# Vina Subbasin GSAs Demand Reduction Strategies: Precision Irrigation Pilot Study Final Report

Prepared for
**Vina Subbasin GSAs**

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# LIST OF ACRONYMS

ac – acres

ac-ft – acre-feet

DWR – Department of Water Resources

EOR – Extend Orchard Replacement

ET – Evapotranspiration

ETc – Crop evapotranspiration

ft - feet

GSA – Groundwater Sustainability Agency

GSP – Groundwater Sustainability Plan

lb - pounds

NASA – National Aeronautics and Space Administration

NDVI – Normalized difference vegetation index

PI – Precision Irrigation

SGMA – Sustainable Groundwater Management Act

SIMS – Satellite irrigation management system

SSURGO – Soil survey geographic database

# EXECUTIVE SUMMARY

## PROJECT PURPOSE

The overall goal of the Precision Irrigation Pilot Program (PI Pilot) is to improve Vina Subbasin sustainability related to groundwater levels and groundwater storage by decreasing consumptive use (i.e., evaporation and transpiration or ET), especially non-beneficial consumptive use, by applying ET-based water management principles of precision irrigation and ET monitoring. The PI pilot study focuses on identifying and implementing irrigation interventions that can reduce non-beneficial ET from almond and walnut orchards in the Vina Subbasin, since these crops represent most cropped acreage.

## STUDY QUESTIONS

1. How and where is non-beneficial ET occurring in almond and walnut orchards, and how can it be addressed using precision irrigation?
2. What is the potential for demand reduction using precision irrigation?
3. How can this knowledge be used to guide the GSA in implementing demand reduction programs?

## APPROACH

The technical approach for the PI Pilot relies on the collection and analysis of spatial data that has been compiled on a field-by-field basis throughout the Vina Subbasin, including the pilot orchards.

Step 1
- **Preparation** - Install field stations to measure field data for ET remote sensing modeling and review current knowledge on potential sources of non-beneficial ET.

Step 2
- **Preliminary analysis** - Use spatial crop/age map data to Identify orchards of same crop type and age range with irrigation scheduling technologies to measure applied water

Step 3
- **Pilot orchard selection** - Select pilot orchards that represent different consumptive use, orchard size, and irrigation approaches

Step 4
- **Field data collection** - Collect irrigation, cultural, production and applied water information from growers

Step 5
- **Consumptive use data collection** - Process consumptive use (ET) data on all orchards in basin using remote sensing modeling

Step 6
- **Data analysis** - Analyze ET, production and yield data and interpret using grower data

Step 7
- **Conclusions** - Identify trends in consumptive use and yield to identify when and where non-beneficial consumptive use can be reduced

Step 8
- **Recommendations** - Recommend strategies, considering irrigation and cultural practices, to reduce non-beneficial consumptive use in the subbasin

**Figure ES- 1. Precision Irrigation Pilot Study technical approach**

## CONCLUSIONS

1. The PI pilot study demonstrated how ET and yield can be used to identify orchards with potential non-beneficial ET. However, there were no consistent relationships between yield and consumptive use data that could be used to identify non-beneficial consumptive use in the short timeframe of this study.
2. There is likely little opportunity to reduce crop evapotranspiration (ETc) with precision irrigation in medium to large size almond and walnut farms. One small farm in this pilot also showed little possibility to reduce ETc but more small farms should be evaluated given their high number across the Vina Subbasin. Improving irrigation management did not reduce crop consumptive use.
3. Irrigation system management was more important than irrigation type in maximizing water use and water productivity (water use as a function of yield).
4. Walnuts appeared to respond to less irrigation while improving production, though this trend was not the same in almonds.
5. There may be potential for improved water management on small farms.
6. There may be potential to reduce the evaporation portion of ET by using more nighttime irrigation and less daytime irrigation.

## RECOMMENDATIONS

- If the Vina GSA wishes to pursue identification of non-beneficial ET in almond and walnut orchards, it would need multiple years of yield and ET data from orchards to determine how and where non-beneficial ET occurs.
- The Vina GSA should focus its efforts related to specific irrigation management practices on the use of pressure chambers and related advanced technology as components of irrigation scheduling, either through outreach and education and/or incentivizing technology, particularly in walnut production.
- To maximize demand reduction from efforts, the Vina GSA should investigate acreage and technology adoption by farm size, then determine potential demand reduction.
- If the Vina GSA wishes to pursue a move away from midday irrigation to reduce ETc, education and outreach would be needed on the associated financial savings, assistance with implementing irrigation system automation, and ensuring adequate orchard re-entry for other cultural practices. The GSA should target orchards that are 3 to 8 years old as a starting point.

# 1 PREFACE

The Vina Subbasin (DWR Basin No. 5-021.57) covers approximately 289 square miles—roughly 185,000 acres—on the western side of Butte County in the Northern Sacramento Valley. The subbasin includes the City of Chico, the communities of Nord and Durham, and the surrounding rural residential and agricultural lands. Approximately 110,000 people reside in the subbasin, with the majority of residents in Chico.

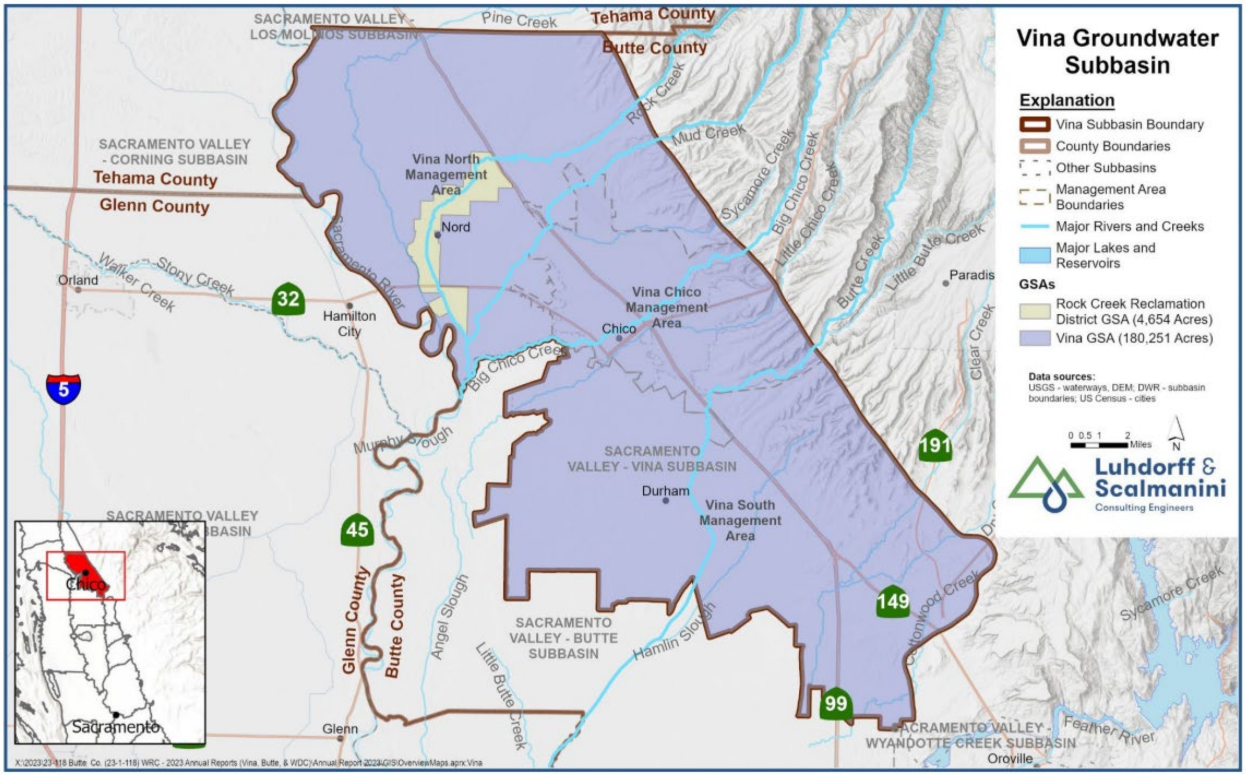


**Figure 1. Vina Groundwater Subbasin.**

The Vina Subbasin is predominantly groundwater dependent. Approximately 89 percent of its water supply comes from groundwater, with the remaining 11 percent from surface water. Agricultural irrigation accounts for 91 percent of total water use, supporting orchards, rice, row crops, vineyards, and grazing. Municipal and domestic uses account for the remaining 9 percent.

*Groundwater Conditions and the GSP*

There are two Groundwater Sustainability Agency's (GSAs) within the Vina Subbasin, the Vina GSA and the Rock Creek Reclamation District (RCRD) GSA that have entered into a cooperative agreement to prepare a single Groundwater Sustainability Plan (GSP). The GSP was submitted in January 2022 (Geosyntec, 2021; GSP), and the California Department of Water Resources (DWR) approved it in July 2023. The GSP estimates the subbasin's sustainable yield at 233,500 acre-feet per year (AFY), based on historical pumping of approximately 243,500 AFY and an annual storage decrease of approximately 10,000 AFY. Subsequent analysis by Butte County in developing the Recharge Action Plan suggests the annual deficit may be as high as 20,000 AFY, based on observed longer-term downward trends in groundwater levels. Although recent wetter years have stabilized groundwater levels, action is still needed to address these longer-term declines and prepare for the next drought. Under SGMA, the subbasin must achieve sustainability by 2042.

### *Approach to Sustainability*

Closing the gap between current groundwater use and sustainable yield requires a portfolio of actions. No single project will likely be sufficient. Grant funds from the California Department of Water Resources (DWR) Sustainable Management grant program (SGM grant) funded a suite of feasibility studies and pilot projects conducted in 2024-26. The Vina and Rock Creek GSAs and their partners—including Butte County, the City of Chico, Durham Irrigation District, Tuscan Water District, and the Agricultural Groundwater Users of Butte County—are advancing a coordinated strategy across four categories:

### *Demand Reduction and Conservation*

Pilot programs for extended orchard replacement and precision irrigation were investigated with SGM grant funds to explore approaches for reducing agricultural water demand. Results of the pilot studies will provide information on potential water savings and costs of the programs.

### *Groundwater Recharge*

The Butte County Recharge Action Plan, adopted by the Board of Supervisors in February 2024, establishes a recharge target of at least 20,000 AFY and prioritizes the Vina Subbasin. The SGM grant funded Recharge Feasibility Analysis identifies potential recharge sites and assessed site feasibility and multi-benefit opportunities throughout the subbasin. Additionally, the Feasibility of Enhanced Recharge in the Lindo Channel study will produce a recharge feasibility and alternatives report.

### *Increasing Surface Water Supplies*

This strategy reduces the reliance on groundwater for water uses in the subbasin by identifying and refining surface water supply projects. This Surface Water Feasibility Study evaluates opportunities to deliver surface water to farms that currently rely entirely on groundwater, directly offsetting pumping through conjunctive use.

### *Planning and Partnerships*

Interbasin coordination, partnerships with water districts (e.g., Western Canal Water District, Paradise Irrigation District), engagement with state and federal agencies, and collaboration with local entities such as Tuscan Water District enable the other strategies to succeed.

### *Potential for Demand Reduction through Extended Orchard Replacement and Precision Irrigation*

Because agricultural irrigation accounts for 91 percent of total water use in the subbasin, and almonds and walnuts represent the majority of cropped acreage, both studies focused primarily on these permanent crops. The full results and analyses of each pilot study are documented in the accompanying technical memoranda: the Extend Orchard Replacement Pilot Study Final Report and the Precision Irrigation Pilot Study Final Report.

The EOR Pilot Study examined whether extending the fallowing period by one to two additional years during orchard replacement could produce meaningful water savings. The study sought to answer three core questions: What types of practices are used on idle orchard ground during the replant period, and how much water do they consume? What are the costs, co-benefits, and water savings of an extended replacement period over the life of an orchard? And how can this knowledge guide the GSA in designing implementable programs? The PI Pilot Study focused on the supply side of on-farm water management, asking: How and where is non-beneficial evapotranspiration (ET) occurring in almond and walnut orchards, and how can it be addressed using precision irrigation? What is the potential for demand reduction using precision irrigation? And how can this knowledge guide the GSA in implementing demand reduction programs?

Both studies relied on the collection and analysis of field-by-field spatial data compiled throughout the Vina Subbasin—including crop type, crop age, consumptive use (ET), soils, and remotely sensed data—combined with on-the-ground data collection from pilot orchards.

The EOR study found that extending the period between orchard plantings can reduce ET by 0.91 to 2.62 acre-feet per acre per year, depending on how the land is managed during the idle period. Winter cover crops and spring sudan grass consumed only 33 to 47 percent of the water used by established orchards, while also providing agronomic co-benefits such as improved soil health and reduced disease pressure. Idle ground produced the greatest water savings but posed risks of dust, erosion, and soil degradation. The study also developed an economic framework showing that incentive payments of up to $790 per acre per year may be needed to encourage grower participation, depending on the practice adopted during the extended replant period.

The PI study found that medium to large almond and walnut farms in the Vina Subbasin generally have good on-farm irrigation efficiency, with approximately 75 percent of pilot growers already using at least two data sources to inform irrigation decisions. As a result, the study found little evidence that precision irrigation alone would substantially reduce consumptive use on these operations. However, the study identified promising areas for further investigation: walnut orchards using pressure chambers to guide irrigation scheduling applied less water while maintaining or improving yields; small farms may have greater potential for improved water management; and shifting irrigation to nighttime hours could reduce the evaporation component of ET by an estimated 350 acre-feet per 1,000 acres of participation. Both studies provide a foundation for the Vina Subbasin GSAs and their partners to develop implementable demand reduction programs as part of the broader portfolio of actions needed to achieve sustainability.

# 2 INTRODUCTION

The Groundwater Sustainability Act (SGMA) legislation passed in 2014, establishes a new structure for managing groundwater resources in California at the groundwater basin/subbasin level. Groundwater basins and subbasins are defined in the Department of Water Resources (DWR) Bulletin 118 document. SGMA requires Groundwater Sustainability Agencies (GSAs) to manage groundwater at the local level through the development and implementation of Groundwater Sustainability Plans (GSPs). The GSPs must ensure sustainable conditions by 2042.

The SGMA compliance process in the Subbasin started with the formation of the Vina GSA and subsequent development and submittal of the Vina Subbasin GSP. The Vina GSA was established in 2019 to meet SGMA requirements on behalf of landowners in the Vina Subbasin. Vina GSA manages GSP development and updates, GSP implementation, administration, and SGMA compliance. The Vina GSA is composed of three member agencies (City of Chico, Butte County, Durham Water District). The Vina GSA is governed by a 5-person board including a representative from each member agency and two community stakeholders.

## 2.1 VINA SUBBASIN GROUNDWATER SUSTAINABILITY PLAN

The Vina Groundwater Subbasin is a portion of the larger Sacramento Valley Groundwater Basin covering approximately 184,917 acres. The Vina Subbasin is a portion of the larger Sacramento Valley Groundwater Basin and is bounded by Tehama County to the north, the county line along the Sacramento River to the west, the foothills to the east (as defined by Bulletin 118), and the Western Canal Water District to the south.

Designated as a high-priority basin by the California Department of Water Resources (DWR), the Vina Subbasin is jointly managed by two Groundwater Sustainability Agencies (GSAs): the Vina GSA and the Rock Creek Reclamation District GSA. The Vina GSA was established through a Joint Powers Agreement (JPA) between the County of Butte, the City of Chico, and the Durham Irrigation District (DID). This collaborative governance structure ensures diverse representation and comprehensive management of the subbasin's groundwater resources.

The Vina GSP serves as the Subbasin's strategic roadmap for achieving and maintaining sustainable groundwater management. Developed through an inclusive and publicly engaged process, the GSP incorporates input from all beneficial uses and users of groundwater in the Subbasin. After being submitted to the DWR for review in January 2022, the GSP was officially approved in July 2023.

## 2.2 GRANT FUNDING FOR DEMAND REDUCTION STRATEGIES

The Vina Subbasin received a grant from California Department of Water Resources: Vina Subbasin GSP projects and Management Actions Implementation (Project). This Project is intended to make progress on GSP implementation actions that advance groundwater sustainability in the Vina Subbasin. The Project includes three categories of activities that will work toward monitoring and eliminating the 10,000 acre-feet (AF) of estimated overdraft per year. Activities include: 1) required GSP implementation tasks such as reporting, responding to DWR GSP determination, continued stakeholder outreach, groundwater model updates, financing strategies, and filling data gaps; 2) improving the monitoring network and developing a domestic well inventory; and 3) implementation of pilot projects for recharge, agricultural irrigation efficiency, and reduced groundwater demand. The Work Plan for the Project includes seven Components:

- Component 1: Grant Agreement Administration
- Component 2: GSP Updates, Data Gaps, and Outreach
- Component 3: Demand Reduction Strategies in the Vina Subbasin
- Component 4: Lindo Channel Surface Water Recharge
- Component 5: Surface Water Supply and Recharge Feasibility Study
- Component 6: Inter-basin Coordination, Modeling and Reporting
- Component 7: Outreach Program

The work documented in this report fulfils the requirements of tasks related to Component 3: Demand Reduction Strategies in the Vina Subbasin, Category b, Precision Irrigation Pilot Program.

Component 3 will improve subbasin sustainability related to groundwater levels and groundwater storage by decreasing consumptive use (i.e., evaporation and transpiration or ET) by applying ET-based water management principles of precision irrigation and ET monitoring. This component will leverage education and outreach, a feasibility study involving the piloting of innovative irrigation technologies, and the development of a precision irrigation implementation plan to improve ET-based water management at a broader scale in the Vina Subbasin.

Additionally, a program for demand-side intervention aimed at extending the fallowing period of an orchard from one to two years during orchard replacement will reduce consumptive use (i.e., evapotranspiration or ET) of groundwater. The reductions in ET are obtained by having one or two additional low ET years at the beginning of the orchard life cycle. This latter pilot study is called Extend Orchard Replacement (EOR) and is documented in a separate report, Vina Subbasin GSAs Demand Reduction Strategies: Extend Orchard Replacement Pilot Study Final Report.

## 2.3 PRECISION IRRIGATION PILOT STUDY BACKGROUND

Irrigation efficiency generally focuses on field-scale water use, relating the amount of water that is consumptively used (plus salinity leaching requirements) to the amount of water that is applied through irrigation. This localized, field-scale viewpoint does not account for the many other beneficial uses of water within the larger hydrologic system, or the important role of non-consumptive use at the subbasin scale. Although crops do not consume all the water that is applied through irrigation, much of the remaining balance of water is still beneficially used in the larger, subbasin-scale system, as it is recycled back to the groundwater system and/or downstream waterways.

Non-consumptive surface water uses, especially for groundwater recharge, are important components of sustainable groundwater management. Unexpected problems can arise when improving irrigation efficiency is used to improve groundwater sustainability. This is especially true if groundwater sustainability requires a decrease in consumptively used water, which is often more strongly correlated with the area of land being irrigated within a subbasin, and not the irrigation efficiency at the field scale.

Technologies and policies that support adoption of higher-efficiency irrigation systems are well-intentioned, but there may be unintended consequences that impede water conservation and sustainable groundwater management. This is highlighted by the following:

- Applying less surface water to an area because of improvements to irrigation efficiency can also reduce deep percolation and seepage to the groundwater system and surface outflows to surface water features.
- Increased irrigation efficiency often leads to an increase in consumptive use of water (i.e., evaporation and transpiration), so while gross volumes of groundwater extraction may be reduced, net volumes of consumptive groundwater use may increase. While more efficient irrigation systems apply irrigation water more precisely and uniformly, they often grow more uniform crops with higher ET and higher yields.
- Behavioral responses and changes in irrigation resulting from improvement to irrigation efficiency can lead to increased consumptive use. If less water can be used to produce the same amount of a crop product, growers may be inclined to use the same amount of water and produce more or use the “conserved” water to irrigate additional land. This highlights the importance of properly coupling land use management together with sustainable water management.

Figure 2 below (from the SGM grant application) provides a conceptual depiction of an agricultural system transitioning from flood irrigation (Scenario 1, left) to micro sprinklers (Scenario 2, right). The irrigation efficiency, or more precisely the consumptive use fraction or CUF, increases from 60% to 87.5%. However, the total amount of consumptive use (i.e., sum of evaporation and transpiration) increases from 60 (10 + 50) units to 70 (15 + 55) units from Scenario 1 to Scenario 2. All else being equal, this increase in consumptive use will drive the subbasin farther away from sustainability by increasing the net outflow of groundwater from the system.

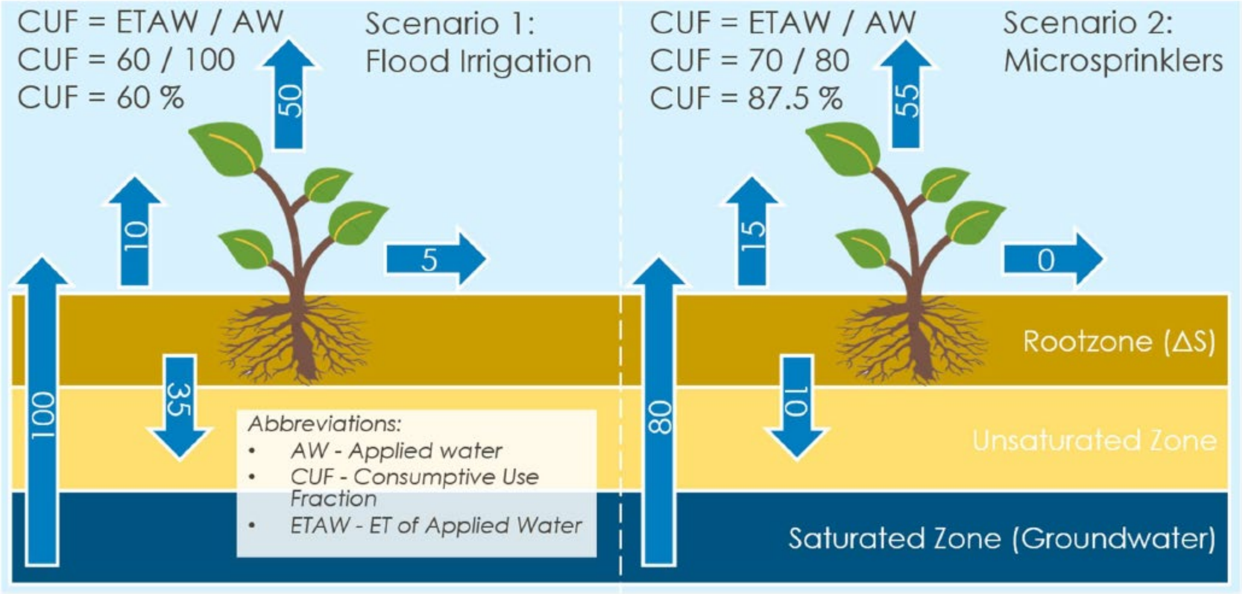


**Figure 2. Agricultural system using flood and micro sprinkler irrigation, illustrating that improving irrigation efficiency doesn't always improve groundwater basin sustainability.**

## 2.4 PRECISION IRRIGATION PILOT STUDY GOALS AND OBJECTIVES

The overall goal of the Precision Irrigation Pilot Program (PI Pilot) is to improve subbasin sustainability related to groundwater levels and groundwater storage by decreasing consumptive use (i.e., evaporation and transpiration or ET), especially non-beneficial consumptive use, by applying ET-based water management principles of precision irrigation and ET monitoring. The PI Pilot focuses on identifying and implementing irrigation interventions that can reduce non-beneficial ET from almond and walnut orchards in the Vina Subbasin, since these crops represent most cropped acreage.

Presently, the Vina Subbasin is almost entirely dependent on groundwater to meet crop water demands. To achieve long-term sustainability, the Vina GSP suggests the need to address a 10,000 AF per year groundwater budget deficit. Moreover, if water managers and stakeholders within the subbasin desire to recover some of the 300,000 to 400,000 AF cumulative reduction in storage that has occurred over the last 20 years, a change greater than 10,000 AF per year is required. This can be achieved by either reducing groundwater demands or increasing availability of surface water supplies. Reducing non-beneficial ET is an essential component of groundwater sustainability.

The overall goal of this component is to improve subbasin sustainability related to groundwater levels and groundwater storage by decreasing consumptive use (i.e., evaporation and transpiration or ET) by applying ET-based water management principles of precision irrigation and ET monitoring. This component will leverage education and outreach, conduct a feasibility study involving piloting innovative technologies, and develop a precision irrigation implementation plan to improve ET-based water management at a broader scale in the Vina Subbasin.

The specific purpose of the PI Pilot Program is to develop strategies that will minimize non-beneficial ET for various field scenarios in the Vina Subbasin. The specific objectives are to determine irrigation technologies and management practices that can be used to reduce non-beneficial ET while maximizing crop yield by evaluating field level ET, major crop type (walnuts and almonds), crop age, crop density, irrigation type, irrigation scheduling method, soil types, and historical yields.

## 2.5 STUDY QUESTIONS AND APPROACH

The questions the PI Pilot aimed to address included the following:

1. What are the irrigation scheduling approaches and technologies in use?
2. What is the potential for demand reduction using precision irrigation?
3. How can this knowledge be used to guide the GSA in implementing demand reduction programs?

The technical approach for the PI Pilot relies on the collection and analysis of spatial data that has been compiled on a field-by-field basis throughout the Vina Subbasin, including the pilot orchards. Spatial data is information that is tied to a specific location. This data can be managed and analyzed in a spreadsheet, or it can be viewed on a digital map.

While traditional agricultural field studies run experiments on a few field plots or fields and then measure and interpret the results of those experiments, the approach to the PI Pilot study leverages information related to agricultural water use efficiency that is already available for every field in the subbasin. This spatial data includes crop type, crop age, consumptive use by field (or ET), other remotely sensed data related to potential yield, and soil type. This information has potential to be analyzed across the Vina Subbasin to find orchards that have high potential for non-beneficial ET. With historical yield and management practice information provided by growers, specific causes of non-beneficial ET, if found in the PI pilot study, can be identified, as well as management strategies to minimize non-beneficial ET and maximize production (yield).

The steps of the technical approach are summarized in Figure 3 and are explained in detail in the following sections.

Step 1
- **Preparation** - Install field stations to measure field data for ET remote sensing modeling and review current knowledge on potential sources of non-beneficial ET.

Step 2
- **Preliminary analysis** - Use spatial crop/age map data to Identify orchards of same crop type and age range with irrigation scheduling technologies to measure applied water

Step 3
- **Pilot orchard selection** - Select pilot orchards that represent different consumptive use, orchard size, and irrigation approaches

Step 4
- **Field data collection** - Collect irrigation, cultural, production and applied water information from growers

Step 5
- **Consumptive use data collection** - Process consumptive use (ET) data on all orchards in basin using remote sensing modeling

Step 6
- **Data analysis** - Analyze ET, production and yield data and interpret using grower data

Step 7
- **Conclusions** - Identify trends in consumptive use and yield to identify when and where non-beneficial consumptive use can be reduced

Step 8
- **Recommendations** - Recommend strategies, considering irrigation and cultural practices, to reduce non-beneficial consumptive use in the subbasin

**Figure 3. Precision Irrigation Pilot Study technical approach**

# 3 METHODS

## 3.1 STEP 1: PREPARATION

Preparation included selecting appropriate sites for field stations in the Vina Subbasins, contacting growers, and installing the stations. Details about how ET data is collected from field stations and used to calibrate remote sensing modeling is provided in Section 3.5 on Consumptive Use Data Collection. Field stations were installed in fall and early winter 2024.

During this time, a review of literature and extension materials on consumptive use in almonds and walnuts was completed. Land IQ also consulted with subject matter experts on almond and walnut production and physiology. The purpose of the review was to understand what types of data can be used as indicators of non-beneficial ET.

## 3.2 STEP 2: PRELIMINARY ANALYSIS WITH SPATIAL DATA

Land IQ compiled spatial data, including:

- Soil texture data from SSURGO
- Crop type data from DWR's land use data set
- Crop age data from DWR's land use data set
- Historical ET data modeled using SIMS

Soil Data - Digitally mapped soil survey data for the Vina Subbasin is available through Soil Survey Geographic Database (SSURGO) that has been collected by field work throughout the last 100 years by the National Cooperative Soil Survey. This database includes soil map units and several other soil attributes such as soil physical and chemical properties (e.g. soil depth, texture, drainage class, available water holding capacity, pH, salinity), topographical information (e.g. slope), and agricultural suitability.

The purpose of compiling soils data was to understand the distribution of soil texture throughout the Vina Subbasin, so that pilot orchards could be selected that were representative of all soil types. Soil texture is a key soil physical property that governs fertility, water holding capacity, and drainage class, which affect irrigation management.

Crop Type and Age Data - Land IQ has been mapping land use in California for the Department of Water Resources (DWR) since 2014. Since 2018, Land IQ has updated the spatial database of land uses, including agriculture (irrigated and fallow fields) and urban footprint annually. Farmed area in fields at least 2 acres in area, excluding roads, buildings and berms, is mapped to achieve an overall accuracy of 97.6%. The database represents 98% of all irrigated cropland. In addition to crop type, Land IQ also maps perennial crop age (planting year), perennial crop planting density, and condition (stressed, short-term abandoned, and long-term abandoned).

The crop type and age spatial data was used to identify walnut and almond orchards in their peak production years from 2019 to 2024, from which pilot orchards were selected. These orchards fit the following age ranges for all analyzed years and include:

- Almond orchards 7-20 years old (282 orchards that remained almonds within the peak production age range from 2019 to 2024) for the entire 6-year window
- Walnut orchards 9-25 years old (297 orchards that remained walnuts within the peak production age range from 2019 to 2024) for the entire 6-year window

<u>Historical ET Data</u> – Satellite Irrigation Management Support (SIMS) ET data was used to analyze historical ET (and its components) as described in the steps below. Use SIMS to calculate monthly ET from 2019 to 2024 for each field. SIMS is an open-source model for estimating ET. Though it is not calibrated with field station data like the Land IQ method, SIMS provides a way to calculate historical ET data where and when field station data is not available. This data was used to ensure that pilot orchard selection represented both high and low water consuming orchards.

## 3.3 STEP 3: PILOT ORCHARD SELECTION

From the selection of almond and walnut orchards within the peak production age range, Land IQ consulted with Subject Matter Experts to prioritize features of pilot orchards. The prioritized features include:

- Orchards with systems to measure applied water
- Ownership range (family farms with one to several orchards, or larger corporate acreage)
- Orchard size (minimum acreage threshold, mix of small and large to the extent possible)
- Geographical distribution (representing all areas of subbasin)
- Soil type (representing diverse soil textures in the Subbasin)
- Orchards with a range of irrigation scheduling tools and approaches

A target minimum number of pilot orchards was determined as 9 to 10 orchards (for each of almond and walnut) based on the estimated level of effort needed to gather data from growers in the 2025 field season.

## 3.4 STEP 4: FIELD DATA COLLECTION

The Subject Matter Experts for the PI Pilot communicated with growers to attain permission for land access and willingness to participate in the PI Pilot. All information from pilot orchard growers was collected by the Subject Matter Experts in a standardized form and kept confidential for the intent of performing analysis. Field data included:

- Quantitative
    - Current growing season yield, and historical yields if possible.
    - Current growing season applied water
- Qualitative (acquired from grower interviews, orchard visits and observations)
    - Irrigation methods, including primary and secondary systems
    - Irrigation scheduling and management, including use of soil-based, plant-based, ET-based, or weather-based irrigation scheduling strategies and irrigation consultants
    - Cultural practices, including pruning, orchard floor management, pest management, disease management, and fertilization
    - Notable production challenges during the growing season other than irrigation. Examples included orchard variability related to soil limitations, root and crown diseases, and orchard pruning practices to manage canopy vigor and tree fruitfulness.

## 3.5 STEP 5: CONSUMPTIVE USE DATA COLLECTION

In autumn 2024, Land IQ installed four ET field stations in the Vina Subbasin in the following locations (Figure 4):

1. 20-year old walnut orchard in the northwest part of the Subbasin, close to the Sacramento River
2. 9-year old walnut orchard in the northwest part of the Subbasin, close to the Sacramento River
3. 8-year old almond orchard on the east side of the Subbasin and SE of Durham
4. 15-year old almond orchard in the southwest part of the Subbasin

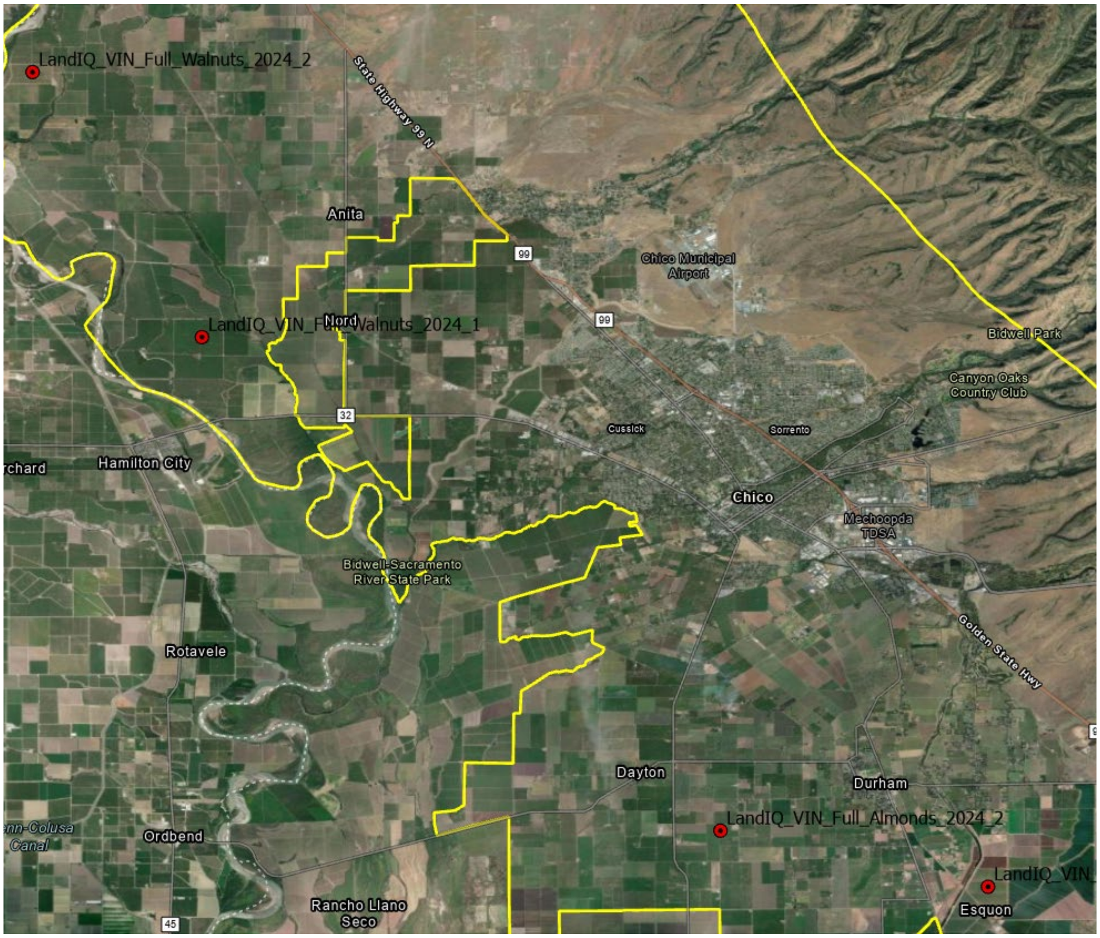


**Figure 4. Land IQ ET Field Stations in the Vina Subbasin**

Land IQ uses meteorological data from these stations to develop a model for calculating ET for each field. The Land IQ data-driven model uses a combination of meteorological data and analysis of remotely sensed imagery in a surface energy balance approach to estimate field by field ET. Inputs to this model include field station data, remotely sensed imagery, and spatial crop data. Outputs include ET by field and precipitation by analyzed area.

The data collected by the field stations is used to calibrate remote sensing models for ET and to extrapolate ET measurements across all fields to produce a complete estimate of monthly ET by crop type by field. Station data is also used to validate results and quantify accuracy. Data stations are fully telemetered (remotely logged) by cellular communication systems to Land IQ servers. Routine maintenance is performed monthly to ensure stations are in working order and data is being logged and transmitted per protocol.

Accuracy assessment with an independent validation dataset (from stations) that were removed from the modeling dataset showed that the modeling coefficient of determination ($R^2$) was 0.95, meaning

95% of the model result was accounted for by the station data. The mean absolute error, another measure of accuracy, was a 0.48-inch difference between the station monthly measurement and the model monthly prediction. Non-statistical checks on Land IQ ET data using applied water data showed that the model results are generally less than irrigation plus precipitation, which is expected. This high accuracy in ET modeling results is achieved on fields with actively growing crops; however, ET estimation models are not as accurate on non-irrigated or deficit-irrigated fields and may have 10% error or more.

Land IQ uses a data-driven model to interpret remotely sensed image data. This approach can employ Landsat 8 and Sentinel 2 satellite imagery (freely available) as well as Planet imagery. Satellite data are screened for cloud cover and corrected for the effects of terrain, or different topographic positions, on reflectance. Remotely sensed satellite imagery of the area is collected on all available cloud free overpass dates within each month to estimate monthly, field by field ET.

Ground measurements from field stations are used to generate hourly ET results correlated to satellite imagery. The results are then used as a dependent variable in the modeling process. The analysis includes data-flagging protocols to identify any inconsistencies in data collection or outages. A thorough QA/QC effort is conducted on all field collected data prior to remotely sensed analysis.

**Figure 5. ET field station in orchard**

## 3.6 STEP 6: DATA ANALYSIS

Data exploration on ETc data from the PI Pilot orchards was carried out to understand trends, if any, related to crop type, age, soil type, irrigation type, or other yield factors as represented by the collected field data. Quantitative and qualitative field and farm information was used to interpret differences in ET results between pilot orchards. Normalized Vegetation Index (NDVI), a component of data used to model ET, was considered to understand the relationship between applied water, yield and canopy development and management. NDVI is a proxy for canopy shading. Specifically, yield and ET data were used to identify orchards with potential for non-beneficial consumptive use. Orchards with high consumptive use (ET) and relatively lower yield indicate the potential for non-beneficial consumptive use.

Irrigation efficiency, though not directly representing consumptive use for reasons described in Section 1.3, is a component of good water management and was also considered as a component of precision irrigation.

# 4 SUPPORTING INFORMATION

While the current study focuses on reducing or eliminating ET that occurs in orchards that does not benefit or contribute to yield, improved water efficiency reduces groundwater pumping even though it also reduces groundwater recharge. Reducing non-beneficial use of water is part of overall water efficiency and is captured in the concept of water productivity, which is a “crop per drop” approach. The Pacific Institute states:

> *Water-efficiency improvements can reduce both consumptive and non-consumptive water uses. By definition the goal of efficiency improvements is to maintain crop production levels. In doing so, crop transpiration rates are maintained. The emphasis is placed on reducing non-beneficial uses of water, such as unproductive evaporation from sprinkler spray or bare soil or transpiration from weeds. Reductions in consumptive use are especially valuable because they create “new supply” that is available for other uses. But there are also compelling reasons to seek reductions in total water withdrawals.*
>
> *From the farmer’s perspective, reducing water withdrawals can provide a number of important benefits. In particular, it reduces the cost to purchase water and, if the farmer is using groundwater, reduces energy costs to pump and apply that water. Many farmers have also found that reducing water withdrawals allows them to apply chemicals more effectively, reducing total chemical use and associated costs. Moreover, studies suggest that improving water management through irrigation scheduling and efficient irrigation technologies can improve crop quality and/or yield, thereby increasing farm revenue. Finally, reductions in applied water improve the reliability of existing supplies and reduce vulnerability to drought and other water-supply constraints.*

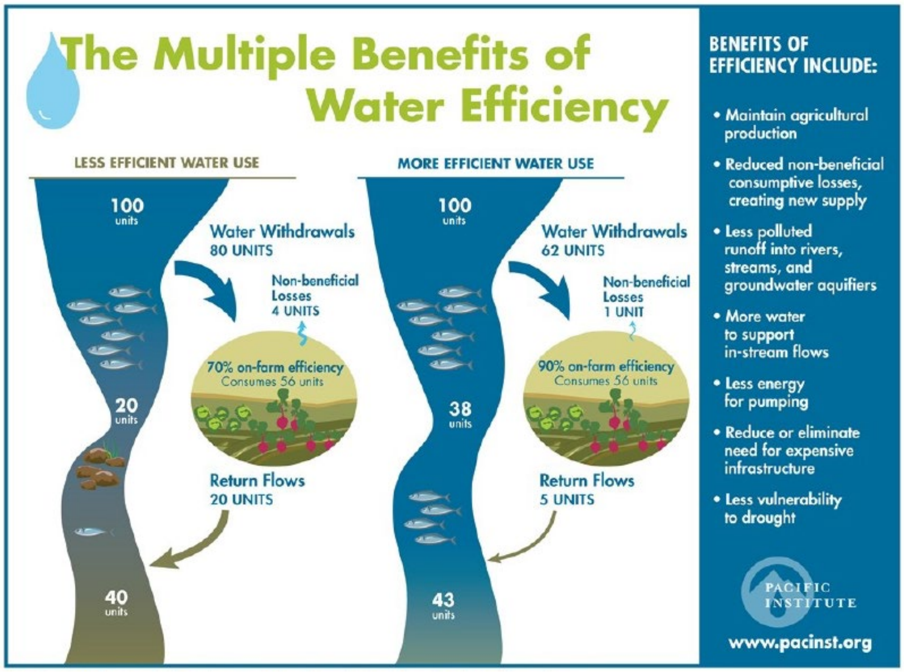


**Figure 6. The Multiple Benefits of Water Efficiency**

*Values in figure are for illustrative purposes. Source: The Pacific Institute.*

## 4.1 RELEVANT RESULTS OF BUTTE COUNTY FARMER SURVEY ON IRRIGATION MANAGEMENT PRACTICES

A survey of Butte County farmers was conducted in 2021 to develop insight on irrigation methods, water management, and attitudes toward potential demand reduction approaches and SGMA in general. Out of the 95 surveys sent, 49 farmers responded. These results often mirror what was found in the PI study but give a broader representation of irrigation management methods that are used and would be considered by growers. These results are not specific to almond and walnut growers.

In summary, some of the relevant conclusions include:

- ET-based measurements are the most common irrigation scheduling tool, but by a small margin compared to other approaches.
- Multiple irrigation scheduling and management approaches are used together.
- While cost is the biggest barrier to using flow meters and soil moisture sensors, the biggest barrier to using ET-based measurements is uncertainty.
- The main barrier to the use of pressure chambers is labor
- The percentage of respondents that were very likely to consider water management tools such as those used to apply irrigation precisely is quite low – in the <10% range.
- Less than 20% of farms participate in the mobile lab program, which evaluates distribution uniformity.

One of the recommendations from this report was to develop programs targeting small farms, which tend to have less information, be less connected to policy discussions and less likely to adopt practices.

### 4.1.1 FARM SIZE, OWNERSHIP AND ACREAGE IN THE VINA SUBBASIN

There were 765 individual farming entities that owned an almond or walnut orchard in the subbasin in 2024. Of these 765 farming entities, 9 had more than 500 acres, 105 had 100-500 acres, 92 had 50-100 acres, and 559 had 1-50 acres. Farming entities under 100 acres make up about 85 percent of landowners but only account for 27 percent of acres in the Vina Subbasin; farming entities under 100 acres also likely account for a similar proportion of groundwater pumping.

## 4.2 FACTORS THAT AFFECT YIELD RESPONSE TO APPLIED WATER AND CONSUMPTIVE USE

Yield doesn't always increase with applied water, nor does it always increase with higher consumptive use. Factors other than water stress influence yield, such as:

- Rootstock and rootstock/scion variety selections
- Canopy management, including tree spacing and pruning practices
- Poor conditions for pollination
- Insect pests
- Foliar and root diseases
- Nutritional deficiencies
- Replant problems
- Aging orchards (potentially)

To identify orchards that are highly responsive to applied water, the following factors can be evaluated:

- Orchard production history
- Applied water measurements
- Midday canopy light interception (potentially using NVDI)
- Familiarity with orchards and other known limitations

Water productivity on orchards can be assessed by comparing yield and/or revenue with applied water. Orchards with higher ratios of yield to applied water have higher water productivity. Orchards with higher yield per unit of canopy light interception are also likely to have higher water productivity. Using the same approach for water productivity, yield can be compared to light interception to assess "light" productivity. Light interception can be measured with specialized equipment, or estimated in the field by estimating proportion of shading in a grid spanning the orchard floor between two tree rows and two trees in each row but remotely sensed NDVI is a proxy measure for light interception (canopy cover) and can be used in its place (Trout, Johnson and Gartung 2008).

### 4.2.1 IRRIGATION SYSTEM DESIGN AND MAINTENANCE

Data for Butte County (2002 to 2025) from the Mobile Irrigation Lab (Resource Conservation District of Tehama County) indicates that about 20 to 25 percent of irrigation systems are underperforming relative to their potential in distribution uniformity. Distribution uniformity measures how evenly an irrigation system applies water across a field. Irrigation systems with poor distribution uniformity require more water to be applied overall to compensate for parts of the field that are not receiving enough water, even though other parts may be receiving enough or even more than they need.

Addressing distribution uniformity results in better water management overall and higher irrigation application efficiency and improves yield consistency. This topic is address in the PI pilot study technical bulletin: *Field Level Measurements of Applied Water*.

## 4.3 SPATIAL DATA COLLECTION

### 4.3.1 SPATIAL CONSUMPTIVE USE (ET) AND PRECIPITATION DATA

Consumptive use (ET) and precipitation data was collected in 2025 using Land IQ's data driven method. For 2019-2024 consumptive use data, the SIMS model was used as described.

Both consumptive use and precipitation datasets were calculated and summarized monthly during 2025. Though this data was originally anticipated to be delivered on a quarterly basis, it was not used in an incentivized pilot study and therefore was only needed for final analysis. Therefore, work was prioritized and four reports of data were modeled and delivered to the Vina GSA on the following schedule:

- January-April 2025 – delivered June 2025
- May-September 2025 – delivered November 2025
- October 2025 – delivered December 2025
- January-February 2026 – delivered March 2026

Both consumptive use and precipitation data were delivered in two forms: raster and vector data, which are the two forms of geographic information system (GIS) data. Raster data is a grid of cells (pixels) where each cell holds a value like elevation or temperature. Vector data is points, lines and polygons that represent discrete features like roads and fields. The raster datasets of both ET and precipitation cover the whole Vina Subbasin and were delivered in units of mm in a 30m-pixel resolution dataset. The vector data uses Land IQ field boundaries and has a zonal statistic result for each field. Zonal statistics calculate statistics (e.g., mean, sum, maximum) on a raster dataset based on defined zones in this cases, a field. They are used to summarize (e.g. calculate an average) pixel values within each field boundary. Therefore, field boundaries and crop type as mapped by Land IQ are included in these datasets, summarized as follows:

- ET raster - 30m pixel in mm
- Precipitation raster – 30m pixel in mm
- Field boundaries with zonal statistics of ETa (mm)
- Field boundaries with zonal statistics of precipitation (mm)

Each monthly dataset was accompanied by an html ET map that visualizes ET by field throughout the Vina Subbasin.

### 4.3.2 IRRIGATION SYSTEM TYPES

Mapping irrigation system types on a field-by-field basis within the Vina Subbasin was achieved using several different methods. Field verification of parcels visible from public roads was used to identify the irrigation method for 39 percent of total crop acreage in the basin (48 percent of the almonds and walnuts in the basin). This vehicle survey was conducted July 10-11, 2024. Another 17 percent of the acreage had an irrigation method assumed according to the crop grown. In these cases, the crops are known to be irrigated almost exclusively via one irrigation method.

For almonds, walnuts, and mixed pasture, multiple irrigation methods are employed within the Vina Subbasin. These three crop types had sufficient data collected during the field verification survey to generate an irrigation method probability. While the irrigation method for individual fields in this category cannot be confidently identified, basin-wide calculations incorporating this irrigation method probability should be considered reasonably accurate given the proportion of fields of each crop type verified. Thirty eight percent of the acreage was assigned an irrigation method probability.

Lastly, 6 percent of the acreage had insufficient data to accurately determine an irrigation method. This category comprised fields containing crops with lower acreage within the basin, and there was insufficient data to assign an irrigation method probability for these crops.

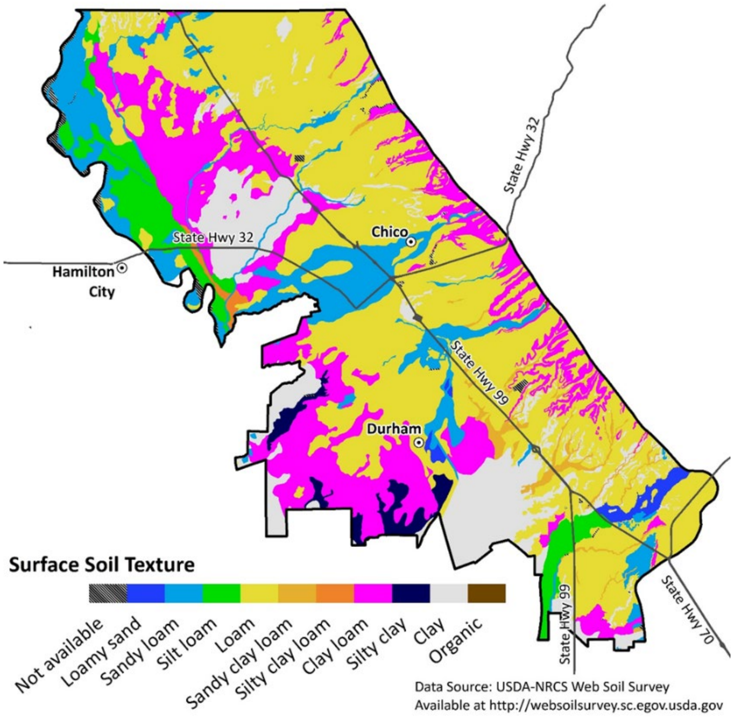
Three irrigation method categories were used—surface irrigation, sprinkler irrigation, and microirrigation. We note that within solid set irrigation system design, there is a continuum of nozzle types and flow rates, and some lower flow microspray-type nozzles were noted on solid set irrigation. In general, all solid set irrigation systems, regardless of nozzle type, were counted as sprinkler irrigation. Any staked spray nozzle which was connected to above ground poly tubing was considered microirrigation.

See the Appendix for a map of the irrigation system type and the method used to determine it for each field in the Vina Subbasin and summary tables.

Tabular results by field were delivered to the Vina Subbasin in Excel format.

### 4.3.3 SPATIAL SOIL DATA

Spatial soil type data is shown in Figure 7.



Data Source: USDA-NRCS Web Soil Survey
Available at http://websoilsurvey.sc.egov.usda.gov

**Figure 7. Soil texture types in the Vina Subbasin**

# 5 PILOT ORCHARD SELECTION

The selected pilot orchards are summarized in Table 1 and include:

- 11 almond orchards
    - Range in age from 6 to 20 years old
    - 6 irrigated with double line drip as main irrigation
    - 5 irrigated with solid set
- 15 walnut orchards
    - Range in age from 8 to 29 years old
    - 1 irrigated with micro sprinkler
    - 14 irrigated with solid set

## 5.1 FIELD DATA COLLECTION

Field data collection included irrigation method and practices, pertinent environmental conditions (i.e. soil type, proximity to surface water, etc.), limiting factors such as disease and production challenges, applied water and yield. Yield data for 2024 and 2025 seasons were collected for all the pilot study orchards but applied water was not available for five of the orchards. Consumptive use data was also collected on all pilot orchard fields.

**Table 1. Almond PI Pilot Study Orchards and Site Conditions**

| # | Pilot Number | Age | Acres | Spacing | Variety | Rootstock | Irrigation Method | 2025 Applied Water Provided | 2025 Yield Provided | 2024 Yield Provided |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | PI0004ALM | 20 | 75.0 | 16 x 21 | Nonpareil (25%), Price (25%), Winters (25%), and Carmel (25%) | 25% Krymsk 86, 75% Mariana 2624 | Double line drip and solid set sprinklers | Y | Y | Y |
| 2 | PI0005ALM | 20 | 76.0 | 16 x 23 | Nonpareil (50%), Price (25%), Winters (12.5%), Carmel (12.5%) | Lovell Peach | Double line drip and solid set sprinklers | Y | Y | Y |
| 3 | PI0006ALM | 20 | 76.0 | 16 x 23 | Nonpareil (50%), Price (25%), Winters (12.5%), Carmel (12.5%) | None provided | Double line drip and solid set sprinklers | Y | Y | Y |
| 4 | PI0010ALM | 16 | 76 | 21 x 16 | Nonpareil (50%), Peerless (12.5%), Winters (12.5%), Monterey(25%) | Krymsk 86 | Solid set | Y | Y | Y |
| 5 | PI00117ALM | 17 | 57.0 | 27 x 27 | Nonpareil (50%), Aldrich (50%) | Lovell Peach & Kymsk86 | Solid set | Y | Y | Y |
| 6 | PI00120ALM | 15 | 115.0 | 22.5 x 17.25 | Nonpareil (66%), Winters (11%), Price (11%), & Carmel (11%) | Krymsk 86 | Solid set | Y | Y | Y |

| # | Pilot Number | Age | Acres | Spacing | Variety | Rootstock | Irrigation Method | 2025 Applied Water Provided | 2025 Yield Provided | 2024 Yield Provided |
|---|---|---|---|---|---|---|---|---|---|---|
| 7 | PI00123ALM | 6 | 30.4 | 24 x 14 | Nonpareil (50% or 75%?) & Bennet (50% or 25%?) | None provided | Double line drip and solid set sprinklers | Y | Y | Y |
| 8 | PI00124ALM | 9 | 42.0 | 24 x 16 | Nonpareil (50%), Aldrich (25%), and Wood Colony (25%) | Krymsk 86 | Double line drip and solid set sprinklers | Y | Y | Y |
| 9 | PI00127ALM | 12 | 50.9 | 22 x 14 | Nonpareil (50%), Monterey (25%), & Aldrich (25%) | Krymsk 86 | Solid set | N | Y | Y |
| 10 | PI00136ALM | 6 | 14.3 | 24 x 14 | Nonpareil (50% or 75%?) & Bennet (50% or 25%?) | None provided | Double line drip and solid set sprinklers | Y | Y | Y |
| 11 | PI00144ALM | 8 | 47.6 | 22 x 14 | Nonpareil (50%), Monterey (25%), & Aldrich (25%) | Krymsk 86 | Solid set | N | Y | Y |

Note: Some orchards had both types of irrigation systems and in these instances double line drip was the used predominantly during the growing season. The exceptions were solid set for frost control during bloom and nut set and post-harvest irrigation for rapid recovery from high crop stress.

**Table 2. Walnut Pilot Study Orchards and Site Conditions**

| # | Pilot Number | Age | Acres | Spacing | Variety | Rootstock | Irrigation Method | 2025 Applied Water Provided | 2025 Yield Provided | 2024 Yield Provided |
|---|---|---|---|---|---|---|---|---|---|---|
| 12 | PI0001WAL | 13 | 63.0 | 25 x 25 | Chandler | VX211 | Solid set | Y | Y | Y |
| 13 | PI0002WAL | 16 | 60.0 | 25 x 25 | Chandler | Paradox Hybrid (seedling) | Solid set | N | Y | Y |
| 14 | PI0008WAL | 22 | 118 | 25 x 12.5 | Howard | Paradox Hybrid (seedling) | Solid set | Y | Y | Y |
| 15 | PI0009WAL | 20 | 156 | 30 x 15 | Chandler | Paradox Hybrid | Solid set | Y | Y | Y |
| 16 | PI00118WAL | 16 | 58.9 | 27 x 27 | Chandler | Paradox Hybrid (seedling) | Solid set | Y | Y | Y |
| 17 | PI00119WAL | 20 | 15.0 | 30 x 30 | Chandler | Paradox Hybrid (seedling) | Solid set | Y | Y | Y |
| 18 | PI0011NWAL | 12 | 80.0 | 28 x 18 | Chandler | Paradox Hybrid | Solid set | Y | Y | Y |
| 19 | PI0011SWAL | 29 | 54.0 | 30 x 30 | Chandler | Paradox Hybrid | Solid set | Y | Y | Y |
| 20 | PI00121WAL | 13 | 61.9 | 24 x 28 | Solano | VX211 | Solid set | Y | Y | Y |
| 21 | PI00122WAL | 16 | 18.3 | 30 x 28 | Chandler | Paradox Hybrid | Solid set | Y | Y | Y |
| 22 | PI00125WAL | 22 | 50.8 | 26 x 22 | Howard | Paradox Hybrid (seedling) | Solid set | N | Y | Y |

| # | Pilot Number | Age | Acres | Spacing | Variety | Rootstock | Irrigation Method | 2025 Applied Water Provided | 2025 Yield Provided | 2024 Yield Provided |
|---|---|---|---|---|---|---|---|---|---|---|
| 23 | PI00126WAL | 15 | 94.1 | 26 x 22 | Solano | Paradox Hybrid (seedling) | Solid set | N | Y | Y |
| 24 | PI00128WAL | 28 | 14.2 | 30 x 30 | Chandler | Paradox Hybrid (seedling) | Micro sprinkler | Y | Y | Y |
| 25 | PI0012WAL | 8 | 39.5 | 28 x 28 | Chandler | Paradox Hybrid (seedling) | Solid set | Y | Y | Y |
| 26 | PI0013WAL | 12 | 64.3 | 28 x 20 | Chandler | Paradox Hybrid (seedling) | Solid set | Y | Y | Y |

# 6 RESULTS

The PI analysis focused on ETc data and irrigation and production data collected from growers on pilot orchards. Though the ETc data came from a larger dataset that measured ETc across the whole Vina Subbasin, that dataset was only used to explore how ETc data might be related to crop type and irrigation type data representing the whole subbasin. Comparisons between yield, applied water, and ETc could not be made for the whole Vina Subbasin because yield and applied water data were only collected for pilot study orchards.

## 6.1 IRRIGATION TYPES

In the pilot study, irrigation type did not appear to influence ET, yield, or water productivity (Figure 8). In almonds, both solid set and drip irrigation were used. In walnuts, solid set was used on all but one orchard. Irrigation system management appeared to be a more important factor than irrigation method in water use and yield. An analysis of irrigation type and ETc for almonds and walnuts across the whole Vina Subbasin also indicated that irrigation method and ETc are not related.

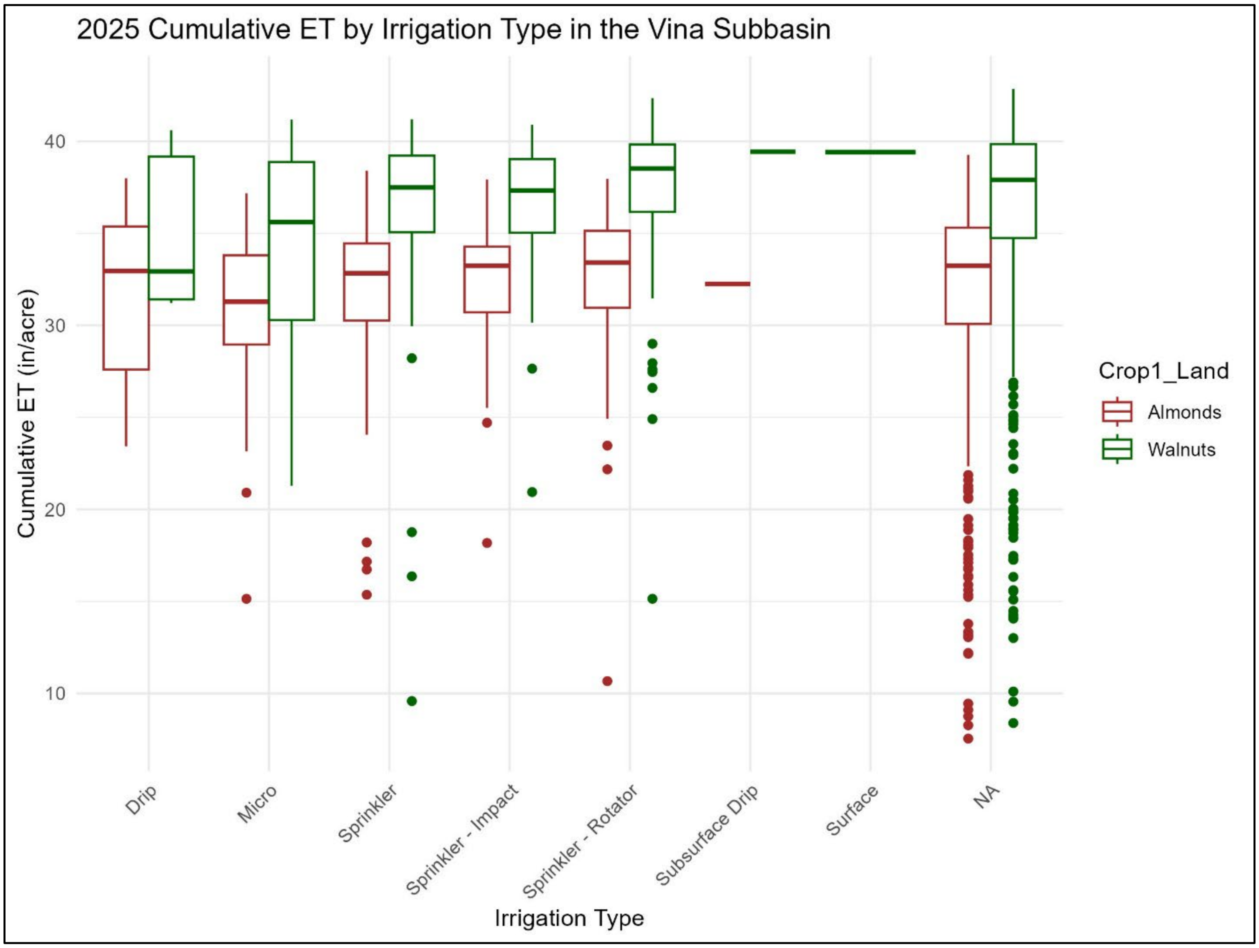


**Figure 8. ET by crop and irrigation type in the Vina Subbasin in 2025.**

## 6.2 IRRIGATION SCHEDULING METHODS

Growers participating in the pilot study used a range of tools and approaches to address the questions of when to irrigate and how long to apply water (see Precision Irrigation Case Study: *Methods for Determining Irrigation Timing and Application Duration,* Attachment A). The PI pilot study revealed that many growers in the Vina Subbasin are using science-based technologies and information to effectively time crop irrigations and determine appropriate durations. 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. Detailed information is provided in the Precision Irrigation Technical Bulletin: *Integrating Field Technologies into Irrigation Decision Support (*Attachment B*).* Though pilot study participants did not use Time of Use rate structures (from PG&E) to modify irrigation timing, the potential to reduce evaporation by switching from midday to nighttime irrigation is addressed in the PI pilot study technical bulletin: *Minimizing Midday Irrigation to Reduce Evaporative Losses from Tree Crops in the Vina Subbasin (*Attachment C*).* Financial aspects of this practice are evaluated in Attachment E.

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. Almost half of growers incorporated SWP measurements either as a primary decision tool or in combination with other data sources. Figure 9 illustrates that in walnuts, orchards irrigated under the guidance of the pressure chamber had slightly higher ET but applied almost 22 percent less water and yielded 9 percent more dry inshell walnuts. In walnuts, lower applied water may have been due to pressure chambers providing justification to begin irrigation later in the spring. This practice represents reduction in groundwater pumping as well as better utilization of stored soil moisture and effective rainfall to supply crop ET. The positive impact of pressure chamber data on water use efficiency in walnuts was documented by Shackel et al. (2021). 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.

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.

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.

However, ETc data and irrigation management information collected from the PI pilot study growers indicated that improved irrigation scheduling did not reduce crop water demand. Instead, careful irrigation management has shifted supplying crop water demand from pumping groundwater to other sources of soil moisture such as stored soil moisture from winter rainfall, in-season rainfall as the crop is growing, and in fewer cases, slow capillary movement of water from nearby streams and river seepage.

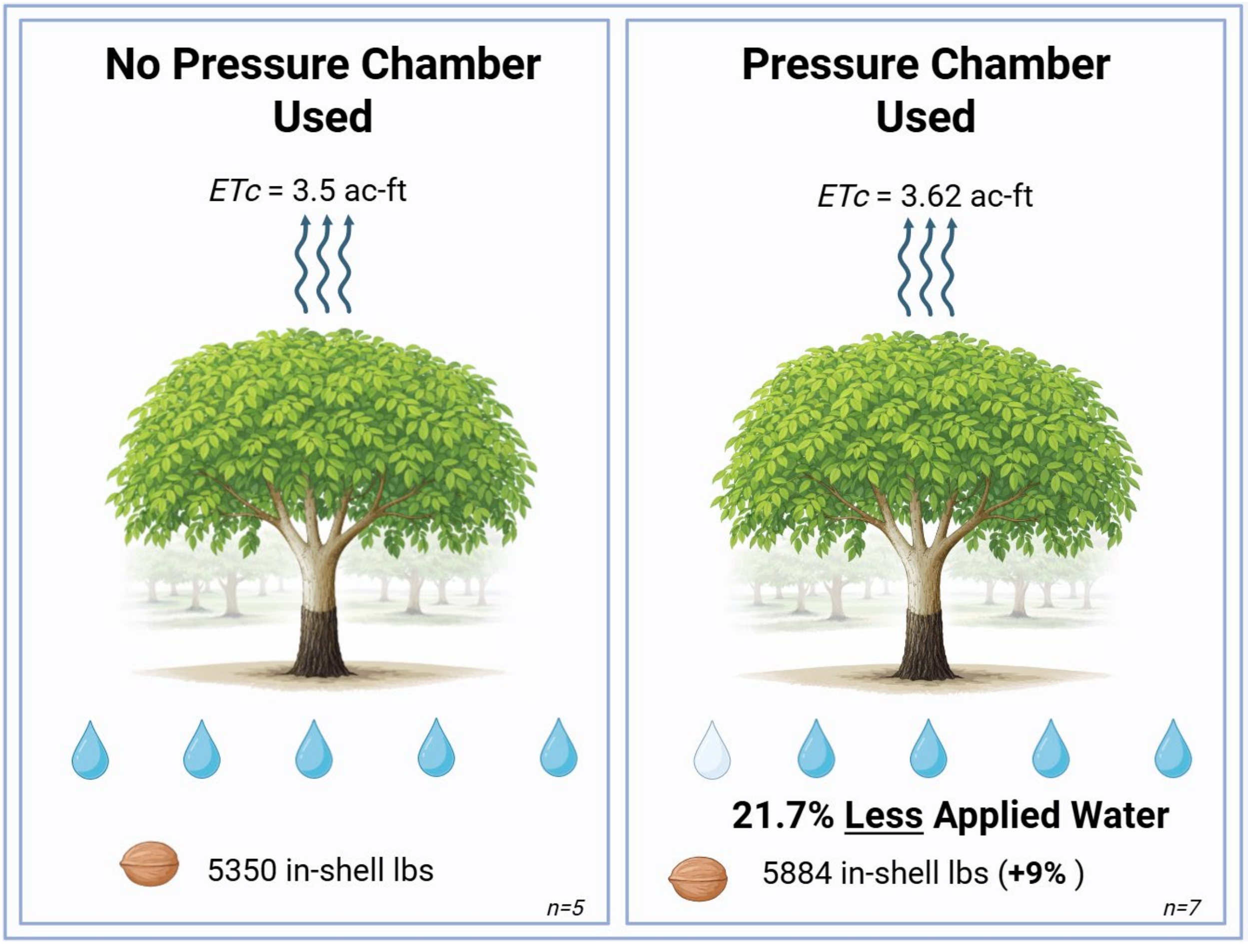


**Figure 9. Walnut ETc and yield of orchards where pressure chambers were used and not used in the PI pilot study.**

## 6.3 APPLIED WATER

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. For this reason, approaches to measuring applied water at the field level are an important part of optimizing irrigation management. Approaches to measuring applied water and their pros and cons are detailed in the Precision Irrigation technical bulletin: *Methods for Determining Irrigation Timing and Application Duration in Pilot Orchards (*Attachment D*).*

Applied water and precipitation in the PI pilot orchards is summarized in Table 3.

**Table 3. Precipitation, Applied Water and ETc of PI Pilot Study Almonds and Walnuts**

| Crop | 2025 January - October Precipitation (inches)[a] | Applied Water (inches) | | | Total Precipitation + Applied Water (inches) | | | ETc (inches) |
|---|---|---|---|---|---|---|---|---|
| | | Min | Mean | Max | Min | Mean | Max | |
| Almonds | 10.56 | 19.97 | 23.83 | 29.30 | 30.53 | 34.39 | 39.87 | 36.3 |
| Walnuts | 10.56 | 21.38 | 28.75 | 44.60 | 31.94 | 39.31 | 55.16 | 41.3 |

[a] Effective precipitation is likely less than total precipitation. The calculation used in this table does not account for the months in which most precipitation occurs and most ET occurs and assumes that all precipitation is available as stored soil water. Therefore, the precipitation plus applied water total is conservatively high.

Applied water was less than ETc in every almond orchard (Figure 10) participating in the pilot study. On average, in almonds, applied water was about 68 percent of ETc. In walnuts, applied water was less than ETc in all but two (of 15) orchards participating in the pilot study (Figure 11). The average applied water in walnuts was 72 percent of ET. Normally, total precipitation plus applied water exceeds ETc because growers need to account for less than 100% efficiency, which likely ranges from 80 to 95 percent with the irrigation types used on walnut and almond orchards in the Vina Subbasin.

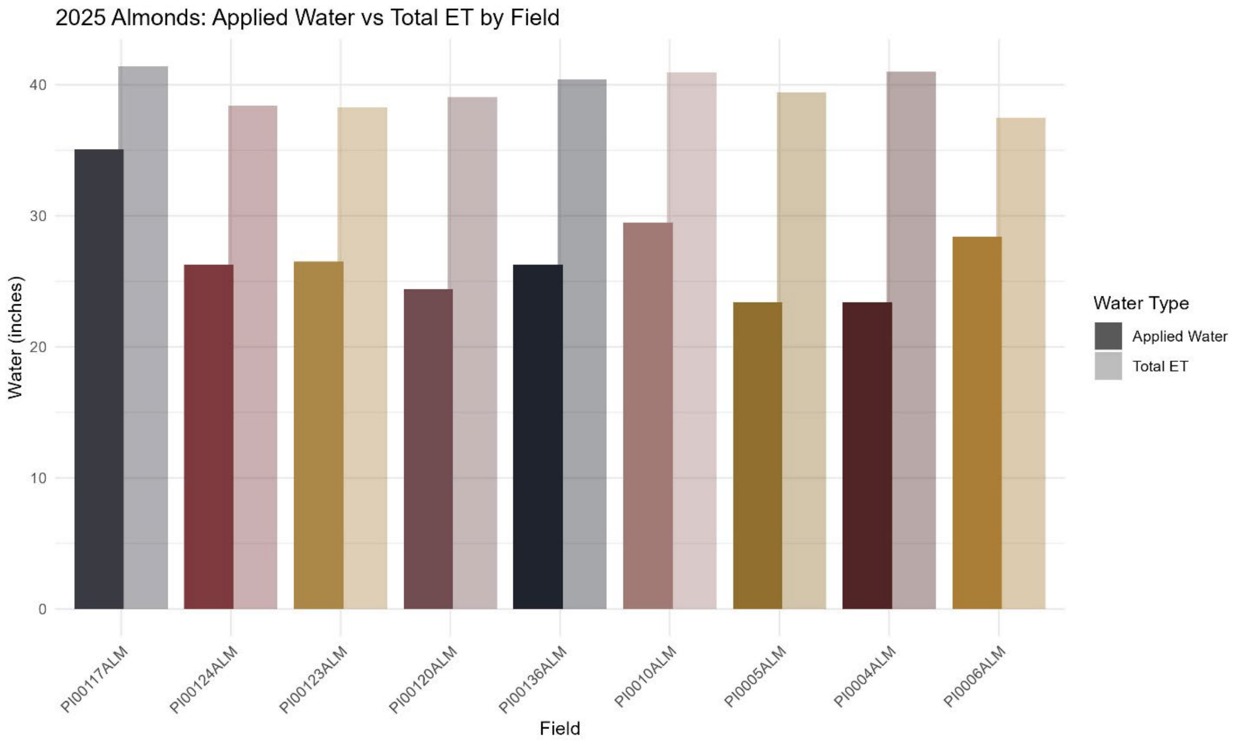


**Figure 10. Applied water and ET by almond pilot orchard.**

These data show the results of PI pilot study growers utilizing technology and science-based information to minimize groundwater pumping for irrigation. The reason growers can irrigate with less water than expected is because the tools they use to measure soil and crop water allow their crops to maximize other sources of water to meet ETc such as stored soil moisture, in-season rainfall, and possibly at times slow capillary movement of soil moisture from seepage from nearby natural water ways.

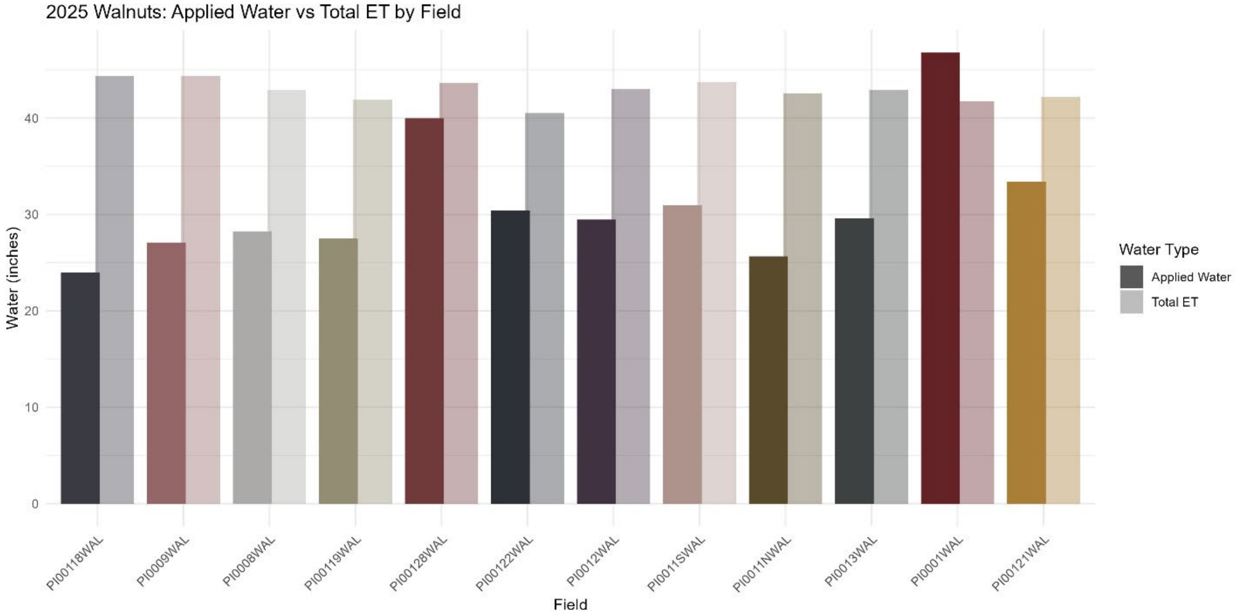


**Figure 11. Applied water and ET by walnut pilot orchard**

An analysis comparing soil types, yield and canopy size (using Normalized Difference Vegetation Index) across the whole Vina Subbasin indicated that walnut orchards on soils with higher water-holding capacity had higher yields and healthier canopies, even though they were not irrigated more and did not consume more water. This is another indication that growers are optimizing available sources of water and optimizing ET; otherwise, stored soil moisture would not influence yield.

## 6.4 YIELD

Variation in yield of the pilot study orchards was not related to applied water or ETc. With the relatively small dataset from the PI pilot study, it is difficult to predict if this lack of relationship is representative of the whole subbasin.

In both crops, applied water did not appear to be strongly related to yield. Though there are not enough data points from the pilot study to perform statistical analysis, Figures 12 and 13 show where the almond and walnut orchards are on the spectrum of applied water and yield, but do not include all orchards in the pilot study because applied water data was not available for all orchards.

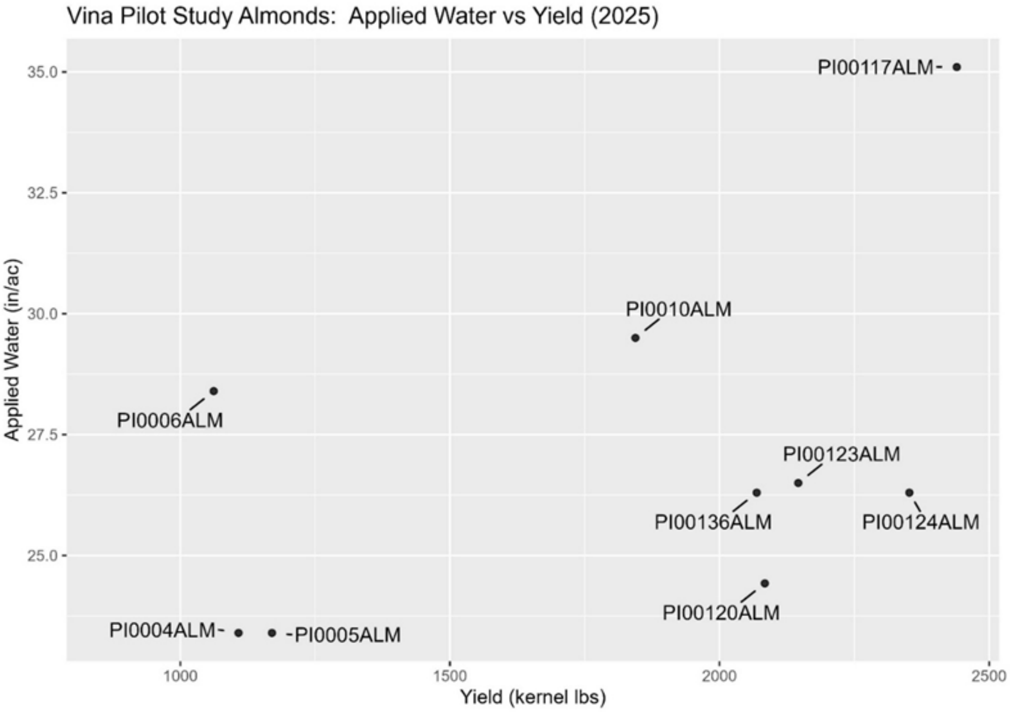


**Figure 12. Applied water and yield of almond orchards in the PI pilot study**

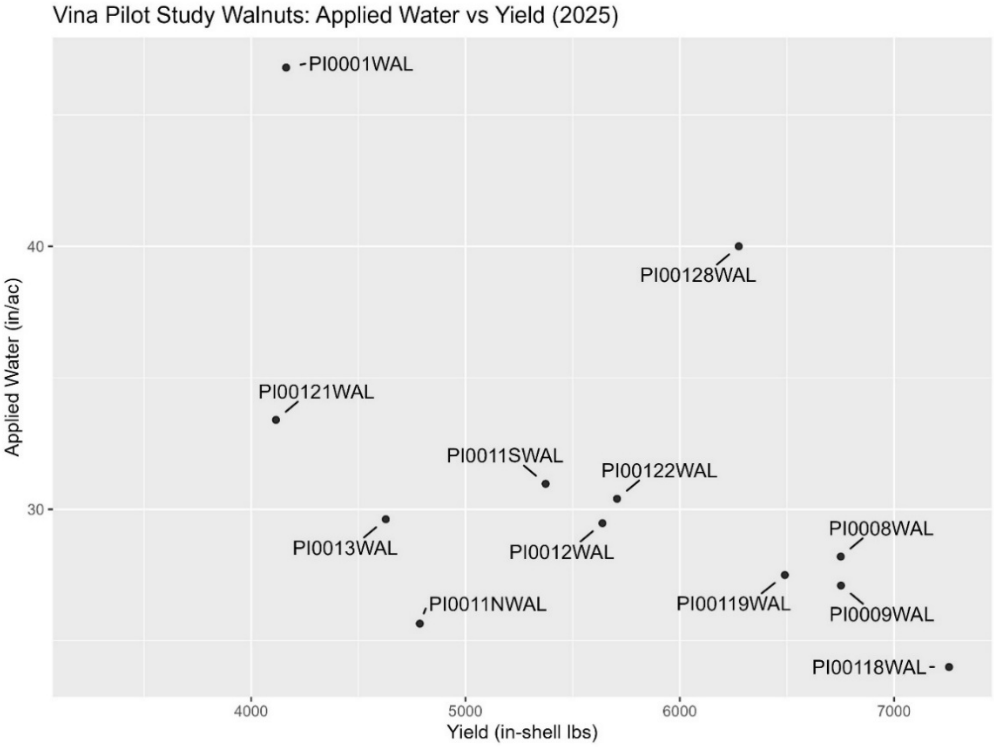


**Figure 13. Applied water and yield of walnut orchards in the PI pilot study**

## 6.5 CONSUMPTIVE USE

In either 2024 or 2025, some orchards exhibited relatively low yields but had relatively high ET (Figures 14 and 15). However, some of these same orchards had relatively high yield and low ET in the other year. Multiple years of data are needed to determine if orchards have consistent high or low productivity. Consistent gaps between consumptive use and yield might indicate inherent limitations on productivity, such as low soil quality or disease. These conditions show up as non-uniformity in orchards such as variations in canopy growth, tree size, and fruitfulness.

Discrepancy between yield and consumptive use may also be caused by pruning practices that influence yield in the year they are carried out but are ultimately intended to increase yield in future years. Hedging and more intensive levels of hand pruning are not usually completed across an entire orchard in one year. When practiced, hedging and more intensive pruning are completed across about 1/3 or 1/4 of the orchard annually. This spreads out the cost of hedging and its impact on productivity over multiple years. Plus, the orchard needs to be given time to regrow new shoots and develop new fruit spurs or buds to increase productivity. If the orchard responds favorably, it may improve its productivity but if the orchard responds poorly, it may still exhibit lower yields than expected. It may take four or more consecutive years of production and ET data to evaluate trends in productivity relative to ET.

In some of the almond and walnut orchards, root and crown diseases such as phytophthora root rot, crown gall, and oak root fungus appeared prevalent and caused significant areas of tree decline or tree death resulting in missing trees which could also be limiting orchard production. When faced with these types of situations, a grower must decide whether to replant seedling trees among larger surrounding mature trees and try to restore orchard canopy and recover orchard production.

Conditions that might be associated with discrepancies between yield and consumptive use were difficult to distinguish with only two years of yield and consumptive use data on a small dataset. They are also less likely to occur where irrigation is well managed using tools that allow for accurate irrigation application.

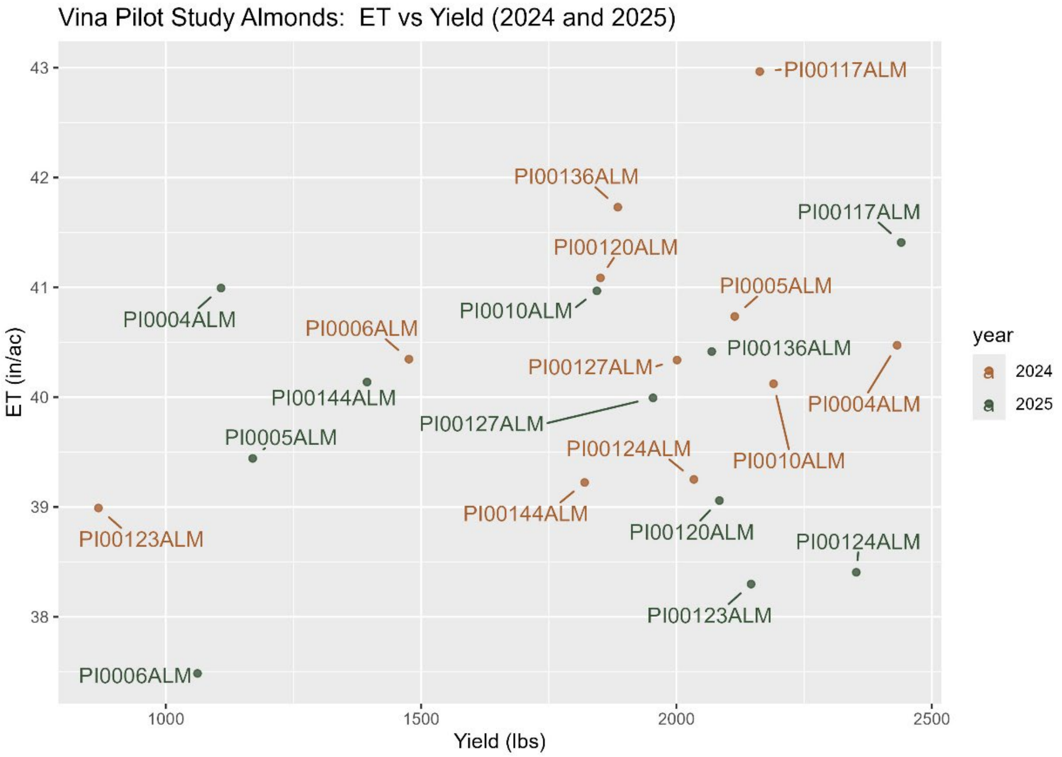


**Figure 14. ET and yield of almond orchards in the PI pilot study.**

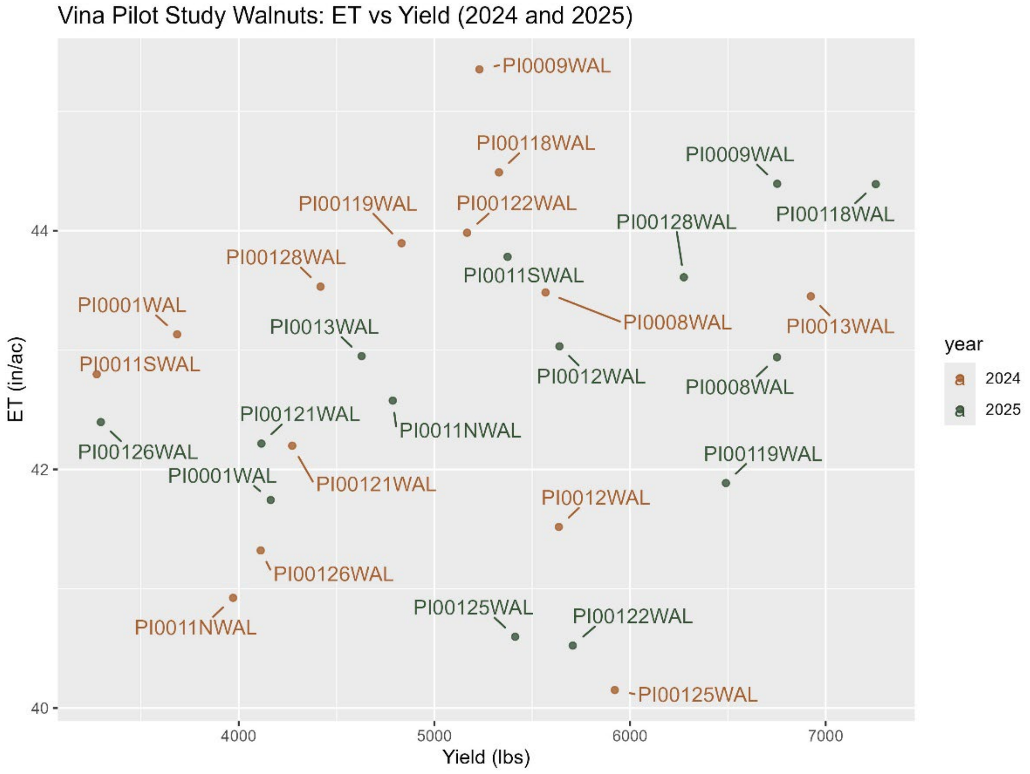


**Figure 15. ET and yield of walnut orchards in the PI pilot study.**

### 6.5.1 ORCHARD AGE

Figure 16 shows paired yields for 2024 and 2025 for eleven almond orchards participating in the PI pilot study, ordered from oldest to youngest orchards. The oldest orchards were planted in 2006 (21 years old) and the youngest was planted in 2020 (6 years old). There was no clear association between orchard age and almond yield.

Yields were lowest at about 800 kernel lbs/ac in 2024 for the youngest orchard PI00123ALM, planted in 2020. Yields were highest at about 2,350 kernel lbs/ac in 2024 for orchard PI0004ALM, one of the older orchards planted in 2006 (21 years old). Yields were most consistent both in 2024 and 2025 for mid-aged orchards planted from 2009 through 2017 (10 to 17 years old). All the orchards within this group were managed by different growers.

Except for two orchards, all the orchards in the pilot study had yields equal to or greater than 2,000 kernel lbs/ac at least one of the two years. The two exceptions were orchards PI0006ALM and PI00144ALM. Orchard PI0006ALM was planted in 2008 (18 years old) and orchard PI00144ALM was planted in 2018 (8 years old).

Figure 17 shows paired yields for 2024 and 2025 for fifteen walnut orchards participating in the PI pilot study. They are arranged from oldest to youngest orchards left to right across the graphic. The oldest orchard was planted in 1997 (29 years old) and the youngest orchard was planted in 2018 (8 years old). Again, there was no clear association between walnut orchard age and walnut yield. Yields ranged from a low of about 3,600 to a high of 7,200 lbs dry in-shell walnuts across both years and all of the orchards. Yields for a group of four mid-aged walnut orchards ranged from about 3600 to 4400 lbs/ac in both 2024 and 2025. They were planted between 2011 (15 years old) and 2014 (12 years old) and managed by four different growers. Overall, orchard age was not indicative of yield.

Similarly (data not shown), there was no relationship between orchard age and consumptive use in pilot study orchards.

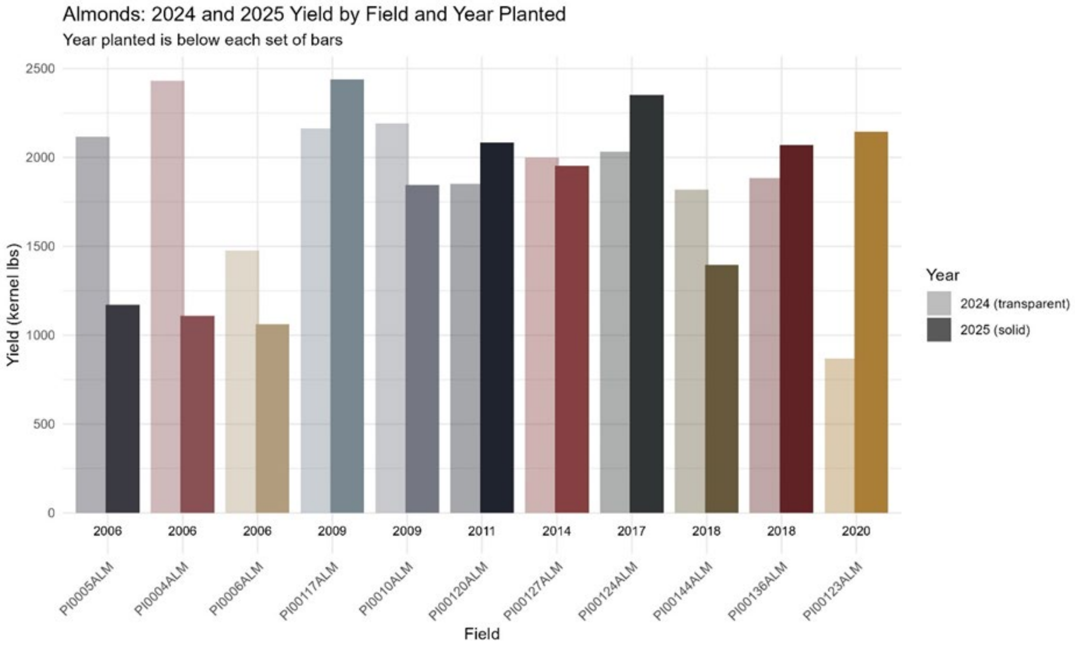


**Figure 16. Paired yields for 2024 and 2025 for eleven almond orchards participating in the PI pilot study.**

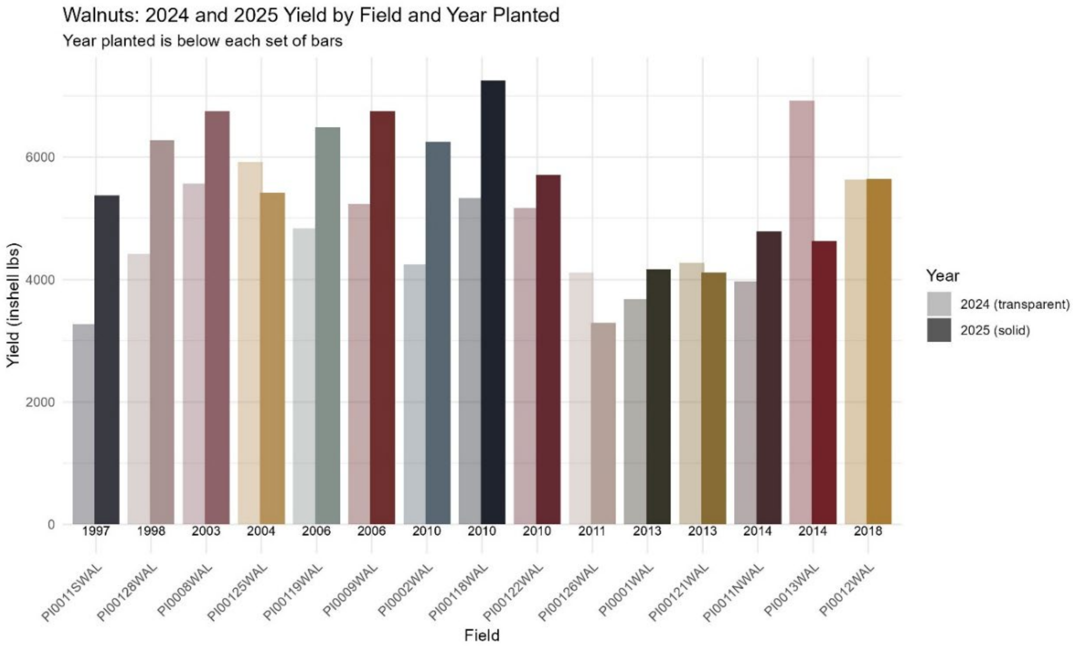


**Figure 17. Paired yields in 2024 and 2025 for fifteen walnut orchards participating in the PI pilot study.**

# 7 CONCLUSIONS

The following conclusions were drawn from analyzing quantitative and qualitative data from the PI pilot study. The relatively small number of orchards in the pilot study and the lack of multiple years of data are limitations that must be considered when interpreting results of the study. Because the pilot study largely included only medium to large farms, these conclusions may be considered representative of medium to large farms but may not be as representative of all and/or small farms.

1. **The PI pilot study demonstrated how ET and yield can be used to identify orchards with potential non-beneficial ET. However, there were no consistent relationships between yield and consumptive use data that could be used to identify non-beneficial consumptive use in the short time-frame of this study.**
    a. Some orchards exhibited relatively low yields but had relatively high ET. This combination can be indicative of non-beneficial ET if it occurs over several growing seasons. However, some of these same orchards had relatively high yield and low ET in the second year. Multiple years of data are needed to determine if orchards have consistent high or low productivity.
    b. Orchard yield depends on myriad factors that change yearly and include but are not limited to water. Factors such as disease can limit yield even when irrigation and consumptive use is optimized. Pruning practices can also impact yield for short periods but may ultimately benefit yield in subsequent years.
2. **There is little evidence from the PI pilot study that there is substantial opportunity to reduce ET with precision irrigation in medium to large almond and walnut farms.**
    a. Improved irrigation scheduling did not reduce crop water demand. Growers in the PI pilot generally had good on-farm irrigation efficiency and minimized groundwater pumping. About 75% of the pilot study (by grower count and acreage) used at least two data sources leading to more effective irrigation decisions. The small proportion of growers and acreage relying on calendar and experience-based irrigation scheduling suggests that adoption of data-informed irrigation practices is feasible and ongoing in the Vina Subbasin. About eighty-five percent of the agricultural groundwater resources are used by farms with over 100 acres, which are well represented in this study compared to small farms.
    b. Irrigation management practices in the PI pilot study are likely representative of medium to large size orchards, which were represented in the Butte County Ag Survey as adopting irrigation scheduling technology more than small farms. However, one the most efficiently irrigated and productive orchards in the pilot study was a small farm that used an irrigation consultant.
    c. Applied water data indicated that orchards in the Vina Subbasin have access to relatively large stores of soil moisture, and growers are using irrigation scheduling technologies that directly measure soil and plant water to maximize the use of this stored water and apply less irrigation accordingly.
    d. Irrigation management can improve irrigation efficiency among orchards (yield compared to applied water, or “crop per drop”) but does not necessarily result in more optimal water use by tree crops (consumptive use compared to applied water), which was the main objective of this pilot study.

3. **Irrigation system management was more important than irrigation type in maximizing water use and water productivity (water use as a function of yield).**
    a. There was little difference in crop productivity or water productivity between dual line drip and solid set irrigation.
4. **Walnuts appeared to respond to less irrigation (based on data from pressure chambers) while improving production, though this trend was not the same in almonds.**
    a. Growers using pressure chambers to guide their irrigation management applied less water, while ETc and dry in-shell yield was higher. This is likely the result of healthier trees with less exposure to saturated soils and root diseases.
    b. The use of pressure chambers likely has a positive effect on water efficiency because they provide growers with data that justifies starting irrigation later in the season instead of growers having no data and erring on the early side of irrigation to ensure trees are not stressed.
5. **There may be more potential for improved water management, including both irrigation efficiency and minimizing non-beneficial ET, on small farms.**
    a. The PI pilot study focused on medium to large sized farms using technologies to schedule irrigation and measure applied water. The Butte County Farmer Survey (2021) indicated that these technologies were not adopted as much on small farms.
    b. A key component for the smaller grower would be working with a consultant, which would provide information, expertise and access to technology advances that are may not be as available or accepted for smaller operations.
    c. The potential to reduce groundwater demand through improving irrigation and farm practices would need to be investigated by the GSA to determine what that potential is and what the associated effort would be needed to realize it.
6. **There may be potential to reduce the evaporation portion of ET by using more nighttime irrigation and less daytime irrigation.**
    a. This practice would need relatively widespread adoption to have impact across the Vina Subbasin to reduce the evaporation portion of ET. It is estimated that about 350 ac-ft reduction of ET or groundwater pumping per 1,000 acres of participation could be realized. It would take about 3,000 acres of adoption to reduce ET by 1,000 ac-ft and 30,000 acres to approach 10,000 ac-ft reduction. Estimates need local validation. (See Attachment C, PI Technical Bulletin: Minimizing Midday Irrigation to Reduce Evaporative Looses from Tree Crops in the Vina Subbasin).
    b. There are numerous obstacles that would need to be overcome in practical use. Likely, automation would need to be implemented to address the otherwise need for labor at night which, for many operations, would be a significant challenge. In addition, fewer hours to irrigate each day means more days of irrigation each week and not enough downtime to dry soils to enable orchard re-entry with tractors and sprayers for pest control.
    c. Financial analysis indicates that approximately $65/acre can be saved by growers leverage time of use rate structures to implement off-peak irrigation. Education and outreach and/or incentives would likely be needed to achieve broad grower acceptance.

7. The quantifiable water savings that can be estimated using information from the PI study and supporting technical information are as follows:
    a. The PI pilot study indicated that 21.7 % of applied water used on walnuts can be saved using pressure chambers, equivalent to 0.65 acre-feet per acre (7.8 inches per acre) in established walnuts. The current number of growers (and acres) currently using this technology is unknown. There are approximately 15,000 acres of established walnuts in the Vina Subbasin (9 to 25 years old). If 20% more acres (3,000 acres) adopted pressure chamber use, the resulting savings in applied water would be 1,950 ac-ft annually. There is no reduction in consumptive use (or yield) associated with this practice.
    b. It is estimated, using literature, that consumptive use could potentially be reduced by 0.35 acre-feet per acre (4.2 inches per acre) using nighttime irrigation instead of midday irrigation. Using the same example, 3,000 acres using nighttime irrigation instead of midday irrigation would reduce ET by 1,000 ac-ft annually, assuming the literature values apply to the Vina Subbasin.

# 8 RECOMMENDATIONS

1. If the Vina GSA wishes to pursue identification of non-beneficial ET in almond and walnut orchards, it would need a minimum of four years of yield and ET data from orchards to determine how and where non-beneficial ET occurs.
2. The Vina GSA should investigate the potential to improve irrigation management with advanced technologies on small farms.
3. The Vina GSA should focus its efforts related to specific irrigation management practices on the use of pressure chambers as components of an advanced technology approach to irrigation scheduling, either through outreach and education and/or incentivizing technology, particularly in walnut production.
4. If the Vina GSA wishes to pursue a move away from midday irrigation, education and outreach would be needed on the associated financial savings, and potentially assistance in implementing automation. The GSA should target orchards that are 3 to 8 years old as a starting point. These orchards may have a higher fraction of evaporation and have less constraints to adoption.

# 9 REFERENCES

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# APPENDIX

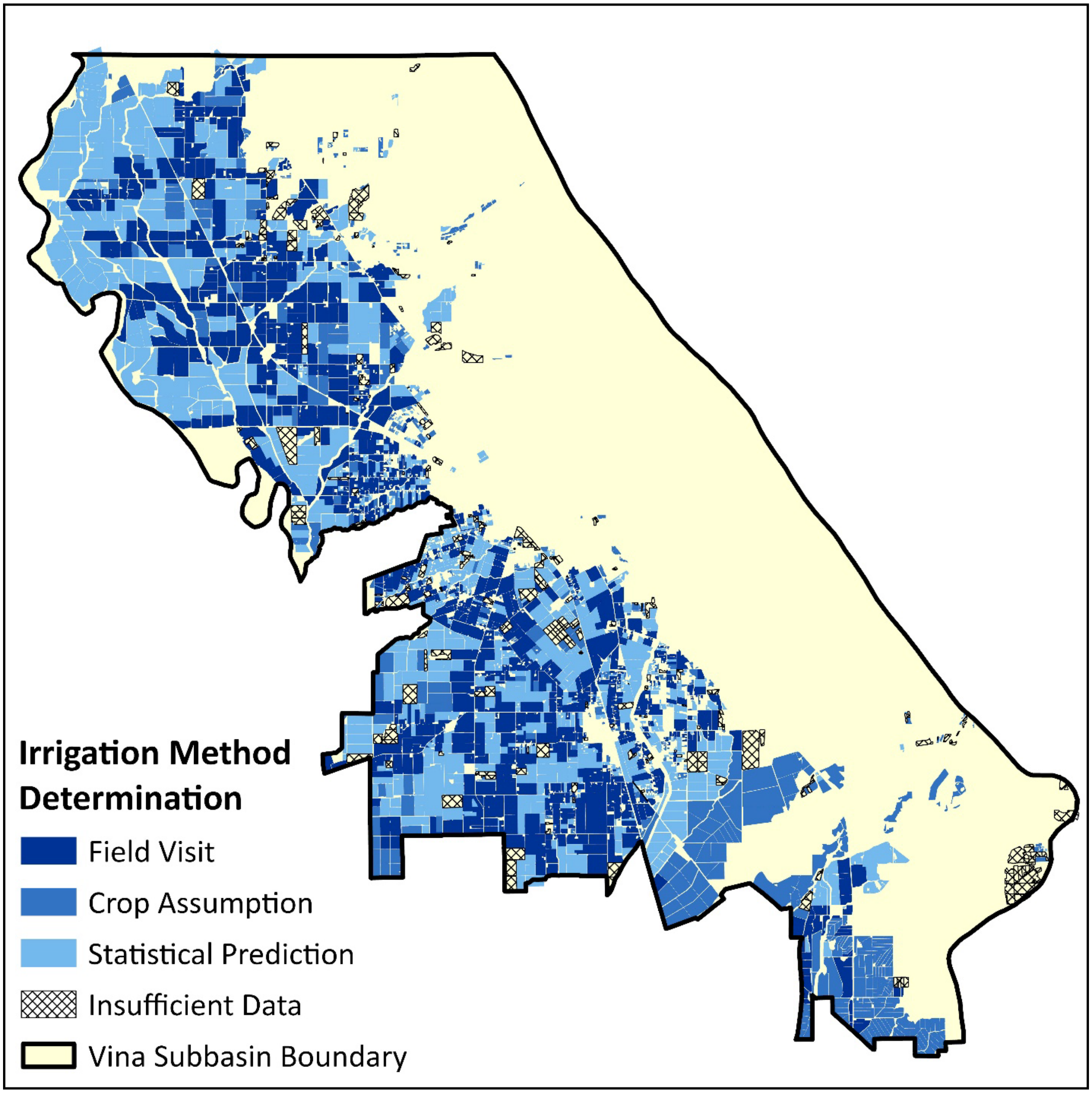


**Figure A-1. Fields in the Vina Subbasin by Irrigation Method Determination**

**Table A-1. Irrigation Method Summarized by Mapping Method**

| Irrigation Method | Determined Acres | Predicted Acres | Total Acres | % of Total |
|---|---|---|---|---|
| Surface | 5,003 | 179 | 5,181 | 7% |
| Sprinkler | 22,298 | 23,825 | 46,122 | 59% |
| Microirrigation | 10,152 | 5,885 | 16,037 | 20% |
| Not Irrigated | 6,575 | - | 6,575 | 8% |
| Insufficient Data | 4,906 | - | 4,906 | 6% |
| Total | 48,933 | 29,888 | 78,821 | 100% |

**Table A-2. Irrigation Method Probability for Crops Using Statistical Prediction**

| Crop Type | % Acreage Visited | % Sprinkler | % Microirrigation | % Surface |
|---|---|---|---|---|
| Almonds (1-20 yrs) | 49% | 68% | 32% | 0% |
| Almonds (20+ yrs) | 56% | 88% | 12% | 0% |
| Walnuts | 44% | 85% | 15% | 0% |
| Mixed Pasture | 29% | 55% | 0% | 45% |

# ATTACHMENTS

**Attachment A:** **Case Study – Methods for Determining Irrigation Timing and Application Duration in Pilot Orchards**

**Attachment B:** **Technical Bulletin – Integrating Field Technologies into Irrigation Decision Support**

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

**Attachment D:** **Technical Bulletin – Field Level Measurements of Applied Water and Opportunities for Improvement**

**Attachment E:** **Off Peak Irrigation for Precision Irrigation Program**

# ATTACHMENT A

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

# Precision Irrigation Case Study

## 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).

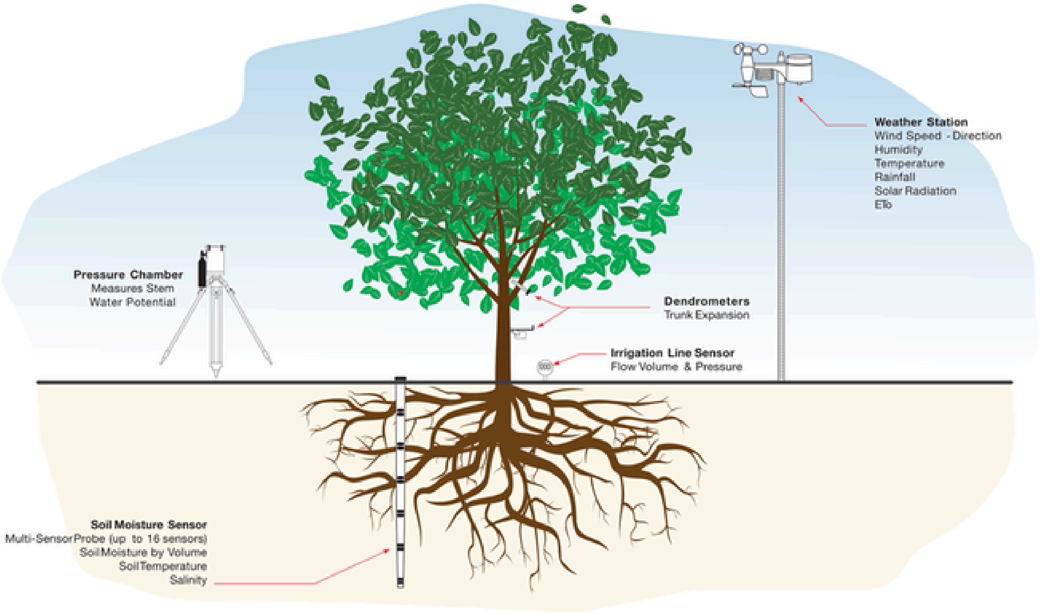


**Figure 1. Example of sampling tools used to determine irrigation timings and duration.**

**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).

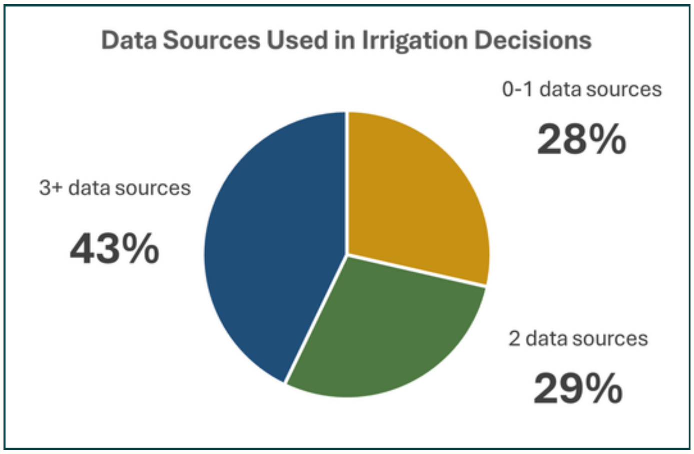


**Figure 2. Distribution of pilot orchards by number of data sources used to guide irrigation decisions.**

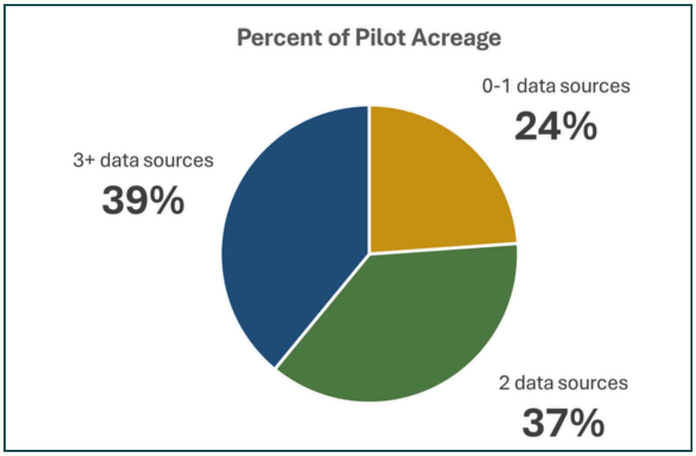


**Figure 3. Acreage distribution by number of data sources used to support irrigation decisions.**

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

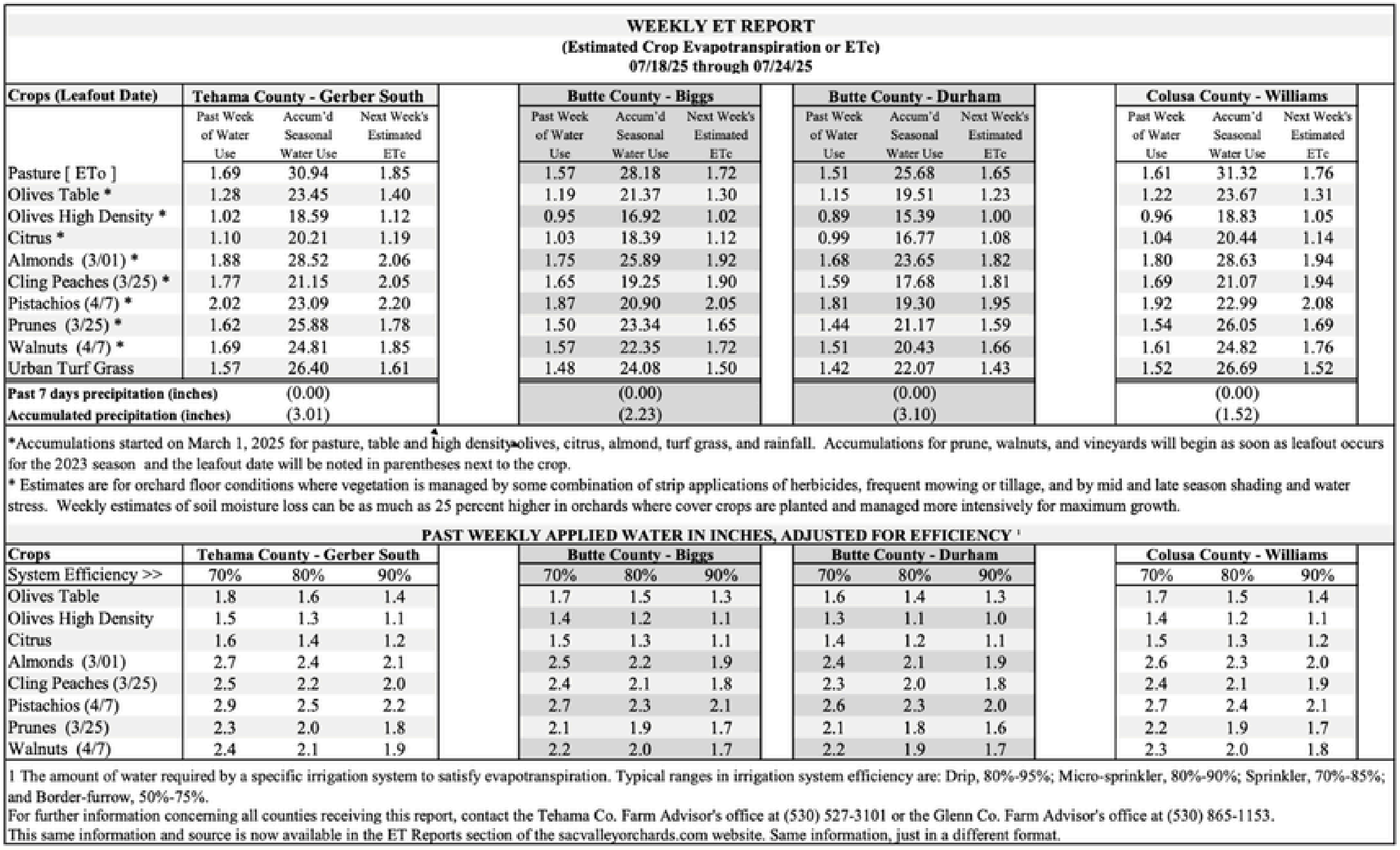
Among the pilot sites using a calendar- or experience-based irrigation approach, results were mixed. Less than 10% of participants and acreage in the pilot study relied primarily on this method. Of that acreage, approximately half achieved productivity and water efficiency comparable to orchards using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

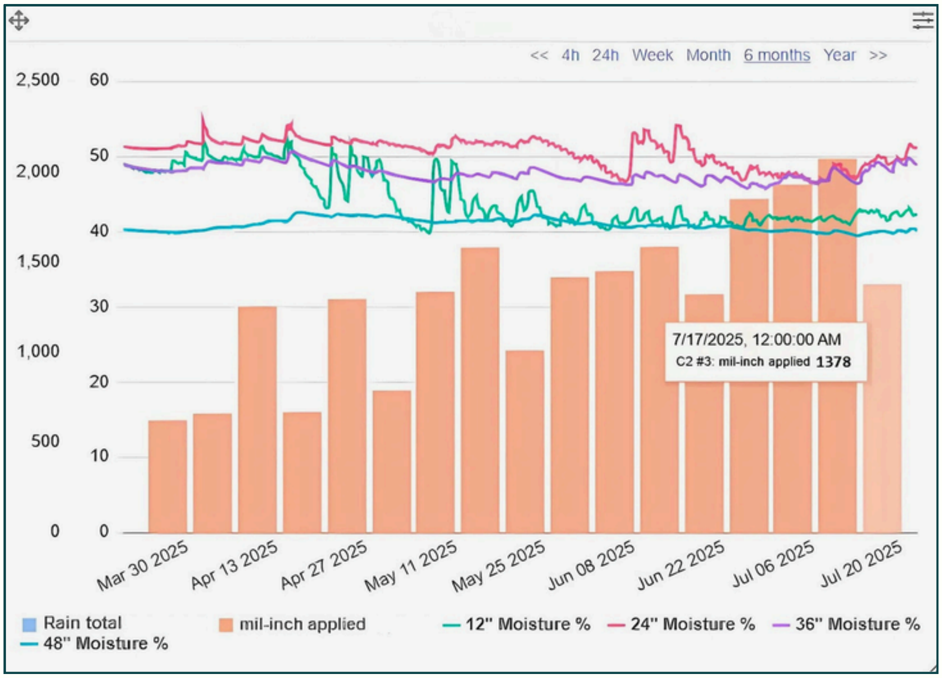


**Figure 5. Soil Moisture, image provided by HotspotAG.**

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

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).

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.

**Figure 9. Dendrometer**

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 ).

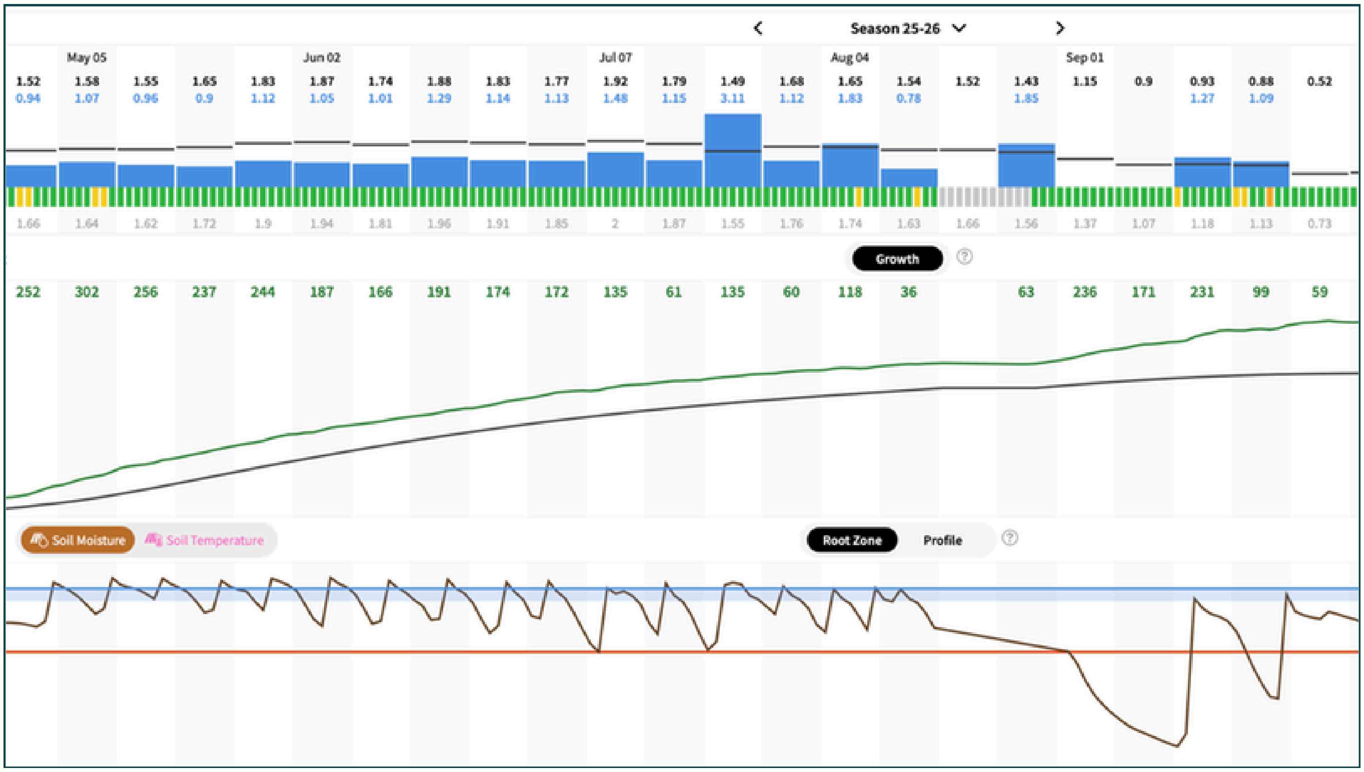


**Figure 10. Dendrometer data from Phytech.**

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).

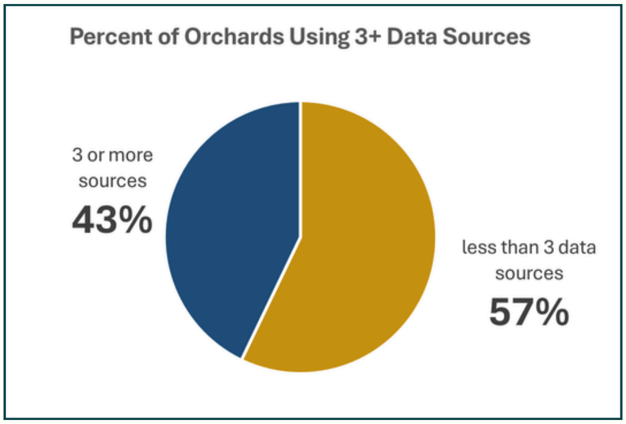
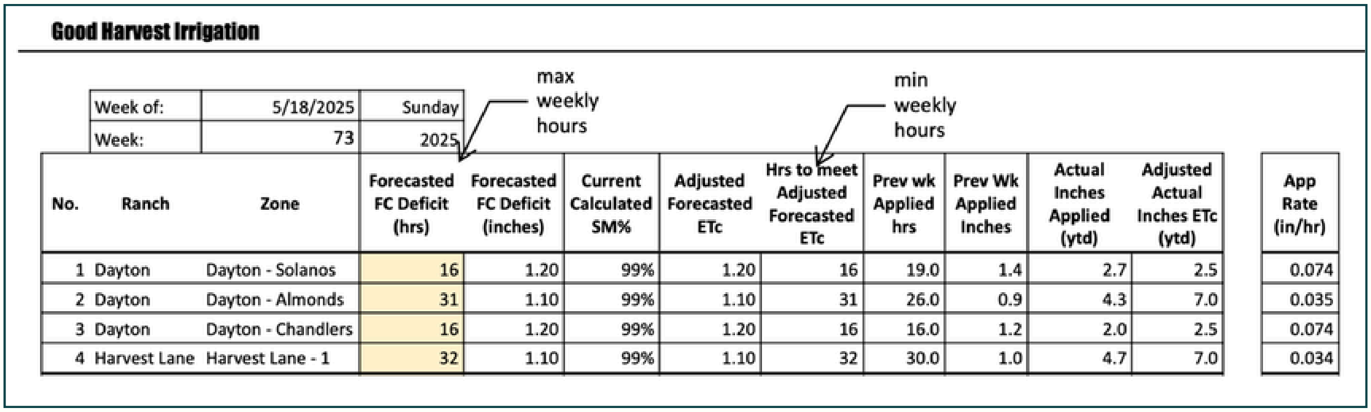


**Figure 11. Percent of Orchards Using Three Plus Data Sources.**

## 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).

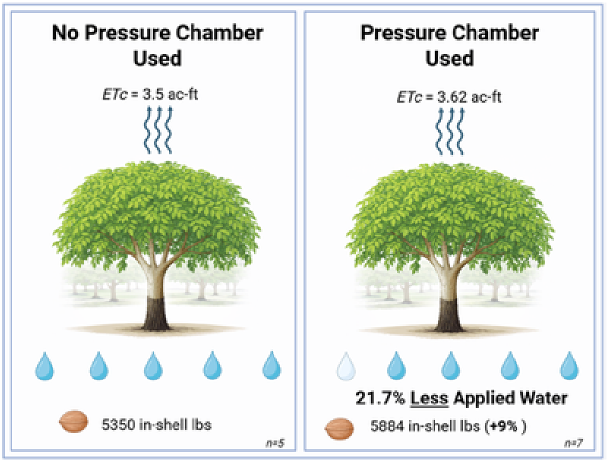


**Figure 14.Average percent of ET over applied water in walnuts.**

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

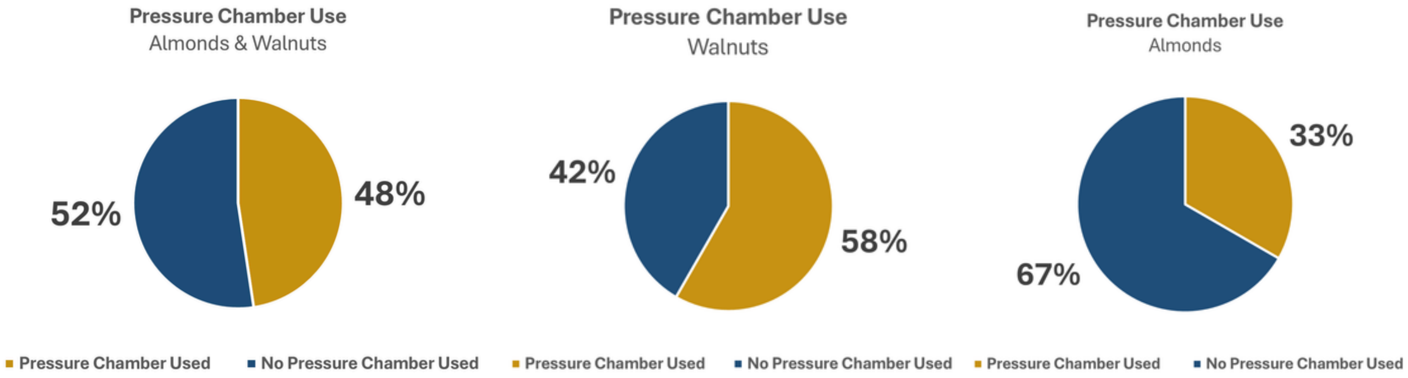


**Figure 15. Percent pressure chamber use of pilot orchards**

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"**

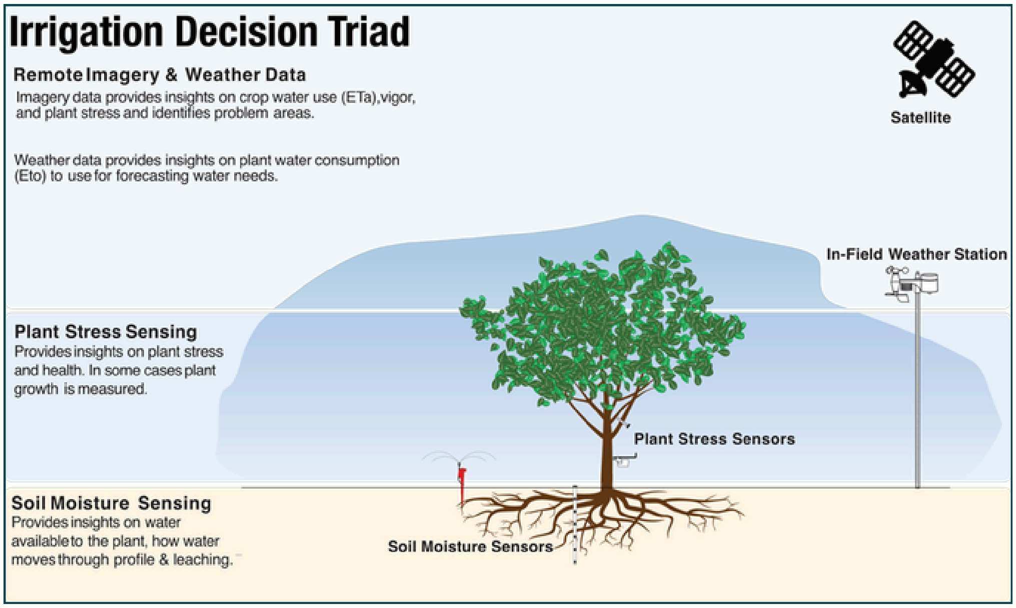
While irrigation management goals vary by operation, common objectives for adopting field monitoring tools include:

- 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.



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.

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

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 SUPPROT 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.<br>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

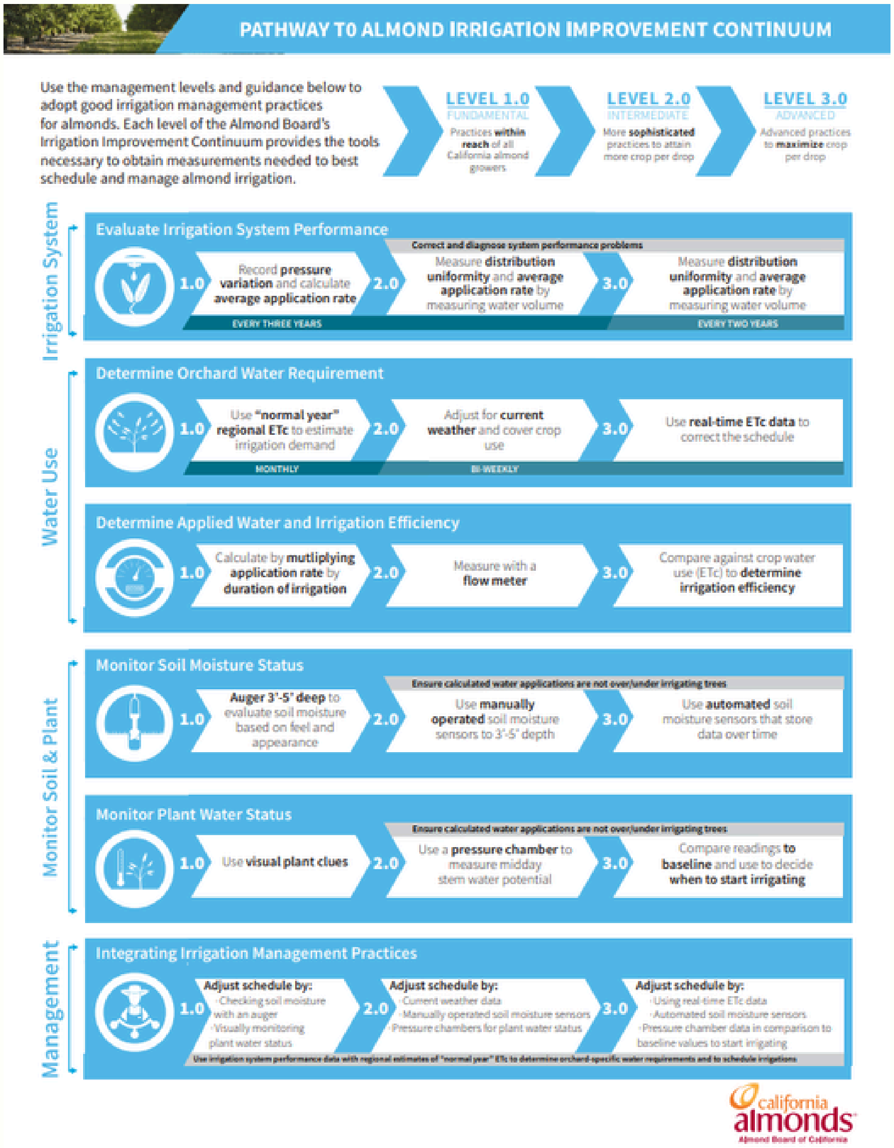
### Almond Irrigation Improvement Continuum

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 | LEVEL 2.0 INTERMEDIATE | LEVEL 3.0 ADVANCED |
|---|---|---|
| Practices **within reach** of all California almond growers | More **sophisticated** practices to attain more crop per drop | Advanced practices to **maximize** crop per drop |

**Irrigation System**

| Evaluate Irrigation System Performance | 1.0 | 2.0 | 3.0 |
|---|---|---|---|
| | Record **pressure variation** and calculate **average application rate** | Measure **distribution uniformity** and **average application rate** by measuring water volume | Measure **distribution uniformity** and **average application rate** by measuring water volume |
| | EVERY THREE YEARS | Correct and diagnose system performance problems | EVERY TWO YEARS |

**Water Use**

| Determine Orchard Water Requirement | 1.0 | 2.0 | 3.0 |
|---|---|---|---|
| | Use **"normal year" regional ETc** to estimate irrigation demand | Adjust for **current weather** and cover crop use | Use **real-time ETc data** to correct the schedule |
| | MONTHLY | BI-WEEKLY | |

| Determine Applied Water and Irrigation Efficiency | 1.0 | 2.0 | 3.0 |
|---|---|---|---|
| | Calculate by **mutliplying application rate** by **duration of irrigation** | Measure with a **flow meter** | Compare against crop water use (ETc) to **determine irrigation efficiency** |

**Monitor Soil & Plant**

| Monitor Soil Moisture Status | 1.0 | 2.0 | 3.0 |
|---|---|---|---|
| | **Auger 3'-5' deep** to evaluate soil moisture based on feel and appearance | Use **manually operated** soil moisture sensors to 3'-5' depth | Use **automated** soil moisture sensors that store data over time |
| | | Ensure calculated water applications are not over/under irrigating trees | |

| Monitor Plant Water Status | 1.0 | 2.0 | 3.0 |
|---|---|---|---|
| | Use **visual plant clues** | Use a **pressure chamber** to measure midday stem water potential | Compare readings **to baseline** and use to decide **when to start irrigating** |
| | | Ensure calculated water applications are not over/under irrigating trees | |

**Management**

| Integrating Irrigation Management Practices | 1.0 | 2.0 | 3.0 |
|---|---|---|---|
| | **Adjust schedule by:**<br>·Checking soil moisture with an auger<br>·Visually monitoring plant water status | **Adjust schedule by:**<br>·Current weather data<br>·Manually operated soil moisture sensors<br>·Pressure chambers for plant water status | **Adjust schedule by:**<br>·Using real-time ETc data<br>·Automated soil moisture sensors<br>·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

# 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.

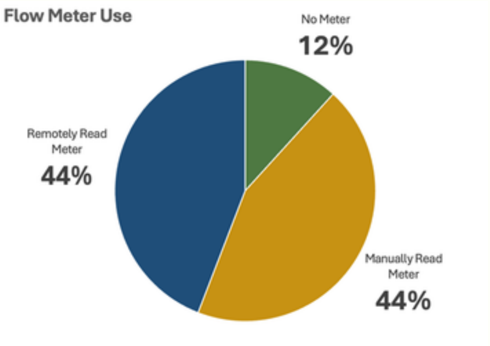

Figure 1. Flow Meter Use

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.

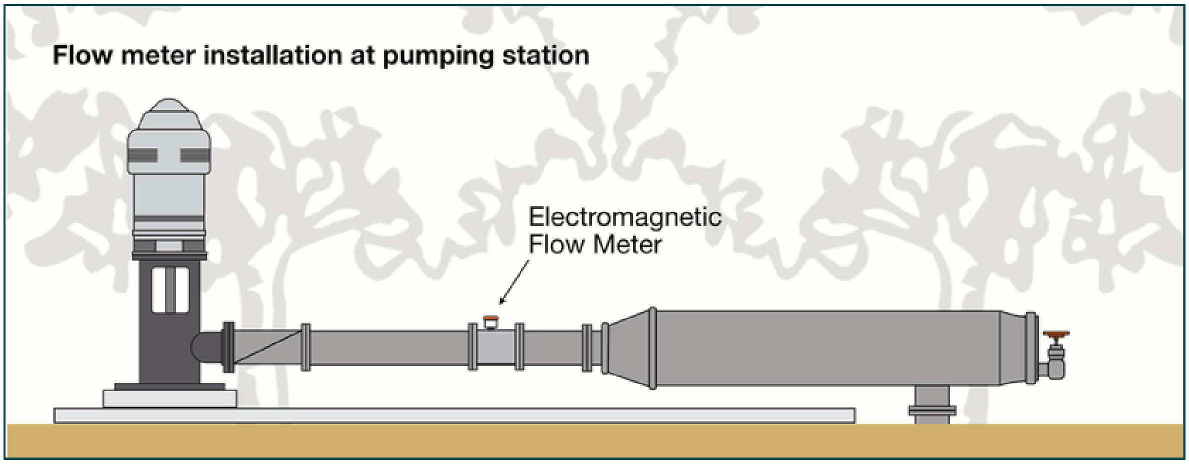

**Figure 2. Flow Meter Installation**

## 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.

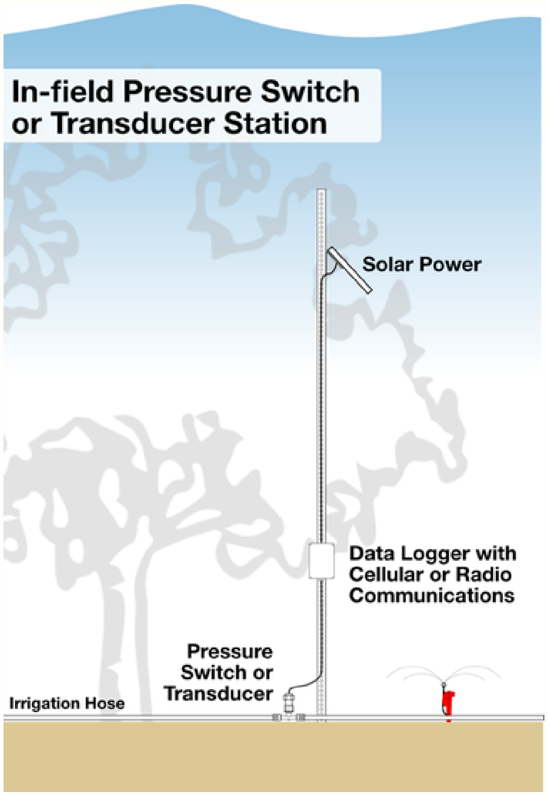

Figure 3. Pressure sensing station.

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.

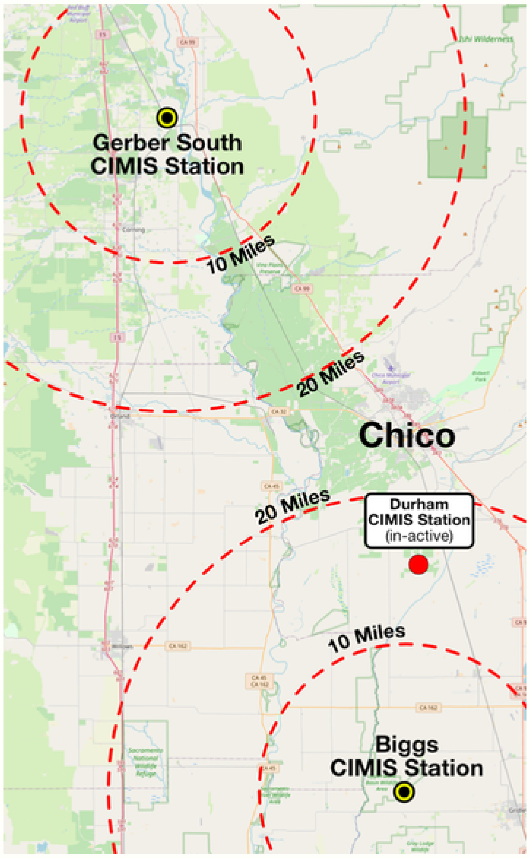

Figure 4. CIMIS station map.

## 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.

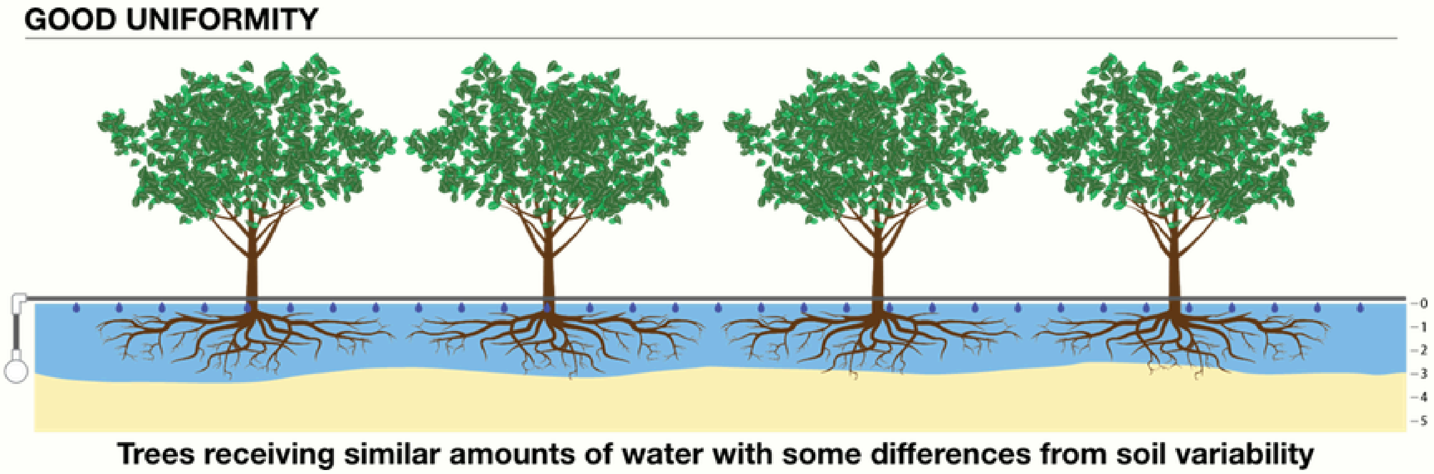

Figure 5. Good distribution uniformity with adequate depth of applied water throughout the orchard.

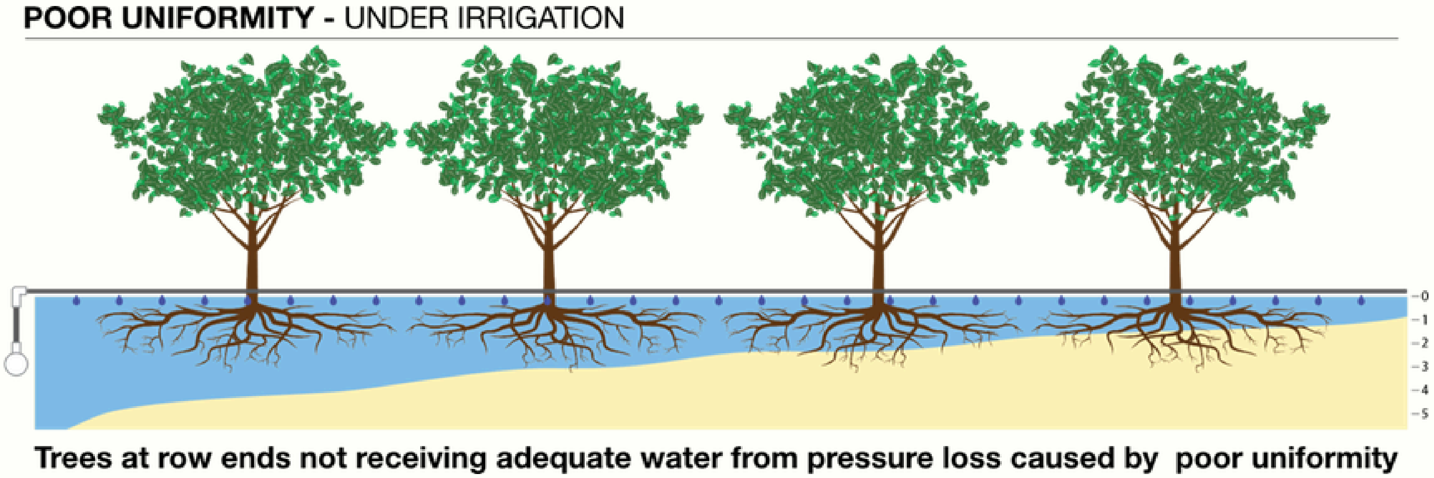

Figure 6. Poor distribution uniformity - under irrigation.

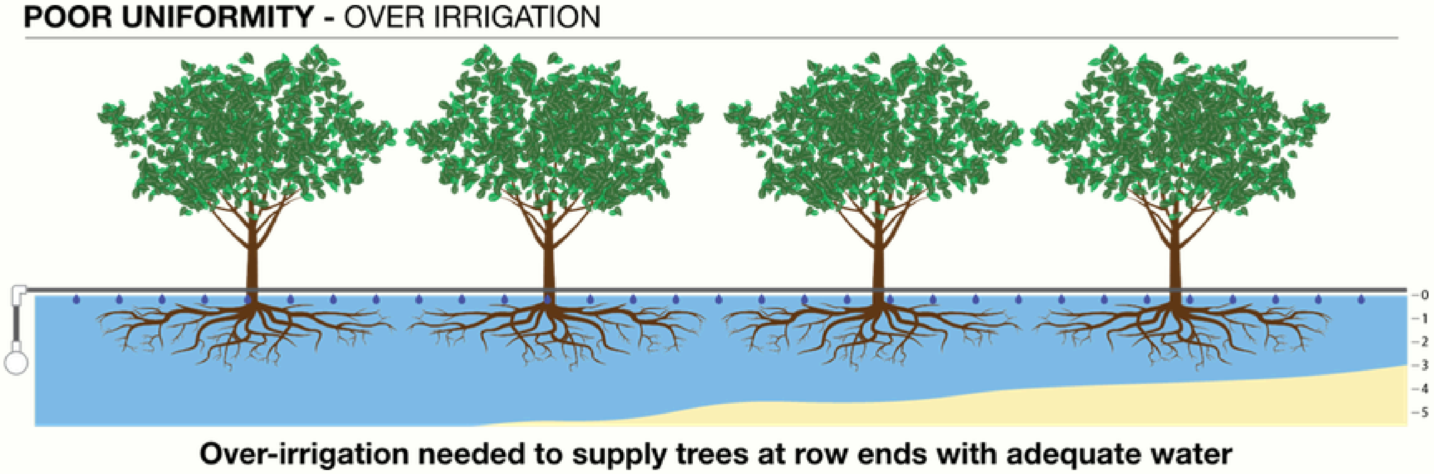

Figure 7. Poor distribution uniformity - over irrigation.

### 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.

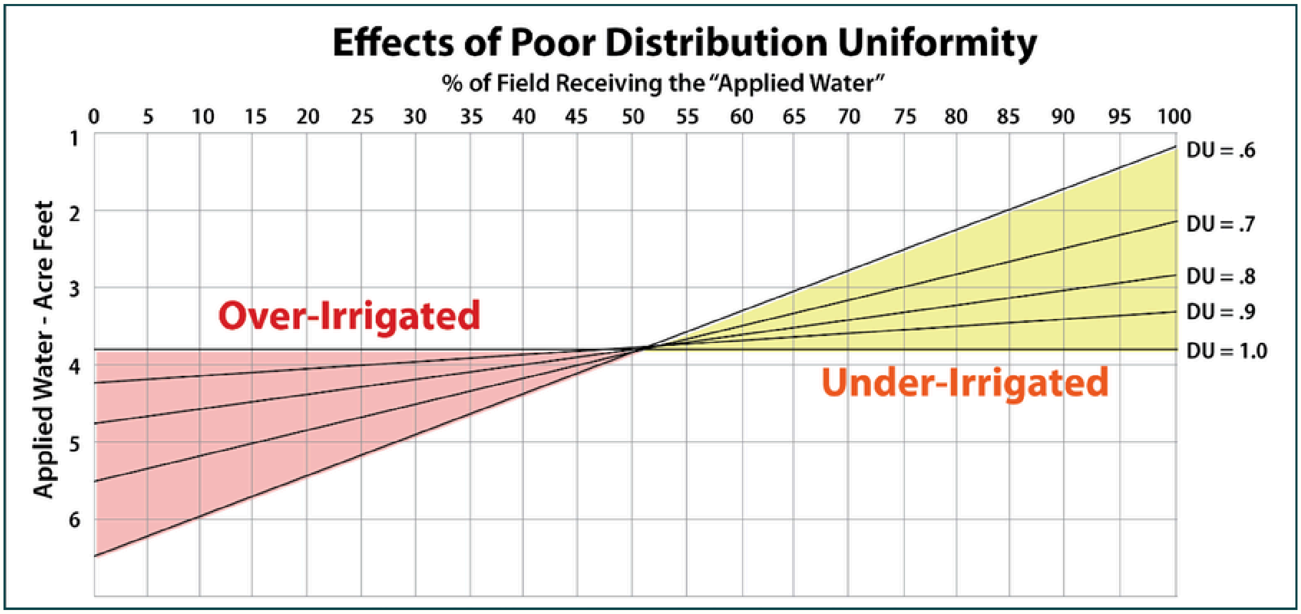

**Figure 9. Impacts of poor DU on applied water**

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.