2023 MADERA VERIFICATION PROJECT

FINAL REPORT

PREPARED FOR
Madera County - Department of Water and Natural Resources

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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
CUF	Consumptive Use Fraction
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
FMA	Flowmeter Account
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
ISRIC	International Soil Reference and Information Centre
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

Abbreviation	Description
P	Precipitation
PEFF	Effective Precipitation
PMAs	Projects and Management Actions
Project	Madera Verification Project
Project Lands	25 Verification Project Participating Growers and 28 Growers with Flowmeter Accounts
QA/QC	Quality Assurance/Quality Control
SEBAL	Surface Energy Balance Algorithm for Land
SGMA	Sustainable Groundwater Management Act
T	Transpiration
TPEFF	Total Effective Precipitation
U/S	Upstream
USBR	United States Bureau of Reclamation
VPP	Verification Project Participant

EXECUTIVE SUMMARY

ES 1 | BACKGROUND, PROJECT OBJECTIVES, AND PROJECT LANDS

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 of the subbasins underlying the County by 2040. The Madera County Groundwater Sustainability Agencies (GSAs)[1] are currently responsible for GSP implementation in the "white areas"[2] of the Chowchilla, Madera, and Delta-Mendota Subbasins. Other GSAs in Madera County are responsible for GSP implementation in the areas they manage in the subbasins. In most years, groundwater is the sole source of water for irrigation of agricultural lands in the Madera County GSAs, although surface water is available for some lands in wet years, such as 2023. Where necessary, 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 that represents the baseline, stable volume of groundwater in storage that is replenished from natural sources, and (2) transitional water that represents continued overdraft of the Chowchilla, Delta-Mendota, and Madera subbasins that will be incrementally reduced over the GSP implementation period (2020 through 2040), culminating in sustainable groundwater conditions. Importantly, the adopted allocation approach is based on the quantity

[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.

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 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 crop evapotranspiration (ET) of applied water (ETAW) – which largely results from groundwater consumption within the GSAs – from crop ET of precipitation (ETPR). Thus, ETAW was adopted as the quantitative accounting metric at the parcel scale for measuring and monitoring groundwater consumption against groundwater allocations within the GSAs. This approach formed the basis for the data collection and analysis documented in this report.

Through extensive public vetting by an independent advisory group, in late 2020, the GSAs chose IrriWatch/Hydrosat[5] as the preferred approach for quantifying ETAW for comparison to groundwater allocations[6]. The 2021 and 2022 calendar years were used to configure, implement, and test the IrriWatch platform prior to the enforcement of allocations and penalties, which began 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 (2022 Project). The 2022 Project was a collaborative effort between the Madera County GSAs and participating growers to compare in-field measurements of AGW using permanent flowmeters to ETAW provided by IrriWatch[7]. The 2022 Project included 16 growers and roughly 12,000 acres of farmed land within the GSAs. One outcome of the 2022 Project was the recommendation that multiple groundwater allocation measurement options be made available to growers. As a result, in 2023, allocation measurement options were expanded to include three allocation measurement options: Flowmeters, IrriWatch, and Land IQ. The Madera Verification Project was continued in 2023 (2023 Project) to advance the 2022 Project recommendations, to evaluate these three allocation measurement options across a more extensive and representative sample of lands within the GSAs (relative to the 2022 Project), and

[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 and 2023 field data collection activities, providing evidence to support this assumption.

[5] IrriWatch/Hydrosat uses remote sensing data and methods to quantify actual evapotranspiration. In 2023, IrriWatch was purchased by Hydrosat. All future references in this report will solely describe IrriWatch.

[6] 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.

[7] The 2022 Project had the following objectives: (1) increase grower engagement, education, and outreach; (2) evaluate flowmeter accuracy; (3) develop and test procedures for use of flowmeter data to quantify AGW; (4) evaluate data needs and data collection methods for both ETAW and AGW; (5) develop improvements to processes of quantifying ETAW and AGW; and (6) to compare ETAW and AGW for participating lands.

to assess year-to-year variability in ETAW measurements (2022 was a “critical” water year, while 2023 was a “wet” water year as classified by the San Joaquin Valley Water Year Index[8]).

The 2023 Project objectives were as follows:

1	**Increase grower engagement, education, and outreach related to SGMA implementation, particularly groundwater allocations and options for measuring groundwater consumption in comparison to the allocations.**
2	**Implement and refine methods and procedures for collecting, developing, and/or processing the data required to quantify AGW/ETAW for the three allocation measurement options (Flowmeters, IrriWatch, and Land IQ).**
3	**Compare and analyze available results across the three allocation measurement options (Flowmeters, IrriWatch, and Land IQ) and a fourth independent ETAW measurement (OpenET).**
4	**Provide conclusions and recommendations for implementing the groundwater allocation program in 2024 and future years.**

As during the 2022 Project, the GSAs coordinated to obtain key data necessary to achieve the 2023 Project objectives through voluntary, collaborative partnerships with 25 participating growers [Verification Project Participants (VPPs)] within the Madera County GSAs. Davids Engineering, Inc. (DE) facilitated a Grower Workshop for potential VPPs on June 15th, 2023, and subsequently met with VPPs individually to discuss the 2023 Project and its objectives and to review potential participating lands and verify field data collection needs. During this process, VPPs identified the locations of their groundwater wells (and associated flowmeters) and the parcel-fields[9] they irrigate. Parcel-fields owned or managed by a common VPP that collectively receive all the irrigation water pumped by one or more groundwater wells were grouped into irrigation units (IUs)[10]. In total, the 25 VPPs farmed 66 unique IUs comprising nearly 14,000 acres. However, the 2023 Project was unique compared to the 2022 Project because additional flowmeter data was available for comparison with remotely-sensed ETAW. The 2023 Project also included data from an additional 28 growers representing roughly 15,000 acres of farmed

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[8] A historical record of the San Joaquin Valley Water Year Index is available through the California Data Exchange Center (CDEC) at: https://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST

[9] 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).

[10] An Irrigation Unit is defined as one or more parcel-fields receiving all the irrigation water pumped from one or more groundwater wells owned or managed by a common grower.

land and 37 IUs for which flowmeter readings were available to compare to the other allocation measurement options. These additional lands, called Flowmeter Accounts (FMAs) represent growers who selected flowmeters as their allocation measurement method for 2023 and consistently reported their volumetric AGW data to the Madera County GSAs throughout the year. Collectively, VPPs and FMAs are referred to as Project Lands.

A summary of the crops and associated acreages in the 2023 Project compared to the overall cropping and acreages in the Madera County GSAs indicates that Project Lands represented roughly 23% of the total farmed land in the GSAs (Table ES-1). The four most common crops grown within the Madera County GSAs (*i.e.*, Almonds, Grapes, Pasture, and Pistachios) were the four most common crops included in the Project[11], and the relative proportion of crop acreages in the 2023 Project were within 5% of the equivalent crop acreage percentage for the Madera County GSAs in every crop category. These results demonstrate a crop composition in the 2023 Project that is generally representative of the GSAs, a significant improvement over the 2022 Project. Project lands included seven different crops (excluding dryland and fallow) distributed among six Farm Unit Zones[12] within the Madera GSAs (Figure ES-1[13]).

After the initial meetings with the VPPs, extensive field data collection on VPP lands began in the latter half of June 2023 and continued through early January 2024[14]. The field data collected[15] on VPPs' lands during the Project included:

[11] Some summary materials present results aggregated by the most common crops. These summary materials exclude pasture because not all of it is irrigated, and because a combination of other crop types could be classified as pasture (e.g. alfalfa, grasses, wheat, etc.).
[12] 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.
[13] Only VPP lands are shown in Figure ES-1, not FMA lands.
[14] Flowmeter data from January through June 2023 were also requested from participating growers and applied to the overall dataset, as available.
[15] The field data collection for the Project is described in more detail in Section 6.2.

Readings of instantaneous flow and totalized volume from permanent flowmeters.

Additional ("spot") flow measurements made with a portable transit time flowmeter for comparison to flow measurements from permanent flowmeters.

Observations of relevant in-field conditions (*e.g.,* evidence of surface water use, irrigation type or equipment, crop type and/or health, evidence of cover crops, presence of tailwater, evidence of shallow perched groundwater, etc.).

Evaluation of permanent flowmeter installation for consistency with manufacturer specifications.

In addition to the field data described above, additional data aggregated[16] for use in the 2023 Project included:

AGW volumes reported directly from FMA growers.

ET, ETAW, P, and ETPR data from IrriWatch, Land IQ, and OpenET.

A variety of other datasets to support the comparison between ETAW from remotely-sensed methods and measured AGW volumes from permanent flowmeters.

The sections following Table ES-1 and Figure ES-1 present a brief summary and discussion of results related to each of the 2023 Project objectives. The final objective includes conclusions and recommendations for the groundwater allocation program moving forward in 2024 and beyond.

[16] The aggregation of additional data for the Project is described in more detail in Section 6.3.

Table ES-1: Summary of Cropping in the Project and GSA lands.

Crop	2023 Madera Verification Project Lands (VPP and FMA lands)[17]			Madera County GSAs			Acreage % Difference (2023 Verification Project – GSAs)
	Parcel-Field Count	Acreage	Acreage %	Parcel-Field Count	Acreage	Acreage %	
Alfalfa	8	494	1.7%	165	5,932	4.7%	-3.0%
Almonds	307	10,403	35.4%	1,474	40,880	32.2%	3.2%
Citrus	60	992	3.4%	68	1,453	1.1%	2.3%
Corn	11	592	2.0%	16	1,074	0.8%	1.2%
Dryland[18]	13	603	2.1%	151	5,060	4.0%	-1.9%
Fallow	27	1,337	4.6%	500	7,049	5.6%	-1.0%
Grapes	101	4,487	15.3%	498	14,218	11.2%	4.1%
Pasture[19]	77	5,012	17.1%	1,486	24,257	19.1%	-2.1%
Pistachios	215	4,583	15.6%	899	20,986	16.5%	-0.9%
Other[20]	36	880	3.0%	263	5,899	4.8%	-1.8%
Totals[21]	**854**	**29,383**	**100.0%**	**5,520**	**126,807**	**100.0%**	**-**

[17] VPP = Verification Project Participants and FMA = Flowmeter Accounts.

[18] Dryland describes lands farmed using only precipitation and no applied water for irrigation. The dryland areas included in the Project are dryland wheat, and the parcel-field Count and Acreage for the Madera County GSAs were determined using IrriWatch's parcel-fields that have a planted crop but are not irrigated and an assumed percentage of overall wheat being dryland farmed.

[19] Pasture crops include irrigated wheat fields.

[20] The other crop classification includes small area crops such as cotton, olives, other deciduous, tomatoes, walnuts, and grasses. In addition, this classification includes land uses/crop classes that make up the rest of the Parcel-Fields in the Madera County GSAs. These include cherries, figs, kiwis, onions, urban areas, unknown land types, and variety of other tree crops.

[21] Although crop type was field verified and is accurate for all lands participating in the 2023 Project, there were some corrections required from the original crop shown in the Allocation Database at the onset of the Project. For cropping in the overall Madera County GSAs, the coverage is generally representative but not expected to be completely accurate. Continuing to improve land use coverage is a recommendation resulting from the Project.

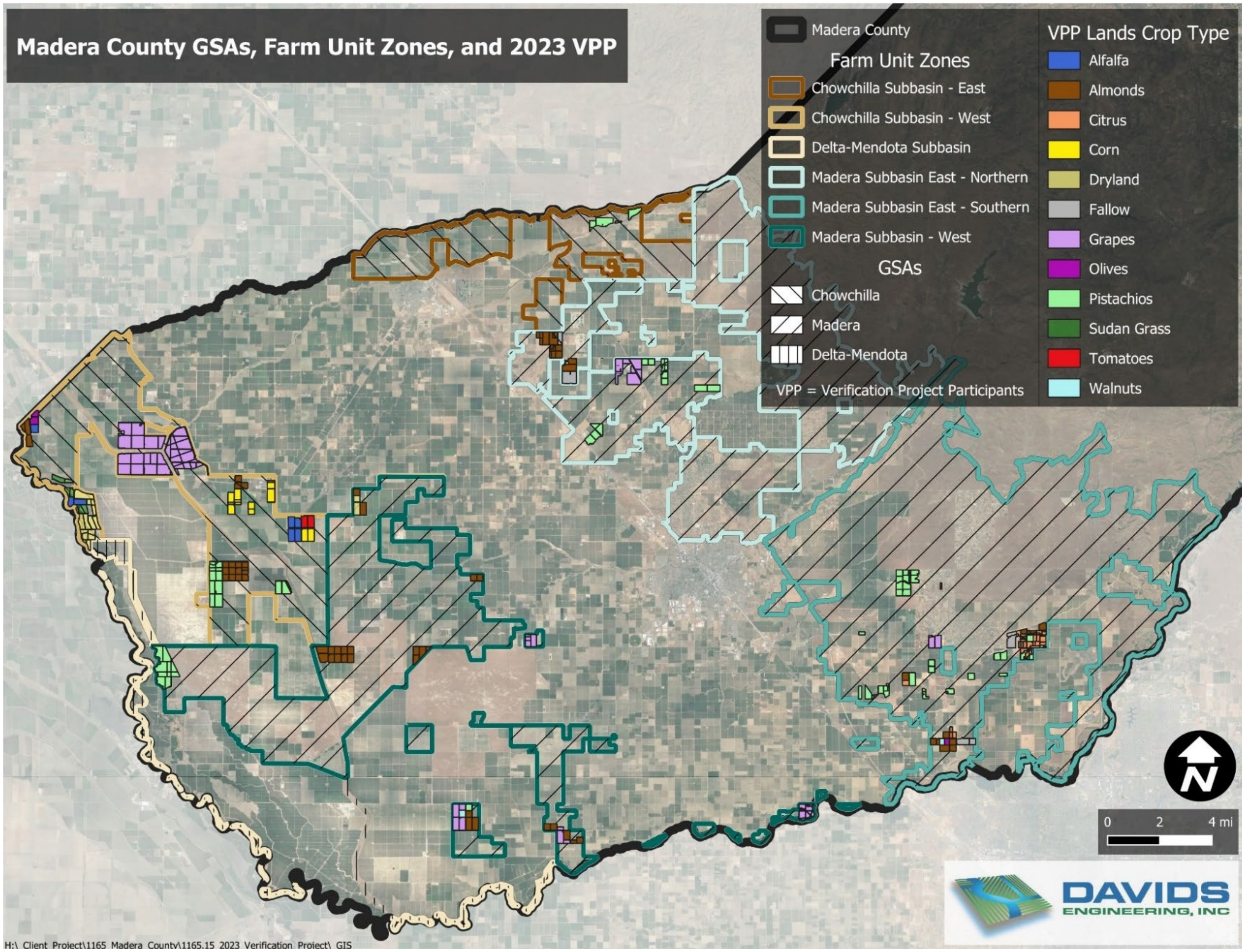

Figure ES-1. Madera County GSAs, Farm Unit Zones, and farmed lands for Verification Project Participants (VPPs).

ES 2 | OBJECTIVE 1: INCREASE GROWER ENGAGEMENT

Due to the dynamic nature of GSP implementation and changing hydrologic conditions, regular grower engagement, education, and outreach is essential. Increased outreach to growers as part of the 2023 Project led to a higher number of VPPs than in the 2022 Project. Project outreach occurred through both grower workshops and individual meetings, and growers had multiple opportunities for individual meetings with GSA and DE staff, in addition to coordination throughout the irrigation season and informal in-field meetings during field data collection. A grower survey was distributed towards the end of the 2023 Project, and all respondents indicated that they clearly understood the intent of the 2023 Project and that it was helpful in leading to practical conclusions and recommendations. Additionally, all respondents indicated support for continuing the Madera Verification Project in 2024 and that they would be willing to participate again in 2024.

Of the 16 2022 Project participants, 12 (75%) also participated in the 2023 Project and all indicated they would be willing to participate for a third year in 2024.

Continuing to maintain and improve long-term relationships with growers through collaborative efforts like the Madera Verification Project is important.

ES 3 | OBJECTIVE 2: FLOWMETER ACCURACY ASSESSMENT

VPPs had a total of 114 permanent flowmeters that were included in the 2023 Project. Based on an in-field review of each flowmeter installation, 97 of the 114 flowmeters (85%) were installed consistent with manufacturer specifications and 17 (15%) were not. When combined with the 2022 Project data, a total of 267 comparison measurements have been made with a portable transit time meter to evaluate the accuracy of the permanent flowmeters. Of the combined measurements collected to date, 206 measurements (77%) were on flowmeters that were installed per manufacturer specifications and 61 measurements (23%) 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 8.8%, while the MAPE for flowmeters not installed per manufacturer specifications was 17.1%. These results illustrate the improvement in accuracy for flowmeters installed per manufacturer specifications versus those that are not. For flowmeters installed per manufacturer specifications, many comparison measurements have a difference of less than 8.8% while a minority have larger differences, sometimes substantially larger. Considering all comparison flow measurements in aggregate (regardless of flowmeter installation), the MAPE was less than 11%.

These results (1) provide evidence that flowmeters can accurately quantify AGW (although there are instances when even a flowmeter installed per manufacturer specifications can be inaccurate) and (2) illustrate that installing and maintaining flowmeters per manufacturer specifications substantially improves accuracy.

ES 4 | OBJECTIVE 2: IMPLEMENT AND REFINE METHODS AND PROCEDURES

Implementation of the groundwater allocation program is a complex process that is dependent on a wide variety of data sources, quality assurance/quality control (QA/QC) and management procedures, assumptions, calculations, etc. which differ for each of the three allocation measurement options. Recent progress to facilitate implementation of the groundwater allocation program and streamline review of ETAW measurement as part of the 2023 Project includes development of a mobile data collection platform and online portal for submittal and review of flowmeter readings, respectively; design and creation of an online database to house and manage all data required for groundwater allocation program implementation (e.g. parcels, parcel-fields, land ownership, flowmeter locations, IU configurations, etc.); and development of automated processes to assist with data processing, management, QA/QC, and quantification of ETAW. These new tools and processes are designed to streamline the management and implementation of the groundwater allocation program. Training with Madera County GSA staff on best practices and use of these tools was conducted over the duration of the 2023 Project. Lastly, as part of the 2023 Project, data for all three allocation measurement options was reviewed, resulting in edits and data improvements such as corrections to errant flowmeter readings and adjustments to IrriWatch ETAW readings for 2023.

While QA/QC by DE staff helped to identify potential issues in submitted data, close coordination with growers and Madera County GSA staff was also needed to ensure an accurate, representative dataset could be used for analysis in this report. Following QA/QC, individual conversations with growers, and coordination with Madera County GSA staff, 21 IUs were identified as having data quality issues that prevented them from being included in the final dataset. Specifically:

1. 16 (15.5%) IUs had incomplete records of flowmeter data submissions for 2023 (i.e., these IUs did not have a 2023 flowmeter reading by April 15, 2023 or earlier)

2. Four (3.8%) IUs were not entirely contained within the Madera County GSAs (i.e., some irrigated lands within the IU were outside of the GSAs). For areas outside of the GSAs, remote sensing results were unavailable and ETAW had to be estimated.

3. Nine (8.7%) IUs had other data integrity issues ranging from (1) uncertainty in location and number of wells being used to extract AGW, (2) uncertainty in the volume of surface water applied to a field for irrigation/recharge purposes, and (3) remote sensing methods programatically setting ETAW to zero for fields that were only partially fallowed.

While every effort was made to identify IUs with potential data quality issues in 2023, additional data quality investigations were ongoing into 2024. More details about IUs with data quality issues are provided in Section 6.4.3.

ES 5 | OBJECTIVE 3: COMPARISON OF AGW AND ETAW

Following data collection and review, monthly ground-based AGW measurements and remotely-sensed ETAW estimates were evaluated for all irrigated IUs (fallow IUs were excluded) without data quality issues (n = 71; see Section 6.4.3 for more details). Summing across all irrigated IUs, the cumulative AGW through December 31, 2023, was 27.1 inches (IN), on average, while cumulative ETAW was 24.4 in., 23.1 in., and 24.5 in. for IrriWatch, Land IQ, and OpenET, respectively (Figure ES-2). An AGW volume greater than ETAW was expected because not all AGW contributes to ETAW; rather, some AGW contributes to deep percolation and runoff[22] during the process of applying irrigation water (the relationship between AGW and ETAW is influenced by a variety of factors, including irrigation method[23]). In summary, when aggregating all data together, ground-based AGW and remotely-sensed ETAW follow anticipated trends.

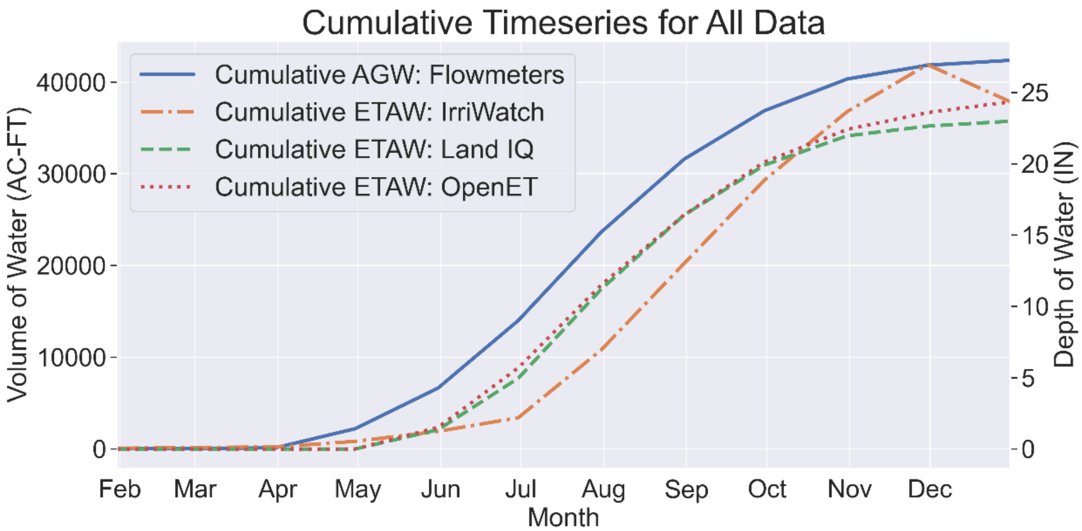

Figure ES-2. Cumulative volume (left) and depth (right) of applied groundwater (blue solid), IrriWatch evapotranspiration of applied water (ETAW; orange dash-dot), Land IQ ETAW (green dash), and OpenET (red dot) for all crops and Irrigation Units (n = 71) for all Project Lands without data quality issues. Cumulative values are calculated by summing up AGW and ETAW values for each month from each Irrigation Unit. The decrease in ETAW for IrriWatch in December 2023 was due to an IrriWatch adjustment. IrriWatch made adjustments that reduced the calculated ETAW for all parcel-fields; this adjustment was applied on December 31, 2023.

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[22] Runoff, or tailwater, from AGW is assumed to be negligible for pressurized irrigation systems.

[23] Irrigation method plays a major role in on-farm water use efficiency, which translates into having a significant impact on Consumptive Use Fractions (CUFs). 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.

Summing all IU data together helps illustrate and aids evaluation of the aggregated, average trends of AGW and ETAW across all irrigated IUs. However, since allocation penalties and carryovers will be assessed on the individual parcels within an IU, an evaluation of AGW, ETAW, and Consumptive Use Fraction (CUF)[24] trends for individual IUs was needed to understand variability of these parameters on a smaller scale. For the 2023 Project, the CUF is a comparison of remotely-sensed estimates of ETAW (by either IrriWatch, Land IQ, or OpenET) to ground-based measurements of AGW by flowmeters. In an agricultural context, the CUF is a metric that describes how much water is consumed by crops for growth relative to the total amount of water applied for irrigation. To assess CUF trends on a smaller scale, distributions of CUF for all IUs and IUs with major crop types are shown in Figures ES-3 and ES-4 for each remotely-sensed ETAW method. While a linear regression of ETAW as a function of AGW (see Section 3.2.2 for more details) in Figure ES-4 indicates representative CUFs between 0.77 and 0.80, many IUs had a CUF greater than one (to the right of 1.0 in Figure ES-2 or above the solid 1:1 line in Figure ES-4). Notably, regardless of the remote sensing method considered, almonds had the most IUs with CUFs greater than one, with many exceeding 1.2. If all applied water, precipitation, evapotranspiration (of precipitation and applied water), and changes in soil moisture were accurately and precisely quantified, a CUF value greater than one would be physically impossible. Due to measurement uncertainty and a variety of influencing factors, some variability in CUF values is anticipated, but values above 1.0 are unexpected because not all water applied for irrigation will be consumed by the crop (e.g. even with precise application of irrigation water through drip or micro-spray systems, there will be some losses).

[24] 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 ASCE 2016 (https://cimis.water.ca.gov/). For example, if 100 acre-feet (AF) were applied and 85 AF were consumed as ETAW, this would result in a CUF value of 0.85 (e.g. 85/100).

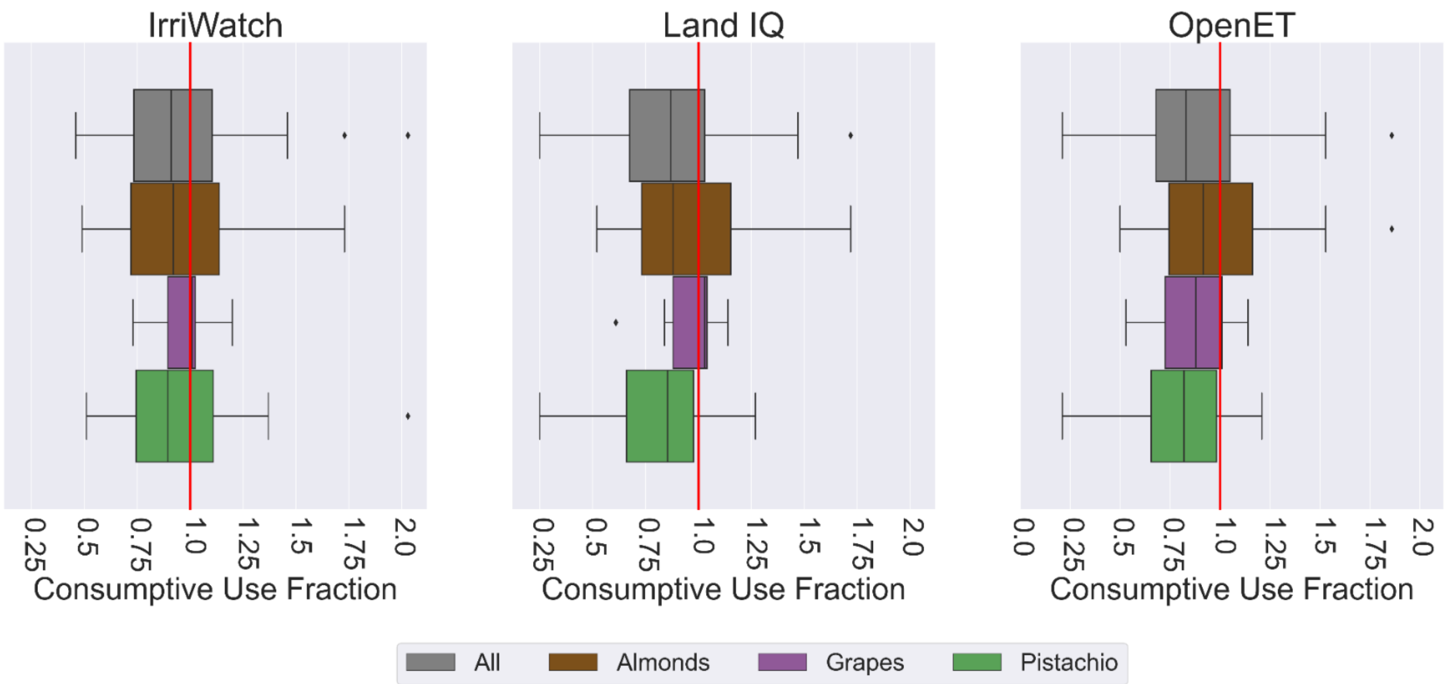

Figure ES-3. Boxplots showing distribution of Consumptive Use Fraction (CUF) for all Irrigation Units (IUs) considered in the 2023 Verification Project (All; n = 71) and IUs with a single major crop type: Almonds (n = 18), Grapes (n = 6), and Pistachios (n = 27). CUFs are shown for each remotely-sensed method used in this study (IrriWatch, Land IQ, OpenET). The results shown include applicable data from all Project Lands. A boxplot shows the median value (line within the box), the 25th and 75th percentile values (left and right edges of each box, respectively), and the minimum and maximum values for the data (excluding any outliers, which are shown as dots).

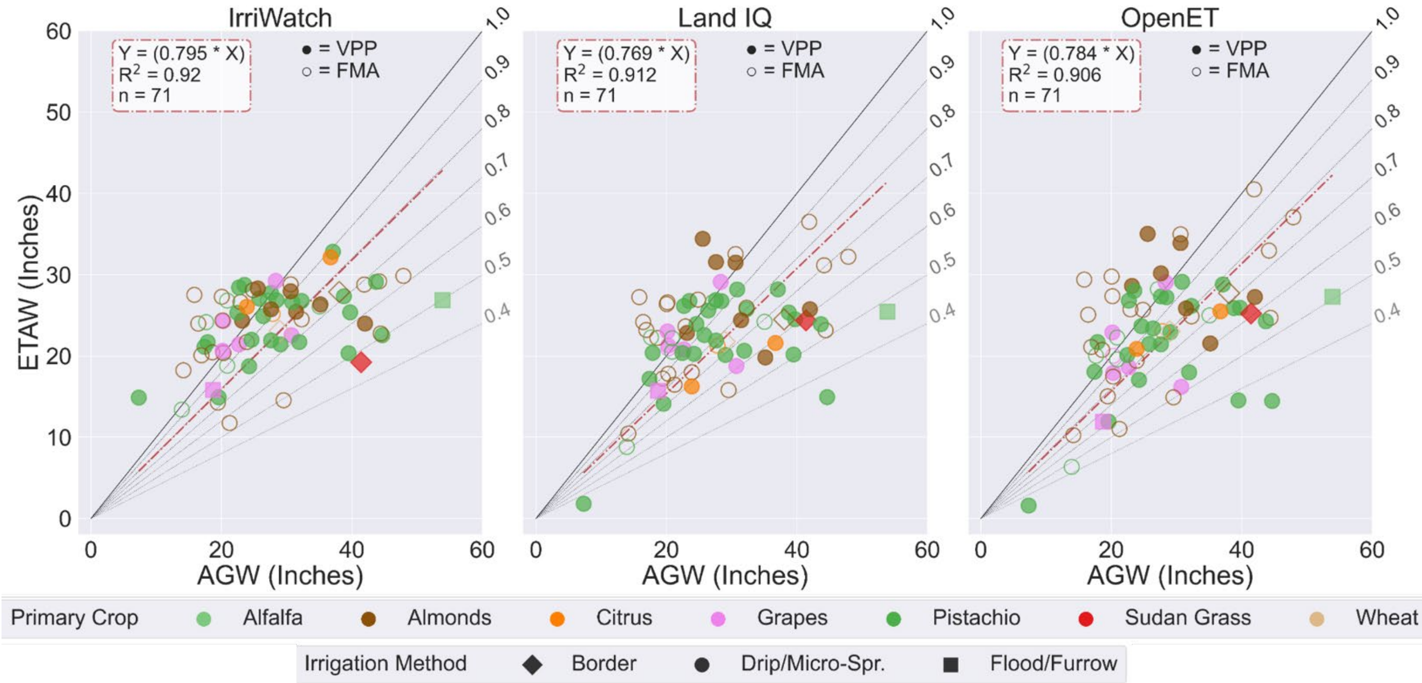

Figure ES-4. Summary of evapotranspiration of applied water (ETAW) and applied groundwater (AGW) for 71 Irrigation Units (IUs) for (1) IrriWatch, (2) Land IQ, and (3) OpenET. "VPP" refers to IUs that participated in the 2023 Madera Verification Project while "FMA" refers to IUs that used flowmeters as their allocation measurement method during 2023. Crop colors represent the primary crop for each IU by acreage (e.g., the crop that covered the largest area within that IU); some of the IUs shown have mixed cropping.

As observed in Figures ES-3 and ES-4, there are multiple IUs with CUFs greater than one, particularly for almond IUs. This result is consistent with the 2022 Project findings as well, which only included IrriWatch ETAW data. This discrepancy for some IUs between ground-based AGW measurements and all remotely-sensed ETAW estimation methods has been present for 2022 and 2023. Contributing factors leading to CUF values greater than one could be one or more of: (1) uncertainty and/or 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 the measured AGW and precipitation) available to crops (*e.g.*, AGW from wells that have not been accounted for, water flowing into the root zone from shallow groundwater or nearby surface water features, such as ditches or ponds, etc.). Use of root-zone soil moisture and a third source of water (2 and 3 above) may have a large impact in individual cases, but the extent of CUF values greater than one (and high variability in CUF values overall) seems to indicate some level of uncertainty/error in quantification of ETAW and/or AGW. This uncertainty/error should be studied further, as described below. 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. 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 and may be supported by new technology and emerging science.

ES 6 | OBJECTIVE 4: CONCLUSIONS AND RECOMMENDATIONS

The groundwater allocation program is irreducibly complex, but is necessary to achieve groundwater sustainability. Successful implementation of the program requires use of the best available information and clear communication of the program and its many facets to growers to ensure that it is operated and enforced in a consistent, fair, and repeatable manner. The 2022 and 2023 Projects provided an important opportunity to review the foundational data and procedures behind the groundwater allocation program. The 2022 Project included conclusions and recommendations for the groundwater allocation program in 2023 and beyond. As part of the 2023 Project, significant improvements were made based on outcomes from the 2022 Project:

1. Ongoing engagement between Madera County GSAs and growers led to increased grower participation as VPPs in the 2023 Project, compared to the 2022 Project, and resulted in participation of lands that were more representative of overall farmed lands in the Madera County GSAs (Objective 1).

2. An online data portal was created (DE Data Portal) where growers can submit their volumetric flowmeter readings via a mobile data collection form accessible from a smartphone or tablet. Flowmeter readings can then be manually reviewed and applied to IUs to track usage relative to groundwater allocations (Objective 2).

3. Development of an online database (Allocation Database) to manage data related to the groundwater allocation program such as groundwater wells, associated flowmeters, associated irrigated lands forming IUs, growers or landowners, and changes occurring over time (Objective 2).

4. The implementation of multiple measurement options for quantification of ETAW under the groundwater allocation program (Objective 2).

5. As described above, the development of new tools and processes to facilitate implementation of the groundwater allocation program for multiple measurement options, along with Madera County GSA staff training on use and implementation of new tools and procedures (Objective 2)

6. The comparison of multiple AGW and ETAW quantification methods revealed high variability and, in some cases, deviations from expected results when comparing ground-based AGW measurements and remotely-sensed ETAW estimates (Objective 3).

As noted above, 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) consistently implement the GSAs' groundwater allocations (including carryover and penalties) for County growers individually and collectively. While there is no strict quantitative definition of what is "sufficiently accurate" in SGMA or otherwise, large uncertainties between methods used to track ETAW need to be understood and minimized to achieve groundwater sustainability in a fair and equitable manner. The 2023 Project was a valuable continuation of the 2022 Project and shows continuing discrepancies and/or uncertainties, in some cases, between ground-based AGW methods (flowmeters) and remotely-sensed ETAW estimation methods (IrriWatch and Land IQ) chosen to enforce groundwater allocations. In this context, the 2023 Project results lead to the following conclusions and recommendations, which are framed around the 2023 Project objectives:

Objective 1: Increase grower engagement, education, and outreach related to SGMA implementation, particularly groundwater allocations and options for measuring groundwater use in comparison to the allocations.

1. Grower engagement, education, and outreach remains critical, and needs to be adaptable and suited to meet grower needs; due to dynamic process of SGMA implementation and changing hydrologic conditions, growers will need to informed of and understand any relevant issues and opportunities over time.

2. Spending time in the field or in individual or small group meetings with growers studying and discussing 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. Improved availability of data related to groundwater usage and allocations should be prioritized to provide growers with on-demand information or more frequent updates on their groundwater usage. A secure and password-protected online data portal with grower-specific information is recommended.

Objective 2: Implement and refine methods and procedures for collecting, developing, and/or processing the required input data to quantify AGW/ETAW for the three allocation measurement options (Flowmeters, IrriWatch, and Land IQ).

1. Improved data systems (i.e., the Data Portal and Allocation Database) were effective at streamlining QA/QC processes, correcting linkage issues between farmed lands and Irrigation Units, and maintaining a record of changes made over time.

2. Semi-automated, near real-time review of flowmeter and remotely-sensed data are necessary to identify and address errors in submitted AGW volumes and refine the methods and assumptions used to estimate ETAW. Close data review needs to continue in 2024 and beyond to ensure data accuracy, and as identified, opportunities to improve data review and management should be implemented.

3. Flowmeters remain accurate for measurement of AGW if installed and maintained correctly, but require QA/QC, understanding of where AGW is applied for irrigation, irrigation method, and CUF for conversion to ETAW.

4. Remote sensing provides spatially explicit data on a large spatial scale but requires quantification of ETPR and conversion from ET to ETAW. Remotely-sensed ETAW from different sources is more similar in aggregate than individually. Differing individual results between sources should be studied to better understand differences and their underlying causes.

Objective 3: Compare and analyze available results across the three allocation measurement options (Flowmeters, IrriWatch, and Land IQ) and a fourth independent ETAW measurement (OpenET).

1. When aggregated for all crop types and lands, the CUF values calculated by comparing ETAW (IrriWatch, Land IQ, and OpenET) to AGW (Flowmeters) are reasonable (e.g. 0.77 to 0.80).

2. However, substantial variability in CUFs exists between crops and for individual IUs for all three remotely-sensed ETAW estimation methods (IrriWatch, Land IQ, and OpenET); this was also true in 2022 for only IrriWatch.

3. Similar to 2022 Project results, CUFs exceeding 1.0 are not uncommon in the 2023 Project and cannot be fully explained by this dataset.

Objective 4: Provide recommendations for the groundwater allocation program for 2024 and future years.

As described above, the 2022 and 2023 Projects have been an important review of the groundwater allocation program, and have provided conclusions and recommendations that have improved the program. Specifically, Madera County GSA staff found that comparing remotely-sensed ETAW to flowmeter AGW on a large-scale was useful to identify IUs with questionable data. Unpermitted and unreported pumped wells represent a “third” source of water not properly accounted for in this report, which could lead to the high variability shown in CUFs. As a result, IUs with unrealistically high CUFs (e.g., exceeding 1.2) were investigated further by Madera County GSA staff to ensure all wells within that IU were properly identified and permitted. It is recommended that this type of investigation be continued in 2024 and beyond to ensure well/flowmeter compliance. Because the 2023 Project was useful to the groundwater allocation program, and considering support from VPPs to continue the Madera Verification Project in 2024, it is recommended that a 2024 Project be completed as well.

Every aspect of the 2022 and 2023 Projects (*e.g.*, grower coordination, field data collection, data review and analysis, etc.) was led by DE staff. For the 2024 Project, it is recommended that DE staff train Madera County GSA staff to lead project activities to the extent possible, with DE staff providing support as needed. Per this recommendation, DE staff would train Madera County GSA staff in processes used for grower coordination, planning field data collection, conducting field data collection, and processing and analyzing data. DE staff would provide support as requested by Madera County GSA staff. Training Madera County GSA staff in these processes will support the GSAs’ internal capacity to continue future iterations of the Madera Verification Project in 2024 and beyond, maintaining a robust dataset to further refine each allocation measurement method while minimizing consultant support from DE staff (with the goal of eliminating it over time).

In addition to the recommendations described above, after observing IUs with CUFs greater than one consistently in 2022 and 2023, a more detailed assessment of water moving in and out of a Parcel/IU is recommended to fully understand AGW vs. ETAW discrepancies. Specifically, it is recommended that the County pursue additional efforts to better quantify uncertainty in ETAW estimates and quantify potential “third” water supply sources. These additional assessments are especially needed for IUs with CUFs exceeding one.

Potential next steps include:

1. **For growers using flowmeters as their allocation method, Madera County GSA staff should ensure all wells are identified and properly permitted.**
2. **Comparison of remotely-sensed ETAW to high-quality, ground-based ETAW within Madera County GSAs.**
3. **Monitoring of soil moisture, shallow groundwater, and irrigation efficiency within IUs.**
4. **Continued coordination with growers to document additional water sources (e.g., surface water) used throughout the irrigation season, if present.**

It is also recommended that collaborative partnerships be developed between the Madera County GSAs, academic researchers, other local agencies and consultants to successfully implement the additional assessments above. This type of collaboration should be designed to materially benefit local end users (e.g., GSAs and growers) while seeking to better understand and improve the accuracy of measurement methods used for SGMA implementation.

1 INTRODUCTION

1.1 2023 Madera Verification Project Location

Madera County (County) has significant and indisputable ties to agriculture. In 2022, approximately 345,000 acres were farmed within the County (excluding rangeland) with a total estimated value of nearly $2 billion (Madera County Department of Agriculture, 2023). Many of these farming operations, particularly those in the Madera County Groundwater Sustainability Agencies (GSAs)[25], 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 the agricultural production occurs and includes lands in three San Joaquin Valley groundwater subbasins: Chowchilla, Delta-Mendota, and Madera. The 2023 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 2023 Madera Verification Project (Project) took place in the Madera County GSAs in the Madera and Chowchilla Subbasins[26] (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)[27]. 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 Verification Project Participants (VPPs) targeted growers in each of the GSAs and FUZs to encourage broad participation and develop 2023 Project results for a representative sample across the Madera County GSAs.

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

[26] 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.

[27] 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.

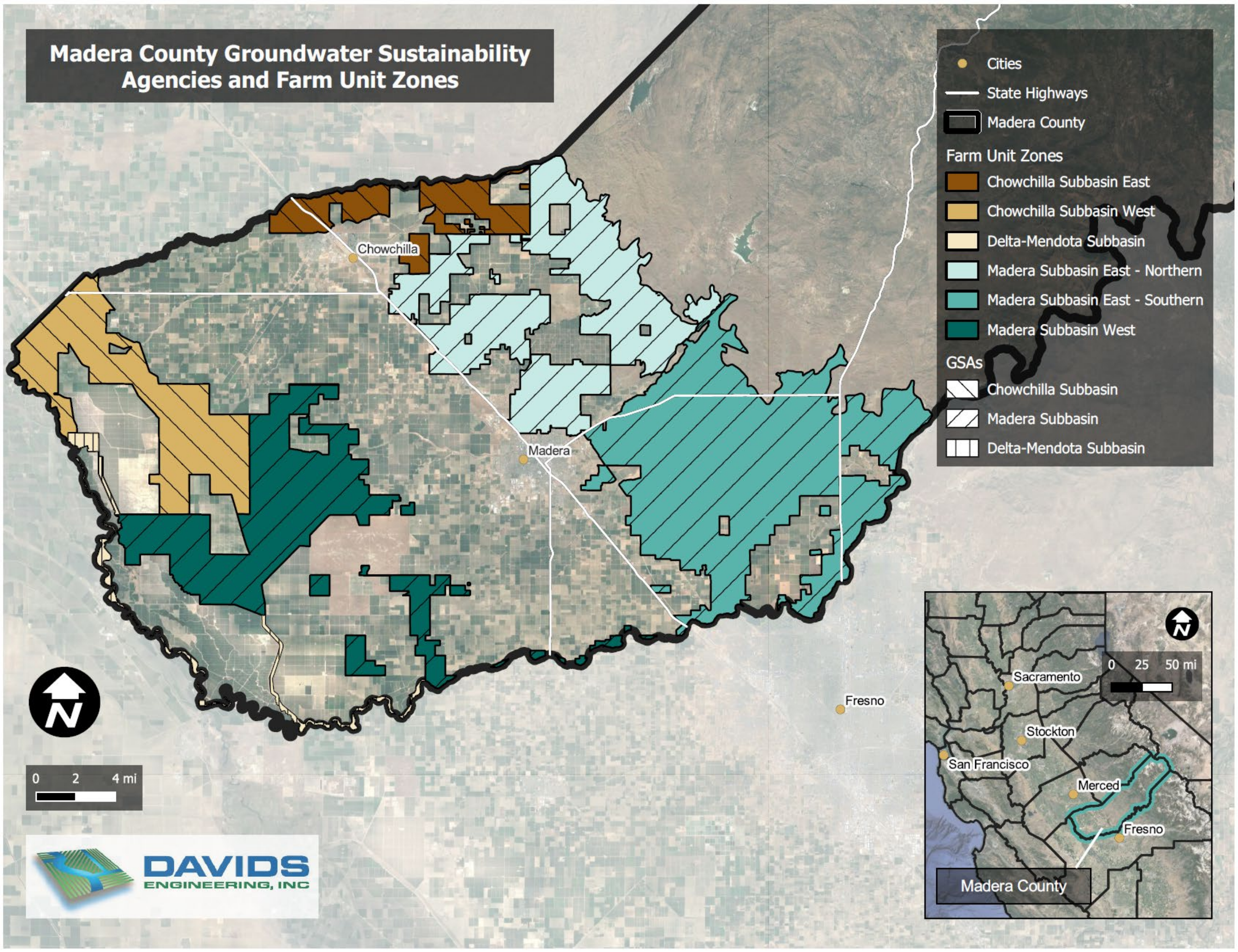

Figure 1-1. Overview of Madera County Groundwater Sustainability Agencies and Farm Unit Zones.

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

1.2.1 Overview of SGMA and GSPs

In 2014, the State of California passed the Sustainable Groundwater Management Act (SGMA)[28] 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 the subbasins in Madera County (Chowchilla, Delta-Mendota, and Madera) were designated as high priority subbasins and

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

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 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[29]) 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. Therefore, to achieve sustainability by 2040, as outlined in the Madera Joint GSP and other GSPs, demand management is an important component of GSP implementation. Demand management 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.

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)[30]. Actual ET can be quantified using satellite-based remote-sensing methodologies, and ETAW can be calculated by subtracting the portion of ET supported by precipitation (ETPR) from ETa. In late 2020, and through extensive public vetting by an independent advisory group, the GSAs selected

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

[30] 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 consumed and no longer available in the subbasin).

a company called IrriWatch/Hydrosat[31] to monitor and quantify ETAW for all lands within the GSAs. IrriWatch data were provided to Madera County GSA growers in 2021 and 2022. Following the 2022 Verification Project (2022 Project) and coordination with Madera County GSAs, multiple groundwater allocation measurement options (Flowmeters, IrriWatch, and Land IQ) were made available for monitoring and quantification of ETAW for GSA lands in 2023 and beyond as part of the Madera County GSAs' groundwater allocation program.

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[32]. Further, recognizing that crops consume precipitation (P) as well as AGW stored in the root zone, it is important for purposes of groundwater allocation and accounting to distinguish between crop ETPR and crop 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.

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%[33]. 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.

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[31] IrriWatch/Hydrosat uses remote sensing data and methods to quantify actual evapotranspiration. In 2023, IrriWatch was purchased by Hydrosat. All future references in this report will solely describe IrriWatch.

[32] 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.

[33] 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.

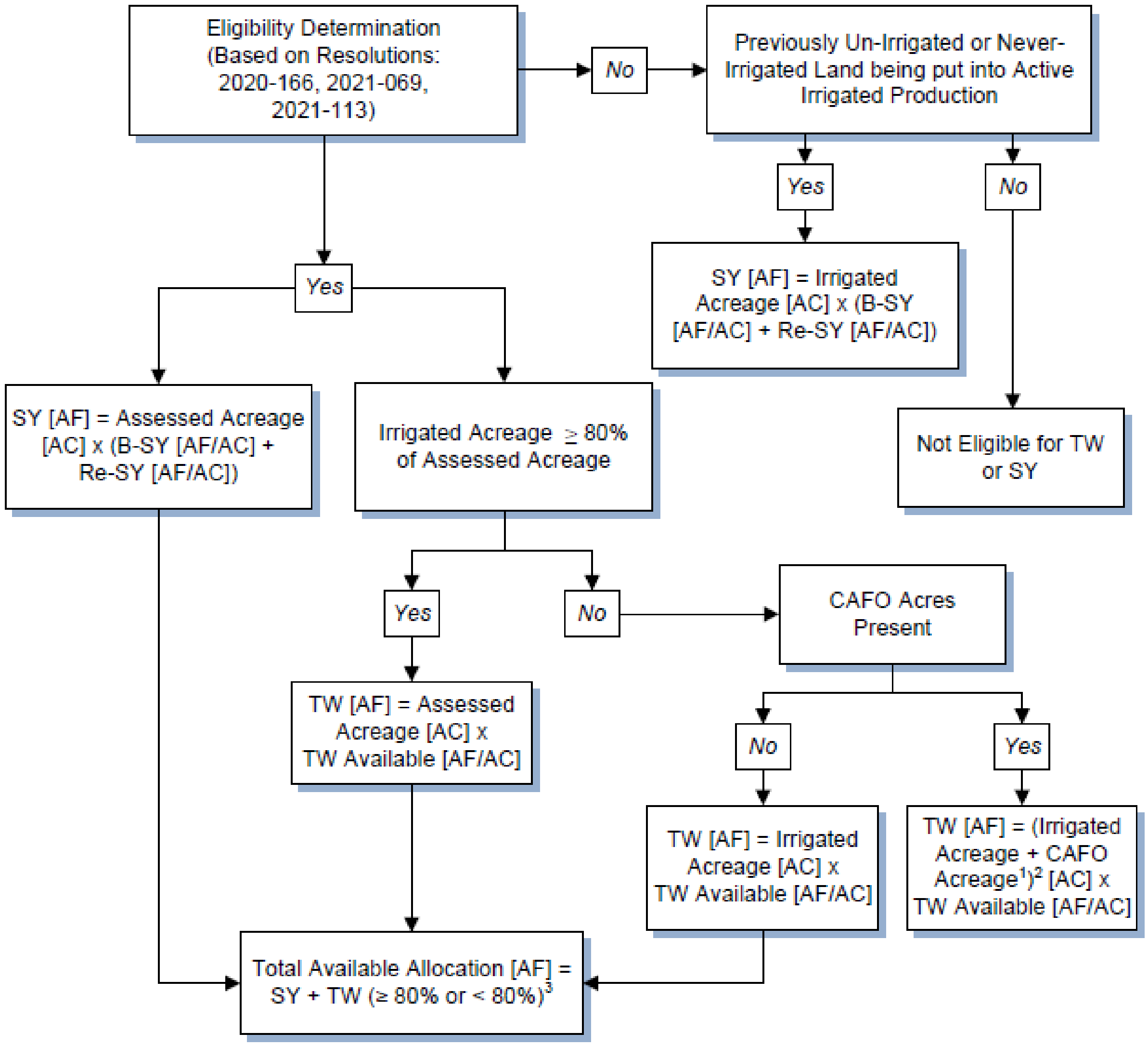
At the farm and field level, allocations will be implemented by the GSAs as a defined number of inches (IN) of ETAW over a respective acreage per year (allowing for calculation of a total volume in AF to monitor implementation against the GSP implementation goals and sustainability targets). Allocations 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		
	Sustainable Yield (in/year)	Transitional Water (in/year)	Total Allocation (in/year)
Chowchilla Subbasin			
2021	7.1	19.6	26.7
2022	7.1	19.2	26.3
2023	7.1	18.8	25.9
2024	7.1	18.4	25.5
2025	7.1	18.0	25.1
Delta-Mendota Subbasin			
2021	8.6	11.2	19.8
2022	8.6	11.0	19.6
2023	8.6	10.7	19.3
2024	8.6	10.5	19.1
2025	8.6	10.3	18.9
Madera Subbasin			
2021	12.7	15.6	28.3
2022	12.7	15.3	28.0
2023	12.7	15.0	27.7
2024	12.7	14.7	27.4
2025	12.7	14.4	27.1

Madera County Groundwater Allocation Logic

- 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.

1.2.4 Summary of Allocation Measurement Methodologies for Madera County GSAs

Unlike the 2022 allocation, the 2023 allocation allowed growers to select among three allocation measurement options (Flowmeters, IrriWatch, and Land IQ) for tracking ETAW at the parcel scale. Each option is briefly introduced below.

1.2.4.1 Overview of Flowmeters

Ground-based measurements of AGW[34] using flowmeters provide growers with real-time information regarding how much water is being applied to their fields. This information is directly controlled and submitted by the grower, so they have real-time information about how much water they are using in comparison to their allocated amount throughout the year. After grower submittal, there is a quality assurance/quality control QA/QC process and development of allocation report that can then be provided to the grower. This process takes some time, but steps to improve the efficiency of this are being implemented. The major drawback of using flowmeters as an allocation measurement method are the substantial efforts required to verify flowmeter accuracy, ensure proper installation and maintenance, and understand where AGW is applied for irrigation from each flowmeter. In addition, a consumptive use fraction (CUF)[35] is estimated based on the irrigation method to convert AGW to ETAW.

1.2.4.2 Overview of IrriWatch

IrriWatch is a platform which utilizes remote sensing data, and associated assumptions and methodologies, to estimate 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. Among the reasons for originally selecting IrriWatch were that it offered a direct estimate of ETAW (rather than actual ET), 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. However, IrriWatch required two adjustments to their ETAW data in 2022 and one adjustment in 2023 (identified during data review as part of the 2022 and 2023 Projects), indicating that the results currently provided by the IrriWatch team benefit from review and QA/QC measures and may need adjustment in future years as well.

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[34] Because 2023 was a Wet year, some growers in the Madera County GSAs had access to surface water for irrigation or groundwater recharge. As a result, some of the water measured via flowmeters included both surface water and groundwater. Accurately accounting for surface water volumes will be critical for successful implementation of flowmeters as an allocation measurement option; initial steps were taken in 2023 to do this in coordination with VPPs.

[35] 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 ASCE 2016 (https://cimis.water.ca.gov/). For example, if 100 acre-feet (AF) were applied and 85 AF were consumed as ETAW, this would result in a CUF value of 0.85 (e.g. 85/100).

1.2.4.3 Overview of Land IQ

Land IQ uses a combination of ground-based measurement stations, remote sensing data, and associated assumptions and methodologies to estimate ET and P. Monthly ET and P results are provided by Land IQ and then converted to ETAW using established methods (see Section 2.2.3for more details). More information about Land IQ is available at: https://www.landiq.com/land-iq-et. Land IQ is a well-established and trusted remote sensing method within the Western United States for measuring crop ETa. Drawbacks include lack of an online portal for real-time data visualization by growers, data latencies of four to six weeks after the end of the month, and the need to convert ET to ETAW after results are provided by Land IQ. Additional information provided by Land IQ includes maps of land use (e.g. crop types) and data about the age of permanent crops.

1.2.5 Summary of Independent Comparison Method for 2023 Madera Verification Project

For the 2023 Project, a fourth, independent method of estimating ETAW was used for comparison purposes. More details on this independent method can be found below.

1.2.5.1 Overview of OpenET

OpenET is an alternative method that uses remotely-sensed data to estimate ET using six different models. Monthly ET results are provided and then converted to ETAW using established methods (see Section 2.2.4 for more details). More information about OpenET is available at: https://openetdata.org/. Like Land IQ, OpenET drawbacks include the lack of an online portal for real-time data visualization by growers, data latencies of four to six weeks after the end of the month, and the need to convert ET to ETAW after results are available and downloaded.

1.3 2023 Madera Verification Project (2023 Project) Background, Objectives, and Report Structure

1.3.1 2023 Project Background

In late 2020, and through extensive public vetting by an independent advisory group, the GSAs chose IrriWatch as the preferred approach for quantifying ETAW for comparison to groundwater allocations[36]. The 2021 and 2022 calendar years were used to configure, implement, and test the IrriWatch platform prior to the enforcement of allocations and penalties, which began in 2023. The 2021 results and grower feedback led to a more extensive review of ETAW from IrriWatch in 2022 through the 2022 Project. The 2022 Project was a collaborative effort between Madera County and growers to compare applied groundwater data collected from on-farm flowmeters to remotely-sensed ETAW from IrriWatch. The 2022 Project included 16 growers and roughly 12,000 acres of farmed land within the GSAs. One recommendation from the 2022 Project was the provision of multiple groundwater allocation measurement options; in 2023, allocation measurement options included Flowmeters, IrriWatch, and Land IQ. The Madera Verification

[36] As described previously, 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.

Project was continued in 2023 (2023 Project) to further 2022 Project objectives and to evaluate these three allocation measurement options and year-to-year variability (2022 was Critical, while 2023 was Wet). Like the 2022 Project, the 2023 Project included grower outreach and collaboration, in-field data collection, development of data acquisition and management methods, special analyses, and a comparison of remotely-sensed ETAW from IrriWatch and Land IQ (and OpenET) to AGW data collected in the field. The 2023 Project objectives and an outline of this report are provided subsequently.

1.3.2 2023 Project Objectives

The 2023 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 and options for measuring groundwater use in comparison to the allocations.
2. Implement and refine methods and procedures for collecting, developing, and/or processing the required input data to quantify ETAW for the three allocation measurement options (Flowmeters, IrriWatch, and Land IQ).
3. Compare and analyze available results across the three allocation measurement options (Flowmeters, IrriWatch, and Land IQ) and a fourth independent ETAW measurement (OpenET).
4. Provide recommendations for the groundwater allocation program for 2024 and future years.

The 2023 Project was unique compared to the 2022 Project given the flowmeter data available for comparison with remotely-sensed ETAW. Specifically, like the 2022 Project, a subset of the data used to achieve 2023 Project objectives were pursued through voluntary, collaborative partnerships with 25 participating growers [Verification Project Participants (VPPs)] within the Madera County GSAs. In coordination with Davids Engineering (DE), VPPs identified the locations of their groundwater wells (and associated flowmeters) and the parcel-fields[37] they irrigate. Parcel-fields owned or managed by a common VPP receiving all the irrigation water pumped by one or more groundwater wells were grouped into irrigation units (IUs)[38]. In total, the 25 VPPs farmed 66 unique IUs comprising nearly 14,000 acres. However, unlike the 2022 Project, the 2023 Project also included data from an additional 28 growers representing 15,000 acres of farmed land and 37 IUs for which flowmeter readings were available to compare to the other allocation

[37] 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).

[38] An Irrigation Unit is defined as one or more parcel-fields receiving all the irrigation water pumped from one or more groundwater wells owned or managed by a common Project Grower.

measurement options[39]. These additional lands, called Flowmeter Accounts (FMAs) represent growers who selected flowmeters as their allocation measurement method for 2023 and accurately reported their totalizer AGW data to Madera County. Collectively, VPPs and FMAs are referred to as Project Lands.

1.3.3 Overview of Report Structure and Contents

The 2023 Project final report is structured as follows:

Introduction (Section 1) – provides an overview of the project location and SGMA (including information on GSP development and implementation in Madera County, including the groundwater allocation program) to provide greater context around the 2023 Project, along with listing the Project Objectives.

Methods (Section 2) – The Methods section describes the methodologies used to pursue and accomplish the Project Objectives. This includes grower outreach and selection of participating growers/lands, collection and management of in-field data, collection of additional data, and data analysis and evaluation.

Results and Discussion (Section 3) – The Results and Discussion section presents data collection results, including analysis of collected in-field data, remotely-sensed ETAW data, and additional data (along with a description of various data issues) and explores and evaluates the results of the 2023 Project.

Conclusions and Recommendations (Section 4) – The report's Conclusions and Recommendations section identifies conclusions and recommended next steps beyond the 2023 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.

References (Section 5) – This section provides a list of references used throughout the report.

Technical Appendices (Section 6) – The Technical Appendices contains additional information and details about the 2023 Project, the methodologies used, and the results obtained. References to relevant sections of the Technical Appendices are included throughout the report.

[39] Conclusions and recommendations in this report were developed using irrigated (i.e., not fallow) Irrigation Unit data that had been verified to have no known issues. Therefore, of the 103 total Irrigation Units at the start of the 2023 Project, only 71 were considered in the data analysis and subsequent conclusions and recommendations sections. See Section 4.4 for more details.

2 METHODS

2.1 Grower Engagement, Education, and Outreach (Objective 1)

Solicitation of grower interest for participation in the 2023 Project was completed during Spring 2023 through both routine and special meetings, and through direct outreach to individual growers, including a grower workshop on June 15th, 2023[40]. Although a larger number of growers expressed interest, ultimately, 25 growers who met the requirements and submitted the necessary information were selected for participation in the 2023 Project. These VPP growers farmed 66 IUs comprising nearly 14,000 acres. In addition to the VPPs, the 2023 Project also included data from an additional 28 growers representing about 15,000 acres of farmed land and 37 IUs for which flowmeter readings were available to compare to the other allocation measurement options. These FMA lands represent growers who selected flowmeters as their allocation measurement method for 2023 and accurately reported their totalizer AGW volume data to Madera County.

All crops and associated acreages in the 2023 Project (both VPPs and FMAs) are presented in Table 2-1 and all VPPs are shown in Figure 2-1. Project Grower lands represent roughly 23% of total farmed land in the GSAs (Table 2-1). Project Lands included a variety of different crops distributed among the six FUZs within the Madera County GSAs (Figure 2-1). The four most common crops grown within the Madera County GSAs (*i.e.*, Almonds, Grapes, Pasture, and Pistachios) were the four most common crops included in the 2023 Project[41], and the crop acreage percentages in the 2023 Project were within 5% of the crop acreage percentage for the Madera County GSAs as a whole in every crop category. These results demonstrate a crop composition in the 2023 Project that was generally representative of the GSAs and a significant improvement over the lands represented in the 2022 Project. Project Lands included seven different crops (excluding dryland and fallow) distributed among six Farm Unit Zones[42] within the Madera GSAs.

Initial meetings with potential VPPs were conducted individually in person and virtually in June 2023 to discuss the 2023 Project, project objectives, review potential participating lands, and define IUs (*i.e.*, establish the connection between GW wells and lands where pumped water is applied for irrigation)[43]. Figure 2-2 visually depicts and describes the differences between

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[40] More information about the solicitation of interest and initial grower workshop can be found in Section 6.1.1.

[41] Some summary materials present results aggregated by the most common crops. These summary materials exclude pasture because not all of it is irrigated, and because a combination of other crop types could be classified as pasture (e.g. alfalfa, grasses, wheat, etc.).

[42] 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.

[43] More information about the initial grower meetings and selection of participating lands can be found in Section 6.1.2.

Parcels/APNs, Fields, Parcel-Fields, and IUs through use of a hypothetical example[44]. The creation of IUs for FMAs was based on information about well and flowmeter locations and irrigated lands submitted by growers, along with necessary grower coordination and outreach to clarify or confirm understanding of the submitted materials.

2.2 Implement and Refine Methods for Data Collection, Management, Processing, and Quantification of ETAW (Objective 2)

2.2.1 Flowmeters

Field data collection included readings of instantaneous flow and totalized volume from permanently installed (grower) flowmeters, flow measurements made with a portable transit time flowmeter for comparison to permanent flowmeters, and review of permanent flowmeter installations for consistency with manufacturer specifications. Flowmeter readings from VPPs were also submitted by growers and reviewed for QA/QC by Madera County or DE staff, including multiple site visits and corresponding readings at every flowmeter location by DE staff. Flowmeter readings from FMAs were also submitted by growers and were reviewed for QA/QC by Madera County staff, with support from DE staff as requested. Flowmeter readings from FMAs were not field verified by DE staff. All data for Project Lands went through an extensive QA/QC process after data collection and submission to ensure data accuracy. Additional details are provided below.

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[44] 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.

Table 2-1. Cropping Summary for the 2023 Madera Verification Project and the Madera County GSAs.

Crop	2023 Madera Verification Project Lands (VPP and FMA lands)[45]			Madera County GSAs			Acreage % Difference (Verification Project - GSAs)
	Parcel-Field Count[46]	Acreage	Acreage %	Parcel-Field Count	Acreage	Acreage %	
Alfalfa	8	494	1.7%	165	5,932	4.7%	-3.0%
Almonds	307	10,403	35.4%	1,474	40,880	32.2%	3.2%
Citrus	60	992	3.4%	68	1,453	1.1%	2.3%
Corn	11	592	2.0%	16	1,074	0.8%	1.2%
Dryland[47]	13	603	2.1%	151	5,060	4.0%	-1.9%
Fallow	27	1,337	4.6%	500	7,049	5.6%	-1.0%
Grapes	101	4,487	15.3%	498	14,218	11.2%	4.1%
Pasture[48]	77	5,012	17.1%	1,486	24,257	19.1%	-2.1%
Pistachios	215	4,583	15.6%	899	20,986	16.5%	-0.9%
Other[49]	36	880	3.0%	263	5,899	4.8%	-1.8%
Totals[50]	**854**	**29,383**	**100.0%**	**5,520**	**126,807**	**100.0%**	**-**

[45] VPP = Verification Project Participants and FMA = Flowmeter Accounts.

[46] 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).

[47] Dryland describes lands farmed using only precipitation and no applied water for irrigation. The dryland areas included in the Project are dryland wheat, and the Parcel-Field Count and Acreage for the Madera County GSAs were determined using IrriWatch's Parcel-Fields that have a planted crop but are not irrigated and an assumed percentage of overall wheat being dryland farmed.

[48] Pasture crops include irrigated wheat fields.

[49] The other crop classification includes small area crops such as cotton, olives, other deciduous, tomatoes, walnuts, and grasses. In addition, this classification includes land uses/crop classes that make up the rest of the Parcel-Fields in the Madera County GSAs. These include cherries, figs, kiwis, onions, urban areas, unknown land types, and variety of other tree crops.

[50] Although crop type was field verified and is accurate for all lands participating in the 2023 Verification Project, there were some corrections required from the original crop shown in the Allocation Database at the onset 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.

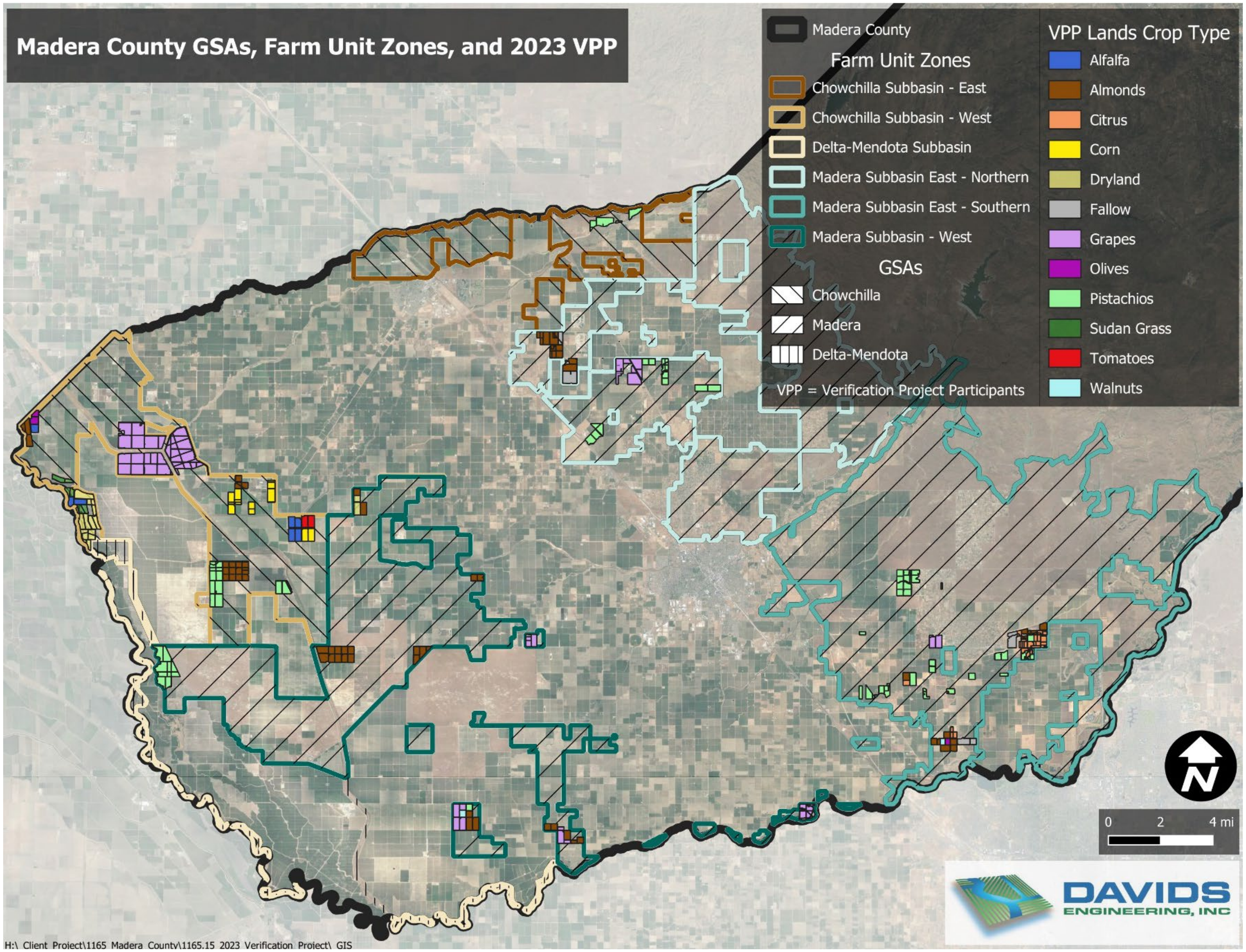

Figure 2-1. Madera County GSAs, Farm Unit Zones, and farmed lands for Verification Project Participants (VPPs).

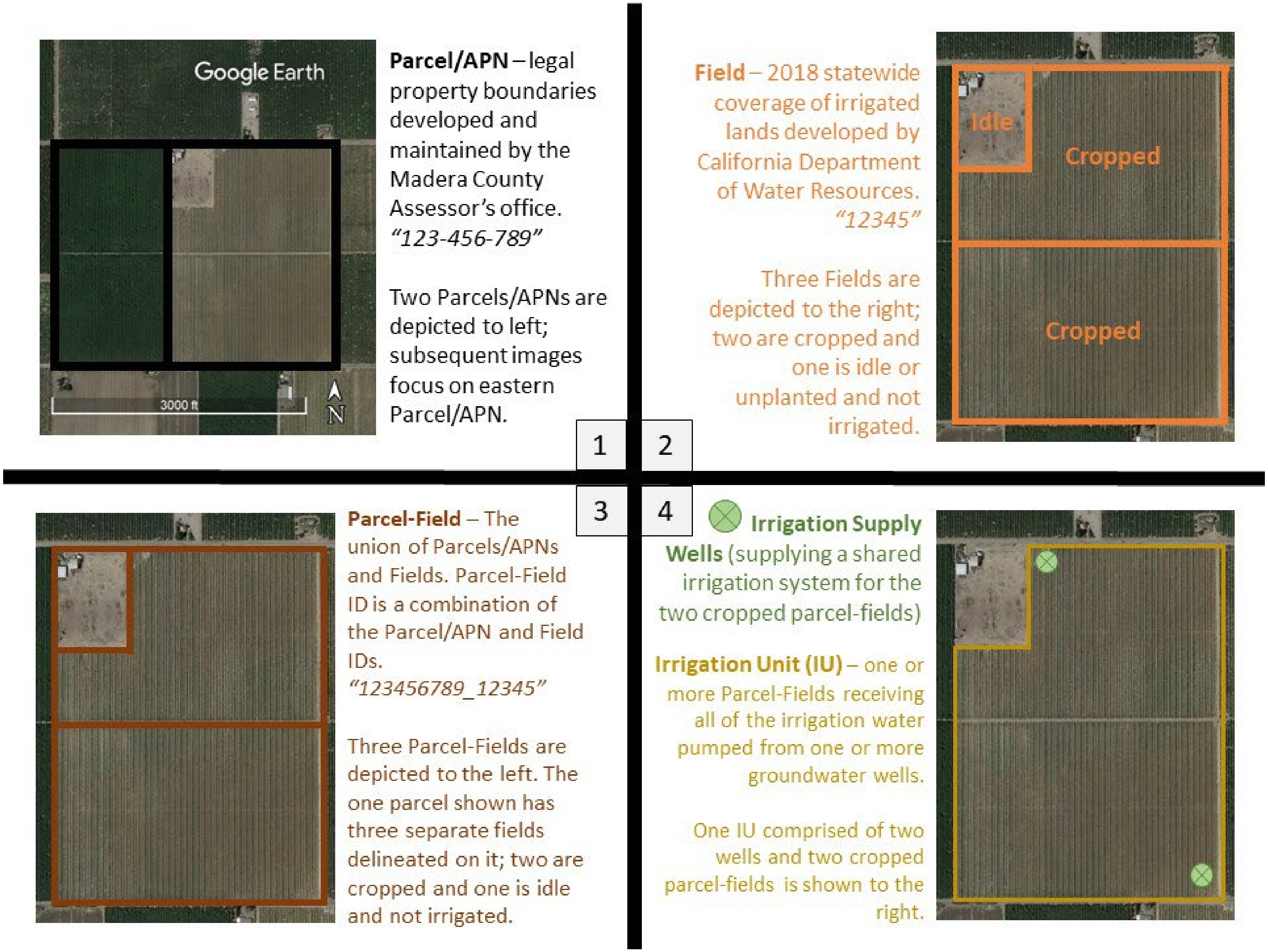

Figure 2-2. Example of Parcel/APN, Field, Parcel-Field, and Irrigation Unit (IU) delineations, including both visual depiction and descriptions.

2.2.1.1 Verification Project Participants

Following the initial meetings with VPPs in June 2023, extensive field data collection began and continued through January 2024[51]. Field data collection included readings of instantaneous flow and totalized volume from permanently installed (grower) flowmeters[52], 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, collection of in-field shallow soil samples[53], and observations of in-field conditions. This required close coordination with VPP growers[54].

Field data were collected and submitted using forms developed in MS Excel using XLSForms and imported into and published via Open Data Kit (ODK)[55]. These data were housed in the DE Data Portal where QA/QC procedures were completed (e.g. verifying readings were attributed to the correct site, the readings were entered into forms correctly, etc.). The data were then processed to calculate the cumulative AGW of each flowmeter and aggregated up to the Irrigation Unit level to determine the AGW of the Irrigation Unit for comparison with the other methods. Additional data regarding flowmeter installation, comparison flow measurements, or other parameters were also processed and incorporated into the final dataset and results, as applicable.

2.2.1.2 Flowmeter Accounts

While FMA flowmeters were not field verified by DE staff, all data went through the same QA/QC process to ensure data accuracy prior to incorporation into the final analysis. Specifically, FMA growers submitted totalized flowmeter data using an ODK Form. These data were then pulled into the DE Data Portal and QA/QC'd to verify the readings were attributed to the correct site and the readings were entered into the form correctly. The data were then processed to get the cumulative AGW of each flowmeter and aggregated up to the Irrigation Unit level to determine the AGW of the Irrigation Unit for comparison with the other methods.

2.2.2 IrriWatch

Daily ET, ETAW, P, and ETPR 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, various other datasets were 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.

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[51] More information about the field data collection can be found in Section 6.2.

[52] Flowmeter data from January through June 2023 were also requested from participating growers and applied to the overall dataset, as available.

[53] See Section 6.5.2.1 for more details about in field shallow soil samples.

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

[55] More information about ODK can be found in Section 6.4.1

IrriWatch estimates actual ET with the Surface Energy Balance Algorithm for Land (SEBAL). ET includes both ETPR and ETAW. Because the GSAs elected to use ETAW as the basis of measurement against groundwater allocations, IrriWatch computes ETAW as the difference between ET and ETPR ((Equation). IrriWatch computes ETPR using precipitation data from the National Oceanic and Atmospheric Association (NOAA)[56] 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.

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

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 ET and ETAW using Equation 1, and evaporation (E) was calculated by subtracting transpiration (T) from ETa.

2.2.3 Land IQ

Land IQ provides 30m x 30m raster files of ET and Precipitation on a monthly timestep. Land IQ uses remote satellite sensing and ground stations to develop these data across the area of interest. Land IQ uses a variety of remote sensing images (Landsat, Sentinel, and other purchased imagery) to get the required initial data and subsequently uses a network of ground stations to help calibrate and create an accurate data set. The underlying model used by Land IQ to estimate ET from remotely-sensed data is currently unknown; however, Land IQ's ground stations use a surface energy balance approach to calibrate remotely-sensed ET data. ET and P data is received from Land IQ approximately four to six weeks after the end of the month.

Since Land IQ does not provide ETPR data directly, DE staff calculate ETPR internally to convert ET to ETAW. Specifically, DE modified the U.S. Bureau of Reclamation (USBR) method (Stamm, 1967) to estimate ETPR from Land IQ P data. The USBR method assigns a percentage to monthly P values to estimate the portion of total P resulting in ETPR with a higher percentage of P resulting in ETPR as P values decrease, and vice versa (see Section 6.3.2.2 for more details). Following the estimation of EPTR, ETAW was calculated using Equation 1 above.

2.2.4 OpenET

OpenET provides open source, 30m x 30m, ET raster files using remotely-sensed datasets. Like IrriWatch, OpenET data is also retrieved via an API. As described above, OpenET is not a current allocation measurement method and was used solely as another independent method for comparison purposes. OpenET estimates ET using a suite of six different models. The ensemble model, which is an average of ET from all six models, was used by DE in the 2023 Project. OpenET only provides ET data (precipitation is not provided). As a result, ET provided by OpenET, P

[56] 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 .

provided by Land IQ, and the USBR method described above were used to estimate ETPR. ETAW was subsequently calculated using Equation 1.

2.3 Comparison and Analysis of Results (Objective 3)

The ratio of ETAW (as quantified by IrriWatch, Land IQ, and OpenET) to AGW (as measured by permanent flowmeters) defines the CUF as shown in$\text{Consumptive Use Fraction (CUF)} = \frac{\text{ETAW}}{\text{AGW}}$ (Equation 2) Although circumstances and results vary due to soil type, crop type, crop age, on-farm practices, geographic location, and other factors, CUF values are expected to be less than one because not all water applied to a field is consumptively used by crops. 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 or additional irrigation water sources being used but not included in the total AGW value. The CUF is the key metric used to facilitate the comparison of ETAW and AGW and evaluate results in Section 5.3 within crop categories, between crop categories, and across all crops for entirety of the lands included in the 2023 Project. To evaluate ETAW, AGW, and the resulting CUF, DE staff developed Python codes to process and organize data. Project results were aggregated to the IU level for all 2023 Project Lands.

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

2.4 Conclusions and Recommendations (Objective 4)

Conclusions and recommendations in this report were developed using data that had been verified to have no known issues. For example, IUs with missing flowmeter data, unreported applied water volumes, missing parcel-field information, and other issues were excluded from the final analysis and subsequent conclusions (see Section 6.4.3 for more details). In addition, the conclusions and recommendations were developed in coordination with growers and Madera County to incorporate their vision for future work within the GSAs. All conclusions and recommendations are framed around the four 2023 Project objectives described above.

3 RESULTS AND DISCUSSION

3.1 Grower Engagement, Education, and Outreach (Objective 1)

Due to the dynamic process of GSP implementation and changing hydrologic conditions, regular grower engagement, education, and outreach is essential. It was grower feedback that led to the first Verification Project in 2022. Increased outreach to growers as part of the 2023 Project led to a higher number of VPPs (25) than in the 2022 Project (16). Project outreach occurred through both grower workshops and individual meetings, and growers had multiple opportunities for individual meetings with County GSAs and DE staff, in addition to coordination throughout the irrigation season and informal in-field meetings during field data collection. More information regarding grower activities is highlighted in Section 6.1.

As described previously, there was an initial grower workshop and individual meetings with VPPs in June 2023, followed by regular coordination and outreach through the 2023 irrigation season. A final grower workshop and final meetings with VPPs, DE staff, and County GSAs staff were held in January 2024. These meetings included an overview of preliminary 2023 Project results, as well as a time for questions and discussion with each grower. Meetings were able to be scheduled with 16 of the 25 VPPs (64%). Based on meeting notes, a summary of important points and topics discussed and communicated by multiple VPPs during the final meetings are listed below. More details regarding the final grower meetings can be found in Section 6.1.4.

1. Growers expressed 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. Roughly half of the growers described changing their land and water management practices for reduced water availability under the groundwater allocation program. The most common practices included reducing irrigated crop acreage, implementing deficit irrigation, and acquiring additional lands currently in production and taking them out of production in order to use the allocation from those lands to provide sufficient water supplies for what they are currently farming.
3. Roughly half of the growers raised cover crops as a topic of concern and wanted to better understand the ET signature of cover crops and associated impacts on their groundwater allocations.
4. The VPPs use all three of the allocation measurement options. In the meetings, more than half of the growers expressed satisfaction with their selected allocation measurement options (inclusive of all three options). Some growers asked about and/or expressed a desire to consolidate allocation measurement options as well.
5. Additional points of topics of interest from the meetings include interest in increasing groundwater allocation program data availability (potentially through an online grower portal), discussion of flowmeter malfunctions, review of groundwater allocation program details, discussion of parcel-field boundary issues, and interest in continuing the Verification Project in future years.

Following the final grower meetings, in February 2024, DE solicited feedback from participating growers via a survey with specific questions related to the 2023 Project. A total of 9 out of 25 growers (36%) responded to the survey. A summary of the grower feedback is included below, and a detailed description of the grower questions and staff responses is available in Section 6.1.5.

1. Most 2023 Project participants who provided feedback (7, 78%[57]) also participated in the 2022 Project. Others learned about the 2023 Project through contact with Madera County staff (2, 22%).
2. A majority of participants (7, 78%) found it helpful to have interaction and coordination during the irrigation season and think it is important (6, 66% - Somewhat Important, 1, 12% - Very Important) to have County engagement and involvement in the field at a farm scale.
3. All respondents (9, 100%) understood the intent of the 2023 Project, thought it led to practical conclusions and recommendations, expressed interest in continuing the Project in 2024 and expressed willingness to continue participating in a 2024 Verification Project.
4. A majority of respondents rated their satisfaction with the 2023 Project as Very Good (5, 56%); the remainder ranked it as Good (3, 33%) and Okay (1, 11%).
5. Lastly, respondents provided additional feedback on what worked well as part of the Project, what did not work well, and any further information or thoughts. These responses are summarized in Section 6.1.5.

3.2 Implement and Refine Methods for Data Collection, Management, Processing, and Quantification of ETAW (Objective 2)

3.2.1 Flowmeters

VPPs had a total of 114 permanent flowmeters that were included in the 2023 Project. Based on DE staff's review of flowmeter installation conditions, of the 114 flowmeters, 97 (85%) were installed consistent with manufacturer specifications and 17 (15%) were not. In addition to inspecting flowmeter installation, DE also performed independent flow measurements using a portable transit time flowmeter (Fuji Electric Portaflow-C FSC-4 Ultrasonic Flowmeter [58]) to compare against the permanent flowmeters instantaneous flow measurement. This comparison between permanent flowmeters and portable Fuji flowmeters occurred during both the 2022 and 2023 Projects. The comparison measurements provide a valuable point of reference for differences in flow measurement between two independent measurement sources, and the review of flowmeter installation conditions allows for evaluation of how flowmeters installed consistent with manufacturer specifications perform relative to those that were not.

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[57] The first value (*i.e.,* 7) represents the number of project participants and the second value (*i.e.,* 78%) represents the percentage out of total respondents.
[58] More information about the Fuji Electric Portaflow-C FSC-4 Ultrasonic Flowmeter can be found here: https://www.instrumentsdirect.com/fuji-electric-portaflow-c-fsc4-portable-ultrasonic-flow-meter/

After combining with the 2022 and 2023 Project data, a total 267 comparison measurements have been made with a portable transit time meter to assess the accuracy of the permanent flowmeters over the course of two years. Of these combined measurements to date, 206 measurements (77%) were on flowmeters that were installed and maintained per manufacturer specifications and 61 measurements (23%) were on flowmeters that were not. Figure 3-1 depicts the results of these comparison flow measurements through a series of scatterplots and histograms. The mean absolute percentage error (MAPE) between the portable transit time meter and permanent flowmeters installed per manufacturer specifications was 8.8%, while the MAPE for flowmeters not installed per manufacturer specifications was nearly twice as high at 17.1%. These results illustrate the difference in accuracy for flowmeters installed per manufacturer specifications versus those that are not. Considering all comparison flow measurements in aggregate (regardless of flowmeter installation), the MAPE was less than 11%. These results (1) provide evidence that flowmeters can accurately quantify AGW and (2) illustrate that installing and maintaining flowmeters per manufacturer specifications is essential and substantially improves accuracy.

The top row in Figure 3-1 depicts 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 (left) column of charts presents comparisons for all measurements, while the second (middle) and third (right) column of charts 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), 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[59] and scales the variable's units to percentage units for easier interpretation of results. When considering 2022 and 2023 comparison data combined, these results illustrate that properly installing a permanent flowmeter per manufacturer specifications cuts the relative error roughly in half when compared to flowmeters not installed properly (*e.g.*, 8.8% compared to 17.1%).

[59] 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%.

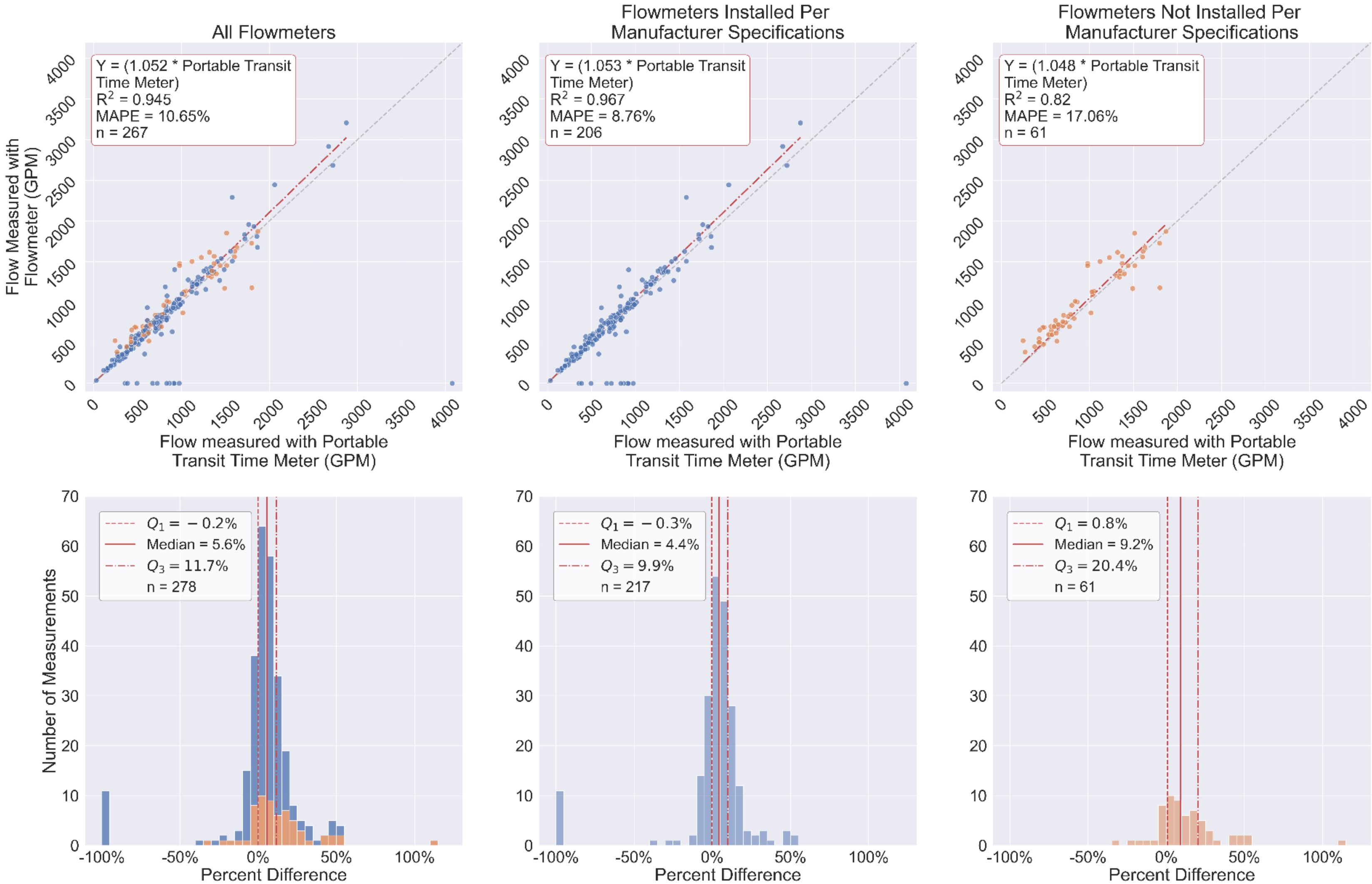

Figure 3-1. Comparison of flow measurements with the portable transit time flowmeter to permanent flowmeters in 2022 and 2023 for (1) all flowmeter measurements (right), (2) only flowmeters installed correctly (center), and (3) only flowmeters installed incorrectly. The top and bottom rows represent individual scatterplot comparisons and percent differences, respectively. Q_1 and Q_3 represent the 25th and 75th percentiles, respectively. A bin frequency of 5% is used for each histogram. Permanent flowmeters that reported zero (i.e., 0) values are shown but excluded from the regression analysis in the top row.

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 Coefficient of Determination (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 slopes of each regression line are all greater than one, indicating that permanent flowmeters tended to measure higher flows than the portable transit time meter. When considering all 2022 and 2023 data, the average difference based on the slope for permanent flowmeters installed per manufacturer specifications was 5.3%[60] and for flowmeters not installed per manufacturer specifications was 4.9%. Overall, the results for all aggregated measurements show close agreement between the permanent flowmeters and the portable transit time flowmeter, with an average 5.2% difference based on the regression.

The bottom row of Figure 3-1 depicts a series of histograms that show 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,50th (median), and 75th percentile values. These charts depict the following:

1. For all 267 comparison measurements, regardless of whether the permanent flowmeters were installed correctly or not, half of the flow measurements were within roughly 10% of the portable transit time flowmeter flow.
2. Of the 64 meters that were not installed correctly, half had flows that were between roughly 0.8% and 20.4% higher than the portable transit time flowmeter flow while one quarter had flows more than 20.4% higher than the portable transit time meter flow.
3. For the 214 flowmeters that were installed correctly, half had flows between roughly -0.3% and 9.9% higher than the portable transit time meter flow while one quarter had flows more than 9.9% higher than the portable transit time meter flow.
4. The median percent difference between the portable transit time flowmeter and all flowmeters, properly installed flowmeters, and incorrectly installed flowmeters was 5.6%, 4.4%, and 9.4%, respectively.

It is worth noting that while the comparisons between the two measurements show relatively close alignment overall (Figure 3-1), there were individual measurements that did not align 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. Nevertheless, both the number of instances and overall differences increase for permanent flowmeters that are not installed per manufacturer specifications. Interestingly, between 2022 and 2023, there were a total of 10 instances where a permanent flowmeter that was installed

[60] It is worth noting that three data points in 2022 and seven data points in 2023 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.

per manufacturer specifications was reading zero flow (i.e. empty pipe) even though flows were observed on site and measured in the range of 400 and 4,000 GPM by the portable transit time flowmeter. The reason behind these zero flow instances could not be determined in the field, but illustrate that flowmeters can malfunction or fail to measure flow properly even when installed per manufacturer specifications[61].

Overall, the results from Figure 3-1 show that permanent flowmeters being installed per manufacturer specifications substantially increase flow measurement accuracy. For the immediate purposes of the 2023 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, Land IQ, and OpenET.

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. Additionally, since the 2022 Project, there have been substantial improvements in how flowmeter data is collected and processed:

Data/Procedural Improvements Since 2022

1. Developed a data portal where growers can submit their totalized flowmeter data via a website on their phone, tablet, or computer.
    a. Regular QA/QC of submitted data and photos is completed by Madera County staff to ensure data was entered properly and accurately.
2. Developed an allocation database to keep track of all active groundwater wells, associated flowmeters, associated irrigated lands forming Irrigation Units, and all changes that may occur over time. The allocation database also allowed DE and Madera County staff to 1) edit entries simultaneously and 2) track and undo changes as needed.
3. Developed a methodology to semi-automatically assemble and process flowmeter readings (and associated data) on a regular basis to identify errors early in the irrigation season and notify growers as necessary.
4. Increased engagement from Madera County staff for handling grower inquiries and supporting data management activities.

However, there are additional data and procedural needs beyond the improvements made during the 2023 Project to further refine the adoption and implementation of flowmeters as an allocation measurement option:

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[61] The groundwater allocation program requires calibration of a flowmeter at least once every two years. The calibration of flowmeters was not reviewed and verified as part of the 2022 or 2023 Projects, and the poor measurement agreement observed for some individual comparison measurements may be influenced by flowmeters that have not been calibrated recently.

Data and Procedural Needs:

1. Developing a procedure for growers to clearly distinguish surface water flowmeter data from groundwater flowmeter data.
2. Developing processes for 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.
4. Performing frequent calibration (every two through three years) and maintenance or replacement of flowmeters.
5. Development of a real-time, accessible platform showing current water usage in comparison to the allocation that growers can interact with throughout the irrigation season to support adaptive management by growers.

3.2.2 IrriWatch

Daily IrriWatch data were retrieved via the IrriWatch Application Programming Interface (API). End of the year cumulative results of ET, adjusted ETAW[62], original ETAW, P, and ETPR are shown for all Project Land Parcel-Fields in Figure 3-2. Since remotely sensed methods like IrriWatch measure total ET, this needs to be subsequently divided into two components: ETPR and ETAW. The comparison of ETPR and ETAW allows for evaluation of the amount of total ET that results from precipitation versus applied water. On the other hand, the comparison of P and ETPR allows for evaluation of how much of total P is effective in supporting ET (*i.e.,* ETPR). IrriWatch's ET and ETAW follow expected trends; ET [median = 39.9 IN] was generally higher when compared to adjusted ETAW (25.7 IN) and ETPR (13.5 IN). However, P and ETPR do not follow the expected trends. Median P (11.3 IN) was lower than the median ETPR (13.5 IN). While ETPR values could be influenced by P that occurred prior to the accounting period, over the course of a year, ETPR is expected to be lower than P in most cases unless there are large changes in soil moisture storage. The upper end of the distribution of ETPR for Project Lands shows ETPR values that were substantially higher than the highest observed P values. For example, P for IrriWatch ranged from 0 to 16.0 IN while ETPR ranged from 0 to 23.9 IN.

Due to periodic processing and analysis of remotely-sensed data throughout the 2023 calendar year, discrepancies between ETPR and P were reported to the IrriWatch team during the 2023 irrigation season. IrriWatch subsequently put out a public memo describing the issue and underlying cause (Section 6.5.3). To avoid this issue in future iterations of the allocation, IrriWatch has 1) redeveloped their methodology for initialized soil moisture from precipitation for the beginning of calendar year 2024, and 2) refined their methodology for ETPR computations in 2024. In addition, preliminary analyses and results of the 2023 Project led to important refinements in the assumptions IrriWatch used to quantify ETAW during the 2023 calendar year. These refinements resulted in one adjustment to ET and ETAW that was applied on December 31, 2023. Adjusted ETAW and original (unadjusted) ETAW are shown in Figure 3-2. IrriWatch ETAW adjustments lead to an overall decrease in ETAW on Project Lands. Specifically, the

[62] See Section 6.5.3 for more information about the 2023 IrriWatch adjustments.

median, unadjusted ETAW for Project Lands was 29.4 IN while the adjusted ETAW was 25.6 IN. IrriWatch adjustments are described in more detail in Section 6.5.3.

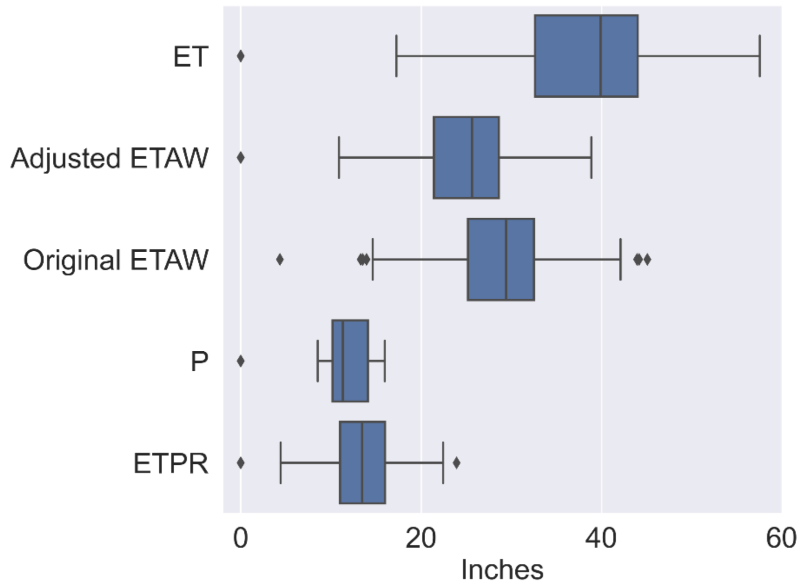

Figure 3-2: Boxplot[63] visualizing the end of the year distributions of actual evapotranspiration (ET), adjusted ET from applied water (ETAW), original ETAW, precipitation (P), and ET from precipitation (ETPR) for Project Lands (excluding fallow/no irrigation parcel-fields) using IrriWatch data. IrriWatch made adjustments that reduced the calculated ETAW for all parcel-fields; this adjustment was applied on December 31, 2023.

3.2.3 Land IQ

Monthly raster files of ET and P were provided by Land IQ staff approximately four to six weeks after the end of each month throughout the calendar year. Apart from the challenges of receiving the data generally a month after the period had ended, this data submission process worked well and was easily incorporated into the existing data workflow. After estimating ETPR and calculating ETAW using the USBR method (see Section 6.3.2.2), all cumulative Land IQ results were processed. A summary of overall results for 2023 is presented in Figure 3-3. The relationships between: (1) ET and ETAW and (2) P and ETPR followed expected trends when considering Land IQ data for all parcel-fields in Project Lands. Median ET was 36.8 in while ETAW and ETPR were 23.6 in and 12.8 in, respectively. As expected, P (18.4 IN) was also always higher

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[63] 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.

than ETPR. P and ETPR variability were low compared to ET and ETAW, indicating greater heterogeneity when measuring ET and ETAW at the Parcel-Field scale.

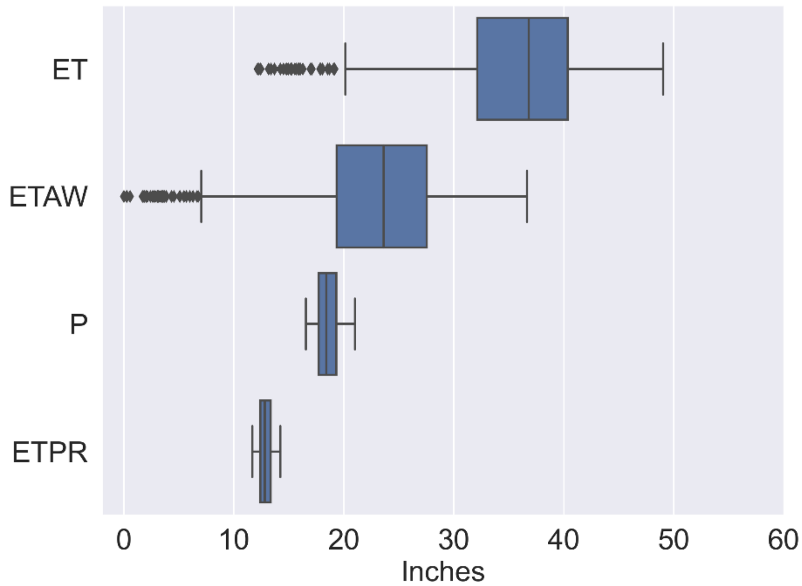

Figure 3-3: Boxplot visualizing the end of the year distributions of actual evapotranspiration (ET), adjusted ET from applied water (ETAW), original ETAW, precipitation (P), and ET from precipitation (ETPR) for Project Lands (excluding fallow/no irrigation parcel-fields) using Land IQ data.

3.2.4 OpenET

Like IrriWatch, OpenET ET data was also retrieved via an API. Data retrieval and processing went well; however, OpenET only provided ET data. As a result, P from Land IQ was used to calculate ETPR and, subsequently, ETAW using Equation 1. The cumulative, December 31, 2023, results are presented in Figure 3-4. The relationships between: (1) ET and ETAW and (2) P and ETPR followed expected trends when considering OpenET data for all Project Land Parcel-Fields. Median ET was 40.1 in while ETAW and ETPR were 25.0 in and 14.8 in, respectively. P (18.4 IN) was also always higher than ETPR. Like Land IQ, P and ETPR variability were low compared to ET and ETAW, indicating greater heterogeneity when measuring ET and ETAW at the Parcel-Field scale.

3.3 Comparison and Analysis of Results (Objective 3)

3.3.1 Comparison of Remotely-Sensed Methods

While 2023 Project Lands are generally representative of the total Madera County GSA cropped area (Table 2-1), statistical biases may still be present when considering data from a subset of lands. To evaluate these potential biases, a comparison needed to be made between 2023 Project Land Parcel-Fields and all Madera County GSA Parcel-Fields. The accessibility of remotely-sensed ET data for both the 2023 Project Lands and the entire Madera County GSA lands made this comparison possible. The differences between the median ET, ETAW, P, and ETPR for all

Madera County GSAs' parcel-fields and Project Lands' parcel-fields for IrriWatch, Land IQ, and OpenET are summarized in Figure 3-5.

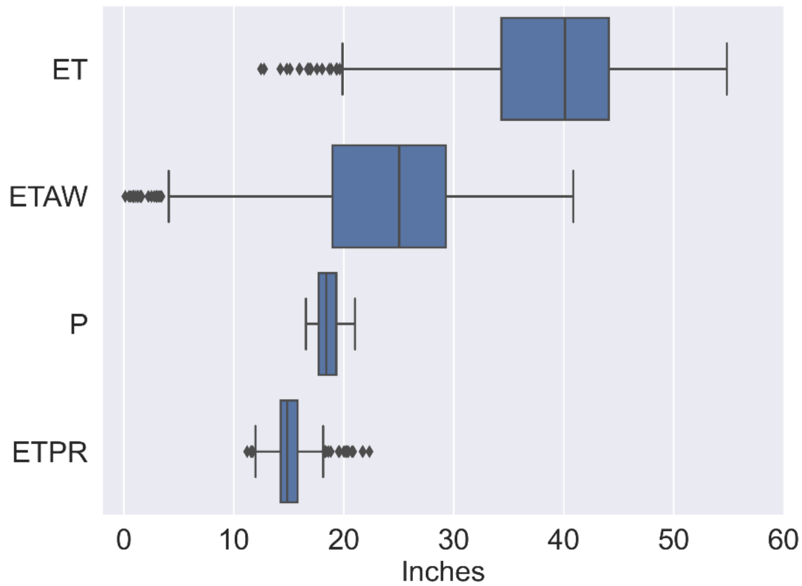

Figure 3-4: Boxplot visualizing the end of the year distributions of actual evapotranspiration (ET), adjusted ET from applied water (ETAW), original ETAW, precipitation (P), and ET from precipitation (ETPR) for Project Lands (excluding fallow/no irrigation parcel-fields) using OpenET data.

Observed differences in P between the 2023 Project Lands and GSA lands were typically around 0 IN for all measurement methods under consideration (excluding almonds when using IrriWatch data). These results indicate that P reported by IrriWatch and Land IQ[64] over Project Lands was representative of the entire GSA. Similarly, observed differences for ETPR for Land IQ and OpenET were minimal to negligible; however, IrriWatch had positive ETPR differences between 0.7 and 2.3 IN depending on crop type. In addition, ETPR within the 2023 Project Lands, calculated using Land IQ and OpenET data, was similar to the entire GSA while IrriWatch's ETPR was higher over 2023 Project Lands compared to GSA Parcel-Fields. When considering differences in ET and ETAW for all crops, IrriWatch showed the largest difference between 2023 Project Lands and all GSA lands (5.1 IN and 2.4 IN, respectively) followed by OpenET (2.4 IN and 2.4 IN) and Land IQ (1.3 IN and 1.5 IN). ET and ETAW differences between the 2023 Project Lands and GSA lands, for all remotely-sensed ET methods, were the highest for grapes (4.1 – 6.4 IN) followed by almonds (3.7 – 5.1 IN) and pistachios (-1.7 – -0.5 IN). The ET and ETAW differences were positive in all cases excluding pistachios, indicating that the 2023 Project Lands had higher median values. The observed differences between 2023 Project Lands and GSA lands could be caused by differing on-farm practices (with irrigation and fertilization practices being major factors), varying crop age (*i.e.*, 2023 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

[64] OpenET does not report precipitation date directly, so Land IQ's precipitation data was used for OpenET related calculations.

GSAs' area, uncertainty in the models used to calculate ET and ETAW, and other factors. Nevertheless, the differences between ETAW for the 2023 Project Lands and GSA lands for grapes and almonds decreased relative to 2022 Project results, which showed differences for these crops at 12 IN or higher. This highlights the improved 2023 Project dataset, which is more representative of all GSA lands.

To further illustrate, compare, and understand differences between the lands included in the 2023 Project and the Madera County GSA cropped lands, it is helpful to evaluate the distribution of results rather than solely a comparison of the median values (as shown previously in Figure 3-5). A series of boxplots were used to depict the distribution of four different parameters of the 2023 Project Lands and the Madera County GSAs' cropped lands, allowing for comparison of the two datasets. Figure 3-6 depicts ET, ETAW, ETPR, and P data from IrriWatch, Land IQ, and OpenET. IrriWatch's adjusted ETAW[65] data was used in Figure 3-6. A comparison of the distribution of ET from IrriWatch, Land IQ, and OpenET between the 2023 Project and GSA datasets further illustrates that 2023 Project Lands tended to have higher ET when compared to the GSA cropped lands. However, measurements of ET and ETAW were highly variable, indicating that the median differences between the 2023 Project Lands and GSA lands may not be statistically significant. In other words, it cannot be certain that the 2023 Project Lands do have higher ET/ETAW compared to GSA lands or if the observed differences in the overall distributions was just due to random variation (Figure 3-6).

Crop type, or land use, is an important factor influencing the evaluation and comparison of results. 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 were originally based on the DWR California Statewide cropping dataset from 2018[66], 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 2023. At the outset of the 2023 Project, DE staff and Madera County solicited and received feedback from growers about what their field crop was. In addition, for the VPP lands, crops in each parcel-field were also defined with growers and verified in the field. This resulted in corrections in crop type to 51 of the 475-VPP parcel-fields (10.7%), which covered 2,151 of the 13,892 VPP acres (15.4%). During the 2022 Project, crop types for 15% of the participating parcel-fields and 12% of participating acres were corrected, indicating the need for continual feedback from growers on at least an annual basis to verify remotely-sensed crop types.

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[65] See Section 6.5.3 for more information about the 2023 IrriWatch adjustments.

[66] 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.

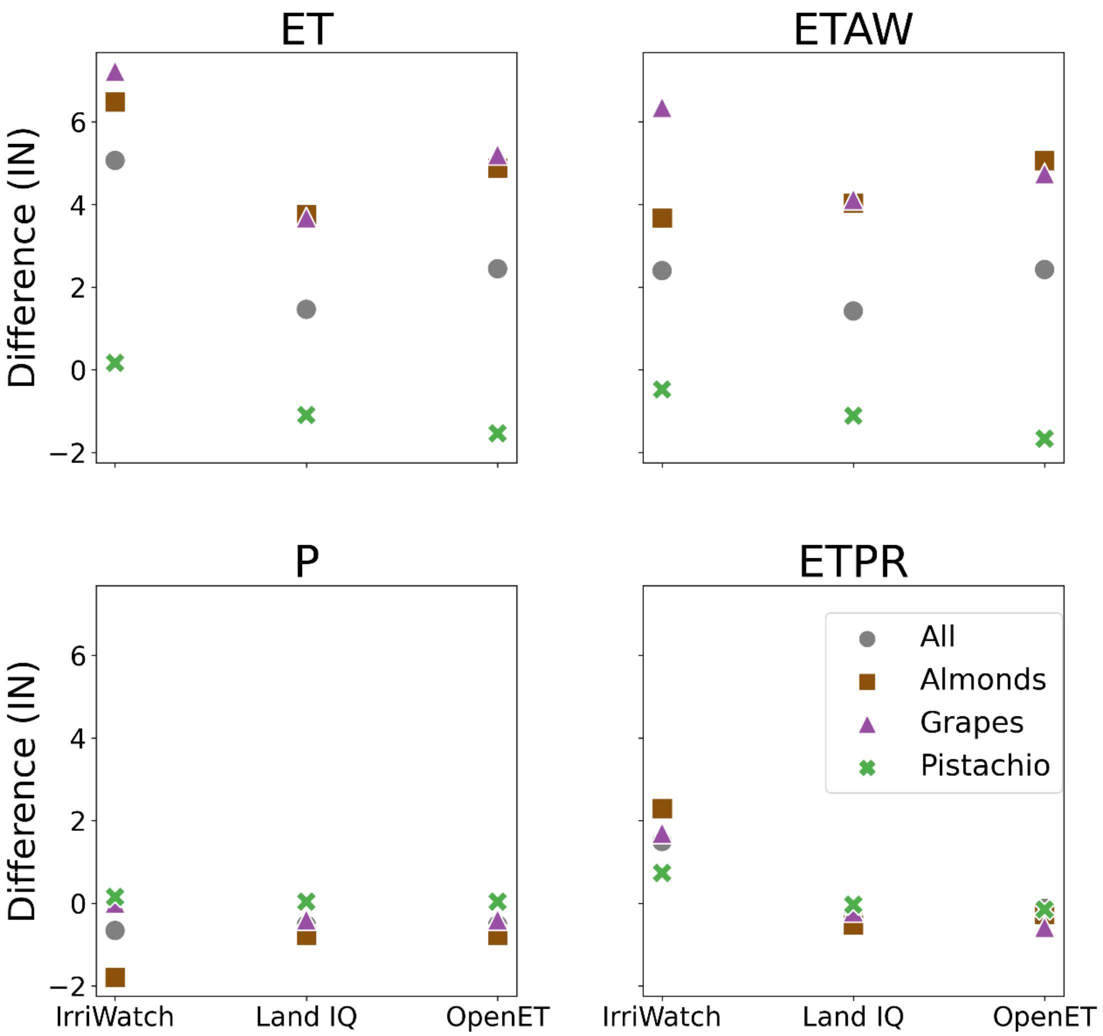

Figure 3-5. The difference between the median values for all Madera County GSAs' parcel-fields and 2023 Project-specific parcel-fields. Differences were calculated as the 2023 Project median values minus overall GSAs' median values; a positive difference indicates the Project had a higher median value than the GSAs, and vice versa. Actual evapotranspiration (ET), ET from applied water (ETAW), precipitation (P), and ET from precipitation (ETPR), were compared using IrriWatch, Land IQ, and OpenET. Results were organized in four different classifications: (1) an aggregation of all crops, (2) almond orchards, (3) grape vineyards, and (4) pistachio orchards.

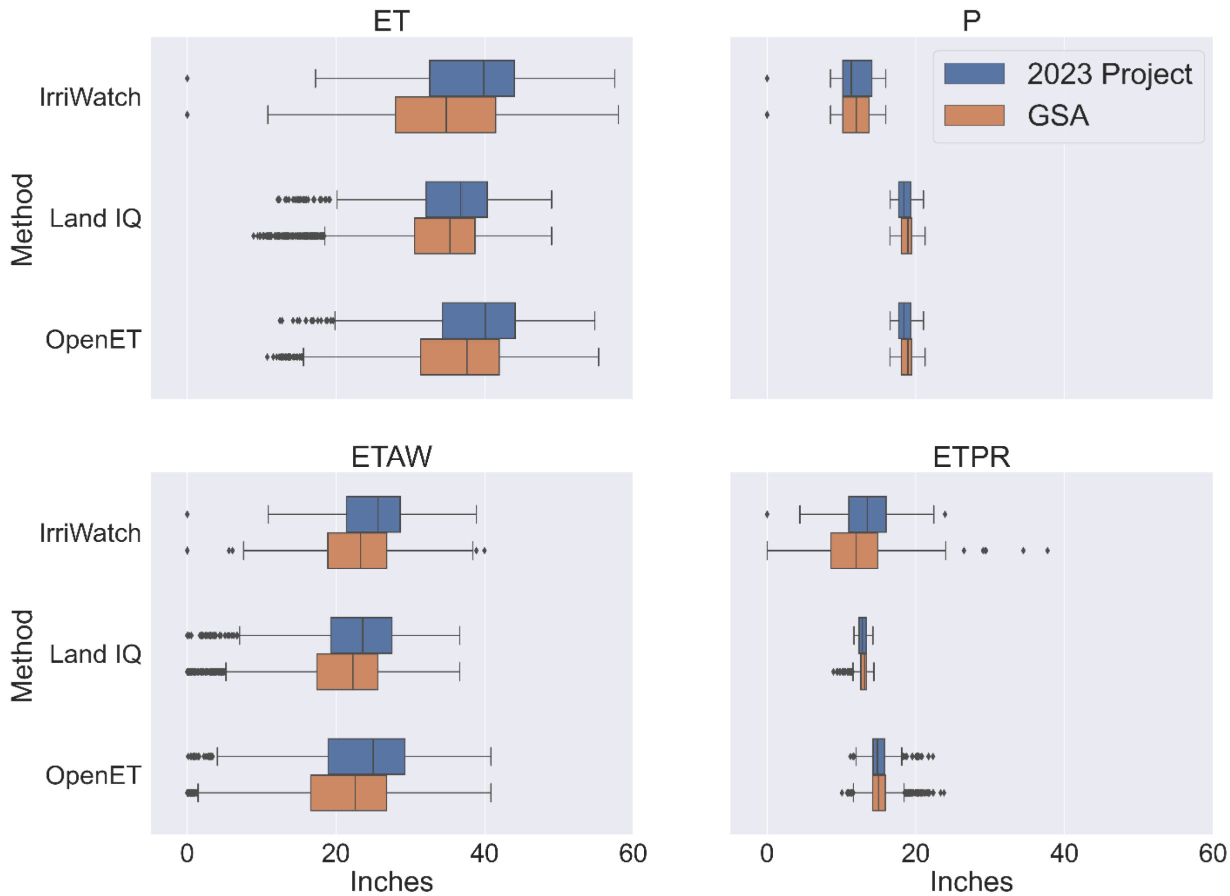

Figure 3-6. Boxplots visualizing the distributions of actual evapotranspiration (ET), ET from applied water (ETAW), precipitation (P), and ET from precipitation (ETPR) for all crops and for each remotely sensed method type (IrriWatch, LandIQ, and OpenET) in 2023. The orange boxplots show distributions for all cropped and irrigated Parcel-Fields (n = 3770) in the GSAs (GSA), while the blue boxplots show distributions for all Parcel-Fields (n = 619) within the 2023 Project Lands.

Additional factors that influence water use and ETAW are irrigation method, soil type, and crop age. Because a parcel-field's irrigation method was not available through the DWR 2018 statewide cropping dataset, irrigation method was assumed based on the typical method for each crop type within the GSAs. A grower's irrigation method was field verified by DE staff for all of the VPP lands. Corrections to the irrigation method were required on 23 of the 475 parcel-fields (4.8%), which covered 818 of the 13,892 VPP acres (5.9%). During the 2022 Project, irrigation methods for 29% of the participating parcel-fields and 20% of participating acres were corrected. Therefore, the 2023 Project saw a reduction in irrigation method changes from the 2022 Project and highlights how initial coordination with growers can lead to sustained improvements in irrigation method information. A comparison of 2023 Project results based on irrigation method is available in Section 6.5.1. Given the uncertainty in knowing the exact irrigation method for each parcel-field, it is recommended that feedback and coordination with growers and Madera County staff continue into 2024 and beyond.

Limited soil sampling was completed as part of field work during the 2022 and 2023 Projects[67]. However, percent sand, silt, clay, and other soil parameters were initially determined using the Natural Resource Conservation Service's (NRCS) Soil Survey Geographic Database (SSURGO[68]). SSURGO contains information about soil as collected by NRCS in tables or as maps and is available for most areas in the United States and the Territories, Commonwealths, and Island Nations. Soils data for all 2023 Project Lands was also obtained from the International Soil Reference and Information Centre (ISRIC) SoilGrids™ [69] (henceforth SoilGrids), which is a system that provides gridded soil information on a global scale. Data visualizations comparing both SSURGO and SoilGrids data to 2023 Project results are shown in Section 6.5.1. An extensive field verification of parcel-field soil information would be helpful in future analyses given the wide variation in soils data collected and aggregated from SSURGO and SoilGrids.

Similar to the 2022 Project, crop age in the 2023 Project was determined in coordination with landowners for almonds, grapes, and pistachios to evaluate the impact of crop age 2023 Project results. Data visualizations comparing results by crop age are available in Section 6.5.1. Starting in 2024, Land IQ will be providing crop age data for perennials, which will allow for further evaluation of how crop maturity influences AGW, ETAW, and CUFs.

The 2023 Project results provided valuable insight into input data and associated computations for ETAW from IrriWatch, Land IQ, and OpenET, leading to the adjustments to IrriWatch values described in Section 6.5.3. Additionally, since the 2022 Project, there have been substantial improvements in how ET/ETAW data is collected and processed:

Data/Procedural Improvements Since 2022 Project:

1. Developed understandable, stable, and reproducible procedure for calculating ETPR using the USBR method.
2. Improved representation of all GSAs' cropped lands in the 2023 Project, which lead to a reduction in differences between GSAs' ET data compared to 2023 Project ET data.
3. Streamlined data management and QA/QC processes for programmatically retrieving data (via APIs when possible), analyzing, visualizing, and reporting data.

However, there are additional data and procedural needs that would be helpful for further evaluation and refinement of ETAW from any allocation measurement option in the future. These include:

Data Needs:

1. Improving the land use coverage used for the GSAs, including both improvements to the specific crop type or land use and improvements to the spatial extent of cropped lands.

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[67] More information about soil moisture and texture sampling is available in Section 6.5.2.1.

[68] More information about the Soil Survey Geographic Database (SSURGO) can be found here: https://www.nrcs.usda.gov/resources/data-and-reports/soil-survey-geographic-database-ssurgo.

[69] More information about SoilGrids can be found here: https://www.isric.org/explore/soilgrids.

   a. Land IQ will be providing land use land cover data for the Madera County GSAs on an annual basis, so updates are planned to be implemented on an annual timestep.
2. Supplementing assumed/spatially estimated information such as irrigation method and soil type with field data collection and verification and data provided directly by growers.
3. Comparing remotely-sensed ET products to ground-based ET stations to assess data accuracy across the Madera County GSAs.

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 ET between ETPR and ETAW (*e.g.,* comparing ET observations on known fallowed or non-irrigated fields as a proxy for ETPR).

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.

3.3.2 Comparison of AGW and ETAW

During the irrigation season (roughly May to September in 2023, although the exact irrigation season length varies from farm to farm and year to year, depending on crop type, grower practices, hydrology, and other factors), crop water demand is at its annual peak. Therefore, it was expected that applied water volumes and subsequent ETAW would rapidly increase during this period. As winter approaches and the irrigation season ends, AGW and ETAW should taper off as crops are harvested, evaporative demand decreases, and less water is applied to support crop growth. Cumulative changes in flowmeter AGW and remotely-sensed ETAW, for Land IQ and OpenET, followed these expected trends throughout the 2023 Project (Figure 3-7). However, IrriWatch reported a rapid, near-linear increase in ETAW beyond the irrigation season even though growers within the 2023 Project Lands started to reduce the volume of water applied to their fields. Because internal procedures were developed by DE staff to periodically process, analyze, and review AGW/ETAW data, internal review of preliminary results was an ongoing process throughout 2023. This internal review led to coordination with IrriWatch staff on ETAW calculations, and ultimately to adjustments to the methodology and assumptions used by IrriWatch to quantify ETAW[70]. This adjustment was applied on December 31, 2023, and is

[70] See Section 6.5.3 for more information about the 2023 IrriWatch adjustments.

represented in Figure 3-7. This adjustment brought IrriWatch's cumulative ETAW to be roughly in line with ETAW measured by Land IQ and OpenET. In summary, the ability to compile, review, and run QA/QC procedures during data collection throughout the irrigation season is an important step for quantifying both ETAW and AGW.

On December 31, 2023, cumulative AGW for all IUs without data quality issues (n = 71) was 27.1 IN while cumulative ETAW was 24.4 IN, 23.1 IN, and 24.5 IN for IrriWatch, Land IQ, and OpenET, respectively (Figure 3-7). An AGW volume greater than ETAW was expected because not all AGW contributes to ETAW; rather, some AGW contributes to deep percolation and runoff[71] during the process of applying irrigation water (the relationship between AGW and ETAW is influenced by a variety of factors, including irrigation method[72]). In summary, when aggregating all data for Project Lands together, ground-based AGW and remotely-sensed ETAW follow anticipated trends.

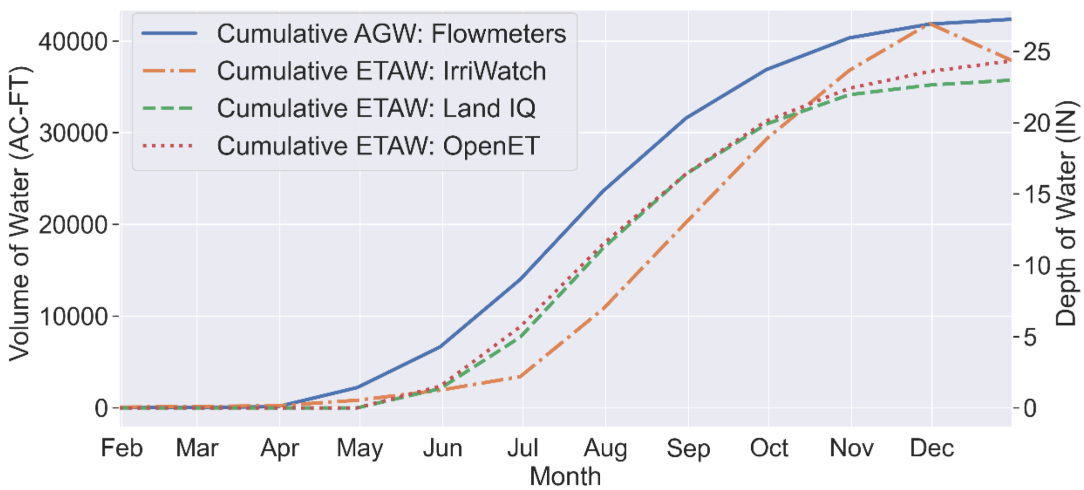

Figure 3-7. Cumulative volume (left) and depth (right) of applied groundwater (blue solid), IrriWatch evapotranspiration of applied water (ETAW; orange dash-dot), Land IQ ETAW (green dash), and OpenET (red dot) for all crops and Irrigation Units (n = 71) for all Project Lands without data quality issues. Cumulative values are calculated by summing up AGW and ETAW values for each month from each Irrigation Unit. The decrease in ETAW for IrriWatch in December 2023 was due to an IrriWatch adjustment. IrriWatch made adjustments that reduced the calculated ETAW for all parcel-fields; this adjustment was applied on December 31, 2023.

Summing all IU data together helps illustrate and aids evaluation of the aggregated trends of AGW and ETAW. However, since allocation penalties and carryovers will be assessed on the individual parcels within an IU, an evaluation of AGW, ETAW, CUF trends for individual IUs was

[71] Runoff, or tailwater, from AGW is assumed to be negligible for pressurized irrigation systems.
[72] Irrigation method plays a major role in on-farm water use efficiency, which translates into having a significant impact on Consumptive Use Fractions (CUFs). 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.

needed to understand variability on a smaller scale. For the 2023 Project, the CUF is a comparison of remotely-sensed ETAW (by either IrriWatch, Land IQ, or OpenET) to ground-based measurements of AGW by flowmeters. In an agricultural context, CUF is a metric that describes how much water is consumed by crops for growth relative to the total amount of water applied for irrigation. For each VPP included in the 2023 Project, a report that was developed summarizing all AGW, ETAW, and the resulting CUF data. Table 3-1 summarizes the average AGW by primary crop, resulting CUFs for each remotely-sensed method (IrriWatch, Land IQ, and OpenET), and acreage information about the Project Land IUs. Note that only IUs without data quality issues are shown in Table 3-1. In addition, crop type in Table 3-1 represents the primary crop for each IU by acreage (e.g., the crop that covered the largest area within that IU), so some of the IUs shown may have mixed cropping regimes.

Of all the irrigated IUs without known data quality issues, IUs comprised of primarily almonds represented the largest area (8,186 ac) followed by pistachios (4,366 ac), wheat (3,013 ac), citrus (1,617 ac) and grapes (1,277 ac). Median CUFs varied substantially between crop types and remotely-sensed methods. For example, Land IQ reported a median CUF of 0.75 for citrus while OpenET and IrriWatch reported 0.82 and 0.92, respectively. Collectively, the area-weighted average CUFs (for irrigated IUs only) fell between 0.83 and 0.89. An overall CUF between 0.83 and 0.89 is reasonable (*i.e.*, less than one, meaning that not all applied irrigation water is consumptively used); however, this is higher than the average CUF obtained from regression analysis (see Figure 3-9 below).

Notably, alfalfa, sudan grass, and wheat IUs had lower CUFs (0.46 – 0.68) compared to almonds, citrus, grapes, and pistachios (0.75 – 0.98). This difference is likely due to the irrigation method; all alfalfa, sudan grass, and wheat IUs used a gravity/flood irrigation method while the dominant irrigation method for the other crop type was drip/micro-sprinklers. For almonds, the 2022 Project had five IUs with almonds as the primary crop and reported a median CUF of 1.22. The 2023 Project significantly increased the number of primary almond crop IUs from five to 28 and none of the methods used reported a median CUF greater than one. These results indicate that a larger sample size is necessary to capture the true variability in this dataset and give reasonable estimates of CUFs. Similarly, for citrus, grapes, and pistachios, median CUFs remained below one for all methods considered. On average, Land IQ tended to report the lowest CUF, followed by IrriWatch and then OpenET. Overall, Table 3-1 highlights that considering representative CUFs across all IUs and crop types leads to reasonable estimates of CUF that could potentially be applied to convert AGW to ETAW.

The full distribution of CUFs for all IUs in the 2023 Project and IUs with a single crop type (almonds, grapes, and pistachios) is presented in Figure 3-8. In this case, only IUs with a single crop type were considered (i.e., the almond, grape, and pistachio IUs presented did not have a secondary crop type). While citrus and wheat IUs took up an overall larger area than grapes, these crops were only represented in three and two single-crop IUs, respectively. Therefore, the sample size in irrigated citrus and wheat were too small to be considered representative or justify further statistical/distribution analysis.

Table 3-1. Summary by primary crop of Irrigation Units (IUs), IU acreage, median applied groundwater (AGW) in inches, and median consumptive use fraction (CUF) for IrriWatch, Land IQ, and OpenET. The results shown include 2023 Verification Project Participant IUs and flowmeter account IUs. Crop type represents the primary crop for each IU by acreage (e.g., the crop that covered the largest area within that IU); some of the IUs shown may have mixed cropping regimes. Only IUs with no known data issues are shown. Fallowed IUs and/or IUs with No Irrigation selected as the irrigation method are excluded from the area-weighted average results.

Primary Crop[73]	Irrigation Units	Area (Acres)	Median AGW (IN)	Median CUF		
				IrriWatch	LandIQ	OpenET
Alfalfa	1	574	53.9	0.50	0.47	0.51
Almonds	28	8,186	26.4	0.95	0.93	0.98
Citrus	3	1,617	28.2	0.92	0.75	0.82
Fallow	7	831	-	-	-	-
Grapes	7	1,277	22.6	0.95	0.93	0.82
Other	1	19	-	-	-	-
Pistachios	30	4,366	26.8	0.94	0.84	0.84
Pomegranate	1	26	-	-	-	-
Sudan Grass	1	236	41.4	0.46	0.59	0.61
Walnuts	1	42	-	-	-	-
Wheat	2	3,013	16.9	0.68	0.64	0.68
Area-weighted Average[74]		**2,753**	**29.7**	**0.89**	**0.83**	**0.89**

While each remotely-sensed method produced similar results, there are some minor differences. For IrriWatch, all crops, almond, grape, and pistachio IUs had CUFs ranging from 0.46 to 2.03, 0.49 to 1.73, 0.73 to 1.20, and 0.5 to 2.03, respectively. For Land IQ, all crops, almond, grape, and pistachio IUs had CUFs ranging from 0.25 to 1.72, 0.52 to 1.72, 0.61 to 1.14, and 0.25 to 1.27, respectively. Lastly, for OpenET, all crops, almond, grape, and pistachio IUs had CUFs ranging from 0.21 to 1.86, 0.50 to 1.86, 0.53 to 1.14, and 0.21 to 1.21, respectively. IrriWatch had eight pistachio IUs with CUFs above one, while Land IQ and OpenET had five and six pistachio IUs with CUFs above one, respectively. All three methods provided similar CUF ranges for almond and grape IUs. However, the median CUF for grape IUs was the lowest (0.80) when considering OpenET data. In most cases, a CUF above one was for an almond IU.

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, surface water diverted and applied to the field, 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

[73] Irrigation Units with alfalfa, sudan grass or wheat as the primary crop type had flood irrigation systems (e.g., border) as the primary irrigation method while all other Irrigation Units primarily used pressurized irrigation systems like drip/micro-sprinklers. Irrigation Units with pomegranate, walnut, or other primary crop types were associated with no irrigation/non-irrigated fields (i.e., no water was applied by growers in 2023).

[74] Fallow, no irrigation, and non-irrigated Irrigation Units were excluded from the area weighted average results.

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 (beyond AGW and precipitation) available to crops (*e.g.*, shallow groundwater from nearby surface water features). Overall, these results demonstrate the variability in CUF between crops and IUs. A larger sample size compared to the 2022 Project helped explain more of this variability and capture reasonable representative CUF results. However, additional work needs to be done to ensure that: (1) all applied water (groundwater and surface water) within an Irrigation Unit is being accounted for and/or (2) remotely-sensed methods are accurately quantifying ETAW for IUs with high CUFs. Additionally, monitoring root zone soil moisture would improve understanding of the availability of water within the root zone regarding both timing and quantity.

The results of comparing ETAW from each method (IrriWatch, Land IQ, and OpenET) to AGW for the 71 IUs in the 2023 Project are depicted in a scatterplot in Figure 3-9, 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 3-9 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 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 0.9. The points shown in the plot represent results for each IU; the color denotes primary crop type (based on acreage), and the symbol depicts the irrigation method.

Based on the regression relationships considering all IUs (except fallow or dryland IUs and IUs with data quality issues[75]), the results show overall CUFs of 0.80, 0.77, and 0.78 for IrriWatch, Land IQ, and OpenET, respectively. This means that on average, 77% - 80% of AGW was consumptively used while 20% - 23% of AGW had a different destination (*e.g.*, deep percolation, runoff, etc.). These results are in line with the 2022 Project, which found that, on average, 84% of AGW was consumptively used. The CUFs presented in Figure 3-9 are lower than but similar to the area-weighted average values calculated in Table 3-1, indicating a reasonable result (*i.e.,* less than one). However, as represented in Figures 3-8 and 3-9, there is substantial variability in CUFs among individual IUs. Specifically, 25 of the 71 IUs (35%), 19 of the 71 IUs (27%), and 21 of the 71 IUs (30%) have a CUF greater than one when considering IrriWatch, Land IQ, and OpenET ETAW data, respectively.

Irrigation methods control how water is applied to irrigated lands for crops and is one of the major factors influencing CUFs. Flood, furrow, and border irrigation methods tend to have lower CUFs, indicating that a larger quantity of water is being applied than is consumptively used by the crop. Typical values are in the 0.55 to 0.70 range. Four of the five IUs in the 2023 Project using flood, furrow, or border irrigation all had CUF values close to this range (between 0.46 and 0.73); however, one primarily grape IU with a furrow irrigation method had a CUF of 0.85, 0.84, and 0.63 for IrriWatch, Land IQ, and OpenET, respectively. This further highlights the variability between methods, with OpenET generally measuring lower ETAW over grape IUs compared to IrriWatch and Land IQ (Figure 3-8). Unlike gravity-based irrigation methods, more precise and

[75] See Section 6.4.3 for more information about Irrigation Units with data quality issues.

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 CUFs for pressurized systems range from 0.70 to 0.90. Of the 71 total IUs presented, 66 (93%) had pressurized irrigation systems. However, only 18 (IrriWatch), 16 (Land IQ), and 20 (OpenET) IUs have CUFs within the 0.70 – 0.90 range. Depending on the method considered, 28 – 35 IUs have CUFs above this range while 13 – 19 IUs have CUFs below this range. See Section 6.5.1.2.3 for more details about how CUFs varied for different irrigation method types across the three ETAW measurement methods (IrriWatch, Land IQ, and OpenET).

While the representative CUF results based on linear regression between AGW and ETAW are reasonable, there is substantial variability in CUFs among crops and within Irrigation Units. On the high end (*e.g.,* CUFs above one) it is possible that 1) ETAW is being overestimated by remote sensing methods or 2) all water within an IU is not being accounted for. On the low end (*e.g.,* CUFs below 0.5) it is possible that 1) ETAW is being underestimated by remote sensing methods or 2) some of the applied water measured in the field is being applied to different lands not currently being monitored. In both cases, it is also possible that some other third factor (*i.e.,* soil type, crop age, shallow groundwater, irrigation unit area, etc.) could be influencing the final CUF results. Additional figures and descriptions that explore some of these factors in more detail are presented in Section 6.5.1. In summary, while the 2023 Project was an improvement over the 2022 Project, uncertainty still exists when comparing to the different groundwater allocation methods. The impacts of these uncertainties, and potential ways to address them, are described in more detail in the Conclusions and Recommendations section.

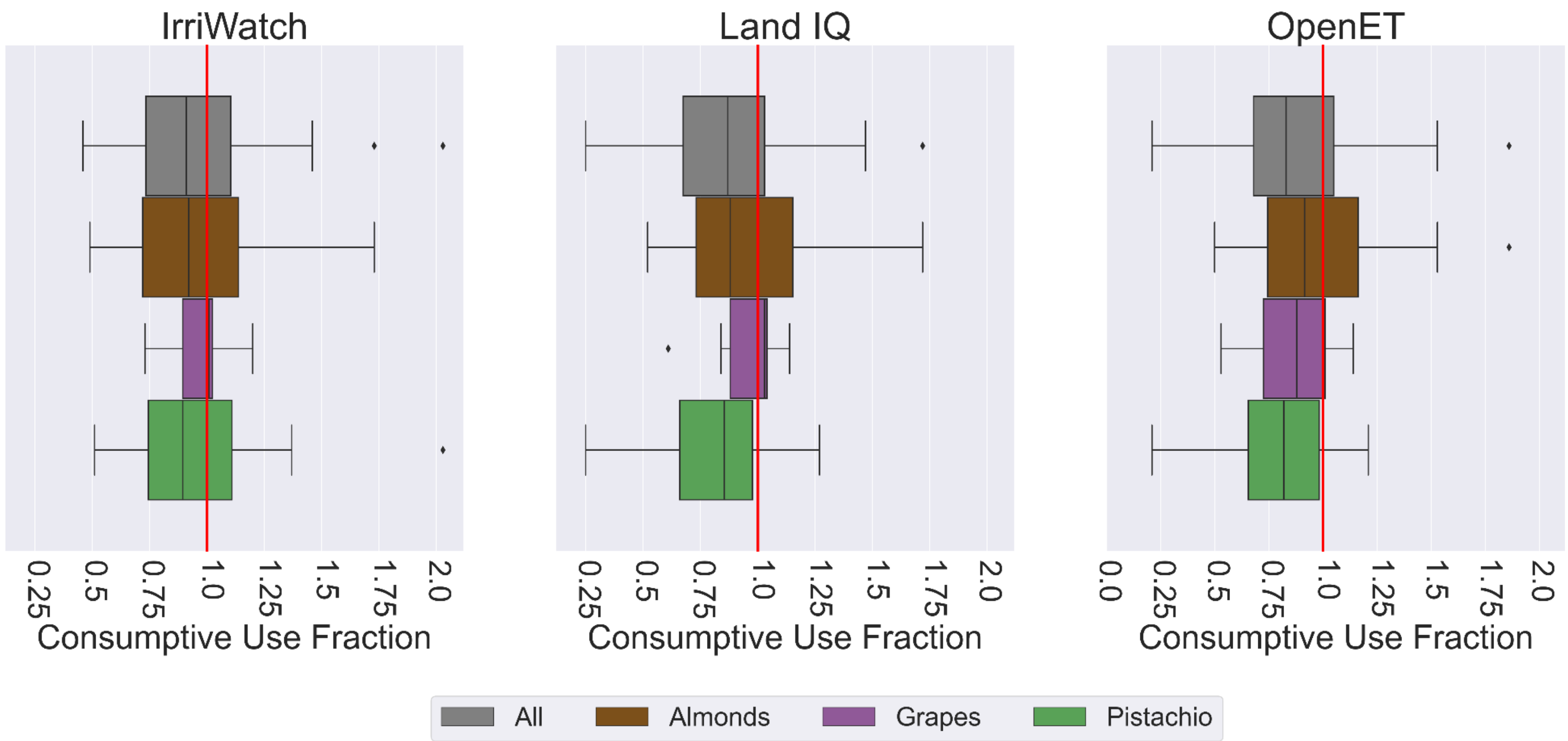

Figure 3-8. Boxplots showing distribution of consumptive use fractions (CUFs) for all Irrigation Units (IUs) considered in the 2023 Verification Project (All; n = 71) and IUs with a single crop type: Almonds (n = 18), Grapes (n = 6), and Pistachios (n = 27). CUFs are shown for each remotely-sensed method used in this study (IrriWatch, Land IQ, OpenET). The results shown include applicable data from all Project Lands. A boxplot shows the median value (line within the box), the 25th and 75th percentile values (left and right edges of each box, respectively), and the minimum and maximum values for the data (excluding any outliers, which are shown as dots).

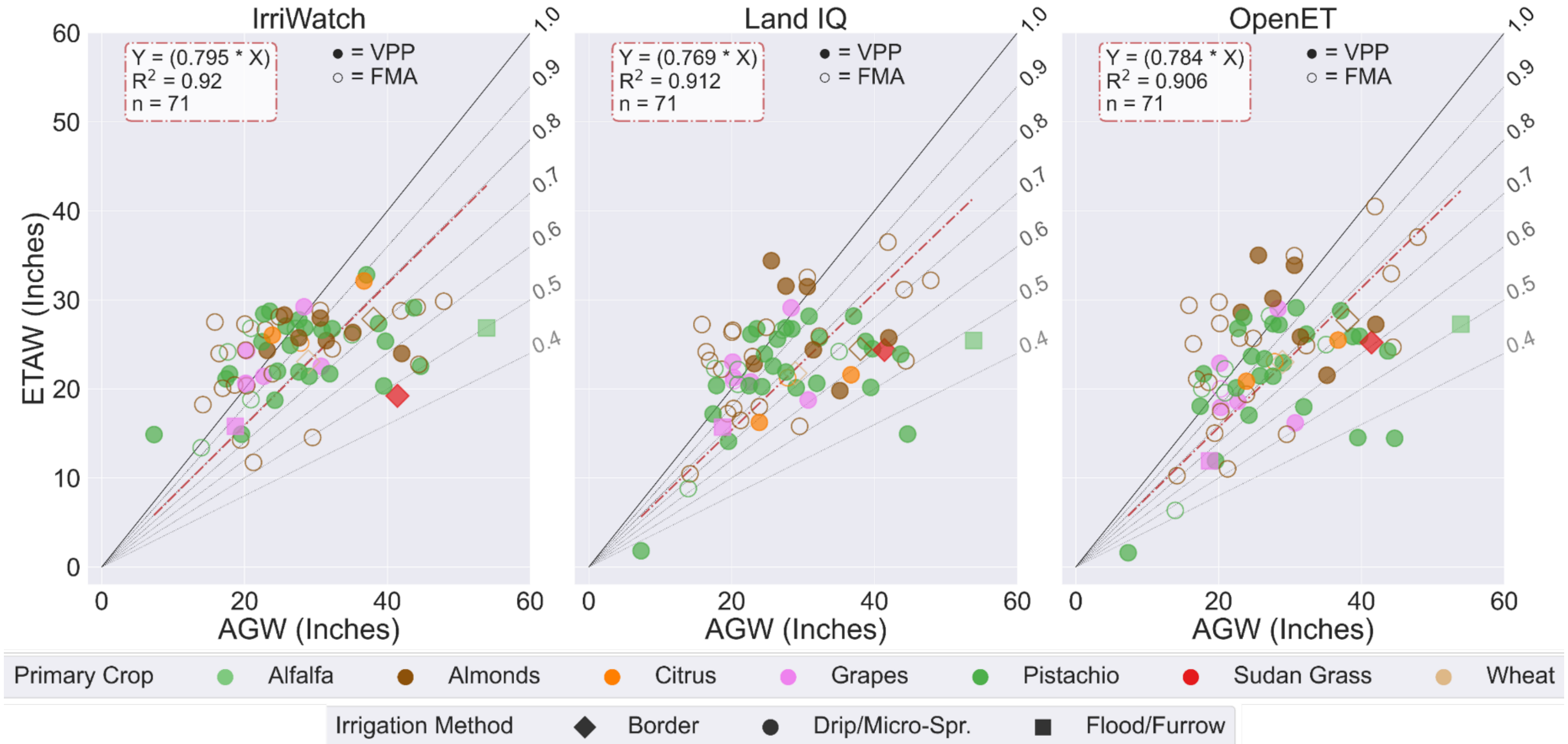

Figure 3-9. Summary of evapotranspiration of applied water (ETAW) and applied groundwater (AGW) for 71 Irrigation Units (IUs) for (1) IrriWatch, (2) Land IQ, and (3) OpenET. "VPP" refers to IUs that participated in the 2023 Madera Verification Project while "FMA" refers to IUs that used flowmeters as their allocation measurement method during 2023. Crop colors represent the primary crop for each IU by acreage (e.g., the crop that covered the largest area within that IU); some of the IUs shown have mixed cropping

4 CONCLUSIONS AND RECOMMENDATIONS

The 2023 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 and options for measuring groundwater use in comparison to the allocations.
2. Implement and refine methods and procedures for collecting, developing, and/or processing the required input data to quantify ETAW for the three allocation measurement options (Flowmeters, IrriWatch, and Land IQ).
3. Compare and analyze available results across the three allocation measurement options (Flowmeters, IrriWatch, and Land IQ) and a fourth independent ETAW measurement (OpenET).
4. Provide recommendations for the groundwater allocation program for 2024 and future years.

Although overall results for the 71 Irrigation Units without known data issues show reasonable average CUFs between 0.77 and 0.89 depending on the analysis method (regression vs. weighted-average) and remotely-sensed method considered (IrriWatch, Land IQ, and OpenET), there is substantial variability between individual IUs and the overall minimum and maximum CUFs. Contributing factors leading to CUFs greater than one could be one or more of: (1) uncertainty and/or 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 (*e.g.*, water flowing into the root zone from shallow groundwater or nearby surface water features, such as ditches or ponds). Use of root-zone soil moisture and a third source of water (2 and 3 above) may have a large impact in individual cases, but the extent of CUF values greater than one (and high variability in CUF values overall) seems to indicate some level of uncertainty/error in quantification of ETAW and/or AGW. Low CUFs (below 0.5 for flood irrigation systems and below 0.7 for pressurized irrigation systems) are also improbable and indicate a potential issue with properly measuring ETAW and water moving in and out of an IU. These uncertainties/error should be studied further, as described below.

The groundwater allocation program is irreducibly complex. Its successful implementation is required to achieve sustainability (per the GSPs), and the best available information needs to be used and the program and its many facets need to be clearly communicated to growers to ensure it is implemented and enforced in a consistent and repeatable manner. The Verification Projects (both 2022 and 2023) are an important review of the data and procedures behind the groundwater allocation program. The 2022 Project included conclusions and recommendations for the groundwater allocation program in 2023 and beyond. As part of the 2023 Project, significant improvements were made based on outcomes from the 2022 Project. These include:

1. Ongoing engagement between Madera County and growers led to increased grower participation in the 2023 Project as VPPs, compared to the 2022 Project, and

participating lands that were more representative of overall farmed lands in the Madera County GSAs (Objective 1).
2. An online data portal was created (DE Data Portal) where growers can submit their volumetric flowmeter readings via a mobile data collection form accessible from a smartphone or tablet; flowmeter readings can then be manually quality controlled and applied to IUs to track usage relative to groundwater allocations (Objective 2).
3. Development of an online database (Allocation Database) to manage data related to the groundwater allocation program such as groundwater wells, associated flowmeters, associated irrigated lands forming IUs, growers or landowners, and changes occurring over time (Objective 2).
4. The implementation of multiple measurement options for quantification of ETAW under the groundwater allocation program (Objective 2).
5. As described above, the development of new tools and processes to facilitate implementation of the groundwater allocation program for multiple measurement options, along with Madera County staff training on use and implementation of new tools and procedures, were completed as part of the 2023 Project (Objective 2)
6. The comparison of multiple AGW and ETAW quantification methods revealed high variability and, in some cases, deviations from expected results when comparing ground-based AGW measurements and remotely-sensed ETAW estimates (Objective 3).

As noted above, 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) consistently implement the GSAs' groundwater allocations (including carryover and penalties) for County growers individually and collectively. While there is no strict quantitative definition of what is "sufficiently accurate" in SGMA or otherwise, large uncertainties between methods used to track ETAW need to be understood and minimized to achieve groundwater sustainability in an equitable and robust manner. The 2023 Project was a valuable continuation of the 2022 Project and shows continuing discrepancies and/or uncertainties, in some cases, between ground-based AGW methods (flowmeters) and remotely-sensed ETAW estimation methods (IrriWatch and Land IQ) chosen to enforce groundwater allocations. In this context, the 2023 Project results lead to the following conclusions and recommendations, which are framed around the 2023 Project objectives:

Objective 1: Increase grower engagement, education, and outreach related to SGMA implementation, particularly groundwater allocations and options for measuring groundwater use in comparison to the allocations.

1. Grower engagement, education, and outreach remains critical, and needs to be adaptable and suited to meet grower needs; due to dynamic process of SGMA implementation and changing hydrologic conditions, growers will need to be informed of and understand any relevant issues and opportunities over time.
2. Spending time in the field or in individual or small group meetings with growers studying and discussing 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. Future work related to the groundwater allocation program should focus on building grower and stakeholder confidence in the approaches used to quantify groundwater use through remotely-sensed ETAW and measured AGW.
4. Opportunities to continue to build Madera County GSAs staff capacity to engage with growers in SGMA-related education and outreach activities should be identified and pursued.
5. Improved availability of data related to groundwater usage and allocations should be prioritized to provide growers with on-demand information or more frequent updates on their groundwater usage. A secure and password-protected online data portal with grower-specific information is recommended.

Objective 2: Implement and refine methods and procedures for collecting, developing, and/or processing the required input data to quantify AGW/ETAW for the three allocation measurement options (Flowmeters, IrriWatch, and Land IQ).

1. Improved data systems (i.e., the Data Portal and Allocation Database) were effective at streamlining QA/QC processes, correcting linkage issues between farmed lands and Irrigation Units, and maintaining a record of changes made over time.
2. Semi-automated, near real-time review of flowmeter and remotely-sensed data are necessary to identify and address errors in submitted AGW volumes and refine the methods and assumptions used to estimate ETAW. Close data review needs to continue in 2024 and beyond to ensure data accuracy, and as identified, opportunities to improve data review and management should be implemented.
3. Flowmeters remain accurate for measurement of AGW if installed and maintained correctly, but require QA/QC, understanding of where AGW is applied for irrigation, irrigation method, and CUF for conversion to ETAW.
4. Remote sensing provides spatially explicit data on a large spatial scale but requires quantification of ETPR and conversion from ET to ETAW. Remotely-sensed ETAW from different sources is more similar in aggregate than individually. Differing individual results between sources should be studied to better understand differences and their underlying causes.
5. Additional recommendations related to Flowmeters and remotely-sensed methods (IrriWatch, Land IQ) were described previously in Sections 3.2.1 and 3.3.1, respectively.

Objective 3: Compare and analyze available results across the three allocation measurement options (Flowmeters, IrriWatch, and Land IQ) and a fourth independent ETAW measurement (OpenET).

1. When aggregated for all crop types and lands, the CUF values calculated by comparing ETAW (IrriWatch, Land IQ, and OpenET) to AGW (Flowmeters) are reasonable (*e.g.*, 0.77 to 0.89).

   a. Given the wide range in CUFs depending on the analysis method (*e.g.*, regression analysis vs. weighted-average), CUFs used to convert AGW to ETAW should be revisited in 2024.
2. However, substantial variability in CUFs exists between crops and for individual IUs for all three remotely-sensed ETAW estimation methods (IrriWatch, Land IQ, and OpenET); this was also true in 2022 for only IrriWatch.
3. Similar to 2022 Project results, CUFs exceeding 1.0 are not uncommon in the 2023 Project and cannot be fully explained by this dataset.

Objective 4: Provide recommendations for the groundwater allocation program for 2024 and future years.

As described above, the 2022 and 2023 Projects have been an important review of the groundwater allocation program, and have provided conclusions and recommendations that have improved the program. Specifically, Madera County staff found that comparing remotely-sensed ETAW to flowmeter AGW on a large-scale was useful to identify IUs with questionable data. Unpermitted and unreported pumped wells represent a “third” source of water not properly accounted for in this report, which could contribute to the high variability shown in CUFs. As a result, IUs with unrealistically high CUFs (> 1.2) were investigated further by Madera County staff to ensure all wells within that IU were properly identified and permitted. It is recommended that this investigation be completed in 2024 and beyond to ensure well/flowmeter compliance. Because the 2023 Project was useful in identifying IUs with questionable data, and considering support from VPPs to continue the Verification Project in 2024, it is recommended that a 2024 Project be completed as well.

Every aspect of the 2022 and 2023 Projects (*e.g.*, grower coordination, field data collection, data review and analysis, etc.) was led by DE staff. For the 2024 Project, it is recommended that DE staff train Madera County staff to lead project activities to the extent possible, with DE staff providing support as needed. Per this recommendation, DE staff would train Madera County staff in processes used for grower coordination, planning for field data collection, conducting field data collection, and processing and analyzing data. DE staff would provide support as requested by Madera County staff. Training Madera County staff in Verification Project procedures will allow for future iterations of the Verification Project in 2024 and beyond to maintain a robust dataset to further refine each allocation measurement method while minimizing consultant support from DE staff (with the goal of eliminating it over time).

In addition to the recommendations described above related to other 2023 Project objectives, after observing IUs with CUFs greater than one consistently in 2022 and 2023, a more detailed assessment of water moving in and out of IUs is recommended to fully understand AGW vs. ETAW discrepancies. Specifically, it is recommended that the County pursue additional efforts to better quantify uncertainty in ETAW estimates and quantify potential “third” water supply sources. These additional assessments are especially needed for IUs with CUFs exceeding one. Potential next steps include:

1. For growers using flowmeters as their allocation method, County staff should ensure all wells are identified and properly permitted.
2. Comparison of remotely-sensed ETAW to high-quality, ground-based ETAW within Madera County GSAs.
3. Field monitoring of soil moisture, shallow groundwater, and irrigation efficiency within IUs.
4. Continued coordination with growers to document additional water sources (e.g., surface water) used throughout the irrigation season, if present.

It is recommended that collaborative partnerships be developed between Madera County, academic researchers, other local agencies, and consultants to successfully implement the additional assessments above. This type of collaboration should be designed to materially benefit local end users (e.g., GSAs and growers) while seeking to better understand and improve the accuracy of measurement methods used for SGMA implementation.

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6 TECHNICAL APPENDICES

6.1 Grower Outreach and Engagement

The sections of the technical appendix below describe efforts of the Project related to Objective 1, which was to increase grower engagement, education, and outreach related to SGMA implementation (in particular groundwater allocations, remote sensing of ETAW, and metering of AGW).

6.1.1 Solicitation of Interest and Grower Workshop on June 15, 2023

It was grower feedback that led to the first Verification Project in 2022. The 2022 Project evaluated the relationship between IrriWatch's reported ETAW and recorded volumes of AGW from flowmeters for participating IUs. In 2023, the Madera County GSAs expanded their methods for tracking groundwater allocations with the addition of Land IQ and flowmeters as an alternative to IrriWatch and the Verification Project was continued through the 2023 Project.

Upon initiation of the Project in Spring 2023, outreach to growers began in order to (1) communicate the details and objectives of the Project and (2) to better understand grower interest and identify Madera County GSA growers who would potentially be interested in 2023 Project participation. This was done informally during meetings and conversations with growers. Additional solicitation occurred through direct targeted outreach to roughly 80 growers who were selected based on available information about their cropping (targeting included lands representative of overall cropping within the Madera County GSAs) or knowledge about existing flowmeters that could be used to measure AGW for the 2023 Project. This direct targeted outreach included an email with a flyer containing more information about the 2023 Project and a phone call to discuss the 2023 Project. Growers were then invited to an initial Grower Workshop on June 15, 2023.

The June 15th workshop included a presentation that included an overview of SGMA and groundwater allocations, a summary of the 2022 Project, and an overview of the 2023 Project and participation requirements. It was followed by questions and discussion, and attendees were encouraged to speak with a DE or Madera County staff member about any further questions or to express their interest and willingness to participate in the 2023 Project. The PowerPoint slides from the Grower Workshop are available in Section 6.5.6.

6.1.2 Initial Grower Meetings and Selection of Participating Lands (June 2023)

Following the June 15, 2023 workshop, individual meetings with interested growers were scheduled. The meetings were held in-person at the Madera Water and Natural Resources Department (200 W. Fourth Street Madera, CA 93637) or virtually via Microsoft Teams between June 15th and June 29th. The primary goal for the individual meetings was to coordinate and communicate directly with potential growers on an individual basis and to establish an overall understanding of all the potential participating lands in the 2023 Project. The objectives of the meetings were to:

1. Determine eligibility and interest for the grower to participate in the 2023 Project.
2. Review flowmeter locations, Parcel-Fields, and establish a linkage between wells and Parcel-Fields.
3. Discuss coordination and communication for site visits throughout the summer.
4. Discuss any additional data the potential participant may have collected and is willing to share.
5. Answer any remaining questions the potential participant may have about the 2023 Project.

The objectives of the meetings were to:

1. Review flowmeter locations, Parcel-Fields, and establish a linkage between wells and Parcel-Fields.
2. Discuss coordination and communication for site visits throughout the summer.
3. Discuss any additional data the potential participant may have collected and is willing to share.

Answer any remaining questions the potential participant may have about the 2023 Project. The initial grower meetings also provided an opportunity to discuss allocation measurement options (i.e., IrriWatch, Land IQ, or Flowmeters) and the factors influencing growers' selection of an option. Additionally, growers were able to provide other important details about their farms (e.g., irrigation type and typical practices, crop age, etc.). Lastly, as described above DE staff and growers reviewed and confirmed the accuracy of geospatial information such as IU boundaries and Parcel-Field linkages, and the locations of wells and associated flowmeters.

After the initial round of grower meetings had been concluded, a group of participants and the corresponding participating lands was developed from the initial list of interested potential parties. To qualify as a participant, a grower and their irrigation unit(s) must, at a minimum, meet the following requirements:

1. The geographic boundaries of the irrigation unit must be entirely within the Madera County GSAs and associated Farm Unit Zones[76].
2. Any groundwater well(s) to be monitored for the 2023 Project must be equipped with an instantaneous and totalizing flowmeter.
3. The operation of at least one well for the irrigation of parcel-fields during the 2023 irrigation season[77].
4. A willingness to for data collected as part of the 2023 Project to be published and included in analysis and documentation of the 2023 Project.

[76] The exception to this are IUs that are partially within one or more of the Madera County GSAs and partially within other GSAs. If the areas of the IU outside of the Madera County GSAs were accurately identified and the AGW for the entire IU was measured through flowmeters, these areas were also eligible for inclusion in the 2023 Project.
[77] The exception to this are Dryland parcel-fields that are cropped but rely solely on precipitation and have no applied water.

5. A willingness to coordinate with and provide access to DE and County staff for project-related monitoring during 2023.

The overall objective for the selection of participating lands to include in the 2023 Project was selecting participants and lands representative of the full diversity of growers and cropped lands existing within the Madera County GSAs. As described in the main body of the report, the lands included in the 2023 Project were more representative of Madera County GSAs' cropped lands as a whole, relative to the 2022 Project. The four most common crops grown within the Madera County GSAs (*i.e.*, Almonds, Grapes, Pasture, and Pistachios) were the four most common crops included in the 2023 Project[78], and the crop acreage percentages in the 2023 Project were within 5% of the crop acreage percentage for the Madera County GSAs as a whole in every crop category. Additionally, all growers interested and eligible to participate had at least one irrigation unit that they farmed included in the 2023 Project, none were excluded from participation. The selection criteria and objectives shown in Table 6-1 below were developed for consideration when identifying, reviewing and selecting lands for the 2023 Project.

Table 6-1. Selection Criteria and Objectives.

Selection Criteria	Objective
Farm Unit Zone and Geographic Location	An even distribution of irrigation units across the Farm Unit Zones as well as an even distribution of irrigation units across each Farm Unit Zone.
Grower	A relatively even distribution between growers, based on both number of irrigation units and irrigation unit size.
Cropping	A diversity of crops.
Field Size	A diversity of field sizes.
Proximity to Surface Water	A diversity of distances from the nearest surface water.
Irrigation Method and On-Farm Practices	A diversity of irrigation methods or other on-farm practices.

After the selection of lands for the 2023 Project was finalized, the results of included participating lands for each participating grower were transmitted, along with the initiation of coordination for monitoring, as described subsequently.

6.1.3 Coordination with Participating Growers (June 2023 to January 2024)

Coordination with participating growers included in-person and online meetings, email correspondence, and phone conversations. During the field data collection period (focused primarily on the irrigation season), most of the communication with participants was done

[78] Some summary materials present results aggregated by the most common crops. These summary materials exclude pasture because not all of it is irrigated, and because a combination of other crop types could be classified as pasture (e.g. alfalfa, grasses, wheat, etc.).

through email. On a weekly basis, participating growers would receive an email from DE field staff with information regarding when and where DE and County staff planned to access their property for data collection. Aside from field data collection coordination, DE staff also coordinated with growers on questions related to remote sensing data, flowmeter issues, irrigation evaluations, on-farm practices, local opportunities and programs, and other data related to the 2023 Project.

6.1.4 Final Grower Meetings and Grower Workshop on January 22, 2024

Towards the end of the monitoring period, once data collection was largely complete, DE staff planned, scheduled, and facilitated a final grower workshop for participating growers, as well as individual meetings with participating growers in January 2024. The final grower workshop was held on the morning of January 22, 2024 at the Madera Water and Natural Resources Department (200 W. Fourth Street Madera, CA 93637). Following the workshop, in-person meetings with individual growers were held in the same location for the remainder of the week (January 22nd through January 26th). Virtual meetings via Microsoft Teams were scheduled that same week or the following week (January 29th through February 2nd) for growers who were unable to meet in-person. During these meetings the following items were reviewed and discussed with each grower:

1. 2023 Project objectives and methods of meeting objectives.
2. Preliminary 2023 Project results (both individually for grower and for Project as a whole).
3. Preliminary conclusions, recommendations, and next steps.
4. Any questions or items for discussion that growers wanted to raise.

The materials shared with each grower included an individual grower report with preliminary results for their participating lands and a PowerPoint slide deck with preliminary overall results for the 2023 Project and draft conclusions and recommendations. The PowerPoint slide deck is available in Section 6.5.6. In these meetings, DE and Madera County staff received valuable feedback from growers providing insight into both the 2023 Project results and grower activities, priorities, and concerns. A summary of some key takeaways and discussion points from the grower meetings is included below, organized into the following sections: (1) General, (2) Allocation Measurement (IW), and (3) Groundwater Allocation Program. This was typically discussed in multiple individual grower meetings and emerged as general themes.

6.1.4.1 Summary of General Points from Final Grower Meetings

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. Roughly half of the growers described changing their land and water management practices for reduced water availability under the groundwater allocation program. The most common practices included reducing irrigated crop acreage, implementing deficit irrigation, and acquiring additional lands currently in production and taking them out of

production in order to use the allocation from those lands to provide sufficient water supplies for what they are currently farming.
3. Roughly half of the growers raised cover crops as a topic of concern and wanted to better understand the ET signature of cover crops and associated impacts on their groundwater allocations. Surface water use and recharge (both of which occurred on Project Lands in 2023) were other topics of discussion and concern.
4. Growers agree that successful implementation of groundwater allocations needs to result in the appropriate response of groundwater levels (i.e., slower decline and, ultimately, stabilization of groundwater levels). In the meetings, most growers indicated interest in continuing the Verification Project in future years and would be open to participating again.
5. Growers agree that successful implementation of groundwater allocations needs to result in the appropriate response of groundwater levels (i.e., slower decline and, ultimately, stabilization of groundwater levels).

6.1.4.2 Summary of Allocation Measurement Points from Final Grower Meetings

1. Many growers commented on the tendency of IrriWatch to report higher ETAW in 2023 relative to ETAW from Land IQ, although this issue was addressed by the IrriWatch correction in late 2023.
2. Discussions of adjustments and differing approaches between IrriWatch and Land IQ were also common. One important distinction between the two is that IrriWatch provides data daily (e.g., a high frequency) and then makes retrospective adjustments when necessary (as seen in the 2022 and 2023 Projects) and Land IQ provides data monthly (e.g., a lower frequency) and not until roughly four to six weeks after the period has ended, allowing them to complete their own QA/QC process prior to delivery and due to this, not requiring data adjustments.
3. Issues with parcel and field boundaries and land use coverages were raised in multiple meetings; there are opportunities to improve these coverages that should be prioritized. These impact allocation measurement in cases where irrigated areas (e.g. fields) are attributed to the wrong parcel or are excluded from the parcel-field coverage.
4. Multiple growers (even some who have currently selected either IrriWatch or Land IQ) stated that they feel flowmeters are the most accurate way of quantifying AGW. Discussions around this idea included the difficulty of measuring all AGW via flowmeters, the importance of understanding where AGW is applied onto irrigated lands, and complications resulting from flowmeter malfunction or failure (which did occur on multiple flowmeters for VPPs during the 2023 Project).

6.1.4.3 Summary of Groundwater Allocation Program Points from Final Grower Meetings

1. Many growers expressed concern over the annual reduction in groundwater under the groundwater allocation program, especially in coming years when the reduction increases from 2% to 6% annually.
2. With the initial penalties for 2023 starting at $100/AF and increasing annually to $500/AF, multiple growers expressed that penalties in the first few years (e.g., $100/AF, $200/AF) are unlikely to be a strong disincentive and that some 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. Growers expressed an interest in increasing groundwater allocation program data availability, potentially through an online grower portal, and in implementing telemetry for totalizing flowmeter measurements so that monthly flowmeter reading submittals by growers are no longer required.
4. The grower meetings were opportunities for education and raising awareness of the steps required and options available for recalibration of flowmeters every two years in order to use flowmeters as an allocation measurement option.
5. The grower meetings were also opportunities for discussion and education about use of surface water (e.g., for groundwater recharge, flood control, or irrigation), reviewing the required steps to document and demonstrate surface water use, and how surface water use intersects with the groundwater allocation program (e.g., recharge credits).

6.1.5 Solicitation of Additional Grower Feedback (February 2024)

DE prepared a list of survey questions related to the 2023 Project and distributed the survey to VPPs to solicit feedback following the final grower meetings in February 2024. The objective of this was to gauge the general satisfaction of growers with the efforts put forth by DE and the County as part of the 2023 Project, understand interest in continuing the Project in 2024, and provide an opportunity for growers to share additional thoughts and feedback. The results of this were broadly described in Section 5.1, and the specific results are presented below.

The questions included in the survey distributed to VPPs were:

1. How were you made aware of the opportunity to participate?
2. Did you clearly understand the intent of the 2023 Verification Project?
3. Did you find it helpful to have interaction and coordination with you in the field over the course of the irrigation season?
4. Do you feel like the 2023 Verification Project was helpful in leading to practical conclusions and recommendations?
5. From your perspective, what are some of the key conclusions and recommendations that have come from the 2023 Verification Project?
6. Overall, how would you rate your interactions with field staff over the course of the irrigation season?
7. How important is it to you to have County engagement and involvement in the field at a farm scale?
8. What worked well as part of the 2023 Verification Project?
9. What didn't work well as part of the 2023 Verification Project?
10. Overall, how would you rate your satisfaction with the 2023 Verification Project?
11. 2023 was the 2nd year of the Verification Project. Do you think the Verification Project should continue for a 3rd year in 2024?
12. If yes to the above, would you be willing to participate in the Verification Project again in 2024?

13. Please provide any additional feedback concerning the project.

A total of 9 out of 25 growers (36%) responded to the survey, but not every survey question was answered in each submitted response. The remaining 16 growers did not provide a survey response. The grower responses to each question are summarized in the sections below.

6.1.5.1 How were you made aware of the opportunity to participate?

The primary means through which responding growers learned of the opportunity to participate in the 2023 Project was through previously participating in the 2022 Verification Project (7 responses, 78%[79]). The remaining responders were made aware of the 2023 Project through outreach by County staff (2 responses, 22%). The results are shown in Figure 6-1.

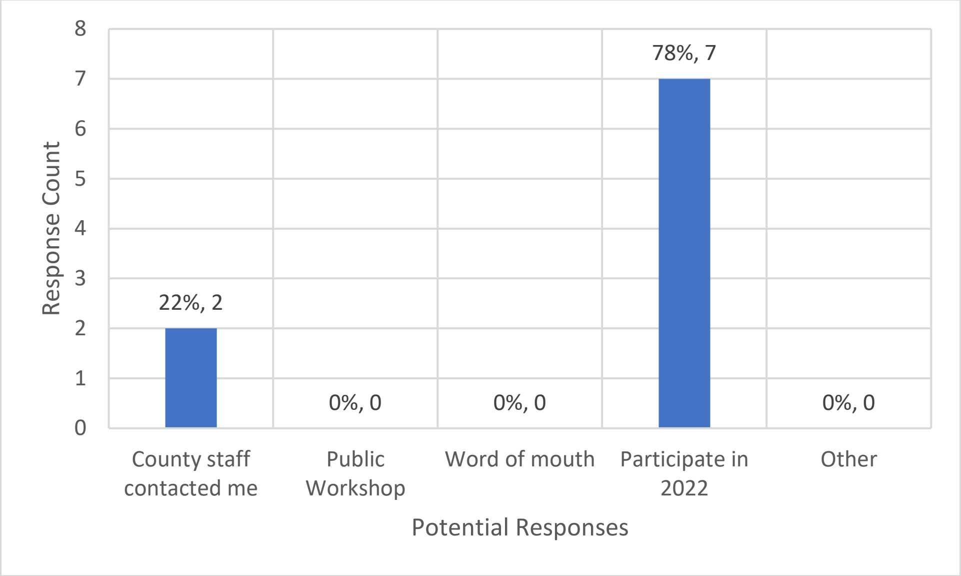

Figure 6-1. Question 1 Response Summary (How were you made aware of the opportunity to participate?).

6.1.5.2 Did you clearly understand the intent of the 2023 Project?

The feedback requested in response to this question was either Yes or No. All responding growers (9 responses, 100%) indicated that they understood the intent of the Project.

6.1.5.3 Did you find it helpful to have interaction and coordination with you in the field over the course of the irrigation season?

The feedback requested in response to this question was either Yes or No. The majority of responding growers (7 responses, 78%) indicated that the interaction and coordination was helpful. Other respondents indicated that it was not helpful (1 response, 11%) or did not answer the question (1 response, 11%).

[79] The first value (*i.e.,* 7) represents the number of project participants and the second value (*i.e.,* 78%) represents the percentage out of total respondents.

6.1.5.4 Do you feel like the 2023 Project was helpful in leading to practical conclusions and recommendations?

The feedback requested in response to this question was either Yes or No. All responding growers (9 responses, 100%) indicated that the information was helpful in leading to practical conclusions and recommendations.

6.1.5.5 From your perspective, what are some of the key conclusions and recommendations that have come from the 2023 MVP?

The feedback requested for this question was an open-ended response. All responses received are copied verbatim below. Although there were nine responses received from growers, not all growers elected to answer the open-ended response questions, which is why there are less than nine responses shown.

1. Land IQ under-records the amount of groundwater used.
2. I think the meters are still the best way to know exactly how much water is applied to the field. Although meters can have inaccuracies, they are the best way to have a real time idea of water use. Satellites have gotten better but still have more inaccuracies that need to be addressed.
3. That satellite is still not 99% accurate but it is getting better. However, I will continue to use my meters for my allocation.
4. That my flowmeter is not that accurate. Land IQ seems to be the best monitoring option.
5. Some key conclusions that we got from the 2023 MVP that the relation between our meter selection vs satellite based mounting is similar but there are still discrepancies. It was also noted that research into how cover crops play a role into the satellite imagery is of huge interest.
6. IrriWatch made some necessary adjustments in their measurement system which seem to make it more accurate. If Davids had anything to do with pointing out the need for adjustments, I say thank you.
7. The monitoring tools we have the ability to use are all within a pretty close margin, when everything is said and done. The verification project helped me be much more comfortable with trusting the satellite measurements because I know it was verified against our actual water applied.

6.1.5.6 Overall, how would you rate your interactions with field staff over the course of the irrigation season?

The feedback requested in response to this question was a selection of numbers ranging from one (Very Bad) through five (Very Good). The meaning corresponding to each number is shown in Figure 6-2. The majority of respondents (5 responses, 56%) indicated that they had Very Good interactions with the field staff. Other respondents indicated that they had Good interactions with the field staff (3 responses, 33%) and one respondent (1 response, 11%) elected not to respond. The results are shown in Figure 6-2.

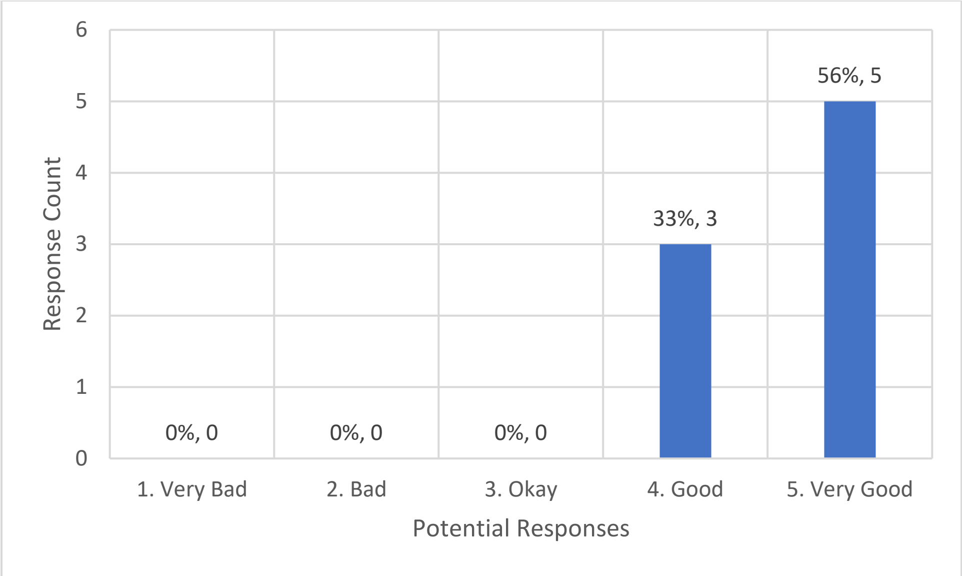

Figure 6-2. Question 6 Response Summary (Overall, how would you rate your interactions with field staff over the course of the irrigation season?).

6.1.5.7 How important is it to you to have County engagement and involvement in the field at a farm scale?

The feedback requested in response to this question was a selection of numbers ranging from one (Not Important at All) through five (Very Important). The meaning corresponding to each number is shown in Figure 6-3. The majority of growers (6 responses, 67%) found County engagement Somewhat Important. Other respondents indicated county engagement was Very Important (1 response, 11%), were Indifferent on the matter (1 response, 11%), or chose not to respond (1 response, 11%). The results are shown in Figure 6-3.

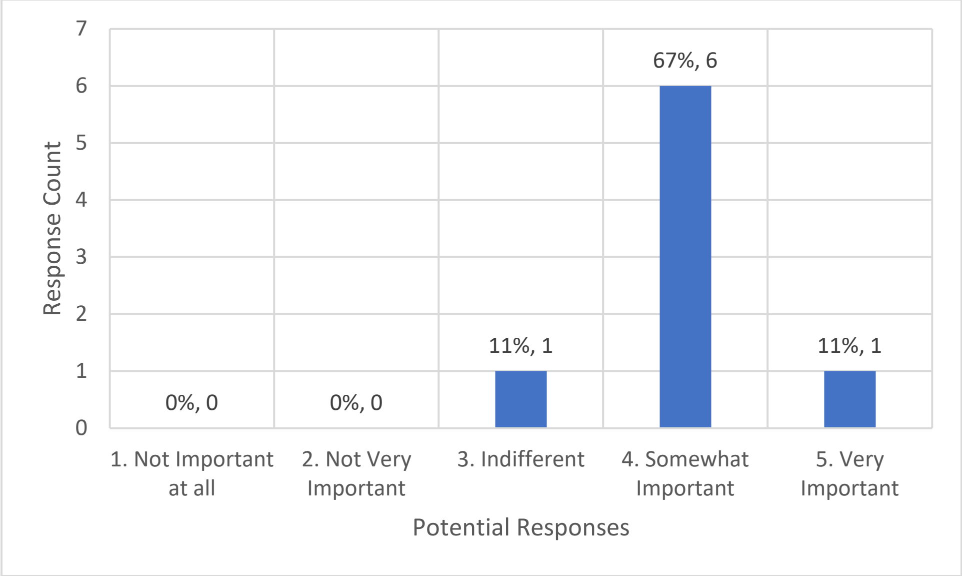

Figure 6-3. Question 7 Response Summary (How important is it to you to have County engagement and involvement in the field at a farm scale?).

6.1.5.8 What worked well as part of the 2023 MVP?

The feedback requested for this question was an open-ended response. All responses received are copied verbatim below. Although there were nine responses received from growers, not all growers elected to answer the open-ended response questions, which is why there are less than nine responses shown. Some ideas present in multiple responses include that coordination and collaboration on the Project with DE went well, grower participation was minimal, and the study did not impede on grower operations.

1. I think that it was very helpful to have Davids Engineering confirming the three measurement methods.
2. I think everything worked well. It didn't impede any operations on the farm.
3. The communication before field visits was very good. It was important to protect visitors from application drift.
4. Not much effort on my part to get the results from monitoring.
5. I think communication was great for the 2023 MVP. I think having the individual grower meetings was helpful and insightful for our farm manager.
6. Communication, data collection and the report itself is helpful. I will be able to make choices for future crops based on the data collected and how much water I used this year.
7. Look, I never saw anyone in my field from Davids this year or from the county, ever. I don’t have a bad relation. I just don’t have a relation in the field.

6.1.5.9 What didn’t work well as part of the 2023 MVP?

The feedback requested for this question was an open-ended response. All responses received are copied verbatim below. Although there were nine responses received from growers, not all growers elected to answer the open-ended response questions, which is why there are less than nine responses shown. Overall the majority of respondents did not have comments on what didn’t work well or elected not to answer.

1. Nothing I can think of.
2. Nothing comes to mind.
3. Having Davids Engineering give thoughts on what the future might look like on restrictions and transferring groundwater allocation from other properties.
4. No complaints, I think it went pretty smoothly, at least on my end.

6.1.5.10 Overall, how would you rate your satisfaction with the 2023 MVP?

The feedback requested in response to this question was a selection of numbers ranging from one (Very Bad) through five (Very Good). The meaning corresponding to each number is shown in Figure 6-4. The majority (5 responses, 56%) of respondents rated the project with a Very Good level of satisfaction. Other respondents’ level of satisfaction was Good (3 responses, 33%) or Okay (1 response, 11%). The results are shown in Figure 6-4.

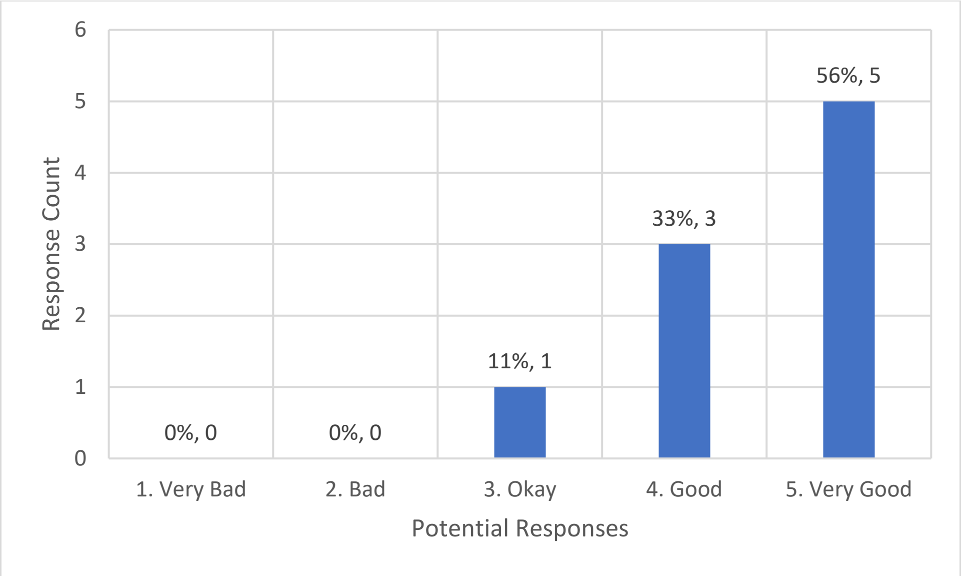

Figure 6-4. Question 10 Response Summary (Overall, how would you rate your satisfaction with the 2023 Project?).

6.1.5.11 2023 was the 2nd year of the Verification Project. Do you think the Verification Project should continue for a 3rd year in 2024?

The feedback requested in response to this question was either Yes or No. All responding growers (9, 100%) expressed approval of the continuation of the Verification Project.

6.1.5.12 If yes to the above, would you be willing to participate in the Verification Project again in 2024?

The feedback requested in response to this question was either Yes or No. All responding growers (9, 100%) who expressed approval of the continuation of the MVP also indicated that they would be willing to participate in a future 2024 Verification Project.

6.1.5.13 Please provide any additional feedback concerning the 2023 Project.

The feedback requested for this question was an open-ended response. All responses received are copied verbatim below. Although there were nine responses received from growers, not all growers elected to answer the open-ended response questions, which is why there are less than nine responses shown.

1. I think that IrriWatch and Land IQ are not as accurate as flowmeters for measuring the amount of groundwater used.
2. Not sure if has been done but have you compared the calculation of water use from a pump test and electrical consumption? I would be interesting to compare with actual meter readings for the season.
3. I think if the project did continue, it would only help to further fine tune the data and in the long run help growers navigate the nightmare that is SGMA. I really appreciate all the help and feedback you have provided for our ranch. This will help me manage the

farm going forward with much more informed water/irrigation decisions; because now I have a rough idea of what each of our crops ETAW is at our traditional irrigation rates. And again it helps me be more comfortable with the IrriWatch readings.

4. I think Davids got a little more into relating ET to crop production situations and less with ET as correlated to the turning of a meter, but I could be wrong. There is a great deal of information to be gained from a GSA-wide ET measurement system. I would like to have some discussion about a 2024 scope of work before a new contract is issued.

6.2 Field Data Collection

The sections of the technical appendix below describe efforts of the 2023 Project related to Objective 2, specifically for the implementation and refinement of procedures for collecting, developing, and/or processing input data to quantify flowmeter AGW. The systems and procedures shared below also contributed to Objective 3, which was comparing remotely-sensed ETAW to on-the-ground measured AGW.

6.2.1 Open Data Kit (ODK) and DE Data Portal System Overview

Developing and implementing an effective system and procedures for accurate data collection and management is critical to the success of any project reliant on individually submitted data or data collected by multiple parties. Accurate data submission is key to inform project results and recommendations, which in turn may guide future planning and policy decisions. Based on the 2023 Project's need for a large quantity of in-field data to be collected, the Open Data Kit (ODK) platform[80] was selected during the 2022 Project and continued through the 2023 Project to facilitate collection, storage, and management of data collected in the field. Reasons for selecting ODK include the following benefits that it offers:

1. The technology is open-source and there are no fees associated with its use.
2. It provides functionality to design custom survey forms to streamline data collection and ensure specific types of data (i.e., date time, location, name, photos) are included with each form submission.
3. It provides functionality to collect and input field data using any device with an internet browser and connection (including handheld devices) as well as any android device with or without internet, allowing multiple users to submit data.
4. It provides a central server where all data submittals are organized and housed, can be reviewed to ensure proper quality assurance/quality control (QA/QC), and are available for download or export.

The ODK system is comprised of two components: data forms and a data server. A data form is a customized survey form where data collection workflows can be completed with a handheld device (*i.e.*, smartphone or tablet); these forms are created using XLSForms and uploaded to the data server (ODK Central) and published. After publishing, the forms can be accessed and

[80] More information about the ODK platform can be found at: https://getodk.org/

completed using Enketo (via a web browser on any device) or ODK Collect (an Android app). ODK Central houses all of the data submitted by the data forms and allows for review and QA/QC of submitted data. From the server, the data can be managed as well as downloaded or exported for analysis. The components of the ODK system are visualized below in Figure 6-5 along with arrows indicating direction of data flow and communication.

The ODK system was a particularly useful application for the 2023 Project since data was collected in areas where a traditional computer was not present, and where wi-fi and/or cellular service were not always available; in these areas, the ability to collect and record data using ODK Collect was still possible.

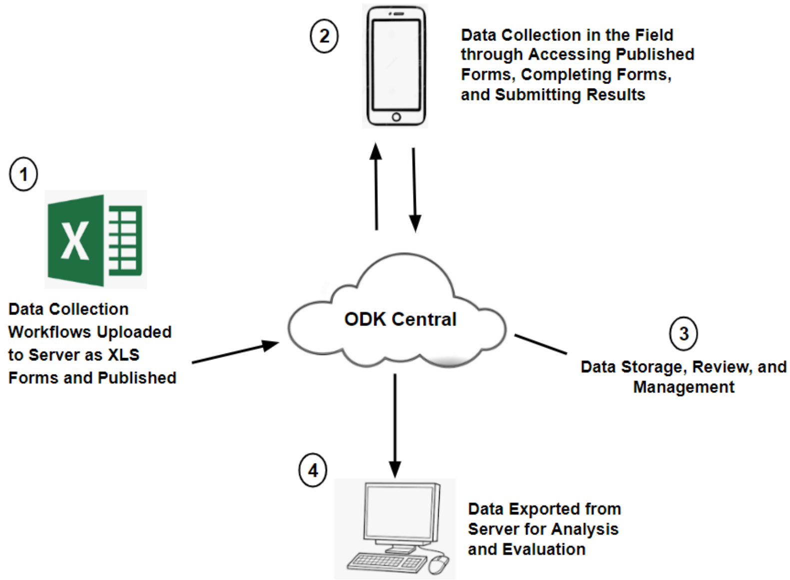

Figure 6-5. ODK Central System Architecture.

To develop a data form, a survey must be created within Excel as an XLSForm in the proper format and with the questions necessary to effectively document the data to be collected. Once the Excel XLSForm file has been created, it can then be converted into an ODK Xform (which allows for the Excel survey to be presented in a format that can be completed through a handheld device). After the Xform file is published through the ODK Central server it can be accessed through ODK Collect for android devices or Enketo through an internet browser. In-field data can then be collected and completed forms can be submitted to the ODK Central server for storage, management, and analysis.

All the forms uploaded to ODK Central were housed within the 2023 Project folder. In this folder, each form had a submissions tab where data was stored. For the data uploaded through completed ODK forms, each entry can be reviewed and, if necessary, edited to ensure all the data was accurate. For the majority of the data submittals associated with these forms, data management and review was delegated to the DE Data Portal web app (discussed further in Section 6.4)

6.2.2 Flowmeter Readings and Comparison Flow Measurements

During initiation of the 2023 Project, potential grower participants were provided with a link to an Enketo form available through an internet browser where they could upload information for their flowmeter(s) that included the flowmeter ID, a photo of the flowmeter, the coordinates of the flowmeter, the flowmeter volume, the flowmeter flow, and any additional information relevant to the 2023 Project[81]. After being selected to participate in the project, growers were asked to continue to submit the forms on a monthly basis to provide updated flowmeter readings throughout the irrigation season. In addition to the flowmeter readings submissions via the form, growers also were asked to supply DE with flowmeter readings dating back to January 2023, if available. This was one of the methods employed to monitor and develop a dataset of AGW volumes for comparison to remote sensing methods.

Following the initial grower meetings in June 2023, DE field staff also began to collect in-field permanent flowmeter[82] readings on a weekly basis during June, July, and August, a bi-weekly basis in September and October, and less frequently in November and December. Flowmeter readings consisted of documentation of the flowmeter's total volume and flow, similar to submittals from participating growers, along with potential documentation of a comparison flow measurement. DE aggregated the available flowmeter observations to determine cumulative pumping volumes for each groundwater well included in the 2023 Project (from both VPP and FMA lands). These resulting volumes were then aggregated for the Irrigation Units associated with each well for comparison to cumulative ETAW from IrriWatch, Land IQ, and OpenET.

In addition to collecting flowmeter readings of instantaneous flow and totalizing volume from the permanent flowmeters, DE also performed independent flow measurements using a portable transit time flowmeter (Fuji Electric Portaflow-C FSC-4 Ultrasonic Flowmeter[83]) to compare against the permanent flowmeter's instantaneous flow measurement. While the permanent flowmeter's corresponding pump was operating, the portable transit time flowmeter was installed in the best measurement location available (dependent on piping configuration at the site; often directly upstream or downstream of the permanent flowmeter) and configured to measure the flow of water within the pipe. The flow measured by the Fuji Flowmeter was then recorded and directly compared to the flow being recorded by the permanent flowmeter. The results of this are summarized in Section 3.2.1. In total, growers in the Madera County GSAs submitted 2,061 flowmeter observations that were considered for inclusion in the 2023 Project and DE staff collected 1,029 flowmeter observations, resulting in a combined total of 3,090 observations.

[81] A copy of the form provided to potential participants is available in Section 6.5.6.
[82] Permanent flowmeters are the grower-installed and maintained flowmeters attached to an irrigation pipeline downstream of the grower's groundwater well and pump.
[83] Fuji Electric Portaflow-C FSC-4 Ultrasonic Flowmeter. The manual to the flowmeter can be found here: https://davidsengineering.sharepoint.com/:b:/s/DE_Projects/EZRPx4XSailIkOlYh9nvZkQBJtdNxUdoC_GXUgkzTj0yhQ?e=lhN8oH

6.2.3 Flowmeter Installation Reviews

Additional information collected for each flowmeter as part of the Project included flowmeter installation reviews, which were completed referencing each flowmeter's manufacturer specifications regarding required installation location and conditions for accurate flow measurement. The purpose of this review was to determine whether flowmeter installation and maintenance aligns with the manufacturer's specifications or not.

The following steps outline the procedure followed to complete a flowmeter installation review:

1. Record the flowmeter's make and model, including a photograph for records.
2. Determine of the outer pipe diameter by using a flexible tape measure to measure the circumference of the pipe directly upstream of the flowmeter and dividing the resulting circumference value by pi[84]. Most flowmeter specifications for installation conditions are based on uniform pipe diameters upstream (U/S) and downstream (D/S)[85] from the flowmeter (*i.e.*, five uniform pipe diameters U/S, or 50 IN for 10-inch diameter pipeline).
3. Measure the distance from the flowmeter to the nearest U/S obstruction using a tape measure or 100' tape, and recording the type of obstruction. The distance was either measured from the flange or center stem of the flowmeter depending on the manufacturer's specifications. This distance was photographed from a perspective that captured both the flowmeter and U/S obstruction.
4. Measurement of the distance from the flowmeter to the nearest D/S obstruction using a tape measure or 100' tape, and recording the type of obstruction. The distance was either measured from the flange or center stem of the flowmeter depending on the manufacturer's specifications. This distance was photographed from a perspective that captured both the flowmeter and D/S obstruction.
5. Documentation and submittal of all of the information above was done through a custom ODK form. This data would then be transmitted to the DE Data Portal where it would be subjected to the QA/QC process before being included in the 2023 Project.

Based on the pipe diameter, the U/S and D/S distances to the nearest obstruction from the flowmeter, and the manufacturer's installation and maintenance specifications, the status of the flowmeter's installation was determined as either per manufacturer specifications or not. Flowmeter inspections were completed for all 114 flowmeters included in the 2023 Project. The results for the flowmeter installation reviews were summarized in Section 3.2.1.

6.2.4 Observation of In-Field Conditions

Additional observations of conditions in the field were recorded through a custom ODK form. The form was designed to provide the flexibility to record any observation in the field of something that may have a potential influence on either the ETAW or AGW. A total of 380 observations of

[84] The circumference of a circle is equal to pi multiplied by the diameter. The diameter was determined in the field by measuring the circumference of pipe directly and dividing that value by pi.
[85] Upstream (U/S), or the section of pipe that water flows through before flowing past the flowmeter, and downstream (D/S), or the section of pipe that water flows through after passing through the flowmeter.

in-field conditions were recorded by DE field staff as part of the 2023 Project, and the different categories of observations are described below.

6.2.4.1 Wind Speed, Air Temperature, and Humidity

With the use of a portable handheld weather meter (Kestrel 3000[86]), DE staff collected in-field spot measurements of air temperature, relative humidity, wind speed, and dew point. These parameters all influence or are related to ET demand. These data were collected for potential comparison to other ground-based measurements of these parameters collected in the region, or for comparison to input data used by remote sensing for quantification of ETAW. The comparison was not completed as part of the 2023 Project, but could be considered in future work to improve understanding of the variability of these parameters over space and time or as a component of a ground-based ET study.

6.2.4.2 Soil Texture and Moisture Content

With the use of a manual soil auger and NRCS feel methods[87], DE field staff conducted soil texture and moisture content sampling. DE field staff took these samples in attempts to better understand the growing conditions of different lands that growers farm, and to determine if shallow groundwater was present in specific areas on VPP lands. An analysis of soil texture results is included in Section 6.5.6.

6.2.4.3 On-farm Observations

Different on-farm practices or conditions have the potential for a large influence on a crop's consumptive use of water, so collecting additional visual observations of on-farm conditions was important. Observations of on-farm conditions collected throughout the Project included, but were not limited to, crop type, irrigation method, crop health, presence of standing water, presence of tailwater, nearby surface water, presence of additional vegetation (*e.g.*, either an intentional cover crop or unintentional weed growth), and any notable changes to field conditions (*e.g.*, the plowing of a field). These observations are important for better understanding differences in ETAW observed between different fields and crop types and locations in the Madera County GSAs.

6.3 Aggregation of Additional Data

The sections of the technical appendix below describe efforts of the 2023 Project related to Objective 2 specifically for the implementation and refinement of procedures for collecting, developing, and/or processing input data to quantify remotely-sensed ETAW (IrriWatch, Land IQ,

[86] The Kestrel 3000 is a portable weather station capable of measuring air temperature, wind speed, and relative humidity.

[87] Descriptions of the soil texture by feel method and soil moisture by feel and appearance method are available at: https://www.nrcs.usda.gov/sites/default/files/2022-11/texture-by-feel.pdf and https://www.nrcs.usda.gov/wps/cmis_proxy/https/ecm.nrcs.usda.gov%3A443/fncmis/resources/WEBP/ContentStream/idd_E053BF62-0000-C91C-BBDE-B93B0CA85EFE/0/EstimatingSoilMoisture.pdf, respectively.

and OpenET). The systems and procedures shared below also contributed to Objective 3: comparing remotely-sensed ETAW to on-the-ground measured AGW.

In additional to Python scripts developed specific to data sources that are described below, additional scripts were created to join the IrriWatch ET data with Land IQ, OpenET, and Flowmeter data, create data summaries that could be sent to VPPs, and generate figures (as seen in this report).

6.3.1 Aggregation of IrriWatch Data from API

A Python script was developed to programmatically access the IrriWatch Application Programming Interface (API) to download large amounts of data, rather than manual download via the IrriWatch Portal. The script specifies a date range and list of IrriWatch Order Numbers as inputs to the API, downloads the data returned by the API, and organizes and renames the downloaded files for future access and analysis. The files returned by the API are shown in Table 6-2.

The JSON files served as the primary file type used during the 2023 Project. The JSON files provided both daily and cumulative ETa, ETAW, ETPR, and P. In addition, percent vegetation cover, rooting depth, soil moisture content, and soil organic matter content were also extracted at the parcel-field scale within the JSON files. After extracting the JSON files vis the API, a second Python script was created to handle the aggregation of all JSON files into a single table. This extraction and aggregation of cumulative ET/P data, along with the other mentioned parameters, happened monthly throughout 2023. The resulting table contained a time series of IrriWatch data for all participating parcel-fields.

Table 6-2. Summary of files returned by the IrriWatch Application Programming Interface (API).

File Type	Data Type	Number of Files Returned from API	Gigabytes of Data	Description
JSON	Tabular	1 per day	6.6	Shows parcel-field level data; all parameters tracked by IrriWatch are present in this file.
TIFF	Raster	1 per parcel-field in the IrriWatch Order per day	160.6	Shows pixel-level data for a single parcel-field; only certain parameters tracked by IrriWatch are present in the TIFF files
TXT	Plain Text	1 per day	~0	Describes the parameters that can be seen in the TIFF files

6.3.2 Aggregation of Land IQ Data

6.3.2.1 Data Download

Instead of retrieving data via an API, Land IQ set up a web portal specifically for downloading cumulative ET and P on a monthly timestep within the Madera County GSAs. The downloaded data were represented by 30m x 30m raster files. ET and P data provided by Land IQ were not available daily like IrriWatch; data were instead downloaded from Land IQ's web portal approximately four to six weeks after the end of the month after notification from Land IQ that updated data were available.

6.3.2.2 Calculation of ETAW using the USBR method

As mentioned in Section 2.2.3, Land IQ does not calculate ETAW directly. Instead, DE staff developed a method to calculate ETAW using the provided ET and P data. To calculate ETAW, DE staff modified the U.S. Bureau of Reclamation (USBR) method (Stamm, 1967) to first calculate effective precipitation (PEFF) from Land IQ precipitation data (Table 6-3). PEFF represents the amount of water from total precipitation that is stored within the root zone for later use by plants vs. the water that runs off the field or becomes deep percolation. Monthly precipitation increments shown in Table 6-3 were refined/localized from the original USBR method based on actual observations of ET from fallowed fields within the Madera County GSAs. Table 6-3 presents an example calculation for PEFF assuming an area had 2.3 IN of precipitation in May. From this example, PEFF was 1.8 IN or 78% of the 2.3 IN precipitation.

Table 6-3. Modified U.S. Bureau of Reclamation (USBR) method for calculating effective precipitation.

Monthly Precipitation Increments (IN)	Effective Precipitation (%)
0.0 – 0.5	95
0.5 – 1.0	85
1.0 – 1.5	75
1.5 – 2.0	70
2.0 – 2.5	65
2.5 – 3.0	60
> 3.0	50
Example calculation assuming 2.3 IN of precipitation in May	$0.5 * (0.95 + 0.85 + 0.75 + 0.70) + 0.3 * (0.65) = 1.8\ \text{IN}$

Following the calculation of PEFF, total effective precipitation (TPEFF) also needed to be determined (Figure 6-6). TPEFF represents the total precipitation soil water storage remaining after accounting for both PEFF and ET from a field. During the winter months, TPEFF is high due to the consistent rainfall during this time (in non-drought conditions) and low ETa. However, as temperatures rise, plants grow, and precipitation rates drop in the spring and summer months, TPEFF is reduced until reaching zero. During this transition, there is no more precipitation soil moisture left for crops to continue growing, so growers begin to irrigate their crops with applied water. Therefore, by May (in a typical year), it is expected that a portion of the ET signature measured by remotely-sensed methods is coming from ETPR and ETETAW.

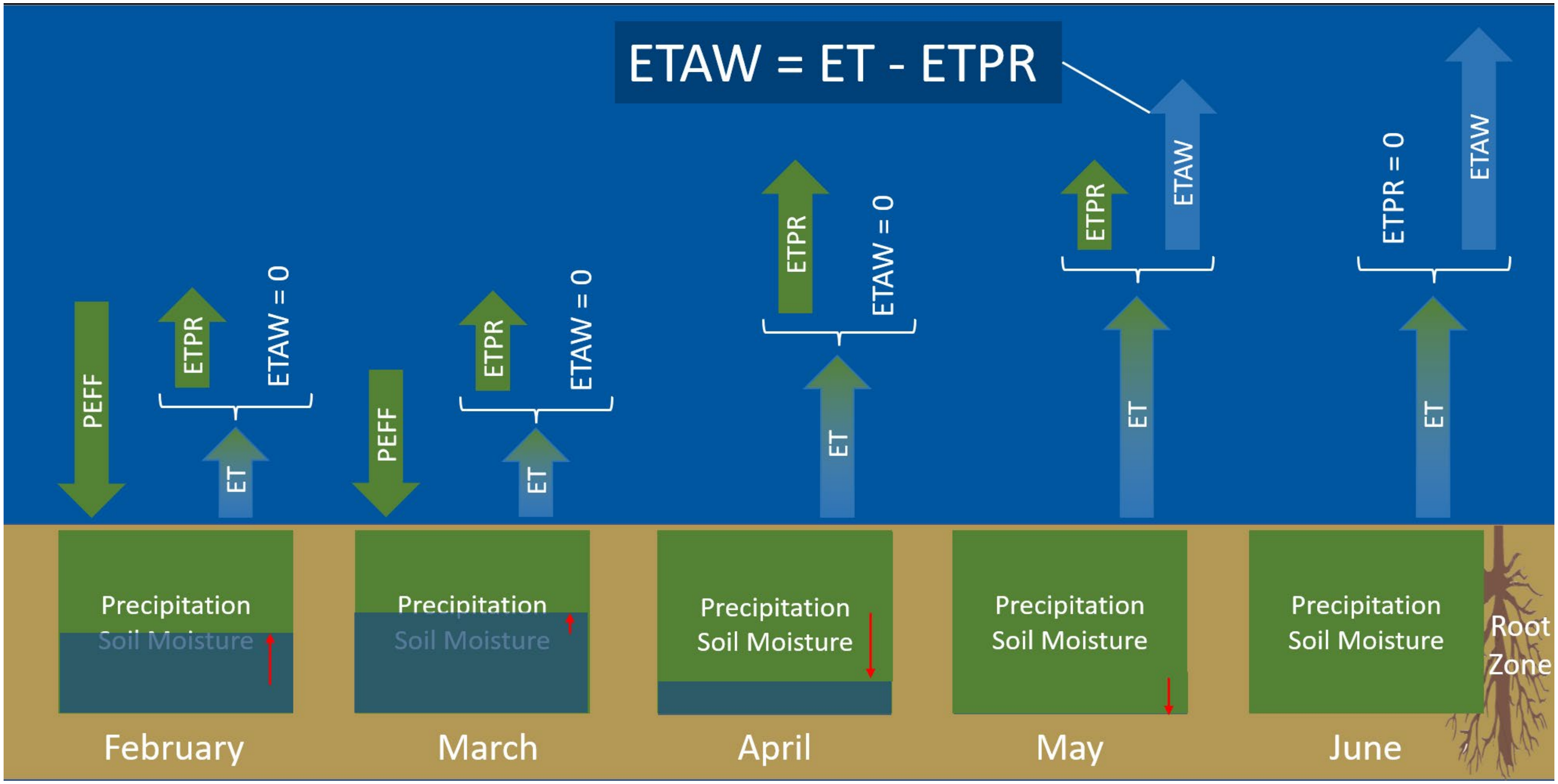

Figure 6-6. Diagram representing how total effective precipitation (TPEFF), represented by Precipitation Soil Moisture in the figure, was used to calculate evapotranspiration of applied water (ETAW) throughout the calendar year (February through June shown in diagram).

6.3.3 Aggregation of OpenET Data

OpenET provides open source, 30m x 30m, ET raster files using remotely-sensed datasets. Like IrriWatch, OpenET data is also retrieved via an API. As described previously, OpenET is not a current allocation measurement method and was used solely as an independent method for comparison purposes. OpenET estimates ET using a suite of six different models. The ensemble model, which is an average of ET from all six models, was used by DE staff in the 2023 Project. OpenET only provides ET data (precipitation is not provided). As a result, ET provided by OpenET, P provided by Land IQ, and the USBR method described above were used to calculate PEFF, TPEFF, and ETPR. ETAW was subsequently calculated using Equation 1.

6.3.4 Additional Data Provided by Growers

Throughout the 2022 and 2023 Projects, VPP growers were encouraged to provide any additional data that they may have collected or are currently collecting that would be beneficial to the 2023 Project. Additional data that was provided to DE staff during the project has included historic flowmeter readings from before the 2022 irrigation season, on-farm irrigation evaluation results, flowmeter calibration documentation, on-farm monitoring data, and data sets to estimate volumes during periods of flowmeter failure or malfunction. These data are useful for further evaluation and building deeper understanding of results related to monitoring of ETAW and AGW.

6.3.5 Overview of GSAs and GSPs in Madera County

When DWR designated the Madera, Chowchilla, and Delta-Mendota subbasins as high priority and COD, it initiated SGMA implementation in each subbasin. An overview of the GSAs development and implementation of GSPs in each of the subbasins is described below.

6.3.5.1 Madera Subbasin

A total of seven GSAs were formed in the Madera Subbasin, which is entirely within Madera County. Of the seven GSAs, four developed a joint groundwater sustainability plan (Madera Joint GSP) and three developed individual GSPs. The implementation of the four GSPs is designed for the Subbasin to reach sustainability within 20 years (i.e., by 2040). Each of the Madera Subbasin GSPs are available online at: https://www.maderacountywater.com/madera-subbasin.

6.3.5.2 Chowchilla Subbasin

A total of four GSAs were formed in the Chowchilla Subbasin, which is entirely within Madera County. These four GSAs developed a single GSP, which will be implemented to achieve sustainability in the Chowchilla Subbasin within 20 years (i.e., 2040). The Chowchilla Subbasin GSP is available online at: https://www.maderacountywater.com/chowchilla-subbasin.

6.3.5.3 Delta-Mendota Subbasin

A total of six GSAs were formed in the Delta-Mendota Subbasin, which is partially within Madera County but also extends into parts of San Joaquin, Stanislaus, Merced, and Fresno Counties. These six GSAs developed a single GSP, which will be implemented to achieve sustainability in the Delta-Mendota Subbasin within 20 years (i.e., 2040). The County of Madera is the exclusive GSA for the portion of the Delta-Mendota Subbasin in the unincorporated area of Madera County, and not otherwise covered by another public agency. The Delta-Mendota Subbasin GSP is available online at https://www.maderacountywater.com/delta-mendota-subbasin.

6.4 Data Management

The sections of the technical appendix below describe data management efforts of the 2023 Project related to Objectives 2 and 3, which were:

1. Implement and refine methods and procedures for collecting, developing, and/or processing the required input data to quantify AGW/ETAW for the three allocation measurement options (Flowmeters, IrriWatch, and Land IQ).
2. Compare and analyze available results across farmed lands for the three allocation measurement options (Flowmeters, IrriWatch, and Land IQ) and a fourth independent ETAW measurement (OpenET).

6.4.1 DE Data Portal Data Management Protocols

In support of Objectives 2 and 3 for flowmeter data, DE continued to use and further developed the DE Data Portal that was created during the 2022 Project. The DE Data Portal provided a centralized location for viewing, quality controlling, analyzing, and applying data collected in the field. The DE Data Portal is password protected to provide the necessary levels of permissions for both users that can only view data and users that can both view and edit data (Figure 6-7). Data can be viewed in tabular or map-based formats. The tabular view allows users to view, filter, sort, edit, and export data (Figure 6-8). A map-based view showing either a Google Map or Google Aerial base with collected data points overlayed is also available via the Map tab (Figure 6-9). Additional information about individual data points is available by clicking on the point of interest, which expands to show a pop-up box with additional information of the data point. All media collected in the field (*e.g.,* pictures, etc.) can be viewed by clicking the hyperlinks in either the tabular or map-based views.

In order to maintain a single quality-controlled dataset, it is essential to perform quality control in a database environment, where concurrent viewing and editing is possible. In the DE Data Portal, each data record collected in the field can be quality controlled by comparing the photographic evidence with the numerical values entered by the field data collector. After making any necessary edits, the data reviewer changes a quality control pulldown to track the quality control status of each record. A log of all the edits is stored in the database, including the time of the edit and who it was performed by. By default, the quality control flag is set to **Unchecked**. After review, if no edits were necessary, the quality control flag is set to

CheckedGood. If edits were made and the record is satisfactory, the quality control flag is set to **CheckedCorrected**. Other quality control flags include **Question**, **Restored**, and **Deleted**.

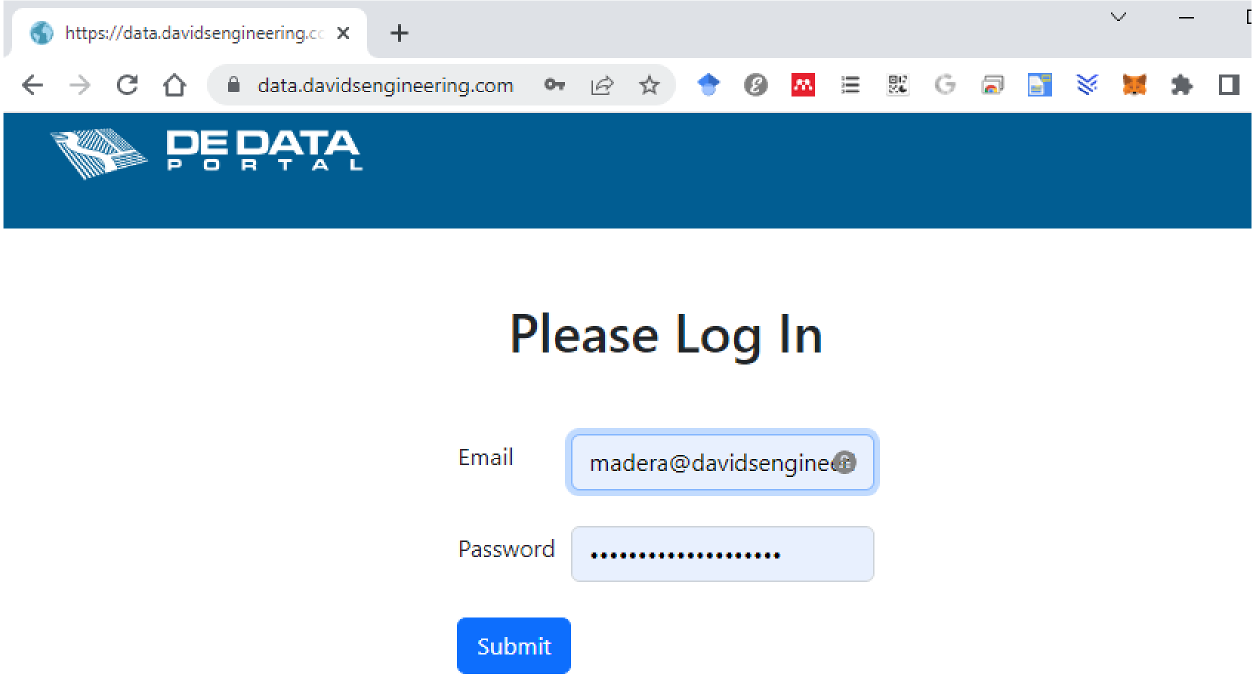

Figure 6-7. Password protected login for the DE Data Portal. Via the Portal, Madera County and DE staff can review, quality control, and use data collected in the field with Open Data Kit (ODK). Field data (e.g., flowmeter readings) can be submitted by growers, DE team members, and the County. All data are saved in a centralized location.

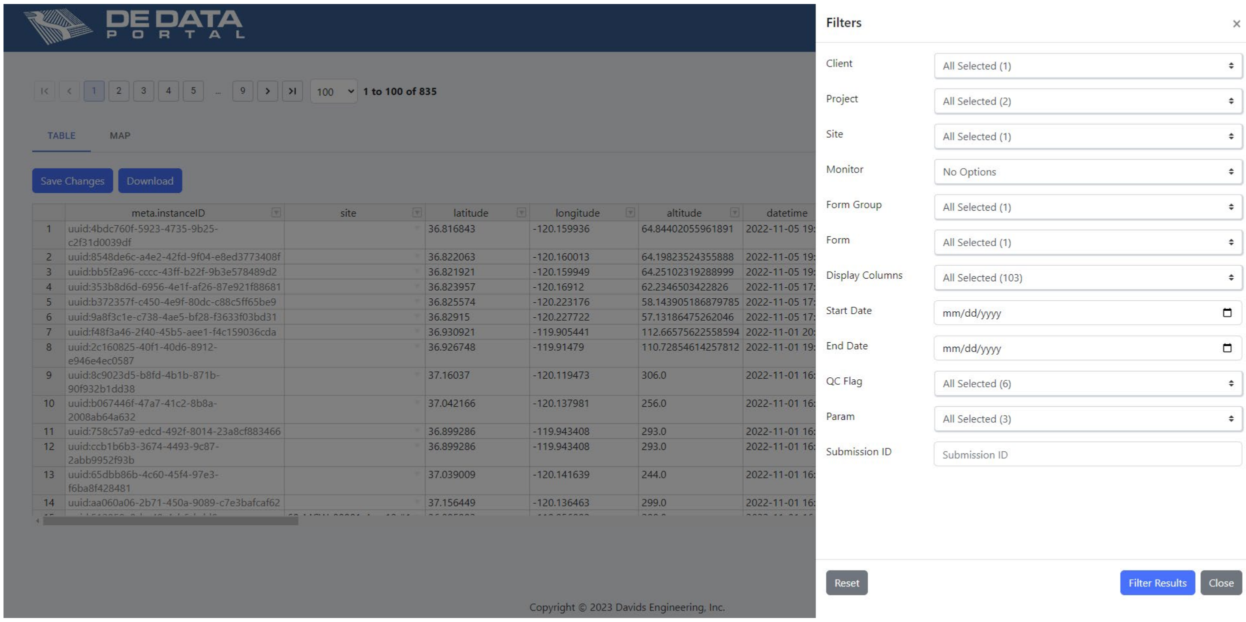

Figure 6-8. Tabular view of data in the DE Data Portal. Data can be filtered with menu options on the right, and via the built-in filtering criteria at the top of each data column. Edits to data can be made directly by double clicking in the desired cell, making the necessary edits, and clicking Save Edits.

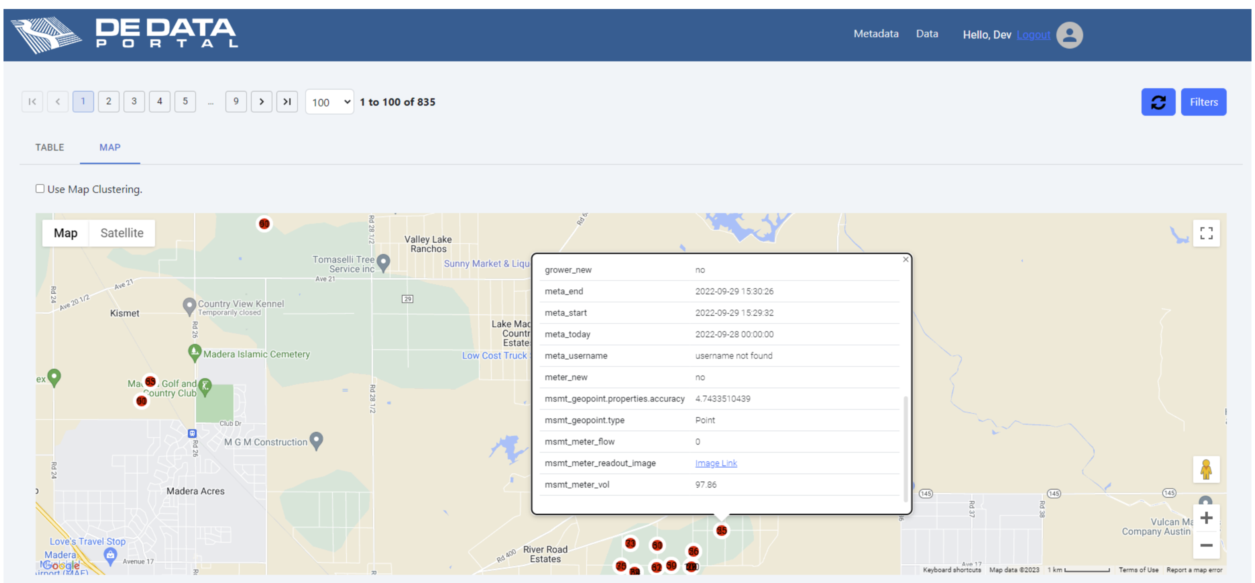

Figure 6-9. Map-based view of data in the DE Data Portal. Details of each data point can be viewed by clicking on the desired point in the map. Each point represents a single data observation collected and recorded in the field. Images associated with data collection points can be viewed via the image links.

Data can be exported from the DE Data Portal via the **Download** button at the top left in the tabular view. Only data meeting the filtering criteria set in the menu will be exported. Even though data pagination is used to improve page loading speeds, all data satisfying the filtering criteria, regardless of if it is currently shown on the screen, will be exported. The resulting export will be automatically saved to the user's default download folder defined by their web browser as a Microsoft Excel spreadsheet with a datetime suffix. Images are retained as clickable hyperlinks in the downloaded spreadsheet.

The DE Data Portal builds off the foundation of the ODK Central server, providing the same functionality through a custom-designed user interface as well as additional functionality and flexibility with data management and access. The DE Data Portal was originally developed during the 2022 Project, improved during the 2023 Project, and designed to be available for data management in 2023 and beyond. The DE Data Portal can be viewed at: https://data.davidsengineering.com.

6.4.2 Use of Python Scripting for Data Aggregation and QA/QC

All flowmeter and remotely-sensed data were processed through a series of Python scripts following initial data collection and QA/QC. During the processing and aggregation process, additional QA/QC steps were done. Specifically, AGW and ETAW were checked for negative values and graphs were created for each Irrigation Unit to spot any inconsistencies/errors in the resulting data. This periodic QA/QC process led DE Staff, in coordination with IrriWatch staff, to make one adjustment to the methodology and assumptions used by IrriWatch to quantify ETAW (see Section 6.5.3 for details). Perodic data checks were also beneficial for the flowmeter data where issues that were not immediately caught in the DE Data Portal were identified in the Python scripting process. The most common issue identified was the presence of negative AGW volumes during the data aggregation process. The root cause of this issue was incorrect data submissions in the DE Data Portal, which were easily corrected after they were identified.

6.4.3 Identification of Irrigation Units with Data Quality Issues

While 103 IUs submitted flowmeter data that could be used in the 2023 Project, not all the submitted data met DE's data quality standards. As described in Section 2.4, IUs with known data quality issues were not considered in the final data analysis and subsequent conclusions and recommendations sections of the report. Nevertheless, this section describes the data quality issues in more detail while Section 6.5.2.2 presents how inclusion of all data collected (both good- and poor-quality data) during the 2023 Project could have impacted the report results.

DE required a complete record of flowmeter data for 2023 to be included in the 2023 Project. Given that 2023 was a wet year, IUs needed to supply flowmeter readings by April 15, 2023, to be included in this dataset. Most IUs with data quality issues fell into this category; a total of 16 IUs (15.5%) had incomplete flowmeter records with the first available reading on a date later than April 15, 2023. For the IUs with incomplete flowmeter records, early season AGW was estimated using Land IQ ETAW data and a CUF of 0.8. This estimation process was done to see how large an impact missing flowmeter data could have on final applied groundwater volumes. For the IUs with missing data, estimated AGW volumes ranged from 18 AF to 342 AF (average = 100 AF), depending on location, crop type, irrigation unit size, and the resulting ETAW demands. In other words, a volume of roughly 100 AF of applied water in an average irrigation unit could go unaccounted for if early season flowmeter data are not supplied by growers. From an allocation management perspective, this highlights the need to collect all flowmeter data throughout the calendar year to ensure all applied water is being accounted for.

IUs with parcel-fields outside of the Madera County GSAs (4 IUs; 3.8%) represented another data quality issue. If a grower is pumping water from inside or outside the Madera County GSAs but applying that water to fields both inside and outside of the GSAs, it quickly becomes difficult to accurately account for only the water pumped, applied, and consumptively used with the Madera County GSAs. To estimate how much pumped groundwater could have been applied to these fields outside of GSA lands, ETAW was based on an area-weighted average for the same crop within the same IU. Estimated ETAW (based on IrriWatch and Land IQ data) ranged from 14.8 AF to 366.2 AF for these parcel-fields outside of the GSAs, depending on location, crop type, irrigation unit size, and the resulting ETAW demands. To ensure all groundwater extracted from inside the GSAs is accounted for, it is important that the County identify and coordinate with growers with parcel-fields inside and outside of the GSAs. These farmed lands that intersect GSA boundaries also will require additional coordinate between GSAs.

Lastly, a total of 9 IUs (8.7%) had other data integrity issues including (1) uncertainty in number of wells being used to extract and applied groundwater, (2) uncertainty in the volume of surface water applied to a field for irrigation/recharge purposes, and (3) remote sensing methods automatically setting ETAW to zero for fields that were only partially fallowed. Methods are currently being developed to identify all wells, properly account for surface water applications, and prevent ETAW from being set to zero for partially fallowed fields.

6.5 Supplementary Materials

6.5.1 Supplementary Results and Figures

This section includes additional tables and figures that were not included in the main body of the report. These additional materials were provided here for greater context and insight into the results and findings of the 2023 Project described in the main body of the report. Each table or figure is described in the caption.

6.5.1.1 Comparison of Reported ET and ETAW between Remotely-Sensed Methods

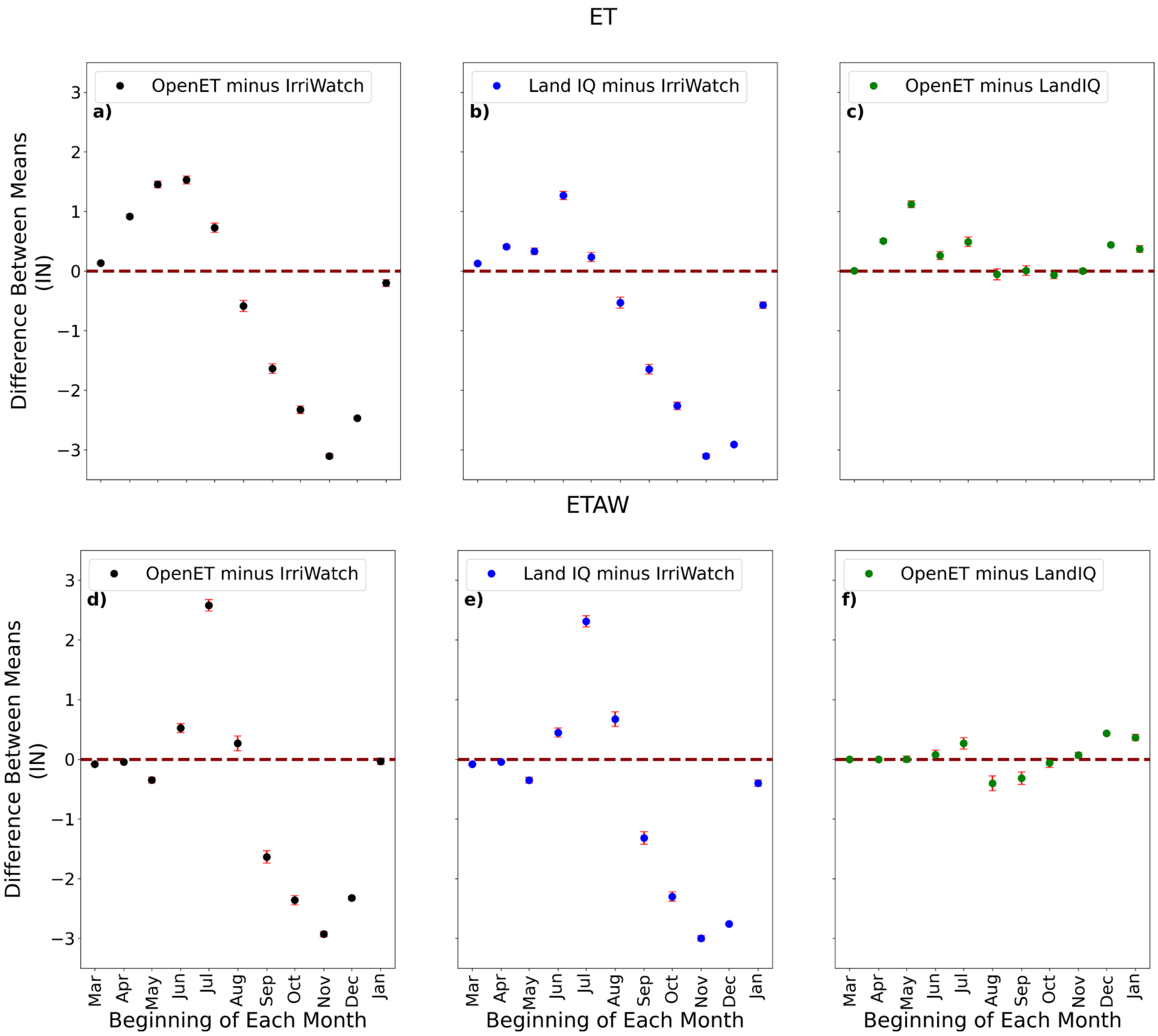

Figure 6-10. Monthly mean differences between remotely sensed methods (IrriWatch, Land IQ, and OpenET) for evapotranspiration (ET) and evapotranspiration of applied water (ETAW) used during the 2023 Project for Project Lands. Differences were calculated by subtracting the mean of one method from the other; a positive difference indicates the method being subtracted by had a higher mean value compared to the other method. Red error bars represent the 95% confidence interval as determined by Tukey's honestly significant difference statistical test. Estimates are considered significantly different if neither the mean difference nor the 95% confidence interval cross the dashed zero line. Prior to the IrriWatch adjustments that were applied on December 31, 2023 (see Section 6.5.3), monthly ET and ETAW provided by IrriWatch varied widely (max difference greater than 3 IN) from the results provided by OpenET and Land IQ. Mean differences between OpenET and Land IQ were typically less than 0.5 IN for any given month, indicating good agreement between those two methods.

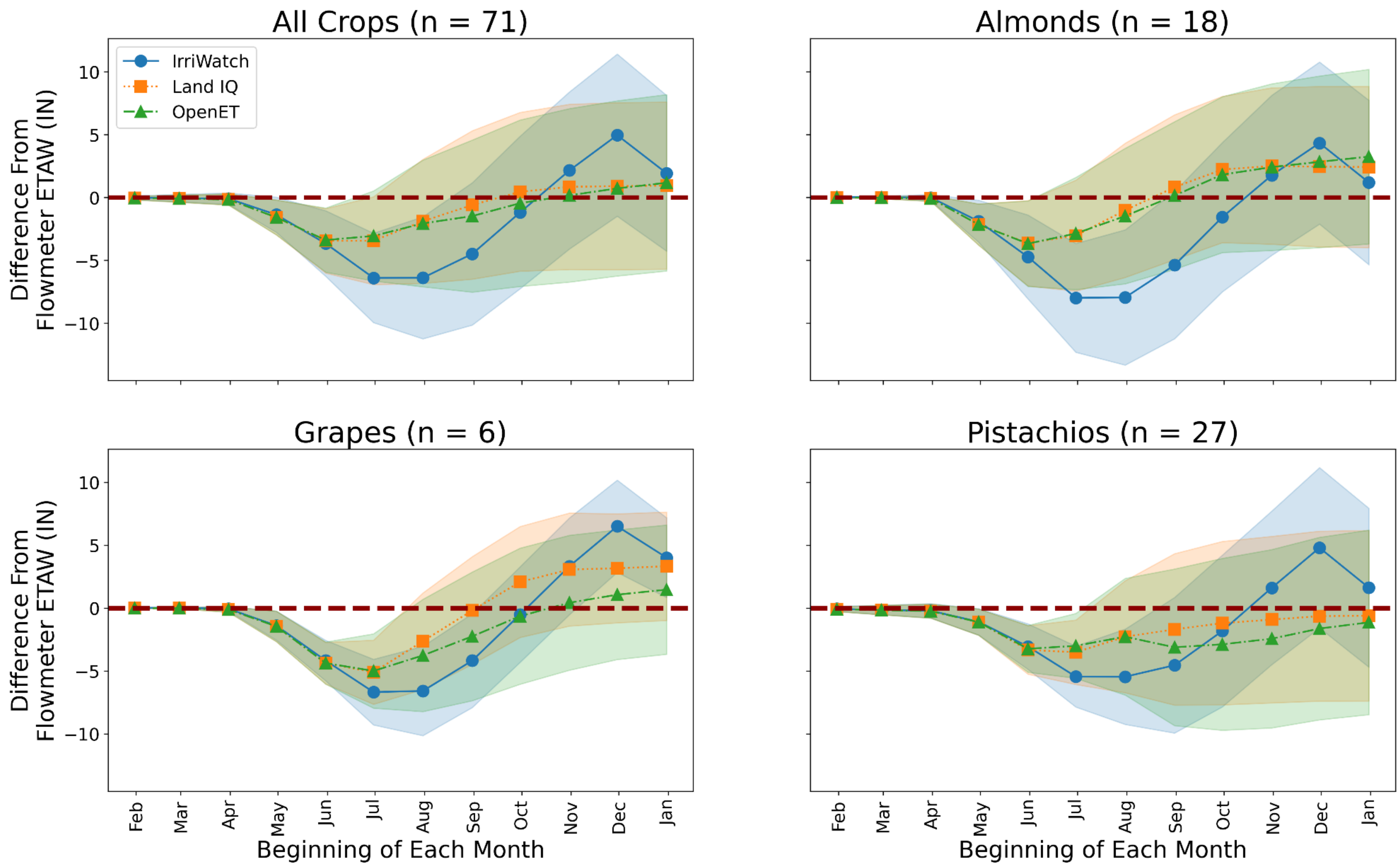

Figure 6-11. Monthly difference between mean cumulative evapotranspiration of applied water (ETAW) estimated by remotely sensed methods (IrriWatch, Land IQ, and OpenET) and mean cumulative ETAW estimated from flowmeter data for Irrigation Units (IUs) without known data quality issues. Results are shown for all IUs (n = 71) and IUs with a single major crop type: Almonds (n = 18), Grapes (n = 6), and Pistachios (n = 27). Shaded areas on either side of the average lines represent the monthly standard deviation. Consumptive use fractions (CUF) of 0.8 for pressurized irrigation systems and 0.65 for flood irrigation systems were used to calculate ETAW from flowmeters for each IU before calculating the differences, which subtracted the ETAW by flowmeters from ETAW estimated by remotely sensed methods. For all crops, by December 31, 2023, the mean difference between remotely-sensed ETAW (all methods) and flowmeter ETAW was between roughly 0 IN and 2 IN. However, there was a greater monthly deviation between IrriWatch ETAW and flowmeter ETAW prior to the data adjustment (see Section 6.5.3). Specifically, between July and September, mean IrriWatch ETAW was around 5 IN lower than the mean flowmeter ETAW. However, by November, mean IrriWatch ETAW was 5 IN higher than the mean flowmeter ETAW. Similar patterns can be found for each of the individual crop types. Overall, the large, shaded regions for each method highlights the substantial variability when comparing remotely-sensed ETAW to flowmeter ETAW.

6.5.1.2 ETAW and AGW Comparisons

6.5.1.2.1 2022 vs. 2023 Results

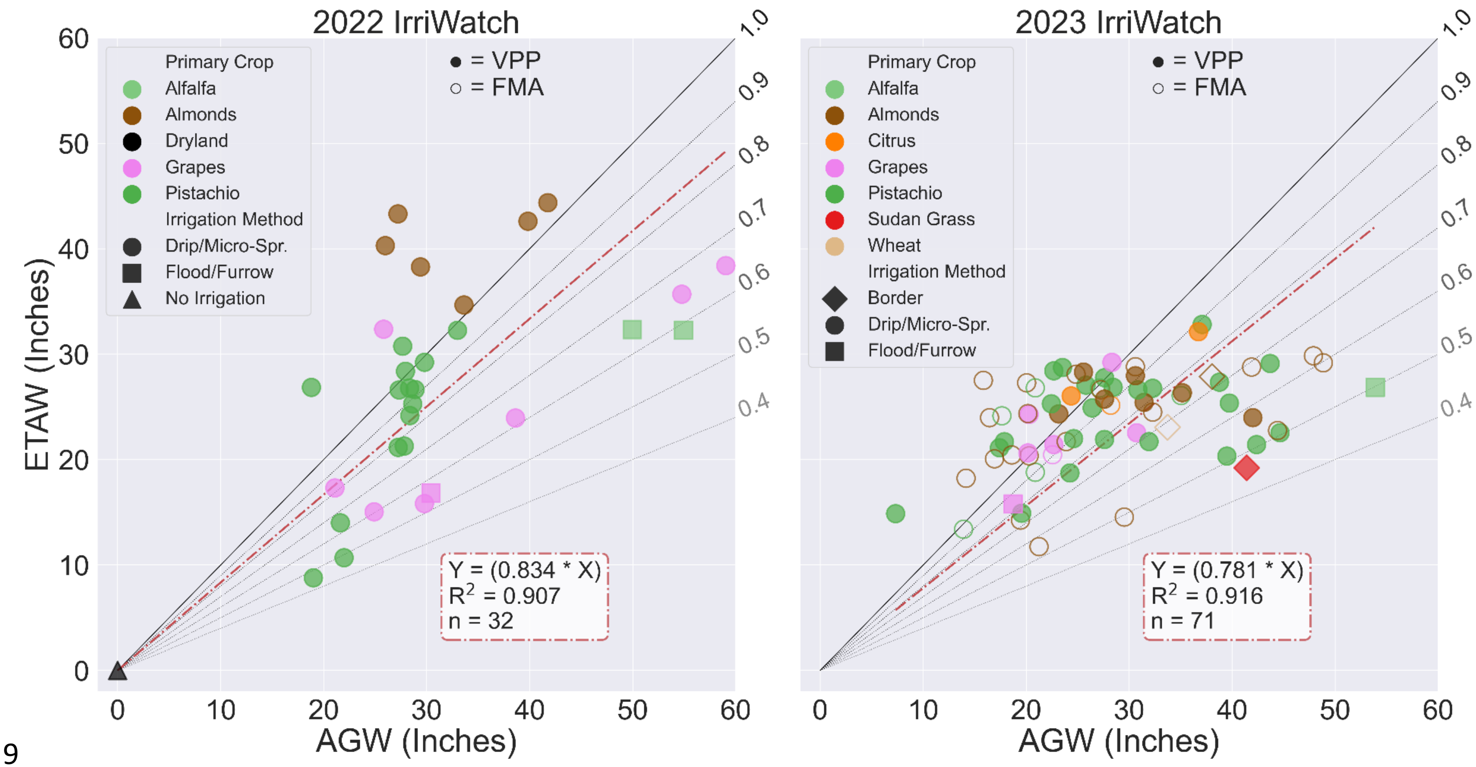

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Figure 6-12. Evapotranspiration of applied water (ETAW) vs. applied groundwater (AGW) for the 2022 Project (left panel) and the 2023 Project (right panel). IrriWatch was the only remotely-sensed method considered during the 2022 Project, so only 2023 IrriWatch data are shown for comparison purposes. "VPP" (Verification Project Participants) refers to IUs that participated in the Madera Verification Project while "FMA" (Flowmeter Accounts) refers to IUs that used flowmeters as their allocation measurement method during 2023. Crop colors represent the primary crop for each IU by acreage (e.g., the crop that covered the largest area within that IU), so some of the IUs shown may have mixed cropping regimes. Increasing the total number of IUs considered in 2023 led to an overall reduction in consumptive use fractions (0.78 in 2023 vs. 0.83 in 2022). Additionally, the sample of IUs is more tightly clustered in 2023 relative to 2022.

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6.5.1.2.2 Crop Type

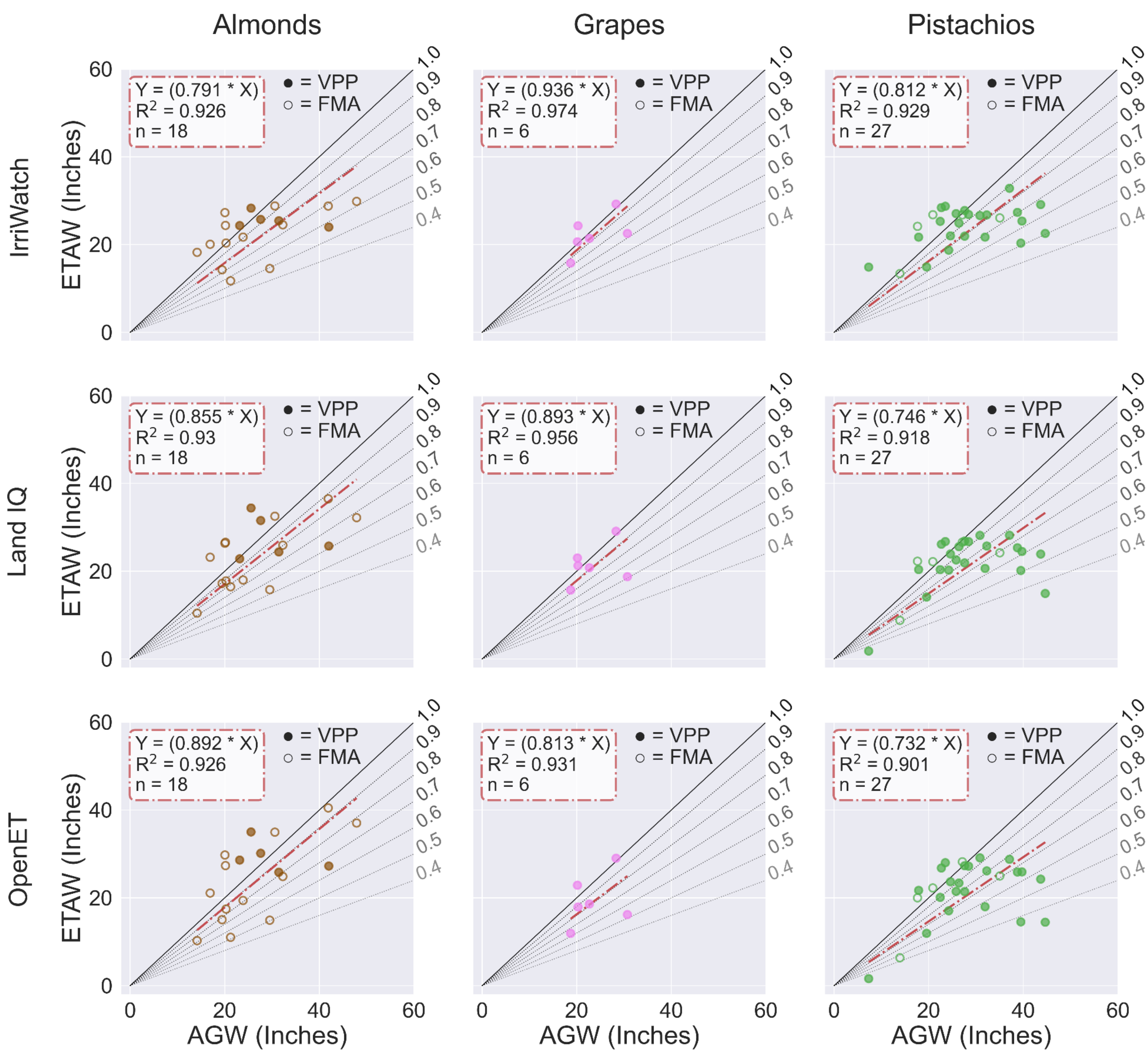

Figure 6-13. Summary of evapotranspiration of applied water (ETAW) and applied groundwater (AGW) for IUs with a single crop type: Almonds (n = 18), Grapes (n = 6), and Pistachios (n = 27). All remotely-sensed methods (IrriWatch, Land IQ, and OpenET) are shown. "VPP" refers to IUs that participated in the 2023 Madera Verification Project while "FMA" refers to IUs that used flowmeters as their allocation measurement method during 2023. Based on regression analysis, for almonds, IrriWatch reported the lowest consumptive use fraction (CUF, 0.79) followed by Land IQ (0.86) and OpenET (0.89). However, the trend was reversed for grape and pistachio IUs. Specifically, OpenET reported the lowest CUFs while IrriWatch reported the highest.

6.5.1.2.3 Irrigation Method

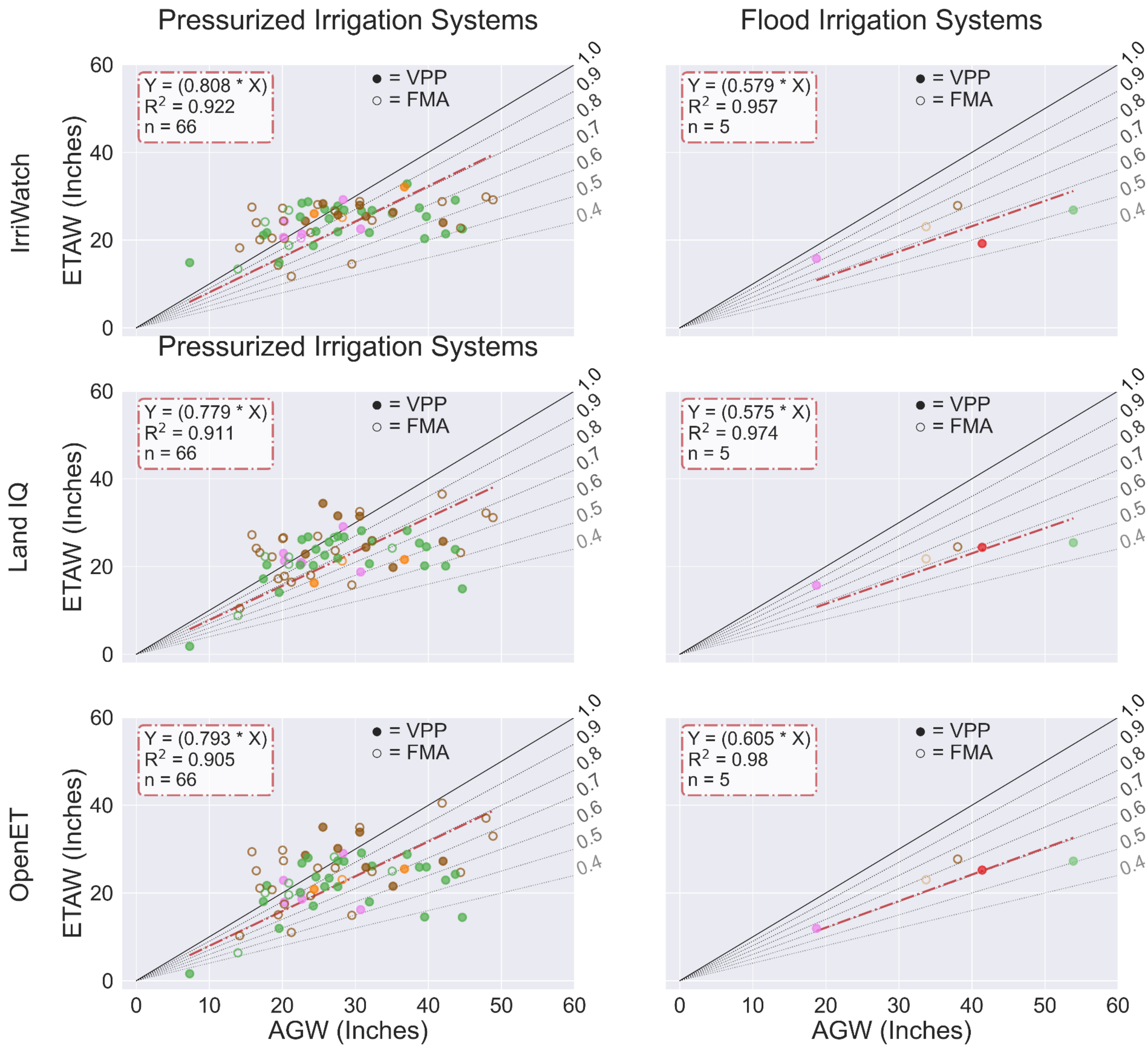

Figure 6-14. Summary of ETAW and AGW for irrigation units (IUs) by irrigation method for pressurized (drip and micro-sprinklers) and flood (flood, furrow, and boarder) irrigation methods. Crop colors represent the primary crop for each IU by acreage (e.g., the crop that covered the largest area within that IU), so some of the IUs shown may have mixed cropping regimes (see legend in Figure 6-12 for crop color codes). Based on regression analysis, flood irrigation systems produced CUFs between 0.58 and 0.60 while pressurized irrigation systems had CUFs between 0.78 and 0.81. These CUFs are within the expected range commonly documented in the literature and observed in the field; however, substantial variability was observed for the pressurized irrigation systems. Specifically, multiple IUs have CUFs greater than 1 and lower than 0.5.

6.5.1.2.4 Irrigation Unit Size

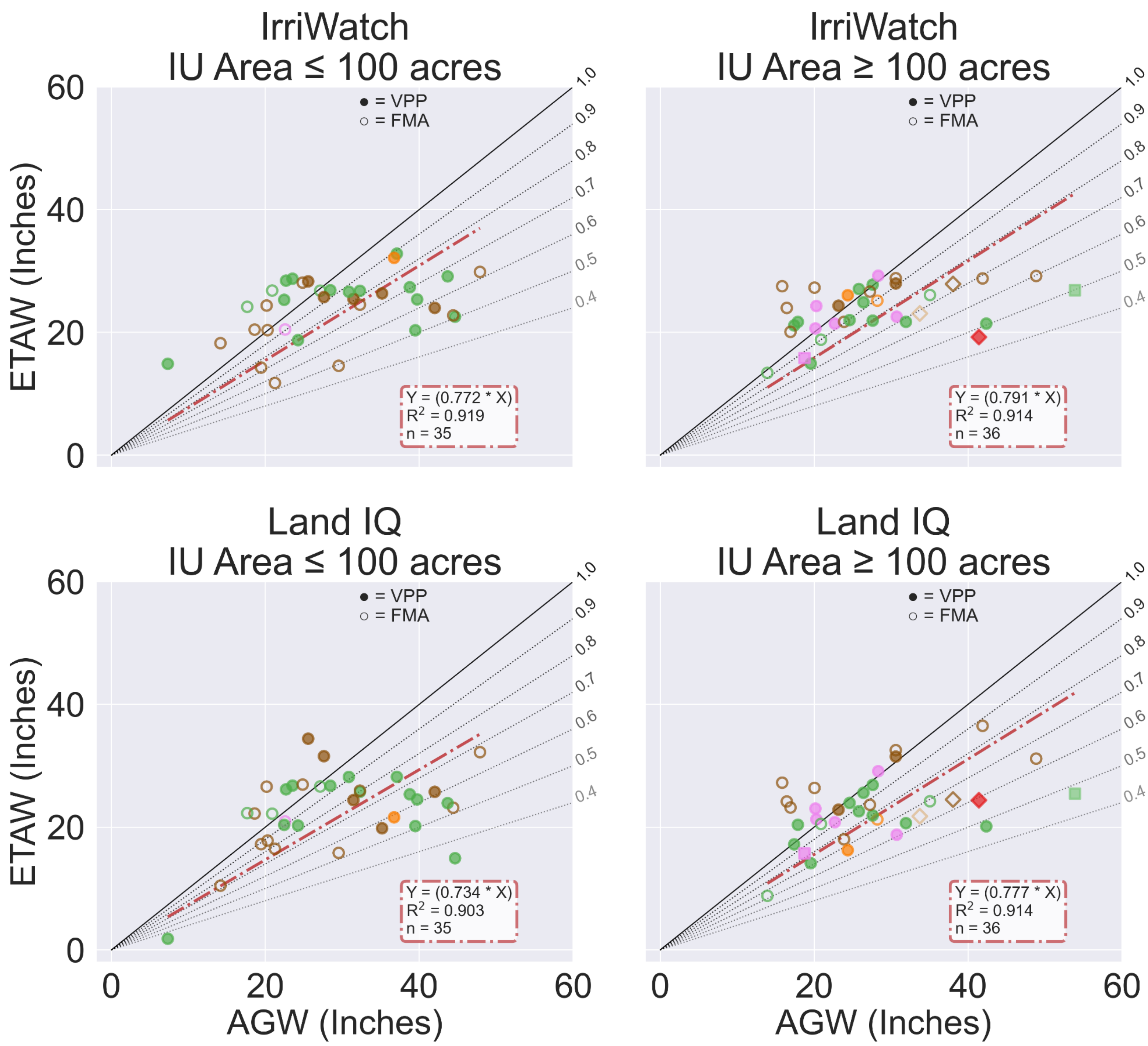

Figure 6-15. Summary of ETAW and AGW for irrigation units (IUs) by irrigation unit size with the 71 included irrigation units being roughly evenly divided into two classifications of those less than 100 acres and those greater than 100 acres. Crop colors represent the primary crop for each IU by acreage (e.g., the crop that covered the largest area within that IU), so some of the IUs shown may have mixed cropping regimes (see legend in Figure 6-12 for crop color codes). Based on regression analysis, the CUF fraction slightly increases for larger IUs, relative to smaller irrigation units, but both classifications produce similar values between 0.73 and 0.79 for both IrriWatch and Land IQ. Both classifications show substantial variability on either side of the regression line for individual IUs, including CUF values greater than one.

6.5.1.3 Comparison of ETAW, AGW, and CUF to Crop Age

Figure 6-16 below represents Land IQ ETAW and CUF results only. Similar results and trends were found between crop age and the other two remotely-sensed methods (IrriWatch and OpenET), so those results are not shown here.

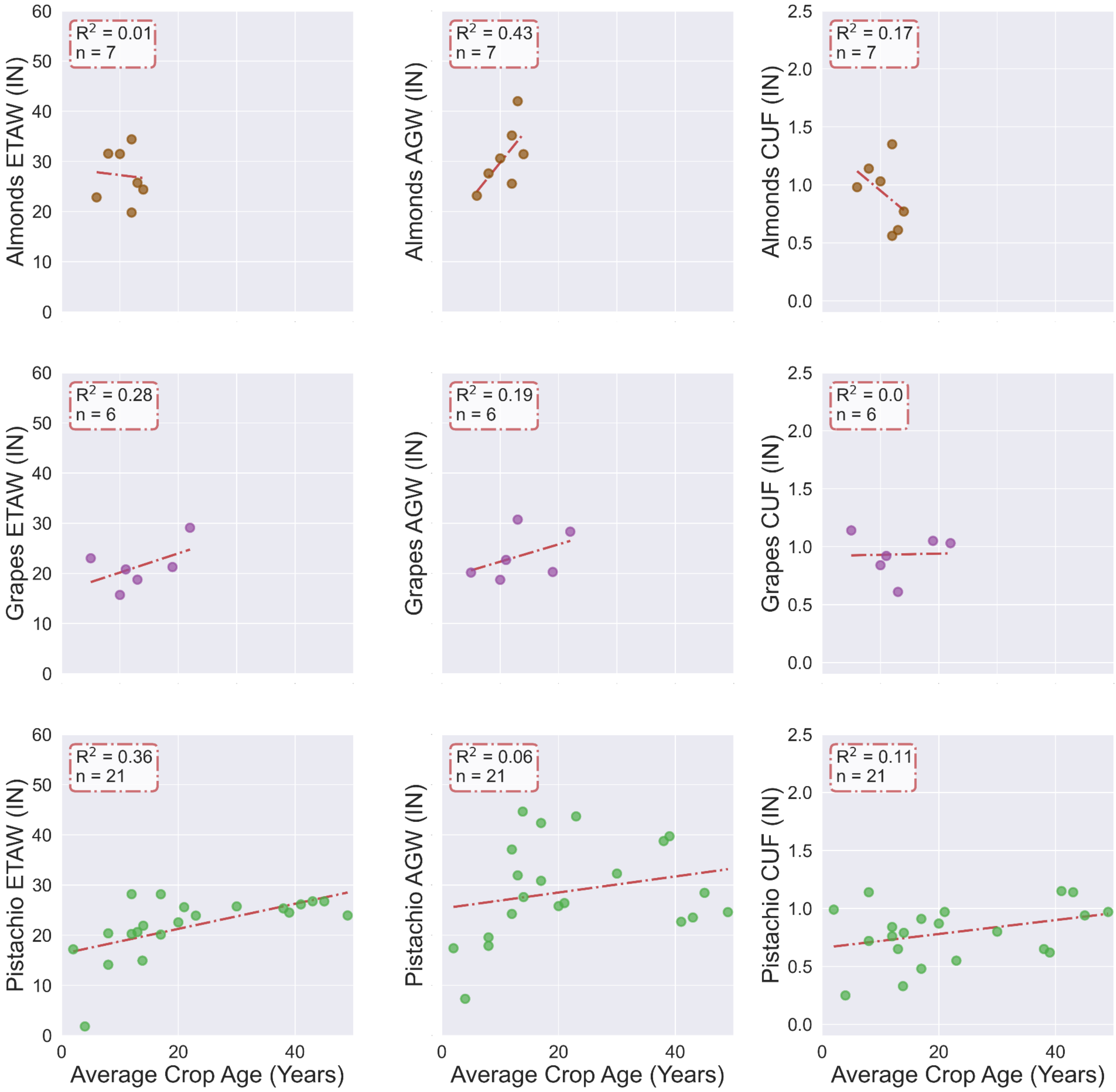

Figure 6-16. Summary of the age of the three main crops (almonds, grapes, pistachios) compared to ETAW, AGW, and CUF for individual IUs using Land IQ data. Crop age was requested from participating growers. If crop age differed within an IU, the average crop age for the IU was calculated. The rows, from top to bottom, depict results for almonds, grapes, and pistachios; the columns, from left to right, present results for ETAW, AGW, and CUF. The x-axis on every figure shows average crop age in years. All almond orchards included in the Project were around the same stage of development and between seven and fifteen years of age. This limits the evaluation of how crop age may influence ETAW, AGW, and CUF for almonds. For grapes, ETAW and AGW tend to increase as crop age increases; however, no trend is observed when comparing crop age and CUF. For pistachios, there was a wide age range from less than 10 years to over 40 years of age. ETAW increased roughly linearly with age (as the trees matured). A linear relationship between AGW and crop age for pistachios was not observed. This results in a CUF that increases as the young crops age and mature; for mature pistachio trees (with exception of a few above one), the CUF is generally at or below one. Similar patterns between ETAW, AGW, CUF, and crop age were found when considering IrriWatch and OpenET data.

6.5.1.4 Comparison of ETAW, AGW, and CUF to Percent Sand Content

Figure 6-17 and Figure 6-18 below represent Land IQ ETAW and CUF results only. Similar results and trends were found between soil texture and the other two remotely-sensed methods (IrriWatch and OpenET), so those results are not shown here.

6.5.1.4.1 SSURGO Sand Content

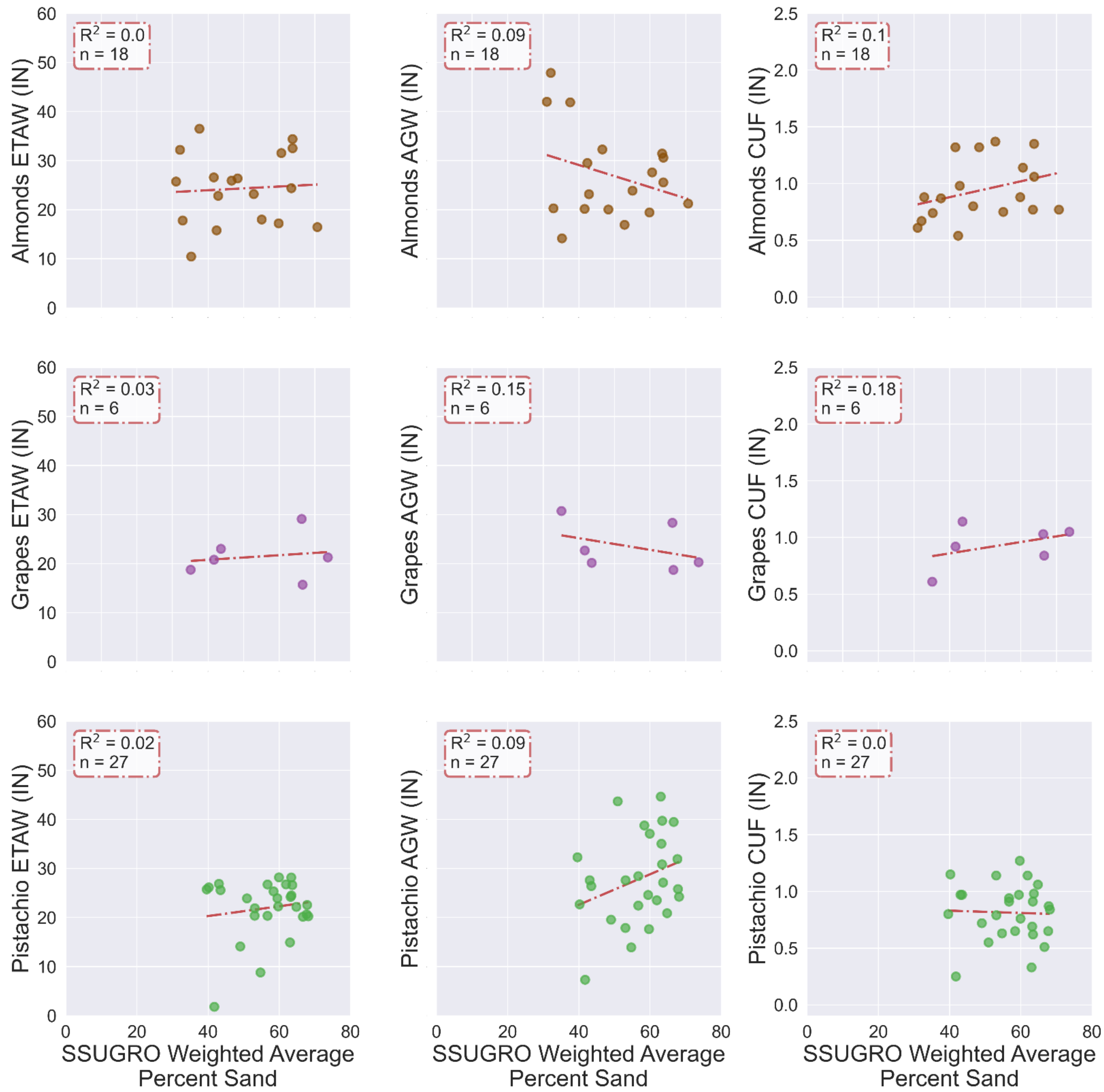

Figure 6-17. Weighted average percent sand content for each IU compared to ETAW, AGW, and CUF. IUs represented had a primary crop of almonds, grapes, or pistachios. Percent sand data was extracted from the Soil Survey Geographic Database (SSURGO) and initially compiled at the parcel-field level. The rows, from top to bottom, depict results for almonds, grapes, and pistachios; the columns, from left to right, present results for ETAW, AGW, and CUF. The x-axis on every figure shows the weighted average percent sand content. For grapes, a negative relationship was found between AGW and sand content while a positive relationship was found between CUF and sand content. No other noteworthy trends were observed for the other crop types or parameters when considering SSURGO sand data.

6.5.1.4.2 SoilGrids Sand Content

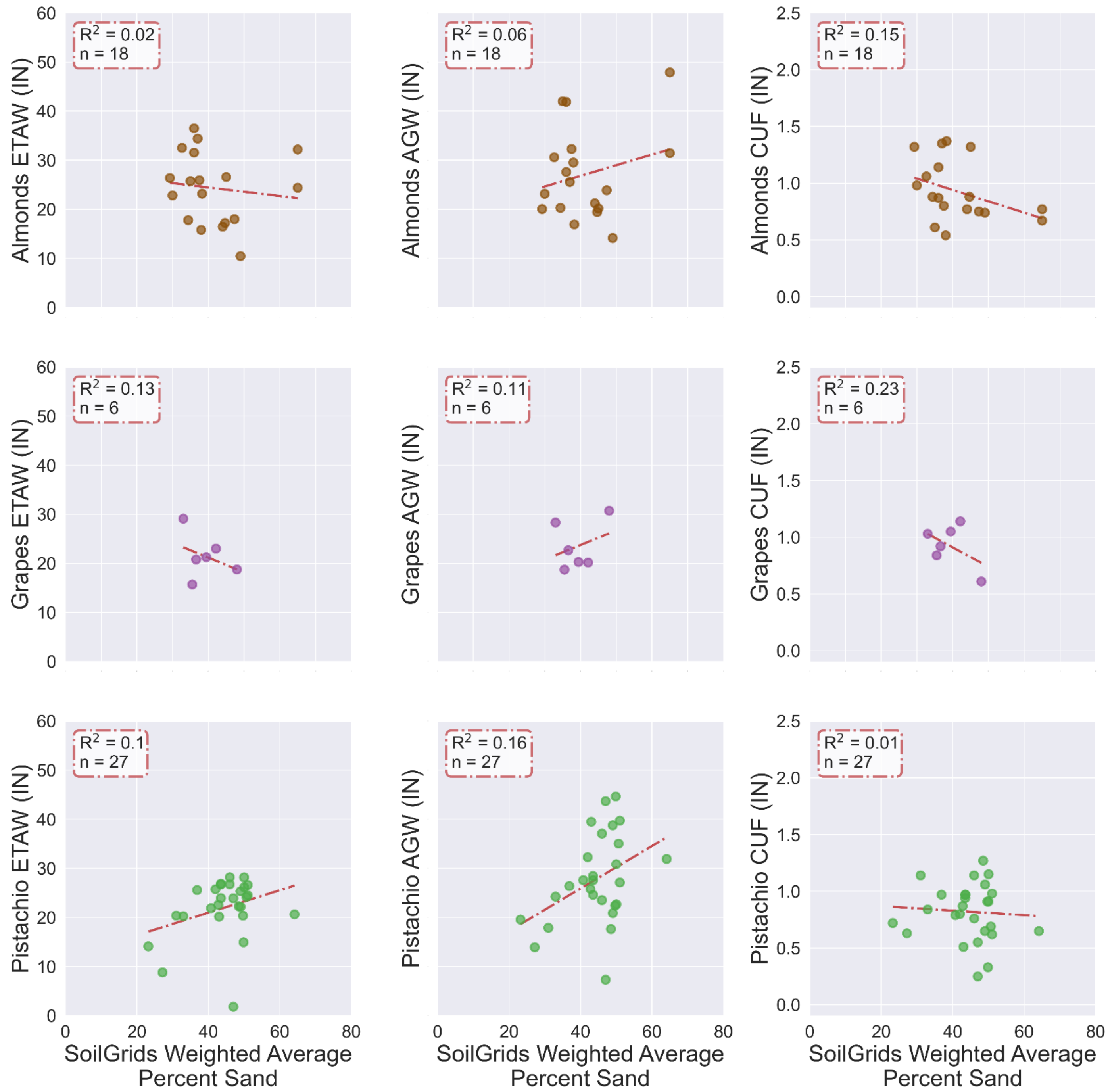

Figure 6-18. Weighted average percent sand content for each IU compared to ETAW, AGW, and CUF. IUs represented had a primary crop of almonds, grapes, or pistachios. Percent sand data was extracted from the SoilGrids and initially compiled at the parcel-field level. The rows, from top to bottom, depict results for almonds, grapes, and pistachios; the columns, from left to right, present results for ETAW, AGW, and CUF. The x-axis on every figure shows the weighted average percent sand content. For almonds, a negative linear relationship between CUF and sand content was observed. However, this trend may be skewed by two outlier IUs with sand contents above 60%. For grapes, there was little variability in sand content between the IUs (30 – 40% generally). One outlier grape IU had a sand content near 50%, which is likely skewing the linear regression results shown. For pistachios, both ETAW and AGW tended to increase as sand content increased. An increase in AGW with increasing sand content was expected given the lower water holding capacity of sandy soils (i.e., more water would need to be applied to account for water loss due to deep percolation).

6.5.1.5 Cumulative Timeseries Plots by Crop Type

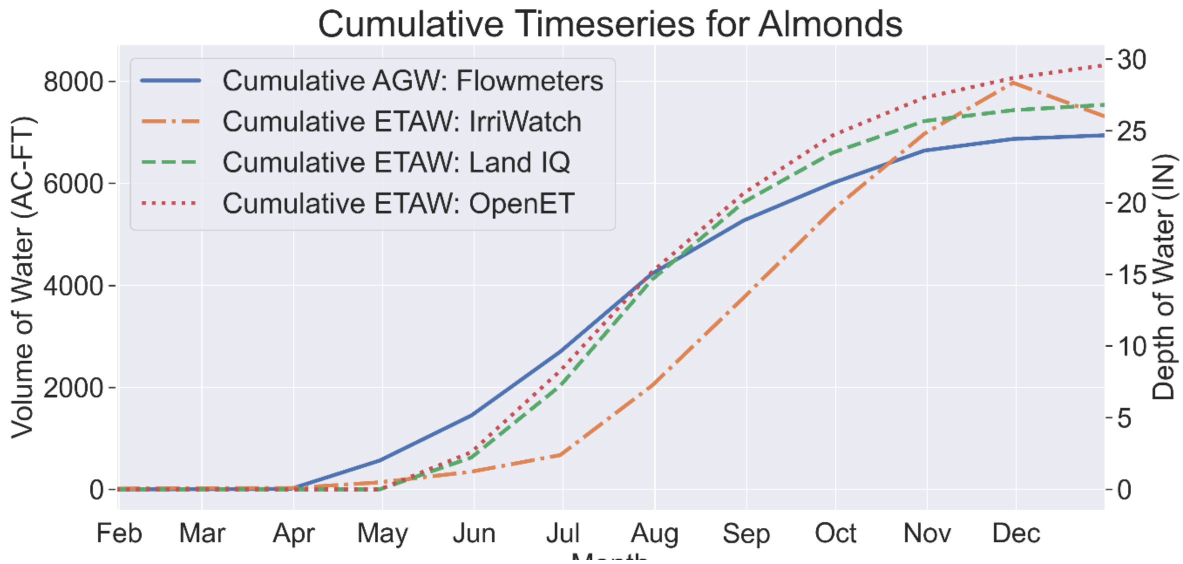

Figure 6-19. Cumulative volume (left) and depth (right) of applied groundwater (blue solid), IrriWatch evapotranspiration of applied water (ETAW; orange dash-dot), Land IQ ETAW (green dash), and OpenET (red dot) for Irrigation Units (IUs) with almonds as the single crop type (n = 18) and IUs without data quality issues. Cumulative values are calculated by summing up AGW and ETAW values for each month from each almond IU. IrriWatch made adjustments that reduced the calculated ETAW for all parcel-fields; this adjustment was applied on December 31, 2023, and is shown in the figure. Both Land IQ (~27 IN) and OpenET (~30 IN) reported higher ETAW by the end of 2023 compared to the reported AGW (~25 IN). After applying the adjustment, IrriWatch ETAW (~26 IN) was closer to the AGW results, but still higher. However, IrriWatch ETAW deviated the most from flowmeter AGW throughout the 2023 irrigation season.

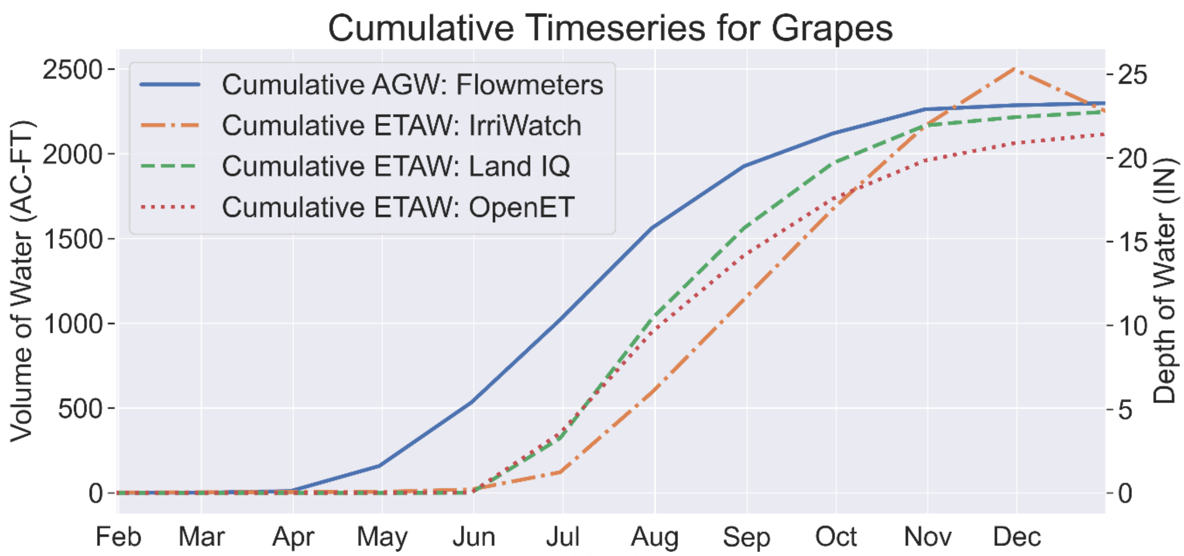

Figure 6-20. Cumulative volume (left) and depth (right) of applied groundwater (blue solid), IrriWatch evapotranspiration of applied water (ETAW; orange dash-dot), Land IQ ETAW (green dash), and OpenET (red dot) for Irrigation Units (IUs) with grapes as the single crop type (n = 6) and IUs without data quality issues. Cumulative values are calculated by summing up AGW and ETAW values for each month from each grape IU. IrriWatch made adjustments that reduced the calculated ETAW for all parcel-fields; this adjustment was applied on December 31, 2023, and is shown in the figure. Unlike almond IUs, all remotely-sensed methods had lower cumulative ETAW by the end of the year when compared to flowmeter AGW. OpenET reported the lowest overall ETAW for grape IUs, followed by IrriWatch and Land IQ (which had very similar final results).

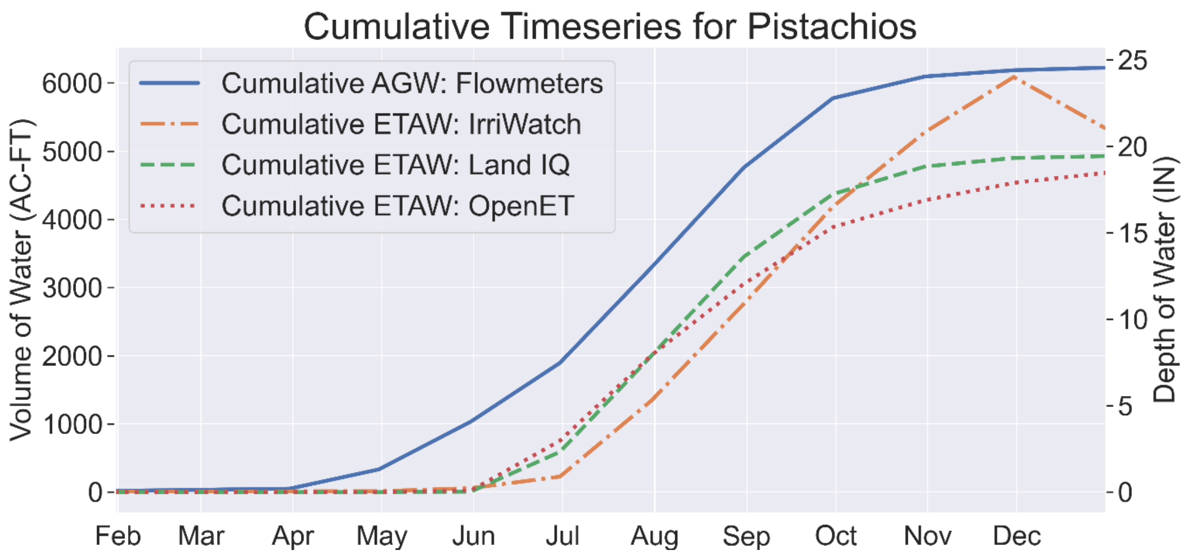

Figure 6-21. Cumulative volume (left) and depth (right) of applied groundwater (blue solid), IrriWatch evapotranspiration of applied water (ETAW; orange dash-dot), Land IQ ETAW (green dash), and OpenET (red dot) for Irrigation Units (IUs) with pistachios as the single crop type (n = 27) and IUs without data quality issues. Cumulative values are calculated by summing up AGW and ETAW values for each month from each pistachio IU. IrriWatch made adjustments that reduced the calculated ETAW for all parcel-fields; this adjustment was applied on December 31, 2023, and is shown in the figure. By the end of 2023, cumulative remotely-sensed ETAW for pistachio IUs was lower for all methods compared to flowmeter AGW. The difference between cumulative AGW and cumulative ETAW was also the highest for pistachios when compared to almonds and grapes. OpenET reported the lowest overall ETAW for pistachio IUs, followed by Land IQ and then IrriWatch.

6.5.2 Special Investigations

The large amount of data and information collected throughout the 2023 Project allowed DE staff to pursue additional investigations related to the 2023 Project objectives. These special investigations are outlined and described in the sections below.

6.5.2.1 Shallow Soil Analysis

Modeling of root-zone soil water holding capacity is a key feature in IrriWatch's ETAW calculations. Soil water holding capacity is heavily influenced by soil texture. IrriWatch estimates percent sand, silt, and clay based on SSURGO data within the Madera County GSAs. Given the important role soil texture plays in IrriWatch's calculations, it is important to verify that the soil types used by IrriWatch's model agree with the soil types as investigated in the field. Therefore, throughout 2022 and 2023, DE collected shallow soil samples at 74 locations throughout the Madera County GSAs. Soil textures were determined in the field and compared with the textures provided by IrriWatch. The full analysis is summarized in the TM attachment included in Section 6.5.6. In summary, when using the common texture name and simplified comparisons, field textures matched IrriWatch reported textures 52% - 61% of the time. If feasible, additional steps can be taken in 2024 and beyond to further refine these results and make robust recommendations for improving soils coverage in the Madera County GSAs.

6.5.2.2 ETAW vs. AGW for all Irrigated Irrigation Units

Irrigation Units identified to have data quality issues were excluded from the conclusions and recommendations described in this report. While exclusion was necessary to give relevant and accurate recommendations based on the best available data, it is also important to present how all data collected during the 2023 Project could have impacted the report results. Figure 6-22 represents ETAW vs. AGW plots for IrriWatch, Land IQ, and OpenET data. For all remotely-sensed methods, including IUs with data quality issues lead to a ~0.02 increase in the representative CUF when compared to Figure 3-9. While the overall change in CUF is small, an increase does indicate all the surface/groundwater that was applied on IUs with data quality issues was fully accounted for. Most of the issues for IUs with poor data were related to unacceptable flowmeter data submissions and applied surface water volume uncertainties. Therefore, a higher CUF was expected given uncertainties in the total amount of water being applied by the IUs with data quality issues. These results highlight the need to continue developing a robust monitoring and inspection system to properly document all pumped wells within an IU and accurately account for where that groundwater is being applied, along with documenting any surface water usage. Fallow and no irrigation IUs are still excluded in Figure 6-21, but more details about these IUs can be found in Section 6.5.2.3.

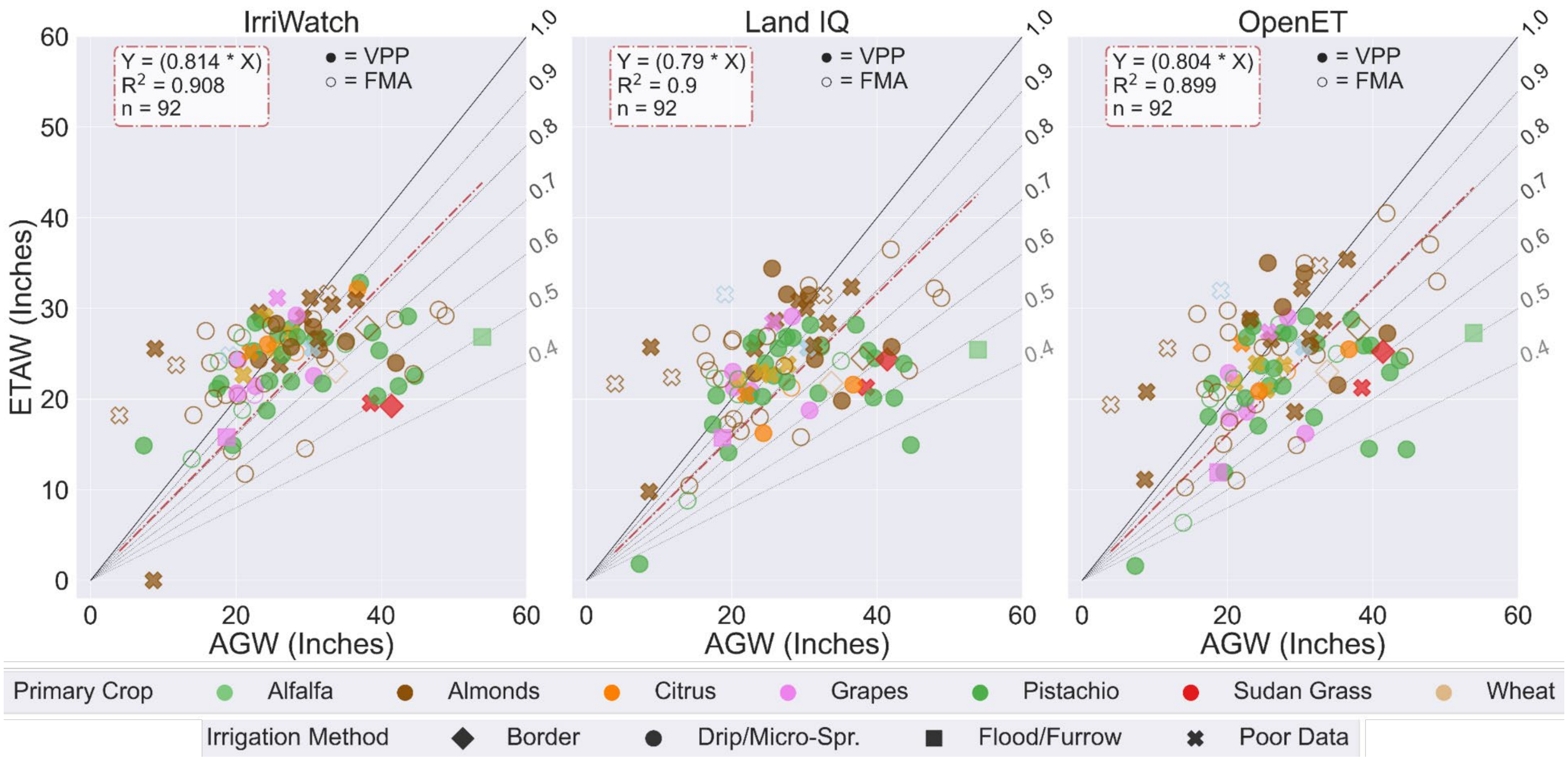

Figure 6-22. Summary of evapotranspiration of applied water (ETAW) and applied groundwater (AGW) for 92 Irrigation Units (IUs) including (1) IUs without data quality issues (n = 71) and (2) IUs with known data quality issues (n = 21; labeled "Poor Data"). Results are shown for IrriWatch, Land IQ, and OpenET. "VPP" refers to IUs that participated in the 2023 Madera Verification Project while "FMA" refers to IUs that used flowmeters as their allocation measurement method during 2023. Crop colors represent the primary crop for each IU by acreage (e.g., the crop that covered the largest area within that IU); some of the IUs shown have mixed cropping.

6.5.2.3 Remotely-Sensed ETAW from No Irrigation and Fallow Irrigation Units

Irrigation Units with primarily fallow fields and/or specified as having no irrigation were also excluded from the results, discussion, conclusions, and recommendations presented in this report. Theoretically, all fallow/no irrigation IUs should have zero ETAW measured by remotely-sensed methods because no water was applied. However, this is not always the case due to a variety of factors, including 1) uncertainties/inaccuracies in remotely-sensed ETAW methods, 2) parcel-fields within the IU being incorrectly labeled as fallow/no irrigation, 3) flooding of parcel-fields within IUs adjacent to surface water features (especially within the floodplain), 4) planted crops (e.g., almonds) on abandoned (no irrigation) lands that may still have access to water through extensive and/or deep rooting systems, and 5) other potential factors. Therefore, the ETAW fallow/no irrigation IUs (a total of 11 IUs) were evaluated in detail and presented in Figure 6-23 from Land IQ and OpenET data. Note that in 2023, IrriWatch was programatically setting the ETAW for fallow and no irrigation parcel-fields to zero, so their results are not shown here.

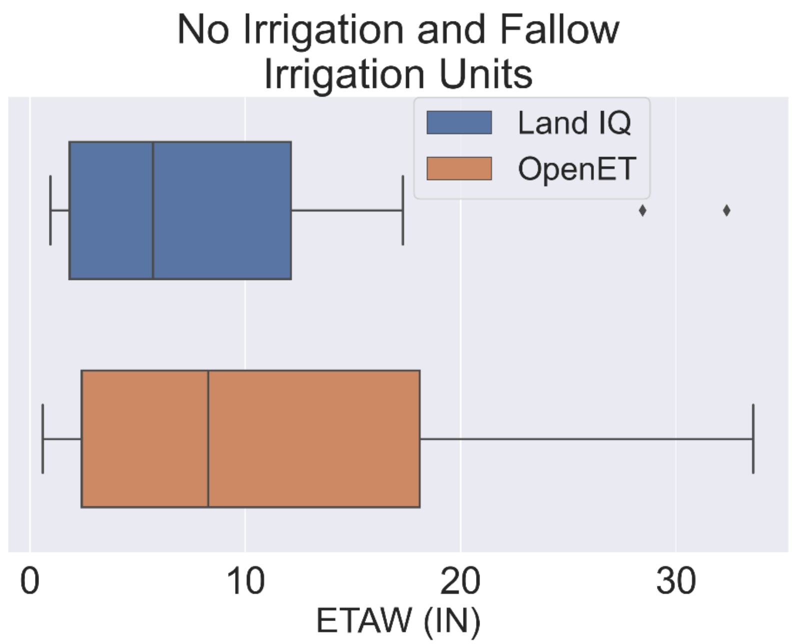

Figure 6-23. Evapotranspiration of applied water (ETAW) boxplots for all no irrigation and fallow Irrigation Units (IUs) in the 2023 Project (n = 11).

Median ETAW for no irrigation and fallow IUs was 5.72 IN for Land IQ and 8.28 IN for OpenET. While zero ETAW would be expected, median ETAW was lower for the no irrigation/fallow IUs when compared to the irrigated IUs (23.6 IN for Land IQ and 25.0 IN for OpenET; see Sections 3.2.3 and 3.2.4). Nevertheless, both Land IQ and OpenET measured relatively high ETAW (> 15 IN) for three IUs even though the landowners reported no applied water. More details about these high ETAW IUs without applied water are provided in Table 6-4 below.

Table 6-4. Description of no irrigation/fallow Irrigation Units with relatively high (> 15 IN) evapotranspiration of applied water (ETAW) measurements.

Irrigation Unit	Land IQ ETAW (IN)	OpenET ETAW (IN)	Description/Potential Cause
1	17.3	24.6	This IU was within the floodplain of the San Joaquin River and was flooded in 2023 (2023 was a wet year). This flooding was confirmed in conversations with the grower and from field visits. Remotely-sensed ETAW cannot distinguish between applied water from wells vs. "applied" water due to flooding, so flood waters can be misclassified as ETAW.
2	28.5	28.2	This IU was also within the floodplain of the San Joaquin River. However, there was no direct communication with the grower in 2023. Spatial evaluation of this IU via Google Earth did not provide conclusive evidence of flooding either. Therefore, flooding at this site was not confirmed, although it is likely, given its location. Alternative scenarios include the application of surface water by the grower that was not directly measured with a flowmeter and reported to the Madera County GSAs.
3	32.4	33.6	This IU was not near any large surface water sources. While the IU was labeled as no irrigation for 2023, the crop was listed as walnuts. The grower also communicated directly with DE that this field was previously irrigated but abandoned in 2023, and field visits verified that there was no irrigation infrastructure present in the field. However, the high ETAW measured for this IU indicates that there is an additional water source that is currently unaccounted for. Potential sources include 1) subsurface flows or runoff from irrigation of nearby fields, 2) deeply rooted plants that have access to shallow groundwater, or 3) unreported applied water. Visual inspection of the IU via Google Earth revealed a dense planting of trees covering the entire IU.

6.5.2.4 Large ETAW Differences Between Remotely-Sensed Methods

While ETAW measured by the IrriWatch, Land IQ, and OpenET were generally in agreement with each other, there were some notable differences in measured ETAW. Specific IUs with relatively large differences, and the corresponding ETAW for each remotely-sensed method, are shown in Table 6-5.

For the first IU shown, IrriWatch measured ETAW as 14.9 IN (twice as large as the reported AGW) while Land IQ and OpenET measured between 1.6 IN and 1.8 IN (over four times smaller than the reported AGW and nearly an order of magnitude smaller than IrriWatch). Given the large differences in ETAW, the reported CUFs also varied widely between IrriWatch (> 2) and Land IQ/OpenET (< 0.3) for this IU. This IU is a young pistachio orchard. Similar ETAW results (i.e., IrriWatch reporting much higher values than Land IQ and OpenET) were noted in another young pistachio orchard in Project Lands, although AGW could not be directly compared for that orchard because it was a mixed crop IU that also included mature almonds.

The other two IUs shown are both almond orchards that are relatively small in size. All three IUs are less than 40 acres in size (and one is smaller than 20 acres); this may be a factor in the uncertainties shown. Depending on the method a grower selects for their allocation, these differences would have a very large impact on how much groundwater was estimated to be consumed by that grower's crops. Therefore, in the future, it will be important to further evaluate these differences between remotely-sensed methods in more detail to fully understand the underlying causes.

Table 6-5. Irrigation Units (IUs) where differences in evapotranspiration of applied water (ETAW) was the highest between IrriWatch, Land IQ, and OpenET. The measured applied groundwater (AGW) for each IU is also shown.

Irrigation Unit	Irrigation Unit Description	AGW (IN)	IrriWatch ETAW (IN)	Land IQ ETAW (IN)	OpenET ETAW (IN)
1	Young pistachio orchard, less than 40 acres in size	7.3	14.9	1.8	1.6
2	Almond orchard, less than 40 acres in size	14.2	18.2	10.5	10.3
3	Almond orchard, less than 20 acres in size	21.2	11.7	16.5	11.0

6.5.2.5 Analysis of Parcel-Field Coverage Issues

Recommendations from the 2022 Project included improving parcel boundaries, field delineations, and cropping and land use information. For the 2023 Project, the parcel-field delineations for VPPs were closely reviewed and evaluated to assess issues and need for improvements. These are summarized in the TM attachment included in Section 6.5.6. In summary, of the 475 parcel-fields covering roughly 14,000 acres for VPPs, there were 330 parcel-field delineation issues[88] identified influencing roughly 1,400 acres. The impacted area representing roughly 10% of the total lands of VPPs (1,400 of 14,000 acres) points to the importance of improving these geospatial coverages.

[88] It is important to note that some parcel-fields had multiple issues identified.

During the 2023 Project, improvements to parcel-field coverages were initiated (through improved parcel delineations available from the Madera County Assessor's office and through improved geospatial coverage of irrigated lands and crop type available for 2023 from Land IQ). These improvements will be implemented in 2024 for the groundwater allocation program.

6.5.2.6 In-Field Review and Verification of Fallow Fields

Another issue identified as part of the 2022 Project was the need to better understand non-irrigated fields each year (which could include both idle lands and lands that are dryland farmed with precipitation only, but no direct irrigation) and to programmatically set ETAW to zero for fields that have been verified to have received no applied water (if a grower is using remote-sensing methods). As part of the 2023 Project, this was completed in two phases, both completed with coordination between DE and IrriWatch staff. The first phase used remote sensing data to identify fields that were marked as fallow or non-irrigated but appeared to be irrigated in 2023; through coordination with landowners, these were visited to verify and document on-the-ground whether they were cropped and/or irrigated. The second phase used remote sensing data to identify fields that were marked as cropped and irrigated, but that might be fallow. Similarly, these fields were visited to verify and document the status of these fields. The status of fields in the allocation database was changed based on the results determined from the in-field review and verification. This analysis and in-field review should continue in 2024 and beyond as part of groundwater allocation program implementation, and opportunities to improve this analysis and process should be identified and implemented, as feasible.

6.5.2.7 Additional Special Investigation Ideas

Additional ideas for special investigations of issues related to the groundwater allocation program that could be pursued in future years include, but are not limited to, the following:

1. Directly comparing ground-based and remotely-sensed ET measurements.
2. Investigating cover crops and their associated ET requirements (including an evaluation of typical cover crops, agronomic practices, and variability in cover cropping across the Madera County GSAs).
3. Studying the effects of surface water features on potential shallow groundwater within the rootzone in nearby irrigated areas within the Madera County GSAs.
4. Investigating typical irrigation efficiencies for the variety of irrigation methods and practices within the Madera County GSAs through aggregation of available data or in-field studies.
5. Incorporating flowmeter calibration data into the evaluation of flowmeter accuracy.
6. Studying crop yields relative to ETAW and AGW volumes to determine how reducing water use on-farm impacts crop yields.
7. Investigating surface water use and recharge practices to better understand how these impact groundwater conditions in the aquifer and on-farm conditions and AGW over time.
8. Studying soil moisture within the rootzone to see if long-term soil moisture depletions over the course of an irrigation season may be influencing CUF values greater than one.

6.5.3 IrriWatch Adjustments

Like the 2022 Project, as preliminary results were developed and reviewed for the 2023 Project, questions and feedback regarding the assumptions and methodologies that IrriWatch used to calculate ET and ETAW were raised and discussed with IrriWatch staff. Based on these discussions and review of preliminary results, IrriWatch made an adjustment that reduced the calculated ETAW for almost all parcel-fields. This adjustment was applied on December 31st, 2023.

Excerpts from technical memos and press releases directly from IrriWatch are given in the following sections to describe how ETPR calculations and cloud filters lead to the 2023 data adjustments.

6.5.3.1 Press Release Regarding ETPR 2023 Values on September 12th, 2023

Rainfall during Spring 2023 was above average. The automatic weather station (AWS) observations that the NOAA network rely on indicated a range of rainfall between 7.4 to 14.1 inch (average 11 .1 inch) across Madera County. The portion of rainfall that contributes to total evapotranspiration (ET) is referred to as effective precipitation or the ET from precipitation (ETPR). Total ET is computed from recurrent satellite measurements and an energy balance equation that partitions available energy (mainly from sun) into vaporization of water vs. heating of air. Recent field measurements of ET fluxes by the University of California - Davis in a pistachio orchard in Madera County confirmed total ET values from IrriWatch to be accurate for the 2023 growing season.

The Madera County GSAs' allocations are based on the evapotranspiration of applied water (ETAW) because this is the portion of ET that growers have control over. However, computing ETAW requires an estimation of ETPR because ETAW equals total ET minus ETPR. Unfortunately, estimating ETPR is challenging, and any error in ETPR will be propagated into error in ETAW. All else being equal, errors are larger when rainfall is high.

Within IrriWatch, ETPR is computed from a custom implementation of the IDC model using a certain IDC-related partitioning between ETAW and ETPR. The IDC model was selected as the basis for daily ETPR computations at the onset of the IrriWatch project in late 2020. Due to above-average rainfall in 2023, the IDC model started to produce high ETPR values in 2023. IrriWatch developers had for this reason built in a safety factor such that ETPR at the regional scale should at all cases be less than 80% of the sum of precipitation in 2023 plus initial rootzone soil moisture storage on 1 January 2023. The latter reflects all water carried over in storage from 2022. Parcel-fields with unique identity in 2023 thus received part of the rainfall from Fall 2022 that was not evaporated in 2022.

On 5 July, the regional 80% limit was reached and ETPR got frozen. As a result, all total ET occurring after July 5th was added to the cumulative ETAW value. This resulted in a faster rise of the ETAW graph with an unavoidable inflection point in the ETAW curve (see Figure 6-24).

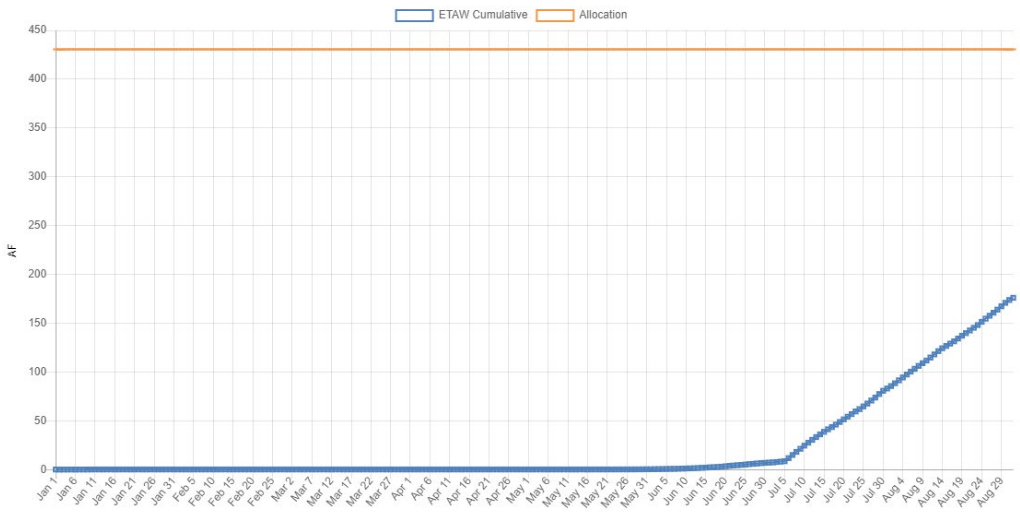

Figure 6-24: Inflection point in ETAW on 5 July due to the global 80% limit on ETPR being reached.

Due to the relatively large rainfall in 2023, ETPR values tended to become overestimated by IDC model. ETPR values rely strongly on the spatial distribution of rainfall and depths of effective roots, which complicates their estimates. For practical reasons IrriWatch decided to introduce a regional cap of effective rainfall of 80%. From 5 July onwards, ETPR did not longer increase and hence all ET is designated to ETAW. The result is a steeper graph of ETAW.

More details are provided in the "2023_IrriWatch_ETPR_Correction_Memo 12Sep.pdf" document, which is attached to this report. This memo is included as an attachment to Section 6.5.6.

6.5.3.2 Press Release Regarding Cloud Filters and Final Corrections on January 15th, 2024

IrriWatch has communicated in various workshops that remote sensing technologies provide the actual crop evapotranspiration (ET). This is the core activity of IrriWatch and we use the Surface Energy Balance Algorithm for Land (SEBAL) for that. In some IrriWatch service areas, water allocation policies require the ET from Applied Water (ETAW) to be known and this is computed with the IDC model from the Department of Water Resources as ETAW = ET – ETPR.

In September 2023, IrriWatch confronted challenges in the cloud filters from NASA (National Aeronautics and Space Administration of USA) and ESA (the European Space Agency) space agencies. Their cloud filters were not tight enough and cloud-contaminated pixels were used to calculate ET. As a result, the computations of ET were higher than what they should have been. IrriWatch has been working on improving the cloud filters from the space agency to recalculate ETAW for the final reporting and to prevent this from happening in the next seasons.

The good news is that accumulated ETAW for all IrriWatch users, world-wide, will go down. We are currently working on these changes on a field – by – field basis and expect to have all corrections made by the end of January 2023.

6.5.4 Irrigation Unit Summary Reports

Summary reports for each IU included in the Project Lands (including both VPPs and FMAs) have been provided to Madera County staff for future reference. The reports include a summary of all data and results collected and compiled for each respective IU as part of the 2023 Project.

6.5.5 Flowmeter Summary Reports

Summary reports for each flowmeter for VPPs have been provided to Madera County staff for future reference. The reports include a summary of the flowmeter installation review completed by DE staff, along with the summarized results of any comparison measurements completed at that flowmeter.

6.5.6 Additional Materials

The additional materials related to Grower Outreach and Engagement outlined below are included as attachments to this report:

1. Materials from June 15, 2023 Grower Workshop and Subsequent Grower Meetings
    a. PowerPoint Slides
    b. Madera County Grower Flowmeter Readings Data Collection Form
    c. Grower Meeting Agenda
2. Materials from January 22, 2024 Grower Workshop and Subsequent Grower Meetings
    a. PowerPoint Slides
    b. Grower Meeting Agenda

The additional materials related to Special Investigations outlined below are included as attachments to this report:

3. Shallow Soils Analysis TM
4. Analysis of Parcel-Field Boundary Issues TM

Finally, the additional materials related to IrriWatch Adjustments outlined below are included as attachments to this report:

5. Memo ETPR 2023 Values

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Agenda

1. Overview of SGMA and Groundwater Allocations
2. 2022 Verification Project Summary
3. 2023 Verification Project Overview
4. 2023 Participation Requirements
5. Questions & Discussion

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Sustainable Groundwater Management Act (SGMA)

- Enacted in 2014, objective of groundwater (GW) sustainability across California achieved by local Groundwater Sustainability Agencies (GSAs)
- Prioritization of every basin in the state
  - Subbasins within the Madera County were all identified as high-priority and critically overdrafted (COD).
- In COD basins, GSAs are tasked with implementing Groundwater Sustainability Plans (GSPs) in order to achieve sustainability by 2040.
- To achieve sustainability, the consumptive use of applied water (Evapotranspiration of Applied Water, ETAW) needs to be reduced.
- The Madera County GSAs have chosen to implement a GW allocation to facilitate this.

https://water.ca.gov/programs/groundwater-management/sgma-groundwater-management

3

Madera County GSA Allocations

- Allocations for all subbasins are determined in acre-feet (AF) based on allotted inches of water and acreage.
- Allocations are quantified by Evapotranspiration of Applied Water (ETAW).

Madera County GSA	Inches of ETAW		
Year	Madera Subbasin	Chowchilla Subbasin	Delta-Mendota Subbasin
2021	28.3	26.7	19.8
2022	28.0	26.3	19.6
2023	27.7	25.9	19.3
2024	27.4	25.5	19.1
2025	27.1	25.1	18.9

1. More information on the Madera County GSA allocations is available at: www.maderacountywater.com/allocations

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Overview of Groundwater Allocations

2020
Madera County BOS adopt allocation approach & IrriWatch is selected as allocation accounting method

2021
IrriWatch data are provided to growers for first time

2022
IrriWatch data are provided & Verification Project is completed

2023
Flowmeters, IrriWatch, and Land IQ are provided as allocation accounting options & Verification Project is underway

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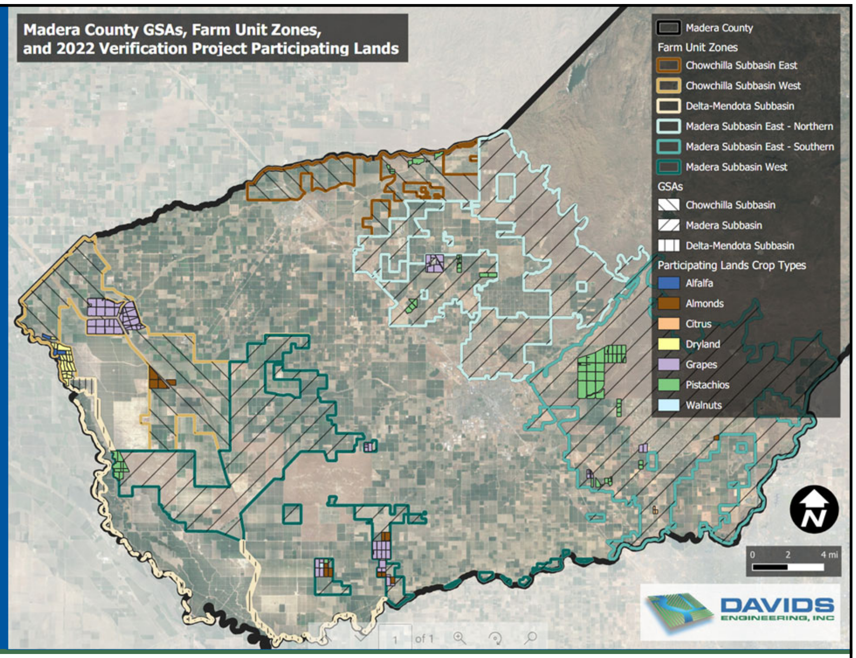
Participating Lands

Crop	2022 Madera Verification Project		
	Parcel-Field Count	Acreage	Acreage %
Alfalfa	4	174	1.5%
Almonds	16	1,053	8.9%
Citrus	4	48	0.4%
Dryland	21	862	7.3%
Grapes	74	4,785	40.5%
Pistachios	86	4,836	41.0%
Walnuts	1	42	0.4%
Other	0	0	0.0%
Totals	**203**	**11,800**	**100%**



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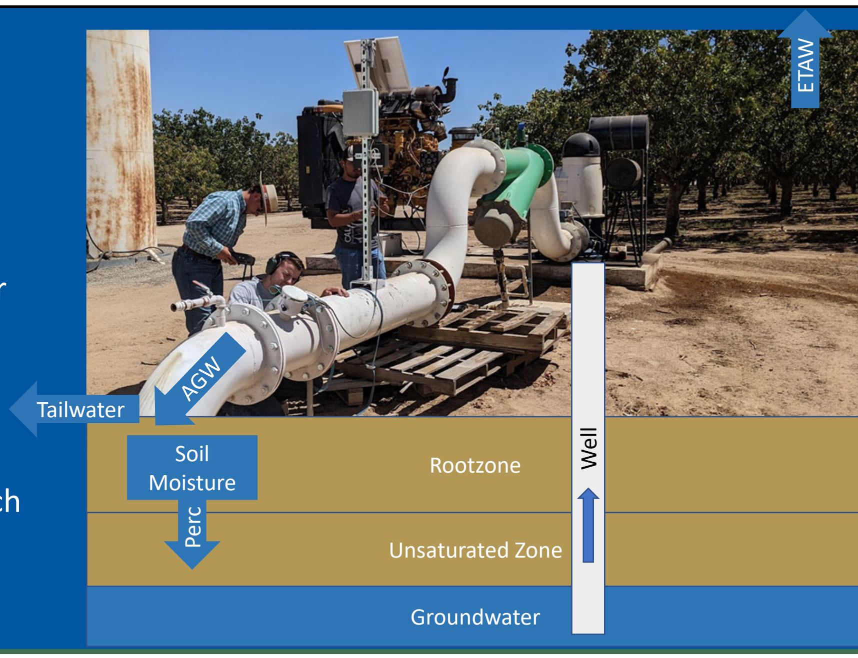
Data Collection

- Applied Groundwater (AGW) measured with permanent flowmeters
- Independent flowmeter measurements with Portable Transit Time Meter
- Evapotranspiration of Applied Water (ETAW) measured with IrriWatch
- CUF[1] = ETAW / AGW



1. CUF = Consumptive Use Fraction

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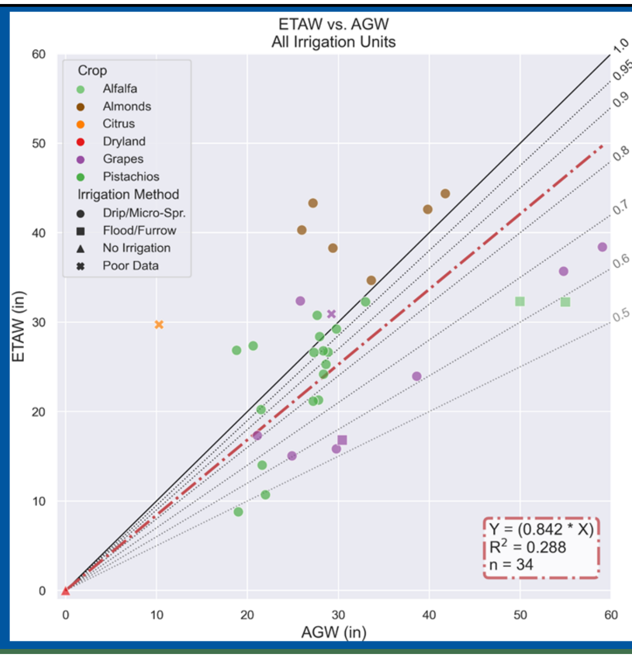
ETAW vs. AGW Results

- 36 Irrigation Units with 6 different primary crops[1]
- Consumptive Use Fraction (CUF) = ETAW / AGW
  - Should be less than one since not all water applied will be consumed
  - Lines show CUF values ranging from 0.5 to 1.0
- **Based on regression, overall CUF = 0.84**
- **There is substantial variability in scatterplot and resulting CUF values, ranging from 0.46 for pistachios to 1.85 for almonds**



1. The two with questionable data are excluded from the regression.

2022 Verification Project Conclusions and Recommendations

1. Grower engagement, education, and outreach is critical
2. Flowmeters accurately measure AGW if installed and maintained correctly
3. Collecting, managing, utilizing, and disseminating flowmeter data requires substantial effort and data management infrastructure
4. Review of ETAW data quality is important, and improvements to input data (land use coverages, parcel and field boundaries (*i.e.,* geometries), precipitation, etc.) should be prioritized
5. Growers should be provided options for measuring ETAW
6. Systematic verification efforts should continue in 2023 and beyond to build understanding and support implementation of the GSA allocations

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Summary of Allocation Accounting Methods

Allocation Accounting Method	Description[1]	Data Availability	Grower Requirements
Flowmeters	Measurement of AGW; Conversion to ETAW	TBD	Submittal of initial information to County; Submittal of monthly flowmeter readings between 1st and 10th of the month
IrriWatch	Measurement of ET; Conversion to and provision of ETAW (ET – ETPR)	Daily	None
Land IQ	Measurement of ET and P; Conversion to ETAW (ET – ETPR)	Monthly	None

1. AGW = Applied Groundwater, ETAW = Evapotranspiration of Applied Water, P = Precipitation, ETPR = ET from Precipitation.

2023 Verification Project Objectives

1. Increase grower engagement, education, and outreach
2. Implement and refine methods for collecting and/or developing the required input data and associated computations for totalizing flowmeters or remote sensing with IrriWatch or Land IQ.
3. Collect, compare and analyze results from the three allocation tracking methodologies across participating lands

IrriWatch

LAND IQ

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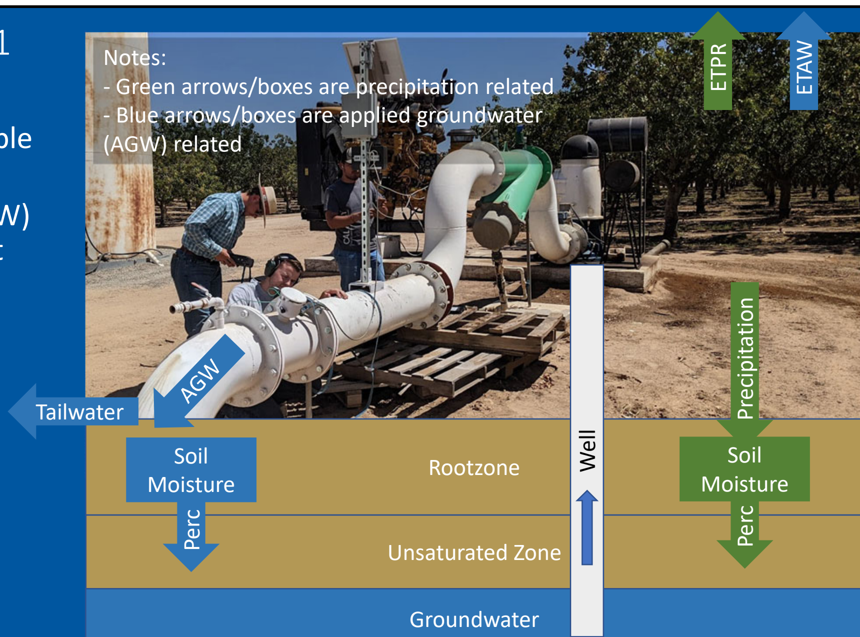
Data Collection[1]

- Independent flowmeter measurements with Portable Transit Time Meter
- Applied Groundwater (AGW) measured with permanent flowmeters
- ET measured and ETAW calculated with IrriWatch
- ET measured with Land IQ
- ETAW = ET - ETPR (ET from Precipitation)
- CUF[2] = ETAW / AGW

1. This does **not** replace/alter grower obligations for appeals process.
2. CUF = Consumptive Use Fraction



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2023 Verification Project Schedule & Next Steps

1. Coordinate with potential participating growers to identify participating lands (*June 2023*)
2. Complete field data collection (*June – December 2023*)
3. Complete data analysis and aggregation; preparation of results (*September – December 2023*)
4. Conduct final meetings with participating growers to discuss project results (*December 2023 – January 2024*)
5. Complete final workshop and final report (*Q1 2024*)

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What Does Participation Look Like?

- Entirely voluntary
- Public use of data collected
- Coordination with project team during 2023
- Access to irrigated lands and groundwater wells to be granted to Madera County and its representatives during the field data collection period (June through December 2023).
- **Note: Participation does not replace or otherwise alter grower obligations related to the appeals process.**

Participation Requirements

- Included lands must be entirely within one or more of the Madera County GSAs.
- Groundwater irrigation well(s) must be equipped with a totalizing flowmeter and flowmeter ID/sticker[1].
- Must be willing to coordinate with the Project team, provide access to farmed lands to the Project team over the remainder of the 2023 calendar year, and consent to public use of the data collected as part of the Project.
- Must be willing to submit monthly permanent flowmeter readings using a pre-made online form[2].

1: Unirrigated lands fitting all other criteria are eligible for inclusion without a well and/or flowmeter.
2: Growers using flowmeters for allocation tracking can continue using the form normally for monthly flowmeter reading submittals; there are no additional flowmeter submittal requirements.

If you are interested in participation, please contact:

Madera County
ETmeasurement@maderacounty.com
(559) 662-8015

You can also submit monthly flowmeter readings[1] using the form here[2]: ***https://bit.ly/3YYXpZm***

1: Growers using flowmeters for allocation tracking can continue using the form normally for monthly flowmeter reading submittals; there are no additional flowmeter submittal requirements. Other participants will need to begin monthly flowmeter submittals as part of participation.

2: Hyperlink is case-sensitive (*i.e.*, capitalization matters).

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Madera County Grower Flowmeter Readings

If you've selected flowmeters as a measurement method for the current year, you are required to upload monthly flowmeter readings through this form.

You are also welcome to upload monthly flowmeter readings if you plan to appeal satellite data and are using flowmeters as a backup method.

If you cannot upload data, or there are issues with your flowmeters, you will be defaulted to Land IQ and get paper reports once a month.

Call us at (559) 598-0301 or email us at ETmeasurement@maderacounty.com with questions.

Are you a new user?

A "new user" means you have never filled out this form or provided your name and email before.

- ◯ Yes
- ◯ No

What is your first and last name?

____

What is your email address?

____

What is your phone number?

Please enter your 10-digit phone number (including area code) with only numbers (no dashes or parentheses). By submitting your phone number, you consent to receive one text message verifying the submission of this form. Message and data rates may apply.

____

1.b.

Select the current date and time.

yyyy-mm-dd

hh:mm

What are the coordinates where the flowmeter is located?

To use your current location, select the target symbol below and ensure that accuracy is within 5m. The target symbol can be clicked multiple times to improve accuracy.

latitude (x.y °)

longitude (x.y °)

altitude (m)

accuracy (m)

Take a photo of the flowmeter's readout.

The value of the flowmeter's totalizer, flow, and Flowmeter ID should be clearly visible and legible in the photo.

Click here to upload file. (< 100MB)

Please enter the number on your Flowmeter ID label.

*Please enter **7** if the ID is 00007 or **286** if the ID is 00286.*

What is the current flow on the flowmeter's readout?

*If possible, have pump running under steady state while capturing flow. Enter flow exactly as it appears on the flowmeter readout, including any number(s) before and after the decimal point. Enter 0 (zero), if the well is not currently operating. Flow volume units (e.g., GPM, CFS) **must remain static** for reporting.*

What is the current volume on the flowmeter's readout?

*Enter volume exactly as it appears on the flowmeter readout, including any number(s) before and after the decimal point. Totalizer units (e.g., AF) **must remain static** for reporting.*

Take an overview photo of the flowmeter if there is anything important to document (optional).

Click here to upload file. (< 100MB)

Enter any comments about the measurement (optional).

Once you click the blue 'Submit' button below to finalize and submit your information, please enusre that you see a "Success!" banner pop up afterwards indicating a successful upload.

2023 Verification Project: Initial Grower Meetings

When: 6/14/2023 – 6/23/2023, Various Times
Where: Madera County Government Offices or MS Teams
Who: Potential 2023 Verification Project Participants

Agenda

1. Introductions
2. Overview of 2023 Verification Project
    a. Background and history
    b. Initial grower questions?
3. Farming and Allocation Tracking Background
    a. Confirm farming locations and review farm characteristics
    b. Review parcel-fields and irrigation wells/flowmeters to establish irrigation units.
    c. Finalize irrigation units and potential selected lands.
4. Discuss Potential Additional Data
5. Provide Overview of Field Data Collection
6. Discuss Coordination
    a. Preference for email or phone?
7. Review Participation Requirements
    a. Monthly flowmeter readings
    b. Review and assign flowmeter IDs
8. Questions/Comments/Concerns?
9. Review Next Steps and Action Items

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1

Agenda

1. Overview of Groundwater Allocations and Verification Project
2. Objectives and Preliminary Results
3. Preliminary Conclusions and Recommendations

2023 Verification Project Preliminary Results

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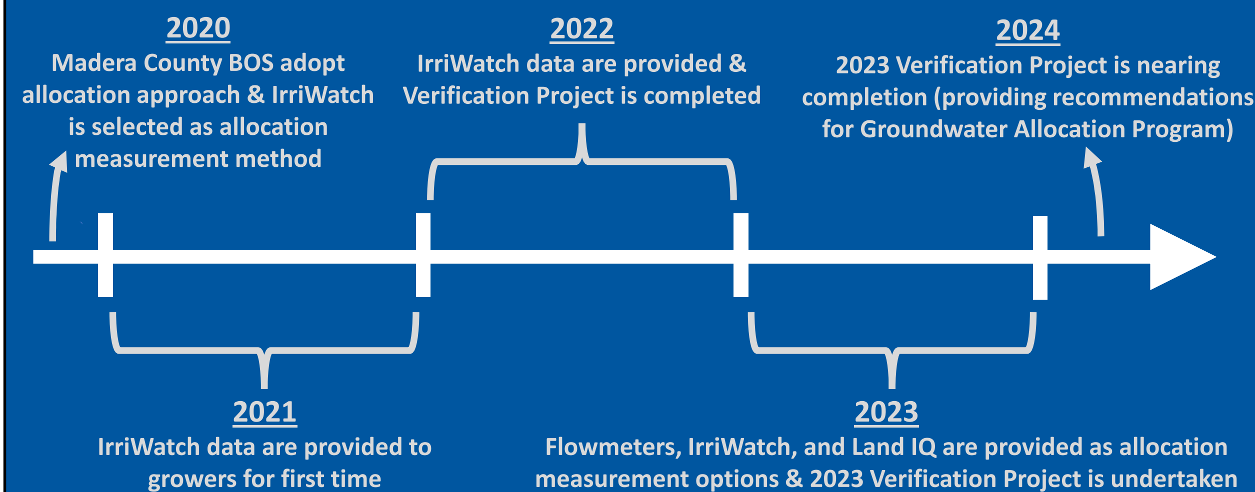
2

Overview of Groundwater Allocations



3

Verification Project Overview

- Groundwater allocation program needs to balance measurement accuracy (across full diversity of growers and on-farm conditions) and grower needs
- Verification Project is in-depth review of quantification of ETAW[1] across all groundwater allocation measurement options (Flowmeters, IrriWatch, Land IQ)
- 2022 to 2023 Differences:
  - Hydrology (Dry to Wet), Included Lands, Measurement Options

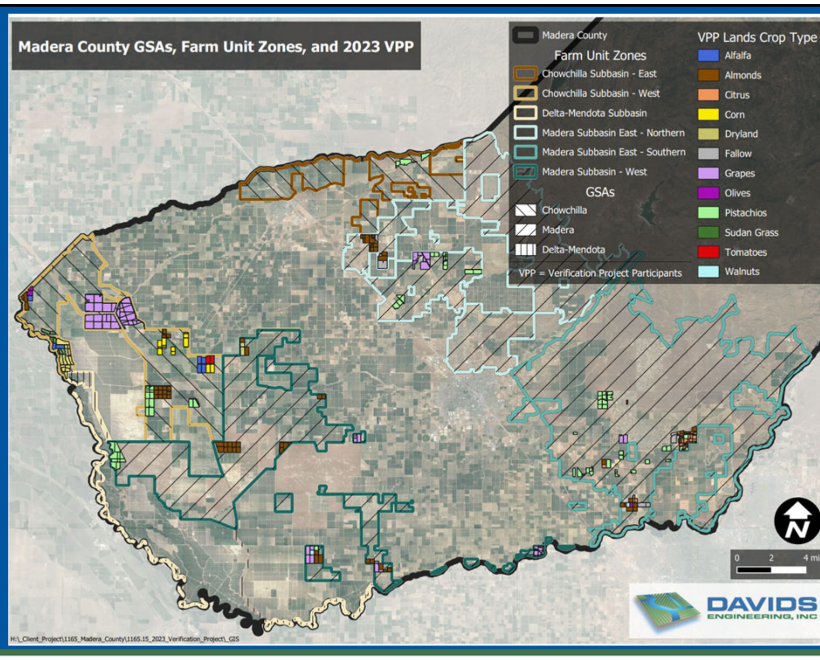
1. ETAW = Evapotranspiration of Applied Water

4

Verification Project Participants (VPP)

Crop	2023 VPP Parcel-Field Count	2023 VPP Acreage	2023 VPP Acreage %
Alfalfa	8	494	3.6%
Almonds	114	3,177	22.9%
Citrus	39	420	3.0%
Corn	11	592	4.3%
Dryland	25	732	5.3%
Fallow	15	577	4.2%
Grapes	89	4,055	29.2%
Pistachios	154	3,244	23.4%
Other Crops[1]	19	601	4.3%
Totals	**474**	**13,892**	**100%**

1. Other crops include olives, tomatoes, walnuts, and sudan grass.



All Verification Project Lands: 2023

Crop	2023 Madera Verification Project (VPP and FMA lands[1])			Madera County GSAs			Acreage % Difference (Verification Project - GSAs)
	Parcel-Field[2] Count	Acreage	Acreage %	Parcel-Field[2] Count	Acreage	Acreage %	
Alfalfa	8	494	1.7%	165	5,932	4.7%	-3.0%
Almonds	307	10,403	35.4%	1,474	40,880	32.2%	3.2%
Citrus	60	992	3.4%	68	1,453	1.1%	2.3%
Corn	11	592	2.0%	16	1,074	0.8%	1.2%
Dryland[3]	26	969	3.3%	151	5,060	4.0%	-0.7%
Fallow	27	1,337	4.6%	500	7,049	5.6%	-1.0%
Grapes	101	4,487	15.3%	498	14,218	11.2%	4.1%
Pasture[4]	64	4,646	15.8%	1,486	24,257	19.1%	-3.3%
Pistachios	215	4,583	15.6%	899	20,986	16.5%	-0.9%
Other Crops[5]	36	879	3.0%	263	5,899	4.8%	-1.8%
Totals	**855**	**29,383**	**100%**	**5,520**	**126,807**	**100%**	-

1. VPP are Verification Project Participants (who are voluntarily participating in the Project) and FMA are Flowmeter Accounts (who have elected to use flowmeters as their 2023 groundwater allocation measurement method).
2. 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).
3. Dryland describes lands farmed using only precipitation and no applied water for irrigation. The dryland areas included in the Project are dryland wheat, and the Parcel-Field Count and Acreage for the Madera County GSAs were determined using IrriWatch's Parcel-Fields that have a planted crop, but are not irrigated and an assumed percentage of overall wheat being dryland farmed.
4. Pasture crops for the Madera County GSAs include both irrigated pasture and an assumed percentage of overall wheat being irrigated.
5. The other crop classification includes small area crops such as cotton, olives, other deciduous, tomatoes, walnuts, and grasses. In addition, this classification includes land uses/crop classes that make up the rest of the Parcel-Fields in the Madera County GSAs. These include cherries, figs, kiwis, undeveloped areas, urban areas, unknown land types, and variety of other tree crops. Although crop type was field verified and accurate for lands participating in the 20223 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.

Agenda

1. Overview of Groundwater Allocations and Verification Project
2. Objectives and Preliminary Results
3. Preliminary Conclusions and Recommendations

2023 Verification Project Objectives

1. Increase grower engagement, education, and outreach
2. Implement and refine methods for collecting and/or developing the required input data and associated computations for totalizing flowmeters or remote sensing with IrriWatch or Land IQ.
3. Collect, compare and analyze results from the three allocation measurement methodologies across Project lands
4. Provide recommendations for the groundwater allocation program

Flowmeters

IrriWatch

LAND IQ

Objective 1
Increase Grower Engagement and Outreach

1. Represents substantial effort by Madera County to increase direct interaction with growers and availability to growers
2. Held two rounds of individual meetings with participating growers, and communicated and coordinated with participating growers throughout the irrigation season
3. Following final round of grower meetings, plan to request grower feedback

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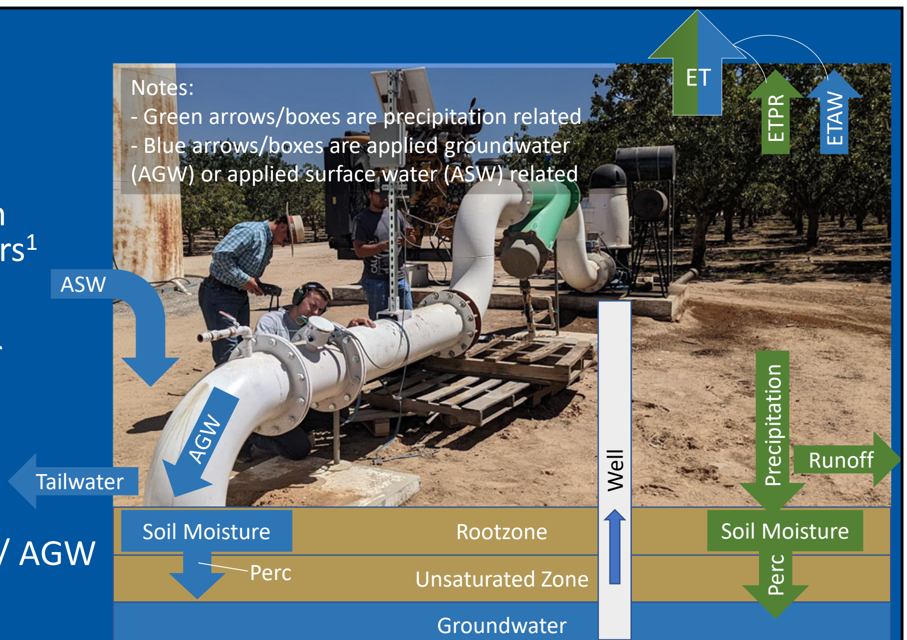
Objective 2
Methods

- Applied Groundwater (AGW) measured with permanent Flowmeters[1]
- Total ET measured by IrriWatch and Land IQ
- ET = ETAW + ETPR, or ETAW = ET - ETPR
- AW = AGW + ASW
- CUF[2] = ETAW / AW, typically CUF = ETAW / AGW



1. Comparison measurements with Portable Transit Time Meter
2. CUF = Consumptive Use Fraction

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Objective 2
Implement and Refine Methods: Evaluate Flowmeter Accuracy

1. Completed an inspection of flowmeter installation on all permanent flowmeters included in study[1]
2. Completed independent flow measurements with a portable transit time flowmeter for direct comparison to permanently installed flowmeters

1. These inspections were for use related to the 2023 Verification Project only and do not constitute an official meter inspection, pursuant to Resolution 2021-113.

2023 Verification Project Preliminary Results

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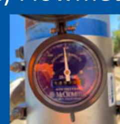
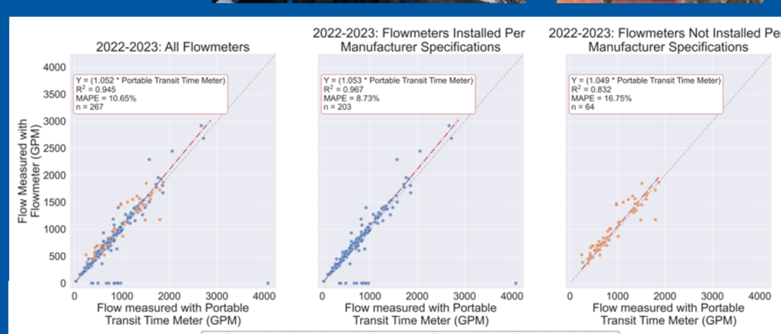
All Flowmeter Comparison Results

- 210 permanent flowmeters
  - 169 (80%) installed per manufacturer specifications
  - 41 (20%) were not
- 267 comparison measurements
- Mean Absolute Percent Error (MAPE):
  - All measurements = **10.7%**
  - Installed per Manufacturer Specs = **8.7%**
  - Not Installed per Manufacturer Specs = **16.8%**
- **Correct installation substantially improves flowmeter accuracy.**

(1) Flowmeter



(2) Portable Transit Time Meter



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Objective 2
Implement and Refine Methods: Data Inputs, Management, and Quantification of ETAW

1. Three Methods: Flowmeters, IrriWatch, and Land IQ
2. For each, we'll present:
    1. Overview of measurement method
    2. Source data and calculations
    3. Benefits and drawbacks

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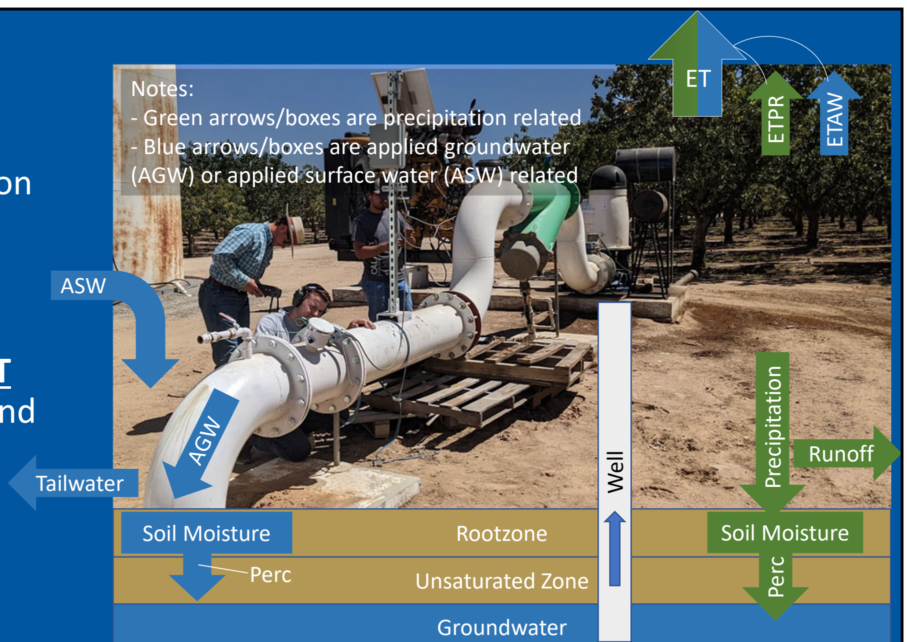
Objective 2
Methods

- Groundwater Allocation is based off of **ETAW**
- Flowmeters measure **AGW**
- IrriWatch measures **ET** and calculates **ETPR** and **ETAW**
- Land IQ measures **ET** and **Precipitation**



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Summary of Allocation Measurement Methods

Allocation Msmt Method	Description[1]	Benefits	Drawbacks
Flowmeters	Direct measurement of AGW; Conversion to ETAW (CUF * AGW)	1. On-the-ground measurement of groundwater use	1. Grower requirements[2] 2. Substantial work to complete QA/QC and convert from AGW to ETAW
IrriWatch	Remote sensing measurement of ET; Conversion to and provision of ETAW (ET – ETPR)	1. No grower requirements 2. Direct provision of ETAW on a daily basis through online Grower Portal	1. Coordination with IrriWatch staff required 2. Adjustments have been required in 2022 and 2023
Land IQ	Remote sensing and ground-based measurement of ET and P; Conversion to ETAW (ET – ETPR)	1. No grower requirements 2. Less substantial work to complete QA/QC and convert to ETAW[3]	1. Provision of ET and P on monthly basis and convert from ET to ETAW 2. Data latency

1. AGW = Applied Groundwater, ETAW = Evapotranspiration of Applied Water, P = Precipitation, ETPR = ET from Precipitation.
2. Grower requirements include cost of purchase, installation and maintenance of flowmeters; annual submittal of initial information to County; and submittal of monthly flowmeter readings between 1st and 10th of the month.
3. Although the initial development of procedures was labor intensive, completing QA/QC and conversion to ETAW using existing procedures is less data intensive relative to other two accounting methodologies.

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Objective 3
Compare ETAW from IrriWatch and Land IQ to AGW from flowmeters

1. Utilized the Consumptive Use Fraction (CUF) to directly compare ETAW and AGW: CUF = ETAW / AGW
2. Evaluated preliminary results by crop, irrigation method, year, farm size
3. Some caveats:
   1. All results are in DRAFT form and subject to change (edits are anticipated)
   2. Results shown are for January through November 2023
   3. For some irrigation units, flowmeter readings from early 2023 still need to be incorporated into the dataset, surface water was available and used in 2023, and updates to flowmeter-field linkages may be necessary
   4. Known issue with IrriWatch (correction pending)

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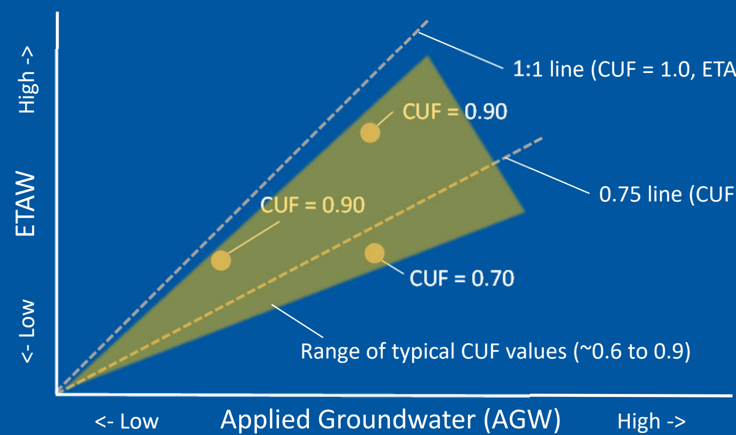
Objective 3
Compare ETAW from IrriWatch and Land IQ to AGW from flowmeters



- Consumptive Use Fraction (CUF) = ETAW / AGW
- Should be less than one since not all water applied will be consumed

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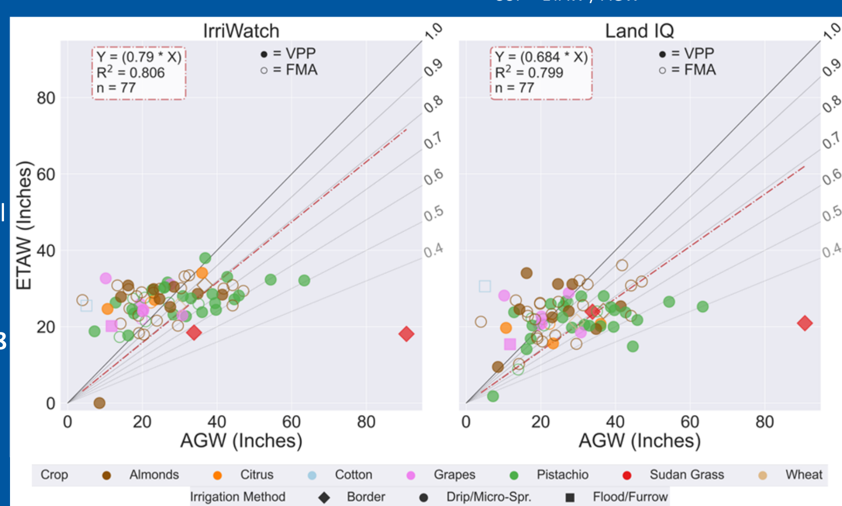
ETAW vs. AGW: 2023 Results

VPP = Verification Project Participant
FMA = Flowmeter Account
CUF = ETAW / AGW

- 77[1] Irrigation Units (ranging from 10 to 2,700 acres) with 7 different primary crops
  - Lines show CUF values ranging from 0.4 to 1.0, actual CUF values range from below 0.4 to above 1.0
- **Based on regression, overall CUF equals 0.79 for IrriWatch and 0.68 for Land IQ**
- **There is substantial variability in scatterplot and resulting CUF values for both methods**



1. Data collection and analysis is on going. Irrigation units with a primary crop of fallowed fields were excluded from this preliminary analysis.

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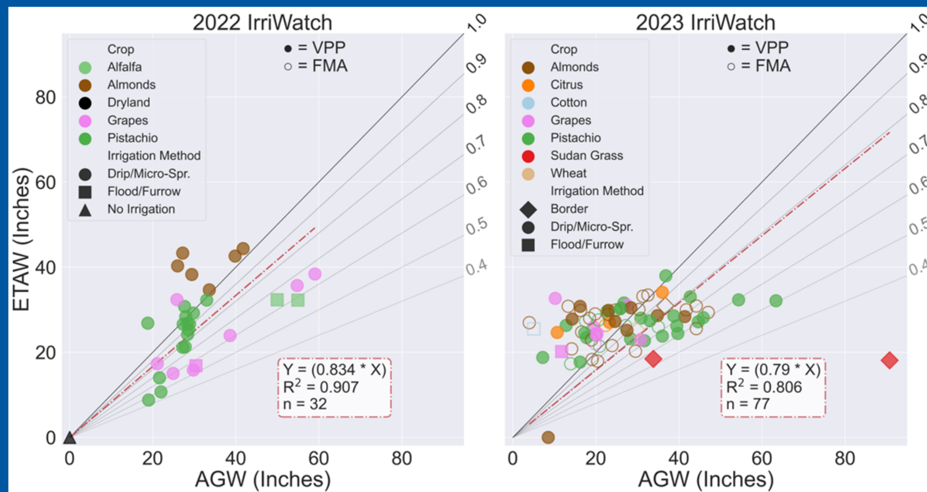
Summary of CUF by Year (2022 to 2023)

- 45 additional Irrigation Units currently under consideration in 2023 compared to 2022.
- **Similar overall CUF for 2022 (0.83) and 2023 (0.79) from linear regression.**
- **Substantial variability in each year; variability increases in 2023 with inclusion of additional irrigation units compared to 2022.**



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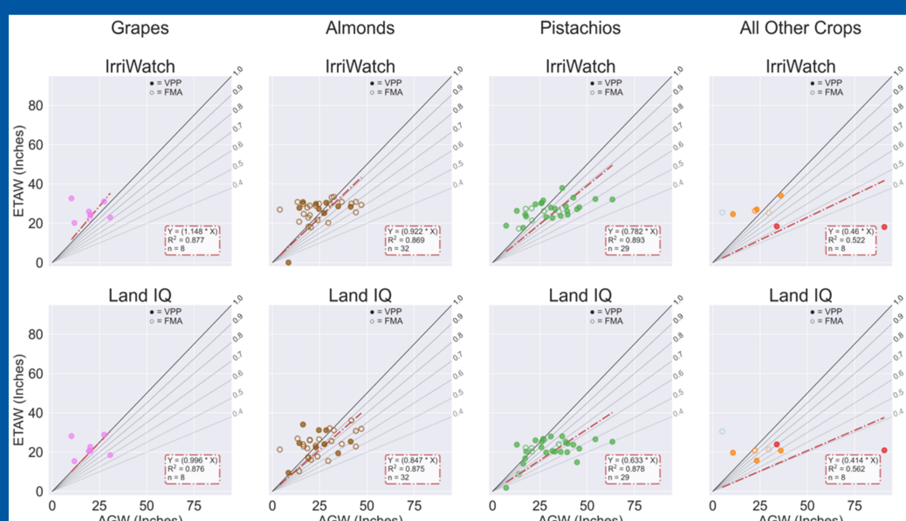
Summary of CUF by Crop

- CUF from linear regression was highest for Grapes, followed by Almonds and Pistachios for both IrriWatch and Land IQ.
- **Substantial variability within each major crop type, including values above the 1:1 line (i.e., ETAW > AGW).**



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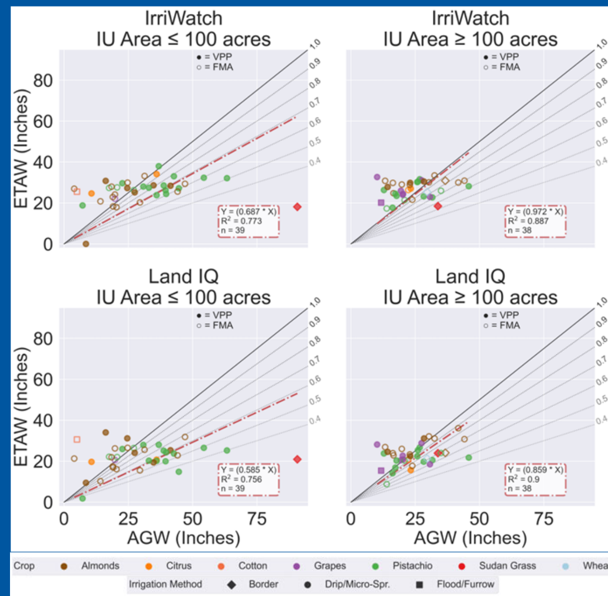
Summary of CUF by Irrigation Unit Size

- AGW shows higher variability for smaller irrigation units (IUs) than larger IUs.
- ETAW shows higher more variability for smaller IUs than larger IUs, but not as pronounced as AGW.
- **The variability is greater for the smaller irrigation units (e.g. lower R^2 value for both IrriWatch and Land IQ).**
- **Both smaller and larger IUs include values above the 1:1 line (i.e., ETAW > AGW).**



Agenda

1. Overview of Groundwater Allocations and Verification Project
2. Objectives and Preliminary Results
3. Preliminary Conclusions and Recommendations

2023 Verification Project Objectives

1. Increase grower engagement, education, and outreach
2. Implement and refine methods for collecting and/or developing the required input data and associated computations for totalizing flowmeters or remote sensing with IrriWatch or Land IQ.
3. Collect, compare and analyze results from the three allocation tracking methodologies across Project lands
4. Provide recommendations for the groundwater allocation program

Flowmeters

IrriWatch

LAND IQ

2023 Verification Project Conclusions and Recommendations

1. Grower engagement, education, and outreach remains critical, needs to be adaptable and suited to meet grower needs (*Objective 1*)
2. Flowmeters remain accurate for measurement of AGW if installed and maintained correctly, but require QA/QC, understanding of where AGW is applied for irrigation, irrigation method, and CUF for conversion to ETAW (*Objective 2*)
3. Remote sensing provides spatially-explicit data on a large spatial scale, but requires quantification of ETPR and conversion from ET to ETAW (*Objective 2*)

2023 Verification Project Conclusions and Recommendations continued

1. Real-time review and QA/QC, including adjustments (as necessary), of data is important for all groundwater allocation measurement methods (*Objective 3*)
2. There is substantial variability when comparing remotely-sensed ETAW from IrriWatch and Land IQ to flowmeter measurements of AGW across cropping and years; less variability is seen for relatively larger field sizes (*Objective 3*)
3. Implementation of the groundwater allocation program requires complex data collection, management, QA/QC, and dissemination systems and procedures and efforts to improve these should continue (*Objective 4*)
4. The availability of groundwater allocation program information to growers should be improved (e.g. develop an online grower portal for all allocation accounting methods) (*Objective 4*)
5. Comparison of remotely-sensed ETAW to field-based measurements of ETAW in select crop fields is necessary to support further implementation of the GSA allocations (*Objective 4*)

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2023 Verification Project: Final Grower Meetings

When: 1/22/2024 – 2/2/2024, Various Times
Where: Madera County Government Offices or MS Teams
Who: 2023 Verification Project Participants

Agenda

1. Introductions
2. Review individual preliminary results
    a. Grower questions?
3. Review preliminary study-wide results
    a. Grower questions?
4. Review preliminary conclusions and recommendations
5. Questions and discussion
a. Grower feedback/suggestions for groundwater allocation program
b. 2024 Verification Project
    a. Do you think the Project should continue in 2024?
    b. Would you be willing to participate again?
6. Complete survey on Multi-benefit Land Repurposing Program (MLRP)

TECHNICAL MEMORANDUM

To: Stephanie Anagnoson
Director of Water and Natural Resources
Madera County

From: Davids Engineering, Inc.

Date: April 30, 2024

Subject: **Shallow Soil Auger Sampling and Comparison**

1 Introduction

The Madera County Groundwater Sustainability Agencies (GSAs) are currently implementing Groundwater Sustainability Plans (GSPs) for the Chowchilla, Madera, and Delta-Mendota Subbasins to achieve groundwater sustainability by 2040. 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[1] of groundwater, which may be accomplished through implementation and enforcement of a groundwater allocation.

Davids Engineering, Inc. (DE) entered into a contract for measurement consulting services with the primary objective of measuring and accounting of evapotranspiration of applied water (ETAW) on irrigated lands within the GSAs. In late 2020, and through extensive public vetting by an independent advisory group, the GSAs chose IrriWatch[2] as the preferred approach for quantifying ETAW for comparison to groundwater allocations[3]. The root-zone modeling of soil water holding capacity is heavily influenced by soil type, therefore it is important to verify the soil types used by IrriWatch's model agree with the soil types as investigated in the field.

2 Methods

Throughout 2022 and 2023 DE used a hand auger to collect shallow soil samples at 74 locations throughout the GSA's (Figure 1). The field investigation of soil types for comparison of soil types used by IrriWatch (Figure 1). Immediately after collecting each soil sample, DE used the Natural Resource Conservation Service's (NRCS) Guide to Texture by Feel (Section 5.2), which is an efficient process of estimating soil type without extensive laboratory testing. The soil texture as determined by the Texture by Feel method was simplified to one (1) of three (3) main soil textures: sand, silt, or clay. This technical memorandum summarizes the results of the comparison of soil types as determined by field

[1] 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 proposal, 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.
[2] IrriWatch uses remote sensing data and methods to quantify actual evapotranspiration. More information about IrriWatch is available at: https://irriwatch.com/ .
[3] 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.

investigation utilizing the Texture by Feel methodology and soil types used by IrriWatch's models. Additionally, the soil types published in the NRCS's Web Soil Survey were included in the comparison.

IrriWatch's model includes soil types by parcel-field[4]. In some cases, the soil samples collected by hand-auger were collected outside of the defined boundaries of a particular parcel-field. In these cases, the soil type as determined by the Texture by Feel method was compared to the soil type of the nearest parcel field. The NRCS Web Soil Survey soil texture was determined at the location of the hand-auger sample regardless of parcel-field boundaries.

Two (2) soil texture comparisons were done between the hand-augured samples, IrriWatch, and NRCS Web Soil Survey:

1. Soil textures determined from the hand-augured samples were named based on a standard naming convention that is common between the NRCS and IrriWatch (Table 1). The comparison was a pass or fail with the criteria being the soil texture name determined by the Texture by Feel method must be an exact match to the soil texture name as found in IrriWatch's database or the NRCS Web Soil Survey.
2. The soil texture names in Table 1 were simplified to the single dominating soil texture present. The four (4) simplified soil texture names are clay, silt, loam, and sand. Once again, the comparison was a pass or fail with the criteria being the simplified soil texture name determined by the Texture by Feel method must be an exact match to the simplified soil texture name as found in IrriWatch's database or the NRCS Web Soil Survey. Note that the four (4) simplified soil textures are also an option for the first comparison (i.e. the full name can also be one of the four (4) simplified names).
3. Total number of unique soil textures present in the two full soil texture names divided into the number of common soil textures present in the two full soil texture names. For example, silty clay loam and silty loam have a total of 3 unique soil textures between them: silt, clay, and loam. There are two soil textures common to both: silt and loam. Therefore, the soils are 66.7% similar (2/3 X 100 = 66.7%).

Comparing the soils in a pass or fail manner is imperfect in that it does not capture the fact some soils may be similar, but if they are not an exact match, it is a failed match. For example, using the methods described in comparison #1 above, a loamy sand and a sandy loam are not an exact match, and therefore are a failed match. These two soils are similar, but the comparison does not capture the similarities in this case. This is why comparison #3, as described above, was done as it captures these similarities. Using comparison #3 In the example of loamy sand and sandy loam, there is a 100% match because both sand and loam are in both soil texture names. For this reason, it should be expected to see a higher correlation between soils compared with method #3 as opposed to method #1.

Table 1. Soil Texture Types.

Soil Texture Types	Silty Clay, Silty Clay Loam, Silt, Clay, Silty Loam, Clay Loam, Loam, Sandy Clay, Sandy Clay Loam, Sandy Loam, Loamy Sand, Sand

[4] 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).

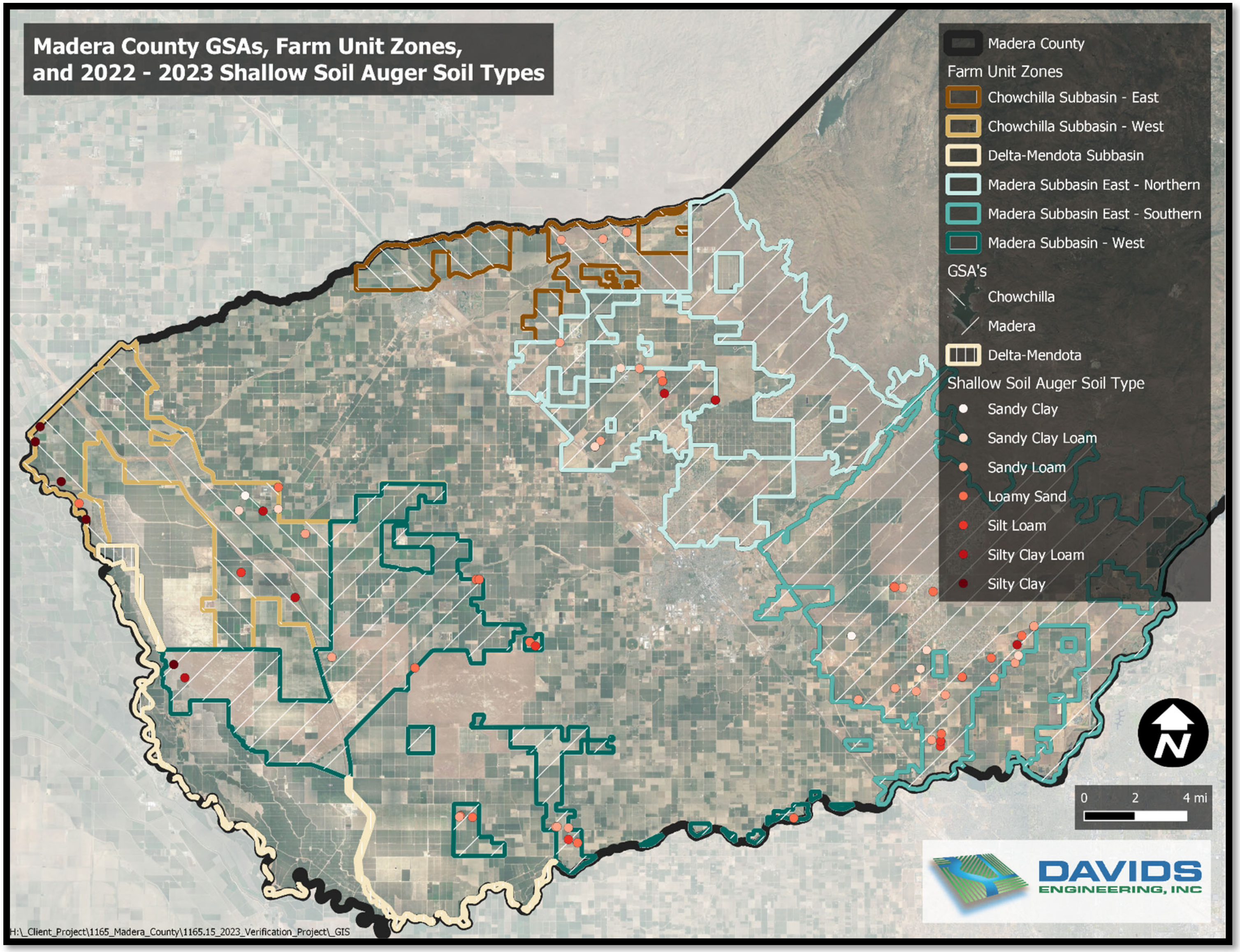


Figure 1. Map of soil types in Madera County as determined by field investigations performed by Davids Engineering, Inc in 2022 – 2023. Soil types were determined using the Natural Resource Conservation Service's Guide to Texture by Feel.

3 Results

The results of soil texture comparisons #1 and #2, as described in the Methods section above, were summarized based on the percentage of soil texture names determined by the Texture by Feel method that are an exact match to the soil texture names as found in the IrriWatch database and the NRCS Web Soil Survey (Table 2). Generally, there is a greater correlation between the soil textures determined by the Texture by Feel method and the NRCS Web Soil Survey soil textures compared to the IrriWatch database for both the full name and simplified name comparisons.

The results of soil texture comparison #3, as described in the Methods section above, was summarized as a percentage based on the number of common soil textures divided by the number of unique soil textures between the two soils being compared. As expected, comparison #3 yielded a higher correlation than comparison #1 for both IrriWatch and NRCS Web Soil Survey comparisons.

Table 2. Comparison of soil texture determined from hand-augured shallow soil samples and soil textures from IrriWatch and the Natural Resource Conservation Service's Web Soil Survey (NRCS WSS). For comparisons #1 and #2, percent matching is determined by the number of soil texture names that are an exact match divided by the total number of samples. For Comparison #3, percent matching is determined by dividing the number of common soil textures by the number of unique soil textures within the full soil texture names being compared.

Soil Texture Comparison	IrriWatch % Matching	NRCS % Matching
#1 - Full Soil Texture Name	12.2%	29.7%
#2 - Simplified Soil Texture Name	60.8%	67.6%
#3 – Common Soil Textures	52.8%	72.3%

The soil texture comparison for each of the 74 soil samples is included in Tables 3 and 4 (Section 5.1). Table 3 includes the full name comparison and Table 4 includes the simplified name comparison.

4 Discussion and Conclusions

The root-zone modeling of soil water holding capacity is heavily influenced by soil texture; therefore, an in-field verification of soil texture was needed to confirm the soil types estimated by IrriWatch. When using the common texture name and simplified comparisons (comparisons #2 and #3), field textures matched IrriWatch reported textures 52% - 61% of the time. While the percentage matching dropped to 12% when comparing full texture names, this is to be expected because soils with different textural classes can still be related depending on the percent sand, silt, and clay. For example, a loam can have 50% sand content while a sandy loam can have 55% sand content. In this case, while the texture class changed, the actual difference in percent sand content was minor.

The field companion conducted by DE was performed as part of the 2022 and 2023 Madera Verification Projects. If feasible, additional steps can be taken in 2024 and beyond to further refine these results and make robust recommendations for improving soils coverage in the Madera County GSAs. Specifically, the in-field soils analysis was limited to the first few inches of soil (~5 – 15 IN) while the soil texture reported by IrriWatch was based on the weighted average of a full soil profile (reaching up to 80 inches in depth in some areas). Soil texture can vary drastically with depth, so adding a depth component to the in-field soils analysis would make direct comparisons with IrriWatch's data more informative. Additionally, analysis of the percent sand, silt, and clay content of in-field soil samples would alleviate the issues described above when comparing soil textural classes.

5 Appendix

5.1 Soil Type Comparisons for all Parcel-Fields

Table 3. Comparison of soil types between hand-augured shallow soil samples, IrriWatch, and Natural Resource Conservation Service's Web Soil Survey (NRCS WSS). The NRCS's Guide to Texture by Feel was used to determine the soil type of the hand-augured shallow soil samples.

Parcel-Field	Soil Texture (Texture by Feel)	Soil Texture (IrriWatch)	Soil Texture (NRCS WSS)
040-171-012_2008057	Loamy Sand	Loam	Loamy Sand
040-171-002_2006850	Silt Loam	Sandy Loam	Loam
040-111-011_2002243	Sandy Loam	Sandy Loam	Sandy Loam
040-056-007_2003868	Sandy Loam	Loam	Sandy Loam
040-111-010_2004838	Sandy Loam	Sandy Loam	Sandy Loam
048-300-004_2001090	Loamy Sand	Loam	Sandy Loam
040-046-003_2005640	Loamy Sand	Sandy Loam	Sandy Loam
040-046-001_2005318	Sandy Loam	Loam	Sandy Loam
040-046-001_2009745	Loamy Sand	Loam	Sandy Loam
048-120-011_2001980	Silt Loam	Loam	Sandy Loam
048-120-011_2001980	Silt Loam	Loam	Sandy Loam
048-120-011_2002533	Sandy Loam	Loam	Sandy Loam
048-120-004_2008008	Loamy Sand	Sandy Loam	Sandy Loam
047-250-016_2004218	Sandy Loam	Loam	Sandy Loam
047-272-011_2006412	Sandy Loam	Loam	Sandy Loam
047-271-013_2009522	Sandy Loam	Sandy Clay Loam	Sandy Loam
047-271-001_2007391	Sandy Loam	Loam	Sandy Loam
041-081-001_2002043	Silty Clay Loam	Sandy Clay Loam	Silt Loam
049-620-003_2002926	Sandy Loam	Sandy Clay Loam	Sandy Loam
049-610-003_2006473	Sandy Clay Loam	Sandy Clay Loam	Sandy Loam
049-610-003_2006473	Loamy Sand	Loam	Sandy Loam
047-190-014_2001597	Sandy Clay Loam	Loam	Sandy Loam
044-011-005_2002959	Loamy Sand	Silty Clay	Sandy Loam
041-010-007_2006020	Silty Clay	Silty Clay	Silt Loam
049-600-008_2002360	Sandy Loam	Sandy Clay Loam	Sandy Loam
049-590-010_2006251	Loamy Sand	Sandy Clay Loam	Sandy Loam
041-051-003_2008317	Sandy Loam	Clay Loam	Sandy Loam
049-600-006_2004746	Sandy Clay Loam	Loam	Sandy Loam
034-226-007_2002862	Sandy Clay Loam	Loam	Sandy Loam

Parcel-Field	Soil Texture (Texture by Feel)	Soil Texture (IrriWatch)	Soil Texture (NRCS WSS)
045-171-004_2000096	Silt Loam	Loam	Sandy Loam
049-650-007_2001450	Silty Clay Loam	Loam	Sandy Loam
045-171-004_2006785	Loamy Sand	Loam	Loam
049-650-014_2003882	Loamy Sand	Loam	Sandy Loam
034-210-031_2000328	Sandy Clay	Sandy Clay Loam	Sandy Loam
049-650-016_2006452	Sandy Loam	Sandy Loam	Loamy Sand
049-650-016_2006452	Sandy Loam	Sandy Loam	Loamy Sand
043-030-030_2000132	Silty Clay Loam	Loam	Sandy Loam
035-280-007_2007191	Loamy Sand	Loam	Sandy Loam
035-254-004_2005412	Sandy Loam	Sandy Loam	Sandy Loam
035-252-003_2002717	Sand	Sandy Loam	Loamy Sand
035-252-003_2002717	Sand	Sandy Loam	Loamy Sand
035-252-003_2002717	Loamy Sand	Loam	Loamy Sand
035-252-003_2002717	Sand	Loam	Loamy Sand
035-252-003_2002717	Sand	Sandy Loam	Loamy Sand
035-252-003_2002717	Loamy Sand	Sandy Loam	Loamy Sand
045-041-008_2001004	Loamy Sand	Loam	Sandy Loam
045-041-008_2004258	Loamy Sand	Loam	Sandy Loam
043-025-002_2004498	Silt Loam	Sandy Clay Loam	Sandy Loam
023-200-001_2010124	Sandy Loam	Loam	Loam
022-010-002_2005322	Silty Clay	Loam	Loamy Sand
022-070-006_2008559	Silty Clay Loam	Loam	Loam
022-060-006_2006726	Sandy Clay Loam	Loam	Loam
022-070-005_2005765	Sandy Clay Loam	Sandy Clay Loam	Loam
022-010-002_2005654	Loamy Sand	Clay Loam	Sandy Loam
021-140-044_2009588	Sandy Clay	Loam	Sandy Loam
022-080-002_2003681	Loamy Sand	Sandy Loam	Sandy Loam
020-200-006_2003043	Silty Clay	Sandy Loam	Sandy Loam
029-110-014_2006914	Loamy Sand	Clay Loam	Sandy Loam
029-110-014_2006914	Sandy Clay Loam	Loam	Sandy Loam
020-140-012_2003593	Silty Clay	Loam	Sandy Loam
029-120-004_2002783	Sandy Loam	Loam	Sandy Loam
020-140-008_2001329	Silty Clay	Silty Loam	Clay Loam
029-080-002_2009303	Sandy Clay Loam	Loam	Sandy Loam
029-080-002_2009303	Silty Clay Loam	Sandy Clay Loam	Sandy Loam
030-302-011_2005464	Silty Clay Loam	Sandy Clay Loam	Sandy Loam
030-302-019_2005464	Loamy Sand	Sandy Loam	Loamy Sand
030-302-019_2005464	Sandy Loam	Sandy Loam	Loamy Sand
030-302-017_2003708	Sandy Loam	Loam	Sandy Loam
030-302-013_2003651	Sandy Loam	Loam	Sandy Loam
030-301-002_2001408	Sandy Clay Loam	Loam	Sandy Loam

Parcel-Field	Soil Texture (Texture by Feel)	Soil Texture (IrriWatch)	Soil Texture (NRCS WSS)
027-072-004_2009390	Sandy Loam	Loam	Sandy Loam
030-061-003_2004106	Sandy Loam	Loam	Sandy Loam
030-031-017_2006823	Sandy Loam	Loam	Loam
030-032-011_2007118	Sandy Loam	Clay Loam	Loam

Table 4. Comparison of soil types between hand-augured shallow soil samples, IrriWatch, and Natural Resource Conservation Service's Web Soil Survey (NRCS WSS). The NRCS's Guide to Texture by Feel was used to determine the soil type of the hand-augured shallow soil samples. Soil texture names have been simplified based on the dominant soil present.

Parcel-Field	Simplified Soil Texture (Texture by Feel)	Simplified Soil Texture (IrriWatch)	Simplified Soil Texture (NRCS WSS)
040-171-012_2008057	Sand	Loam	Sand
040-171-002_2006850	Loam	Loam	Loam
040-111-011_2002243	Loam	Loam	Loam
040-056-007_2003868	Loam	Loam	Loam
040-111-010_2004838	Loam	Loam	Loam
048-300-004_2001090	Sand	Loam	Loam
040-046-003_2005640	Sand	Loam	Loam
040-046-001_2005318	Loam	Loam	Loam
040-046-001_2009745	Sand	Loam	Loam
048-120-011_2001980	Loam	Loam	Loam
048-120-011_2001980	Loam	Loam	Loam
048-120-011_2002533	Loam	Loam	Loam
048-120-004_2008008	Sand	Loam	Loam
047-250-016_2004218	Loam	Loam	Loam
047-272-011_2006412	Loam	Loam	Loam
047-271-013_2009522	Loam	Loam	Loam
047-271-001_2007391	Loam	Loam	Loam
041-081-001_2002043	Loam	Loam	Loam
049-620-003_2002926	Loam	Loam	Loam
049-610-003_2006473	Loam	Loam	Loam
049-610-003_2006473	Sand	Loam	Loam
047-190-014_2001597	Loam	Loam	Loam
044-011-005_2002959	Sand	Clay	Loam
041-010-007_2006020	Clay	Clay	Loam
049-600-008_2002360	Loam	Loam	Loam
049-590-010_2006251	Sand	Loam	Loam
041-051-003_2008317	Loam	Loam	Loam
049-600-006_2004746	Loam	Loam	Loam
034-226-007_2002862	Loam	Loam	Loam
045-171-004_2000096	Loam	Loam	Loam

Parcel-Field	Simplified Soil Texture (Texture by Feel)	Simplified Soil Texture (IrriWatch)	Simplified Soil Texture (NRCS WSS)
049-650-007_2001450	Loam	Loam	Loam
045-171-004_2006785	Sand	Loam	Loam
049-650-014_2003882	Sand	Loam	Loam
034-210-031_2000328	Clay	Loam	Loam
049-650-016_2006452	Loam	Loam	Sand
049-650-016_2006452	Loam	Loam	Sand
043-030-030_2000132	Loam	Loam	Loam
035-280-007_2007191	Sand	Loam	Loam
035-254-004_2005412	Loam	Loam	Loam
035-252-003_2002717	Sand	Loam	Sand
035-252-003_2002717	Sand	Loam	Sand
035-252-003_2002717	Sand	Loam	Sand
035-252-003_2002717	Sand	Loam	Sand
035-252-003_2002717	Sand	Loam	Sand
035-252-003_2002717	Sand	Loam	Sand
045-041-008_2001004	Sand	Loam	Loam
045-041-008_2004258	Sand	Loam	Loam
043-025-002_2004498	Loam	Loam	Loam
023-200-001_2010124	Loam	Loam	Loam
022-010-002_2005322	Sand	Loam	Sand
022-070-006_2008559	Loam	Loam	Loam
022-060-006_2006726	Loam	Loam	Loam
022-070-005_2005765	Loam	Loam	Loam
022-010-002_2005654	Clay	Loam	Loam
021-140-044_2009588	Clay	Loam	Loam
022-080-002_2003681	Sand	Loam	Loam
020-200-006_2003043	Clay	Loam	Loam
029-110-014_2006914	Sand	Loam	Loam
029-110-014_2006914	Loam	Loam	Loam
020-140-012_2003593	Clay	Loam	Loam
029-120-004_2002783	Loam	Loam	Loam
020-140-008_2001329	Clay	Loam	Loam
029-080-002_2009303	Loam	Loam	Loam
029-080-002_2009303	Loam	Loam	Loam
030-302-011_2005464	Loam	Loam	Loam
030-302-019_2005464	Sand	Loam	Sand
030-302-019_2005464	Loam	Loam	Sand
030-302-017_2003708	Loam	Loam	Loam
030-302-013_2003651	Loam	Loam	Loam
030-301-002_2001408	Loam	Loam	Loam
027-072-004_2009390	Loam	Loam	Loam

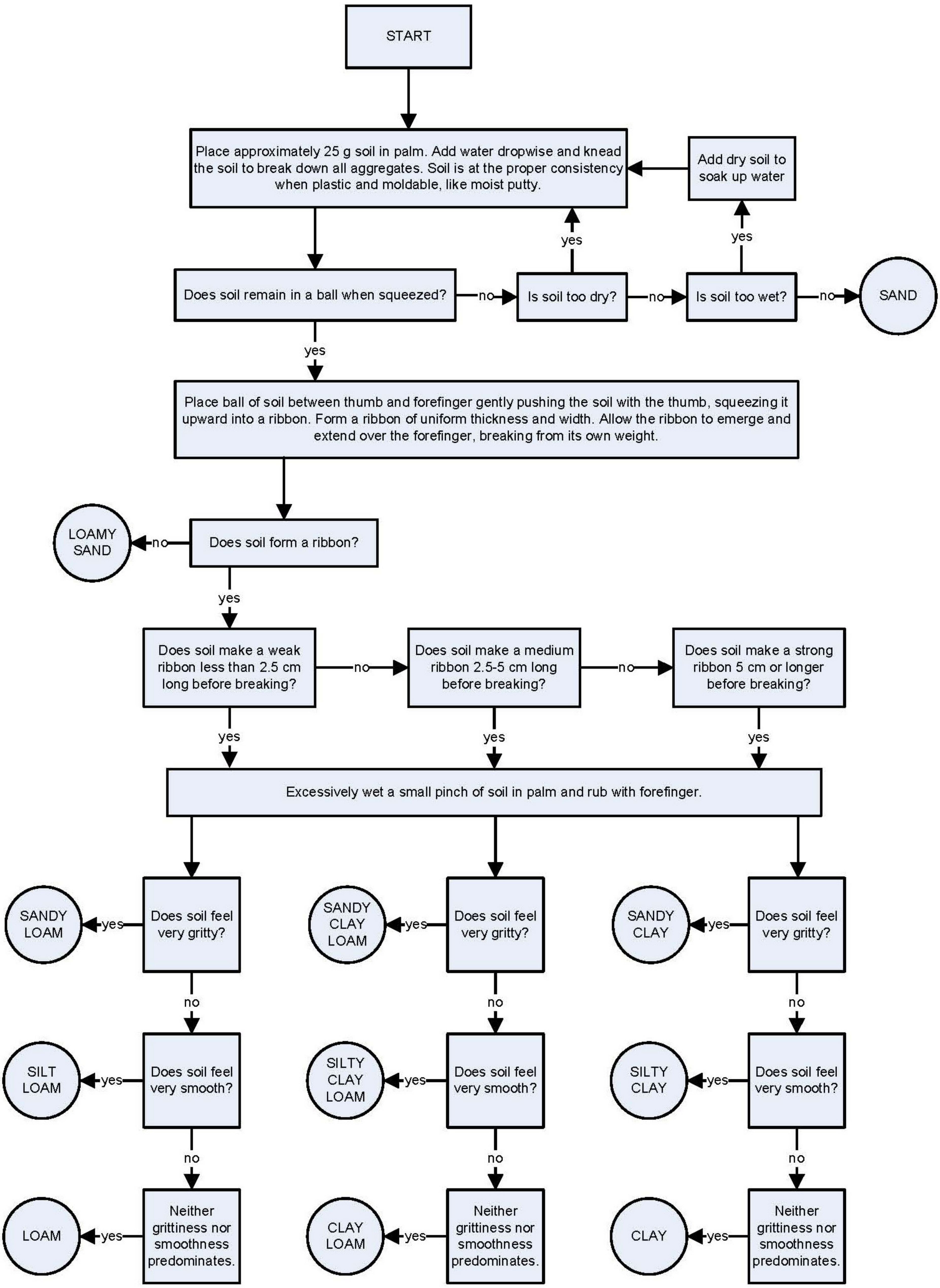
Parcel-Field	Simplified Soil Texture (Texture by Feel)	Simplified Soil Texture (IrriWatch)	Simplified Soil Texture (NRCS WSS)
030-061-003_2004106	Loam	Loam	Loam
030-031-017_2006823	Loam	Loam	Loam
030-032-011_2007118	Loam	Loam	Loam

5.2 NRCS Texture by Feel Documentation

The following documentation provides more details about the NRCS Texture by Feel method.

Guide to Texture by Feel

Modified from S.J. Thien. 1979. *A flow diagram for teaching texture by feel analysis.* Journal of Agronomic Education. 8:54-55.



Texture class is one of the first things determined when a soil is examined. It is related to weathering and parent material. The differences in horizons may be due to the differences in texture of their respective parent materials.

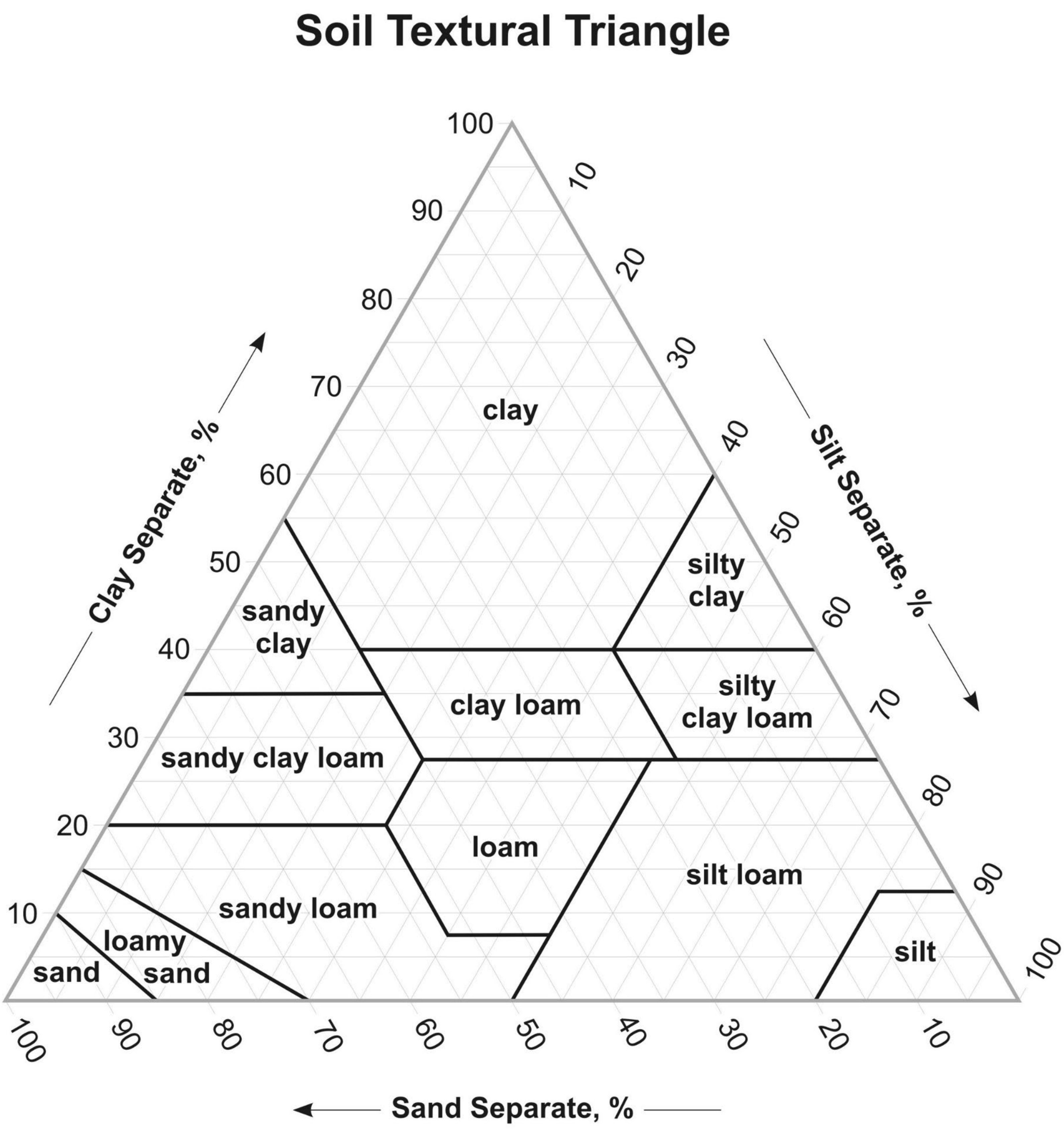
Texture class can be determined fairly well in the field by feeling the sand particles and estimating silt and clay content by flexibility and stickiness. There is no field mechanical-analysis procedure that is as accurate as the fingers of an experienced scientist, especially if standard samples are available. A person must be familiar with the composition of the local soils. This is because certain characteristics of soils can create incorrect results if the person does not take these characteristics into account.

In some environments clay aggregates form that are so strongly cemented together that they feel like fine sand or silt. In humid climates iron oxide is the cement. In desert climates silica is the cement and in arid regions lime can be the cement. It takes prolonged rubbing to show that they are clays and not silt loams.

Some soils derived from granite contain grains that resemble mica but are softer. Rubbing breaks down these grains and reveals that they are clay. These grains resist dispersion and field and laboratory determinations may disagree.

Many soil conditions and components mentions earlier cause inconsistencies between field texture estimates and standard laboratory data. These are, but not limited to, the presence of cements, large clay crystals, and mineral grains. If field and laboratory determinations are inconsistent, one or more of these conditions is suspected.

Soil Textural Triangle



DAVIDS ENGINEERING, INC

TECHNICAL MEMORANDUM

To: Stephanie Anagnoson
Director of Water and Natural Resources
Madera County

From: Davids Engineering, Inc.

Date: April 30, 2024

Subject: **Analysis and Overview of Parcel-Field Boundary Issues for 2023 Lands Included in Madera Verification Project**

1 Introduction

Comprehensive and consistently accurate coverage of geospatial data related to parcel-fields is critical for successful implementation of the groundwater allocation program. These geospatial data include parcel delineations (establishing and defining boundaries of legal ownership) and field delineations (establishing and defining land use, cropping, and the extent of irrigated areas). These two coverages are combined to from parcel-fields[1] which is the most discrete spatial scale at which information is measured and recorded for the groundwater allocation program. During the 2022 Madera Verification Project, uncertainties and errors related to parcel, field, and the subsequent parcel-field coverages were identified and recommendations were made to improve parcel boundaries, field delineations, and cropping and land use information.

In the 2022 Project, issues were identified but not quantitatively evaluated. As part of the 2023 Project, the parcel-fields managed by Verification Project Participants (VPPs) were reviewed to quantify the number and extent of boundary discrepancy issues related to these geospatial coverages. There were a total of 475 parcel-fields covering roughly 14,000 acres included in the 2023 Project through VPPs, and within this these, there were 330 parcel-field delineation issues[2] identified influencing roughly 1,400 acres (roughly 10% of total VPPs' lands). The issues were classified into three different categories: (1) exclusion of irrigated area, (2) parcel-field boundary delineation issue, and (3) parcel-field delineation issue.

The analysis methodology (including a description and example of the three classifications above) and the results and conclusions are presented and described subsequently.

2 Methods

The analysis was completed through review of parcel-fields in Google Earth Pro[3]. A coverage of parcel-fields and wells/flowmeters was developed in Google Earth during initiation of the 2023 Project to

[1] 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).
[2] It is important to note that some parcel-fields had multiple issues identified.
[3] More information available at: https://www.google.com/earth/about/

catalogue and organize information about participating lands. During this process, the parcel-fields were reviewed to identify and track any boundary issues that may be present. When an issue was identified, it was classified according to one of the three categories, the spatial extent of the issue was delineated as a new polygon in Google Earth (noting the resulting acreage), and a record of the issue was saved in a corresponding MS Excel spreadsheet used to document all issues. The sections below provide a description and example of each of the three issue categories.

2.1 Exclusion of Irrigated Area

Exclusion of irrigated area issues typically occurred at the edges of currently irrigated areas. These could be caused by either inaccurate delineation of the irrigated area in the original coverage, by expansion of the irrigated area since the time the original coverage was developed, or by exclusion of the irrigated area since it crosses another boundary (e.g., Groundwater Sustainability Agency or Subbasin boundaries). An example of an excluded irrigated area is shown below in Figure 1.

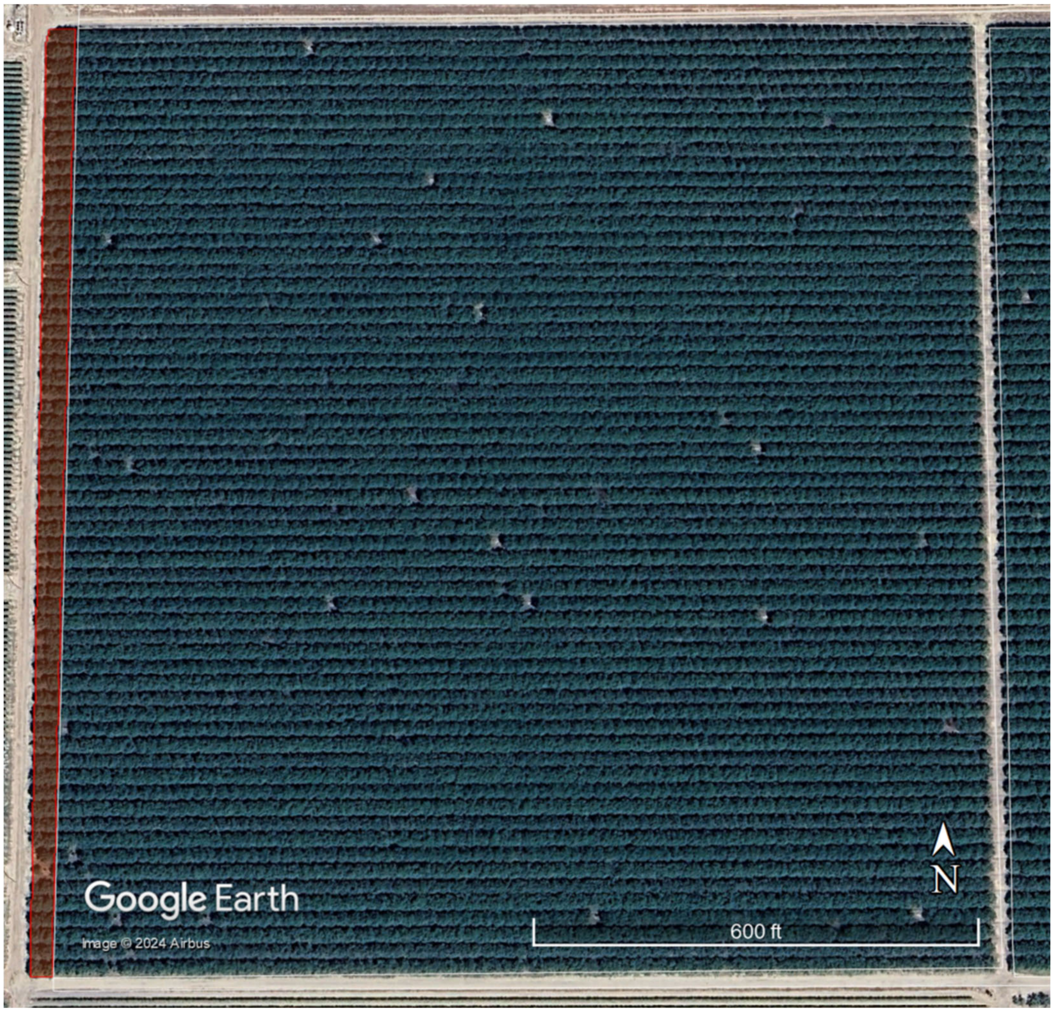


Figure 1. Example of an Excluded Irrigated Area. In this example, parcel-fields are outlined in white and relatively square orchard is shown as the central parcel-field. The area outlined and shaded in red along the western edge (roughly 1.1 acres) is part of this orchard, but was excluded from the parcel-field coverage.

2.2 Parcel-Field Boundary

Parcel-field boundary issues are caused by discrepancies between parcel boundaries and field boundaries. There is not a one-to-one relationship between parcels and fields: one irrigated field can stretch across multiple parcels, or multiple irrigated fields can exist within one parcel. However, in many instances it was noted that a small portion of an irrigated field appears in an adjacent parcel, even though that parcel appears to generally have other land and water management. In these cases, if the irrigated field is incorrectly assigned to the wrong parcel and remote sensing is used to measure ETAW, the evapotranspiration of applied water (ETAW) for the small area of the irrigated field in another parcel will be mistakenly attributed to the incorrect parcel and master account. Examples of parcel-field boundary issues are shown below in Figure 2.

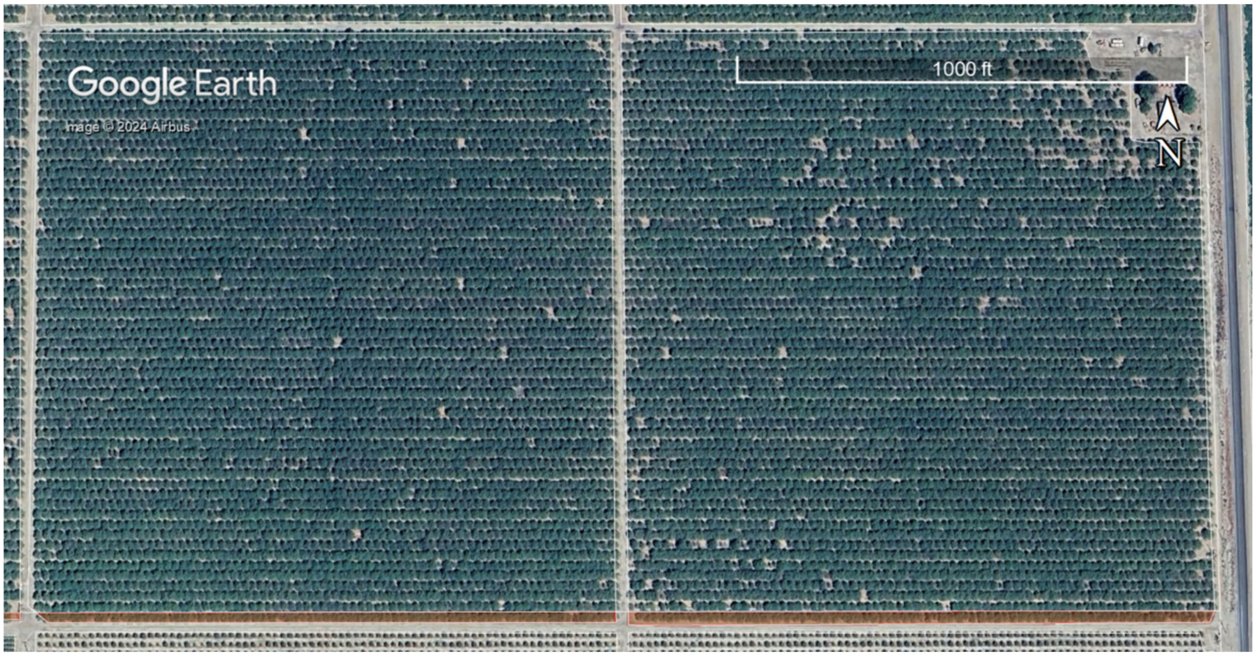


Figure 2. Example of Parcel-Field Boundary Issue. In this example, parcel-fields are outlined in white and two relatively square orchards are shown as the central parcel-fields. The areas outlined and shaded in red along the southern edge (roughly 1.5 acres in total) are part of these orchards, but are to the south of the parcel boundary (the white line separating them from the remainder of the orchard to the north). Instead they are included with the parcel to the south, which, based on the differences observable in the image, is a different crop type and/or age.

2.3 Parcel-Field Delineation

Parcel-field delineation issues are caused by changes to parcel boundaries or fields (i.e., cropping or land management practices) in the time since the last geospatial coverages of these were created. For example, the current field coverage used for creation of parcel-fields dates back to 2018, and changes irrigated areas and land use in the time since may not be accurately reflected. Based on the most recently available imagery and verified by field visits, changes to land use were identified and delineated in Google Earth as part of this analysis. They included cropped areas being taken out of production and left idle, or cropped areas being shifted to another crop type or land use. An example of a parcel-field delineation issue is shown below in Figure 3.

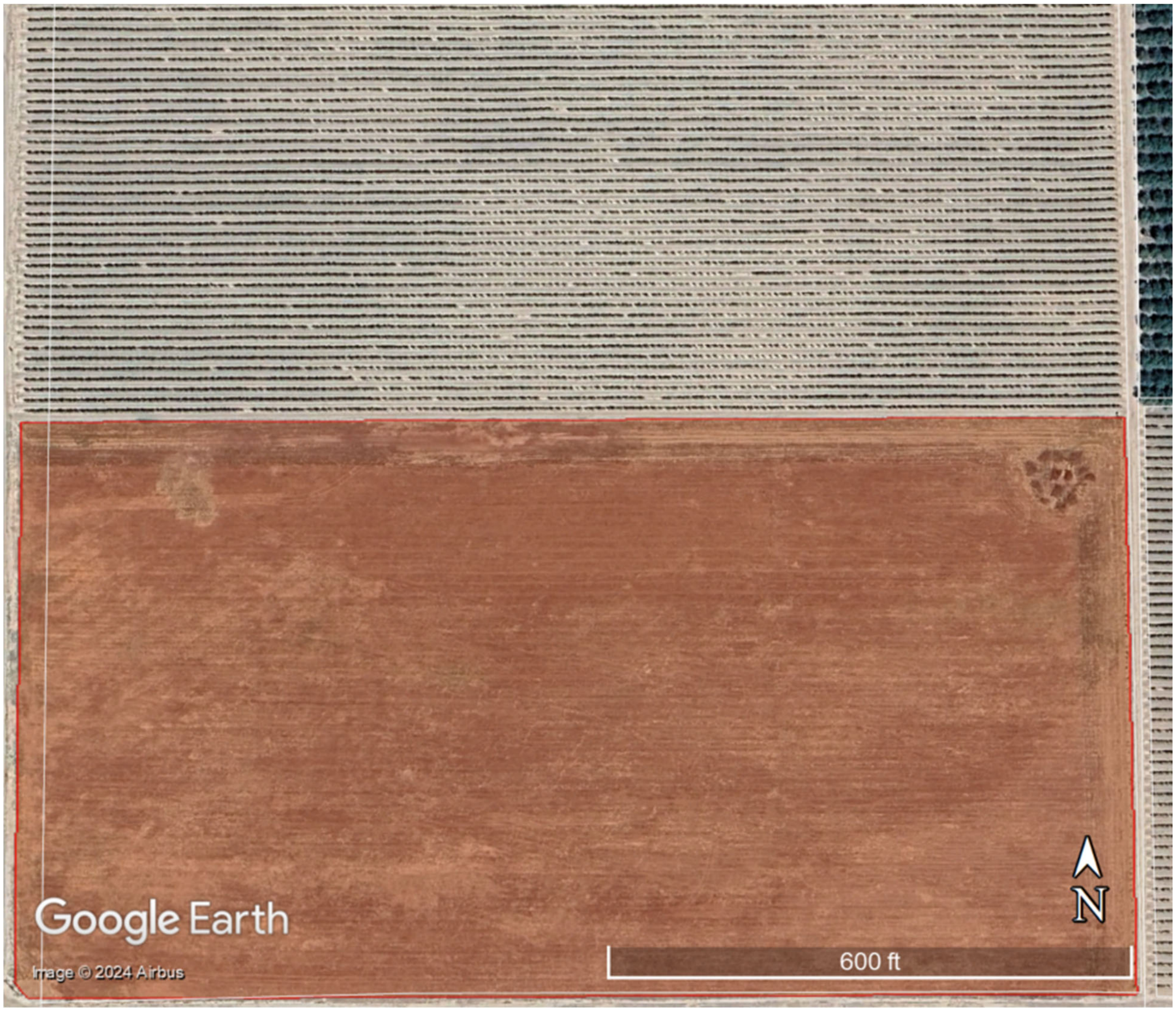


Figure 3. Example of Parcel-Field Delineation Issue. In this example, parcel-fields are outlined in white and the southern portion of a vineyard as the central parcel-field. The area outlined and shaded in red along the southern edge (roughly 19 acres) is currently idle and has not been irrigated in recent years, but is included as part of this vineyard's parcel-field (i.e., there is no east-west white line marking the boundary between the two fields). Note also that the western portion of the vineyard is an example of an excluded irrigated area.

3 Results

The results of this evaluation are summarized in Table 1 below, organized by the three categories. There were a total of 475 parcel-fields covering roughly 14,000 acres included in the 2023 Project through VPPs, and within this these, there were 330 parcel-field delineation issues[4] identified influencing roughly 1,400 acres (roughly 10% of total VPPs' lands). The instances of parcel-field boundary issues were the most common, with 208 of the 330 total issues (63%). The acreage associated with exclusion of irrigated areas was the greatest, with roughly 1,060 of the roughly 1,400 total impacted acres (roughly 76%).

[4] It is important to note that some parcel-fields had multiple issues identified.

Table 1. Summary of Parcel-Field Boundary Issue Analysis Results.

Discrepancy Type	Count	Total Acreage	Average Acreage	Median Acreage	Maximum Acreage
Irrigated Area Exclusion	108	1,059	9.8	1.9	78.7
Parcel-Field Boundary	208	252	1.2	0.7	23.9
Parcel-Field Delineation	14	90	6.4	3.6	19.3
Totals	***330***	***1,401***			

4 Discussion and Conclusions

The impacted area of these issues was roughly 1,400 acres, which is 10% of the total area of 14,000 acres included in the 2023 Project through VPPs that was reviewed as part of this analysis. If these lands are assumed to be representative of the Madera County GSAs lands overall, the impacted area will grow substantially across all Madera County GSA lands, pointing to the importance of improving these coverages.

There is also an important distinction to make between the exclusion of irrigated area and parcel-field boundary and delineation issues. The parcel-field boundary and delineation issues are related to improving the groundwater allocation program and accuracy of measuring the ETAW for each parcel-field and grower within the Madera County GSAs, but the overall measurement of ETAW for the Madera County GSAs is not impacted by any issues under these two categories. However, the exclusion of irrigated areas not only impacts the measurement and quantification of ETAW for the specific growers in these areas, but also for the Madera County GSAs as a whole. Since these excluded areas are not part of the parcel-field coverage, ETAW is not being quantified and attributed to any parcel-fields or to the overall Madera County GSAs ETAW usage. The exclusion of irrigated areas also represents the largest issue from a total acreage perspective (i.e., over 1,000 acres just within the participating lands for the 2023 Project).

This analysis was completed as part of the 2023 Madera Verification Project. During the 2023 Project, improvements to parcel-field coverages were initiated (through improved parcel delineations available from the Madera County Assessor’s office and through improved geospatial coverage of irrigated lands and crop type available for 2023 from Land IQ). These improvements will be implemented in 2024 for the groundwater allocation program and are anticipated to address most of the issues identified above. However, a similar review of the new parcel, field, and resulting parcel-field coverage would be beneficial to understand any potential issues that may still exist and if further refinements and improvements are warranted.

MEMO ETPR 2023 VALUES

Rainfall during Spring 2023 was above average. The automatic weather station (AWS) observations that the NOAA network rely on indicated a range of rainfall between 7.4 to 14.1 inch (average 11 .1 inch) across Madera County. The portion of rainfall that contributes to total evapotranspiration (ET) is referred to as effective precipitation or the ET from precipitation (ETPR). Total ET is computed from recurrent satellite measurements and an energy balance equation that partitions available energy (mainly from sun) into vaporization of water vs. heating of air. Recent field measurements of ET fluxes by the University of California - Davis in a pistachio orchard in Madera County confirmed total ET values from IrriWatch to be accurate for the 2023 growing season.

The Madera County GSAs' allocations are based on the evapotranspiration of applied water (ETAW) because this is the portion of ET that growers have control over. However, computing ETAW requires an estimation of ETPR because ETAW equals total ET minus ETPR. Unfortunately, estimating ETPR is challenging, and any error in ETPR will be propagated into error in ETAW. All else being equal, errors are larger when rainfall is high.

Within IrriWatch, ETPR is computed from a custom implementation of the IDC model using a certain IDC-related partitioning between ETAW and ETPR. The IDC model was selected as the basis for daily ETPR computations at the onset of the IrriWatch project in late 2020. Due to above-average rainfall in 2023, the IDC model started to produce high ETPR values in 2023. IrriWatch developers had for this reason built in a safety factor such that ETPR at the regional scale should at all cases be less than 80% of the sum of precipitation in 2023 plus initial rootzone soil moisture storage on 1 January 2023. The latter reflects all water carried over in storage from 2022. Parcel-fields with unique identity in 2023 thus received part of the rainfall from Fall 2022 that was not evaporated in 2022.

On 5 July, the regional 80% limit was reached and ETPR got frozen. As a result, all total ET occurring after July 5th was added to the cumulative ETAW value. This resulted in a faster rise of the ETAW graph with an unavoidable inflection point in the ETAW curve (see Figure below).

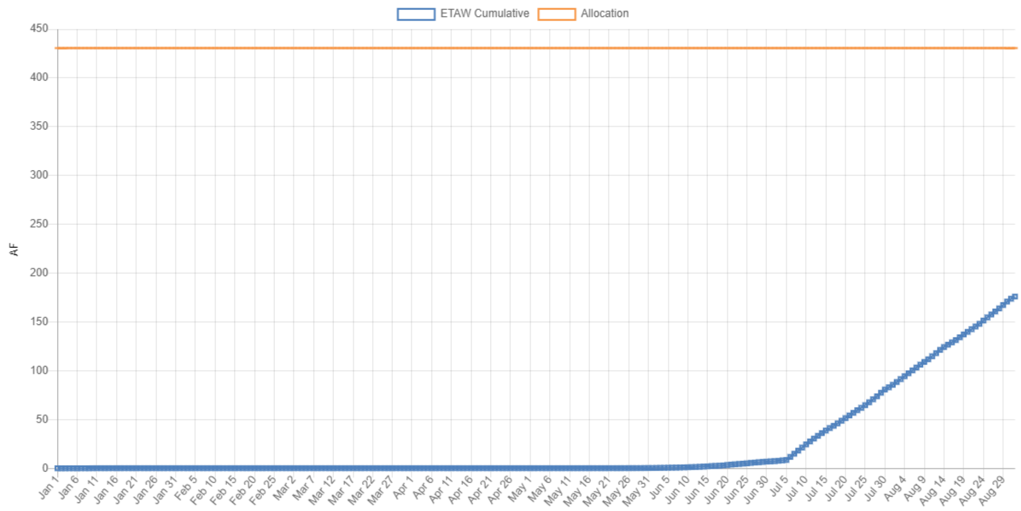


Figure: Inflection point in ETAW on 5 July due to the global 80% limit on ETPR being reached.

Conclusion

Due to the relatively large rainfall in 2023, ETPR values tended to become overestimated by IDC model. ETPR values rely strongly on the spatial distribution of rainfall and depths of effective roots, which complicates their estimates. For practical reasons IrriWatch decided to introduce a regional cap of effective rainfall of 80%. From 5 July onwards, ETPR did not longer increase and hence all ET is designated to ETAW. The result is a steeper graph of ETAW.

Appendix: Why 80% Effective Precipitation is a reasonable value?

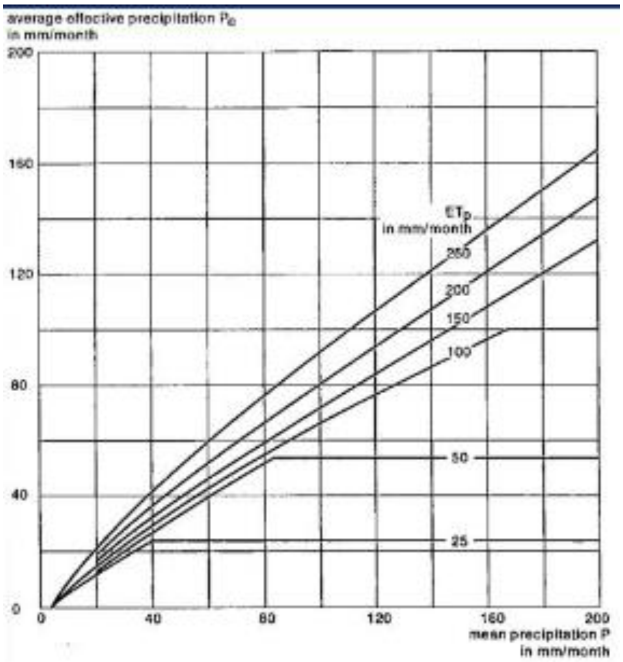
Several methods exist to compute effective precipitation and they reflect the condition that not all gross precipitation infiltrates into the soil. Part of the gross precipitation is intercepted by crop leaves or runs off due to limited soil infiltration capabilities. Net precipitation is the amount that infiltrates into the soil. Effective precipitation is that part of the total precipitation that replaces, or potentially reduces, a corresponding net quantity of required irrigation water. This definition of effective precipitation is the formal terminology introduced by the International Commission on Irrigation and Drainage ICID (Bos and Nugteren 1974; Bos, 1980). It is also in line with the ETPR concept commonly known and accepted in California.

Effective rainfall is a critical indicator for characterizing green water consumption. The majority of the water footprint analyses employ empirical or numerical models to predict effective rainfall, and the number of studies for experimental validation of these models are quite insufficient. Muratoglue et al. (2023) tested the performance of commonly used effective rainfall estimation methods.

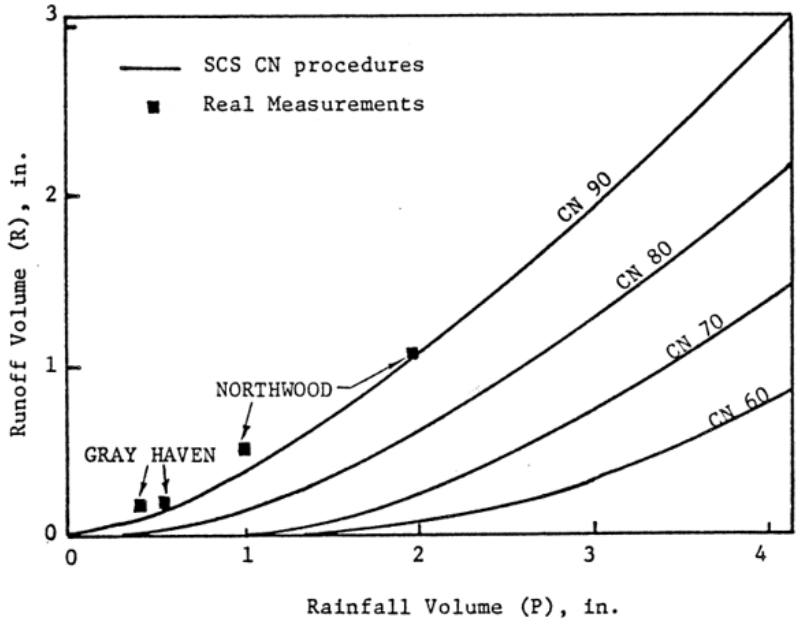
Soil moisture infiltrated into the soil is not necessarily available for root water uptake by crop. Typical examples are the presence of a shallow root depth that has insufficient capacity to retain larger amounts of infiltrated water. Soil moisture above field capacity cannot retain water, and the percolation recharges the aquifer or flows to nearby drainage systems.

Different semi-empirical methods exist to calculate effective precipitation. It is also not uncommon that the user sets the effective precipitation as a fixed percentage of total precipitation. Below are some typical references commonly accepted in the international literature.

The U.S. Department of Agriculture USDA (1970) published a method that can be used if monthly precipitation data is available. Analytical equations are available that reproduces the following graph.



Another method is based on the Curve Number CN Method as developed by the U.S. Soil Conservation Service (1964 and 1972). The Curve Number method estimates surface runoff, see below.



Another method is suggested by the US Bureau of Reclamation USBR. The USBR has published a look up table method that directly relates monthly rainfall to effectiveness of precipitation (Stamm, 1967). Percentage marks are given to increments of monthly rainfall ranging from greater than 90 percent for the first 25 mm (1 in) or fraction thereof, to 0 percent for precipitation increments above some 150 mm (6 in), as is shown in Table 5 taken from a FAO report.

Table 5: EFFECTIVE PRECIPITATION BASED ON INCREMENTS OF MONTHLY RAINFALL (U.S. BUREAU OF RECLAMATION METHOD)

Precipitation increment range		Percent	Effective precipitation accumulated - range	
mm	in		mm	in
0.0 - 25.4	0 - 1	90-100	22.9 - 25.4	0.90 - 1.00
25.4 - 50.8	1 - 2	85 - 95	44.4 - 49.5	1.75 - 1.95
50.8 - 76.2	2-3	75 - 90	63.5 - 72.4	2.50 - 2.85
76.2 - 101.6	3-4	50-80	76.2 - 92.7	3.00 - 3.65
101.6 - 127.0	4-5	30-60	83.8 - 107.9	3.30 - 4.25
127.0 - 152.4	5-6	10 - 40	86.4 - 118.1	3.40 - 4.65
Over 152.4	Over 6	0-10	86.4 - 120.6	3.40 - 4.75

In Canada, the FarmWest method is commonly used. During extended warm dry periods rainfall less than 5 mm may not add any moisture to the soil reservoir as most of it is evaporated before entering the soil. Therefore, if rainfall is less than 5mm the FarmWest calculator does not enter a value for effective precipitation. In addition, a fixed 75% of the rainfall over 5mm is considered to be effective precipitation. The equation used in the FarmWest calculator is:

Effective Precipitation (mm) = (RAIN – 5) x 0.75

The Food and Agricultural Organization (FAO) provides a synthesis of different methods to compute effective precipitation analytically. One of the equations is the Renfro method that triangulates ET to P and AW. For semi-arid and arid environments where ET/P is 3.0, effective precipitation is 80%. Hence Renfro includes the climatology for estimating effective precipitation.

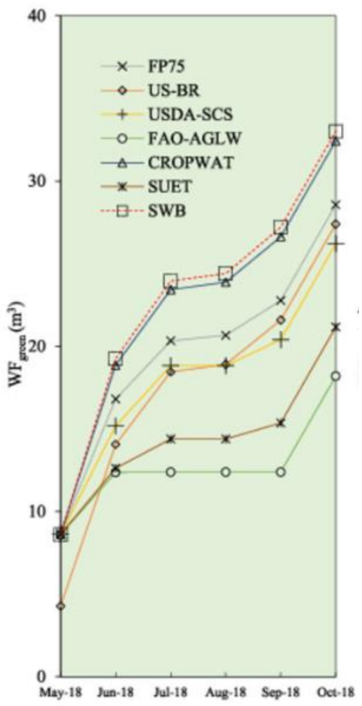
The FAO program in India works with a simplified 10-day interval assessment procedure that is based on P and potential ET. Their monthly values vary from 60 to 100% with an average value of 80%. For 10 day periods with less than 60 mm, the effectiveness is 100%.

Period	Potential evapotranspiration (mm)	Rainfall (mm)	Percentage ratio	Mean ratio for the month(%)
July 1-10	60	80	75	
11-20	80	0	0	87
21 - 31	65	60	100	
Aug. 1 - 10	60	150	40	
11-20	65	100	65	60
21 - 31	60	80	75	
Sept. 1 - 10	60	60	100	
11 - 20	70	40	100	100
21 - 30	80	20	100	
Oct. 1 - 10	80	0	0	
11 - 20	85	0	0	75
21 - 31	60	80	75	
Total	825	670	-	322
Mean	...	...	...	80%

In Thailand, (Kung, 1971) apply an effective precipitation of 80% in November and 90% during the period December to March. In Japan a standard value of 80% is practiced. Vietnam is taking 75% for the wet season, 80% for the dry season and 90% for the dry and cool season.

Ali and Mubarak (2017) recently reviewed most of the FAO proposed methods and drew the following conclusions: "*It is evident that the calculation methods have certain limitations, and also have merits and demerits. Performance of different methods was evaluated for effective rainfall of rice. New formulations pertinent to different practical / field situations are suggested, which will be useful for calculation effective rainfall under different field and climatic condition*".

Moratuglo et al. (2023) conducted a research in Turkey on the performance, accuracy, and reliability of commonly used effective rainfall models (FP, US-BR, USDA-SCS, FAO/AGLW, CROPWAT, SuET, and SWB). The authors showed very large differences between green water consumption which can be directly related to variations in effective precipitation, see graph below.



Conclusion on 80%

The overall conclusion is that effective rainfall lays typically in the range between 60 to 90%. Rather different methodologies exist from extreme simple to complex models. In all cases, the success of a certain method depends on climatological input data. Access to local accurate rainfall data is a pre-requisite for successful estimation of the effective percentage.

Considering this uncertainty of ETPR, IrriWatch uses an upper bound of effective rainfall with a higher acceptance level by growers than a lower bound. Therefore a regional scale average of 80% has been selected for the 2023 growing season.

The IDC model performance will be evaluated at the end of the year, and eventually adjustments to the model will be made for future applications. It is not recommended to modify an operational model during the growing season as it creates unnecessarily confusion. The cap of 80% is merely meant as a safety factor and worked well for this wet year.

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