Appendix G. Madera County Groundwater Allocation Market Simulation Final Report.

Madera County

Groundwater Allocation Market Simulation

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Table of Contents

1. Introduction

In 2019, Madera County applied for and received a grant through the Bureau of Reclamation's WaterSMART Water Market Strategy Program to evaluate the potential for a water market that would allow certain irrigated parcels within the County to buy and sell groundwater pumping allocations. A water market is being considered as one possible component of the County's overall approach for sustainably managing groundwater resources pursuant to the requirements of the California Sustainable Groundwater Management Act (SGMA). The goal of the market is to potentially mitigate some of the adverse effects associated with necessary SGMA-related water use reductions by providing flexibility to manage groundwater allocations across irrigated parcels.

In theory, a market promotes the efficient use of limited groundwater supplies, and greater overall economic outcomes, compared to regulations alone. In Madera County, a market could also reduce extractions in areas where continued pumping may adversely affect domestic wells or result in other undesirable outcomes. However, the appropriateness and success of a market in helping to meet groundwater management goals depends on several factors, including local land use and cropping patterns, basin conditions, allocation policies, and stakeholder perceptions, among others. Water markets must be carefully designed and implemented to avoid unintended consequences and/or adverse effects.

The WaterSMART Water Market Strategy grant provided funding for Madera County to explore the potential viability and functionality of a groundwater market in the Madera County context; key objectives of the grant included:

- Conduct outreach and work with local stakeholders to define opportunities, identify concerns, and obtain feedback on alternative groundwater market strategies
- Assess the feasibility of a groundwater market in Madera County, including any potential environmental, economic, and social impacts and unintended consequences
- Develop a market strategy framework, outlining the market structure, rules, and strategies for reducing adverse effects
- Conduct a pilot groundwater market demonstration program

This report describes the process and outcomes of the two-year grant-funded effort, which was led by the County in partnership with consulting team members Corona Environmental Consulting (Corona), Kearns & West, and Wood Rogers. The remainder of this report is organized as follows:

- Section 2 provides background on groundwater management in Madera County and describes the potential role of a groundwater market in sustainably managing groundwater resources
- Section 3 describes the groundwater market stakeholder engagement process and key findings
- Section 4 highlights key considerations and factors that will affect the design and implementation of a groundwater market in Madera County
- Section 5 describes the methodology and results of the pilot groundwater market program
- Section 6 provides the project team's recommendations, lessons learned, and next steps for the County's consideration.

As an important note, the WaterSMART Water Market Strategy grant was written to include all Groundwater Sustainability Agencies (GSAs) within Madera County. However, as described in more detail in Section 4, groundwater allocations are a prerequisite for a functioning market. Currently, the Madera County GSA is the only GSA within the County that is using allocations as a strategy for demand management. In the future, other GSAs may participate in the market; however, they would need to establish groundwater allocations in order to have a tradeable commodity necessary for a market. In addition, the groundwater market being considered in Madera County would be limited to irrigated parcels with a groundwater allocation, as defined by the County GSA; at this time, the County is not considering the allowance of third parties (e.g., cities, environmental organizations) to buy or sell groundwater allocations.

2. Background

2.1 Groundwater Management in Madera County

SGMA has significantly changed the way California manages its groundwater resources. Through this legislation, the California Department of Water Resources (DWR) designated 127 high- and medium-priority groundwater basins throughout the state. Stakeholders in these basins were required to form Groundwater Sustainability Agencies (GSAs) and develop Groundwater Sustainability Plans (GSPs) to achieve sustainable groundwater management by 2040. GSAs in high-priority basins were required to begin implementation of their GSPs by 2020.

Madera County encompasses three subbasins within the San Joaquin Valley groundwater basin – the Madera, Chowchilla, and a portion of the Delta-Mendota. Each of these subbasins has been designated by DWR as "high-priority" and critically over-drafted under SGMA. Madera County serves as the GSA for the portions of each subbasin that fall within undistricted areas of the Valley in the County and are not covered by another public agency (the County GSAs cover the "white areas" shown in Figure 1). As the GSA for these areas, the County is responsible for ensuring implementation of programs and management actions necessary to achieve sustainability by 2040. Sustainable yield reflects native groundwater levels that naturally exist in the subbasin from seepage and percolation; sustainability is reached when groundwater extraction equals groundwater recharge.

As shown in Figure 1, there are seven GSAs responsible for managing groundwater in the Madera Subbasin. Four of these GSAs (Madera County, City of Madera, Madera Irrigation District, and Madera Water District), representing 94% of the area in the Madera subbasin, adopted a joint GSP in December 2019 for submittal to DWR in January 2020 (Joint GSP). There are four GSAs in the Chowchilla Subbasin (Chowchilla Water District, Madera County, Triangle T Water District and Merced County); these GSAs also worked together to develop a GSP that was submitted to DWR in January 2020.

Per the Joint GSP, approximately 545,200 acre-feet (AF) of groundwater is extracted each year in the Madera subbasin, on average. The GSP for the Chowchilla subbasin reports that total groundwater extractions in the subbasin average 308,000 AF annually. In each of these subbasins, agricultural growers within the County GSAs have very little access to surface water supplies; approximately 95% of groundwater use within these areas is used for agricultural irrigation. While some percentage of the groundwater extracted from each subbasin returns to the aquifer, much of it is "consumed" through evapotranspiration or lost to surface runoff and is no longer available to the subbasin. As defined in the respective GSPs, current average consumptive use of groundwater within the County GSA boundaries exceeds sustainable yield by approximately 111,000 AF per year in the Madera subbasin and 59,700 AF

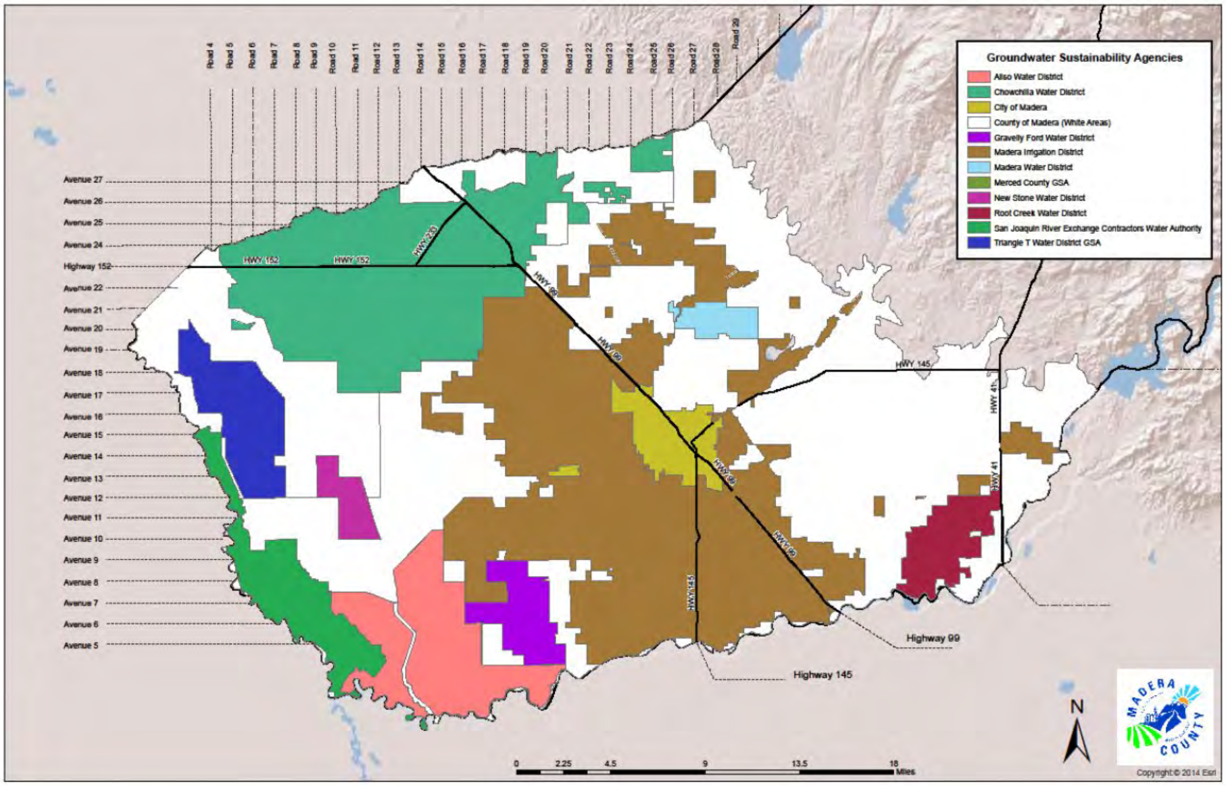

Figure 1. Map of Groundwater Sustainability Agencies in Madera County

per year in the Chowchilla, when using 2015 land use conditions as a constant.[1] This exceedance represents the amount by which the Madera Subbasin GSAs must increase recharge from new surface resources and/or reduce consumptive use demand to achieve sustainability objectives by 2040.

As described in the GSPs, the Madera County GSAs plan to implement strategies and capital projects that will result in new water supplies, including surface water purchases, new water right filings, and improved flood management to capture high flows for direct use or groundwater recharge (flood management projects will be supported by construction of various facilities to distribute captured flows). In addition to these efforts, the Madera County GSAs recognize that it will be necessary to reduce overall consumptive use of groundwater to achieve sustainable yield. Per the GSPs, Madera County GSA has committed to reducing groundwater consumption by an average of 90,000 AF per year in the Madera Subbasin and 30,000 AF per year in the Chowchilla subbasin by 2040 (note that these averages reflect the combined effect of reducing consumptive use of native groundwater and increasing the consumptive use of new surface water supplies). The County GSAs have adopted groundwater allocations for irrigated agricultural water users to help meet this goal and are considering additional strategies such as incentivizing land conservation and a groundwater allocation market.

The County GSAs' implementation plans include a gradual transition to sustainability by 2040. This allows time for the County GSAs to study, develop, finance, and build capital projects, and to develop monitoring, measurement, and enforcement programs. It also provides time for current groundwater users to

[1] Average consumptive use values using actual historic land use conditions between 1989 and 2014 were estimated to be lower than estimates that assumed a static 2015 land use as if it were in place during this same entire period.

implement demand management programs to limit groundwater consumption. Reductions in consumptive use of water will be made over the 20-year timeline, seeking to reduce the previously noted exceedance of groundwater by a rate of 2% per year for the first five years and then 6% per year thereafter, until sustainability is achieved.

While the County GSAs are working to reduce adverse effects associated with SGMA compliance, reducing consumptive use of groundwater will impact many agricultural users and have ripple effects across the local economy. Growers in the San Joaquin Valley have depended on groundwater pumping to support their agricultural livelihood for decades. Approximately half of the Madera County economy and one in three jobs is linked to Madera County agriculture (ERA Economics, 2020).[2] In 2019, Madera County GSA commissioned a study that examined the economic impact of groundwater use reductions in the area managed by Madera County within the Madera Subbasin (Madera Subbasin Joint GSP Appendix C, ERA Economics, 2020). Direct economic impacts (e.g., changes in irrigated acreage and associated revenues) occur in the Madera Subbasin as a whole and regional multiplier effects (e.g., changes in farm labor income) occur in the broader Madera County area.

The impact assessment found that the demand management program outlined in the Madera Subbasin Joint GSP would require the idling of 28,400 acres (approximately 13% of current irrigated acreage), causing direct farm revenue losses of $130 million per year. Water use reductions would result in a gradual fallowing of land – averaging an additional 1,350 acres every year. Additionally, full time jobs in the County would decrease by approximately 575 per year (including direct, indirect, and induced jobs), with wage income falling by $52.9 million annually. This equates to between 1,200 and 1,800 seasonal jobs in Madera County; many of these jobs and income support disadvantaged communities (DACs) in the county. Finally, Madera County tax revenues would fall by approximately $1.4 million per year by 2040 (~3.3%). The loss in tax revenue reflects local revenue to the County, so local services provided by these agencies might be impacted as revenues fall. As an important note, the economic study assumes an optimized outcome, meaning that water is transferred to its highest value use within some bounds (as specified within the economic model). This approach results in outcomes similar to those that might expected with a market or similar mechanism for transferring allocations across parcels. Without this flexibility, individual growers may not be able to achieve these optimal outcomes.

2.2 Potential Role of Water Market in Madera County

SGMA offers GSAs significant flexibility to tailor management activities to best meet local needs. This includes the ability to assign groundwater allocations (e.g., a set amount of water per acre or irrigated acre) to groundwater users and to authorize transfers of these allocations. In this way, SGMA opens the door for local groundwater markets that can facilitate the transfer of groundwater allocations from willing sellers to willing buyers using appropriately structured market mechanisms.

A market-based approach can offer several benefits compared to a strict allocation method where landowners are only able to pump and use a set amount of water on a parcel-by-parcel basis. Markets allow users to reallocate limited groundwater resources to the highest value uses; this can lessen the economic impacts of temporary shortages and support long-term shifts in water use patterns. In addition,

[2] Madera Subbasin Join Groundwater Sustainability Plan, Appendix C (ERA Economics, 2020). Available: https://www.maderacountywater.com/wp-content/uploads/2020/02/Madera_Appendix3_Final_2020.pdf

market participants can often sell or lease their allocations for a higher value than they could earn if they put to use on the original parcel to which it was assigned. This allows limited groundwater resources to not only be used in more valuable ways while compensating the original owner.

Another benefit of a groundwater market is that it offers more flexibility and autonomy to stakeholders in making decisions that directly affect their business. Markets can also incentivize water conservation and investment in water efficiency technologies, as well as new infrastructure such as groundwater storage. For example, Ayres et al. (2021) note that trading can incentivize formal groundwater banking projects that store water underground on behalf of specific parties. This is an important supply augmentation and risk management strategy that will likely prove key for SGMA implementation.

While markets have the potential to offer additional benefits, they can also have unintended or incidental effects on third parties or the environment. When a trade is made, sellers forego pumping while buyers pump the groundwater they have purchased (i.e., the water is not pumped from one location and conveyed to another for use). This change in the location of where groundwater pumping occurs can result in adverse effects if it results in increased pumping or continued overdraft pumping in areas of concern (e.g., areas located near at-risk domestic wells or in areas of high subsidence). Similarly, allowing for carryover of an annual allocation to a subsequent year(s) can have temporal impacts, especially in years of drought where large amounts of carryover could be pumped in one year. Water quality and total extraction quantity concerns are also important to address early in the planning phases. Potential adverse effects can be minimized through intentional protections and market rules. This is discussed in more detail in Section 5.

3. Stakeholder Engagement – Overview and Key Findings

There are several enabling conditions and key elements that must be in place to ensure the success of a local groundwater market. Chief among these is the support of key stakeholders, including market participants and other potentially affected parties. Without input and buy-in from these groups, it will be difficult for a market to gain traction. The WaterSMART Water Market Strategy grant incorporated significant stakeholder outreach, including initial one-on-one stakeholder interviews and three strategic workshops (Figure 2) held over the course of 2020. This section provides an overview of the stakeholder process, as well as key findings and outcomes.

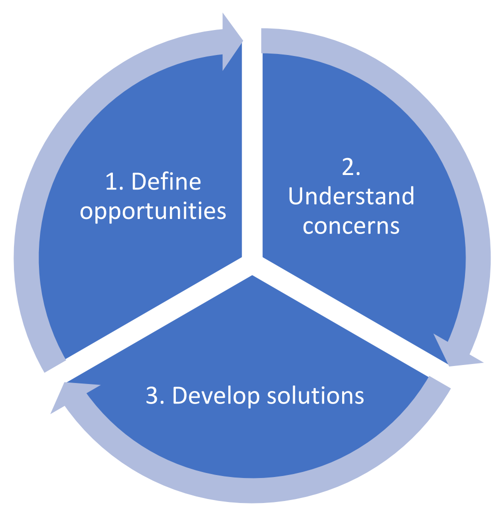

Figure 2. Outreach and engagement strategy

3.1 Stakeholder Interviews

The consultant team conducted interviews with key stakeholders through phone, email, and in-person meetings to build relationships across organizations. Interviewees included representatives from the Chowchilla and Madera subbasin GSAs, disadvantaged communities (DACs, including representatives from Self Help Enterprise and the Leadership Council for Justice and Accountability), Madera Ag Water

Association, Cattlemen's Association and Farm Bureau, resource conservation districts, water companies, and relevant County officials. In total, the team conducted 12 interviews in early 2020. The interviews gauged the level of knowledge of water market strategies in general and inquired about support for a market-based solution to managing water demand. Input was solicited on opportunities, challenges, affected parties, and anticipated impacts.

Overall, most interviewees supported a groundwater market pilot program as a general concept but expressed only a cursory understanding of the complexities of market tools. Concerns were voiced around transparency, anonymity, and equity of the market structures, rules, and trading process. Partners were vocal about the potential impacts on communities that rely on groundwater for drinking water supplies, especially those that are economically disempowered, and expressed the need for additional tools to reduce water consumption. Most participants were challenged to offer ideas for mitigating negative impacts given the early stage of market development, and broadly encouraged ongoing education of and support from the majority of stakeholders before moving forward. Input received during these initial interviews informed the outreach leading up to subsequent workshops, as well as the content of workshops. Appendix A contains a complete summary of the findings from these early partner interviews.

3.2 Workshops/Meetings

After conducting individual interviews, the project team held a series of three workshops for the larger community that would be impacted by changing groundwater demand management. The workshops served to present information and to promote understanding of water markets as well as to gather information on concerns, opportunities, and perspectives of implementing a water market in Madera County. The workshops successively built knowledge and gathered increasingly complex feedback from the community regarding concerns with specific elements of water markets. Summaries of each workshop including participant information and detailed feedback is available in Appendix B. The presentations from these workshops are also included.

Workshop 1 – Defining Opportunities[3]

The initial workshop was held in person at the Madera County offices in Madera, CA on February 25, 2020. It was attended by 43 participants in addition to County staff and members of the consultant team. The objectives of this meeting included:

- Introduce water market concept, tools, and context
- Identify and discuss partner opportunities, constraints, and concerns
- Initiate discussion on affected parties and impacts
- Gain insights and begin to brainstorm for future partner discussions

The County reviewed the concept of water rights within the context of markets and described reasonable and beneficial use and surface and groundwater differences, per the California State Water Code. Corona provided an overview of groundwater markets, potential benefits, and rules and strategies for reducing adverse effects or unintended consequences. Corona also presented an overview of the groundwater market recently established by the Fox Canyon Groundwater Management Agency in Ventura County, CA.

[3] Madera County Water Market Workshop #1. February 25, 2020. Agenda, summary and presentation available: https://www.maderacountywater.com/water-markets/

Attendees participated in an interactive mapping exercise to identify geographical concentrations of opportunities and challenges.

Key questions raised in the workshop included how the County would set, manage, and track tradeable allocations and year to year carryover amounts. There was also an extensive discussion among participants regarding finding the appropriate balance of transparency and confidentiality of water sales, quantities, and prices. There was some concern that larger growers would be able to monopolize the market and that small agricultural operations would not fare well in a market system. The authority of the County to monitor and enforce compliance, as well as to administer an accounting system, was also questioned. Some workshop participants were concerned with allocations to irrigated and non-irrigated lands; others voiced concerns regarding the potential for water supply/quality impacts to domestic and municipal wells if pumping were increased or concentrated in areas where wells are located.

At the same time, many agreed that a market could provide significant opportunities, including incentivizing groundwater recharge and conservation, helping to maintain the viability of permanent crops while providing income to those who choose to sell their allocations, providing short-term flexibility to growers, and creating incentives and rules to reduce pumping in areas of concern (e.g., areas around domestic or small community wells, groundwater dependent ecosystems, and areas of high subsidence).

Workshop 2 – Understanding Concerns[4]

Due to the Covid-19 pandemic, the second workshop was held virtually on April 19, 2020. Close to 100 participants attended the virtual meeting, in addition to County staff and members of the consulting team. The primary objectives for the meeting were to:

- Share information on groundwater allocations under water markets and SGMA regulations
- Provide an overview of water market strategies and solicit partner feedback through online polling and written feedback
- Discuss next steps and partner solutions workshop

The session began with an overview of the County's efforts to establish groundwater allocations to help achieve sustainable yield within the County GSAs. Presenters explained how allocations fit within the context of SGMA and water markets. They also reviewed additional initiatives/tools that the County GSAs are exploring to further demand management. Corona presented an overview of "market basics" including key prerequisites, the potential role of a groundwater market in Madera County, and potential strategies for reducing or avoiding adverse effects.

For the remainder of the workshop, the consultant team focused on using online survey questions and encouraging written feedback (via the webinar chat function) on four key aspects of market design, including: 1) rules and strategies for reducing potential adverse impacts associated with trading (e.g., rules to protect domestic wells and other concerns identified in Workshop 1); 2) rules related to carryover of allocations for use in future years; 3) market exchange methods/platforms; and 4) issues and concerns regarding participant anonymity and confidentiality.

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[4] Madera County Water Market Webinar #2. April 19, 2020. Agenda, summary, video recording and presentation available: https://www.maderacountywater.com/water-markets/

Feedback offered ranged across participants. In general, participants seemed supportive of putting rules in place to protect domestic and municipal wells. Some expressed concerns over prohibiting the resale of water once purchased, as well as a desire to be able to tap into or purchase future allocations. There seemed to be strong support for allowing carryover of allocations in the context of a market, with reasonable limitation. Several participants had questions about how groundwater use would be monitored, and rules enforced. One point of agreement was on the method for market exchanges – the majority of participants showed support for the use of an electronic "smart market" for matching buyers and sellers (described in more detail in Section 5). Feedback relating to market transparency was somewhat mixed – many felt that information on individual trades should be made publicly available (e.g., volume traded, price, in some cases information on buyers and sellers), while others felt this information should only be reported in aggregate and that information on individual buyers and sellers should not be disclosed.

Workshop 3 – Developing Solutions[5]

The final workshop, also held virtually, took place on December 1, 2020. Key objectives included:

- Review outcomes from previous partner engagement
- Share results of the water market impacts analysis
- Present market structure and rules for pilot program
- Provide overview of pilot project process and recruit participants.

The project team incorporated feedback from the previous two workshops to develop a structure for a pilot groundwater trading program. The goals and key tenets of the pilot project were presented, including market structure, potential market rules, and the process for facilitating market exchanges. Wood Rodgers also presented a geospatial analysis of potential water market impacts and strategies for offsetting any adverse effects (discussed in detail in the next section). The workshop was also used to recruit potential participants for the simulation of a water market, a yearlong project that required significant participant feedback.

Many participants expressed a strong desire for allowing larger carryover amounts/period and multi-year trades to help provide flexibility in drought years. Several also advocated for allowing trading of transitional water (a term unique to the County GSAs' allocation approach) as a way to generate initial supply in the market itself. Feedback was also provided on any aspects of the market participants found confusing and where additional information could help participants make better decisions. Comments showed some participants to be optimistic about the information that could be gathered from engaging stakeholders in a market simulation.

4. Key Considerations for a Groundwater Market in Madera County

This section provides an overview of key market considerations specific to Madera County, including:

- The County's method for assigning individual groundwater allocations to landowners within the County GSAs
- Compliance, monitoring, and enforcement procedures

[5] Madera County Water Market Webinar #3. December 1, 2020. Agenda, summary, video recording and presentation available: https://www.maderacountywater.com/water-markets/

- Legal considerations
- Understanding any potential adverse effects, and identifying rules to offset anticipated impacts

These different factors influence what is possible in terms of market structure and design in Madera County.

4.1 Background and Existing Markets

Groundwater markets are not a new concept in California; however, according to the Public Policy Institute of California (PPIC, 2021), groundwater markets have been slow to develop in the state because tradable groundwater allocations are still rare. A handful of adjudicated basins—where such allocations do exist—have adopted water market strategies. For example, in 1996, the Mojave Groundwater Basin established a "cap-and-trade" system and groundwater market to provide flexibility to agricultural growers in meeting groundwater use restrictions. Today the market is one of the most active water markets in the U.S. and is credited with stabilizing groundwater levels in the Basin. Several other successful surface water and groundwater markets have been established in other areas of California and throughout the country.

The onset of SGMA has heightened interest in groundwater markets in high- and medium-priority basins(as designated by DWR). The Fox Canyon Groundwater Management Agency in Ventura County is credited with establishing the first SGMA-related groundwater market. While the market was a bit slow in its initial year of implementation, it is now experiencing successful trades. In the Borrego sub-basin, located in eastern San Diego County, groundwater pumpers reached an agreement in early 2021 on a new system that includes a market. Interest reportedly continues to grow in other basins (PPIC 2021).

A review of existing water markets provided insights into the analyses and proposed design of a potential groundwater market in Madera County (see Appendix C for lessons learned and key elements associated with select water markets). The structure and rules of existing markets varies considerably based on local conditions and management objectives. Several markets report that it is essential to have accurate water use data to ensure compliance in a water market; in addition, the goals and rules of a water market should be tailored to participants' interests and needs. In learning about how rules are established, it is often best to start with minimal and simple rules and to adaptively manage the program over time to implement rules and trading restrictions as needed. Finally, the development of a market requires significant agency, stakeholder, and technical expertise, so pilot programs were widely utilized before adopting market-based strategies.

4.2 Sustainable Yield and Groundwater Allocations

Key prerequisites to a functioning groundwater market include 1) the development of an allocation system that establishes the amount of groundwater each landowner or pumper will be allowed to extract from the basin for consumptive use or transfer to other users, and 2) an accounting system that measures and tracks the use of allocations. This section provides an overview of Madera County GSA's allocation system. Section 4.3 describes the County's approach for measuring and tracking the allocations.

Allocations are designed to protect the groundwater resource, collectively amounting to a cap on total consumptive use of native groundwater resources (i.e., sustainable yield). Without a strict adherence to fixed allocations, a cap-and-trade style water market will not function because users will be able to continue pumping water in excess of sustainable use.

As described above, the GSPs adopted for the Madera, Chowchilla, and Delta-Mendota subbasins establish the level of groundwater consumptive use that will be required to reach sustainable yield by 2040. This represents the total cap. On June 8, 2021, the County GSAs adopted a strategy for allocating this total amount across irrigated acres within the County GSAs for the Madera, Chowchilla, and Delta-Mendota subbasins. This allocation approach uses two designations of groundwater access:

1. Sustainable yield, which is tied to the overall sustainable yield of each subbasin, such that if land users consumed the maximum groundwater allocation for every eligible acre, the subbasin would still achieve sustainable yield.
2. Transitional water, which is a continued quantity of consumptive use that exceeds sustainable yield (i.e., overdraft). Transitional water availability will incrementally decrease over the 20-year implementation period until reaching zero. This is when sustainable yield is reached.

The allocation approach provides a per-acre allotment of sustainable yield and transitional water to participating eligible parcels. The baseline quantity for the allocations is the average evapotranspiration of applied water (ETAW) within each County GSA, rather than total groundwater extracted. This method for quantifying allocations is a direct result of the method used for measuring water use (see Section 4.3). The approach for determining per-acre sustainable yield allocations will remain consistent over time while per-acre transitional water allocations will decrease in availability every year until no transitional water is available by 2040.

Each year, eligible parcels will receive a designated quantity of sustainable yield and transition water. Eligible parcels include those with currently irrigated acreage (as of June 8, 2021) or that were last irrigated as recently as January 1, 2015 but that have been fallowed or idled since that time. Parcels that are part of an active irrigated agricultural operations or permitted confined animal operations are also eligible to receive an allocation of sustainable yield and transition water. Lands that are not categorized as irrigated, using the parameters discussed above, may opt-in for an allocation of sustainable yield for acres being put into active irrigated agriculture for sustainable yield only, as demonstrated to the satisfaction of the County GSA.

The per-acre allocations allow for both sustainable yield and transition water to be used flexibly across eligible parcels and shared across parcels within a designated farm unit. Farm units represent groups of parcels that are collectively managed and located in the same farm unit zone (see Figure 3). The purpose of farm unit zones is to limit potential adverse effects associated with the transfer of allocations among parcels in different zones. From a practical operations perspective, the farm units provide functions similar to a partial groundwater market in that an allocation can be shifted from one parcel to another to facilitate flexibility for the operator of a farm unit so long as those parcels are within the same zone.

At this juncture, the allocation approach applies to County GSAs only, with other GSAs planning to manage their portion of sustainable yield differently.

4.3 Compliance, Monitoring, Tracking and Enforcement

Reliable measurement, reporting, tracking and enforcement procedures are essential to establishing trust in market transactions (PPIC 2021). All water users must trust that the system is accurately measuring and tracking water. For example, it is key to ensure that a seller is only selling water to which they have valid rights or have been authorized an allocation of use, and not water that belongs to another party. It is also important to ensure that growers are not using more water than they have purchased and/or has been allocated to them. Lessons learned from other markets indicate that enforcement procedures must be sufficiently severe to encourage market participation.

Within the County GSAs, monitoring of evapotranspiration (ET) and ETAW will be done with remote sensing methods, using satellite technology, provided by IrriWatch using SEBAL (Surface Energy Balance Algorithm for Land). Quality assurance and quality control will be performed by IrriWatch, Davids Engineering, and Madera County staff.

4.4 Legal Statute

SGMA provides the legal statute that allows GSAs to control extractions by "establishing groundwater extraction allocations." (Water Code, § 10726.4, subd. (a)(2).) GSAs also have the authority to "regulate groundwater extraction" by "authoriz[ing] temporary and permanent transfers of groundwater extraction allocations within the agency's boundaries." (Water Code, § 10726.4, subd. (a)(3).)

4.5 Analysis of Supply and Demand and Potential Adverse Effects

To assess the potential for a groundwater market in Madera County, the consultant team examined the distribution of irrigated acreage by crop type within each farm unit zone. This analysis examined overall supply and demand in the market, as well as the potential for changes in the location of pumping within individual subbasins (and any associated adverse effects). The project team also assessed the potential for concentrated pumping to occur in areas of concern as a result of market trades. To conduct these analyses, the project team used historical crop data and analyses conducted for the relevant GSPs. The section presents the results of these analyses and discusses the potential implications for if a groundwater market were to be implemented.

4.5.1 Distribution of market supply and demand across farm unit zones

Table 1 shows total irrigated acres, by crop type, within the portions of the Madera and Chowchilla subbasins that fall within the County GSAs. In the initial years of the market, crops that are "more likely to buy" include perennial, high value crops (e.g., citrus, nuts). As shown below, these crops make up a relatively high percentage of total irrigated acreage in both subbasins. Crops considered "more likely to sell" groundwater allocations include annual crops that have a lower return to water (e.g., corn, grains, hay, pasture, and alfalfa). While in many cases, the crops identified as "more likely to sell" will serve as an initial source of supply for the market; this is not to say that all growers of these crops will elect to sell their groundwater allocations. For example, some of these crops are tied to dairy nutrient management plans, while others serve as an important local feed source and/or cannot easily be fallowed without affecting overall farm operations.

Table 1. Distribution of irrigated acreage within County GSAs

	Madera subbasin, County GSA		Chowchilla subbasin, County GSA	
	Acres	**% of total**	**Acres**	**% of total**
Almonds	35,961	40%	13,430	37%
Citrus and Subtropical	1,622	2%	11	0%
Corn	5,038	6%	7,331	20%
Grain and Hay Crops	6,202	7%	2,805	8%
Grapes	16,569	18%	4,877	13%
Miscellaneous Deciduous	1,092	1%	259	1%
Miscellaneous Field Crops	163	0%	399	1%
Miscellaneous Truck Crops	2,120	2%	819	2%
Pasture and Alfalfa	3,260	4%	3,850	11%
Pistachios	18,446	20%	2,726	7%
Walnuts	472	1%	0	0%
Idle	941	1%	49	0%
Total	**90,947**		**36,508**	

Source: Annual Land Use Time Series for GSAs based on County Land Use Data, 2019

Further analysis of irrigated acreage within the Madera subbasin portion of the County GSA indicated the following:

- Crops that fall within the "more likely to buy" category are distributed across the three farm unit zones relatively proportional to how overall irrigated acreage is distributed. This makes it more likely that the demand for groundwater allocations will be somewhat evenly distributed across the GSA (relative to existing distribution of irrigated acreage), rather than concentrated in any one area/zone. This makes it difficult to predict where increased pumping would occur as a result of market trades because individual circumstances will dictate who decides to buy water on the market.
- Crops that fall within the "more likely to sell" category are more concentrated in the West Farm Unit Zone (Figure 3).
- The demand for groundwater allocations from higher value and perennial crops (i.e., more likely to buy) will be greater than the supply available from annual crops and crops that have a lower return to water (i.e., more likely to sell). Specifically, the ratio of irrigated acreage that falls within the category of "more likely to buy" versus "more likely to sell" is close to 3. In addition, if growers are only allowed to sell to buyers located within the same farm unit zone, more demand will go unmet in the East Northern and East Southern zones due to lack of supply (i.e., the concentration of crops that are more likely to sell in the West farm unit zone).

For the Chowchilla subbasin portion of the County GSA:

- Overall, the ratio of irrigated acreage that falls within the category of "more likely to buy" versus "more likely to sell" is less than 1, meaning it is likely that there will be an adequate supply of groundwater allocations for the market.

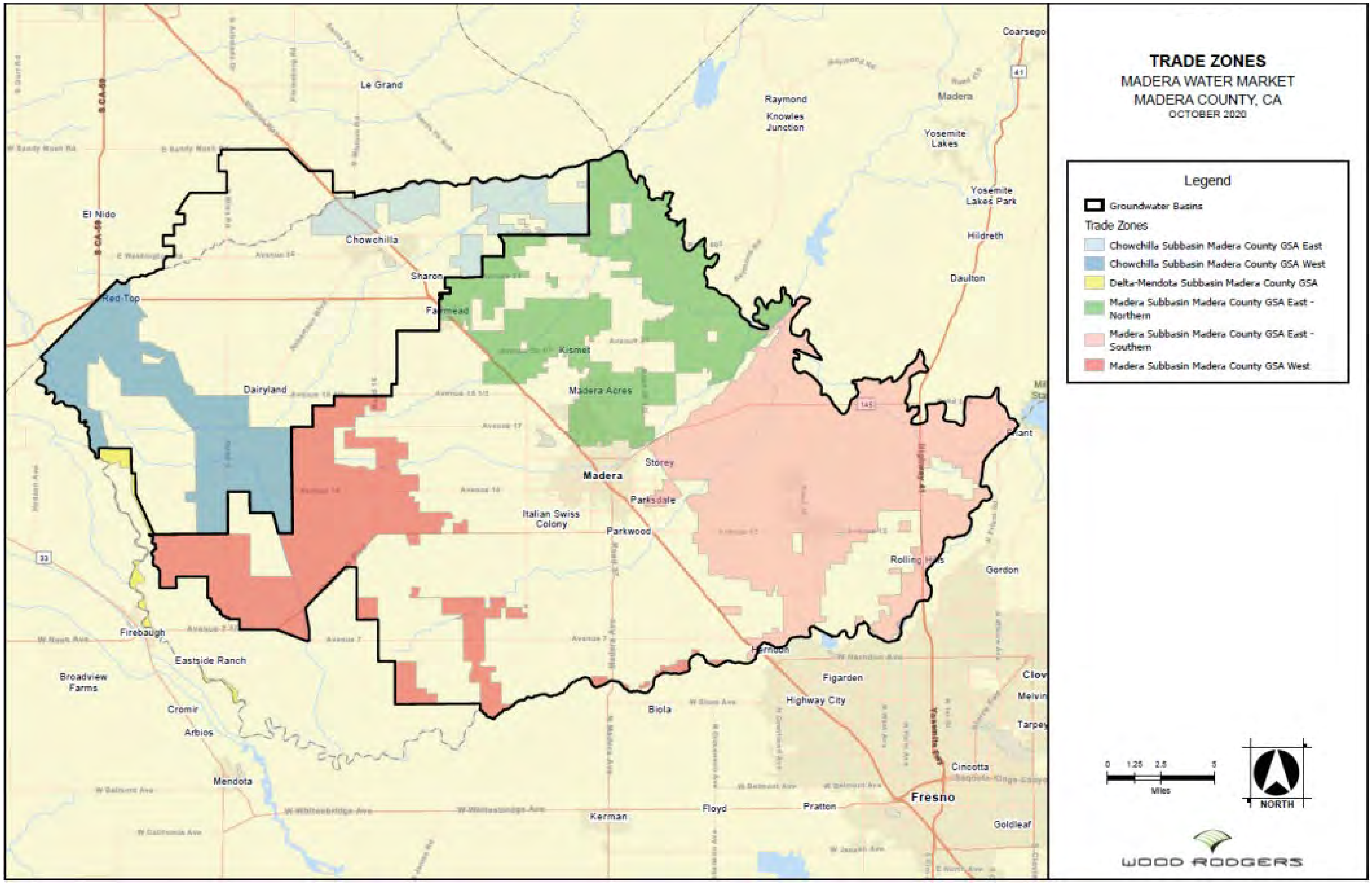


Figure 3. Madera County farm unit zones

- This varies by farm unit zone. The West Chowchilla farm unit zone contains a higher percentage of the irrigated acreage that falls within the "more likely to sell" category; in this zone, the ratio of irrigated acreage that falls within the "more likely to buy" vs. "more likely to sell" categories is 0.7. The East farm unit zone has a buy to sell ratio of 1.8, indicating a higher level of demand relative to initial supply. Thus, more sales would be expected to come from the West farm unit zone, with more pumping of the marketed allocations occurring in the East farm unit zone (if trading was allowed to occur across zones).

In the Delta-Mendota portion of the County GSA, there is a relatively even split between crops that are more likely to sell versus buy. However, there is a relatively small number of irrigated acres overall.

4.5.2 Analysis of potential adverse effects due to changes in the location of pumping

The project team also evaluated whether there are areas of the County GSA where continued (or increased) consumptive use of groundwater has the potential to adversely affect the following areas by further lowering groundwater levels:

- Domestic, municipal, and other water supply wells
- Local surface waters and associated habitat, also referred to as groundwater dependent ecosystems (GDEs) [6]
- Areas with high potential for increased land subsidence

Figure 4 shows areas located within the Madera, Chowchilla, and Delta-Mendota subbasins where the potential for adverse effects may exist. Each area includes a one-mile buffer area around it. The project team examined irrigated acreage within each buffer area by crop type. This allowed us to evaluate the extent to which growers in these areas are more likely to buy (to maintain current consumption rates as allocations quantities decrease) or sell allocations and the resulting (potential) effects on groundwater levels. It also allows us to examine the potential effect of limiting groundwater purchases within these areas (in some way). Key findings of this analysis include:

- In the Madera subbasin portion of the County GSA, a relatively small portion of crops that are "more likely to buy" fall within the areas identified as having a higher potential for surface water interaction/GDEs or subsidence. Further, these areas contain a higher percentage of potential sources of supply, when compared to the overall basin. Again, when a parcel or farm unit is a source of supply, less groundwater is pumped from that parcel or farm unit. This high-level analysis indicates that a market may result in limited impacts and even positive outcomes related to subsidence and GDEs in the Madera Subbasin portion of the County GSA.

- Conversely, approximately 31% of the "more likely to buy" crops fall within the identified buffer areas for domestic wells and municipal wells, while 17% of supply crops fall within these areas. The buy to sell ratio is more than 5, compared to approximately 3 for the overall basin. This indicates that subject to monitoring of groundwater levels and market transactions, rules to limit market purchases that would result in increased pumping in these areas may be warranted.

[6] Modeling conducted for the GSPs indicate there is no hydraulic connection between regional groundwater and streams in the Madera and Chowchilla subbasins. The team analyzed the areas around the San Joaquin River to better understand the sustainable yield allocations that might be sold from within this area, which would potentially augment groundwater levels.

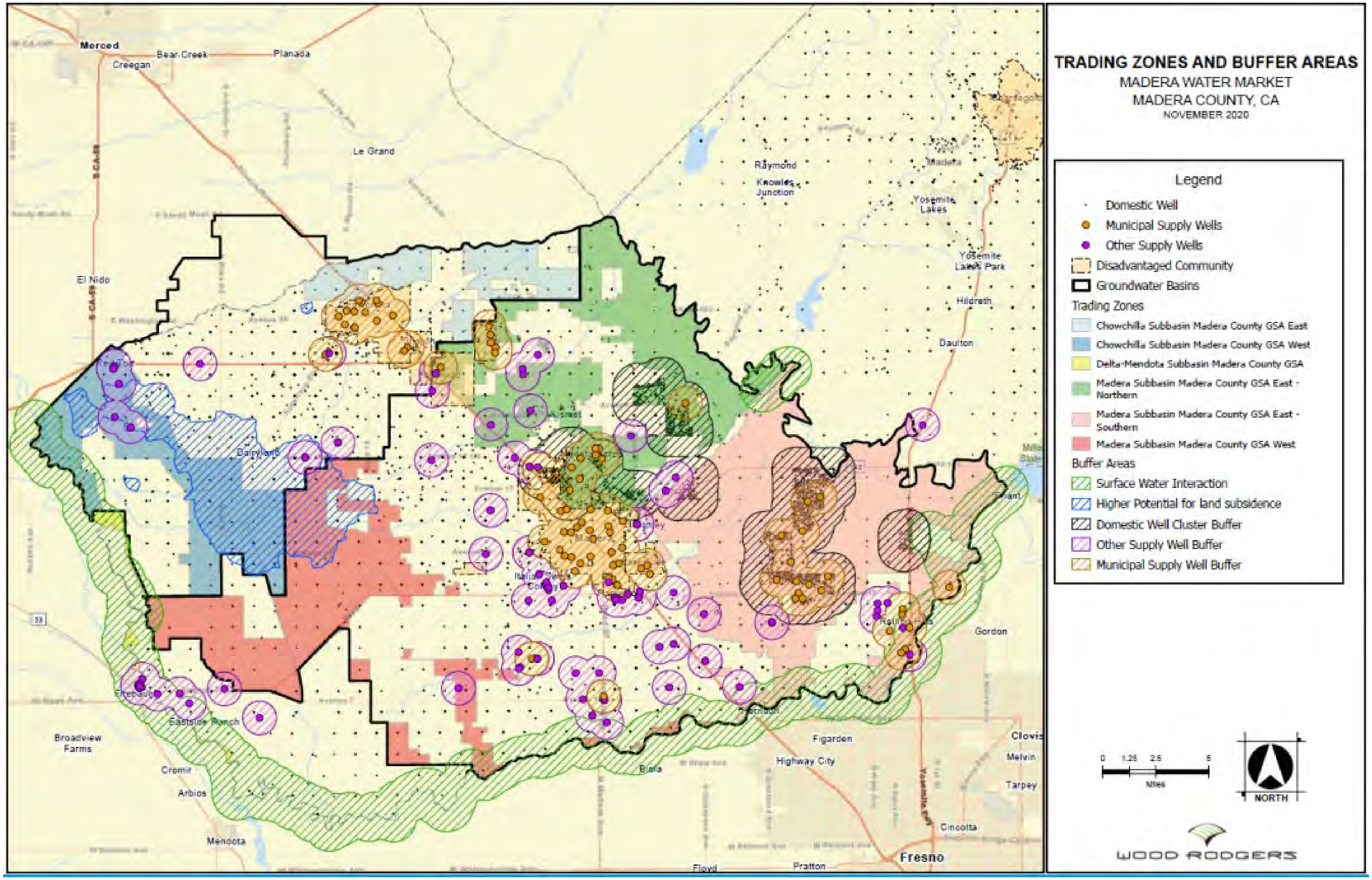


Figure 4. Buffer areas to protect wells, subsidence prone areas and surface water sources.

- In the Chowchilla subbasin portion of the County GSA, more irrigated acreage classified as “more likely to sell” falls within the potential GDE and subsidence buffer areas compared to irrigated acreage classified as “more likely to buy.” This means that there more groundwater could be left in the basin in these areas as pumping of allocations would be transferred to a buyer located elsewhere.
- Slightly more irrigated acreage within the municipal well buffer areas falls within the “more likely to buy” category in the Chowchilla portion of the County GSA. However, irrigated acreage within these areas account for a relatively low percentage of total irrigated acreage within the subbasin (13% and 10% of likely to buy and sell, respectively). The ratio of “more likely to buy” to “more likely to sell” crops indicates that there is a chance for continued or increased pumping from these areas. This again indicates the need for market rules to limit this outcome, subject to monitoring of groundwater levels and market transactions.
- Most of the irrigated acreage within the Delta-Mendota subbasin portion of the County GSA fall within area that has the potential for surface water interaction/GDEs.

4.5.3 Summary of potential impacts and related market implications

In the Madera subbasin, a much higher proportion of irrigated acres fall within the “more likely to buy” category compared to the “more likely to sell” (i.e., initial demand will likely be much greater than initial supply). Some growers of higher value crops will likely begin to sell their allocations as it becomes in their best economic interest to do so. It is impossible to predict where these growers will be located, as this decision depends on individual circumstances.

Based on the existing distribution of crops, it is likely that the demand for groundwater purchases will be distributed relatively evenly across the County GSAs, rather than concentrated in a specific area(s). In both the Madera and Chowchilla subbasin portions of the County GSA, likely sources of supply are more concentrated in specific areas of the subbasin. However, as noted above, not all growers of crops that are in the “more likely to sell” category will sell their groundwater allocations.

In the Madera subbasin, the buffer areas around municipal and domestic wells contain a relatively high percentage of crop types that fall within the “more likely to buy” category. In the other buffer areas identified (in both subbasins), there is a higher percentage of crops that are “more likely to sell” allocations compared to the overall subbasin. This could result in positive effects and/or support rules that limit buyers located in buffer areas to purchasing allocations from sellers located within the same buffer area.

While analysis of the distribution of different types of crops helps to provide an indication of where potential sources of supply and demand are located, it does not provide an exact prediction of where or how many trades will occur. For reasons outlined above, there is uncertainty as to where buyers and sellers will be located. Rather than adopting rules at the outset to mitigate against potential adverse effects, lessons learned from other markets indicate a need for more adaptive management and monitoring over time. The GSPs include sustainability indicators and minimum thresholds for groundwater levels and groundwater quality that will be continually monitored. Rules can be triggered, or trades limited if the need is indicated by these monitoring efforts.

5. Pilot Market Simulation

Following the extensive research, analyses, and stakeholder engagement efforts described above, the project team initiated a year-long "virtual" pilot groundwater market simulation program. This section describes the pilot market simulation program, including its key objectives, methodology, the general structure and rules of the market, and key findings and results.

5.1 Overview and Objectives

The pilot program was executed over nine months, with each month representing one year/irrigation season. The design and structure of the pilot market were driven by the feedback received during outreach efforts described in Section 3. Objectives of the pilot included:

- Simulate multiple years of trading under different conditions.
- Test market structure, potential rules, and administrative processes.
- Understand participant decisions under different conditions.
- Obtain participant feedback.

The pilot market allowed farmers and agricultural growers within the County to buy and sell groundwater allocations, subject to market rules and limitations. Each simulated year, participants were provided information on their irrigated acreage, sustainable yield allocations, the quantity of transitional water available to them, the farm unit zone in which their farming operation was located, and other relevant factors. Based on this information, participants provided input on how they would manage their crops in response to decreased groundwater availability, as well as whether they would like to buy or sell water on the market. They also provided feedback on key elements of market design and the pilot process.

Transitional water allocations decreased each month for the first seven months until transitional water was no longer available in the final two months of simulation. The water year classification (i.e. wet, average, or dry years) varied across the simulation periods. Rules, fines, and incentives were introduced in later rounds to determine their effect on participant behavior (Table 2). Each round, administrators applied a matching algorithm to match buyers and sellers (anonymously) and published aggregate information on trades each month. Aggregate trading results and individual results were provided to participants following each round.

5.2 Methodology and Logistics

Through the GSP process and subsequent workshops related to the potential groundwater market, the County has developed an extensive network of stakeholders. The County recruited participants for the pilot from this existing network. Agricultural growers who own lands located within Madera County were eligible to participate in the pilot market regardless of whether they farmed land within the County GSAs or in other GSAs. Invitations to participate were also extended to ranchers and other key stakeholders who engaged in the workshops.

Each participant was assigned characteristics that they assumed for their role as a grower in the pilot market (e.g., irrigated acres by crop type, farm unit zone, groundwater allocations, crops grown in buffer areas). As applicable, this information was closely matched to the actual characteristics of participants. However, participants were provided an ID so that their market participation and cropping decisions would remain publicly anonymous. A total of 68 participants agreed to join the pilot project. They were

Table 2. Simulated conditions each round of pilot

Pilot Round	Sustainable yield allocation per irrigated acre	Transition Water per irrigated acre	Rainfall year type	Carryover Allowed	Rules (implemented continuously once introduced)
Round 1	0.75	1.75	Normal	1 years' worth of SY allocation	Cannot buy transition water and sell water in the same year
Round 2	0.75	1.55	Normal	1 years' worth of SY allocation	
Round 3	0.75	1.35	Normal	1 years' worth of SY allocation	Trading limited to within County and within subbasins
Round 4	0.75	1	Dry	1 year's worth of SY allocation	
Round 5	0.75	0.75	Dry	2 years of SY	Increase allowable SY Carryover from 1 to 2 years' worth of groundwater
Round 6	0.75	0.5	Dry	2 years of SY	
Round 7	0.75	0.25	Wet	2 years of SY	$600/AF incentive to fallow land in buffer area
Round 8	0.75	0	Normal	2 years of SY	$200/AF penalty for water purchased to irrigate land in buffer area
Round 9	0.75	0	Dry	2 years of SY	

assigned crops in proportions representative of the actual cropping patterns in the Chowchilla and Madera County GSAs (with the Delta Mendota subbasin folded into the Chowchilla). The total acreage of the pilot represented approximately 68% of the total irrigated acreage within the County GSAs.

Each month of the pilot, participants received an information packet containing key information for that trading year or round. Table 3 shows an example of a key data table included in the information packet for an anonymous participant from Round 2. To ensure that the information presented in the table was not interpreted as decisions or policies that the County has made with respect to the market (rather than decisions or policies being tested), the project team highlighted all hypothetical information in yellow.

In addition to this table, the project team provided a table to participants showing their irrigated acreage by crop type going into the current round. This table reflected any changes participants made to their irrigated acreage in the previous round. The table also included consumptive use demand (ETAW) by crop type and typical revenues and costs per acre. Participants were instructed to use the ETAW estimates to determine how much water they would need for that simulation year (after accounting for any deficit irrigation). ETAW estimates varied by rainfall year type, as crops require more water in dry years and less water in wet years. The estimates were based on data from the GSP.

Table 3. Participant Information for Trading Simulation #3 (Year 3)

Participant ID	MW5555	This is the number assigned to you for tracking your responses/participation each month.
Irrigated acreage in your farm unit	140 acres	This is the irrigated acreage by crop type that you are to assume for this trading simulation for your farm unit.
Subbasin/farm unit zone	Madera West farm unit zone	Farm unit zones are zones identified by the County within which individuals can form farm units - groups of parcels owned by the same person or entity. Water use can be managed flexibly across parcels within a farm unit zone.
Buffer areas	20 acres almonds – Well buffer area	These are areas where the County will be monitoring groundwater levels for any potential impacts related to municipal and domestic wells, subsidence, and/or potential surface water interaction. For this simulation year, there are no rules in place related to identified buffer areas. The County will continue to monitor market activity associated with lands in identified buffer areas.
Idle or rangeland acreage	40 acres idle	Idled land is land that has been irrigated within the past 3 years but is not currently irrigated. You will receive a SY allocation for these lands. You can use this allocation within your farm unit, sell it, and/or carry it over into the next year. For participants with non-irrigated rangeland, you will receive SY allocations for that rangeland. You cannot sell SY allocations associated with your rangeland.
Sustainable Yield (SY) Allocation	0.75 acre feet (AF) per acre	This is the hypothetical SY allocation available this year based on the total available divided by the total number of acres that opted in. You can choose to sell or use this water. You can carryover up to 1 year of SY allocation for use or sale into the next year.
Carryover from previous year	30 AF	For the first trading simulation, assume no carryover amount is available for use. You can carry over up to 1-year's worth of SY allocation into next year. This includes groundwater allocations purchased on the market and any transitional water purchased. Total carryover cannot exceed the SY allocation amount from previous year.
Maximum transition water available.	0.75 AF/acre at $200/AF	The County GSAs will be making "transitional" water available to growers for a fee. The amount of transitional water available will decline over time as we progress towards SY in 2040.
Rainfall	Normal year (average rainfall)	The consumptive use demand for your crops (provided below) represents the consumptive use demand over and above what is met through precipitation for a normal (average) rainfall year. We will vary precipitation and associated consumptive use demand over the course of the pilot.
Penalty for using more groundwater than allocated to you	$1,500/AF	If the County determines that your use has exceeded your total consumptive use demand, you will be charged an additional fee per AF for the additional groundwater used. County will compare the consumptive use demand for the irrigated crops you report to the total amount of water you have available (i.e., transitional, SY allocations, groundwater purchased from market).
Additional market rules/conditions	**Minimal rules:** Trading limited to individual subbasins. Water cannot be sold for use on lands outside of the County. You cannot buy transition water and sell your SY allocations in the same year.	For this trading simulation, minimal rules are in place. Different market rules will be tested over the course of the pilot. These may include trading restrictions related to farm unit zones and/or identified buffer areas.

To help participants estimate the effect of changes in cropping patterns and inform their decisions with respect to market participation, the project team utilized crop cost and return studies published by University of California Davis and applied the most recently published studies from the closest geographic region. Product prices were also available in these studies; however, the project team relied on the Madera County Annual Crop Reports for per acre crop values to estimate revenues associated with different crop types. Participants were cautioned that the typical costs and revenues presented were intended to be used as a guide in making decisions but that, when possible, they should rely on cost/revenue data that reflects the actual conditions at their farm. Table 4 shows an example of the table participants received with this information, for an example participant from Round 3.

For participants with nut trees (pistachios, walnuts, and almonds), tree age was taken into consideration when applying ETAW estimates, as consumptive use demand changes as trees age and come into production. The project team provided participants with an initial age distribution for their treed acreage, as well as the corresponding consumptive use. Each round, participants reported changes to their tree age distribution (e.g., if they ripped out old trees and planted new ones). Otherwise, trees were automatically aged over the course of the pilot.

Finally, participants were provided with the total sustainable yield amount they had available for use across their farm unit(s) in the simulated year, the maximum amount of transition water available to them, and the total consumptive use demand of applied water associated with their irrigated acreage. Using this information, participants let us know how much groundwater they would like to buy or sell (if applicable) and submitted their irrigated acreage by crop type (and other management actions such as deficit irrigation), reflecting any changes they made in response to decreased water availability. Participants who wanted to buy water were also asked what changes they would make to their irrigated acreage if they did not receive the full amount of water that they wanted to purchase. Participants were instructed to assume that they did not have access to surface water for irrigation purposes.

In addition to the information packet, the project team developed an Excel workbook with information on consumptive use demand by crop type (including for younger trees), typical costs and revenues for different crops, and other key decision inputs. Participants could enter their irrigated acreage into the spreadsheet to determine how much water they would need and how profitable their operation would be based on their cropping and market decisions.

To accomplish the exchange of information between the pilot administrators and participants, the project team utilized Google Forms, which deposits participant responses to a Google spreadsheet. Based on the information provided to them, participants would report their decisions and activities each round. Participants would enter their ID in the Google Form and fill out fields/respond to questions related to the key topic areas outlined in Figure 5 below. Each month, administrators would aggregate participant responses by analyzing their decisions, updating a database with current cropping patterns, matching trades of groundwater allocations, calculating overall changes in transitional water demand, and aggregating changes in consumptive use and irrigated acreage across the entire simulated management area.

Table 4. Irrigated/Agricultural Acreage by Crop Type for Your Farm Unit (For Purposes of Trading Simulation)

			To be used as guide; please consider revenues/costs as appropriate for your farming operations; Rangeland revenues/costs not available.		
Crop type	Irrigated/ agricultural acres: Trading Simulation Year 3	Consumptive use demand (evapo-transpiration of applied water for NORMAL rainfall year (AF/acre/yr)[a]	Gross revenue per acre ($/acre/yr)[b]	Typical production & overhead costs ($/acre/yr)[c]	Annualized establishment costs (yrs. to full production)
Citrus, Subtropical, and Misc. Deciduous		2.71	$9,344	$7,428	$534 (6)
Pasture and Alfalfa		2.60	$1,603	$1,492	$206 (1)
Miscellaneous Truck Crops (Processed tomatoes)		2.08	$3,895	$3,781	N/A
Miscellaneous Field Crops (Corn silage)		2.06	$1,840	$1,634	N/A
Walnuts		2.76	$2,810	$3,568	$971 (8)
Grapes (Raisins)	40 acres	2.1	$4,221	$3,126	$900 (4)
Grain and Hay crops (Wheat)		1.17	$716	$ 765	N/A
Almonds	100 acres	2.83	$5,475	$ 3,301	$769 (6)
Pistachios		2.49	$4,650	$ 3,786	$609 (8)
Idle/Fallow	40 acres		--		--
Rangeland			--		--

a. Consumptive use is the amount of water transpired during plant growth plus what evaporates from the soil surface and foliage. The portion of water consumed in crop production depends on many factors, including irrigation technology. This table reflects the additional consumptive use demand above and beyond the consumptive use demand met by rainfall for the water year identified in Table 1.
b. Based on 2019 data from the Madera County Crop Report
c. Source: University of California Davis, Commodity Cost and Return Studies for San Joaquin Valley; does not account for fixed/capital expenses. These costs are intended to represent typical costs and have been updated to 2020 USD.

As the market administrator for the pilot, the consultant team facilitated trades based on a methodology being used in the groundwater market in developed by the Fox Canyon Groundwater Management Agency (located in Ventura County) for market exchanges (e.g., anonymous trading). As described previously, this method was selected based on input from stakeholders from Workshop 2. Administrators tracked simulated trades over the course of the pilot, allowing for monitoring of activity in areas of concern (i.e., groundwater withdrawals) and test the effectiveness of market rules. Each month, in addition to farm zone specific information, the County also provided a summary on trades and average water prices, and elicited feedback from participants.

Figure 5 provides a summary of the information provided to participants each month, as well as the information that participants provided each round.

County provided information to participants	Participant monthly responses
• Basic information on parcel/farm unit area, irrigated acreage by crop type • Groundwater allocation + carryover from previous round • Type of rainfall (wet, average, dry) • Consumptive use demand by crop type (changes based on rainfall type) • Amount of transitional water available to them in each simulated year and the cost of transitional water • Minimum economic information necessary for participants to make decisions with respect to market for each simulated year (e.g., average net returns over operating costs by crop type per acre) • Average sales price from previous year of trading • Information on available incentives or new rules, when applicable	• Decision to buy or sell groundwater allocations, if applicable, and associated "bid" • Amount of water they used that year • Irrigated acres by crop type, including changes made in response to reduced groundwater availability (e.g., fallowing or idling irrigated acreage) • Other management actions taken to reduce water demand/use • Feedback on market rules, process and factors that influenced their decision to participate/not participate in market in given year

Figure 5. Information provided to participants and participant responses for each month of the pilot

5.3 Market Structure and Rules

A key objective of the pilot project was to test the market structure and administrative processes, as well as the effect of market rules on growers' decisions to participate (or not) in the market. This section describes the general structure of the market (as developed for the pilot), as well as the different rules that were put in place over the course of the pilot. Some rules were established immediately, while others were crafted and implemented during the pilot based on participant feedback and need to mitigate unintended consequences.

As an important note, the County's adopted allocation policy was finalized after the pilot program was developed and initiated. As such, there are some key differences in the way that the simulated allocation approach was crafted for the pilot program. Specifically, sustainable yield allocations were held constant over the course of the pilot at 0.75 acre-feet per irrigated acre. Rangeland participants were assigned a sustainable yield allocation for their rangeland; however, they were not able to sell the sustainable yield allocations associated with the rangeland on the market (they could however, apply them for use on any irrigated acreage within their farm unit). Other variances between the market structure and the County GSA's allocation approach exist but are not relevant to the objective of this pilot market exercise.

5.3.1 General pilot market structure

Tradeable allocations. The units of trade in the market are sustainable yield allocations, which are bought and sold on a volume basis (acre-feet, AF). The pilot market was predicated on the sustainable yield allocation and farm unit approach that was being considered by the County GSA and ultimately adopted by the County GSA Board in December 2020, June 2021, and August 2021. Specifically, the pilot market program assumed the "opt-in" process for all landowners/farm units. It also assumed that individuals who "opt-in" declare their intent to pump groundwater and/or sell their sustainable yield allocation in any given year. Participants received their sustainable yield allocation each year, even if they chose to idle/fallow any of their irrigated acreage.

As noted above, for the purposes of the pilot program, participating ranchers were assigned sustainable yield allocations for their rangeland. However, sustainable yield allocations associated with rangeland were not eligible for sale on the market. Participants in the pilot could use the sustainable yield allocations associated with their rangeland on irrigated land that was part of their farm unit (for the pilot, all rangeland owners were assigned irrigated acreage in addition to their rangeland acres). These market structure rules were established to help test groundwater market concepts and functionality but were not mimicking the County GSA's detailed allocation approach that was subsequently adopted.

Transitional water purchases. Participants were offered the opportunity to buy transitional water (up to a set AF/acre quantity) at a cost of $200 per AF. As described previously, the quantity (AF/acre) of transitional water available to participants decreased over the course of the pilot, until no transition water was available in Rounds 8 and 9. The cost of transition water was established for the purposes of the pilot only. The amount that individuals will actually pay for transition water is pending an ongoing rate study being conducted by the County GSA.

Transitional water allocations could not be sold on the market.

Eligible participants. Eligible market participants include agricultural growers and farmers who would be eligible to receive a sustainable yield allocation for their irrigated acreage (or previously irrigated acreage), consistent with the County's allocation approach. Notably, the pilot included participants who did not meet these criteria; in these cases, participants were assigned hypothetical irrigated acreage and other characteristics so that they could participate in the pilot.

Non-eligible participants. While all pilot participants were assumed to meet the criteria for eligible participants, in an actual market, landowners who opt out of receiving a sustainable yield allocation would not be able to participate in the market nor would residential, commercial, or similar landowners.

Ranchers who do not have sustainable yield allocations associated with irrigated acreage (or previously irrigated acreage per the requirements above) also would not be eligible to participate.

Geographic location: The County GSA allowed all growers within the County to participate in the pilot program. However, as noted above, groundwater allocations are a prerequisite for a functioning groundwater market. Currently, the County GSA is the only GSA within Madera County that is using allocations as a method for complying with SGMA. In the future, other GSAs may opt to participate in a market; however, interested GSAs would need to establish allocations that are consistent with the sustainable yield identified in relevant GSPs.

Water purchase transfers. Buyers of sustainable yield allocations will pump more water where they are located, while sellers will forego pumping and using the sustainable yield allocations they sell. There is no physical transfer of groundwater allocations (e.g., a groundwater allocation is not pumped by the seller and conveyed to the buyer).

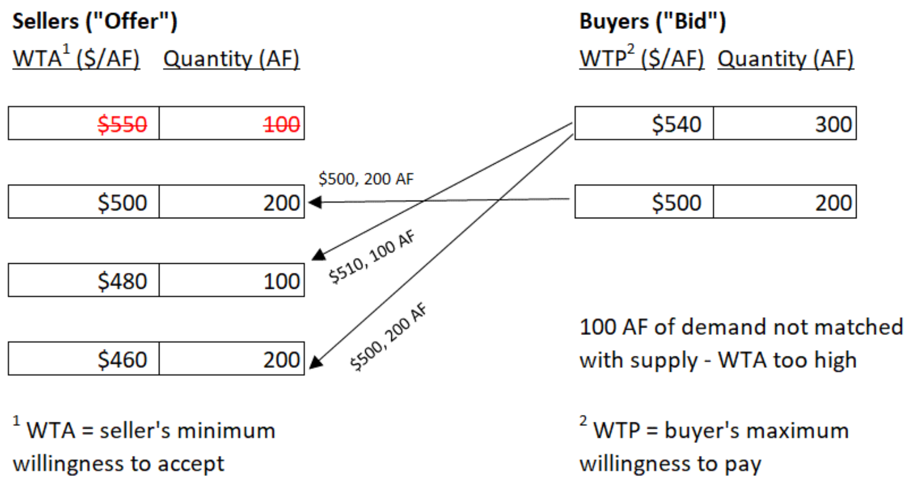
Matching buyers and sellers. Based on feedback received during previous workshops, market participants bought and sold groundwater allocations by submitting "bids" to the market administrator. Buyers and sellers were matched using a blind matching process to protect the anonymity and confidentiality of participants. Sellers were sorted in a spreadsheet according to their willingness to accept (WTA) when selling, and buyers according to their willingness to pay (WTP) when buying. First, the buyer with the highest WTP was matched with the seller with the lowest WTA. The price for this transaction is the midpoint between the WTP and the WTA.

With this process, multiple sellers (the ones with the lowest WTA remaining on the market) might be matched with a single buyer in order to provide the full amount requested by the buyer. If the first buyer's request for water is fully satisfied and there is additional water available for sale in the market, then the buyer with the second highest WTP is considered, and the seller with the next lowest WTA is matched to that buyer. This matching process continues until all available water for sale is matched with a willing buyer as long as the seller's WTA does not exceed the next buyer's WTP.

The average price from a match between buyer and seller will always be lower than the WTP of the buyer and higher than the WTA of the seller from the match. The gains from trade are split evenly between the parties in the transaction. This approach provided anonymity and confidentiality of participants, removing the bias in trading so that all parties were neutral to one another. It also provides for more equitable access to the market across all participants. Figure 6 depicts the matching process.

Serving as the market administrator, the project team published information on total groundwater allocation sales and average price paid ($/AF) each month by subbasin. Names/parties associated with individual sales were not published.

Trading intervals. In an actual market, trades could be made at set intervals during the growing season and individual growers may have the opportunity to buy or sell allocations multiple times throughout the year, subject to the market rules. For the purposes of the pilot, participants made virtual trades once per month based on simulated information provided by the County GSA, which represented trading over a simulated year. During the stakeholder engagement process, some participants expressed a desire to buy or sell water much more frequently (e.g., on a weekly basis); however, as discussed in more detail below, given the expected limited supply of groundwater for sale, this may not be feasible.



Matching rules basics:

- Highest WTP is matched with lowest WTA.
- The price is the midpoint between WTA and WTP.
- Multiple sellers may be matched to a buyer and amounts for sale may be split between two buyers if needed to match amount demanded.

Note: Prices shown in diagram are hypothetical and do not reflect actual bids/offers from the market simulation.

Figure 6. Process for Matching Buyers and Sellers

Sustainable yield allocations can only be traded for use within a growing season or year (or within carryover limits, as discussed below). The market platform/administrator did not facilitate multi-year trades.

5.3.2 Market rules

Trading areas: Trading could only occur within each subbasin and was not allowed across subbasins or outside of the County. Trading was not restricted to specific trading zones, but in the last few rounds of the pilot program, trading rules were applied to buffer areas.

Purchasing transitional water: If a participant purchased transition water, they were not allowed to sell groundwater allocations on the market that round. This prevents purchasing affordable transition water and selling the water for a profit on the market.

Buffer areas: For the first seven rounds, no rules were applied to buffer areas. In Year 7, simulated dry conditions were assumed to result in a hypothetical decline in groundwater levels that had the potential to impact domestic wells and subsidence areas. Administrators therefore established an additional fee of $200/AF to groundwater allocation purchases that would result in additional pumping from within a buffer area. Revenues from the fee would be put towards recharge projects and/or to offset impacts to domestic wells or other sensitive areas.

Additionally, the County began offering an incentive to growers who fallow irrigated acres located within a buffer area. Specifically, if a participant idled acreage located in an identified buffer area, the County offered them $600 per idled acre. This incentive was offered every year from Round 6 onwards, renewable as long as the land continued to not be irrigated. This incentive was offered in addition to any proceeds received from selling the groundwater allocations associated with the fallowed acres (if the participant chose to sell them). The incentive applied to irrigated acres that were fallowed in previous rounds, as long as that acreage continued to be fallowed.

Carryover: At the start of the pilot, participants were allowed to carryover an amount of groundwater equivalent to 1-years' worth of their sustainable yield allocation into the next year. This means that a seller can sell up to two years' worth of the sustainable yield allocation in any given year. Buyers can carry over 1-years' worth of total allocations (including their own unused allocations and any water purchased, with the total not to exceed two years' worth of allocations). After month 5, the carryover limit was increased to 2 years' worth of total sustainable yield allocations based on participant feedback.

Resale of water: Once a buyer purchases water, it cannot be resold on the market that year.

Cap on purchases: For the purposes of the pilot, there was no limit on the amount of water per irrigated acre that a buyer could purchase. However, as noted above, there were limits to the amount of carryover that participants could save for use in the following year(s). During the pilot, the project team did evaluate whether water purchases would result in an exceedance of allowed carryover amounts for individual participants.

Penalties for overuse: Each month, participants reported their total irrigated acreage (by crop type), any deficit irrigation amount they applied, the amount of transition water they wanted to purchase, as well as the amount of water they would like to buy or sell on the market (if applicable). After accounting for these factors and completing market trades, the market administrator calculated the total consumptive use demand for each participant and compared it to the total groundwater available to them. If consumptive use exceeded groundwater supplies, the participant was assessed a penalty of $1,500 per AF of exceedance. Participants were given a 10% credit on overuse to account for measurement error. In a real-world setting, penalties would be assessed based on monitoring efforts conducted by the County.

The impacts of some of these rules are difficult to test, as in reality the consequences of trading could vary based on rainfall in wet and dry years, by well depth, and a variety of other factors. Rules based on the buffer areas or trading zones may also create inequities that do not benefit the groundwater basin. Throughout the pilot, the County obtained feedback from participants regarding the effect of different rules and parameters on their decisions.

5.4 Pilot Program Results and Key Findings

Over the course of the nine-month pilot, the project team tracked participant decisions and related outcomes to better understand the role of a potential groundwater market in meeting SGMA-related water use reductions. This section presents the results of the pilot effort, providing an overview of the following:

- Changes in irrigated acreage, farm unit management, and overall consumptive use
- Market trends, including supply, demand, and changes in the price of groundwater allocations
- Characteristics of buyers, sellers, and those who did not participate in the market

In addition to these measurable outcomes, this section summarizes participant feedback collected throughout the pilot, including overall impressions of (and need for) the market, reasons for buying and selling water (or not participating in the market), and the effects of incentives, fees, and market rules on their decisions.

As detailed in Figure 7, this section only describes results for participants who consistently participated in the pilot. The pilot results should not be interpreted as reflecting the exact outcomes of a potential future market (e.g., it was not intended to predict a future market price for water). However, the results and feedback received provide valuable indications of overall market trends and perceptions.

Figure 7. Participant Information for Pilot Market Analysis

A total of 58 stakeholders registered to participate in the market simulation. These 58 stakeholders were assigned to 62 farm units, with several participants being assigned crops in farm units located within two different farm unit zones. Crops were assigned to closely resemble participants' real life farming situation and to represent the actual crops grown in Madera County, proportionally. Additionally, the administrators made choices for five farm units. In total, the pilot included 67 farm units.

However, not every participant responded every round. In most rounds, the administrators chose three to five nonrespondent participants to idle land and sell the associated sustainable yield allocations on the market. These participants were chosen because they had not participated in previous rounds and their crop assignments included low-value crops, making fallowing and selling water a sensible economic choice.

Of the 67 farm units initially developed for the pilot, participants representing 34 farm units responded three times or more during the 9-round simulation. Of those, four were non-respondent participants for which the administrators made choices and five were county staff. In total, 25 official participant choices were analyzed.

All results presented in this report are based on the 34 farm units that participated regularly.

5.4.1 Changes in Irrigated Acreage and Associated Water Use

The consumptive use reductions necessary to meet sustainable yield in the Madera County GSAs will result in changes in irrigated acreage and the adoption of other farm management strategies. This was simulated in the pilot, as the sustainable yield and transitional water allocations available to growers only covered a portion of participants' consumptive use demand on a per-acre basis. For example, in a normal year, ETAW requirements for typical crops range from 1.17 AF per acre (hay and pasture) to 2.83 AF per acre (almonds). For the pilot, the sustainable yield allocation was set at 0.75 AF per irrigated acre, while transitional water allocations started at 1.75 AF per acre and decreased over time. These quantities were established for the purposes of the pilot but were intended to simulate a range of potential future conditions. In actuality, allocations will depend on various factors and will be re-evaluated by the County over time based on groundwater levels and the status/progress of projects implemented to increase water supplies.

Under a strict allocation approach, growers may opt to fallow land within their farm unit and use the associated groundwater allocations to continue irrigating the remaining acreage. Some may also opt to switch to lower water use crops and/or adopt other management strategies (e.g., deficit irrigation) to maximize the groundwater available to them. A groundwater market introduces additional flexibility by allowing growers to fallow land and sell the associated allocations on the market - this begins to make economic sense when an acre foot of water used to irrigate can be sold on the market for a higher price than the (per AF) profits earned from the crops that would use that acre foot of water. It also provides growers with the opportunity to purchase water on the market, thereby keeping more irrigated acreage in production on their farm unit than they would otherwise be able to.

Over the course of the pilot, participants adopted various strategies in response to decreased groundwater availability. In Round 1, pilot participants started out with 35,400 acres, 98% of which was cropped and irrigated (the remaining 2% represented fallowed, previously irrigated land). Over 10,000 of these acres were almond trees, representing nearly a third of all irrigated land (generally consistent with cropping patterns within the Madera County GSAs). Grapes were the next largest represented crop, with over 7,000 acres represented in the pilot, accounting for 20% of all irrigated acreage.

In total, participants idled 13,566 acres, leaving only 61% of the total original acres irrigated. The highest proportional fallowing occurred for crops of alfalfa/pasture, field crops and grains.[7] Nearly 2,700 acres of miscellaneous field crops, 2,300 acres of alfalfa/pasture, and 2,000 acres of grain were fallowed over the course of the simulation. These crops were fallowed almost immediately, with significant declines in acreage in the first two rounds of trading.[8]

Almonds and grapes also faced relatively significant declines in total acreage with just over 2,700 acres fallowed of each crop. Almonds and grapes are high value crops and were not fallowed in large quantities until the second half of the simulation when transition water became scarce. As discussed in more detail in the next section, some participants idled land for the purpose of being able to sell the associated groundwater allocations on the market; however, many participants who idled land used the “freed up” groundwater allocations to maintain other irrigated acreage within their farm unit.

Figure 8 shows the change in total acreage for each crop category from the beginning of Round 1 through the end of the pilot. The bold percentage indicates the proportional change in that crop over the duration. Overall, participant irrigated acreage decreased by 38%. In general, the results of the pilot were consistent with findings from the farm unit analysis described in Section 3in that “more likely to sell” crops were fallowed at a higher proportion. However, due to the nature of cropping patterns in Madera County (with a percentage of nut trees and other high value crops with relatively high consumptive use requirements), as expected, crops that fall within the “more likely to buy” category were also fallowed in response to reduced groundwater availability.

Participants took advantage of the lowest cost groundwater available to them. Transitional water was available from Round 1 through Round 7 but decreased over time from 1.75 AF/ per acre of irrigated or idled land until no transitional water was available by Round 8. As noted in the rules, participants who elected to sell water on the market were prohibited from purchasing transitional water during that round of trading. Participants who could purchase transition water purchased between 81% and 96% of the total available to them each round.

[7] Walnuts also saw a high proportion of crops fallowed, but the total walnut trees planted at the start of the pilot include <1% of all cropped acreage. The proportional loss is representative of a single farmer fallowing 60 acres of older walnut trees.

[8] As a note, these crops have been on the decline in general in the County GSAs (although grain and hay acreage in the Chowchilla subbasin have remined relatively stable over time).

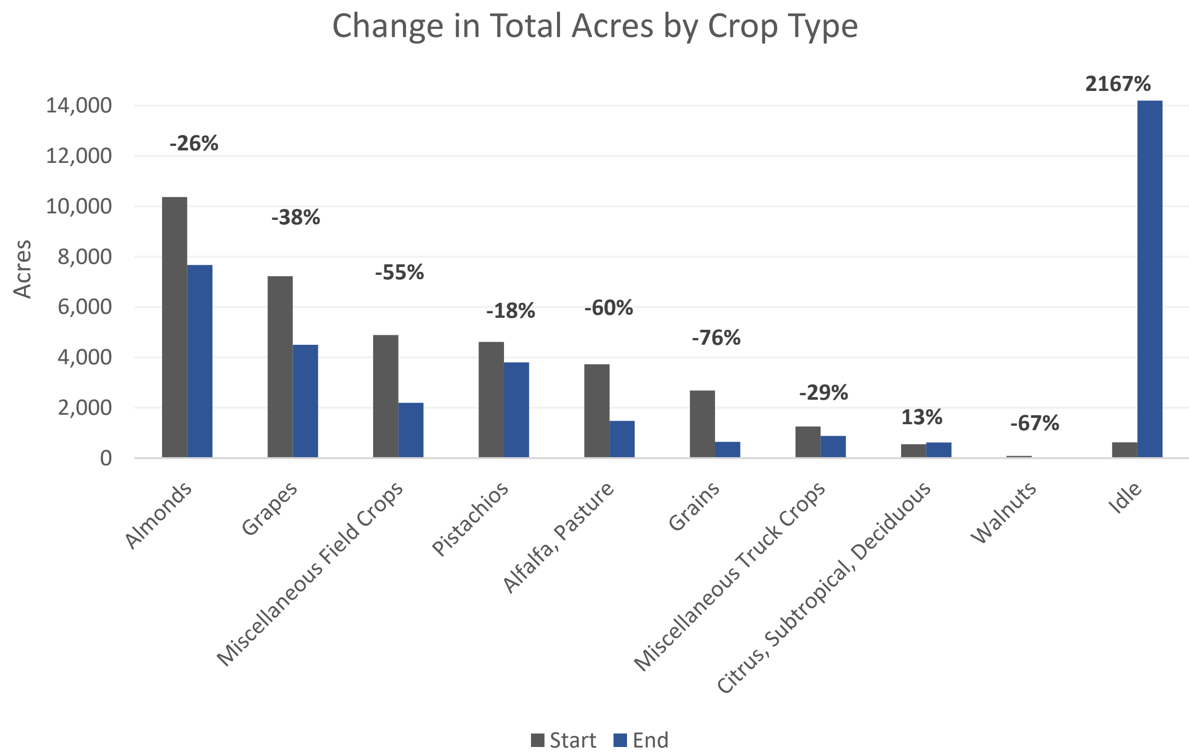


Figure 8. Change in total acreage by crop type from original assignments through the end of the pilot
Note: For Round 1 of the pilot, the project team assigned a total of 626 idled acres to participants. By the end of the pilot, idled acreage had increased to 14,192 – a 2,167% increase.

During the pilot, the project team also tracked nut tree ages over time, assuming (unless otherwise indicated by the participant) that fallowed nut tree acreage came from the oldest trees. Nut trees are of particular interest due to the lower water requirements of young nut trees (i.e., before they full reach full production) relative to older trees (which generally reach peak production between 15 and 20 years), as well as the prevalence of older nut trees in the County. The County was curious how farmers might respond to acres of aging trees in the face of water scarcity. Of the participants that were assigned almond crops in Round 1, more than half (6 out of 12) ripped up old almond trees and replanted new trees at some point during the pilot project. A total of 3,775 acres of new almond trees were replanted. One participant ripped out 80 acres of old almond trees and replanted new trees every round they participated. For pistachios, only one participant chose to plant new trees. This farmer chose to fallow 500 acres of old almond trees and move those trees into pistachios. No new walnut trees were planted during the pilot; one participant fallowed 60 acres of walnut trees in Round 2 and used the associated allocations to irrigate existing almond trees. Relatively few acres of walnuts are currently planted within the Madera County GSAs.

Replanting nut trees represents a short-term strategy for reducing consumptive use as trees will require their full ETAW after about 5 years, when less transition water will inevitably be available. However, replanting nut trees will extend the productive life of an orchard, perhaps biding time for additional recharge projects or new water supplies to come online.

Changes in irrigated acreage resulted in associated changes in the consumptive use of groundwater. It is difficult to compare year over year changes in the consumptive use of groundwater because the amount of rainfall (i.e., wet, dry, or normal year as simulated in the pilot) affects the ETAW requirements of crops. By the final round of the pilot, consumptive use was down 35% from the consumptive use associated with the initial crop allocations (under normal year conditions). Some of the largest decreases in consumptive use came in the first three rounds of trading, as participants decided to fallow less lucrative crops, as well as in later rounds when transition water was no longer available. Changes in consumptive use and overall irrigated acreage are summarized in Table 5.

Table 5. Consumptive Use and Transitional Water changes over duration of pilot program

Round[a]	Irrigated Acres			Consumptive Use			
	Total Acres	Year over year change	Change from R1	Water year type	Acre Feet	Year over year change	Change from R1
1	35,404	-13%	-13%	Normal	83,382	-	-
2	30,777	-13%	-13%	Normal	67,406	-19%	-19%
3	31,499	2%	-11%	Normal	69,485	3%	-17%
4	31,278	-1%	-12%	Dry	61,312	-12%	-26%
5	27,941	-11%	-21%	Dry	60,083	-2%	-28%
6	27,389	-2%	-23%	Dry	56,464	-6%	-32%
7	25,937	-5%	-27%	Wet	53,523	-5%	-36%
8	24,815	-4%	-30%	Normal	45,515	-15%	-45%
9	21,792	-12%	-38%	Dry	53,818	18%	-35%

a. irrigated acres and consumptive use reported reflects the numbers going into the respective round (i.e., based on conditions/decisions made in the previous round).

Participants provided information on other strategies they might use to decrease their consumptive use. Every round, between 4 and 6 participants indicated they would deficit irrigate their crops. Others suggested soil moisture monitoring, installing drip irrigation if they could afford it, rainfall capture infrastructure, and adding compost and bark chips around tree bases. However, as an important note, not all of these strategies reduce the consumptive use demand of crops – some only result in more efficient use of total groundwater extractions, likely having no significant net effect on groundwater levels.

5.4.2 Market Trends: Supply, Demand, and the Price of Water

In the first couple rounds of the pilot, the project team matched buyers and sellers regardless of which subbasin they were located in. While in reality this would not be allowed, a key objective of these initial rounds was to help participants become familiar with the market and pilot process, including the process for matching buyers and sellers. Thus, all participants were treated as though they were located within the same subbasin to maximize trading. In Round 3, the project team only matched participant buyers and sellers if they were located in the same subbasin.

Throughout the course of the pilot, participants with farm units located in the Chowchilla subbasin consistently had an excess supply of water while Madera subbasin had unmet demand. The price per acre foot of water was therefore lower every round in Chowchilla than in Madera. Tables 6 and 7 show total demand, supply, and market price by round, as well as excess supply and unmet demand, for the

Chowchilla and Madera subbasins, respectively. In some cases, unmatched supply was to due sellers requesting a price that was higher than any buyers were willing to pay. For example, in Round 3 of trading, two participants in Chowchilla were unable to sell their water due to an asking price that was too high for other farmers to purchase. In Madera, the supply was so low that the highest bidder bought all the water up for sale. The administrators of the pilot alleviated this mismatch in future rounds with additional non-respondent sellers.

Table 6. Trading results by round, Chowchilla subbasin

	R1[a]	R2	R3	R4	R5	R6	R7	R8	R9
Demand (AF)	8,005	4,265	611	1,001	1,102	1,557	636	986	1,609
Supply (AF)	1,227	1,119	620	920	2,438	2967	1,497.5	2,490	1,925
Total traded (AF)	1,227	1,119	20	920	1,102	1,557	539	986	1,609
Market price/AF	$574	$642	$891	$840	$940	$934	$991	$917	$863
% Demand met	15%	26.2%	3%	92%	100%	100%	85%	100%	100%
Excess supply	0	0	600[b]	0	1,336	1,410	958.5	1,504	316

a. For Rounds 1 and 2, results presented are for all participants (trades were not limited by subbasin)

b. In Round 3, two of three sellers in the Chowchilla subbasin priced their water higher than any buyers were willing to pay.

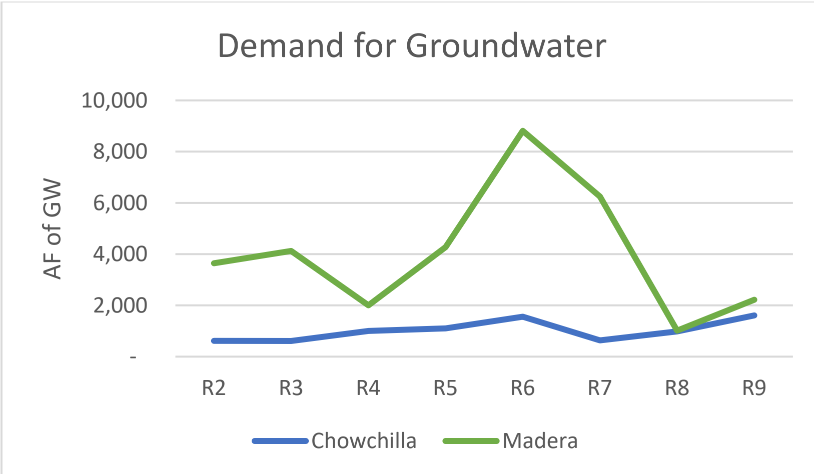
Table 7. Trading results by round, Madera subbasin

	R1	R2	R3	R4	R5	R6	R7	R8	R9
Demand (AF)	8,005	4,265	4,126	2,003	4,278	8,813	6,246	5,350	2,219
Supply (AF)	1,227	1,119	525	2,263	2,280	2,263	2,553	2,923	3,078
Total traded (AF)	1,227	1,119	385	2,000	2,280	2,263	2,553	2,923	2,219
Market price/AF	$574	$642	$905	$864	$ 982	$1,042	$1,038	$928	$858
% Demand met	15%	26.2%	9%	100%	53%	26%	41%	55%	100%
Excess supply	0	0	140	263	0	0	0	0	859

a. In Round 9 there were fewer participants than normal participating, particularly in the Madera subbasin, this is primarily why total demand is lower than the previous rounds, resulting in excess supply.

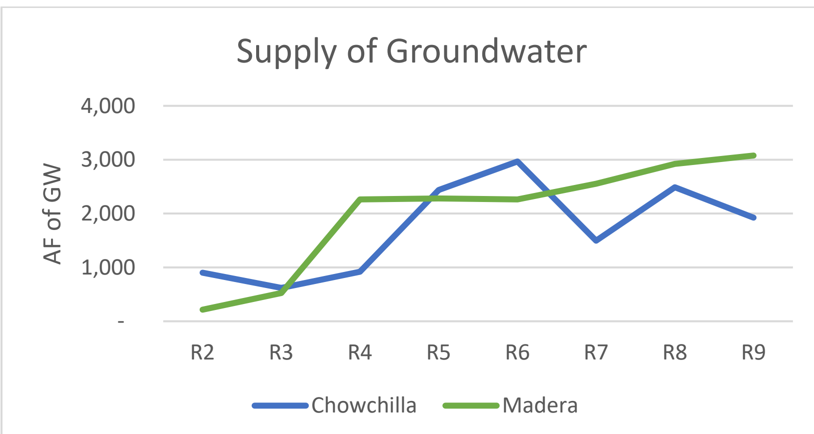
Figures 9 – 11 show demand, supply, and price per acre foot of groundwater over the course of the pilot. While specific results are in part a factor of who participated each round, the trendline for demand steadily increases until Round 6, after which there is a sharp decline. Rounds 4 – 6 were dry years, so the peak in demand may reflect increasing water scarcity (in addition to decreasing availability of transitional water). In addition, Round 7 was a wet year, which reduced the ETAW requirements for crops. The decline in demand after Round 6 may also reflect farmers' unwillingness to risk attempting to buy water on the market. Participants' comments reflect their aversion to the risk of basing cropping decisions on shifting market supply and price.

While supply also increases over time (Figure 10), the rate of increase does not keep pace with demand. In Madera subbasin, supply was often only 25% - 55% of total demand, while in Chowchilla, supply was regularly greater than demand.



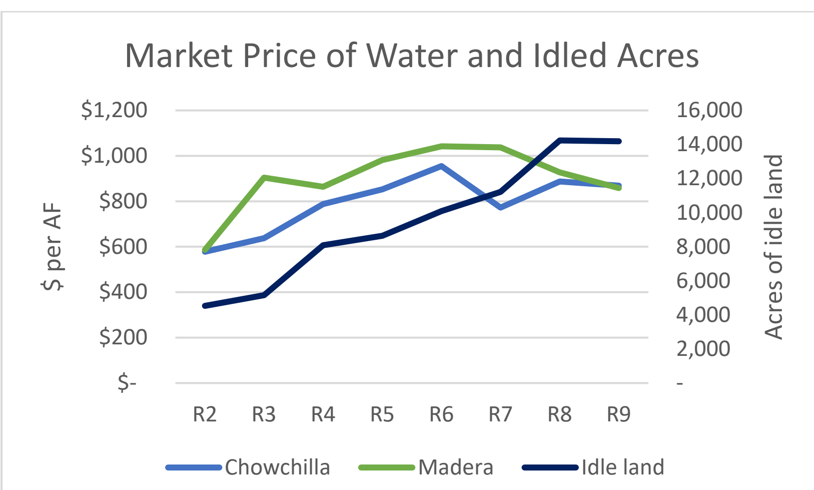
Demand peaked in Round 6 in the Madera subbasin, perhaps due to three years of drought, decreasing transitional water availability, and questions/uncertainty regarding market price and supply.

Figure 9. Demand for groundwater by subbasin and total over time



Supply in Chowchilla was consistently greater than demand in that subbasin. Although supplies are similar in quantity, there was typically excess demand in Madera.

Figure 10. Supply of groundwater by subbasin and total over time



Decisions about fallowing land in response to price would happen the year after a given price. The Rounds on the X axis indicate the price that round, and the idled acreage reflects the following round's decisions (i.e. R3 $/AF corresponds to total idled acres in R4).

Figure 11. Price per AF of groundwater and idled acreage by subbasin over time

Figure 11 shows that throughout the course of the pilot, the price of water on the market increased, as did the amount of acres fallowed. These trends outpaced the increase in demand, perhaps underscoring a reluctance to purchase water on the market.

Participants often commented about the high price of water on the market. To demonstrate this point, assume that a farmer must rely on market water to water some acres of his or her farm unit (see Table 5). The average price of water on the market from Rounds 4 - 9, ($971/AF in Madera and $851/AF in Chowchilla) was applied to the consumptive use per acre of each crop, after accounting for sustainable yield allocations of 0.75 AF/acre. As shown, the cost of water per acre exceeds accounts for a relatively high percentage of "typical" revenues for different crops (based on Madera County 2019 crop data). For low-value crops like pasture, alfalfa, grain and hay crops, the cost to purchase water exceeds the typical revenues from irrigated an acre of those crops.

Table 8. Per acre consumptive use, finance and cost of water statistics by crop type

Crop type	Consumptive Use: Normal Rainfall, after SY allocation applied	Revenue per acre (2019)	Cost to water 1 acre using water purchased on the market (% of revenues)	
			Madera	Chowchilla
Citrus, subtropical, deciduous	1.96	$9,344	$1,903 (20%)	$1,668 (18%)
Pasture, Alfalfa	1.85	$1,603	$1,796 (112%)	$1,574 (98%)
Misc. Truck Crops	1.33	$3,895	$1,291 (33%)	$1,132 (29%)
Misc. Field Crops	1.31	$1,840	$1,272 (69%)	$1,115 (61%)
Walnuts	1.45	$2,810	$1,408 (50%)	$1,234 (44%
Grapes	0.9	$4,221	$874 (21%)	$766 (18%)
Grain and hay	0.42	$716	$408 (57%)	$357 (50%)
Almonds	2.08	$5,475	$2,020 (37%)	$1,770 (32%)
Pistachios	1.74	$4,650	$1,690 (36%)	$1,481 (32%)

Source: Revenue data from the Madera County Annual Crop Report. Consumptive use data was derived from data from the GSPs.

Despite the high prices of water on the market, participants generally offered positive feedback about utilizing a groundwater allocation market as a tool to achieve groundwater sustainability. They recognized that the flexibility of the market helps manage the required decrease in groundwater pumping, with one participant calling the market a "necessary evil." Much of this support was caveated with concerns about how the market would be managed and wariness of larger investors or big farmers buying up all the water.

5.4.3 Buyers, Sellers and Non-Market Participants

As described in Section 4, It is suspected that growers who would be more likely to sell groundwater allocations (at least in the initial years of the market) primarily grow low-value crops such as grains, hay, pasture, alfalfa and other field crops. Those who are more likely to buy cultivate perennial, high value crops such as citrus and nuts. This economic reasoning held true in the market simulation, although with some important caveats.

Sellers: The largest amount of land idled over the course of the pilot happened immediately after Round 1, where nearly 4,600 acres of irrigated land was fallowed. Nearly half of the fallowed acres that round came from sellers fallowing pasture, alfalfa, and field crops. While grain crops were also fallowed to sell water over the course of the pilot, those crops did not see the same decline in acreage as pasture, alfalfa, and other miscellaneous field crops. Between 7 and 11 participants sold water each round and they mostly remained consistent as sellers.

Very few responders offered insights into their decisions to sell water on the market. One participant sold their allocations associated with a farm unit in the Chowchilla subbasin (where they grew wheat) in order to finance the purchase of water for tree crops on their farm unit in Madera subbasin. Participants were asked if there was a guaranteed price at which they would sell their allocations instead of watering crops. Responses ranged between $600 and $3,000 per AF, with one participant consistently concluding that they would not sell water without a long-term commitment from the purchaser.

Some respondents indicated they would sell water when it became more profitable than the crops they grow. However, this was not necessarily reflected in participant decisions as many individuals chose not to sell water even though it would likely be in their economic interest to do so. In comparing the revenues from Table 5 (above) to the "typical" operating and overhead costs for different crop types (based on local crop budgets published by UC Davis), the expected profits from selling water exceed or come close to the typical profits that growers in the area receive from most crops, with the exception of almonds, citrus trees, and grapes. This is based on average data; the economics of individual farm units vary based on several different factors.

Buyers: Participants who attempted to buy water on the market grew citrus/subtropical/deciduous, nut trees, and grapes. Every round between 6 and 12 participants attempted to buy water. Successful buyers offered a very high willingness to pay for water and often bought, or tried to buy, large quantities (>1,000 AF). In the first several rounds, participants reported only buying water to keep as carryover for the following years. By Round 6, buyers in Madera reported that they wanted to buy water due to lack of transition water and expressed frustration with the risk of relying on market water to irrigate their crops. However, as one buyer in Chowchilla pointed out during Round 7, there "always seems to be enough" supply in their subbasin.

> *Not interested in relying on the market for water anymore. The pilot was very useful in pointing us in that direction after several rounds. Just too risky! – Buyer turned non-market participant, Round 9*

Non-Market Participants: Participants who chose not to buy or sell water (non-market participants) mostly grew high value crops. In Round 4 there were 14 non-market participants. In the final rounds of trading, those numbers dwindled to 6 and then 3. This reflects the hard choices farmers had to make as water became scarce. Early in the pilot, many reported that they were able to survive by buying their maximum amount of transition water or fallowing a portion of land to continue to water their other crops. Without transition water, and with variable market supply of water to purchase, participants decided to either try to buy water on the market or fallow more land and sell.

> *"I'm assigned permanent crops in the simulation (and real life as well) …at what point do you want to rip out the permanent crop, get out of farming, and exploit the property's SY market value. Difficult decision to make for a permanent crop grower. At this point, my objective in the simulation is to keep farming as long as possible."*
> *– Small grape farmer who had idled half his land, Round 4*

In many cases, participant decisions demonstrated an attachment to farming that supersedes the economic value of selling water on the market. As early as Round 1, participants responses indicate they would rather fallow land (or in some cases, specifically older nut trees) and continue to farm (i.e., use the allocations to continue irrigating other acreage within their farm unit) rather than fallow the land to sell the associated allocations on the market. Even when transition water was no longer available, participants reported that their goal was "to maintain as much irrigated acreage as possible." In Rounds 4-7, participants were asked how groundwater availability would affect their decision to buy or sell water: fallowing more land consistently outranked buying more water on the market every round. Occasionally participants commented they would crop shift from current crops to higher yield nut crops, which was not an uncommon occurrence.

This trend of farming at all costs reflects the specific preferences of the farmers in this region at this time. These preferences might not always prevail. In the future, as the lower available groundwater supply stabilizes, farmers in the next generation might have a change in attitudes.

5.4.4 Incentives, Fees, and Rules

Throughout the course of the pilot, the project team evaluated the effect and/or role of different potential market rules. This section describes these rules and summarizes feedback from participants on how these regulations affected their decision-making process.

$1,500/AF Penalty: Implemented from the start of the program, the County assessed a $1,500 penalty for every acre foot of consumptive use that exceed the groundwater available for the participant by more than 10%. The penalty essentially serves as a price ceiling for what farmers would be willing to pay for water on the market (i.e., rather than pay a higher price on the market, they could simply pay the penalty). Occasionally participants would report drastic deficit irrigation, presumably to avoid paying the penalty. Most participants managed their farm unit to avoid penalties throughout the course of the pilot. At the outset of the pilot, the County considered a lower penalty amount; however, stakeholders suggested a higher price for the penalty to ensure compliance, indicating that many growers would be willing to pay a lower amount (e.g., $500 to $1,000 per AF).

Allowable Carryover: In Round 5, allowable carryover from year to year was increased from 1 years' worth of sustainable yield allocation (i.e., 0.75 AF/acre could be carried over for use or sold in the next year) to 2 years' worth of sustainable yield. One third of responders indicated that the increase in carryover helped with planning and security, as well as possible financing for water sales in the next round. The majority, though, reported that there generally is not enough water to carry over from year to year to meet this threshold. Very few participants ever met the carryover threshold once it was increased.

Incentive for Idle Land: Starting in Round 7, participants were offered an incentive of $600 per acre for land fallowed in an identified buffer area. The incentive was offered every year as long as the land continued to not be irrigated. In each round that this incentive was offered, the majority of responders suggested that the incentive program did not influence their decision to fallow land and sell sustainable yield allocations on the market. These folks suggested that they wished to keep farming and use their water on their own land; they would not sell water even if they fallowed the land and received an incentive. The participants that were influenced by the incentive reported that it was more profitable to be paid not to farm. The incentive was large enough to not have to rely on selling water on the market and still be able to make a profit. By the end of the simulation, 22 of 34 participants idled land in the buffer areas and were eligible for an incentive. This idled land only constituted a third of all land in buffer areas. The results are summarized in Table 9.

Fee for Purchasing Water to Irrigate in Buffer Areas: In Round 7, an additional fee of $200/AF was applied to the purchase of water on the market that would be utilized to irrigate in a buffer area. Fees were calculated based on the shortage of water needed to irrigate crops in the buffer area that was purchased on the market (instead of all water that was purchased on the market).[9] One third of participants reported that this influenced their decision to fallow the land in their buffer area, as they could no longer afford to buy water to continue irrigating. The remaining responses indicated that the fee was not a concern or did not understand the question. Only 6 participants in Round 8 and 5 participants in Round 9 incurred a fee for the purchase of their water on the market.

Table 9. Aggregated results for incentive for idled land in buffer area and fee for purchasing water to irrigate in buffer areas

Round	Incentive for Idle Land in Buffer Area				Fee for BA Irrigation	
	# of participants	Buffer area acres idled	% Idled of Total Buffer Areas	Total incentive payout	# of participants	Total fees paid
Round 7	18	2,469	18%	$1,481,422	--	--
Round 8	22	4,375	32%	$2,624,760	6	$465,165
Round 9	22	4,375	32%	$2,625,000	5	$218,169

Timing of trades. Over the pilot, participants had the opportunity to make virtual trades once per round, which represented trading over a simulated year. During the stakeholder engagement process, some participants expressed a desire to buy or sell water much more frequently (e.g., on a weekly basis); given the expected limited supply of groundwater for sale, this may not be feasible as it would likely exacerbate the mismatch of supply and demand. However, a market could easily be structured to implement multi-trading opportunities within a growing season (which could depend on trading activity). This would also provide an opportunity for sellers who may have priced their allocations too high to revisit their asking price.

Over the course of the pilot, several participants also commented on the need for multi-year or long-term trades. This could be facilitated through the market administrator and would need to be monitored for any potential unintended consequences.

Locational restrictions. Due to the limited number of participants, the project team was not able to test the effect of limiting trading to farm unit zones or to within (or across) identified buffer areas, or other directional/locational restrictions. The farm unit analysis described in Section 4 indicates that while crops that are likely to have more demand for water are relatively evenly distributed across farm unit zones, crops that are more likely to sell are more concentrated in some areas. This has the potential of limiting trading activity in areas that are anticipated to have less supply of groundwater allocations on the market.

[9] The fee for buying water on the market to irrigate buffer areas was calculated by determining the sustainable yield + carry over available to water crops. Within the buffer area, if the consumptive use for crops was greater than the available water, the fee was applied to the amount of water purchased on the market that would be necessary cover the exceedance. It was possible to buy water on the market but not have a shortage in the buffer area and therefore not be assessed a fee on their purchases.

6. Conclusions, Lessons Learned, and Recommendations

Stakeholders, participants, and County officials expended significant efforts to undertake a pilot groundwater market trading program. The feedback from workshops, results from monthly rounds of trading, participant feedback and implications of different market elements offer insights into the value of a market-based solution for managing groundwater demand in the Madera and Chowchilla subbasins. This section summarizes lessons learned and makes some recommendations for the County to consider moving forward.

6.1 Conclusions and lessons learned

Several key themes emerged from the implementation of the pilot:

- Particularly in early rounds, many participants opted to not participate in the market (i.e., buy or sell groundwater), preferring to deficit irrigate, and/or fallow land and use the associated allocations to irrigate other acreage within their farm unit. Market activity/interest picked up over the course of the pilot as the availability of transitional water decreased.
- Many participants were reluctant to try to buy water on the market due to uncertainty related to available supply and the price per acre-foot of groundwater on the market. As described in Section 5, in the Madera subbasin, there was often not a sufficient amount of supply to meet the demand for purchasing groundwater allocations; this likely resulted in a higher price for water and provided additional uncertainty as to whether a potential buyer would be able to purchase water on the market.
- Several respondents indicated they would sell water when it became more profitable than continuing to grow crops. Based on participant comments, it is likely that additional supply would begin to be available on the market over time. However, if a market is implemented, trading activity would likely be relatively limited in the early years.
- Some participants made decisions to help buy them time while the County or others develop new water supplies and expressed optimism that this would occur (e.g., several ripped out old trees and planting new ones, fallowing land with the option for returning them to production).
- High-value, permanent crops make up a large percentage of total irrigated acreage in the County GSAs; as expected, this meant that some of these lands were fallowed over the course of the pilot. This also makes it difficult to predict where purchases will come from (i.e., where additional pumping will occur) because growers with the same crops will make different decisions based on their individual circumstances and preferences (i.e., some almond growers may try to buy water while others will not, still some may even sell water). There is some evidence that incentives could be used to encourage individuals located in buffer areas to fallow and sell their groundwater allocations. In this way, a market could reduce potentially adverse effects on the groundwater basin.
- The high price of water could pose a greater challenge for small farmers, but this will depend on individual circumstances. Compared to a strict allocation approach, many farmers may be better off financially because they are able to sell allocations.

- Many participants provided positive feedback with respect to the pilot, indicating it was a valuable exercise. Several participants also provided comments indicating wariness or mistrust of the County/state and motivations behind SGMA.

- Although some expressed concerns, participants were generally supportive of the market as a useful tool to provide flexibility on the path to sustainability, with caveats regarding management and concern for their future as farmers. This positivity regarding the market is especially poignant given that many farmers saw the "writing on the wall," as one participant put it, and were not hopeful about their future in profitable farming. Overall, a market does seem to provide more flexibility in allowing farmers to make choices about their water usage.

> *"I am learning a lot from the pilot process and would very much like to see it implemented during the upcoming years in SGMA"*
>
> *"Great game!!! Especially if it's BOTH sides that are learning they're going to have to change and be more flexible. . . "*
>
> *-Round 4 participants*

- Trading was done using an algorithm that matched the highest bidder with the lowest willingness to accept and averaging the price of water between the two to complete the sale. The method of "nearest neighbors" was also tested every round, matching the highest bidder to the highest willingness to accept. There was very little variation between the outcomes of these two methodologies in terms of market price. However, there was often water left unsold on the market because sellers asking price exceeded any buyers' willingness to pay. This inefficiency might not be desirable given the water scarcity that so many farmers will be facing in the coming years, although it would likely be minimized over time as the market price begins to stabilize.

- Given the small sample size, conflicting feedback from participants and few rounds in which transition water was unavailable, it is difficult to determine the effect of incentives or fees on participant behavior; generally, the incentive program received positive feedback.

- Farmers lead very full and busy lives. This project could not have happened without the participants that volunteered their time to respond consistently. However, participants often needed multiple nudges and extensions of deadlines to submit their responses.

- Finally, the groundwater pilot market was time consuming to administer; it required tracking participant decisions/data, predicting consumptive use, reporting individual results, in addition to matching buyers and sellers. An actual market would not require the same level of data collection and much of the necessary data would likely be tracked as part of the groundwater allocation tracking and monitoring. Conceivably, administrative processes could be streamlined into the overall process for the GSAs.

6.2 Recommendations

The purpose of the pilot was not necessarily to definitively determine whether the County should implement a groundwater market. Initial results indicate that it could be a useful tool for meeting SGMA requirements but that there are some challenges. If the County moves forward with a market, there are several key things to consider for implementation. The following recommendations are derived from the experience of administering the pilot market and the feedback received along the way from County officials and participants alike.

> *Thank you for letting me participate and putting together a very interesting and enlightening program! I really wish I could have run several farms in order to see if my operation would have fared better with different decisions over the course of the game. I do not like the buffer zones… all of the drinking wells in our area are at depths below the ag wells, our groundwater levels have been steady for decades and the shallow ag wells we have do not cause subsidence. But…our farm that has been around for nearly 80 years will likely get swept up in a "buffer zone" because of [our neighbors'] farm practices. It is not sustainable for them to drill 80+ new deep wells in the last dozen years and convert 12,000 of permanent pasture to trees when the natural resources out here cannot support it. – Small farmer growing almonds in a buffer area, Round 9*

Hire a neutral third party to administer trading and enforce rules or assess penalties. Many stakeholders expressed distrust of government officials and their capacity to neutrally administer a groundwater market. This could be alleviated in part by allowing a third party to administer the market, and to keep key information confidential.

Keep the matching process simple. Initial stakeholder engagement indicated a preference for confidentiality and anonymity related to groundwater market trades. For the pilot, the project team adopted the smart market method adopted by Fox Canyon Groundwater Management Agency in Ventura County (as described in Section 5). While this approach worked well and is economically efficient, it did introduce uncertainty as to whether a buyer would receive the full amount of water they wanted to purchase (although this is not necessarily unique to this approach). Publishing results regarding the cost and magnitude of trades after each trading period should reduce uncertainty to some extent. Other markets have also successfully employed more traditional approaches, whereby willing sellers and buyers bid through a more open forum rather than matched by the market administrator based on WTP and WTA. This type of trading was suggested by a participant in the final round of comments, but this approach does not offer obvious additional benefits. The matching algorithm used in the pilot can be administered using a simple spreadsheet.

Financial transparency for funds generated from the groundwater market. For similar reasons as above, provide as much transparency as possible with the fees and fines that are collected on behalf of Madera County. If these funds are used to finance projects that increase groundwater recharge or increase flood flow capture, publicize this information widely.

Only implement rules when it is absolutely clear that a rule needs to be put in place. As noted earlier, it is difficult to predict where a groundwater market might result in increased groundwater pumping (i.e., where purchasers will be located). This is due in part to the high percentage (and relatively even distribution) of crops that are "more likely to buy" groundwater. The farm unit analysis described in Section 4 does provide some insights as to where supply (and in some cases demand) might be more concentrated. Given the inability to predict specific impacts or trades, it does not make sense for the County to put restrictions in place that would limit trading to particular buffer areas or zones (perhaps with the exception of farm unit zones, addressed below). It would be important for the County to monitor sales, and the effects of other SGMA-related management actions, and to proactively manage the program consistent with thresholds and objectives outlined in the GSPs**.** This is consistent with lessons learned from other markets, where the consequences and benefits of market rules were not fully understood.

Rules such as limiting carryover and penalties for overuse would play a key role in the market and should be implemented at the outset. The amount of allowable carryover could be revisited over time.

Rules for matching buyers and sellers could also be adapted over time. For example, sales could be capped to a set amount per irrigated acre as a way to allow more people access to available supply. A certain proportion of available supply could also be designated for small farmers to ensure equitable access.

Limit trades to farm unit zones. The County GSA's allocation approach limits the use of groundwater allocations to lands collectively operated within the same farm unit zone. This leads to a default assumption that trades would also likely only be able to occur within the same farm unit. However, this has the effect of limiting market activity/flexibility, particularly because obvious sources of supply are somewhat concentrated in specific farm unit zones. The County may consider allowing trades across farm unit zones subject to review and careful consideration of net benefits and impacts. This would likely need to be integrated into the allocation approach, such that it would also allow farmers who collectively manage irrigated acres across zones to manage that water flexibility (subject to review and potentially fees).

Incentivize strategies to reduce consumption and generate supply. Participants made very thoughtful suggestions throughout the pilot on how to conserve water. If there is a means to support a program that would incentivize recharge projects that could generate allocations for sale on the market or land conservation (as is being considered by the County), particularly in areas where it is most needed, those avenues should be explored in tandem with the market. The County could also explore a purchase guarantee program whereby unsold allocations would be purchased by the County at a price slightly lower than the market price. This provides additional certainty to sellers that allocations will be sold, which could help to ensure additional supply.

Appendix H. 2022 Madera Verification Project Final Report.

2022 MADERA VERIFICATION PROJECT

Final Report

PREPARED FOR

Madera County - Department of Water and Natural Resources

PREPARED BY

Davids Engineering, Inc.

FEBRUARY 2023

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Abbreviation	Description
AF	Acre-feet
AGW	Applied Groundwater
API	Application Programming Interface
CAFO	Concentrated Animal Feeding Operation
CIMIS	California Irrigation Management Information System
COD	Critically Overdrafted
County	Madera County
D/S	Downstream
DU	Distribution Uniformity
CUF	Consumptive Use Fraction
DE	Davids Engineering, Inc.
DWR	California Department of Water Resources
E	Evaporation
ET	Evapotranspiration
ETa	Actual Evapotranspiration
ETAW	Evapotranspiration of Applied Groundwater
ETo	Reference Evapotranspiration
ETPR	Evapotranspiration from Precipitation
FUZs	Farm Unit Zones
GPM	Gallons Per Minute
GSAs	Madera County Groundwater Sustainability Agencies
GSP(s)	Groundwater Sustainability Plan(s)
IDC	Integrated Water Flow Model Demand Calculator
IU(s)	Irrigation Unit(s)
IW	IrriWatch
MAPE	Mean Absolute Percentage Error
MBE	Mean Bias Error
MCFB	Madera County Farm Bureau
MVP	Madera Verification Project
NOAA	National Oceanic and Atmospheric Association
NRCS	Natural Resource Conservation Service
ODK	Open Data Kit
P	Precipitation
Participants	16 Project Participating Growers
PMAs	Projects and Management Actions
Project	2022 Madera Verification Project
QA/QC	Quality Assurance/Quality Control
SEBAL	Surface Energy Balance Algorithm for Land
SGMA	Sustainable Groundwater Management Act

Abbreviation	Description
T	Transpiration
U/S	Upstream

EXECUTIVE SUMMARY

The objective of the Sustainable Groundwater Management Act (SGMA) and implementation of Groundwater Sustainability Plans (GSPs) in Madera County is to achieve groundwater sustainability in each subbasin by 2040. The Madera County Groundwater Sustainability Agencies (GSAs)[1] are currently implementing GSPs for the "white areas"[2] of the Chowchilla, Madera, and Delta-Mendota Subbasins. Other GSAs in Madera County are responsible for GSP implementation in their own management areas. In most years, groundwater is the sole source of water for irrigation of agricultural lands in the Madera County GSAs. Where required, an important component of GSP implementation and achieving sustainability is reducing consumptive use[3] of groundwater, which may be accomplished through implementation and enforcement of a groundwater allocation.

On December 15, 2020, the Madera County Board of Supervisors adopted Resolution 2020-166 describing the groundwater allocation approach to be used for GSP implementation in the GSAs. The resolution describes two designations of groundwater: (1) sustainable yield of native groundwater and (2) transitional water that is continued overdraft of the Chowchilla, Delta-Mendota, and Madera subbasins that will incrementally decline over the GSP implementation period (2020 through 2040). Importantly, the adopted allocation approach is based on the quantity of groundwater consumed, not pumped. This distinction recognizes that the consumption of groundwater causes subbasin depletion (and therefore affects sustainability), while groundwater that is pumped but not consumed returns to the groundwater system (as deep percolation) and does not cause depletion[4]. Further, recognizing that crops consume

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[1] The Madera County GSAs are the three GSAs managed by Madera County in the Chowchilla, Delta-Mendota, and Madera Subbasins, respectively.

[2] "White areas" represent lands outside of the boundaries of cities and surface water district service areas (i.e. areas not governed or managed by another local agency).

[3] Consumptive use refers to "that part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment" (ASCE, 2016). In this report, consumptive use of groundwater is considered equal to evapotranspiration of applied groundwater (ETAW), and the two terms (*i.e.,* consumptive use and ETAW) will be used interchangeably.

[4] Because pressurized drip and micro-sprinkler on-farm irrigation systems are dominant in the three Madera County GSAs, the assumption was made that there is negligible surface runoff from the GSAs that could cause groundwater depletion. The limited nature of runoff from AGW was reviewed during 2022 field data collection activities, providing evidence to support this assumption.

precipitation (P) as well as applied groundwater (AGW) stored in the root zone, it is important for purposes of groundwater allocation and accounting to distinguish between crop ET of P (ETPR) and crop ET of applied water (ETAW). Thus, ETAW was adopted as the quantitative accounting metric at the parcel scale against groundwater allocations for the GSAs. This approach formed the basis for the data collection and analysis documented in this report.

In late 2020, and through extensive public vetting by an independent advisory group, the GSAs chose IrriWatch[5] as the preferred approach for quantifying ETAW for comparison to groundwater allocations. The 2021 and 2022 calendar years were used to configure, implement, and test the IrriWatch platform prior to the enforcement of allocations and penalties, currently slated to begin in 2023. The 2021 results and grower feedback led to a more extensive review of ETAW from IrriWatch in 2022 through the 2022 Madera Verification Project (Project). The Project was a collaborative effort undertaken by Madera County (County) within the GSAs in partnership with local growers. Project objectives were as follows:

1. **Increase grower engagement, education, and outreach related to SGMA implementation, particularly groundwater allocations, remote sensing of ETAW, and metering of Applied Groundwater (AGW).**
2. **Evaluate flowmeter installations, maintenance, and accuracy based on site inspections and comparisons to independent on-site flow measurements.**
3. **Develop and test procedures for collecting, quality controlling, and using totalizing flowmeter readings to quantify volumes of AGW.**
4. **Evaluate methods for collecting and/or developing required input data and associated computations for remote sensing of ETAW with IrriWatch.**
5. **Develop and implement improvements to the processes for quantifying AGW and ETAW volumes.**
6. **Compare and analyze AGW to remotely sensed ETAW provided by IrriWatch.**

The Project objectives were pursued through voluntary, collaborative partnerships with 16 participating growers (Participants) within the Madera County GSAs. Davids Engineering, Inc. (DE) met with individual Participants in June 2022 to discuss the Project and its objectives and review potential participating lands. Additionally, Participants identified the locations of their groundwater wells (and associated flowmeters) and the parcel-fields[6] they irrigate. Parcel-fields owned or managed by a common Participant receiving all the irrigation water pumped by one

[5] IrriWatch uses remote sensing data and methods to quantify actual evapotranspiration. More information about IrriWatch is available at: https://irriwatch.com/ .

[6] A parcel-field is the union of legal parcel boundaries from the Madera County Assessor's Office and 2018 California statewide irrigated and urban lands coverage from the California Department of Water Resources (DWR).

or more groundwater wells were grouped into irrigation units (IUs)[7]. In total, the 16 Participants farmed 36 unique IUs comprising nearly 12,000 acres. A summary of the crops and associated acreages in the Project compared to the overall cropping and acreages in the Madera County GSAs indicates that Project lands represented roughly 10% of total farmed land in the GSAs (Table ES-1). The three primary crops grown within the Madera County GSAs (*i.e.*, Almonds, Grapes, and Pistachios) were the three most common crops included in the Project, thus providing a crop composition generally representative of the GSAs as a whole. Project lands included seven different crops distributed relatively evenly among five Farm Unit Zones[8] within the Madera GSAs (Figure ES-1).

[7] An Irrigation Unit is defined as one or more parcel-fields receiving all of the irrigation water pumped from one or more groundwater wells owned or managed by a common Participant.
[8] Farm Unit Zones are the geographic areas defining the bounds within which a Farm Unit (*i.e.*, cropped lands owned and/or managed by one entity) is able to aggregate and manage its groundwater allocation.

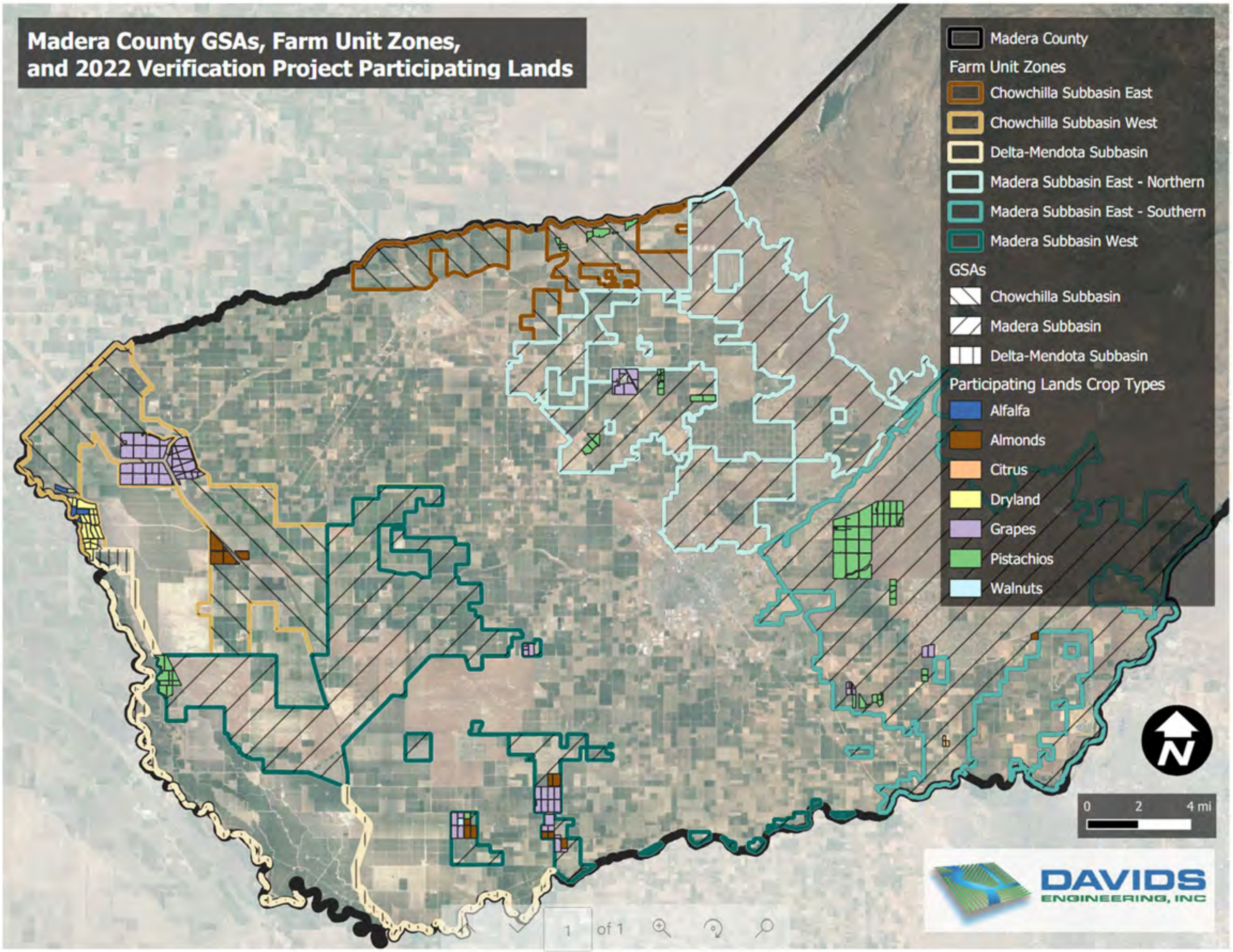

Figure ES-1. Madera County GSAs, Farm Unit Zones, and Project Participating Lands.

Table ES-1. Summary of Cropping in the Project and GSAs.

Crop	2022 Madera Verification Project			Madera County GSAs		
	Parcel-Field Count	Acreage	Acreage %	Parcel-Field Count	Acreage	Acreage %
Alfalfa[9]	4	174	1.5%	184	6,580	5.4%
Almonds	16	1,053	9.0%	1,606	43,059	35.4%
Citrus	4	48	0.4%	59	1,327	1.1%
Dryland[10]	21	862	7.4%	133	3,963	3.3%
Grapes	74	4,785	40.8%	512	14,625	12.0%
Pistachios	83	4,764	40.6%	1,000	22,204	18.2%
Walnuts	1	42	0.4%	26	653	0.5%
Other[11]	0	0	0.0%	1,782	29,261	24.1%
Totals[12]	**203**	**11,729**	**100%**	**5,302**	**121,672**	**100%**

After the initial meetings with the Participants, extensive field data collection on participating lands began and continued through early January 2023[13]. The field data collected[14] during the Project included:

1. Readings of instantaneous flow and totalized volume from permanent flowmeters[15].
2. Additional ("spot") flow measurements made with a portable transit time flowmeter for comparison to flow measurements from permanent flowmeters.
3. Evaluation of permanent flowmeter installation and maintenance for consistency with manufacturer specifications.
4. Observations of relevant in-field conditions (*e.g.,* evidence of cover crops, presence of tailwater, evidence of shallow perched groundwater, etc.).

[9] Alfalfa is currently not a specific crop class available from IrriWatch. The Madera County GSAs Parcel-Field Count and Acreage were calculated using IrriWatch's "Irrigated Pasture" crop class.

[10] Dryland is currently not a specific crop class available from IrriWatch; it describes lands farmed using only precipitation and no applied water. The dryland areas included in the Project are dryland wheat, and the Parcel-Field Count and Acreage were calculated using IrriWatch's parcel-fields that have a planted crop, but are not irrigated.

[11] There are other land uses/crop classes that make up the rest of the parcel-fields in the Madera County GSAs. These include cherries, figs, kiwis, olives, pasture, pomegranates, wheat, fallowed fields, and variety of other tree crops. The two largest crop classes that had no representation in the Project were irrigated wheat fields and fallowed fields, which comprise roughly 10,000 acres each (a total of approximately 17%) of the Madera County GSAs according to IrriWatch.

[12] Although crop type was field verified and is accurate for all lands participating in the 2022 Verification Project, there were some corrections required from the original crop shown in IrriWatch at the outset of the Project. For cropping in the overall Madera County GSAs, the coverage is generally representative but not expected to be completely accurate. Improving land use coverage is a recommendation resulting from the Project.

[13] Flowmeter data from January through June 2022 were also requested from participating growers and applied to the overall dataset, as available.

[14] The field data collection for the Project is described in more detail in Section 6.2.

[15] Permanent flowmeters are the grower-installed and maintained flowmeters attached to an irrigation pipeline downstream of the grower's groundwater well and pump.

In addition to the field data described above, additional data aggregated[16] for use in the Project included:

1. ET, ETAW, precipitation (P), and ET from P (ETPR) data from IrriWatch.
2. ET data from OpenET[17].
3. Reference ET (ETo) data from the Fresno State California Irrigation Management Information System (CIMIS) station.
4. A variety of other datasets to support the comparison between ETAW from IrriWatch and measured AGW volumes from permanent flowmeters.

A total of 97 permanent flowmeters were included in the Project, 74 (76%) of which were installed and maintained consistent with manufacturer specifications and 23 (24%) of which were not. In addition, 193 comparison flow measurements made with a portable transit time meter were completed to assess the accuracy of the permanent flowmeters. Of these, 146 measurements (76%) were on flowmeters that were installed and maintained per manufacturer specifications, and 47 measurements (24%) were on flowmeters that were not.

The mean absolute percentage error (MAPE) between the portable transit time meter and permanent flowmeters installed per manufacturer specifications was 7.7%, while the MAPE for flowmeters not installed per manufacturer specifications was 16%. These results illustrate the difference in accuracy for flowmeters installed and maintained per manufacturer specifications versus those that are not. Considering all comparison flow measurements in aggregate (regardless of flowmeter installation), the MAPE was less than 10%. These results (1) provide evidence that flowmeters can accurately quantify AGW and (2) illustrate that installing and maintaining them per manufacturer specifications substantially improves accuracy.

As detailed in subsequent sections of this report, a linear regression of ETAW as a function of AGW using data from 34 IUs without data quality issues indicates an overall average Consumptive Use Fraction (CUF)[18] of 0.84 (Figure ES-2). A CUF value less than one is expected for all IUs because not all AGW contributes to ETAW; rather, some AGW contributes to deep percolation and runoff[19] during the process of applying irrigation water (the CUF is influenced by a variety of

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[16] The aggregation of additional data for the Project is described in more detail in Section 6.3.1.
[17] OpenET is an alternative source of remotely-sensed ET data based on six different models. More information is available at: https://openetdata.org/ .
[18] CUF, or Consumptive Use Fraction, is the ratio of ETAW to AGW (with ETAW in the numerator and AGW in the denominator, as defined in Section 2.4 (Equation 1).
[19] Runoff, or tailwater, from AGW is assumed to be negligible for pressurized irrigation systems.

factors, including irrigation method[20]). 13 IUs have a CUF greater than one (*i.e.*, they plot above the dot-dashed red 1:1 line on (Figure ES-2). Notably, all six almond IUs have CUFs greater than one. CUFs greater than one are physically impossible if all applied water, precipitation, and changes in soil moisture are perfectly accounted for. Therefore, further investigation is needed to better understand why CUFs exceeding one were observed. Contributing factors causing unexpected CUF values could be some combination of: (1) error in the quantification of ETAW or AGW or both, (2) use of previously stored root-zone soil moisture by crops, or (3) a potential third source of water (above AGW and precipitation) available to crops (*i.e.*, water flowing into the root zone from shallow groundwater or nearby surface water features, such as ditches or ponds.).

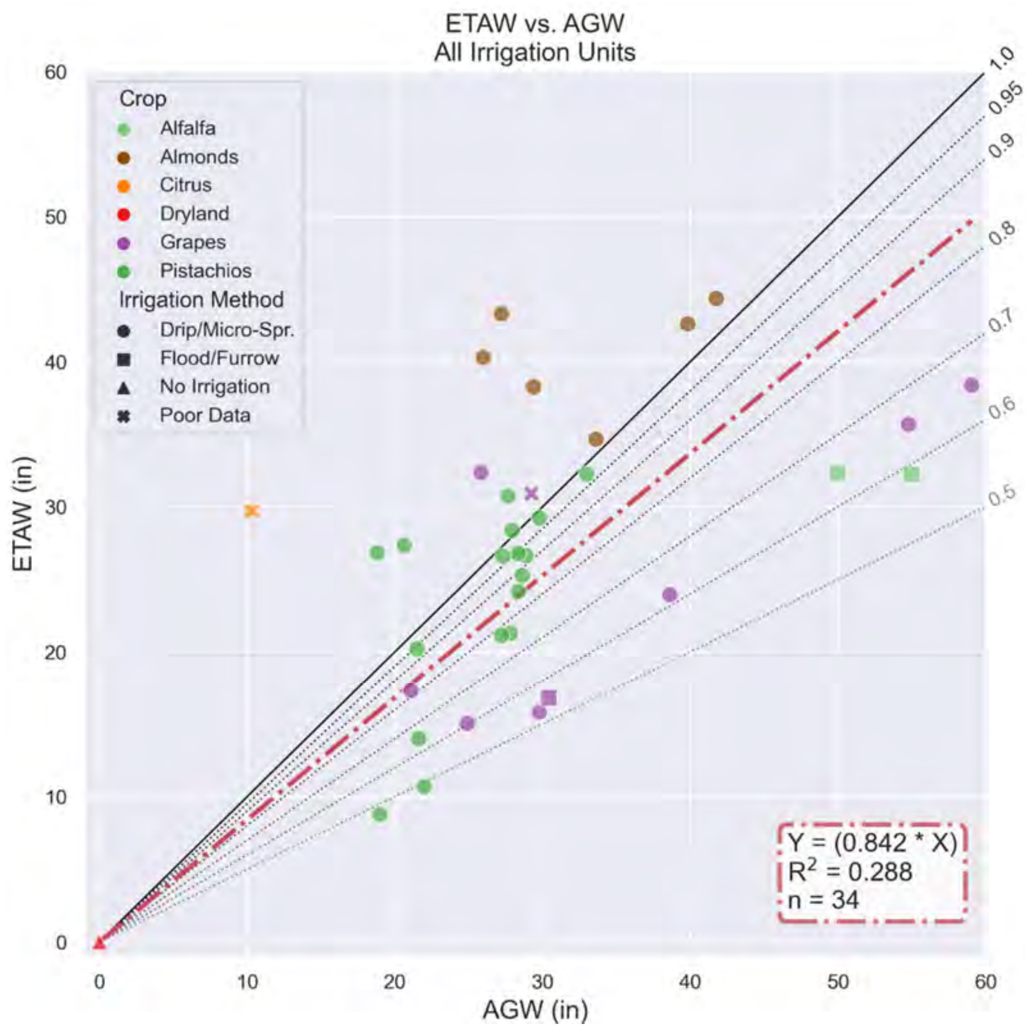


Figure ES-2. Summary of ETAW and AGW for 36 irrigation units (IUs) in the Project.

Note: The dashed red line is the overall regression line; IUs with flowmeter issues were not included in the regression calculation, so only 34 IUs were used. Lines representing a CUF of 1.0, 0.95, 0.9, 0.8, 0.7, 0.6, and 0.5 are shown on the graph as gray dotted lines. The primary crop within each IU is indicated by the color of

[20] Irrigation method plays a major role in on-farm water use efficiency, which translates into having a significant impact on CUF. All else being equal, lower efficiency irrigation methods, such as flood or furrow, would be expected to have lower CUFs than more precise irrigation methods, such as drip emitters or micro-sprinklers.

the symbol and the type of symbol indicates the irrigation method. The "X" symbol shown for two IUs indicates that the IU had flowmeter data quality issues that were either: (1) not corrected or (2) were corrected but with highly uncertain methods. The "X" is not indicative of irrigation method; both IUs that had flowmeter issues utilized pressured drip or micro-sprinkler irrigation systems.

Assuming that: (1) AGW measurements were perfectly accurate, (2) there were no unaccounted changes in soil moisture storage, and (3) no third water sources were available, the appreciable variability in individual IU CUFs observed in the Project, and the occurrence of CUFs exceeding one, would be attributed primarily to uncertainty in ETAW estimates for individual IUs. For successful implementation and enforcement of groundwater allocations, ETAW estimates need to be sufficiently accurate for each parcel-field and in aggregate for all parcel-fields comprising each IU for the purposes described below. There is no strict quantitative definition of what is "sufficiently accurate" in SGMA or otherwise; rather, this needs to be determined over time through collaboration between the GSAs and their growers.

In those subbasins where groundwater allocations are necessary, the methodology for tracking and enforcing allocations needs to be sufficiently accurate to: (1) assess the effectiveness of GSP implementation efforts towards groundwater sustainability and (2) fairly and equitably implement the GSAs' groundwater allocations (including carryover and penalties) for County growers individually and collectively. The 2022 Verification Project was a valuable review of the original methodology (*i.e.*, estimating ETAW using IrriWatch) chosen to enforce groundwater allocations, leading to the following conclusions and recommendations, which are framed around the original Project objectives.

OBJECTIVE 1: Increase grower engagement, education, and outreach related to SGMA implementation, particularly groundwater allocations, remote sensing of ETAW, and metering of AGW.

1. Due to the dynamic and quickly evolving process of GSP implementation and changing hydrologic conditions, regular grower engagement, education, and outreach is essential over the implementation horizon.
2. Spending time in the field with growers studying their operations and listening to their ideas and concerns is an essential part of developing trust and successfully implementing the projects and management actions set-forth in the GSP.
3. Strategic use of both large (group) and small (individual) meetings should be used for dissemination of information and stakeholder engagement.

OBJECTIVE 2: Evaluate flowmeter installations, maintenance, and accuracy based on site inspections and comparisons to independent on-site flow measurements.

1. Permanent flowmeters installed and maintained according to manufacturer specifications can accurately measure AGW.
2. A system should be developed and implemented for periodic inspection of permanent flowmeters used to track AGW for purposes of allocation management to ensure they

are installed correctly, maintained correctly, and measuring accurately (described further and expanded upon under Objective 3 below).

OBJECTIVE 3: Develop and test procedures for collecting, quality controlling, and using totalizing flowmeter readings to quantify volumes of AGW.

1. Collecting and quality controlling permanent flowmeter data to quantify AGW requires substantial effort and additional procedures beyond simply verifying flowmeter accuracy, correct installation, and proper maintenance. Among others, these additional procedures include identification of well/flowmeter locations, establishing linkage between wells/flowmeters and irrigated lands, establishing a workflow for field data collection, reviewing and quality controlling AGW data, estimating AGW volumes when flowmeters malfunction or fail, and assembling and reporting AGW results to growers frequently enough to support timely, adaptive management throughout the irrigation season.
2. As part of the Project, a smartphone based mobile data collection platform that growers and County staff and consultants can collectively use to enter data collected in the field was developed. Additionally, a portal that the County can use to view and quality control the data from a single shared location was created. The GSAs should continue the use and development of these system in support of the 2023 allocation and beyond.

OBJECTIVE 4: Evaluate methods for collecting and/or developing required input data and associated computations for remote sensing of ETAW with IrriWatch.

1. The preliminary analyses and results of this Project led to important refinements in the methodology and assumptions that IrriWatch used to quantify ETAW during 2022[21]. These included adjustments influencing ETAW on parcel-fields with sparse vegetative cover and setting ETAW equal to zero for fallowed parcel-fields. Further evaluation of remote sensing input data and ETAW accuracy is needed for ongoing assessment of the reliability of IrriWatch.
2. Additional procedures should be developed to: (1) verify fallow fields (*i.e.*, fields with no applied water) in consultation with growers each year, (2) categorically set ETAW to zero for verified fallow fields, and (3) use fallowed fields as validation points for the calculation of ETAW by IrriWatch.
3. An improved and locally-refined spatial precipitation product using ground-based precipitation observations within the Madera County GSAs should be developed to improve estimates of precipitation (P) and ET of precipitation (ETPR) at the parcel-field scale.

[21] See Section 6.4.4 for more information about the 2022 IrriWatch adjustments.

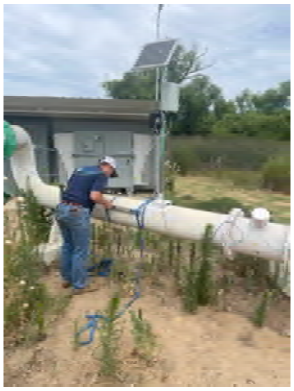
OBJECTIVE 5: Develop and implement improvements to the processes for quantifying AGW and ETAW volumes.

1. With the large volume of data generated during the Project (and with more data recommended), substantial support staff and robust automated or semi-automated procedures is recommended to support successful implementation of continued data collection, management, quality control, and dissemination in the Madera County GSAs.
2. Growers in the Madera County GSAs should have the discretion to choose the method of quantifying ETAW that is best suited to their operations and field conditions in each farm unit. Optional methods include direct use of ETAW estimates from IrriWatch, or calculating ETAW based on AGW volumes measured with properly installed, maintained, and sufficiently accurate permanent flowmeters multiplied by appropriate CUFs (yet to be established).
3. A semi-automated or automated process should be developed to generate monthly grower reports and carryover and penalty reports regardless of the source of ETAW data (*e.g.,* remote sensing, flowmeters, etc.). An online portal providing grower access to allocation reports should be developed.

OBJECTIVE 6: Compare and analyze AGW to remotely sensed ETAW data provided by IrriWatch.

1. Although the overall average ETAW, AGW, and CUF values for participating IUs in the Project are reasonable, there is substantial variability in these values among crops and IUs. At the IU scale, there were unexplainable variations in ETAW without commensurate variation in AGW.
2. To ensure successful implementation and enforcement of the GSA allocations, systematic verification efforts should continue in 2023 and beyond. Verification should include comparisons between AGW and ETAW and also ground based ET and ETAW methods (*e.g.,* eddy-covariance and soil water balances). In order to facilitate these comparisons, ETAW should be computed with remote sensing even if growers elect to use flowmeters for allocation tracking on a subset of parcel-fields.

The Conclusions and Recommendations section includes a full description and explanation of all conclusions and recommendations resulting from the Project.



1 Introduction

1.1 2022 Madera Verification Project Location

Madera County (County) has significant and indisputable ties to agriculture. In 2021, nearly 352,000 acres were farmed within the County (excluding rangeland) with a total estimated value of over $2 billion (Madera County Department of Agriculture, 2022). Many of these farming operations, particularly those in the Madera County Groundwater Sustainability Agencies (GSAs)[22], rely on groundwater as their sole source of water for irrigation. Due to the economic impact and importance of agriculture to the community and to comply with the Sustainable Groundwater Management Act (SGMA), it is important that sustainable groundwater resource management is achieved and maintained into the future.

Madera County is located near the geographic center of California. The eastern portion of the county includes the high elevation Sierra Nevada Range, while the western portion of the county is on the San Joaquin Valley floor. The western portion of the County is where nearly all of the agricultural production occurs and includes lands in three San Joaquin Valley groundwater subbasins: Chowchilla, Delta-Mendota, and Madera. The 2022 Madera Verification Project exclusively focused on the portion of Madera County within the groundwater subbasins in the San Joaquin Valley. The borders of Madera County in the San Joaquin Valley are defined by waterways: the northern boundary is marked by the Chowchilla River, and the southern and western boundaries of Madera County are formed by the San Joaquin River as it flows westward out of the Sierra Nevada and then north towards the Sacramento San Joaquin River Delta. Madera County is bordered by Merced and Mariposa Counties to the north, Mono County to the east, and Fresno County to south and west. The primary urban centers within the County include the Cities of Madera and Chowchilla.

The 2022 Madera Verification Project (Project) took place in the Madera County GSAs in the Madera and Chowchilla Subbasins[23] (Figure 1-1). The Madera County GSAs incorporate all white areas within the Subbasins (*i.e.*, all areas not already under the jurisdiction of another local agency, such as a city or water district, that has formed its own GSA). The Madera County GSAs are further divided into six Farm Unit Zones (FUZs). The FUZs are used to delineate areas within which growers (either owners or managers) can consolidate their groundwater allocations. The six FUZs in the Madera County GSAs are: Madera Subbasin East – Northern, Madera Subbasin East – Southern, Madera Subbasin West, Chowchilla Subbasin East, Chowchilla Subbasin West, and Delta-Mendota Subbasin. Outreach to potential participants targeted growers in each of the GSAs and FUZs in order to encourage broad participation and develop Project results for a representative sample across the Madera County GSAs.

[22] The Madera County GSAs are the three GSAs managed by Madera County in the Chowchilla, Delta-Mendota, and Madera Subbasins.
[23] Lands in the Madera County GSA in the Delta-Mendota Subbasin were also eligible, but no growers who met the required criteria for Project participation expressed interest in participating.

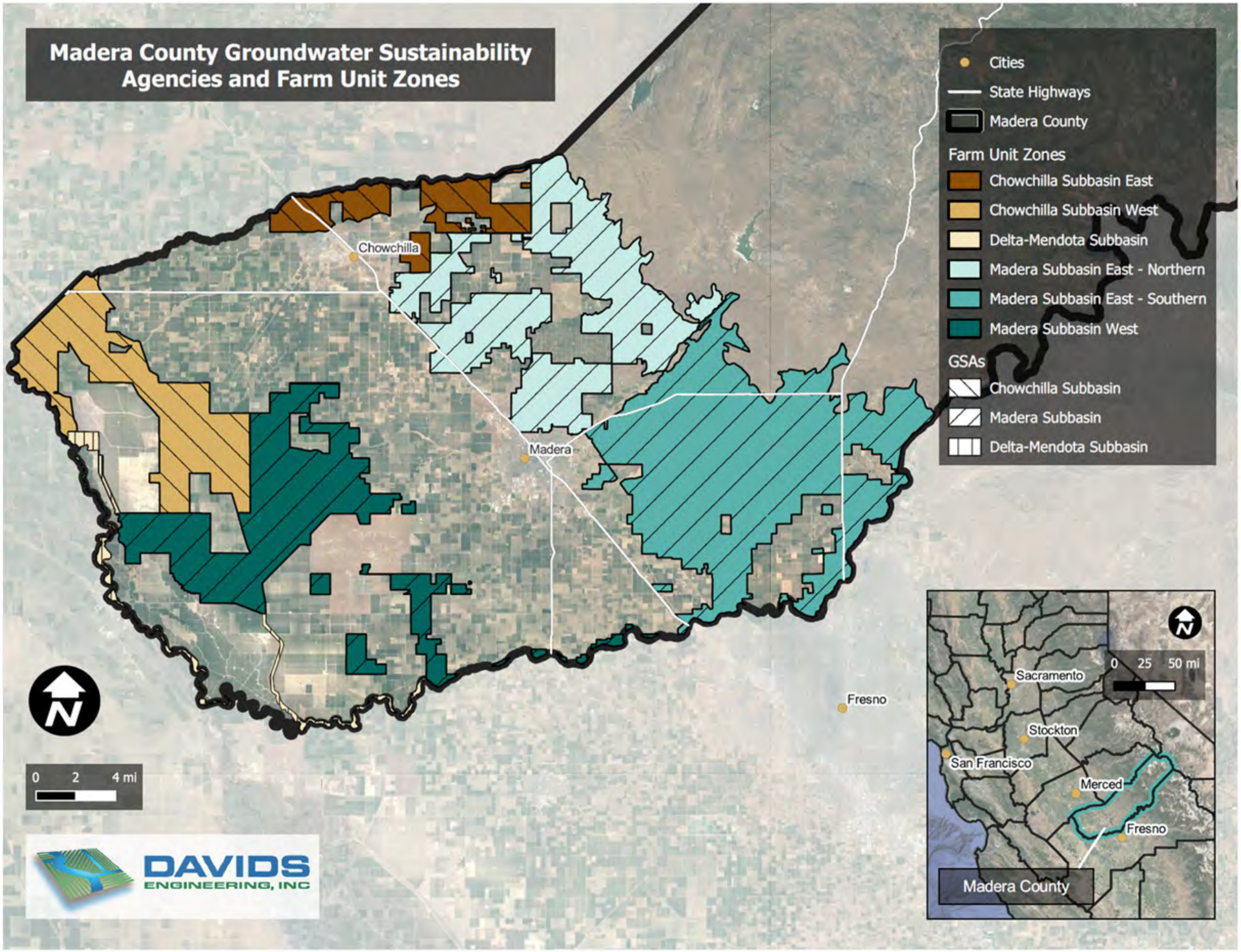


Figure 1-1. Overview of Madera County Groundwater Sustainability Agencies and Farm Unit Zones.

1.2 Overview of Sustainable Groundwater Management Act (SGMA), Madera County Groundwater Sustainability Plans (GSPs), and 2022 Madera Verification Project

1.2.1 Overview of SGMA and GSPs

In 2014, the State of California passed the Sustainable Groundwater Management Act (SGMA)[24] with the goal of curbing ongoing overdraft and degradation of groundwater resources in many of California's groundwater basins. Under SGMA, if designated by the California Department of Water Resources (DWR) as medium or high priority, the groundwater basin is required to comply with SGMA. Following a medium or high priority designation, SGMA required one or more local governing bodies in each groundwater basin or subbasin to form one or more groundwater sustainability agencies (GSAs); the GSA(s) were then to develop and implement one or more Groundwater Sustainability Plans (GSPs) to achieve sustainability. All of the subbasins in Madera County (Chowchilla, Delta-Mendota, and Madera) were designated as high priority subbasins and critically overdrafted (COD) by DWR. The GSPs for these subbasins were all developed and submitted to DWR by the deadline of January 31, 2020. The implementation period for the GSPs is a 20-year period from 2020 through 2040 with the subbasins required to be fully sustainable by 2040. Sustainability of groundwater is defined by SGMA as "the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from a groundwater supply without causing an undesirable result" (CWC Section 10721(w)).

More information about the GSAs and GSPs within the Madera County subbasins of Chowchilla, Delta-Mendota, and Madera can be found in Section 6.3.4.

1.2.2 GSP Implementation Impacts on Groundwater Pumping (Demand Management)

The GSPs include a suite of Projects and Management Actions (PMAs) that will be implemented in order to achieve sustainability in each of the subbasins. These include both projects to increase groundwater recharge and projects and management actions to reduce evapotranspiration (*i.e.,* consumption[25]) of applied groundwater (AGW). Since the projects outlined by the GSPs to increase recharge (*e.g.*, the Madera County Chowchilla Bypass Flood Water Recharge Basins) are not estimated to have the capability to reach groundwater sustainability on their own, reducing the consumptive use of groundwater is a critical component of GSP implementation to achieve sustainability.

Due to the limited availability of surface water for irrigation within the Madera County GSAs, irrigated agriculture (the primary water demand in the GSAs) has historically been dependent solely on groundwater. In order to achieve sustainability in these areas, demand management is an important component of GSP implementation. Demand management is a coordinated approach to reducing consumptive use of groundwater throughout the GSAs in order to reach sustainability targets and achieve sustainability by 2040, as outlined in the Madera Joint GSP and other GSPs. It will be implemented and enforced through a groundwater allocation for each grower that defines the amount of water they can consumptively use based on their irrigated acreage. To achieve sustainability goals and enforce the groundwater allocation, it is necessary to define where water use will be quantified on-farm and to have a methodology in place to monitor the amount of water being used by each grower.

[24] Additional information about SGMA can be found online at: https://water.ca.gov/programs/groundwater-management/sgma-groundwater-management.

[25] The terms "consumptive use" and "evapotranspiration" are used interchangeably throughout this report.

Due to this need, the Madera County GSAs defined the quantification point as evapotranspiration (ET) of applied water (ETAW) from irrigated lands (*i.e.*, consumptive use of applied water as it evaporates and transpires from irrigated lands and crops, returning to the atmosphere)[26]. Actual ET (ETa) can be quantified using satellite-based remote-sensing methodologies, and ETAW can be calculated by subtracting the portion of ETa supported by precipitation (ETPR) from ETa. In late 2020, and through extensive public vetting by an independent advisory group, the GSAs selected a company called IrriWatch to monitor and quantify ETAW for all lands within the GSAs. IrriWatch is described in more detail below in Section 1.2.2.1.

1.2.2.1 Overview of IrriWatch

Among the reasons for selecting IrriWatch were that it offered a direct estimate of ETAW (rather than actual ET, or ETa), provided results on a near real-time basis (generally one day of latency), and included an already developed online data portal providing growers and Madera County staff access to their data whenever needed or beneficial.

IrriWatch is a platform which utilizes remote sensing data, and associated assumptions and methodologies, to estimate evapotranspiration of applied water (ETAW), or the consumptive use of applied water. The IrriWatch platform uses remote sensing methods based on the Surface Energy Balance Algorithm for Land (SEBAL) that have been developed and extensively tested and validated over the past 20 years. More information about IrriWatch is available at: https://irriwatch.com.

1.2.3 Summary of Allocations for Madera County GSAs

On December 15, 2020, the Madera County Board of Supervisors adopted Resolution 2020-166 describing the groundwater allocation approach to be used for GSP implementation in the GSAs. Irrigated lands in the GSAs are solely dependent on groundwater. The resolution describes two designations of groundwater: (1) sustainable yield of native groundwater and (2) transitional water that is continued overdraft of the Chowchilla and Madera subbasins that will incrementally decline over the GSP implementation period (2020 through 2040). Importantly, the adopted allocation approach is based on the quantity of groundwater consumed not pumped. This distinction recognizes that the consumption of groundwater causes subbasin depletion (and therefore affects sustainability) while groundwater that is pumped but not consumed returns to the groundwater system (as deep percolation) and does not cause depletion[27]. Further, recognizing that crops consume precipitation (P) as well as applied groundwater (AGW) stored in the root zone, it is important for purposes of groundwater allocation and accounting to distinguish between crop ET of P (ETPR) and crop ET of applied water (ETAW). Thus, ETAW was adopted as the quantitative accounting metric at the parcel scale against groundwater allocations in the GSAs. This approach formed the basis for the data collection and analysis documented in this report.

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[26] Among the reasons for selecting to quantify ETAW rather than directly measuring groundwater pumping volumes was a desire to avoid the complexity and labor-intensive process required to (1) directly measure and record groundwater pumping at every agricultural production well in the Madera County GSAs, and (2) convert this to an equivalent volume of ETAW (or the portion actually consumed and no longer available in the subbasin).

[27] Because pressurized drip and micro-sprinkler on-farm irrigation systems are dominant in the three Madera County GSAs, the assumption was made that there is negligible surface runoff from the GSAs that could cause groundwater depletion.

The groundwater allocations within the GSAs vary by subbasin and by year. In alignment with the Madera Joint GSP (and other GSPs), groundwater allocations were to be phased-in as of 2020 and to continue through 2040, the end of GSP implementation. From 2020 through 2025, groundwater extractions will be reduced by 2% per year to reach a total reduction of 10%[28]. Beginning in 2026, groundwater extraction will be further reduced by 6% per year through 2040. As an example, for the Madera Subbasin, out of the 545,200 acre-feet of current annual groundwater extractions, these reductions will decrease groundwater extractions by an estimated 90,000 acre-feet (AF) per year by 2040. This reduction is the largest anticipated volume change resulting from a PMA in the Madera Subbasin as a whole, making it a critical part of the Subbasin reaching its sustainability goals by 2040.

At the farm and field level, allocations will be implemented by the GSAs as a defined number of inches of ETAW over a respective acreage per year (allowing for calculation of a total volume in AF to monitor implementation against the GSP implementation goals and sustainability targets). Allocations are comprised of both sustainable yield and transitional water (Figure 1-2). Sustainable yield is based on the legal parcel acreage as determined by the Madera County Assessor's Office. Transitional water is based on the number of irrigated acres, and concentrated animal feeding operation (CAFO) acres, if present. Table 1-1 shows groundwater allocations for 2021 to 2025 for the subbasins in Madera County. The allocation has the potential to be enforced by the GSAs and Madera County through penalties applied based on the quantified volume above the defined allocation that a grower uses (*i.e.*, $ / AF in exceedance of allocation).

Table 1-1. Madera County GSA Groundwater Allocations (Madera County GSA Resolution No. 2021-069). These allocation values assume that the sum of irrigated acres and concentrated animal feeding operations equals at least 80% of the parcel resulting in the parcel receiving transitional water based on its full assessed acreage. See Figure 1-2 for additional details regarding allocation logic.

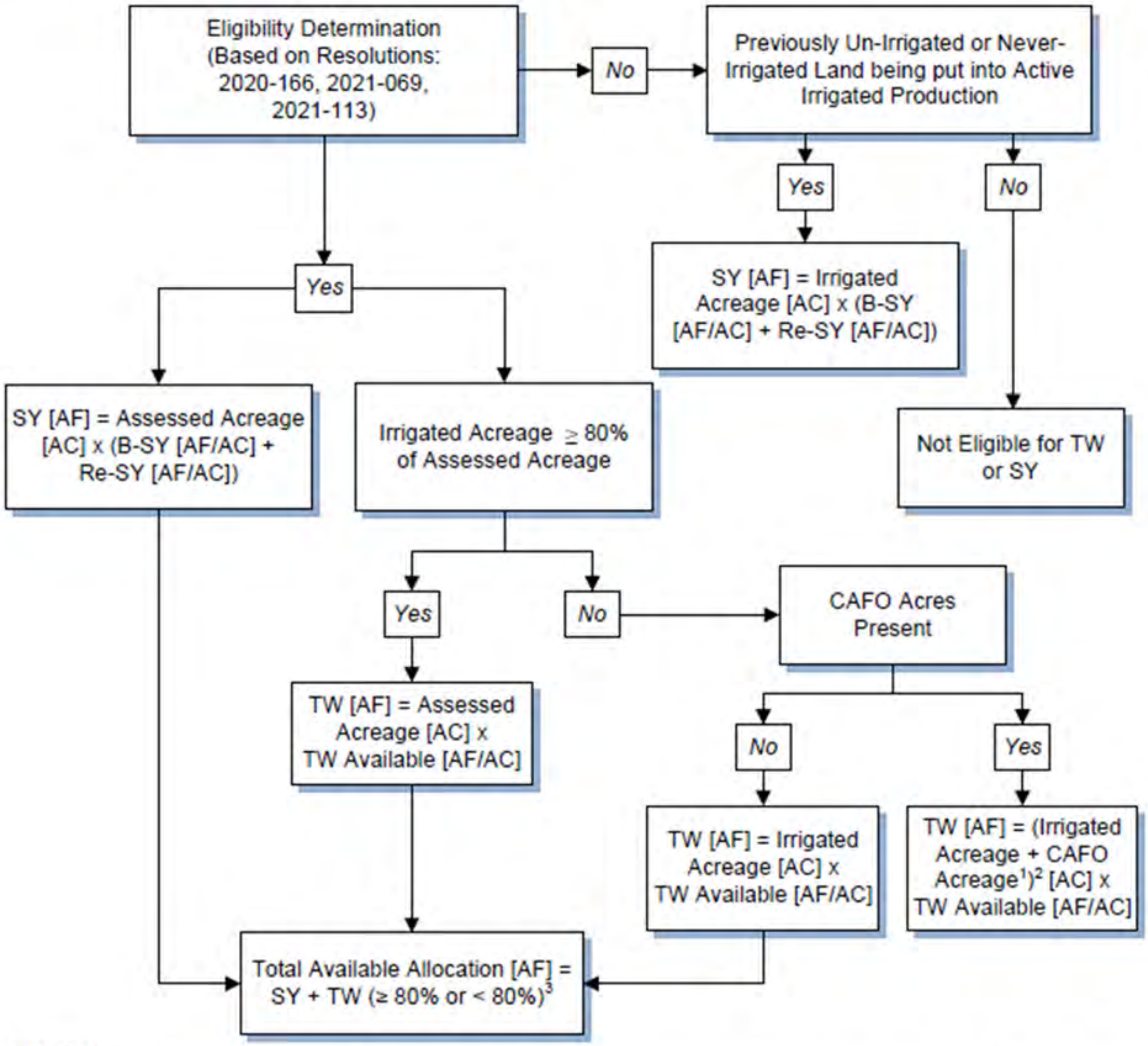
Year	Groundwater Allocation in Inches of ETAW per Year		
	Chowchilla Subbasin (in/year)	Delta-Mendota Subbasin (in/year)	Madera Subbasin (in/year)
2021	26.7	19.8	28.3
2022	26.3	19.6	28.0
2023	25.9	19.3	27.7
2024	25.5	19.1	27.4
2025	25.1	18.9	27.1

[28] Percentages are calculated relative to the current total groundwater extraction of the agricultural community at the time of GSP development and as defined in the Madera Joint GSP.

Madera County Groundwater Allocation Logic

MADERA COUNTY

- The following logic diagram is based on relevant Madera County resolutions (i.e., 2020-166, 2021-069, 2021-113) available at: https://www.maderacountywater.com/allocations/
- Assessed and Irrigated acreage based on records from the Madera County Assessor's Office. Contact the Madera County Assessor's Office at (559) 675-7710 or assessor@maderacounty.com for information.



Footnotes:

[1] CAFO Acreage is from the State Water Resources Control Board and may not match Madera County Assessor's Office records.

[2] Total of Irrigated Acreage and CAFO Acreage is not to exceed the total Assessed Acreage of the parcel.

[3] Total available allocation is the sum of sustainable yield (SY), both base (B-SY) and re-allocated (Re-SY), and transitional water (TW).

List of Abbreviations:

AC = Acres
AF = Acre-Feet
AF/AC = Acre-Feet per Acre
B-SY = Base Sustainable Yield
CAFO = Concentrated Animal Feeding Operations
Re-SY = Re-allocated Sustainable Yield
SY = Sustainable Yield
TW = Transitional Water

Figure 1-2. Madera County groundwater allocation logic flowchart based on resolutions 2020-166, 2021-069, and 2021-113.

1.3 2022 Madera Verification Project (Project) Background, Objectives, and Report Outline

1.3.1 2022 Project Background

After being selected for use in the GSAs in late 2020, the 2021 and 2022 calendar years were used to develop the necessary input files for IrriWatch, initiate data collection, and introduce the IrriWatch platform and data to growers in the GSAs. This provided a test period for growers to compare ETAW data from IrriWatch against their groundwater allocations prior to the implementation and enforcement of allocations through penalties. During these years, IrriWatch calculated and provided ETAW for all agricultural fields in the GSAs, and growers had access to IrriWatch data via the online portal for review. Based on their review during the 2021 calendar year, numerous growers within the GSAs communicated to Madera County the need for a more thorough review and verification of ETAW from IrriWatch before its full implementation (including penalties) for groundwater allocations. Madera County chose to implement the 2022 Verification Project (Project) in response to grower feedback, in an effort to continue to refine, adapt, and implement remote sensing technology, and to ensure the best available information is being used to quantify ETAW in support of the implementation of groundwater allocations. The Project included grower outreach and collaboration, in-field data collection, development of data acquisition and management methods, a comparison of ETAW from IrriWatch and AGW data collected in the field, and more. The Project objectives and an outline of this report are provided subsequently.

1.3.2 2022 Project Objectives

The Project was a collaborative effort undertaken by Madera County within the Madera County GSAs (in partnership with local growers and including extensive in-field data collection) with the following overall objectives:

1. Increase grower engagement, education, and outreach related to SGMA implementation, particularly groundwater allocations, remote sensing of ETAW, and metering of AGW.
2. Evaluate flowmeter installations, maintenance, and accuracy with site inspections and comparisons to independent on-site flow measurements.
3. Develop and test processes for collecting, quality controlling, and using totalizing flowmeter readings to quantify volumes of AGW.
4. Evaluate methods for collecting and/or developing required input data and associated computations for remote sensing of ETAW with IrriWatch.
5. Develop and implement improvements to the processes for quantifying AGW and ETAW volumes.
6. Compare and analyze AGW to remotely sensed ETAW data provided by IrriWatch.

The Project required voluntary partnerships with growers and landowners within the GSAs during the 2022 calendar year (focused primarily on the irrigation season) to collect and assemble these in-field data for evaluation and comparison. The sections described below include the content necessary to document our findings with respect to the objectives above.

1.3.3 Project Report Outline

The following is an outline of this Project report:

Introduction (Section 1) - provides an overview of the project location and SGMA (including information on GSAs and GSP development and implementation in Madera County) in order to provide greater context around the 2022 Verification Project, along with listing the Project objectives.

Methods (Section 2) - The Methods section describes the methodologies utilized to pursue and accomplish the Objectives. This includes solicitation of interest from growers and selection of participating growers/lands, collection and management of in-field data, and collection of additional data.

Results and Discussion (Section 3) - The Results and Discussion section presents data collection results, including analysis of collected in-field data, IrriWatch data, and additional data (along with a description of various data issues) and explores and evaluates the results of the Project.

Conclusions and Recommendations (Section 4) - Lastly, the report ends with a series of that stem from this work. Conclusions and Recommendations are meant to identify next steps beyond the Project to help Madera County, the GSAs, and growers within the GSAs continue forward with GSP implementation on the path towards groundwater sustainability using methods and practices agreeable to all parties and in a locally cost-effective manner.

Section 5 provides a list of references while Section 6 includes Technical Appendices containing additional information and detail about the Project, the methodologies used, and the results obtained. References to relevant sections of the Technical Appendices are included throughout the report

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2 Methods

2.1 Grower Participation and Coordination (Objective 1)

Solicitation of grower interest for participation in the Project was completed during Spring 2022 through both routine and special meetings, including a grower workshop on April 25th, 2022[29]. Although a larger number of growers expressed interest, 16 growers who met the requirements and submitted the necessary information were selected for participation in the Project. These growers farmed 36 irrigation units (IUs)[30] comprising nearly 12,000 acres. The crops and associated acreages in the Project are presented below in comparison to the overall cropping and acreages in the Madera County GSAs indicating that Project lands represent roughly 10% of total farmed land in the GSAs (Table 2-1). Project lands included seven different crops distributed relatively evenly among five Farm Unit Zones (FUZs)[31] within the Madera County GSAs (Figure 2-1).

Table 2-1. Cropping Summary for the 2022 Madera Verification Project and the Madera County GSAs.

Crop	2022 Madera Verification Project			Madera County GSAs		
	Parcel-Field[32] Count	Area (Acres)	Area (%)	Parcel-Field Count	Area (Acres)	Area (%)
Alfalfa[33]	4	174	1.5%	184	6,580	5.4%
Almonds	16	1,053	9.0%	1,606	43,059	35.4%
Citrus	4	48	0.4%	59	1,327	1.1%
Dryland[34]	21	862	7.4%	133	3,963	3.3%
Grapes	74	4,785	40.8%	512	14,625	12.0%
Pistachios	85	4,827	40.6%	1,000	22,204	18.2%
Walnuts	1	42	0.4%	26	653	0.5%
Other[35]	0	0	0.0%	1,782	29,261	24.1%
Totals	**203**	**11,791**	**100%**	**5,302**	**121,672**	**100%**

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[29] More information about the solicitation of interest and initial grower workshop can be found in Section 6.1.1.
[30] An irrigation unit is an aggregation of parcels or parcel-fields that are owned, managed, and/or irrigated by the same grower and same well(s). These are typically contiguous lands. See Figure 2-2 for more information.
[31] Farm Unit Zones are the geographic areas defining the bounds within which a Farm Unit (*i.e.*, cropped lands owned and/or managed by one entity) is able to aggregate and manage its groundwater allocation.
[32] A parcel-field is the union of legal parcel boundaries from the Madera County Assessor's Office and 2018 California statewide irrigated and urban lands coverage, from the California Department of Water Resources (DWR). See Figure 2-2 for more information.
[33] Alfalfa is currently not a specific crop class available from IrriWatch. The Madera County GSAs Parcel-Field Count and Acreage were calculated using IrriWatch's "Irrigated Pasture" crop class.
[34] Dryland is currently not a specific crop class available from IrriWatch; it describes lands farmed using only precipitation and no applied water. The dryland areas included in the Project are dryland wheat; the Parcel-Field Count and Acreage were calculated using IrriWatch's parcel-fields that have a planted crop, but are not irrigated.
[35] There are other land uses/crop classes that make up the rest of the parcel-fields in the Madera County GSAs. These include cherries, figs, kiwis, olives, pasture, pomegranates, wheat, fallowed fields, and variety of other tree crops. The two largest crop classes that had no representation in the Project were irrigated wheat fields and fallowed fields, which comprise roughly 10,000 acres each (a total of approximately 17%) of the Madera County GSAs according to IrriWatch.

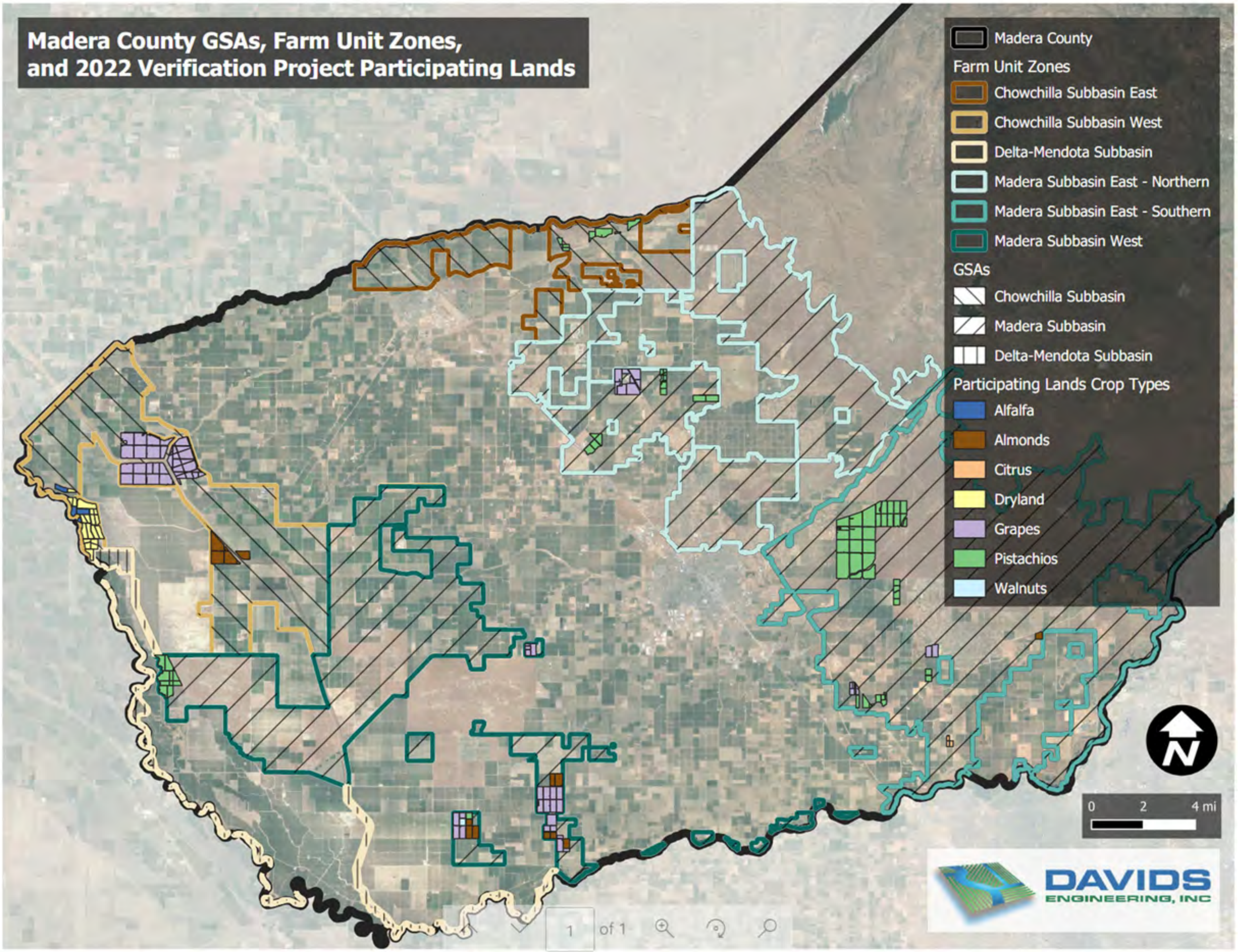


Figure 2-1. Madera County GSAs, Farm Unit Zones, and Project Participating Lands.

The three primary crops grown within the Madera County GSAs (*i.e.*, Almonds, Grapes, and Pistachios) were the three most common crops included in the Project, thus providing a crop composition generally representative of the GSAs as a whole[36]. The Project lands included seven different crops distributed relatively evenly among five FUZs[37] within the Madera GSAs.

Initial meetings with participating growers were conducted individually in June 2022 to discuss the Project and its objectives, and to review potential participating lands and define irrigation units, or IUs (*i.e.*, establish the connection between GW wells and lands where pumped water is applied for irrigation)[38]. Figure 2-2 visually depicts and describes the differences between Parcels/APNs, Fields, Parcel-Fields, and IUs through use of a hypothetical example[39].

Towards the end of the monitoring period in December, individual meetings with participating growers were held again to review and discuss Project objectives, preliminary results for growers and for the Project as a whole, and conclusions and recommendations resulting from the Project[40]. A final grower workshop was scheduled for January 25, 2023 to review and solicit feedback on final project results, answer questions, and discuss conclusions and recommendations and upcoming plans for 2023[41]; however, it was canceled at the last minute. In addition to grower meetings and workshops, feedback from participating growers was solicited on the Project in January 2023. The final report for the project was finalized in February 2023 following the date of the final grower workshop.

2.2 Flowmeter Evaluations and Flowmeter Data Management (Objectives 2 and 3)

Following the initial meetings with growers in June 2022, extensive field data collection began and continued through December 2022[42]. Field data collection included readings of instantaneous flow and totalized volume from permanently installed (grower) flowmeters[43], additional Project flow measurements made with a portable transit time flowmeter (*i.e.*, Fuji Electric Portaflow-C FSC-4 Ultrasonic Flowmeter) for comparison to permanent flowmeters, evaluation of permanent flowmeter installations for consistency with manufacturer specifications, review of permanent flowmeter

[36] Although crop type was field verified and is accurate for all lands participating in the 2022 Verification Project, there were some corrections required from the original crop shown in IrriWatch at the outset of the Project. For cropping in the overall Madera County GSAs, the coverage is generally representative but not expected to be completely accurate. Improving land use coverage is a recommendation resulting from the Project.
[37] Farm Unit Zones (FUZs) are the geographic areas defining the bounds within which a Farm Unit (*i.e.*, cropped lands owned and/or managed by one entity) is able to aggregate and manage its groundwater allocation. These are described in Section 1.1.
[38] More information about the initial grower meetings and selection of participating lands can be found in Section 6.1.2.
[39] Although Figure 2-2 shows multiple Fields and Parcel-Fields and one IU within a single Parcel/APN, reality is more complex. There are also instances where a Field and/or IU stretch across multiple Parcels/APNs and where multiple Parcels/APNs are included in one field.
[40] More information about the final grower meetings can be found in Section 6.1.4.
[41] More information about the final grower workshop can be found in Section 6.1.5.
[42] More information about the field data collection can be found in Section 6.2.
[43] Flowmeter data from January through June 2022 were also requested from participating growers and applied to the overall dataset, as available.

1

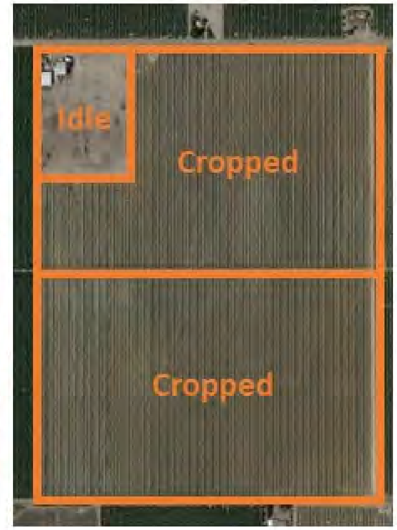
Parcel/APN – legal property boundaries developed and maintained by the Madera County Assessor's office. *"123-456-789"*

Two Parcels/APNs are depicted to left; subsequent images focus on eastern Parcel/APN.

2

Field – 2018 statewide coverage of irrigated lands developed by California Department of Water Resources. *"12345"*

Three Fields are depicted to the right; two are cropped and one is idle or unplanted and not irrigated.



3

Parcel-Field – The union of Parcels/APNs and Fields. Parcel-Field ID is a combination of the Parcel/APN and Field IDs. *"123456789_12345"*

Three Parcel-Fields are depicted to the left. The one parcel shown has three separate fields delineated on it; two are cropped and one is idle and not irrigated.

4

Irrigation Supply Wells (supplying a shared irrigation system for the two cropped parcel-fields)

Irrigation Unit (IU) – one or more Parcel-Fields receiving all of the irrigation water pumped from one or more groundwater wells.

One IU comprised of two wells and two cropped parcel-fields is shown to the right.

Figure 2-2. Example of Parcel/APN, Field, Parcel-Field, and Irrigation Unit (IU) delineations, including both visual depiction and descriptions.

maintenance, and observations of in-field conditions. This required close coordination with participating growers[44].

2.3 Remote Sensing of ETAW from IrriWatch and Data Management (Objective 4)

Daily ET, precipitation (P), ET from P (or ETPR), and ETAW data were developed by IrriWatch at a 10m x 10m pixel level and subsequently aggregated to average values per parcel-field. IrriWatch data were retrieved via the IrriWatch Application Programming Interface (API). Additionally, the following datasets were also used for comparison purposes: ET data available through OpenET[45] and the Fresno State CIMIS station[46]; and various other datasets used to provide additional information and context supporting comparisons to ET and ETAW from IrriWatch and between ETAW from IrriWatch and measured AGW from permanent flowmeters[47].

IrriWatch computes actual ET (ETa) with the Surface Energy Balance Algorithm for Land (SEBAL). ETa includes both ET from precipitation (ETPR) and ET from applied water (ETAW). Because the GSAs elected to use ETAW as the basis of measurement against groundwater allocations, IrriWatch computes ETAW as the difference between ETa and ETPR (Equation 1).

IrriWatch computes ETPR using precipitation data from the National Oceanic and Atmospheric Association (NOAA)[48] together with a pixel-scale implementation of the California Department of Water Resources (DWR) integrated Water Flow Model Demand Calculator (IDC) daily rootzone water budget model.

$$\boldsymbol{Evapotranspiration\ of\ Applied\ Water\ (ETAW) = ETa - ETPR} \quad \textbf{(Equation 1.)}$$

Among other parameters, IrriWatch reports ETa, ETAW, transpiration (T), and 10-day precipitation (P) as outputs from their API. These parameters are provided on a daily timestep and spatially aggregated to the parcel-field level. ETPR was back calculated from ETa and ETAW using Equation 1, and evaporation (E) was calculated by subtracting transpiration (T) from ETa.

2.4 Comparison of ETAW and AGW (Objectives 5 and 6)

The ratio of ETAW as quantified by IrriWatch to AGW as measured by permanent flowmeters defines the consumptive use fraction (CUF) as shown in Equation 2. Although circumstances and results will vary due to soil type, crop type, crop age, on-farm practices, geographic location, and other factors, CUF values are generally less than one, since not all water applied to a field is consumptively used. As ETAW approaches AGW, CUF approaches one, indicating perfectly efficient application of water. CUFs greater than one are physically impossible without a depletion of moisture stored within the rootzone.

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[44] More information about coordination with participating growers during the monitoring period can be found in Section 6.1.3.

[45] OpenET is an alternative source of remotely-sensed ET data. More information is available at: https://openetdata.org/

[46] The Fresno State CIMIS Station is No. 80. More information about it specifically and CIMIS stations generally is available at: https://cimis.water.ca.gov/stations.aspx

[47] More information about IrriWatch data aggregation and the additional datasets utilized for the Project can be found in Section 6.3.

[48] Additional information about the NOAA precipitation dataset that IrriWatch uses can be found here: https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.ncdc:C00313 .

$$\textit{Consumptive Use Fraction}\ (CUF) = \frac{ETAW}{AGW}\ \textit{(Equation 2.)}$$

The CUF is the key metric used to facilitate the comparison of ETAW and AGW and evaluate results in Section 3.4 both within crop categories, between crop categories, and across all crops for entirety of the lands included in the Project.

To evaluate ETAW, AGW, and the resulting CUF, DE staff developed Python codes to process and organize data in a variety of different ways. Data relating to AGW and flowmeters were organized into flowmeter reports for each flowmeter included in the Project (Section 6.5.3), and data for each irrigation unit were organized into an irrigation unit report that includes all ETAW and AGW data (and the resulting CUF) for the irrigation unit (Section 6.5.2). Additionally, project results were aggregated for all Project lands to better understand overall Project results and to inform conclusions and recommendations resulting from the Project.

3 Results and Discussion

3.1 Grower Participation and Coordination (Objective 1)

16 growers participated in the Project. There were a greater number of potentially interested growers initially in Spring 2022, and a greater number of growers initially submitted the necessary information to participate in the Project. Some growers, however, were disqualified from participation due to not farming irrigation units exclusively within the Madera County GSAs, or due to not having flowmeters installed on all active irrigation wells upon initiation of the Project.

Grower outreach, engagement, and participation activities completed as part of the Project are summarized in Section 6.1. In particular, grower feedback concerning the Project was solicited and obtained through the final grower meetings and solicitation of grower feedback on the Project, as described below.

The final individual grower meetings in December 2022 included review and discussion of Project results, and more broadly, discussion of SGMA activities and GSP implementation overall. The grower meetings, including a summary of key points emerging from the collective grower meetings, are described in Section 6.1.4. Key points discussed and communicated by the growers during the final meetings include:

1. Growers communicated an appreciation for outreach, communication, and engagement on an individual level or in smaller, more focused group settings, as opposed to large public meetings with a greater number of participants.
2. With the initial penalties for 2023 starting at $100/AF and increasing annually to $500/AF, multiple growers expressed that $100/AF is unlikely to be a strong disincentive and that growers will likely continue to pump as much water as they deem necessary for their crop health and yields and pay the subsequent fines.
3. Multiple growers have expressed a long-term plan to acquire additional lands currently in production and take them out of production in order to use the allocation from those lands to provide sufficient water supplies for what they are currently farming.
4. There are a number of questions related to groundwater allocations that need to be clearly answered and communicated to growers (see Section 6.1.4.3 for a list of these questions).

In January 2023, DE solicited feedback from participating growers on specific questions related to the Project and was able to obtain feedback from 11 of the 16 growers (69%). A summary of the grower feedback is included below and a detailed description of the questions are responses is available in Section 6.1.6.

1. The majority of project participants (7, 64%[49]) learned about the Project through a public workshop. Others learned about it through contact with Madera County staff (3, 27%) or through a GSA email (1, 9%).

[49] The first value (*i.e.,* 7) represents the number of project participants and the second value (*i.e.,* 64%) represents the percentage out of total respondents.

2. The majority of project participants (7, 64%) indicated that it is very important to have County engagement in the field at the farm scale. Other responses were somewhat important (2, 18%), indifferent (1, 9%), and not very important (1, 9%).
3. All respondents (11, 100%) understood the intent of the Project, found it helpful to have interactions in the field during the irrigation season, rated interactions with field staff as good or very good, rated satisfaction with the Project as good or very good, and felt the Project was helpful in leading to practical conclusions and recommendations.
4. Lastly, respondents provided additional feedback on what worked well as part of the Project, what didn't work well, and any further information or thoughts. These responses are included in Section 6.1.6.

3.2 Flowmeter Evaluations and Flowmeter Data Management (Objectives 2 and 3)

There were a total of 97 permanent flowmeters measuring groundwater pumped from wells for irrigation of Project lands. The installation reviews revealed that 74 flowmeters (76%) were installed per manufacturer specifications, while the remaining 23 (24%) were not. The field data collection objective was to complete three comparison flow measurements using a portable transit time meter for each permanent flowmeter; however, this turned out to be impossible because some wells serve as "back-up" supply sources and therefore were never or rarely used during the 2022 irrigation season. Additionally, the timing of site visits by Project field staff did not always coincide with the timing of pumping and water application. In total, 193 comparison flow measurements were completed. Of these, 146 measurements (76%) were on flowmeters installed per manufacturer specifications and 47 measurements (24%) were on flowmeters that were not installed per manufacturer specifications. The results of these comparison flow measurements are presented in Figure 3-1 below.

The top row of charts in Figure 3-1 depict scatterplots comparing flow measured with the portable transit time meter on the x-axis to flow measured with the permanent flowmeter on the y-axis, with both values expressed in gallons per minute (GPM). The first (leftmost) scatterplot presents comparisons for all measurements, while the second (middle) and third (rightmost) scatterplots present comparisons for flowmeters installed per manufacturer specifications and not installed per manufacturer specifications, respectively. The 1:1 line is shown as a dashed gray line; a point along this line represents exact agreement between the portable transit time meter and the permanent flowmeter. A point above the 1:1 line represents a higher permanent flowmeter reading than the portable transit time meter, and vice versa for a point below the 1:1 line. A linear regression line applying the best fit to the available data is shown in red on each scatterplot. The call out boxes in each scatterplot indicate the equation for the regression line, R^2 value, Mean Absolute Percentage Error (MAPE), Mean Bias Error (MBE), and sample size (n).

The MAPE is a measure of relative error that calculates absolute errors to avoid the potential issue of positive and negative errors canceling each other out[50] and scales the variable's units to percentage units for easier interpretation of results. The MAPE is 7.7% for permanent flowmeters installed per manufacturer specifications, 16.0% for flowmeters not installed per manufacturer specifications, and 9.7% for all flowmeters. These results illustrate the difference in accuracy for flowmeters either installed or not installed per manufacturer specifications, with a relative error that is roughly twice as large for

[50] The canceling out of positive and negative errors can result in false conclusions about the accuracy of a dataset. For example, if two errors were +10% and -10% and the overall percentage error did not use absolute values, the two errors would cancel out, resulting in an average percentage error of 0%.

flowmeters not installed per manufacturer specifications (*e.g.*, 7.7% compared to 16.0%). Overall, the relative error for all flowmeters is within 10% (*e.g.*, 9.7%). The MBE is a measure of bias that is expressed in the same units as the variable. The MBE results reveal a positive bias, where permanent flowmeters tended to measure higher flows than the portable transit time meter, and similar results to the MAPE, with the lowest and highest MBE values for flowmeters installed per manufacturer specifications and flowmeters not installed per manufacturer specifications, respectively.

A linear regression can also be applied to model a linear trend based on the best fit to the scatterplot dataset. This regression line is defined by the equation shown at the top of the callout box, and the R^2 value is a measure of how closely the regression line fits the data in the scatterplot (with a value closer to 1 being indicative of a better fit). The average difference based on the regression for permanent flowmeters installed per manufacturer specifications is 1.4%[51] and for flowmeters not installed per manufacturer specifications is 3.9%. Overall, the results for all aggregated measurements show close agreement between the permanent flowmeters and the portable transit time flowmeter, with an average 2.2% difference based on the regression.

The bottom row of charts in Figure 3-1 depict histograms showing the percent difference between flow measured with the portable transit time meter and flow measured with permanent flowmeters. The histogram provides more information on the distribution of differences and highlights the positive bias, where permanent flowmeters tended to measure higher flows than the portable transit time meter. The vertical lines on the charts depict the 25th and 75th percentile and median values. These charts depict the following:

1. For all 193 comparison measurements, regardless of whether or not the permanent flowmeters were installed correctly, half of the measurements had flows within roughly 10% of the portable transit time flowmeter flow.
2. Of the 47 meters that were not installed correctly, half had flows that were between roughly 1% and 19% greater than the portable transit time flowmeter flow, and one quarter had flows more than 19% greater than the portable transit time meter flow.
3. For meters that were installed correctly, half had flows between roughly 0% and 9% greater than the portable transit time meter flow.
4. The median percent difference between the portable transit time flowmeter and (1) properly installed flowmeters was 3.8%, (2) incorrectly installed flowmeters was 8.8%, and (3) all flowmeters was 4.5%.

It is worth noting that while the comparison between the two measurements shows relatively close alignment overall (Figure 3-1), there are individual measurements that do not align as well. For instances where a permanent flowmeter flow reads higher or lower than the portable transit time flowmeter, this could be influenced by uncertainty in either flow measurement device, but both the number of instances and overall differences increase for permanent flowmeters that are not installed per manufacturer specifications. Also, interestingly, there were three instances where a permanent flowmeter that was installed per manufacturer specifications was reading zero flow (i.e. empty pipe)

[51] It is worth noting that three data points along the x-axis were excluded from the regression calculation. They are examples of instances when a permanent flowmeter installed per manufacturer specifications was reading zero flow (i.e. empty pipe) while water was flowing and able to be measured using the portable transit-time flowmeter.

when flows were observed on site and measured in the range of 500 and 1,000 GPM by the portable transit time flowmeter.

Overall, the results from Figure 3-1 show that permanent flowmeters being installed per manufacturer specifications substantially increases accuracy. For the immediate purposes of the Project, the comparison flow measurements with the portable transit time flowmeter provide evidence supporting the accuracy of volumes of AGW measured with permanent flowmeters for comparison to ETAW as quantified by IrriWatch. In instances where permanent flowmeters were observed to be faulty or inaccurate, methods of estimating volumes during these periods have been applied[52].

These results provide evidence to support the use of flowmeters installed and maintained per manufacturer specifications as an accurate means of quantifying AGW for comparison to groundwater allocations. However, there are additional data and procedural needs beyond flowmeter accuracy that should be considered and addressed before adoption and implementation of flowmeters as a measurement standard. These additional needs include the following:

<u>Data Needs:</u>

1. Identifying locations of all active groundwater wells and associated flowmeters, and tracking location changes over time
2. Verifying flowmeter installation, calibration, and accuracy
3. Recording groundwater pumping volumes over time, and review and QA/QC of groundwater pumping volumes over time
4. Defining the lands irrigated by one or more wells (i.e. irrigation units, or IUs) and applying volumes to these lands
5. Recording changes to wells, flowmeters, and/or IUs over time

<u>Procedural Needs:</u>

1. Identifying staffing, methods, and a schedule for obtaining and managing the necessary data described above
2. Addressing flowmeter functionality issues that inevitably occur, including a procedure for estimating water volumes for periods when groundwater wells are pumping but flowmeters are malfunctioning or have failed
3. Developing a methodology for evaluating flowmeter accuracy over time and specifying when a flowmeter needs maintenance or replacement
4. Developing a methodology for converting AGW to ETAW for direct comparison against groundwater allocations
5. Developing a methodology for assembling and reporting flowmeter readings (and associated data) at an appropriate frequency to support adaptive management by growers throughout the irrigation season

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[52] The methods used to estimate volumes for a faulty or inaccurate flowmeter are described in Section 6.4.3 Permanent Flowmeter Data Adjustments.

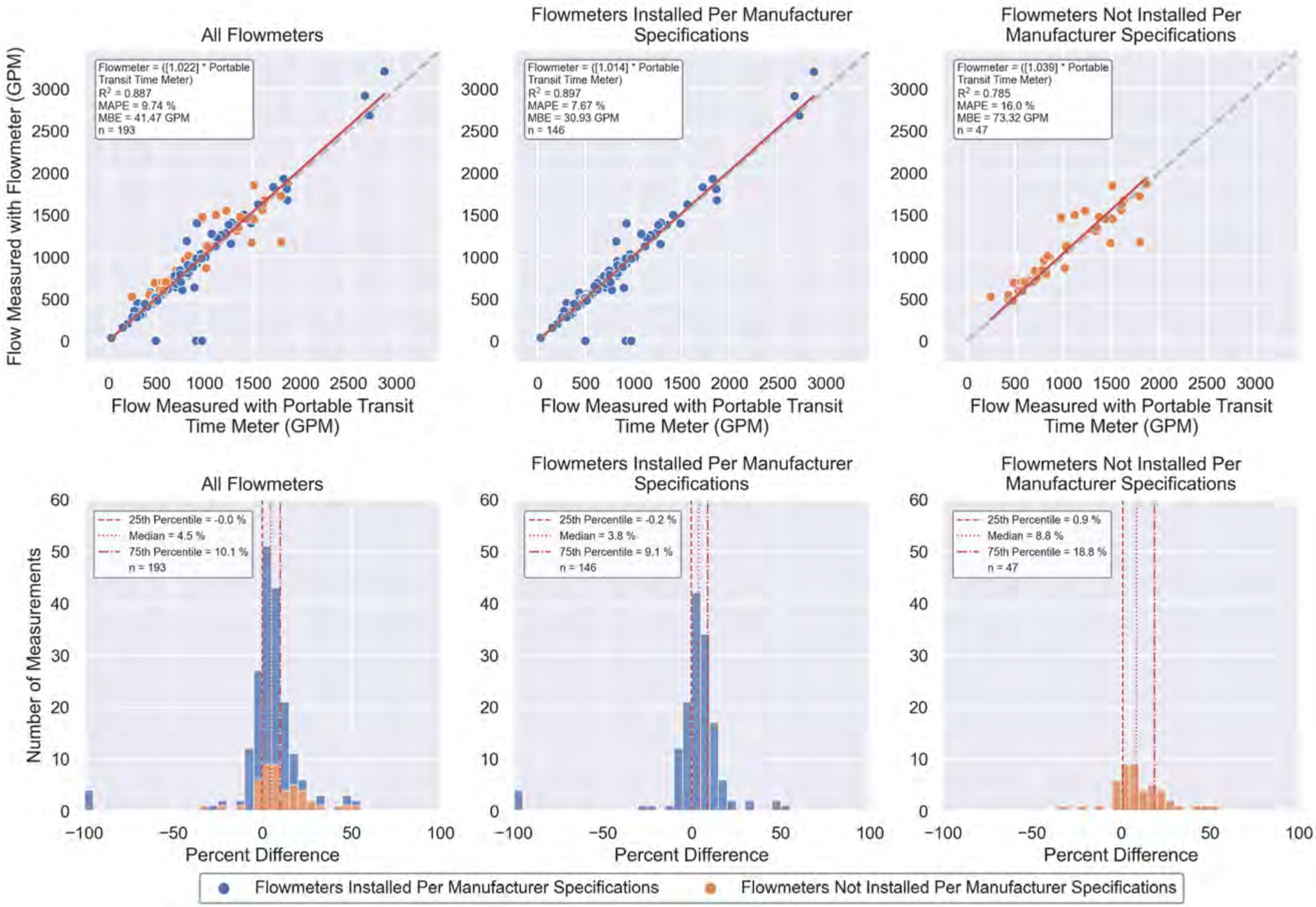

Figure 3-1. Comparison of flow measurements with the portable transit time flowmeter to permanent flowmeters.

Lands participating in the Project included roughly 10% of the cropped lands in the GSAs, and issues related to each of the data and procedural needs listed above arose as part of Project implementation during 2022. Assuming a similar number of issues occur across the total GSAs' area and the entire area uses flowmeters to compare to groundwater allocations, there will be roughly ten times more issues that would need to be addressed and resolved, which will require both substantial effort and robust procedures for management of issues. It is anticipated that additional County and/or GSA staffing will be necessary for this to be successful, at any level of flowmeter usage across the GSAs.

3.3 Remote Sensing of ETAW from IrriWatch and Data Management (Objective 4)

Retrieval of IrriWatch data via the API worked well throughout the Project. The accessibility of IrriWatch data for not only the Project's participating lands, but the entire Madera County GSAs' area, facilitated a comparison between the distributions of data for GSAs' parcel-fields and Project-specific parcel-fields. The purpose of this comparison was to evaluate if there is a statistical bias in the lands participating in the Project when compared to typical agricultural lands in the Madera County GSAs as a whole. As described previously, the Project lands comprise roughly 10% of the total Madera County GSA cropped area. The results from this comparison related to the parameters used to calculate ETAW are summarized in Table 3-1.

Table 3-1. The median values (in inches) for Actual ET (ETa), Precipitation (P), ET from Precipitation (ETPR), and ET from Applied Water (ETAW) for all Madera County GSAs' parcel-fields and Project-specific parcel-fields, as well as the difference between the two. Results were organized in four different classifications: (1) an aggregation of all crops, (2) almond orchards, (3) grape vineyards, and (4) pistachio orchards. Differences were calculated as the GSAs' median value subtracted from the Project median value (i.e., a positive difference indicates the Project had a higher median value than the GSAs).

Parameter	Calculation Type	Parcel-Field Groups			
		All Crops (in)	Almonds (in)	Grapes (in)	Pistachios (in)
ETa	Project Median	35.1	46.4	36.9	30.4
	GSA Median	28.0	31.7	25.3	28.2
	Difference	**7.1**	**14.6**	**11.6**	**2.2**
P	Project Median	7.9	8.6	7.7	8.8
	GSA Median	8.6	8.6	8.6	8.7
	Difference	**-0.7**	**0.0**	**-0.9**	**0.1**
ETPR	Project Median	6.5	7.7	7.2	5.6
	GSA Median	5.9	6.5	6.5	5.7
	Difference	**0.6**	**1.2**	**0.7**	**-0.1**
ETAW	Project Median	27.3	38.5	30.1	24.6
	GSA Median	21.9	25.2	18.0	22.4
	Difference	**5.4**	**13.2**	**12.1**	**2.2**

Observed differences in P and ETPR are typically less than one inch and relatively small compared to observed differences in ETa and ETAW. Differences in ETa and ETAW range from 2.2 inches for pistachios to roughly 12 inches for grapes and over 12 inches for almonds. Considering all crops together, differences were in the range of 6 inches for ETa and ETAW. In every case, the ETa and ETAW differences are positive, indicating that the participating Project lands had higher median values. These results suggest that Project lands are likely representative of Madera County GSA lands with higher than median vegetation cover and related ETa and ETAW (especially for grapes and almonds). In subsequent phases of future analysis, it is recommended that additional analysis be undertaken to further refine and understand the observed differences between Project lands and other GSA lands, especially with respect to grapes and almonds. The observed differences could be caused by differing on-farm practices (with irrigation and fertilization practices being a major factors), varying crop age (*i.e.*, Project lands may have more mature crops with higher ET demand than GSA cropped areas as a whole), uncertainty and error in land use classifications for the entire Madera County GSAs' area, and other factors. Further investigation would be required to better understand these differences. As described previously and subsequently in Section 4, future studies with a similar objective should seek to include lands representative of the Madera County GSAs as a whole, and to the extent differences are present, these should be investigated to be better understood.

To further illustrate, compare, and understand differences between the lands included in the Project and the Madera County GSA cropped lands in their entirety, it is helpful to evaluate the distribution of results rather than solely a comparison of the median values (as shown previously in Table 3-1). A series of boxplots depict the distribution of eight different parameters of the Project's participating lands (*i.e.*, Madera Verification Project, or MVP shown in orange) and the Madera County GSAs' cropped lands (*i.e.*, GSA shown in blue), allowing for comparison of the two (Figure 3-2). The left column of parameters are the same as those shown in Table 3-1 (ETa, Precip, ETPR, ETAW from IrriWatch); the right column includes ETa data from OpenET (for comparison to ETa from IrriWatch), Transpiration from IrriWatch, Evaporation from IrriWatch, and total adjustments to ETa from IrriWatch[53].

A comparison of the distribution of ETa from IrriWatch between the MVP and GSA datasets shows results for MVP lands tend to be higher than the GSA cropped lands from most of the included lands, although the maximum value for the GSA lands is higher than the maximum for the MVP lands. The ETa from OpenET also shows MVP lands tending to have higher ETa than the GSA cropped lands but a higher maximum value for MVP lands, making the trends consistent with IrriWatch.

The ETa from IrriWatch can be divided into two components in two separate ways with (1) a division into ET from Precipitation (ETPR) and ET from Applied Water (ETAW) and (2) with a division into transpiration (*i.e.*, water use by plants with water exiting plant stomata as water vapor) and evaporation (*i.e.*, conversion of water from a liquid to a vapor from an open water surface, including soil moisture or moisture on the outside of plant tissues). The comparison of ETPR and ETAW allows for evaluation of the amount of total ET (ETa) that results from precipitation versus applied water. The comparison of precipitation (P) and ETPR allows for evaluation of how much of total P results in ETPR. The comparison shows that, as expected, ETPR tends to be lower than P for both MVP and GSA lands[54]. However, the upper end of the distribution of ETPR for both MVP and GSA lands shows ETPR values that can be substantially higher than the highest observed P values. This could be influenced by P that occurred prior to the accounting period (*i.e.*, the 2022 calendar year), but the differences are large enough in some instances to warrant further investigation and analysis[55]. ETAW is the majority of ET demand and met by applied irrigation water; however, since ETPR directly influences the calculation of ETAW

[53] See Section 6.4.4 for more information about the 2022 IrriWatch adjustments.

[54] ETPR is expected to be lower than P because a portion of P is expected to result in deep percolation and/or runoff (*i.e.*, overland flow) if the soil profile is already saturated and/or rainfall intensity is high.

[55] Recommendations related to P and ETPR are included in Section 4.

(Equation 1), further review and potential refinement of P and ETPR would be beneficial. The distribution of ETa between transpiration and evaporation shows that the majority of ET occurs as transpiration and the minority as evaporation; this distribution is influenced by irrigation method and application of water to crops. The results for these parameters are also consistent with overall ETa results when comparing the MVP and GSA lands.

Review of preliminary analyses and results of the Project led to important refinements in the methodology and assumptions that IrriWatch used to quantify ETAW during 2022, resulting in an adjustment to ETa and the resulting ETAW values. The adjustments to ETa shown in Figure 3-2 are described in more detail in Section 6.4.4; they included adjustments to areas with sparse vegetative cover and programmatically setting ETAW equal to zero for fields that are not irrigated. In every instance, the adjustments resulted in a net decrease in ETa.

Table 3-1 and Figure 3-2 show the results for all fields, regardless of crop type. Crop type is an important factor for evaluation of these results. In Section 6.5.1.1, a table and figure with the same structure are included to compare MVP and GSA lands, but they depict the results organized by the three major crop types: almonds, grapes, and pistachios.

Crop type, or land use, is an important factor influencing the evaluation and comparison of results by crop. Having an accurate understanding of crop type is also important for the Madera County GSAs to understand land use trends and changes over time (and the associated water use). The crops shown in IrriWatch were originally based on the DWR California Statewide cropping dataset from 2018[56], but the DWR dataset has some level of uncertainty and does not account for any land use or crop type changes that occurred between 2018 and 2022. At the outset of the Project, the crops for participating lands were defined with growers and verified in the field, resulting in corrections in crop type to 33 of the 203 participating parcel-fields (16%), which covered 1,422 of the 11,800 participating acres (12%). It is anticipated that there is similar land use uncertainty and similar trends across the Madera County GSAs' cropped lands. Additionally, discrepancies between the spatial coverage of cropped area (as defined in the DWR 2018 coverage) and the actual cropped area were noted for participating lands in the Project. These discrepancies were typically minor, but have an impact on the quantification of ETAW using remote sensing technology such as IrriWatch.

[56] More information about this is available at: https://data.cnra.ca.gov/dataset/statewide-crop-mapping. The 2018 dataset was the most recent available data at the time when crops were originally added to the IrriWatch dataset.

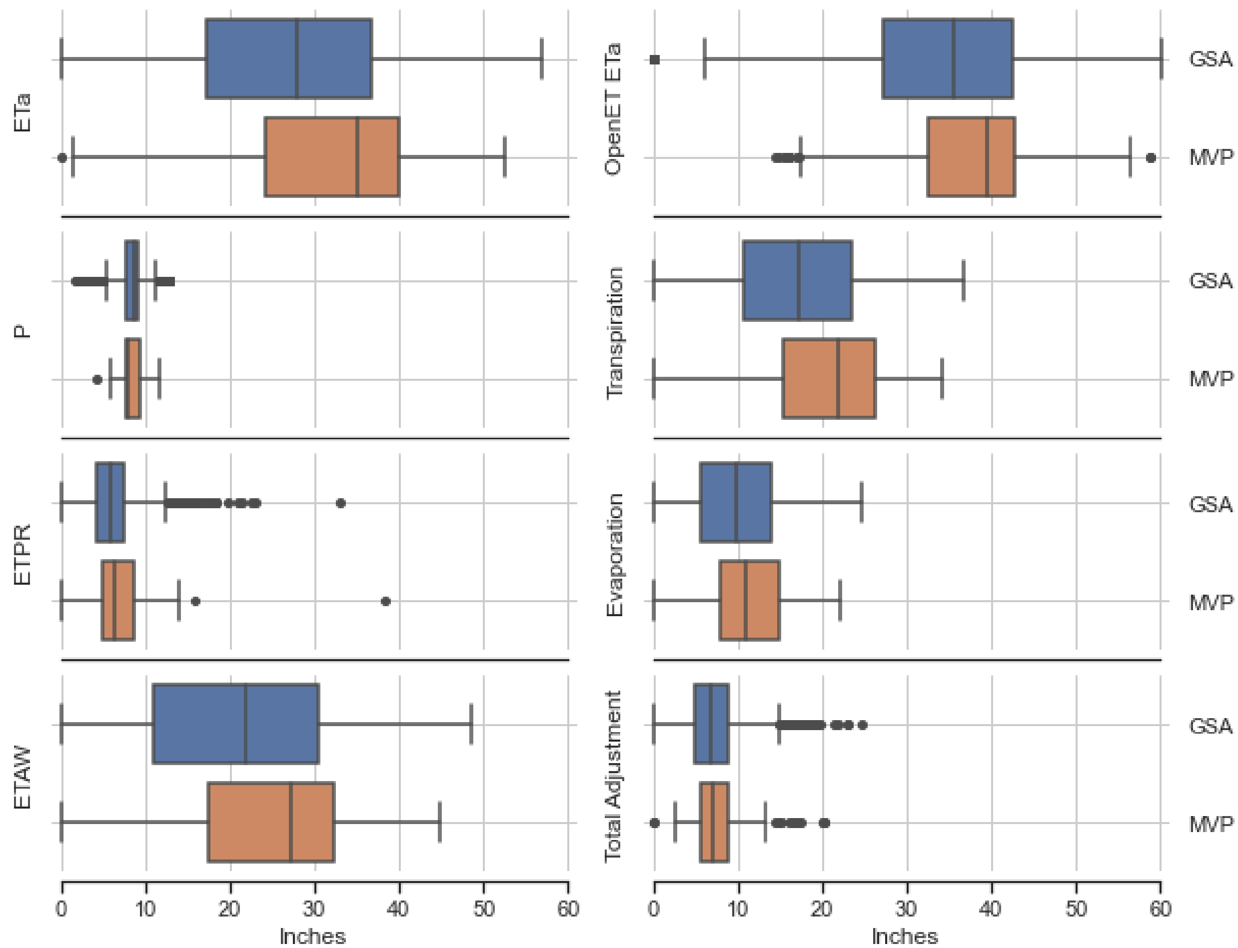

Figure 3-2. Boxplots[57] visualizing the distributions of (1) ETa, (2) Precipitation, (3) ETPR, (4) ETAW, (5) ensemble ETa from OpenET, (6) Transpiration, (7) Evaporation, and (8) Total ETa Adjustment. All parameters, except for ETa from OpenET (5), were taken from the IrriWatch API. The blue boxplots show distributions for all cropped parcel-fields in the GSAs (GSA), while the orange boxplots show distributions for all parcel-fields within the participating lands (i.e., the Madera Verification Project, or MVP).

Additional factors that influence water use and ETAW are irrigation method, soil type, and crop age. Both irrigation method and soil type are currently included in IrriWatch, but crop age is not. Irrigation method was chosen based on the typical method for each crop type, since it is not available through the DWR 2018 statewide cropping dataset. Irrigation method was field-verified for the Project's participating lands. Corrections to the irrigation method were required on 58 of the 203 parcel-fields

[57] A boxplot depicts the full distribution of a dataset. Boxes show the interquartile range between the first and third quartiles (25th and 75th percentile, respectively) of the dataset, while whiskers extend to show minimum and maximum values of the distribution. Diamonds shown beyond the whiskers represent points considered outliers; they are more than 1.5 times the interquartile range away from the first or third quartiles. The middle line of a boxplot shows the median (50th percentile) of the dataset. For a given scale, a large boxplot shows a relatively broader distribution of values, while a smaller boxplot (which can more closely resemble a line than a box in some instances) shows a relatively narrow distribution of values.

(29%), which covered 2,402 of the 11,800 participating acres (20%). A comparison of Project results based on irrigation method is available in Section 6.5.1.2. It is anticipated that there is similar irrigation method uncertainty and similar trends across the Madera County GSAs' cropped lands. Soils data was originally determined based on the Natural Resource Conservation Service (NRCS) soils coverage underlaying each parcel-field. Limited soil sampling was completed as part of field work[58]. Crop age, which is not tracked by IrriWatch, was determined in coordination with landowners for almonds, grapes, and pistachios to evaluate its impact on Project results. Data visualizations comparing results by crop age are available in Section 6.5.1.2. Additional data for further evaluation of results would be helpful to better understand the influence of these factors.

The Project results provided valuable insight into input data and associated computations for ETAW from IrriWatch, leading to the adjustments described in Section 6.4.4. However, there are additional data and procedural needs that would be helpful for further evaluation and refinement of ETAW from IrriWatch. These include:

Data Needs:

1. Evaluating and improving the quantification of precipitation (P) and ETPR.
2. Improving the land use coverage that IrriWatch uses for the GSAs, including both improvements to the specific crop type or land use and improvements to the spatial extent of cropped lands.
3. Improving coverage of supplemental land use information, such as irrigation method and soil type.
4. Furthering understanding of how factors such as crop type, crop age, irrigation method, soil type, and more impact ETAW from IrriWatch.

Procedural Needs:

1. Continuing a detailed review of ETAW results for the Madera County GSAs, including evaluation of whether future study areas are representative of all cropped lands in the Madera County GSAs and improving understanding of differences if they exist.
2. Developing a system (including staffing, procedures, and schedule) for tracking land use (including identification of fallow/unirrigated fields on an annual basis), crop type, irrigation method, soils information, and potentially crop age.
3. Evaluating potential refinements to the methodology for partitioning ETa between ETPR and ETAW.

Many of the data and procedural needs described above are also included in the conclusions and recommendations in Section 4. The results demonstrate and recommendations outline the importance of additional data and analyses to provide greater background and context for the application of remote sensing technologies within the Madera County GSAs.

3.4 Comparison of ETAW and AGW (Objectives 5 and 6)

As described in Equation 2, the Consumptive Use Fraction (CUF) is equal to ETAW divided by AGW. A CUF value less than one is expected for all IUs because not all AGW results in ETAW; rather, some AGW contributes to deep percolation and runoff during the process of applying irrigation water (the CUF is influenced by a variety of factors, including irrigation method). CUFs greater than one are physically

[58] More information about soil moisture and texture sampling is available in Section 6.2.4.2.

impossible if all applied water, precipitation, and changes in soil moisture are perfectly accounted for. For CUF values greater than one, contributing factors could be some combination of: (1) error in the quantification of ETAW or AGW or both, (2) use of previously stored root-zone soil moisture by crops, or (3) a potential third source of water (above AGW and precipitation) available to crops (*i.e.*, water flowing into the root zone from shallow groundwater or nearby surface water features, such as ditches or ponds.).The CUF is the primary metric used for the comparison of ETAW and AGW.

During the 2022 irrigation season, as AGW data were being collected in the field and ETAW data were obtained from the IrriWatch API, internal procedures were developed by DE staff to process, analyze, and review data as it was collected, including comparisons of ETAW and AGW. This allowed for internal review of preliminary results as the Project was ongoing, rather than waiting until the irrigation season and field data collection were complete to compile and review results. This, in turn, created opportunities for further analysis and exploration of potential issues or discrepancies as they were identified. For example, as described previously, this led to coordination with IrriWatch staff on ETAW calculations, and ultimately to adjustments to the methodology and assumptions used by IrriWatch to quantify ETAW[59]. Other examples of this included identifying clarifying questions or additional data requests for participating growers and focusing field data collection on specific parameters or areas that would benefit from additional data. The ability to compile, review, and run QA/QC procedures during data collection is an important step for quantifying both ETAW and AGW. This is a recommendation included in Section 4.

For each irrigation unit included in the Project, a report that was developed summarizing all ETAW and AGW data collected as part of the Project (and the resulting CUF); these are available in Section 6.5.2. Additionally, results for all Project lands were summarized, analyzed and evaluated using a variety of methods. Table 3-2 summarizes the average ETAW, AGW, and resulting CUF values by crop, along with information about the irrigation units and total area within each crop included. For the CUF, the average, standard deviation, minimum, and maximum are all shown in order provide a sense of the variability of results within the crop category.

Although the sample size of IUs within each crop category is too small to be considered representative or to justify statistical analysis, organizing results by crop and calculating minimums, maximums, and standard deviations within crops illustrates and allows for evaluation of differences based on crop type. The results vary substantially from crop to crop. Excluding the citrus and dryland crop categories, the ETAW ranges from a low of 23.3 for grapes to a high of 41.0 inches for almonds with an area-weighted average of 25.7 inches. The AGW ranges from a low of 25.8 inches for pistachios to a high of 52.5 inches for alfalfa with an area-weighted average of 29.8 inches. Lastly, the average CUF ranges from a low of 0.62 for alfalfa to a high of 1.22 for almonds, with an area-weighted average of 0.86 across the crops shown. The overall average value of 0.86 is reasonable (*i.e.*, less than one, meaning that not all applied irrigation water is consumptively used).

[59] See Section 6.4.4 for more information about the 2022 IrriWatch adjustments.

Table 3-2. Summary by Crop of Irrigation Units (IUs), Acres, Average Evapotranspiration of Applied Water (ETAW), Average Applied Groundwater (AGW), and Consumptive Use Fraction (CUF)[60]. For the CUF, the average, minimum, and maximum values, along with the standard deviation, are all shown.

Crop	Irrigation Units	Area (Acres)	Average ETAW (IN)	Average AGW (IN)	CUF			
					Avg	St.Dev.	Min	Max
Alfalfa	2	174	32.3	52.5	0.62	0.04	0.59	0.65
Almonds	5	863	41.0	33.7	1.22	0.28	1.03	1.59
Citrus	1	48	29.7	10.3	2.88	--	--	--
Dryland	1	862	0.0	0.0	--	--	--	--
Grapes	7	1,666	23.3	36.9	0.63	0.10	0.53	0.82
Pistachios	17	4,789	23.6	25.8	0.91	0.25	0.46	1.43
Area-weighted Average[61]		**3,535**	**25.7**	**29.8**	**0.86**	**0.22**	**0.54**	**1.29**

Notably, Table 3-2 shows average ETAW estimates to be higher than average AGW measurements for both almonds and citrus. For citrus, only a single irrigation unit was included in the Project, and while no flowmeter malfunctions or data quality issues were noted, the AGW volumes measured don't appear to be enough to support the crop health and growth observed in 2022. For almonds, there were no flowmeter data quality issues identified, and all five IUs included showed CUF values greater than one, ranging from 1.03 to 1.59. Additionally, although the average CUF for pistachios was less than one, they had the highest range from minimum CUF (0.46) to the maximum (1.43) with multiple pistachio IUs with a CUF greater than one. CUFs greater than one are physically impossible if all applied water, precipitation, and changes in soil moisture are perfectly accounted for, and if no "third" water source (*e.g.,* shallow groundwater or lateral seepage from creeks or canals) is available. Therefore, further investigation is needed to better understand why CUFs exceeding one were observed. Contributing factors that may influence unexpected CUF values include: (1) error in the quantification of ETAW or AGW or both, (2) use of previously stored root-zone soil moisture by crops, or (3) a potential third source of water (above AGW and precipitation) available to crops (*i.e.*, shallow groundwater from nearby surface water features). In contrast to results described above, for alfalfa and grapes the average ETAW estimates were consistently lower than average AGW measurements. The average CUF values for alfalfa and grapes were 0.62 and 0.63, respectively. For grapes, the range from minimum to maximum CUF was 0.53 to 0.83. Considered overall, these results demonstrate the variability in CUF between crops and among IUs within crops (*i.e.*, Standard Deviation, or St.Dev., values). Including a larger sample size would improve understanding of results (and the variability of results) between crops and within crops for any future potential work evaluating ETAW and AGW. Additionally, monitoring root zone soil moisture would improve understanding of the availability of water within the root zone regarding both timing and quantity.

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60 The number of irrigation units and acreage here differ from Table ES-1 in some cases due to (1) some irrigation units including multiple crop types and (2) some IUs being excluded from aggregated results due to data quality issues. As an example of the first case, walnuts are not included in this table because the only participating lands with walnuts were from an irrigation unit that also included grapes. As an example of the second, one IU had flowmeter functionality issues at multiple wells, some lasting for a substantial portion of the irrigation season. Estimates of AGW during these periods were completed using available data, but this substantially increases uncertainty in estimates of pumped volumes for this IU.

61 The area-weighted average calculations do not factor in the citrus or dryland crop types and results.

The results of comparing ETAW and AGW for the 36 individual IUs in the Project are depicted in a scatterplot in Figure 3-3, along with a linear regression line created to define the overall relationship between the two parameters based on the available data. The lines depicted in Figure 3-3 include the regression for the scatterplot data as a red dashed line, a solid dark gray line along the 1:1 line (representing a CUF equal to one), and dashed gray lines representing CUF values of 0.5, 0.6, 0.7, 0.8, 0.9, and 0.95. The points shown in the plot represent results for each IU; the color denotes crop type, and the symbol depicts either the irrigation method or an irrigation unit with data quality issues. Figure 3-4 has the same design and structure of Figure 3-3, but depicts scatterplot data for IUs within the four main crops (alfalfa, almonds, grapes, and pistachios), along with linear regression lines based on results for each crop individually.

Based on the regression relationship considering all IUs (except those with data quality issues) [62], the results show an overall CUF of 0.84, meaning that on average, 84% of AGW is consumptively used and 16% of AGW has a different destination (*e.g.*, deep percolation). Similar to the overall area-weighted average calculated in Table 3-2, this is a reasonable result (*i.e.*, less than one). However, although the average result is reasonable, there is substantial variability within the data among individual IUs. 14 of the 36 IUs (39%) appear above the 1:1 line with a CUF greater than one[63]. For the 22 of 36 IUs (61%) below the 1:1 line, six have values between 0.9 and 1.0, three have values between 0.8 and 0.9, two have values between 0.7 and 0.8, six have values between 0.6 and 0.7, three have values between 0.5 and 0.6, and two have a value less than 0.5.

One of the major factors influencing CUF is the method of applying water to lands for irrigation of crops. Flood or furrow irrigation tends to have a lower CUF, typically with a larger quantity of water applied than is directly consumptively used by the crop. Typical values are in the 0.55 to 0.70 range; the three IUs using flood or furrow irrigation all had CUF values close to this range (0.59 and 0.65 for two IUs with alfalfa, and 0.55 for one IU with grapes).

More precise and uniform application of irrigation water through pressurized irrigation systems (*e.g.*, drip emitters or micro-sprinklers) tends to have a higher CUF with less overall water applied and a higher percentage consumptively used by the crop. Typical values range from 0.70 to 0.90. The majority of the lands included in the Project and in the Madera County GSAs use pressurized irrigation systems, but only three of the IUs included in the Project fall within this range of 0.70 to 0.90, and 25 do not. For the IUs outside of this range, six are below and 19 above, with 11 above the 1:1 line representing a CUF value greater than one.

The overall average results based on the linear regression relationship between AW and ETAW results in a CUF of 0.84, which is a reasonable value (*i.e.*, a value less than one) and within the typical expected range for pressurized irrigation systems (*i.e.*, the systems used on a majority of IUs). The regression line does not fit the data very well with an R^2 value equal to 0.29, however, the regression is statistically significant at a 99% confidence level using a Pearson's Correlation critical value test. For the regressions developed for individual crops in Figure 3-4, the regression lines also do not fit well and there are issues

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[62] Although they are included in the scatterplot in Figure 3-3, the two IUs with data quality issues are excluded from the regression calculation. This is why the scatterplot includes 36 IUs, but the sample size for the regression shows 34 IUs.

[63] Two of the 13 IUs with a CUF greater than one had data quality issues.

with small sample sizes within each crop category. Pistachios, with the largest sample size of 17 IUs and an R^2 value of 0.396, has the only regression that is statistically significant with a 99% confidence level.

Additional data visualizations presenting results from the Project are included and described in Section 6.5.1. These include a scatterplot of results by irrigation method (with a similar format to the scatterplots show previously), an evaluation of how crop age might influence results, and inclusion of a timeseries of AGW and ETAW over the Project monitoring period in 2022.

As described above, based on review of the results and how poorly the regression lines match the available data, there is substantial variability among crops and within individual IUs categorized by crop. The impacts of this variability on utilizing these data to compare against groundwater allocations are described in the conclusions and recommendations in Section 4.

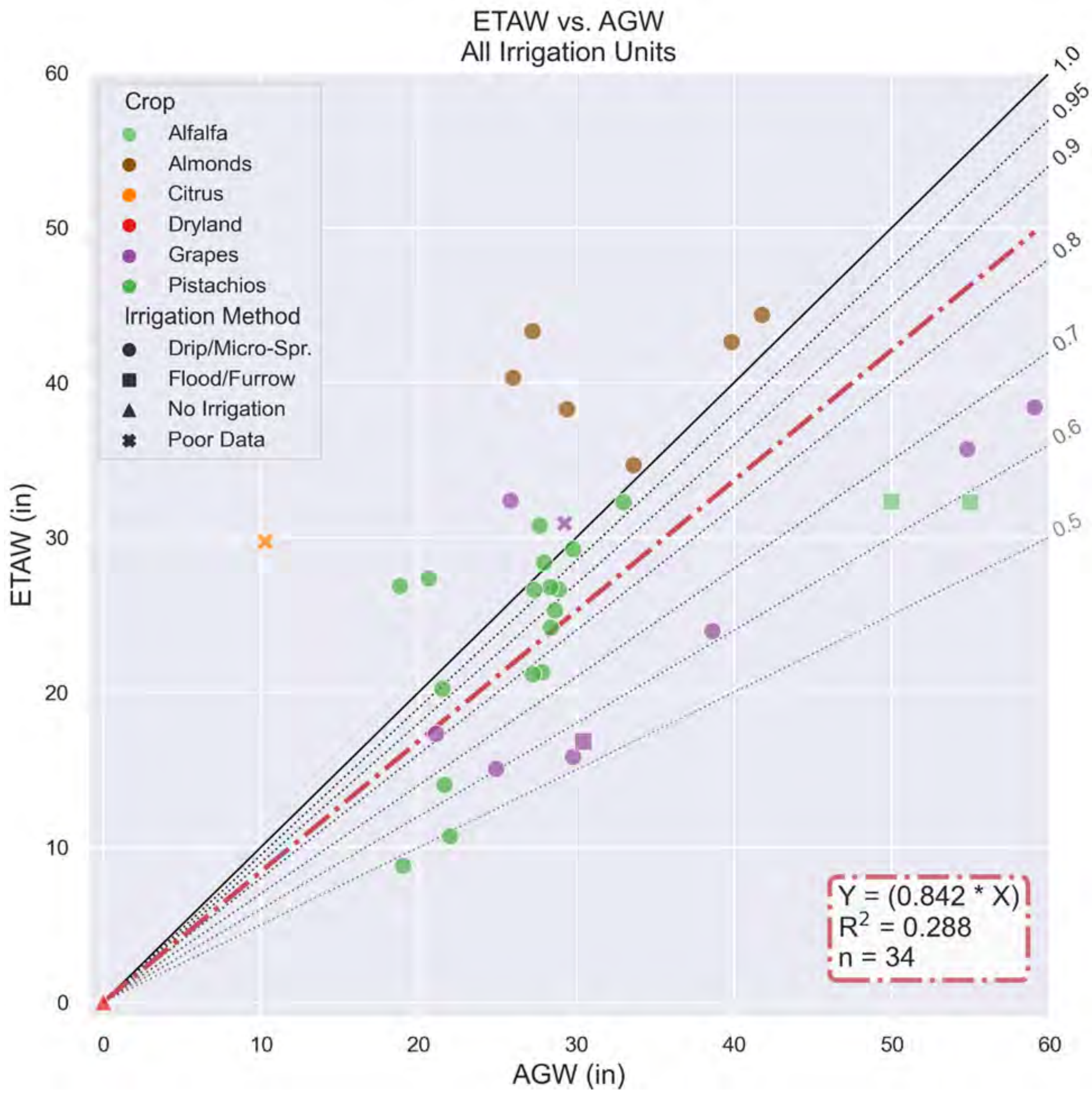

Figure 3-3. Summary of ETAW and AGW for the 36 irrigation units (IUs) in the 2022 Madera Verification Project. The color of the symbol indicates the primary crop within each IU, and the type of symbol indicates the irrigation method[64]. IUs with data quality issues were not included in the regression calculation, resulting in a sample size of 34 for the regression.

[64] The "Poor Data" symbol type (*e.g.*, "X") indicates that the IU had data quality issues. The symbol is not indicative of irrigation method; the two IUs in this category both have pressurized drip or micro-sprinkler irrigation systems.

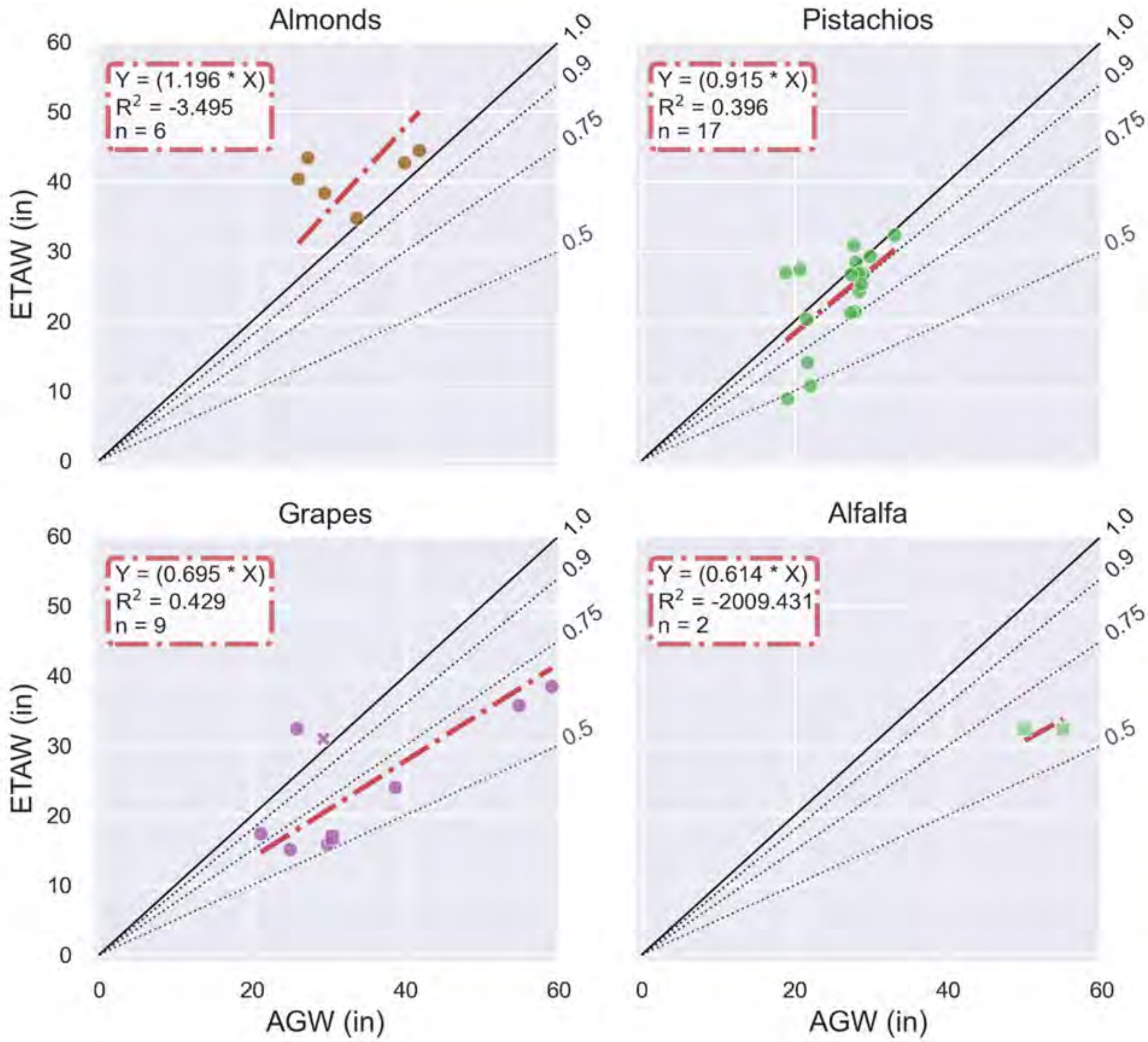

Figure 3-4. Summary of ETAW and AGW for irrigation units (IUs) by crop type for four main crops in the Project: Almonds, Pistachios, Grapes, and Alfalfa. Styling and coloring of markers on the scatterplot is the same as Figure 3-3. IUs with major flowmeter issues were not included in the regression calculations.

4 Conclusions and Recommendations

The Project was a collaborative effort undertaken by the County within the Madera County GSAs in partnership with local growers with the following objectives:

1. Increase grower engagement, education, and outreach related to SGMA implementation, particularly groundwater allocations, remote sensing of ETAW, and metering of AGW.
2. Evaluate flowmeter installations, maintenance, and accuracy based on site inspections and comparisons to independent on-site flow measurements.
3. Develop and test procedures for collecting, quality controlling, and using totalizing flowmeter readings to quantify volumes of AGW.
4. Evaluate methods for collecting and/or developing required input data and associated computations for remote sensing of ETAW with IrriWatch.
5. Develop and implement improvements to the processes for quantifying AGW and ETAW volumes.
6. Compare and analyze AGW to remotely sensed ETAW data provided by IrriWatch.

A variety of conclusions and recommendations stem from the completion of this Project and the results described previously. They are organized below in Table 4-1 based on the six objectives above.

Although overall results for the 36 participating IUs show a CUF of 0.84, the substantial variability between individual IUs and the overall minimum and maximum bounding values illustrate the challenges in using these data to compare against groundwater allocations. Based on these results, at the GSA level, the overall ETAW results would potentially correspond closely and reasonably to overall AGW results. However, for successful implementation and enforcement of groundwater allocations, ETAW estimates need to be determined with sufficient accuracy and accepted at a local level for each parcel-field and in aggregate for all parcel-fields comprising each IU to (1) assess the effectiveness of GSP implementation efforts towards groundwater sustainability and (2) fairly and equitably implement the GSAs' groundwater allocations (including carryover and penalties) for County growers individually and collectively. Groundwater allocations are an important component of GSP implementation and necessary to achieve sustainability, as outlined in the GSPs.

Recommendations below are meant to identify next steps beyond the Project to help Madera County, the GSAs, and growers within the GSAs continue forward with GSP implementation on the path towards groundwater sustainability using methods and practices agreeable to all parties and in a locally cost-effective manner.

Table 4-1. Conclusions and Recommendations from the 2022 Madera Verification Project.

<table>
<tr><th>Conclusions</th><th>Recommendations</th></tr>
<tr><td colspan="2">Objective 1: Increase grower engagement, education, and outreach related to SGMA implementation, particularly groundwater allocations, remote sensing of ETAW, and metering of AGW.</td></tr>
<tr><td>1. Due to the dynamic and quickly evolving process of GSP implementation and changing hydrologic conditions, regular grower engagement, education, and outreach is essential over the implementation horizon.
2. Collaborative projects like this Project can serve as a catalyst for building trust between growers and the County, and add significant value, insights, and a basis for refining implementation of the allocation program.
3. Spending time in the field with growers studying their operations and listening to their ideas and concerns is an essential part of developing trust and successfully implementing the projects and management actions set-forth in the GSP.
4. Due to the technically challenging nature of SGMA implementation, online grower meetings with larger audiences are insufficient for effectively communicating information and building working relationships with growers.</td><td>1. Continue grower engagement, education, and outreach activities including collaborative projects, webinars, in-person workshops, and private grower consultations. Both larger meetings for dissemination of information and smaller, more focused meetings for grower and stakeholder engagement should be planned.
2. Focus future work on building grower and stakeholder confidence in the approaches used to quantify groundwater use through remotely-sensed ETAW and measured AGW.
3. Continue to build Madera County Water and Natural Resources staff capacity to engage with growers in SGMA-related education and outreach activities.</td></tr>
<tr><td colspan="2">Objective 2: Evaluate flowmeter installations, maintenance, and accuracy with site inspections and on-site validation flow measurements.</td></tr>
<tr><td>1. The Project results confirm that properly installed and maintained flowmeters can accurately measure AGW.
2. On-site comparison flow measurements with a transit time meter are an effective means of evaluating permanent flowmeter accuracy.
5. The degree of consistency of flowmeter installation with manufacturer specifications affects flowmeter accuracy. On average, installation of flowmeters per manufacturer specifications improved Mean Absolute Percentage Error (MAPE) from 16.0% to 7.67%.</td><td>1. Develop programmatic procedures for periodic inspection of permanent flowmeters to ensure are they are installed correctly, including conducting periodic comparison measurements, especially on flowmeters that did not accurately measure flow despite being installed correctly.
2. Consider developing permanent flowmeter correction factors where measurement biases occur.
3. Refine third party flowmeter inspections to include automated confirmation of submissions.</td></tr>
</table>

Conclusions	*Recommendations*
Objective 3: Develop and test procedures for collecting, quality controlling, and using totalizing flowmeter readings to quantify volumes of AGW.	
1. Collecting and quality controlling permanent flowmeter data to quantify AGW requires substantial effort and additional procedures beyond simply verifying flowmeter accuracy, correct installation, and proper maintenance. Among others, these additional procedures include identification of well/flowmeter locations, establishing linkage between wells/flowmeters and irrigated lands, establishing a workflow for field data collection, reviewing and quality controlling AGW data, estimating AGW volumes when flowmeters malfunction or fail, and assembling and reporting AGW results to growers frequently enough to support timely, adaptive management throughout the irrigation season.	1. Continue improving processes for collecting, quality controlling, and processing data from totalizing flowmeters. 2. As soon as possible, initiate efforts to address the additional procedures described in the conclusions to the left for successful implementation of flowmeters for measuring AGW. 3. Develop programmatic procedures for estimating AGW volumes during periods when flowmeters malfunction or fail. 4. As part of the Project, a smartphone based mobile data collection platform that growers and County staff and consultants can collectively use to enter data collected in the field was developed. Additionally, a portal that the County can use to view and quality control the data from a single shared location was created. The GSAs should continue the use and development of these system in support of the 2023 allocation and beyond.
Objective 4: Evaluate methods for collecting and/or developing required input data and associated computations for remote sensing of ETAW with IrriWatch.	
1. Evaluation of input data for remote sensing of ETAW is crucial; this evaluation and analysis of preliminary results of the Project led to two adjustments to the methodology and assumptions that IrriWatch uses to quantify ETAW during 2022. 2. With the large volume of data generated during the Project (and with more data recommended), substantial staffing effort, robust procedures, or a combination of both will be required to successfully manage continued data collection, management, and dissemination in the Madera County GSAs.	1. See list of recommendations for this objective below the table.

<table>
<tr><th>Conclusions</th><th>Recommendations</th></tr>
<tr><td colspan="2">Objective 5: Develop and implement improvements to the processes for quantifying AGW and ETAW volumes.</td></tr>
<tr><td>1. See Conclusion 2 for Objective 4 above.
2. Increased coordination and planning between GSAs is necessary to provide clarification on how ETAW and/or AGW on lands that intersect boundaries should be quantified and managed[65].</td><td>1. See list of recommendations for this objective below the table</td></tr>
<tr><td colspan="2">Objective 6: Compare and analyze AGW to remotely sensed ETAW data provided by IrriWatch.</td></tr>
<tr><td>1. 39% of all IUs (14 of 36) had an ETAW greater than AGW and CUF greater than 1. Assuming water did not come out of soil moisture storage in the rootzone, and a “third” water source other than precipitation and AGW was not available (e.g., shallow groundwater), these results are implausible.
2. 61% of all IUs (22 of 36) had an ETAW less than AGW and a CUF less than 1. While this is a plausible value, additional monitoring and information about these IUs would improve understanding of ETAW, AGW, and factors influencing each.
3. At the irrigation unit scale, there were unexplainable variations in ETAW without commensurate variation in AGW.
4. Completing systematic comparisons between AGW and ETAW led to important adjustments to the methodology and assumptions used by IrriWatch to quantify ETAW, including adjustments influencing ETAW on parcel-fields with sparse vegetative cover and setting ETAW equal to zero for fallowed parcel-fields.
5. Grower feedback from Project participants following the two IrriWatch adjustments showed increased support or acceptance of IrriWatch ETAW results.</td><td>1. Continue systematic comparisons between AGW and ETAW in 2023 and beyond. In order to facilitate comparisons, this requires obtaining ETAW results even for lands utilizing flowmeters and AGW volumes for allocation tracking.
2. For future systematic comparisons, continue to seek to include a coverage of lands representative of Madera County GSA lands as a whole. To the extent differences are present between future lands included in systematic comparisons and all Madera County GSA lands, continue to investigate conditions that may cause or influence those differences.
3. Perform additional research with academic partners to better understand potential “third” water supply sources, especially for parcel-fields with CUFs exceeding 1 near streams and unlined water conveyance facilities.

This could include:
a. Shallow groundwater monitoring
b. Monitoring of nearby streams or surface water conveyance
c. Detailed ground-based in-field data collection on both ETAW and AGW</td></tr>
</table>

[65] Multiple growers expressed interest in including privately-owned lands that were unable to be included because the irrigation units intersected jurisdictional GSA boundaries (these included irrigation district boundaries, county boundaries, and subbasin boundaries). In these cases, a well in one GSA could be used to irrigate lands in another GSA, and the procedures for quantifying and documenting either ETAW or AGW between the two GSAs need to be established.

Conclusions	*Recommendations*
6. Systemic comparisons between AGW and ETAW should be continued to improve understanding of ETAW, AGW, and CUF.	

Recommendations associated with Objective 4 include the following:

1. Continue evaluation of input data, assumptions, and results for ETAW with IrriWatch (Ongoing).
2. Develop a system for (1) verifying fallow parcel-fields with participating landowners before the start of each year (*i.e.,* parcel-fields that have no applied water for the accounting period), (2) programmatically set ETAW to zero for verified fallowed parcel-fields, and (3) use fallowed fields for the selection of the hot pixels for each IrriTile.
3. Develop an improved and locally-refined spatial precipitation dataset using ground-based precipitation observations within the Madera County GSAs to improve estimates of precipitation (P) and ET of precipitation (ETPR) at the parcel-field scale.
4. Consider development of simplified procedure for computing and applying effective precipitation (*i.e.,* evapotranspiration of precipitation or ETPR) based on ranges of precipitation (*i.e.*, a specified percentage effective (*e.g.*, 75%) for different ranges of precipitation (*e.g.*, 5 to 10 inches).

Recommendations associated with Objective 5 include the following:

1. Allow growers in the Madera County GSAs the discretion to choose the method of quantifying ETAW that is best suited to their operations and the field conditions in each farm unit. Optional methods include direct use of ETAW estimates from IrriWatch, or calculating ETAW based on AGW volumes measured with properly installed, maintained, and sufficiently accurate permanent flowmeters multiplied by appropriate CUFs (yet to be established).
2. Continue to build Madera County Water and Natural Resources staff capacity to manage various aspects of GSP implementation, including collection and quality controlling of flowmeter data and coordination and communication with growers on results.
3. Improve understanding of irrigation efficiency for the major white area crops, on-farm practices, and other conditions in order to be understand CUF and differences between ETAW and AGW.
4. Develop a systematic procedure to convert AGW to ETAW. This could be done utilizing published average irrigation efficiencies corresponding to irrigation method, utilizing on-the-ground results of distribution uniformity (DU) and on-farm water use, or some combination of the two. Coordination and cooperation with existing programs (East Stanislaus RCD had a grant-funded program offering free irrigation evaluations to growers in Madera County in 2022) is crucial for utilizing on-the-ground data sources.
5. Consider transitioning the allocation water accounting period from a calendar year basis (January 1 through December 31) to a water year basis (October 1 through September 30) to better capture the cycle of wet and dry conditions and the associated applied water requirements for irrigated agriculture in California.
    a. Based on feedback from participating growers, some were supportive of this idea while others preferred the calendar year basis. Solicitation of grower feedback to better understand grower concerns and priorities, and how this transition would impact grower operations and farm management, should be completed prior to any accounting period changes.
6. Develop semi-automated or automated process to generate monthly grower reports and carryover and penalty reports regardless of the source of ETAW data (*e.g.,* flowmeters, remote sensing, etc.).

7. Compare IrriWatch remotely-sensed ET to other remote sensing products, such as OpenET or Land IQ.
8. Install or identify ground-based ET stations to compare to IrriWatch remotely sensed ET.
9. Install a series of shallow monitoring wells in key locations to assess, quantify, and determine if subsurface flows in specific regions of the Madera County GSAs are contributing to variation in ETAW and AGW.

Recommendations associated with both Objectives 4 and 5 include the following:

1. Remove parcel-fields less than one acre in size from allocation tracking program.
2. Improve coverage of land use and cropping.
3. Improve parcel boundary and field delineations.
4. Improve frequency of land use surveys.

5 References

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6 Technical Appendices

The Technical Appendices supporting the Final Report are listed below and available in subsequent pages:

6.1. Grower Outreach and Engagement
- 6.1.1. Solicitation of Interest and Grower Workshop on April 25, 2022
- 6.1.2. Initial Grower Meetings and Selection of Participating Lands (June 2022)
- 6.1.3. Coordination with Participating Growers (June 2022 to January 2023)
- 6.1.4. Final Grower Meetings (December 2022 to January 2023)
- 6.1.5. Grower Workshop on January 25, 2023
- 6.1.6. Solicitation of Additional Grower Feedback (January 2023)

6.2. Field Data Collection
- 6.2.1. Open Data Kit (ODK) System Overview
- 6.2.2. Flowmeter Readings and Comparison Flow Measurements
- 6.2.3. Flowmeter Inspections
- 6.2.4. Observation of In-Field Conditions

6.3. Aggregation of Additional Data
- 6.3.1. Aggregation of IW Data from API
- 6.3.2. Aggregation of CIMIS Data from CSU Fresno State Location
- 6.3.3. Additional Data Provided by Growers
- 6.3.4. Overview of GSAs and GSPs in Madera County

6.4. Data Management
- 6.4.1. Open Data Kit (ODK) Protocols
- 6.4.2. Web App Development
- 6.4.3. Permanent Flowmeter Data Adjustments
- 6.4.4. IrriWatch Adjustments

6.5. 2022 Verification Project Results and Outreach Materials
- 6.5.1. Supplementary Results and Figures
- 6.5.2. Irrigation Unit Summary Reports
- 6.5.3. Flowmeter Summary Reports
- 6.5.4. Materials from Grower Outreach and Engagement

Please see the 2022 Madera Verification Project Report for all Technical Appendices.