling. There are additional benefits. Shifting irrigation to cooler, off-peak periods can reduce incidental ET losses by limiting evaporation during periods of high temperature, solar radiation, and wind. The magnitude of these savings is modest on a per-acre basis, but reduced incidental ET slightly improves irrigation efficiency and lowers the effective volume of applied water required to meet crop demand, contributing to incremental cost and water savings when aggregated across acres and seasons. In water stressed areas, the economic benefit (monetary value) of this modest water savings can be substantial. This may be quantified in future iterations of this analysis.