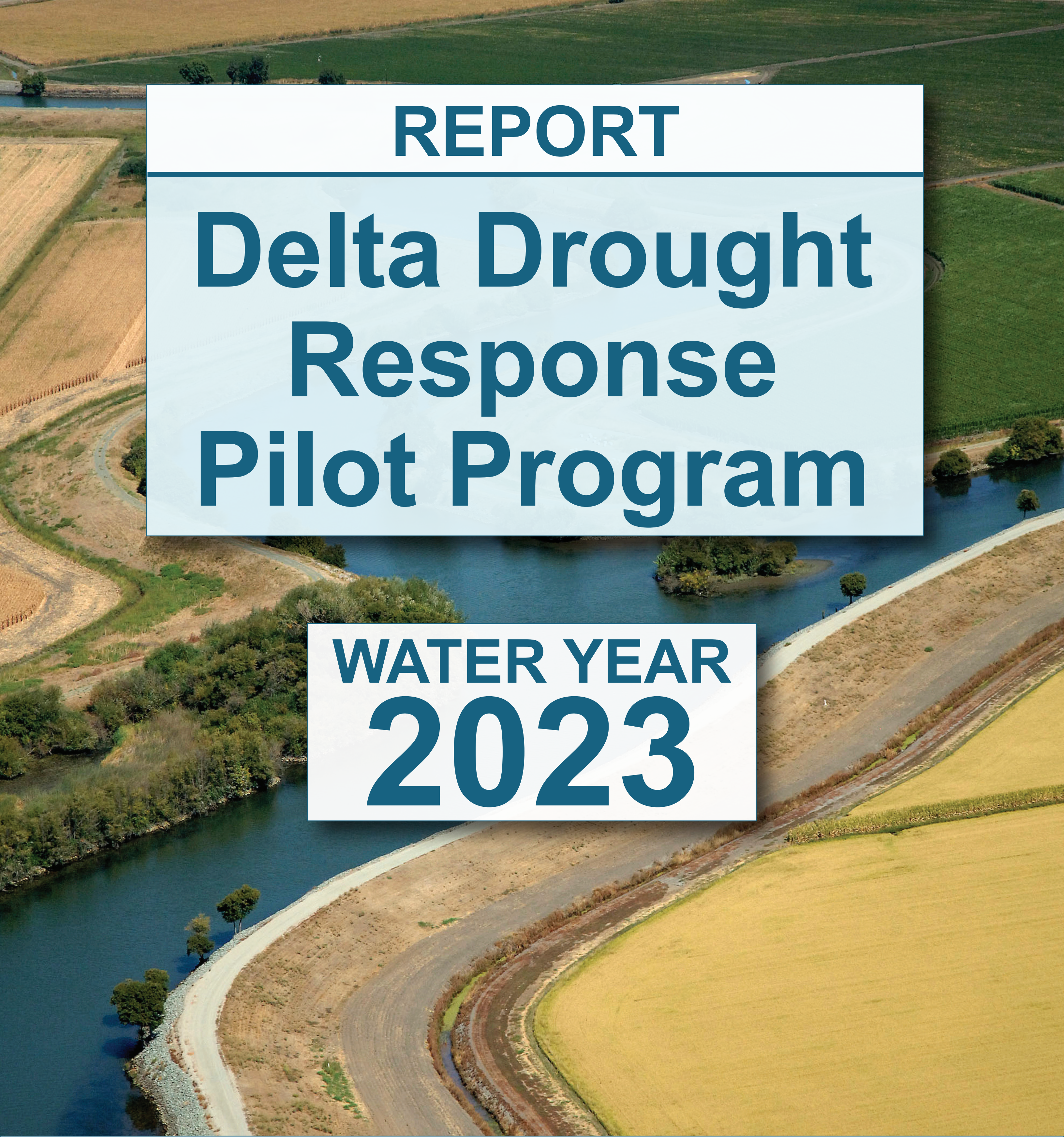
REPORT

Delta Drought Response Pilot Program

WATER YEAR 2023



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DELTA CONSERVANCY
A California State Agency

DEPARTMENT OF WATER RESOURCES
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The Nature Conservancy

Report on the Delta Drought Response Pilot Program for Water Year 2023

July 24, 2024

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Thank you to the members of the 2023 DDRPP Oversight Committee, Selection Committee, and Planning Committee. Members of the 2023 DDRPP committees (in alphabetical order) were Mandana Azar (DWR), Julia Barfield (TNC), Jeanne Brantigan (TNC), Andy Chu (DWR), Lisa Crowley (ODWM), Bradley Franklin (TNC), Seth Gack (DWR), Michael George (ODWM), Greg Golet (TNC), Jason Harbaugh (DWR), Daniyal Hassan (DWR), Campbell Ingram (Delta Conservancy), Lindsay Kammeier (State Water Resources Control Board, SWRCB), Rodd Kelsey (TNC), Sierra Kennison (SWRCB), Rachel Lane (Delta Conservancy), Michelle Leinfelder-Miles (UC Cooperative Extension), Erik Loboschefsky (DWR), Idy Lui (DWR), Josue Medellin-Azuara (UC Merced), Hope Miller (Delta Conservancy), J. Andres Morande (UC Merced), Pablo Ortiz (SWRCB), Martha Ozonoff (Delta Conservancy), Jeff A. Smith (DWR), Kosana Suvočarev (UC Davis), Rae Vander Werf (California Department of Food and Agriculture), Lauren Wacker (DWR), and Rachel D. Wigginton (Delta Conservancy).

Rachel Lane led the writing of this report, coordination with grantees, management of grant agreements, and co-chaired the Oversight Committee. Lindsay Kammeier and Lisa Crowley led the GIS analysis and co-chaired the Oversight and Selection Committees. Rachel D. Wigginton led the writing of the technical appendix, the statistical analysis/data visualization, and co-chaired the Oversight and Selection Committees.

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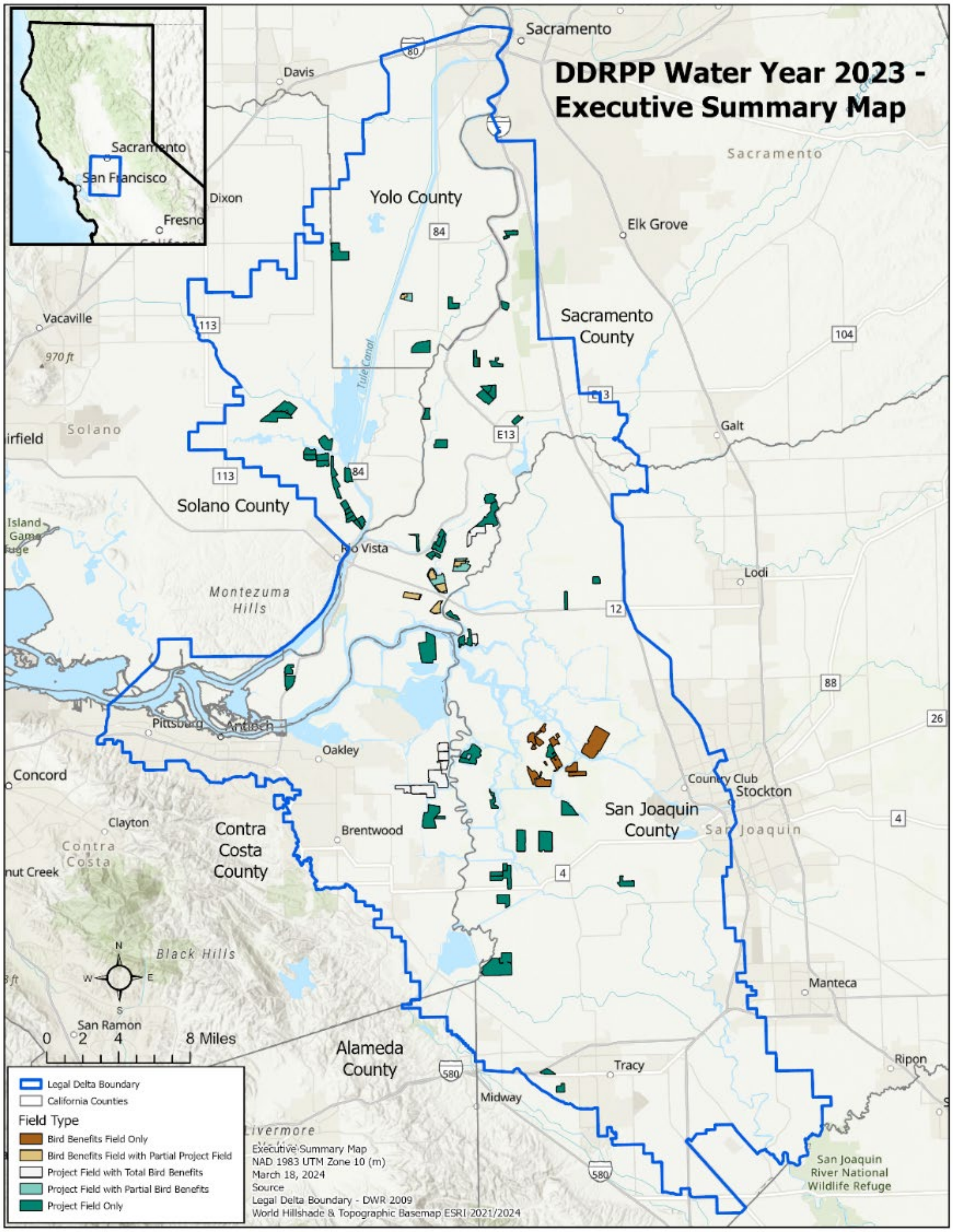

Figure 1. Map of 2023 DDRPP projects.

Executive Summary

Background

This report describes the 2023 Delta Drought Response Pilot Program (DDRPP/Program), provides an analysis of the Program's effectiveness, and describes the Program outcomes, including findings and recommendations for application in future agricultural water conservation programs. The DDRPP launched in January 2022 as a response to the continuing risk of drought in the Sacramento-San Joaquin Delta Watershed. This report focuses on the results of the 2023 Program, with a brief analysis comparing both years of the Program. For detailed information on the 2022 Program and 2022 analysis, see the 2022 DDRPP Final Report (Sacramento-San Joaquin Delta Conservancy, 2023).

The Program was developed and overseen through a partnership with the California Department of Water Resources (DWR), the Sacramento-San Joaquin Delta Conservancy (Delta Conservancy), the Office of the Delta Watermaster (ODWM), The Nature Conservancy (TNC), the California Department of Food and Agriculture (CDFA), the University of California (UC), Merced and Davis, the UC Cooperative Extension, and conducted in coordination with Delta water users.

Objectives

The objectives of the 2023 DDRPP were to:

- Evaluate if changing specific field management practices could result in water savings during water year 2023,
- Protect Delta water quality by providing additional incremental instream flow benefits to reduce salinity effects on water quality,
- Mitigate potential drought impacts on fish and migratory birds,
- Promote soil health.

To achieve these objectives, the Delta Conservancy established a grant program to incentivize growers to carry out water conservation and beneficial bird habitat practices in the legal Delta during the 2023 water year. The overall goal of this approach was to enhance important habitat and provide flow benefits while reducing consumptive use. With $10.8 million dollars provided by DWR, the Delta Conservancy solicited bids from growers through a reverse auction process (Appendix E: Solicitation of Applicants). The competitive aspect of the auction, combined with the variety of costs across different farmers and locations, brought the cost per acre enrolled down substantially when compared to the fixed price process used for DDRPP 2022 (Appendix G: Optimization and Reverse Auction). All fields enrolled in beneficial bird habitat practices were predicted to have overall water savings. A total of 61 projects, encompassing 18,450 acres, were enrolled in the 2023 Program (Appendix F: 2023 Grant Summaries). Enrolled fields were assigned to a variety of water conservation practices and beneficial bird habitat practices.

Water Conservation Practices:

- **Shift Crop Type** – shifted from a more water-intensive crop, such as corn, tomatoes, or alfalfa, to a crop that was thought to use less water, such as safflower or small grains
- **Deficit Irrigation** – did not apply a portion of the business-as-usual irrigation amount
- **Forgo Cash Crop** – did not grow a crop on the project site during the months of June, July, August, and September 2023
- **Other** was split into two categories for analysis
    - **Other Perennial** – included a deficit-irrigated mature vineyard and a young almond orchard
    - **Other Annual** – included drip-irrigated peppers and tomatoes

Beneficial Bird Habitat Practices:

- **Spring Flood-up** – shallowly flooded the field for at least four weeks during spring 2023 with an average depth of 4 inches
- **Nesting** – delayed harvest to protect nesting cover by leaving non-irrigated small grains and cover crops on the field until at least July 1, 2023
- **Fall Flood-up** – shallowly flooded the field for at least four weeks during fall 2023 with an average depth of 4 inches

Methods

The DDRPP Oversight Committee used OpenET, a non-invasive satellite-based method, to evaluate consumptive water use and estimate water savings. Appendix A: Technical Appendix provides a detailed description of this analysis. Members of the Oversight Committee worked with grantees to map project and comparison fields, then queried OpenET to retrieve estimates of actual evapotranspiration values (ETa), reference ET values (ETo), and precipitation values. Evapotranspiration (ET) is a measure of water transferred from the land surface to the atmosphere. Additional data about field conditions were collected through surveys sent to grantees and a DWR Light Detection and Ranging (LiDAR) dataset of land surface elevation.

Three response variables were assessed:

- **Consumptive Use** – measured as ETa
- **Comparative Savings Estimate** – water savings calculated using a comparison field carrying out the business as-usual practices as a baseline

- **Normalized Savings Estimate** – water savings calculated using the averaged condition of the project field from 2017-2021 as a baseline and using reference evapotranspiration fraction (EToF) to account for weather/climate differences among years

Outcomes

Objective A: Water Savings and Consumptive Use

Reducing consumptive water use on fields enrolled in the 2023 DDRPP was challenging, and overall estimated water savings were lower than anticipated (see Appendix A: Technical Appendix). Reducing applied irrigation amounts through deficit irrigation of crops, changing crop type, and even fallowing or idling cropland may not be sufficient to produce substantial water savings on farm fields within the legal Delta, especially on low elevations fields. Though growers in the Delta were willing to undertake water conservation practices, and all growers decreased applied water, there was wide variation in the estimated reduction in consumptive use among fields. Appendix B: Case Studies describes the variable field conditions on three fields enrolled in the 2023 Program and speculates about the connections between field conditions and ET estimates.

Estimated water savings were notably different based on the calculation method used. Due to wet conditions in water year 2023, it is likely that comparing project fields to comparison fields in the same year (comparative savings estimate) better included relative changes in consumptive water use. However, the comparative savings estimate was highly influenced by the selection of the comparison field, which was challenging. Because the normalized savings estimate compared the very wet year of 2023 to a range of previous years, most of which were not as wet, this method may be underestimating water savings. Additionally, consumptive use and water savings estimates did not significantly differ among water conservation practice types, implying this method of categorizing fields was not useful in explaining variations in water use/savings among fields.

The average annual consumptive use of water for fields enrolled in the 2023 Program was 2.7 acre-feet/acre (ac-ft/ac). However, there was wide variation in consumptive use for fields enrolled in the 2023 Program. Average annual consumptive use for fields enrolled in the 2023 Program ranged from 1.4 to 4 ac-ft/ac. There was an average annual water savings—as estimated by the comparative savings estimate method—of 0.2 ac-ft/ac, or 1,890 ac-ft total for all fields enrolled. When estimated using the normalized savings estimate method, there was no water saved on average. To put these results in context, consumptive use for several crops commonly grown in the Delta was estimated at 2.9 ac-ft/ac for corn, and 3.5 ac-ft/ac for pasture in 2015 (a critically dry year) (Medellín-Azuara, et al., 2018). Compared to these 2015 estimates, consumptive use was reduced by 7-20% on average for fields enrolled in the 2023 DDRPP.

Impacts of Elevation

Although estimated water savings were low, these results are likely specific to the Delta region, and it is expected that water conservation practices carried out in other regions—especially those at higher elevations—could lead to water savings. Results from both years of the Program support the finding that elevation is an important factor determining potential water savings. Carrying out water conservation practices at lower elevations resulted in water savings less consistently. For fields below sea level, rain and irrigation water used by crops is likely supplemented by shallow groundwater and surface water filtering under levees (seepage), which leads to crop growth and high ET, even without applied irrigation. While nearly 30% of the legal Delta is below sea level (California Department of Water Resources, elevation/SacDelta_Lidar_201712, 2017), remaining areas at higher elevations have potential for application of water savings practices.

During water year 2023, fields above sea level saved a larger proportion of water than fields below sea level. 76% of total water savings—when calculated using the comparative savings estimate method—came from fields above sea level, even though only 20% of the total acres analyzed were above sea level. Therefore, fields at higher elevations likely have the potential to save more water, and thus to provide more cost-effective and efficient water savings compared to fields below sea level.

However, elevation only partially explained the patterns of water savings/use among Program fields, and several fields below sea level showed water savings. Variation in water saved/used on fields may also have been driven by vegetation management, crop type, soil type, and local flooding. More study is needed to fully understand how specific field characteristics impact patterns of water savings/use in the Delta.

Projects Enrolled in Both the 2022 and 2023 DDRPP

The Program benefits from analysis of projects enrolled in both water year 2022, which was an extremely dry year, with fields also enrolled in water year 2023, which was a wet year. When comparing fields enrolled in both years of the Program, average consumptive use across the two years was similar, but slightly higher in water year 2023 than in water year 2022. This was likely driven by higher precipitation and cooler temperatures in water year 2023 and subsequently higher, sustained soil moisture available for plant growth, even in the absence of applied irrigation. However, the sample size of fields enrolled in both years of the Program was very small. An ongoing partnership with UC Davis will supplement the findings from this report by taking field-level measurements of evapotranspiration and other measurements of six

DDRPP fields continuing to perform water conservation practices through September 2026 (Appendix D: UC Davis Study Update).

Objective B: Water Quality Impacts

Even the maximum estimated DDRPP savings of up to 1,890 ac-ft is a small fraction of estimated in-Delta water use—which includes all agricultural water use in the legal Delta, plus riparian use and channel evaporation. In-Delta water use was estimated at 1.8 million acre-feet (ac-ft) in 2021 (Gartrell, Mount, & Hanak, 2022). The effects of marginal increases in localized flows that would have remained in Delta channels are difficult to calculate, and the relatively small amounts of conserved water would likely be overwhelmed by predictable tidal conditions in the Delta. Consequently, the estimated volume of water saved by the 2023 DDRPP is not expected to significantly impact water quality. Understanding how interactions among in-channel flows, seepage, applied water, shallow groundwater, and consumptive water use may impact water quality is an important avenue for future study.

Objective C: Beneficial Bird Habitat

Beneficial bird habitat practices implemented during the 2023 water year provided valuable bird habitat enhancement (Appendix C: Beneficial Bird Habitat Practices Monitoring) but were challenging to integrate into the Program and analysis of the 2023 DDRPP. Available wetland habitat is severely limited in drought years. Wetland creation in drier years can provide an important buffer for significantly reduced wetland habitat conditions in the Pacific Flyway. Due to the relative availability of water in the Delta, it is a practical place to supplement bird habitat—even in drier years.

One of the best indicators of habitat performance is bird abundance. Bird abundance observed on the Spring Flood-up fields was consistent with observations at other habitat locations in the Delta. Notably, high levels of precipitation and flooding in water year 2023 led to substantial wetland conditions across the Delta, in contrast to water year 2022 when wetland habitat was severely reduced from normal levels. Bird abundances observed on the Nesting fields were relatively low. In most months during the practice implementation time frame (January-April), fields carrying out Spring Flood-up practices showed little difference in consumptive use compared to Program fields that did not carry out Spring Flood-up.

Objective D: Promoting Soil Health

In addition to the requirements of the water conservation and/or beneficial bird habitat practices, the Program required grantees to protect the soil health of project fields. Grantees were permitted to exercise their independent farming judgement to protect soil health. The Program guidelines laid out in each grant agreement encouraged field management practices such as minimizing or delaying tillage, maintaining crop stubble on fields, and controlling weeds primarily through spraying or mowing.

Implications for Future Programs

Future water conservation programs and regulations will need to balance actions that produce the most water savings with consideration for climate and biodiversity objectives. For example, beneficial bird habitat practices were challenging to incorporate into the analysis of water savings, but these practices resulted in substantial numbers of birds observed on fields.

Growers in the Delta begin making major crop planning decisions in the fall when precipitation levels for the upcoming water year are still unknown. Future water conservation programs should work closely with growers to build flexibility into funding programs and water conservation practice guidelines to allow for postponement or rapid deployment of practices, depending on water year conditions.

Open-source remote sensing satellite estimates of evapotranspiration—like those from OpenET—make it possible to cost-effectively measure water use, index overall water use, and study the factors that drive evapotranspiration changes. As additional studies use these remote sensing methods, findings from regional programs like the DDRPP along with studies evaluating larger geographic areas can begin to identify the specific regions, field characteristics, crops, and field management practices likely to produce the most cost-effective and efficient agricultural water savings during future droughts, both in the Delta and further upstream.

To better understand sources of variation in relation to potential reductions in consumptive use future studies could:

- Require more specific management actions to limit variability among samples.
- Select fields to specifically address how different field characteristics, such as soil type, elevation, and vegetation density/height, impact potential water savings.
    - For example, selecting fields with a more even distribution across the elevation gradient in the Delta watershed could better assess the impacts of elevation on water savings within the legal Delta.
- Directly measure applied water and seepage across a range of elevations

Background

This report describes the development of the 2023 DDRPP, the process of selecting fields to enroll in the Program, a summary of the analysis performed to assess Program outcomes, conclusions, and recommendations for the future.

Delta Watershed

The Delta watershed is dominated by the Sacramento River and its tributaries flowing south from the northern Central Valley and the San Joaquin River and its tributaries flowing north from the southern portion of the Valley. Much of the natural flow in those rivers and streams is diverted for use in the watershed or exported for use outside the watershed. The remaining, variable flows of the two main rivers and a few much smaller rivers converge in the legal Delta. The legal Delta, defined in Water Code section 12200 (California Water Code, 1959), covers about 750,000 acres (Figure 1). This inverted river delta is the inland portion of the San Francisco estuary, which is subject to highly variable inflow from the rivers along with extremely strong and predictable tidal ebbs and flows from the Pacific Ocean, which define salinity conditions at any point in time.

2022 Program

In 2022, the DDRPP was launched in response to persistent drought conditions, substantially reduced inflow conditions, and consequently constrained water deliveries to project contractors (Sacramento-San Joaquin Delta Conservancy, 2023). The Program was developed and overseen through a partnership with the California Department of Water Resources (DWR), the Sacramento-San Joaquin Delta Conservancy (Delta Conservancy), the Office of the Delta Watermaster (ODWM), the California Department of Food and Agriculture (CDFA), the University of California (UC), Merced and Davis, the UC Cooperative Extension, and conducted in coordination with Delta water users. Farmers received financial incentives to perform water conservation practices on their fields, and water savings were estimated using OpenET's remote sensing approach and several different calculation methods (OpenET, 2024). In the first year of the Program, DWR allocated $8 million for grants to enroll more than 8,700 acres during the extremely dry 2022 water year.

In water year 2022, water savings estimates varied substantially among and within water conservation practices and among methods of calculating estimated savings. Sites at higher elevations appeared to consistently demonstrate some estimated water savings. Deficit irrigating crops and managing idle lands were the water conservation practices with the highest estimated potential for saving water, although there was substantial overlap among estimated savings across all practice types in water year 2022. The collaborative Program helped advance important informational studies, engage stakeholders, and improve mutual understanding of agricultural practices and water conservation opportunities in the legal Delta.

Initiation and Development of the 2023 Program

Though overall 2022 Program savings were modest (Sacramento-San Joaquin Delta Conservancy, 2023), drought conditions continued through October 2022 and into the new water year. With funding allocated in the Budget Act of 2022, the 2023 Program launched with an additional $10.8 million in grant funding to enroll over 18,000 acres. TNC was added to the collaboration to support the addition of practices designed to enhance bird habitat. Over 5,000 acres were enrolled in optional beneficial bird habitat practices for additional incentive payments during the 2023 Program. Wetland habitat conditions contract substantially across the Pacific Flyway during drought years. The creation of “surrogate wetland” habitat on farmland areas in the Delta represents an important habitat enhancement opportunity due to the comparative availability of water in the Delta, even in dry years (Golet G. H., Dybala, Reiter, Sesser, & Kelsey, 2022).

Starting in summer 2022, the 2023 DDRPP Planning Committee met to discuss the 2023 Program. The committee consisted of staff from DWR, the Delta Conservancy, the ODWM, and TNC. The purpose of the committee was to decide how 2023 grantees would be evaluated and selected, set a timeline for project initiation, and develop a methodology to incorporate beneficial bird habitat practices into the 2023 Program. The Planning Committee agreed the 2023 Program would be a continuation of the 2022 Program, but with additional goals and an updated implementation approach.

Program Objectives

The objectives of the 2023 Program were to (1) evaluate if changing specific field management practices could result in water savings during water year 2023, (2) protect Delta water quality by providing additional incremental instream flow benefits to reduce salinity effects on water quality, (3) mitigate potential drought impacts on fish and migratory birds, and (4) promote soil health. The third goal was implemented by the addition of bird habitat practices to the 2023 Program, which incentivized farmers to provide crucial habitat for migratory waterbirds, particularly shorebirds. The Program provided waterbird habitat through short-term shallow flooding of fields and delaying harvest of non-irrigated small grains to protect nesting cover.

Reverse Auction

To support all Program goals the 2023 Planning Committee sought to align incentive payments more closely with the costs of Program implementation for growers and anticipated water savings. In 2022, growers received a uniform payment of $900 per acre for all water conservation practices and were selected on a first come, first served basis. The 2022 Final Report suggested some water saving practices were more effective on average, and the Planning Committee wanted to define a process that would assign more of the budget to water conservation practices likely to provide the highest measurable water savings. To that end, the 2023 Program shifted from paying on a per-acre basis to a reverse auction process where growers bid a per-acre price to implement water conservation practices. The Planning Committee sought to apply this methodology based on the assumption that incorporating these factors would bring the cost per acre down, allowing for more acres to be enrolled through the available budget.

Unlike a typical auction, in a reverse auction there is one buyer (the State) and multiple competing sellers (the applicants/bidders). This process was used to select the combination of bids that maximized expected water savings within the limited budget, while compensating grantees fairly. All accepted bids were offered grants at the market clearing price, which was defined as the highest price accepted for all similar water saving practices.

Solicitation

Bidding opened on October 3, 2022, and closed at 5:00 p.m. on October 18, 2022. The solicitation content can be found in the Appendix E: Solicitation of Applicants.

Criteria used to evaluate the bids included estimated water savings, cost per acre-foot of estimated savings based on bid price, geographic distribution, field shape and size, and the diversity of proposed water conservation practices. Bidders were asked to assign their bids to one of four practice type categories:

- Shift Crop Type
- Deficit Irrigation
- Forgo Cash Crop
- Other

There was no limit on total acres bid by any applicant and applicants could submit the same area in multiple bids if proposed practices were different among bids. The minimum acreage for each bid was 100 contiguous acres. These bids were reviewed individually. Ultimately, each applicant was limited to enrolling a maximum of 1,000 acres.

Evaluation and Selection Process

Bid Review

A Selection Committee, supported by staff from the Delta Conservancy and the ODWM, met three times between October 21, 2022, and November 4, 2022, to evaluate the bids. Selection committee members included individuals from the Delta Conservancy, DWR, CDFA, UC Merced, UC Cooperative Extension, ODWM, and TNC. The goal of the Selection Committee was to fairly evaluate all bids, include projects across the Delta region, and judiciously allocate state funds.

The support staff reviewed each bid, validated performance objectives, and communicated with bidders to clarify proposed practices. Based on this approach, some bidders' practice types were changed to better reflect the water conservation practices proposed in the bid. Expected water savings for each bid were estimated based on the water conservation practice type, using the savings estimates from the 2022 DDRPP preliminary data (Sacramento-San Joaquin Delta Conservancy, 2023). Staff removed identifying material from bids before they were considered by the Selection Committee.

109 qualifying bids were considered for the 2023 DDRPP. There were 20 bids to forgo a cash crop (no crop grown on the project site during at least the months of June, July, August, and September 2023), 29 bids to deficit irrigate fields (business-as-usual crop went without a portion of the business-as-usual irrigation cycle), 48 bids to Shift Crop Type (crop grown on the project site shifted from a more water-intensive crop to a crop that uses less water), four bids for area performing only bird habitat beneficial practices, and eight bids categorized as other (innovative water saving practices that were not represented in the other categories).

Optimization Model

TNC collaborators developed an optimization model that selected the combination of bids that sought to optimize water savings per dollar invested and used this model to determine a clearing price for each water conservation practice (See Appendix G: Optimization and Reverse Auction). The optimization model used water saving estimates for each water conservation practice that were determined by the 2022 DDRPP Oversight Committee. The model took these water savings estimates and multiplied them by the bid acreage to estimate potential water savings for each bid. Bids were then ranked by their water savings potential, and the model worked to accept as many bids as possible up to the point where selecting additional bids would exceed the budget. For most bidders, bidding too high reduced the chances of selection without increasing the amount paid if selected. Because of the uniform payment offered to all selected bids within each practice type, the bidders had an incentive to offer the lowest bid price that they found acceptable.

Based on the preliminary results of the 2022 DDRPP, the Selection Committee sought to prioritize Program funding for Deficit Irrigation and Forgo Cash Crop practices. Therefore, the Selection Committee determined the model should allocate 25% of the budget to bids for Shifting Crop Type, 37.5% of the budget to Deficit Irrigation bids, and 37.5% of the budget to bids to Forgo a Cash Crop. Less of the budget was allocated to shifting crop type to maximize potential 2023 DDRPP water savings while continuing to gather data on the water savings potential of all water conservation practices.

Because of the constraints on the model, and the fact that the market-clearing price was applied to all successful bids, the total spent increased in a stepwise fashion and the model could not choose enough bids to fully spend the budget without overshooting. To use part of the remaining budget, the selection committee chose to increase the clearing price to select the bid closest to being selected, which resulted in increasing the clearing price for Deficit Irrigation bids by $50. Selected bidders willing to perform bird beneficial habitat practices on the same fields were given additional incentive payments of $75/acre for shallow flooding and $30/acre for delaying harvest. These adjustments resulted in a small overrun of the budget, which was resolved through attrition from bidders who were offered grants but did not accept. The final clearing price for each water conservation practice type was $695/acre to Forgo a Cash Crop, $675/acre for Deficit Irrigation, and $500/acre to Shift Crop Type. The weighted price paid across the three water conservation practices was $638.75 per acre, which is 29% lower than the fixed price offered in the 2022 Program.

For practices categorized as Other, where there was no data from 2022, the selection committee used their expert judgement to evaluate each bid, set a clearing price, and select bids to spend the remainder of the budget not spent by the optimization model. Projects selected from the Other category include deficit irrigating permanent crops (specifically wine grape vines and almond trees) and converting annual crops (specifically peppers or tomatoes) to drip irrigation. Similarly, TNC spoke with the farmers enrolled in only the beneficial bird habitat practices to verify overall reductions in applied water, and the selection committee chose to enroll areas estimated to have overall reductions. An objective of this approach was to advance conservation benefits for important habitat and flow benefit while reducing consumptive use.

Execution of Grant Agreements

On November 16, 2022, the Delta Conservancy Board approved 64 DDRPP grants for the 2023 water year. Delta Conservancy staff worked with the selected bidders to draft grant agreements. Field sizes were verified using Google Earth Pro to standardize payments across grantees who might have used different methods to calculate field sizes; a few fields measuring less than 100 acres with Google Earth Pro were included because grantees showed their own data with supporting field measurements, but grantees were all paid based on the calculated area of the field in Google Earth Pro. No grantee enrolled more than 1,000 total acres, though individual grantees may have been awarded grants for multiple projects in different geographic areas or with different crops or water conservation practices. During the grant development process, four proposals were withdrawn from the Program. Ultimately, the Delta Conservancy entered into 61 grant agreements with 33 individual grantees, totaling just over $10.5 million and enrolling 18,450 acres in the Program (see Appendix F: 2023 Grant Summaries). Of the acres enrolled to implement beneficial bird habitat, 2,892 acres occurred on fields that were also performing other water conservation practices and 2,334 acres did not overlap with any other water conservation practices. The second year of the Program was underway by February 2023.

Table 1. Summary of projects by water conservation practice type at the time of grant execution.

Water Conservation Practices	Number of Projects	Total Project Area (ac)	Mean Field Area (ac)	Median Field Area (ac)	Minimum Field Area (ac)	Maximum Field Area (ac)	Mean Field Elevation (ft)
Shift Crop Type*	19	4,533	239	174	98	520	-8.54
Deficit Irrigation†	18	5,164	287	219	93	768	- 4.41
Forgo Cash Crop‡	17	4,840	285	180	103	1,000	-2.52
Other	4	1,579	395	240	99	1,000	-1.75
Total	58	16,116	278	184	93	1,000	- 4.69

*Three fields had beneficial bird habitat practices being performed on all or part of the field. Total area with beneficial bird habitat was 566 acres.

†Two fields had beneficial bird habitat practices being performed on all or part of the field. Total area with beneficial bird habitat was 286 acres.

‡Five fields had beneficial bird habitat practices being performed on all or part of the field. Total area with beneficial bird habitat was 1,917 acres.

Table 2. Summary of projects by beneficial bird habitat practice type at the time of grant execution and whether they overlap with other water conservation practice types.

Beneficial Bird Habitat Practices	Number of Projects	Total Project Area (ac)	Mean Field Area (ac)	Median Field Area (ac)	Minimum Field Area (ac)	Maximum Field Area (ac)	Mean Field Elevation (ft)
Spring Flood-up Overlapping	4	1,436	359	163	111	1,000	-13.01
Spring Flood-up Only	3	2,304	768	919	309	1,076	-13.34
Fall Flood-up Overlapping	4	1,262	570*	570*	139*	1,000*	-11.78*
Nesting Only	1	30	30	30	30	30	- 5.10
Nesting Overlapping	5	1,194	239	108	50	620	-7.03
Total†	16	5,226	365*	163*	30*	1,076*	-11.80*

*Two fall flooding fields totaling 123 acres were amended out of the grant agreements before maps were finalized and data was not gathered on their field characteristics.

†One field of 1,000 acres was flooded for both fall and spring beneficial bird habitat. This field was included only once in these totals.

Addressing Uncertainties

California's 2023 water year was characterized by extreme weather whiplash, with the driest recorded three-year period (the 2020-2022 drought) coming to a dramatic close after a series of atmospheric river storms left behind one of the largest snowpacks on record (Department of Water Resources, 2023). When water supplies are limited, like during drought, the State Water Board can restrict a person's legal right to divert water; this restriction is called a curtailment (State Water Resources Control Board, 2022). The State Water Board issued curtailment orders to water right holders in the Delta Watershed on August 21, 2021, (State Water Resources Control Board, 2021). However, in December 2022, the State Water Board temporarily suspended curtailments in the Delta Watershed. In response to these rapid hydrological changes, the Delta Conservancy conducted outreach in March 2023 to explore options to adjust the 2023 Program. Curtailments in the Sacramento-San Joaquin Delta Watershed were formally rescinded on April 3, 2023.

The Delta Conservancy reached out to all 33 enrolled grantees and surveyed 31 growers over the phone about the status of their water conservation practices, their ability to withdraw from the Program voluntarily, and their ability to postpone their water conservation practices to the following water year. Every grantee the Delta Conservancy spoke with preferred to maintain their grant agreement for the 2023 water year, indicating that for planning purposes, they had had already made irreversible decisions based on their enrollment in the Program and could not return to business-as-usual practices. The main drivers reported that precluded flexibility included planting less water intensive/lower value crops, missing planting windows for business-as-usual crops, missing purchasing contract windows, purchasing seed and feed, downsizing or relocating staff, obtaining new fields to offset anticipated yield losses, and applying herbicides that are incompatible with business-as-usual crops. Many growers also noted that they would not be interested in postponing their water conservation practices to a future year, given high levels of uncertainty in future conditions and commodity pricing.

Based on feedback from growers, as well as the results of the 2022 DDRPP, the Delta Conservancy concluded that the continuation of the 2023 Program as planned would enable the collection of useful data to build on the previous year's analysis and that grantee water conservation efforts would likely produce some water savings during the hottest summer months.

The rainy season brought localized flooding and saturated fields to many growers enrolled in the 2023 DDRPP. In response to these changing conditions, the Delta Conservancy worked with growers to modify their grant agreements on a case-by-case basis. These modifications included changes such as pivoting from growing a low-water crop to fallowing the project field or shifting the original crop to another low-water or deficit-irrigated crop. In other instances, growers were unable to carry out their beneficial bird habitat practices as planned. In these cases, the Delta Conservancy worked with growers to either adjust the timing of beneficial bird habitat practice or to remove the beneficial bird habitat practice from the grant agreement altogether.

Analysis Methods

During DDRPP 2023, several different groups were studying enrolled fields: a team of researchers from UC Davis, The Nature Conservancy, and the DDRPP Oversight Committee.

The UC Davis research team, led by Dr. Kosana Suvočarev, purchased and installed micrometeorological equipment at six research sites throughout the Delta in summer 2023 (Appendix D: UC Davis Study Update). Delta Conservancy staff worked with UC Davis and members of the 2023 DDRPP Planning and Selection Committees to identify the six locations, and Conservancy staff worked with the growers to amend their grant agreements. Updated agreements extended the grant term for three additional years ending on December 31, 2026, detailed the water conservation practices farmers could implement over the three-year period, and adjusted the grant budget to pay for the implementation of these practices. This study recently began analyzing preliminary data, and data collection will continue through September 2026. See Appendix D: UC Davis Study Update for details.

The Nature Conservancy team, led by Julia Barfield and Greg Golet, studied the DDRPP fields enrolled in Beneficial Bird Habitat practices. A subset of these fields was monitored to characterize relative bird species diversity and abundance. Details of this analysis are described in Appendix C: Beneficial Bird Habitat Practices Monitoring.

Members of the Oversight Committee worked with grantees to draw polygons for project fields and comparison fields using Google Earth Pro and Esri ArcGIS Pro, then queried OpenET to retrieve ensemble actual evapotranspiration values (ETa), reference ET values (ETo), and precipitation values. Additional data about field conditions was collected through surveys sent to grantees through Microsoft Forms. Three fields (356 acres) were excluded from the analysis because the fields experienced persistent weather-related flooding, and the field management resulted in plantings that did not align with field size criteria or the water conservation practice definitions. Two fall flooding beneficial bird habitat fields totaling 123 acres were amended out of the grant agreements before maps were finalized and data was not gathered on their field characteristics. In total 18,092 acres were analyzed during some portion of the analysis.

Three response variables were assessed by the Oversight Committee:

- **Consumptive Use** – measured as ETa
- **Comparative Savings Estimate** – water savings calculated using a comparison field carrying out the business as-usual practices as a baseline
- **Normalized Savings Estimate** – water savings calculated using the averaged condition of the project field from 2017-2021 as a baseline and using reference evapotranspiration fraction (ETоF) to account for weather/climate differences among years

The results of this analysis are detailed in Appendix A: Technical Appendix. The analysis results and the implications of those results are summarized in the below conclusions.

Conclusions

Throughout both years of the Program, farmers in the Delta were willing to undertake water conservation practices, and demand for the Program exceeded available funding. In water year 2022, the Program received 85 qualified project proposals and 35 projects were executed. In water year 2023, the Program received 109 qualified project proposals and 61 projects were executed. In feedback collected during the Program, grantees reported that commencing the Program by the beginning of the water year (October 1) would best support field management and crop planning for growers. However, the 2023 water year shows that this timing is challenging since precipitation totals, and the subsequent necessity of water conservation practices for the water year, are still unknown in early October.

The reverse auction and bid selection approach brought the cost per acre enrolled down substantially. The competitive aspect of the auction combined with the heterogeneity of costs across different farmers and locations allowed for the selection of lower-cost bids than would have otherwise been possible. The objectives of the Program included considerations such as collecting information from a diversity of locations and water-saving practices, therefore the prices paid were not as low as they could have been if cost-effectiveness had been the sole basis for bid selection. In particular, allocating a pre-specified percentage of the Program budget to the three practices meant some bids that may have saved more water at a lower cost were not selected. This may be thought of as the cost of learning what is the most effective means of conserving water. Given what has been learned over the two years of the Program, it is very likely the use of a reverse auction in future water-savings programs would result in much lower costs than would be expected under a fixed price scheme. Despite these cost savings, conducting the reverse auction lengthened the selection process timeline. Based on grower feedback, timeliness is critical for effective grower participation and implementation of water conservation practices, so this must be considered along with the potential for increased cost-effectiveness.

Mean annual consumptive use was 2.70 ± 0.06 ac-ft/ac and ranged from 1.43 to 4.01 ac-ft/ac. Water savings as measured by the comparative savings estimate ranged from -0.53 to 1.98 ac-ft/ac with a mean of 0.18 ± 0.07 ac-ft/ac. The normalized savings estimate showed no water saved on average, with a mean difference from the baseline of -0.08 ± 0.07 ac-ft/ac and ranged from -1.15 to 2.00 ac-ft/ac. Overall, the total estimated volume of water saved by the 2023 DDRPP (up to 1,890 ac-ft) was unlikely to significantly impact water quality. The ability to measure the effects of marginal increases in localized flows that would have remained in Delta channels is difficult to calculate. Compared to the overall volume of water flowing into the Delta during the same water year (32 million ac-ft of water according to USGS gauge data), daily tidal volumes (between 15,300 and 267,500 ac-ft according to USGS gauges), and proportion of estimated in-Delta use (1.8 million acre feet in 2021 (Gartrell, Mount, & Hanak, 2022)), water savings from the 2023 DDRPP were not substantial. Understanding how interactions among in-channel flows, seepage, applied water, shallow groundwater, and consumptive water use may impact water quality is an important avenue for future study.

Overall, consumptive use and water savings estimates did not significantly differ among water conservation practice types, implying this method of categorizing fields was not useful in explaining variations in water use/savings among project fields. There were, however, notable differences in estimated water savings based on the calculation method used. Because the

2023 water year had such wet conditions, it is likely that comparing project fields to comparison fields during the same water year (comparative savings estimate) better incorporated relative changes during the very wet conditions. Although, the comparative savings estimate was highly influenced by the selection of the comparison field, and locating an appropriate comparison field for each project was challenging. Alternatively, the normalized savings estimate compared a field in water year 2023 to the same field across a range of previous years and attempted to account for variations in atmospheric conditions among years. In water year 2023, precipitation was higher and average air temperatures were lower, likely resulting in higher soil moisture in 2023 compared to some of the previous years, allowing plants to grow more vigorously. Thus, the normalized savings estimate method may have underestimated water savings for 2023. This analysis did not consider soil moisture directly, but the UC Davis study currently in progress (Appendix D: UC Davis Study Update) is compiling soil moisture measurements to better resolve relationships between field level conditions and water usage.

Though all enrolled growers decreased applied water on their DDRPP project sites, there was wide variation in estimated consumptive use and savings. Appendix B: Case Studies describes specific field conditions and speculates about their connections to ET estimates. Though no single factor in the analysis explained the variation among fields in water saved/used with statistical significance, several patterns emerged that suggest field characteristics that may contribute to differences among fields. This analysis examined elevation, crop type, and local flooding as potential sources of variation among fields, but vegetation management, soil type, and numerous other influences may be at play. More study is needed to fully understand how specific field characteristics impact patterns of water savings/use in the Delta.

Fields above sea level account for a disproportionate amount of total water savings. Fields above sea level make up 20% of the total acreage analyzed, but 76% of estimated ET savings for water year 2023 (using the comparative savings estimate calculation). There was substantial variability in the relationship between elevation and estimated water savings. However, fields above sea level likely have higher potential water savings than fields below sea level in the Delta, and therefore have the potential to provide more cost-effective and efficient water savings compared to fields below sea level. Crop water usage on some fields in the Delta is likely supplemented by shallow groundwater and channel surface water that percolates under levees (seepage), especially in areas below sea level. These areas are likely sub-irrigated by high water tables, resulting in crop growth and high ET even without applied irrigation. Elevation only partially explained the patterns of water savings/use among 2023 DDRPP fields, and several fields below sea level showed some water savings.

There was variability in consumptive use and savings estimates among crop types. For example, shifting away from alfalfa had estimated water savings across water conservation practices in water year 2023; only shifting from alfalfa to sorghum-sudangrass calculated by the normalized savings estimate method did not show savings. A three-year old almond orchard had the lowest consumptive use of any crop type, but also had low estimated savings. This field is explored further in Appendix B: Case Studies. Using the comparative savings estimate, deficit irrigated pasture saved water across varying elevations. When comparing the 2023 DDRPP findings to a study of crop ET in 2015 (Medellín-Azuara, et al., 2018), shifting away from a business-as-usual crop of alfalfa reduced consumptive use by 20-39%, shifting away from a business-as-usual crop of corn reduced consumptive use by 0-35%, deficit irrigating corn reduced consumptive use by 0-21%, and deficit irrigating pasture decreased consumptive use by 36-57%. These examples demonstrate how some fields show decreased consumptive use while others show minimal or no savings when compared to reference crop ET measurements.

When comparing fields enrolled in both years of the Program, average consumptive use across both years was similar, but slightly higher in water year 2023 than in water year 2022. California Irrigation Management Information System (CIMIS) data from across the Delta showed higher precipitation and lower average air temperatures in water year 2023 than water year 2022 (California Department of Water Resources, 2024), likely resulting in higher soil moisture in 2023. High soil moisture available for plant growth can lead to increased evapotranspiration. Three fields out of the thirteen fields enrolled in both years of the Program had higher consumptive use in water year 2022 than in water year 2023, but the mechanism behind these differences is not clear. Additional study across multiple years would be needed to understand the interactions between water year type and the effectiveness of water conservation actions.

Beneficial bird habitat practices implemented during water year 2023 provided valuable bird habitat but were challenging to integrate into the Program and analysis, and future water conservation programs and regulations will need to balance actions that produce the most water savings with consideration for climate and biodiversity objectives. Bird abundance observed on the Spring Flood-up fields was consistent with what has been observed at other habitat locations in the Delta. Bird abundance observed on the nesting habitat fields was relatively low. Habitat value for nesting could likely be enhanced by introducing more heterogeneity to the fields. Many of the nesting fields had very dense canopy coverage. While this is attractive to some species, other bird species may have been more likely to use these sites if there were gaps in the vegetation. Additional details about bird responses to beneficial bird habitat practices can be found in Appendix C: Beneficial Bird Habitat Practices Monitoring.

In most months during implementation of the beneficial bird habitat Spring Flood-up practices (January-April), fields carrying out Spring Flood-up practices showed little difference in consumptive use compared to Program fields that did not carry out spring flooding for beneficial bird habitat. There was widespread weather-related flooding during that same period. When comparing average annual consumptive use for fields that implemented Spring Flood-up practices to fields that experienced weather-related flooding during at least one month and to fields that experienced no weather-related flooding, Spring Flood-up fields had the highest consumptive use. However, the Spring Flood-up fields are also positioned at lower elevation on average than the other two groups.

Research being carried out in partnership with Dr. Kosana Suvočarev of UC Davis through September 2026 will supplement the findings from this report by providing water budgets for six DDRPP fields, assessing the application of OpenET to estimate consumptive use on each of these fields, and providing additional insight into ETa on agricultural fields across multiple water years (Appendix D: UC Davis Study Update). Preliminary results from the micrometeorological study recorded high ET and carbon uptake measurements. High readings for these metrics can challenge the model assumptions used to estimate ET. The researchers will continue collecting data across the three years of the study and explore how these high readings may impact model estimates and methods to improve model estimation accuracy. This highlights the importance of field level measurements to the continued improvement of the models.

Future project iterations should consider which baseline is most useful when estimating water savings. Comparisons to the business-as-usual practice will give an estimate of short-term potential savings on specific fields, based on individual field management practices. Fields with higher consumptive use business-as-usual practices may have a higher potential for water savings. If long-term reductions in consumptive use are desired, consumptive use is likely more meaningful than estimated water savings as a metric. Focusing on practices with lower consumptive use against the background of all regional practices could allow program managers to choose practices that lower consumptive use in the long-term.

The voluntary enrollment process may have impacted the types of fields enrolled in the Program. When selecting fields to apply for the Program, some growers reported enrolling fields that were less likely to experience crop yield losses when decreasing applied water through deficit irrigating or shifting to a lower water-use crop. These voluntarily selected fields may not have had the highest water saving potential relative to other fields in the region. Additionally, voluntarily recruiting fields resulted in low replication across several factors of interest (elevations, crop types, weed management practices), and these small sample sizes limited statistical inference. To better understand sources of variation in the estimated reduction in consumptive use, future programs could require specific management actions to limit variability among samples and select fields to get a dataset with a more even distribution across the elevation gradient in the Delta to better assess the impacts of elevation on water savings.

The findings from the DDRPP are likely to be applicable beyond the Delta region. The approach used by the Program in the legal Delta can be adapted in other regions to further examine the relationships among elevation, biodiversity, water conservation strategies, and their resulting savings. Open-source remote sensing satellite estimates of evapotranspiration—like those from OpenET—make it possible to cost-effectively measure water use, index overall water use, and study the factors that drive evapotranspiration changes. Synthesizing region-specific findings, like those from the DDRPP, with landscape-level estimates of ET can help identify the locations and region-specific field characteristics and practices likely to produce the most cost-effective and efficient water savings during future droughts. Lessons learned from Program implementation can help to improve future programs providing incentives to land managers carrying out water conservation practices.

Appendix A: Technical Appendix

Abstract

This appendix reports the outcomes of the DDRPP Oversight Committee's analysis of estimated consumptive water use and water savings, the cost of water used/saved, the impacts of implementing beneficial bird habitat practices on water use/savings, and a brief comparison of the 2022 and 2023 DDRPP. Using OpenET, the Oversight Committee retrieved ensemble actual ET values (ETa) and reference ET values (ETo) monthly for the 2017 through 2023 water years. These metrics were used to calculate annual values for consumptive use and two methods of estimating water savings. The results show that reductions in applied water carried out by all DDRPP grantees did not consistently result in reductions in ET for fields enrolled in the Program during the 2023 water year. The 2023 DDRPP saved up to 1,890 ac-ft of water, and, as estimated water savings were low, costs were correspondingly high. Multiple factors likely impacted savings potential on enrolled fields. First, fields above sea level accounted for most of the estimated water savings and had a lower cost per ac-ft of water saved than fields below sea level. The business-as-usual crop and the 2023 planted crop also impacted water use/savings. For example, shifting away from alfalfa consistently showed estimated water savings, while Deficit Irrigation of corn only saved water on some fields. Consumptive use and water savings estimates did not significantly differ among water conservation practice types, implying this method of categorizing fields was not useful in explaining variations in water use/savings among enrolled fields. Finally, savings varied between the two different methods of estimating savings, with more savings estimated by a comparison between a project and a comparison field during the 2023 water year. When examining fields enrolled in both years of the DDRPP, average consumptive use across both years was similar, but slightly higher in the 2023 water year than in the 2022 water year, likely driven by higher soil moisture available to plants in the 2023 water year, but soil moisture was not directly measured as part of this analysis. Fields implementing shallow flooding for bird habitat benefits did not appear to have higher ET rates than other project fields with weather-related flooding. Future studies should select fields with a more even distribution across the elevation gradient in the Delta to better understand the relationship between elevation and water savings within the legal Delta. Low estimated water savings may also have been driven by shallow groundwater and seepage of surface water from channels onto Delta fields, and a future study could directly measure the relationships among applied water, seepage, and in-channel water quality across a range of elevations.

Research Questions

The Oversight Committee developed a list of research questions to guide this analysis by considering both the importance and feasibility of each potential question. To help understand the outcomes of the 2023 Delta Drought Response Pilot Program and inform future drought relief efforts, the Oversight Committee sought to address the following questions:

1. Does water conservation practice type or crop type impact consumptive water use and/or estimated water savings on experimental fields?
2. Do fields have lower consumptive water use in treatment years as compared to previous years, back to the 2017 water year?
3. Does average field elevation impact consumptive water use and/or estimated water savings on experimental fields?
4. What was the cost per acre-foot of water saved/used?
5. How do bird benefit practices impact consumptive water use and/or estimated water savings?
6. When looking at the areas enrolled in both DDRPP 2022 and 2023, how do consumptive water use and/or estimated water savings compare between Program years? (*n*=13)

Summary of Project Field Characteristics

All fields enrolled in the 2023 Program (Table 1, Table 2) were considered for this analysis. Three fields (356 acres) were excluded from the analysis because the fields experienced persistent weather-related flooding and the field management resulted in plantings that did not align with field size criteria or the water conservation practice definitions. Two fall flooding beneficial bird habitat fields totaling 123 acres were originally enrolled but could not be successfully implemented, thus these fields were not included in this analysis. In total, 18,092 acres enrolled in the 2023 Program were analyzed during some portion of this study. All results and calculations in this appendix represent the fields as analyzed, which are detailed in Table 3 and Table 4.

Field characteristics varied greatly across the enrolled acreage. Fields varied in their field management practices. These practices were separated into several water conservation practice types, which were assigned at the time of bidding. The water conservation practices assigned to nine fields were changed for this analysis. For many of these fields, weather-related flooding caused changes in field management between the time of bid and the time of water conservation practice implementation. The original descriptions of the water conservation practice type categories can be found in Appendix E: , and they have been further refined to reflect the groups as analyzed. In other cases, additional information provided by growers during grant reporting resulted in recategorization. Two fields were split to reflect different field management in portions of the enrolled acreage; these changes were caused by weather related flooding.

Shift Crop Type (*n*=22) fields shifted from a more water-intensive crop, such as corn, tomatoes, or alfalfa, to a crop thought to have lower irrigation water requirements, such as safflower or small grains. Deficit Irrigation (*n*=18) fields planted their business-as-usual crop and withheld a portion of the business-as-usual irrigation cycle. Most projects had no irrigation events, but a few were allowed a maximum of 1-2 irrigation events during the water year. Forgo Cash Crop (*n*=14) meant growing no crop on the project field during the months of June, July, August, and September 2023. Some projects had no crop grown for the entire water year, but there was wide variation in vegetation management on these idled fields. Growers were asked to use their farming expertise to manage weeds and other vegetation; some sites mowed, applied herbicides, and brought in animals to graze, while other sites performed minimal vegetation management and had extensive weed cover. Other Annual (*n*=2) fields grew annual crops (peppers and tomatoes) and installed more efficient irrigation systems. Other Perennial (*n*=2) fields grew perennial crops (almonds and grapes) and deficit irrigated by 20%.

Some fields were implementing beneficial bird habitat practices. Fields implementing Nesting habitat delayed harvest to protect nesting cover by leaving non-irrigated small grains and cover crops in the field until at least July 1, 2023. Spring Flood-up involved minor field preparation to incorporate leftover vegetation into the soil and shallow flooding during spring 2023 for at least four weeks with an average depth of 4 inches on a minimum of 30 contiguous acres. Fall Flood-up called for minor post-harvest field preparation to incorporate leftover vegetation into the soil and shallow flooding during fall 2023 for at least four weeks with an average depth of 4 inches on a minimum of 30 contiguous acres. Because of concerns about mosquito abatement, fall flooding happened in October 2023, at the beginning of water year 2024. Beneficial bird habitat practices were performed on a total of 5,103 acres. On average, bird benefit fields were 365 acres, ranging from 30 to 1,076 acres. 2,334 acres had only beneficial bird habitat practices performed. 2,769 acres had beneficial bird habitat practices and additional water conservation practices implemented. One field of 1,000 acres implemented both Spring Flood-up and Fall Flood-up, and it was not double counted in the proceeding summary statistics.

Ground subsidence is a major issue on cultivated lands in the Delta and can vary greatly across the landscape. Fields were spread across a range of elevations from a low of -18 feet below sea level to 75 feet above sea level, but most fields were below sea level (74%). For Shift Crop Type fields 5 of the 22 fields were above sea level, 4 of 18 Deficit Irrigation fields were above sea level, 4 of 14 Forgo Cash Crop fields were above sea level, 1 of 2 Other Annual fields were above sea level, and 1 of 2 Other Perennial fields were above sea level. Only 1 field with beneficial bird habitat was above sea level, and that 50-acre field overlapped a Shift Crop Type field.

Fields also varied by the primary crop cultivated in the 2023 water year and the crop that would have been planted under business-as-usual conditions (Table 5). Table 5 excludes areas enrolled exclusively for beneficial bird habitat but includes some areas that were used for beneficial bird habitat during some portion of the water year and implemented additional water conservation practices during the remainder of the water year. Deficit Irrigation of corn was the most common sub-practice (*n*=11), followed by shifting from planting corn to planting triticale (*n*=6) or safflower (*n*=6), and forgoing a cash crop of corn and, instead, planting winter wheat harvested by July 2023 (*n*=6).

Analyzed field areas varied from 93 to 1,004 acres. Mean field area was 272 acres, and the median field area was 180 acres. Some samples have slightly different areas analyzed than those defined in original maps created during grant execution; some fields were divided into sub-samples after the execution of grant agreements, and these subdivisions result in an analyzed acreage that differs slightly from grant acreage.

Table 3. Summary of project field characteristics by water conservation practice type as analyzed.

Water Conservation Practices	Number of Projects	Total Project Area (ac)	Mean Field Area (ac)	Median Field Area (ac)	Minimum Field Area (ac)	Maximum Field Area (ac)	Mean Field Elevation (ft)
Shift Crop Type*	22	5,048	229	171	59	542	-5.12
Deficit Irrigation†	18	4,769	265	181	93	768	-4.56
Forgo Cash Crop‡	14	4,362	312	195	98	1,004	-5.74
Other Perennial	2	1,370	685	685	370	1,000	-1.57
Other Annual	2	209	105	105	99	110	-3.05
Total Analyzed	58	15,758	272	180	59	1,004	-4.77

*Five fields in this water conservation practice type had beneficial bird habitat practices being performed on all or part of the field. Total area with beneficial bird habitat was 713 acres.

†Three fields in this water conservation practice type had beneficial bird habitat practices being performed on all or part of the field. Total area with beneficial bird habitat was 436 acres.

‡Two fields in this water conservation practice type had beneficial bird habitat practices being performed on all or part of the field. Total area with beneficial bird habitat was 1,620 acres.

Table 4. Summary of projects by beneficial bird habitat fields as analyzed organized by practice type and if they overlap with other water conservation practice types.

Beneficial Bird Habitat Practices	Number of Projects	Total Project Area (ac)	Mean Field Area (ac)	Median Field Area (ac)	Minimum Field Area (ac)	Maximum Field Area (ac)	Mean Field Elevation (ft)
Spring Flood-up Overlapping	4	1,436	359	163	111	1,000	-13.01
Spring Flood-up Only	3	2,304	768	919	309	1,076	-13.34
Fall Flood-up Overlapping	2	1,139	570	570	139	1,000	-11.78
Nesting Only	1	30	30	30	30	30	- 5.10
Nesting Overlapping	5	1,194	239	108	50	620	-7.03
Total	14	5,103*	365*	163*	30*	1,076*	-11.80*

*One field of 1,000 acres was flooded for both fall and spring bird habitat. This field was included only once in these totals.

Table 5. Summary of projects by water conservation practice, the primary crop planted in the 2023 water year, and the business-as-usual crop that would have been planted if the field had not been enrolled in the DDRPP.

Water Conservation Practices	Business-as-Usual Crop	Planted Crop	Number of Projects	Total Project Area (ac)	Mean Field Area (ac)	Median Field Area (ac)	Minimum Field Area (ac)	Maximum Field Area (ac)	Mean Field Elevation (ft)
Shift Crop Type	Alfalfa	Safflower	2	324	162	162	150	174	3.41
Shift Crop Type	Alfalfa	Sorghum-sudangrass	1	136	136	136	136	136	2.40
Shift Crop Type	Alfalfa	Triticale	1	271	271	271	271	271	-0.70
Shift Crop Type	Corn	Barley	1	168	168	168	168	168	-16.90
Shift Crop Type	Corn	Safflower	6	1,057	176	139	122	367	-3.81
Shift Crop Type	Corn	Triticale	8	2,565	321	342	127	542	-9.68
Shift Crop Type	Corn	Wheat	1	117	117	117	117	117	74.60
Shift Crop Type	Tomatoes	Corn	1	59	59	59	59	59	-9.80
Shift Crop Type	Tomatoes	Wheat	1	351	351	351	351	351	-8.80
Deficit Irrigation	Corn	Corn	11	2,273	207	172	93	530	-9.88
Deficit Irrigation	Hay	Hay	1	729	729	729	729	729	6.54
Deficit Irrigation	Irrigated Pasture	Pasture	3	1,321	440	450	103	768	-2.55

Water Conservation Practices	Business-as-Usual Crop	Planted Crop	Number of Projects	Total Project Area (ac)	Mean Field Area (ac)	Median Field Area (ac)	Minimum Field Area (ac)	Maximum Field Area (ac)	Mean Field Elevation (ft)
Deficit Irrigation	Triticale	Triticale	3	446	149	141	97	208	-2.34
Forgo Cash Crop	Alfalfa	None	1	105	105	105	105	105	-9.50
Forgo Cash Crop	Alfalfa	Wheat	1	106	106	106	106	106	1.30
Forgo Cash Crop	Corn	None	3	1,758	586	620	135	1,004	-8.86
Forgo Cash Crop	Corn	Triticale	1	98	98	98	98	98	-12.40
Forgo Cash Crop	Corn	Wheat	6	1,845	308	229	103	605	-2.98
Forgo Cash Crop	Tomatoes	None	1	201	201	201	201	201	1.80
Forgo Cash Crop	Wheat	Wheat	1	249	249	249	249	249	-8.80
Other Perennial	Almonds	Almonds	1	1,000	1,000	1,000	1,000	1,000	-3.20
Other Perennial	Grapes	Grapes	1	370	370	370	370	370	2.90
Other Annual	Corn	Peppers	1	99	99	99	99	99	2.90
Other Annual	Corn	Tomatoes	1	110	110	110	110	110	-8.80

OpenET Background

OpenET provides satellite-based estimates of water transferred from the land surface to the atmosphere through the process of evapotranspiration (ET). This is referred to as actual ET (ETa) because it represents an estimate of the amount of ET that occurred at targeted fields/crops under actual conditions. Existing uses of OpenET include groundwater management, irrigation and crop management, regulatory compliance, watershed management, water trading, and research (OpenET, 2024). The Committee's analysis estimated water savings and explored patterns in consumptive water use by using data from OpenET.

OpenET uses six satellite-driven models (Table 6) to calculate a single ensemble value. These six models have been reviewed and applied by a range of government agencies responsible for water use reporting and management in the western U.S. The value added through OpenET is based on a multi-year development process to make data from these models publicly available with exhaustive query and display tools to support consistent decision making by water users, researchers, and regulators. OpenET is a scientifically rigorous, consistent, credible (with both water users and regulatory agencies), transparent, accessible, and inexpensive source of data to compare ET across practices and evaluate the water savings attributable primarily to the incentivized water conservation practices under the Program.

The models in Table 6 use Landsat satellite imagery to produce ETa data at a spatial resolution of 30 by 30 meters (0.22 acres per pixel). Additional inputs vary across models and include gridded weather variables such as solar radiation, air temperature, humidity, wind speed, and precipitation. These weather variables in OpenET models use inputs from the CIMIS, developed and maintained by DWR. CIMIS is a network of over 145 weather stations throughout California (several stations are located within or near the legal Delta). More information about CIMIS can be found at: https://cimis.water.ca.gov.

More information about the models, development team, their funders, and an accuracy assessment can be found on the OpenET website: https://openetdata.org

Table 6. Models currently Included in OpenET.

Model Acronym	Model Name	Primary References
ALEXI/DisALEXI	**A**tmosphere-**L**and **Ex**change **I**nverse / **Dis**aggregation of the **A**tmosphere-**L**and **Ex**change **I**nverse	(Anderson, Norman, Mecikalski, Otkin, & Kustas, 2007); (Anderson, et al., 2018)
eeMETRIC	Google **E**arth **E**ngine implementation of the **M**apping **E**vapo**t**ranspiration at high **R**esolution with **I**nternalized **C**alibration model	(Allen, Tasumi, Morse, & Trezza, 2005); (Allen, Tasumi, & Trezza, 2007); (Allen, et al., 2011)
geeSEBAL	**G**oogle **E**arth **E**ngine implementation of the **S**urface **E**nergy **B**alance **A**lgorithm for **L**and	(Bastiaanssen, Menenti, Feddes, & Holtslag, 1998); (Laipelt, et al., 2021)
PT-JPL	**P**riestley-**T**aylor **J**et **P**ropulsion **L**aboratory	(Fisher, Tu, & Baldocchi, 2008)
SIMS	**S**atellite **I**rrigation **M**anagement **S**upport	(Melton, et al., 2012); (Pereira, et al., 2020)
SSEBop	**Op**erational **S**implified **S**urface **E**nergy **B**alance	(Senay, et al., 2013); (Senay, 2018)

Data Gathering

Querying OpenET

Identifying Comparison Fields

The purpose of identifying business-as-usual comparison fields was to provide ET comparisons for the water conservation practices in the Program. Bidders were asked to identify a comparison field for their submitted project field during the bidding process, and Committee members worked with growers to identify a comparison field if one had not been submitted. Grantees provided Google Maps images or crop maps highlighting their project and comparison fields. The Committee then transferred them over to Google Earth polygon files (zipped keyhole markup language, KMZ) and confirmed field boundaries with the grantee. Paved roads and large drainage ditches were excluded from the polygons to increase precision of ET estimates.

The Committee developed primary and secondary selection criteria for identifying comparison fields. Primary criteria were necessary metrics for comparison fields to meet, whereas secondary criteria were not crucial but still beneficial to the analysis. Primary criteria included having similar crops, being at least 10-acres in total area or 201.2-meters wide to ensure an accurate query of OpenET containing at least 45 pixels, which are each 30 by 30 meters, and having the same farmer/land manager as the project field. Secondary criteria included having similar soil classifications based on USDA SoilWeb interface, similar elevations and relation to the water course, and comparable farming practices, including irrigation type, and planting and harvesting dates. In some instances, multiple project fields with similar business-as-usual scenarios were paired with the same comparison field. Ultimately, comparison fields were identified for all the project fields, except for the three projects carrying out beneficial bird habitat practices only.

OpenET Query

Individual polygons for project and comparison fields were converted into shapefiles and combined using Esri ArcGIS Pro. A 30-meter negative buffer was applied (hereafter: buffered area) on all sides. This was done to avoid distorting the data with edge effects by excluding ET from nearby areas, including roads, water bodies, nearby fields, and buildings. The combined shapefile attribute table was updated to include a unique name for each shape, the water conservation practice category, crop type information, and other data related to the project or comparison fields. LiDAR data was used to calculate average field elevation for each project and comparison field, and these elevations were added to the attribute table (California Department of Water Resources, 2017).

The combined shapefile was added to a Google Earth Engine account and used to query the OpenET API using Google Collaboratory, an online python code executor, using code written by Will Carrara (CSU Monterey Bay and the OpenET team). The data query used the buffered shapes to retrieve ensemble ETa values, reference ET values (ETo), and precipitation values. Following a training period, it took about five minutes to upload a shapefile, update Collaboratory code to reference this shapefile, run the code, and retrieve the OpenET data. OpenET data was queried by Committee members with access to its beta application programming interface (API). OpenET has monthly data back to 2016, enabling the Committee to query ET data monthly from the 2017 to 2023 water years for this analysis.

Surveys

In addition to data sampled from OpenET, the Delta Conservancy worked with the grantees to gather more information about conditions on their fields. Over the course of the 2023 Program, the Delta Conservancy sent out four surveys to the 2023 DDRPP grantees using Microsoft

Forms. As needed, additional information was collected from grantees through phone conversations, email exchanges, and site visits.

As part of the application process, each Program applicant completed a survey describing their proposed project, including site location, water conservation practice, business-as-usual practice, potential comparison field, and bid price. This information was used to inform the selection process.

Once the grantees were selected, three surveys were sent out to the selected grantees: a grant agreement questionnaire, a progress report, and a grant summary. The grant agreement questionnaire was developed by the Delta Conservancy to update or confirm the information collected during the application phase and to aid in the development of individual grant agreements. The progress report and grant summary questions were developed with consultation from the Oversight Committee. These two surveys were intended to assess the status of the tasks/deliverables outlined in each grant agreement and to gather additional details about the practices carried out on the DDRPP project sites. The questions were designed to collect information on field management practices including crop type, planting dates, harvest dates, weed control, irrigation methods, and drainage methods. Grantees were also asked about beneficial bird habitat nesting cover and shallow flood-up implementation, weather-related flooding, and any changes or issues with the tasks/deliverables outlined in the individual grant agreements. These surveys also collected optional feedback from the grantees about Program delivery and structure, as well as suggestions for future programs/research to support economic well-being and environmental protection in the Delta.

Site Visits

The Oversight Committee and the Delta Conservancy carried out site visits to verify grower practices and to discuss any potential issues or concerns. All grantees enrolled in water conservation practices were visited at least once during the grant term. TNC conducted compliance visits for grantees enrolled in beneficial bird habitat practices. The beneficial bird habitat site visit protocols and results are detailed in Appendix C: Beneficial Bird Habitat Practices Monitoring.

Consumptive Water Use and Estimated Water Savings

15,758 acres of the 16,116 acres enrolled in water conservation practices were analyzed for patterns in consumptive use and estimated water savings. This analysis included 2,769 acres where beneficial bird habitat practices were also being implemented. The total 5,103 acres enrolled in beneficial bird habitat were analyzed separately to explore patterns in consumptive use. Characteristics of analyzed fields are presented in Table 3, Table 4, and Table 5.

OpenET data were processed in R (version 4.3.1) and Python (version 3.10.12). Data were downloaded at a monthly resolution for each field from October 2016 through September 2023. Fields that were divided into separate polygons due to barriers between the two sections of the field (e.g., road, canal) were queried from OpenET as subsamples and combined into a single sample for analysis by summing the subsamples of ETa (ac-ft), ETo (ac-ft), precipitation (ac-ft), buffered field area (ac), and actual field area (ac); taking a weighted average of the mean elevation values (ft); taking the minimum of the field elevation values (ft); and taking the maximum of the field elevation values (ft).

The first response variable included in the analysis is consumptive use (ETa) (Table 7). For consumptive use, higher values indicate higher water loss from the system by ET, and lower values show less water loss. The other two response variables included in the analysis are estimates of water savings produced using two different calculation methods (Table 7). These methods to estimate ET savings were developed by Oversight Committee members and in consultation with OpenET and DWR staff. Each water savings estimation method represents a different way to estimate ET savings, each of which attempts to minimize different potential sources of error.

The comparative savings estimate compares ETa per unit area, in ac-ft/ac, on the project field during the project year to ETa on a comparison field performing business-as-usual field management practices during the project year (Table 7). Positive values indicated consumptive use on the project field for water year 2023 was less than the consumptive use of the comparison field. This method used measurements from the project year only, eliminating sources of interannual variability. However, the degree to which the comparison field accurately represented business-as-usual for the project field also impacted savings estimates.

The normalized savings estimate calculated the difference between mean reference evapotranspiration fraction (EToF, which is calculated as ETa/ETo) for water years 2017-2021 and EToF in water year 2023 monthly. This value was then multiplied by the 2023 ETo, which allowed for a comparison of DDRPP practices to actions on the same field in previous years while removing the effects of differences in past climate conditions represented by field ETo values. This would be the change in ETa relative to past years assuming all years had the same meteorology. Positive savings values indicated consumptive use on the project field for water year 2023 was less than the baseline, while negative values indicated the project field had higher consumptive use in water year 2023 relative to past years. This measurement did not require a comparison field and attempted to remove the impact of interannual variation in atmospheric water demand. Comparing a field during the 2023 water year to the same field during the 2017-2021 water years may have resulted in an underestimate of savings because soil moisture was likely higher in water year 2023 compared to the 2017-2021 water years.

Unfortunately, this study did not directly measure soil moisture. Water year 2022 was eliminated from this estimate to prevent comparing to a DDRPP field enrolled in the 2022 Program.

Water savings estimates were calculated at a monthly timescale to correspond with the monthly consumptive use data. The ETa (ac-ft) was divided by the buffered field area (ac) to convert figures into acre-ft/acre so values could be compared among fields. Annual estimates of consumptive water use, and water savings were calculated by summing estimates across the months of the water year to create an annual total for each project or comparison field. Total savings and use were calculated by multiplying savings and consumptive use (ac-ft/ac) by the enrolled acreage of each field.

Analysis of differences in mean annual water use/savings among water conservation practice types was performed in R using a one-way analysis of variance (ANOVA). The Other Annual and Other Perennial fields were not included in this analysis of differences among groups because of low replication. Though the data residuals were not normally distributed, ANOVA is robust to deviations from normality.

For the analysis to explore the relationship between mean field elevation and annual consumptive use, annual comparative savings, or annual normalized savings, both linear and polynomial regression models were used, with polynomial degrees ranging from 2 to 4. Linear regression models are typically used to represent straight-line relationships between variables, whereas polynomial models are more effective when there is curvature in the data. To assess the performance of each model, they were applied to two datasets: (1) the full dataset, and (2) data partitioned by 5-fold cross-validation. Two metrics were used, R^2 and Mean Squared Error (MSE). R^2 indicates the goodness of fit. A higher R^2 value generally suggests the model explains a larger proportion of the variance in the data. However, it is important to note that a high R^2 value does not necessarily confirm the model's accuracy. MSE quantifies the average squared difference between the observed outcomes and the predictions made by the model. A model with a lower MSE generally provides a closer fit to the data.

Total cost was calculated using the amounts paid in grants for implementation of practices and does not include the costs of administering the Program. Cost per ac-ft of water was calculated by dividing the total cost by the total estimated savings. Error was calculated and is displayed as one standard error about the mean in all tables. Figures comparing elevation and one of the response variables show a linear regression line with 95% confidence intervals around the regression line.

Many factors may lead to ET variations among fields and regions, even within the same vegetation or crop type. Factors driving this variation include soil texture, salinity, ground cover, crop maturity, irrigation system type and distribution uniformity, production goals, fertilizer application, pest and pathogen pressure, field management practices, and other factors. This high level of variability is reflected in the analysis.

Table 7. Response variables included in the analysis. Methods show how data extracted from OpenET were used to determine each response variable.

Variable Name	Method
Consumptive Use (ac-ft/ac)	ETa
Comparative Savings Estimate (ac-ft/ac)	2023 Comparison Field ETa – 2023 Project Field ETa
Normalized Savings Estimate (ac-ft/ac)*	[(Average EToF 2017-2021) - (2023 EToF)] * 2023 ETo

*Where the average EToF across the 5 years is calculated for each month of the water year and compared to monthly 2023 EToF.

Results

Total Consumptive Use and Estimated Water Savings

Table 8. Annual estimated consumptive water use and estimated water savings for the two different estimation methods.

	Area (ac)	Consumptive Use (ac-ft)	Comparative Savings Estimate (ac-ft)	Normalized Savings Estimate (ac-ft)
Total	15,758	43,067	1,890	-2,507

Consumptive Use and Estimated Water Savings by Water Conservation Practice Type

Mean annual consumptive use was 2.70 ± 0.06 ac-ft/ac and ranged from 1.43 to 4.01 ac-ft/ac. Average consumptive use by water conservation practice type can be found in Table 9. The spread of consumptive use measurements among water conservation practice types shows substantial overlap among water conservation practices (Figure 3) ($F_{2,51}$=2.41, p=0.10, does not include Other Annual or Other Perennial). Comparative savings estimates range from -0.53 to 1.98 ac-ft/ac with a mean of 0.18 ± 0.07. On average the normalized savings estimate showed no saved water, with an average savings of -0.08 ± 0.07 and ranging from -1.15 to 2.00 ac-ft/ac. Average comparative savings estimate and normalized savings estimate by water conservation practice type can be found in Table 10. Figure 4 and Figure 5 show substantial overlap among the different water conservation practices for both the comparative savings estimate ($F_{2,51}$=0.43, p=0.65, does not include Other Annual or Other Perennial) and the normalized savings estimate ($F_{2,51}$=0.35, p=0.71, does not include Other Annual or Other Perennial). Figure

2, Figure 6, and Figure 7 show the spread of average consumptive use, comparative savings estimate, and normalized savings estimate across the Delta landscape.

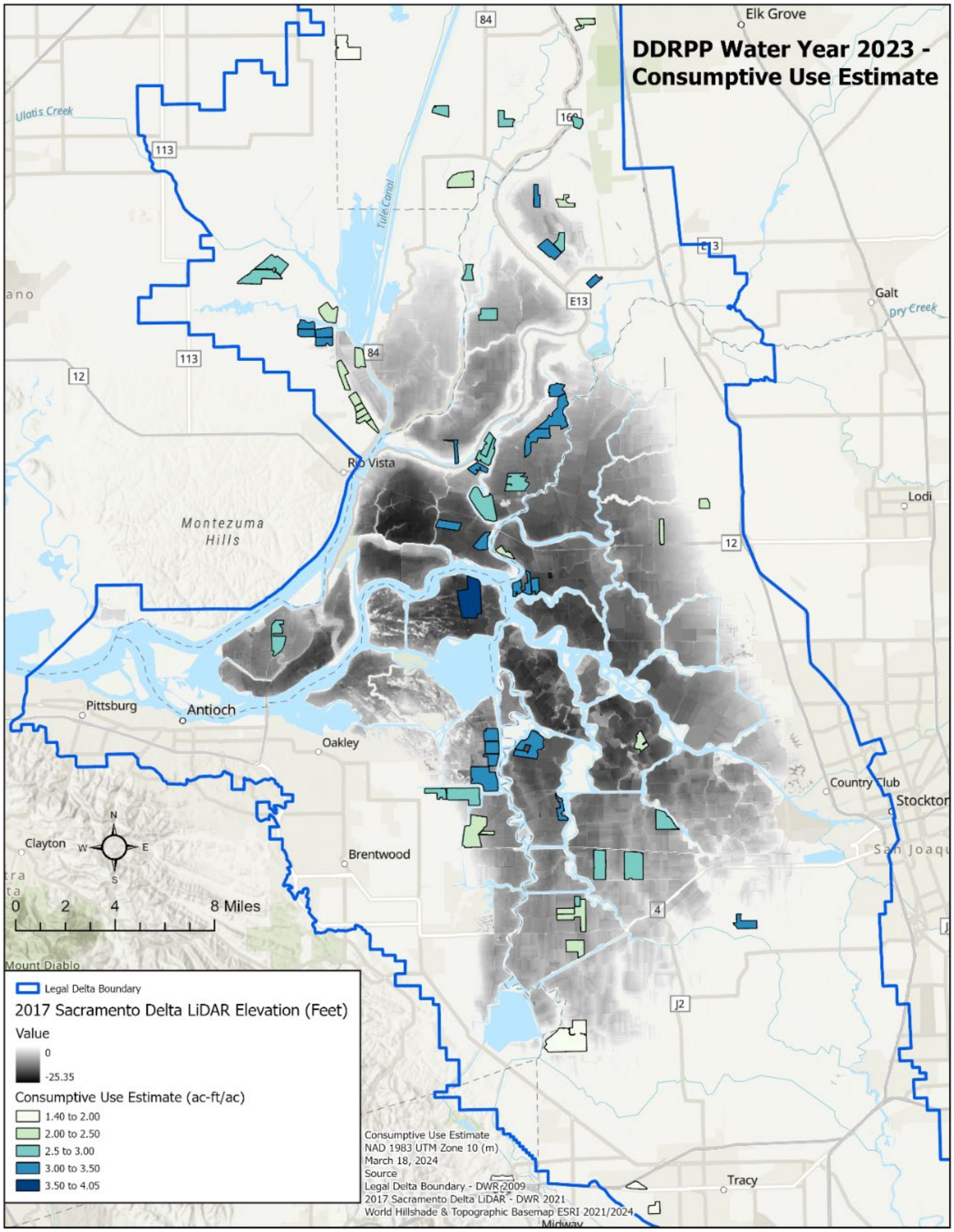

Figure 2. DDRPP water year 2023 consumptive use estimate map.

Table 9. Summary of 2023 consumptive use by water conservation practice type.

	Shift Crop Type	**Deficit Irrigation**	**Forgo Cash Crop**	**Other Perennial**	**Other Annual**
Sample Size	22	18	14	2	2
Total Area (ac)	5,048	4,769	4,362	1,370	209
Total Consumptive Use (ac-ft)	13,843	13,906	12,153	2,653	512
Mean Consumptive Use (ac-ft/ac) ± standard error	2.72 ± 0.07	2.90 ± 0.11	2.55 ± 0.15	2.08 ± 0.32	2.45 ± 0.05
Median Consumptive Use (ac-ft/ac)	2.78	3.03	2.43	2.08	2.45
Range Consumptive Use (ac-ft/ac)	1.95 to 3.11	1.58 to 4.01	1.43 to 3.37	1.77 to 2.40	2.40 to 2.49

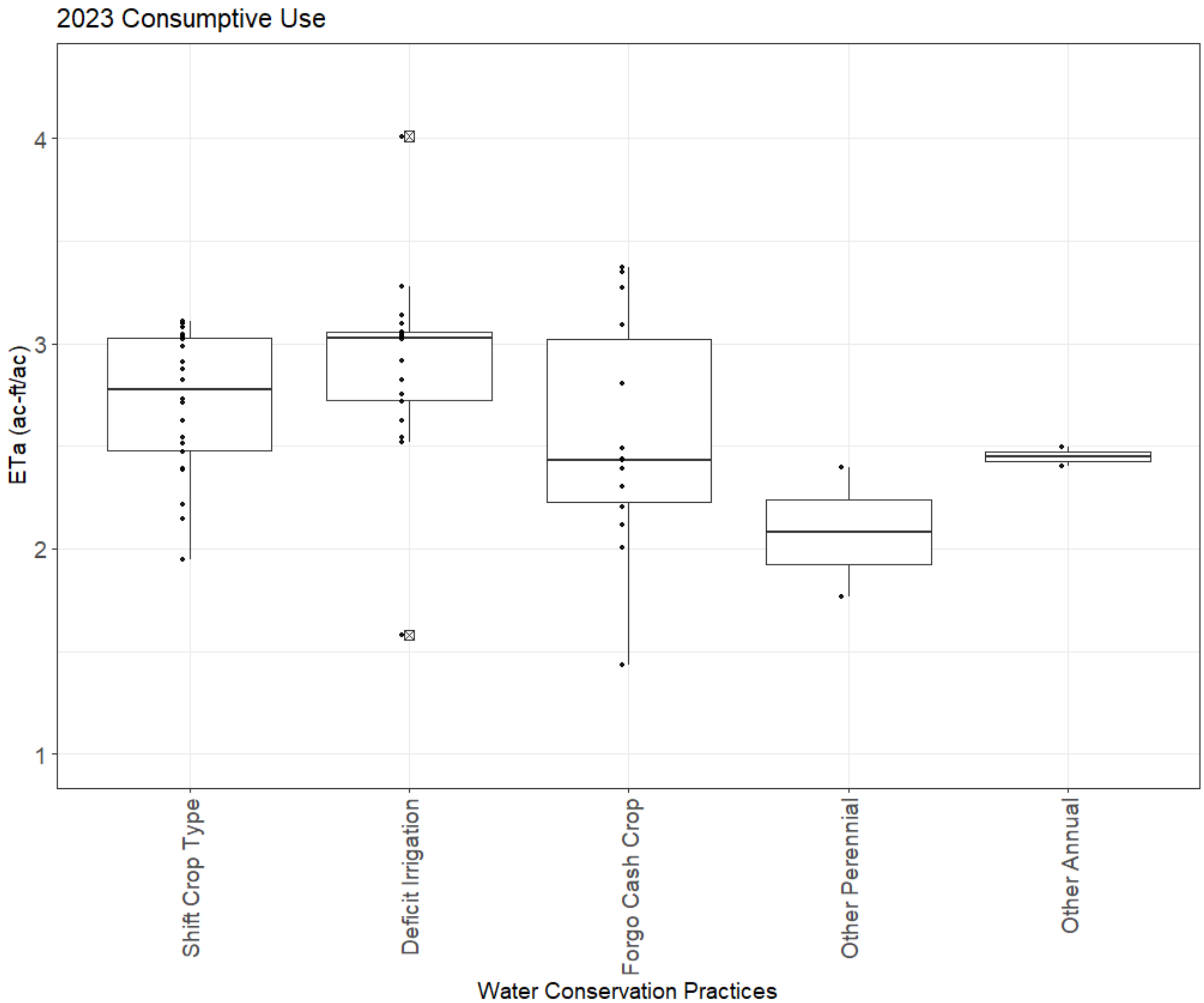

Figure 3: Boxplot of annual consumptive use (ac-ft/ac) among water conservation practices. Median values are indicated by the horizontal bar in each box. The lower and upper ends of the box correspond to the first and third quartiles (the 25th and 75th percentiles). The upper whisker extends from the box to the largest value no further than 1.5 times the interquartile range from the top of the box. The lower whisker extends from the box to the smallest value, at most 1.5 times the interquartile range of the box. Outliers are shown as x in a square. Points represent ETa values of individual fields.

Table 10. Summary of water savings estimates by water conservation practice type.

	Shift Crop Type	Deficit Irrigation	Forgo Cash Crop	Other Perennial	Other Annual
Sample Size	22	18	14	2	2
Total Area (ac)	5,048	4,769	4,362	1,370	209
Total Comparative Savings Estimate (ac-ft)	547	1,160	150	123	-90
Mean Comparative Savings Estimate (ac-ft/ac) ± standard error	0.14 ± 0.11	0.21 ± 0.12	0.30 ± 0.14	0.03 ± 0.13	-0.43 ± 0.05
Median Comparative Savings Estimate (ac-ft/ac)	-0.06	0.07	0.32	0.03	-0.43
Range Comparative Savings Estimate (ac-ft/ac)	-0.50 to 1.35	-0.42 to 1.98	-0.53 to 1.11	-0.09 to 0.16	-0.47 to -0.38
Total Normalized Savings Estimate (ac-ft)	-674	-427	-1,474	52	17
Mean Normalized Savings Estimate (ac-ft/ac) ± standard error	-0.16 ± 0.06	-0.07 ± 0.14	-0.01 ± 0.19	-0.02 ± 0.12	0.09 ± 0.22
Median Normalized Savings Estimate (ac-ft/ac)	-0.15	-0.13	-0.01	-0.02	0.09
Range Normalized Savings Estimate (ac-ft/ac)	-0.65 to 0.38	-1.15 to 2.00	-1.01 to 1.07	-0.14 to 0.10	-0.14 to 0.32

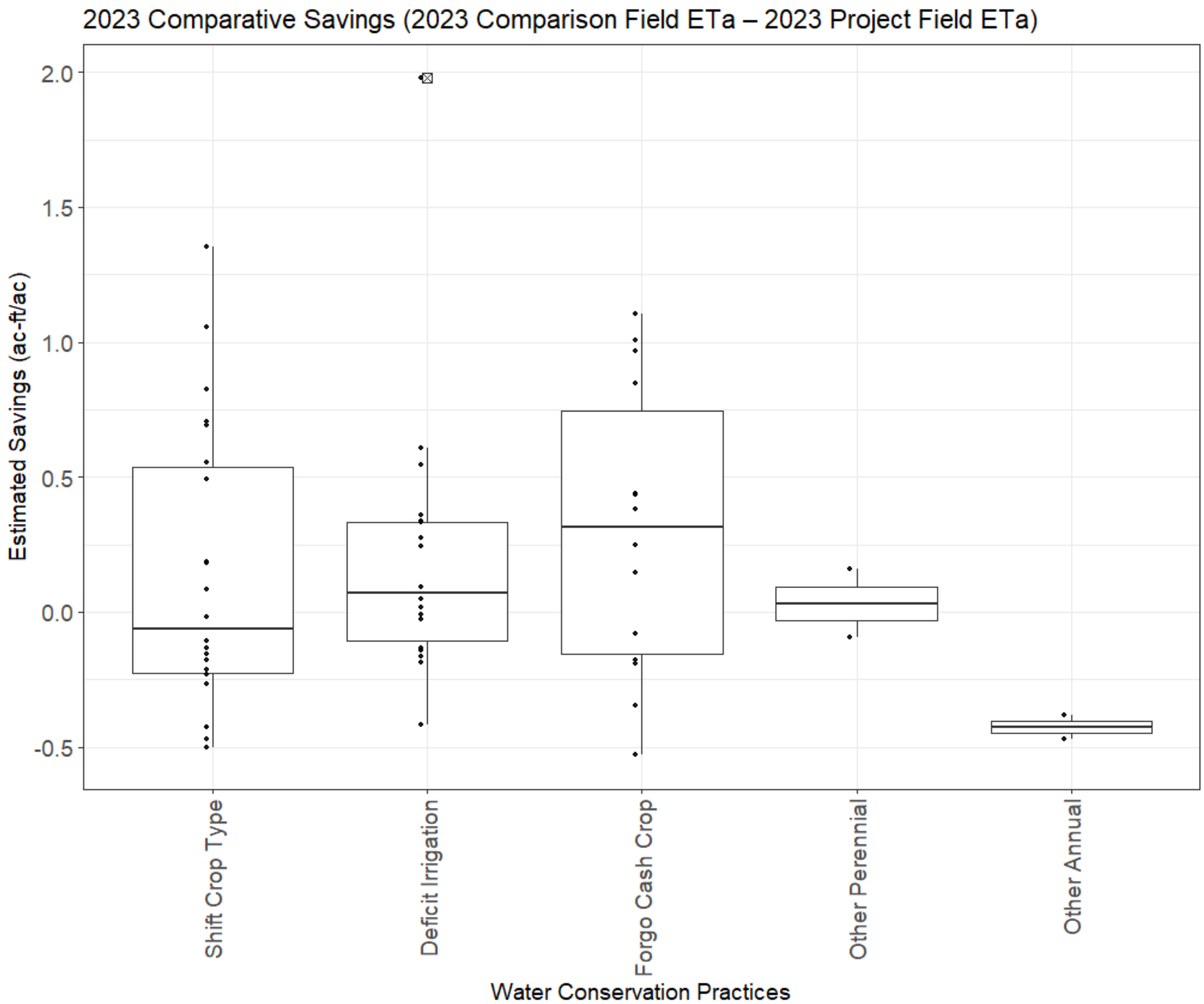

Figure 4. Boxplot of annual estimated water savings (ac-ft/ac) using the comparative savings estimate among water conservation practice types. Median values are indicated by the horizontal bar in each box. The lower and upper ends of the box correspond to the first and third quartiles (the 25th and 75th percentiles). The upper whisker extends from the box to the largest value no further than 1.5 times the interquartile range from the top of the box. The lower whisker extends from the box to the smallest value, at most 1.5 times the interquartile range of the box. Outliers are shown as x in a square. Points represent ETa values of individual fields.

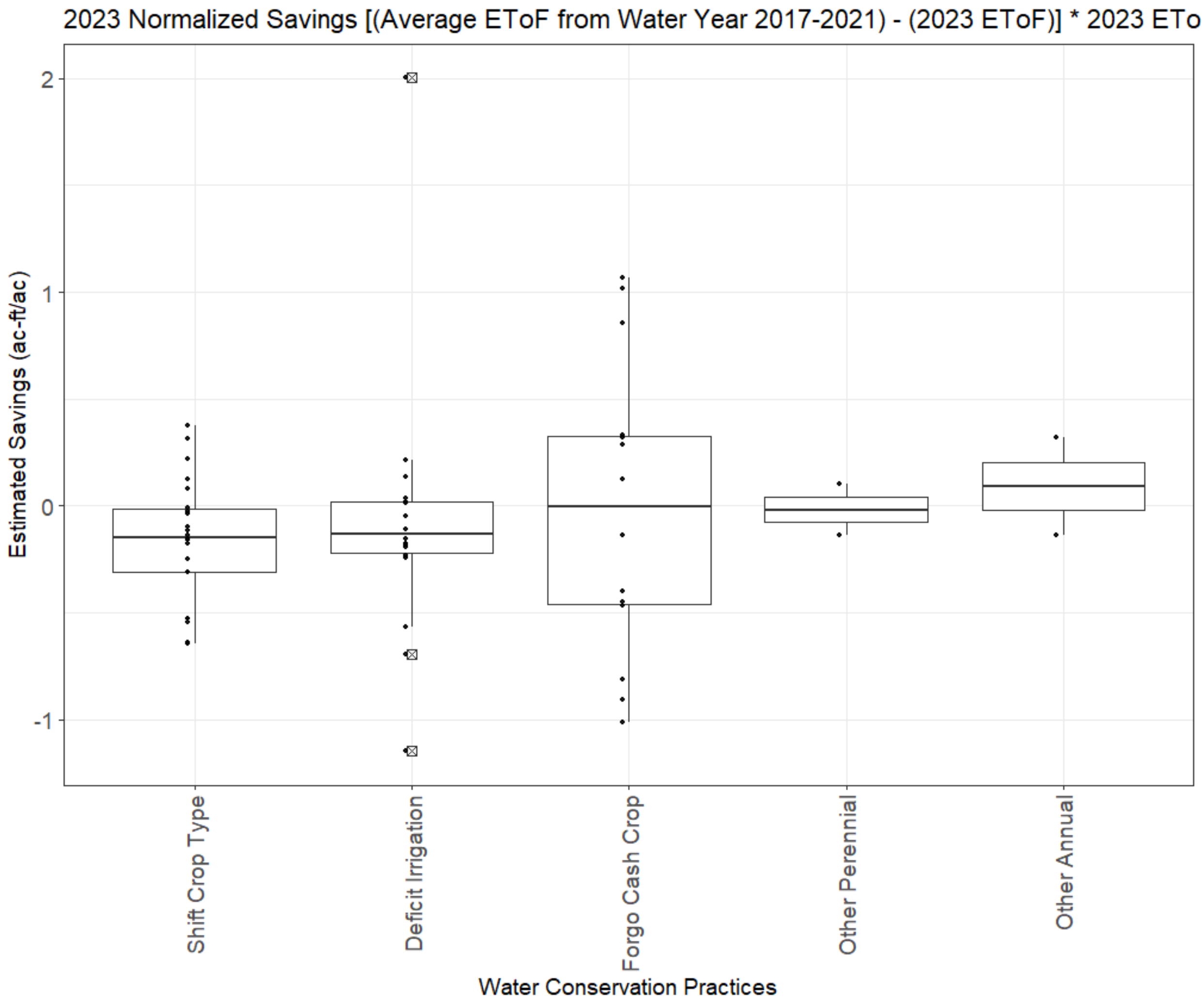

Figure 5. Boxplot of annual estimated water savings (ac-ft/ac) using the normalized savings estimate among water conservation practices. Median values are indicated by the horizontal bar in each box. The lower and upper ends of the box correspond to the first and third quartiles (the 25th and 75th percentiles). The upper whisker extends from the box to the largest value no further than 1.5 times the interquartile range from the top of the box. The lower whisker extends from the box to the smallest value, at most 1.5 times the interquartile range of the box. Outliers are shown as x in a square. Points represent ETa values of individual fields.

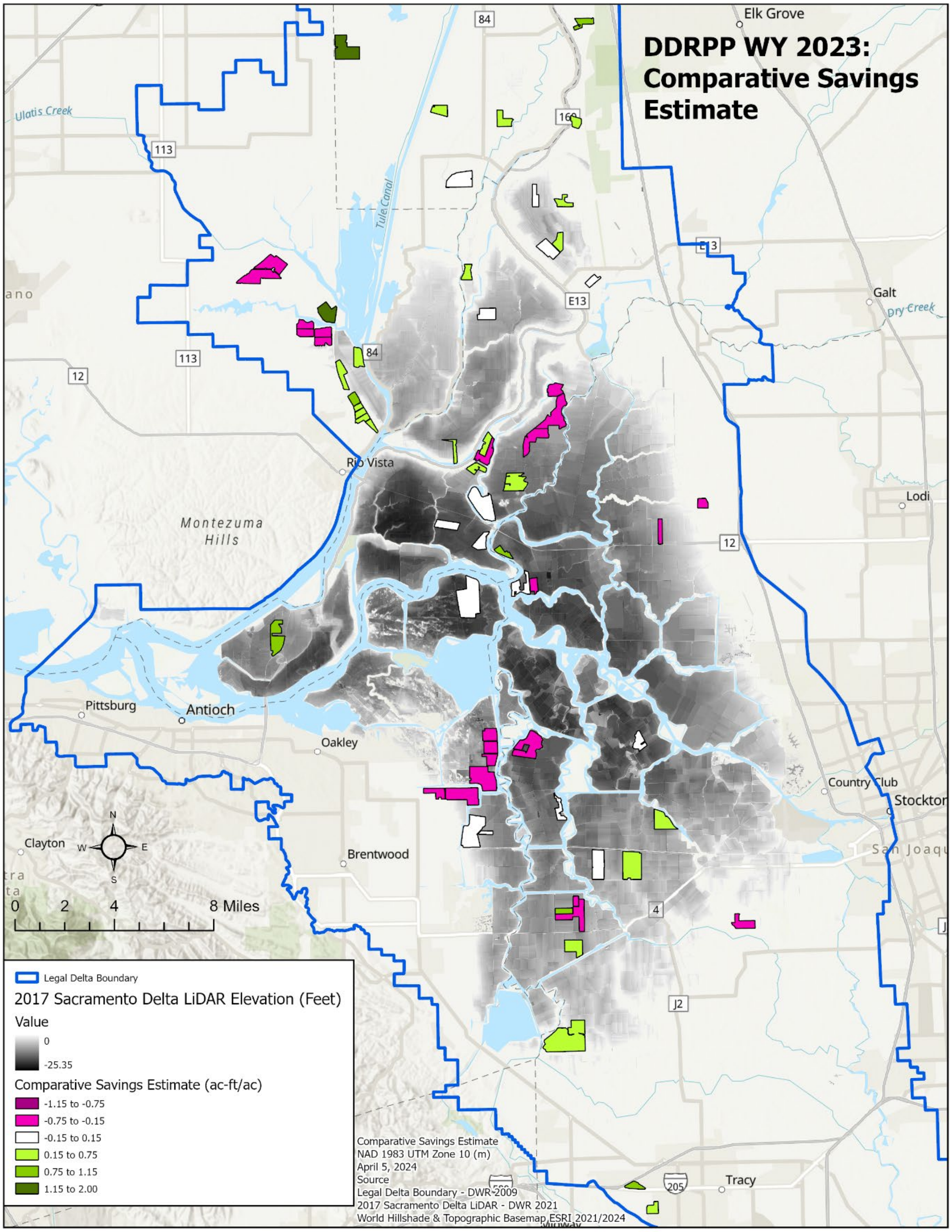

Figure 6. DDRPP water year 2023 comparative savings estimate map.

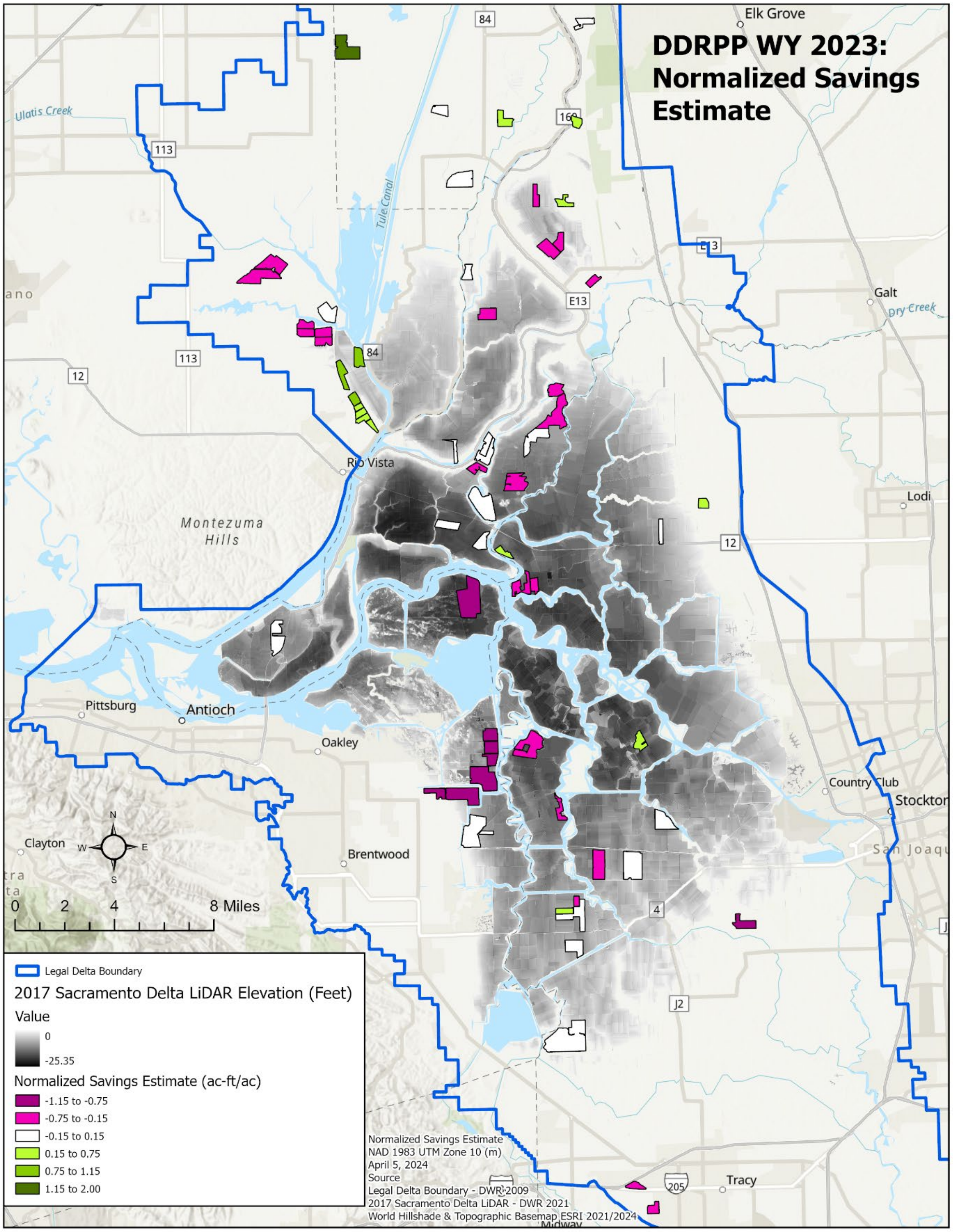

Figure 7. DDRPP water year 2023 normalized savings estimate map.

Consumptive Use and Estimated Water Savings by Sub-practice

The project fields varied in their current and interannual field management conditions, and these sub-practices varied in their level of replication in the dataset. Deficit Irrigation of corn was the most common sub-practice (*n*=11), followed by shifting from planting corn to planting triticale (*n*=6) or safflower (*n*=6), and forgoing a cash crop of corn and instead planting winter wheat harvested by July 2023 (*n*=6). Of these more highly replicated sub-practices, only forgoing a summer cash crop of corn with a crop of winter wheat showed estimated savings using both estimation methods. Deficit Irrigation of corn showed some saving, but only using the comparative savings estimate. Growing corn without a winter crop of wheat (*n*=3) had the highest consumptive use and showed no savings with either calculation method. Deficit Irrigation of almonds (*n*=2) had the lowest consumptive use and showed some small level of estimated savings using both calculation methods. Shifting away from alfalfa had estimated water savings across water conservation practices in water year 2023; only shifting from alfalfa to sorghum-sudangrass calculated by the normalized savings estimate method did not show savings.

Table 11, Table 12, and Table 13 detail all the sub-practices, most of which are not replicated; data is displayed by water conservation practice type, the primary business-as-usual crop that would have been planted if the field had not been enrolled in the DDRPP, and the primary crop planted in the 2023 water year.

Because there was widespread flooding during the implementation of spring flooding for bird habitat in Jan-April 2023 and consumptive use was similar across all field types during this period, areas implementing overlapping beneficial bird habitat and other water conservation practices were included in the analysis of the water conservation practices (see Beneficial Bird Habitat Practices below for details).

Table 11. Summary of consumptive water use by crop and water conservation practice types.

Water Conservation Practice	2023 Planted Crop	Sample Size	Total Area (ac)	Mean Consumptive Use (ac-ft/ac) ± standard error	Median Consumptive Use (ac-ft/ac)	Range Consumptive Use (ac-ft/ac)
Shift Crop Type	Barley	1	168	2.15	2.15	-
Shift Crop Type	Corn	1	59	2.73	2.73	-
Shift Crop Type	Safflower	8	1,381	2.83 ± 0.12	3.01	2.21 to 3.10
Shift Crop Type	Sorghum-Sudangrass	1	136	2.47	2.47	-

Water Conservation Practice	2023 Planted Crop	Sample Size	Total Area (ac)	Mean Consumptive Use (ac-ft/ac) ± standard error	Median Consumptive Use (ac-ft/ac)	Range Consumptive Use (ac-ft/ac)
Shift Crop Type	Triticale	9	2,836	2.82 ± 0.08	2.87	2.39 to 3.11
Shift Crop Type	Wheat	2	468	2.17 ± 0.22	2.17	1.95 to 2.39
Deficit Irrigation	Corn	11	2,273	2.98 ± 0.07	3.04	2.52 to 3.28
Deficit Irrigation	Hay	1	729	2.82	2.82	-
Deficit Irrigation	Pasture	3	1,321	2.78 ± 0.70	2.75	1.58 to 4.01
Deficit Irrigation	Triticale	3	446	2.77 ± 0.15	2.72	2.54 to 3.06
Forgo Cash Crop	None	5	2,064	2.90 ± 0.24	3.09	2.00 to 3.34
Forgo Cash Crop	Triticale	1	98	2.21	2.21	-
Forgo Cash Crop	Wheat	8	2,200	2.37 ± 0.19	2.42	1.43 to 3.37
Other Perennial	Almonds	1	1,000	1.77	1.77	-
Other Perennial	Grapes	1	370	2.4	2.4	-
Other Annual	Peppers	1	99	2.4	2.4	-
Other Annual	Tomatoes	1	110	2.49	2.49	-

Table 12. Summary of estimated savings using the comparative savings estimate method by crop and water conservation practice types.

Water Conservation Practice	Business-as-Usual Crop	2023 Planted Crop	Sample Size	Total Area (ac)	Mean Estimated Savings (ac-ft/ac) ± standard error	Median Estimated Savings (ac-ft/ac)	Range Estimated Savings (ac-ft/ac)
Shift Crop Type	Alfalfa	Safflower	2	324	0.70 ± 0.01	0.70	0.69 to 0.71
Shift Crop Type	Alfalfa	Sorghum-Sudangrass	1	136	1.06	1.06	-
Shift Crop Type	Alfalfa	Triticale	1	271	1.35	1.35	-
Shift Crop Type	Corn	Barley	1	168	-0.14	-0.14	-
Shift Crop Type	Corn	Safflower	6	1,057	-0.02 ± 0.12	-0.17	-0.23 to 0.55
Shift Crop Type	Corn	Triticale	8	2,565	-0.04 ± 0.16	-0.06	-0.50 to 0.83
Shift Crop Type	Corn	Wheat	1	117	0.49	0.49	-
Shift Crop Type	Tomatoes	Corn	1	59	-0.43	-0.43	-
Shift Crop Type	Tomatoes	Wheat	1	351	-0.27	-0.27	-
Deficit Irrigation	Corn	Corn	11	2,273	0.14 ± 0.08	0.05	-0.16 to 0.61
Deficit Irrigation	Hay	Hay	1	729	-0.19	-0.19	-
Deficit Irrigation	Irrigated Pasture	Pasture	3	1,321	0.80 ± 0.59	0.33	0.09 to 1.98
Deficit Irrigation	Triticale	Triticale	3	446	-0.01 ± 0.23	0.02	-0.42 to 0.36

Water Conservation Practice	Business-as-Usual Crop	2023 Planted Crop	Sample Size	Total Area (ac)	Mean Estimated Savings (ac-ft/ac) ± standard error	Median Estimated Savings (ac-ft/ac)	Range Estimated Savings (ac-ft/ac)
Forgo Cash Crop	Alfalfa	None	1	105	1.11	1.11	-
Forgo Cash Crop	Alfalfa	Wheat	1	106	0.97	0.97	-
Forgo Cash Crop	Corn	None	3	1,758	-0.21 ± 0.08	-0.19	-0.35 to -0.08
Forgo Cash Crop	Corn	Triticale	1	98	0.85	0.85	-
Forgo Cash Crop	Corn	Wheat	6	1,845	0.37 ± 0.16	0.41	-0.18 to 1.01
Forgo Cash Crop	Tomatoes	None	1	201	-0.53	-0.53	-
Forgo Cash Crop	Wheat	Wheat	1	249	0.25	0.25	-
Other Perennial	Almonds	Almonds	1	1,000	0.16	0.16	-
Other Perennial	Grapes	Grapes	1	370	-0.09	-0.09	-
Other Annual	Corn	Peppers	1	99	-0.38	-0.38	-
Other Annual	Corn	Tomatoes	1	110	-0.47	-0.47	-

Table 13. Summary of estimated savings using the normalized savings estimate method by crop and water conservation practices.

Water Conservation Practice	Business-as-usual Crop	2023 Planted Crop	Sample Size	Total Area (ac)	Mean Estimated Savings (ac-ft/ac) ± standard error	Median Estimated Savings (ac-ft/ac)	Range Estimated Savings (ac-ft/ac)
Shift Crop Type	Alfalfa	Safflower	2	324	0.23 ± 0.15	0.23	0.08 to 0.38
Shift Crop Type	Alfalfa	Sorghum-Sudangrass	1	136	-0.10	-0.10	-
Shift Crop Type	Alfalfa	Triticale	1	271	0.13	0.13	-
Shift Crop Type	Corn	Barley	1	168	0.31	0.31	-
Shift Crop Type	Corn	Safflower	6	1,057	-0.38 ± 0.14	-0.53	-0.65 to 0.22
Shift Crop Type	Corn	Triticale	8	2,565	-0.16 ± 0.04	-0.15	-0.31 to -0.02
Shift Crop Type	Corn	Wheat	1	117	-0.54	-0.54	-
Shift Crop Type	Tomatoes	Corn	1	59	-0.25	-0.25	-
Shift Crop Type	Tomatoes	Wheat	1	351	-0.01	-0.01	-
Deficit Irrigation	Corn	Corn	11	2,273	-0.13 ± 0.07	-0.11	-0.69 to 0.14
Deficit Irrigation	Hay	Hay	1	729	-0.24	-0.24	-
Deficit Irrigation	Irrigated Pasture	Pasture	3	1,321	0.36 ± 0.91	0.22	-1.15 to 2.00
Deficit Irrigation	Triticale	Triticale	3	446	-0.25 ± 0.17	-0.19	-0.56 to 0.01
Forgo Cash Crop	Alfalfa	None	1	105	0.33	0.33	-

Water Conservation Practice	Business-as-usual Crop	2023 Planted Crop	Sample Size	Total Area (ac)	Mean Estimated Savings (ac-ft/ac) ± standard error	Median Estimated Savings (ac-ft/ac)	Range Estimated Savings (ac-ft/ac)
Forgo Cash Crop	Alfalfa	Wheat	1	106	1.07	1.07	-
Forgo Cash Crop	Corn	None	3	1,758	-0.74 ± 0.18	-0.81	-1.01 to -0.40
Forgo Cash Crop	Corn	Triticale	1	98	0.29	0.29	-
Forgo Cash Crop	Corn	Wheat	6	1,845	0.19 ± 0.26	0.09	-0.47 to 1.02
Forgo Cash Crop	Tomatoes	None	1	201	-0.91	-0.91	-
Forgo Cash Crop	Wheat	Wheat	1	249	0.13	0.13	-
Other Perennial	Almonds	Almonds	1	1,000	0.10	0.10	-
Other Perennial	Grapes	Grapes	1	370	-0.14	-0.14	-
Other Annual	Corn	Peppers	1	99	0.32	0.32	-
Other Annual	Corn	Tomatoes	1	110	-0.14	-0.14	-

Estimated Consumptive Use and Water Savings vs Elevation

Two fields had elevations substantially higher than the rest of the sample set (Figure 8); these fields were removed from the remaining regression plots to better display data trends. Though overall savings were modest, on average sites above sea level (n = 15) had lower consumptive use and higher estimated savings than sites below sea level (n = 43) (Table 14). Though sites above sea level appeared to save more water, numerous sites below sea level had some estimated water savings (Figure 11, Figure 13) or more moderate consumptive use (Figure 9).

All regression models exploring annual use/savings vs elevation showed low R^2 values when using the whole dataset (Table 15) or when excluding the two outliers (Figure 9, Figure 11, Figure 14). However, polynomial models showed a slight improvement in performance compared to the simple linear model. This improvement in the polynomial models indicated a nonlinear relationship between elevation and consumptive use. To assess the performance of all regression models on unseen data, 5-fold cross-validation was employed. During cross-validation, the mean squared error (MSE) values for all polynomial models were significantly higher, indicating that these models were excessively overfitting the data (Table 16). Given the limited data availability, training more complex models such as random forests or support vector regression was not viable. Consequently, simple linear regression models, which outperformed polynomial models in cross-validation and extend ease of interpretation, were the preferred approach for this analysis. Dispersion of data and the low R^2 value suggest a weak negative linear relationship between elevation and water use (Figure 8, Figure 9) and a weak positive relationship between elevation and estimated water savings (Figure 11, Figure 13).

The relationship between elevation, ET, and crop type was explored for the six crop types with some replication (triticale n = 13, corn n = 12, wheat n = 10, safflower n = 8, no crop n = 5, and pasture n = 3). Though no regression analysis was done on this data subset, linear trend lines are still shown to aid in interpretation. Deficit irrigated pasture had estimated water savings across elevations when using the comparative savings estimate and saved water above sea level using the normalized savings estimate.

Table 14. Consumptive use and estimated savings for fields above and below sea level.

Response Variable	Count	Area (ac)	ET (ac-ft/ac)	Median ET (ac-ft/ac)	Maximum ET (ac-ft/ac)	Minimum ET (ac-ft/ac)
Consumptive Use: above sea level	15	3,226	2.43 ± 0.13	2.43	2.09	1.43
Consumptive Use: below sea level	43	12,532	2.80 ± 0.07	2.87	4.01	1.77

Response Variable	Count	Area (ac)	ET (ac-ft/ac)	Median ET (ac-ft/ac)	Maximum ET (ac-ft/ac)	Minimum ET (ac-ft/ac)
Comparative Savings: above sea level	15	3,226	0.47 ± 0.17	0.49	1.98	-0.53
Comparative Savings: below sea level	43	12,532	0.07 ± 0.07	-0.02	1.35	-0.50
Normalized Savings: above sea level	15	3,226	0.11 ± 0.18	0.08	2.00	-0.90
Normalized Savings: below sea level	43	12,532	-0.15 ± 0.06	-0.14	1.02	-1.15

Table 15. Performance of linear and polynomial models using full data set.

	Linear	Polynomial (Degree 2)	Polynomial (Degree 3)	Polynomial (Degree 4)
R^2 Consumptive Use	0.27	0.29	0.30	0.31
MSE Consumptive Use	0.15	0.15	0.14	0.14
R^2 Comparative Savings	0.13	0.16	0.22	0.23
MSE Comparative Savings	0.22	0.21	0.20	0.19
R^2 Normalized Savings	0.04	0.14	0.17	0.23
MSE Normalized Savings	0.26	0.22	0.21	0.20

Table 16. Performance of linear and polynomial models using 5-fold cross-validation.

	Linear	Polynomial (Degree 2)	Polynomial (Degree 3)	Polynomial (Degree 4)
MSE Consumptive Use	0.19	0.62	56.5	2224.8
MSE Comparative Savings	0.32	4.6	41.9	91.2
MSE Normalized Savings	0.51	6.52	69.4	8.8

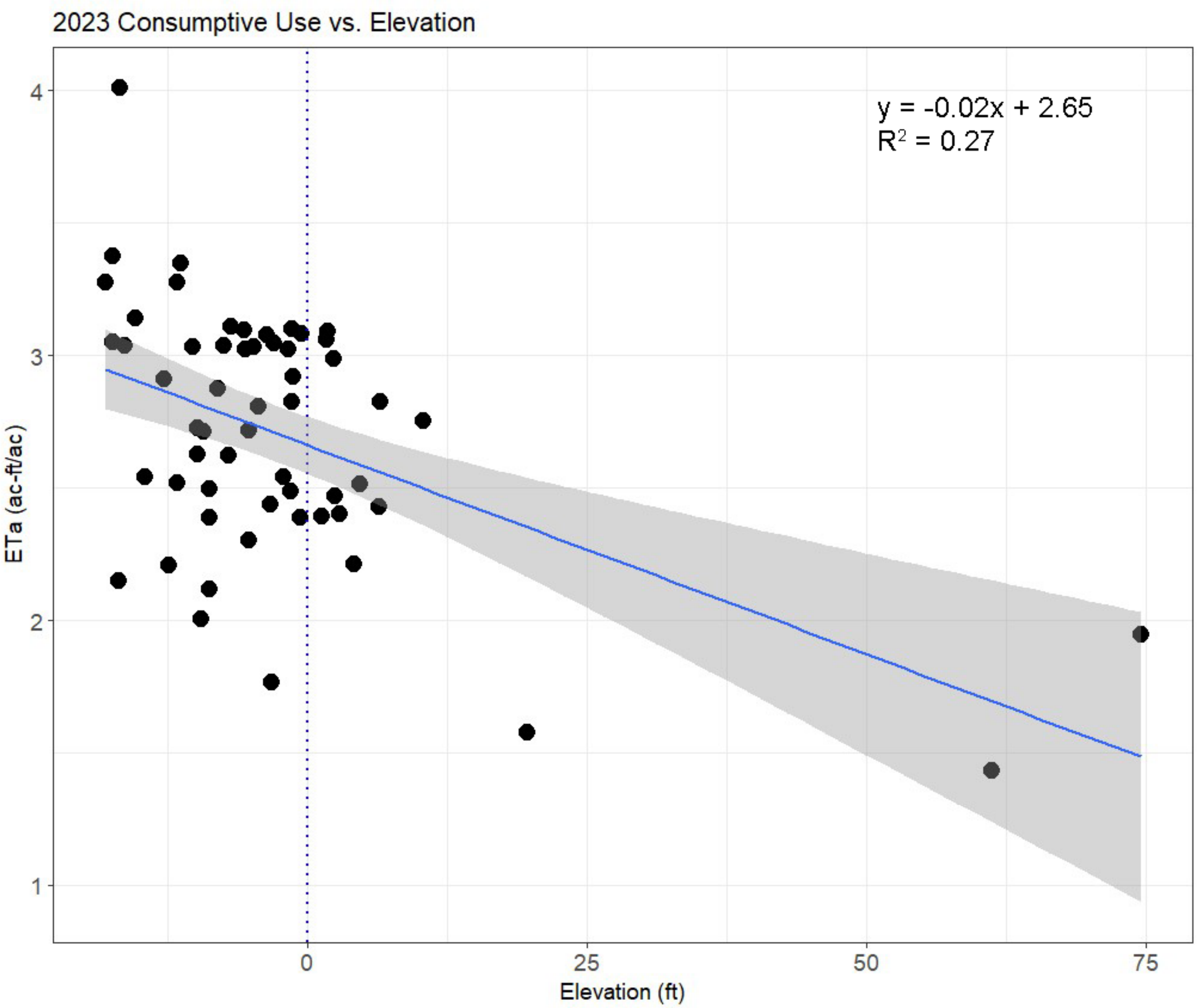

Figure 8. Consumptive use (ac-ft/ac) vs elevation (ft) with outliers. The blue line represents the linear model for elevation and consumptive use, and the grey represents a 95% confidence interval.

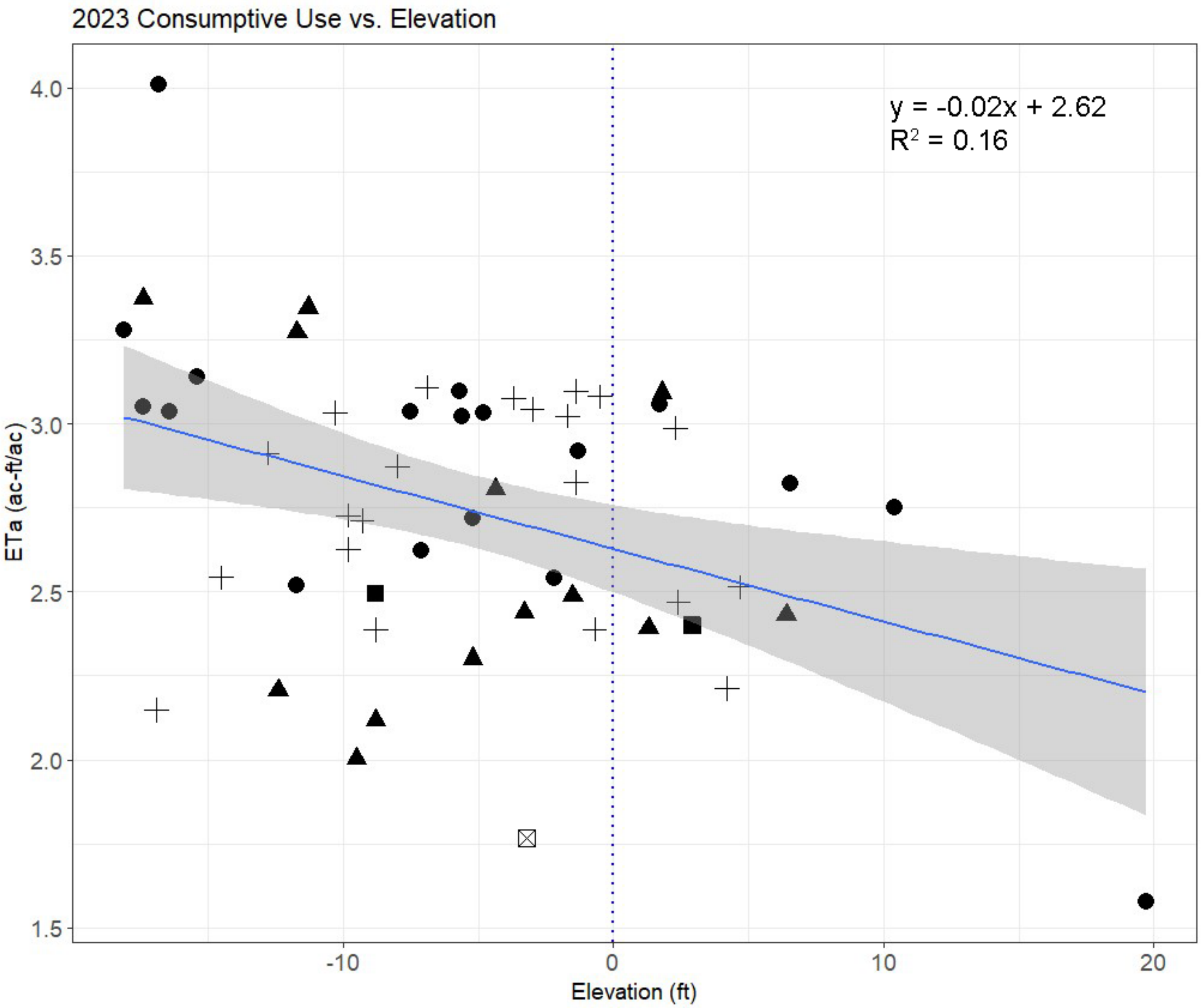

Figure 9. Consumptive use (ac-ft/ac) vs elevation (ft) without outliers. Deficit Irrigation is symbolized as a circle, Forgo Cash Crop is symbolized as a triangle, Shift Crop Type is symbolized as a cross, Other Annual is symbolized as a square, and Other Perennial is symbolized as a box with an x. The solid blue line represents the linear model for elevation and consumptive use pooled across water conservation practice types and excluding outliers, and the grey represents a 95% confidence interval.

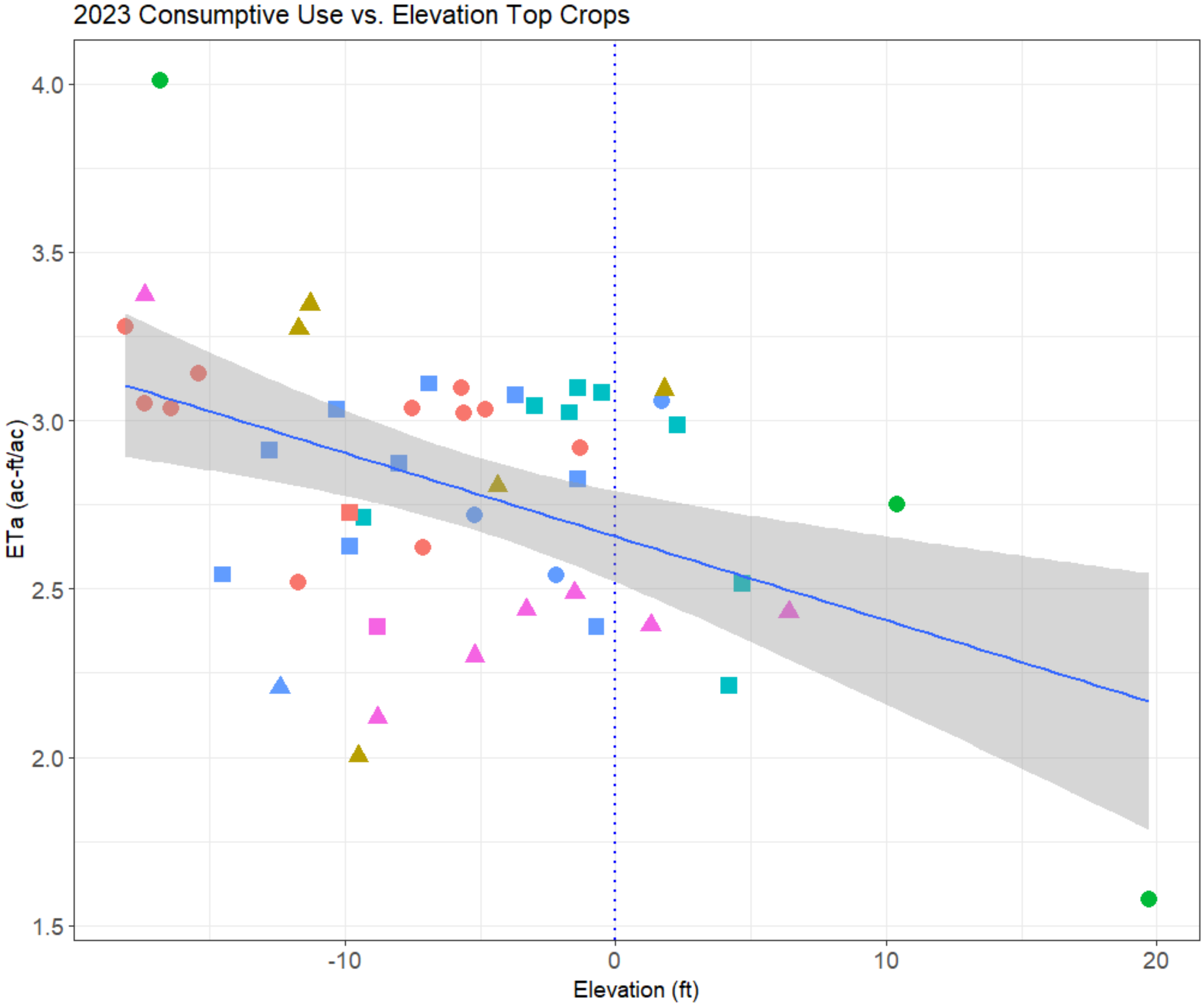

Figure 10. Consumptive use (ac-ft/ac) vs elevation (ft) for top six crop types without outliers. Deficit Irrigation is symbolized by a circle, Forgo Cash Crop is symbolized by a triangle, and Shift Crop Type is symbolized by a square. Corn is shown in red, fallow fields are gold, pasture is green, safflower is blue-green, triticale is blue, and wheat is pink. The linear trend line is shown only to assist in graphic interpretation.

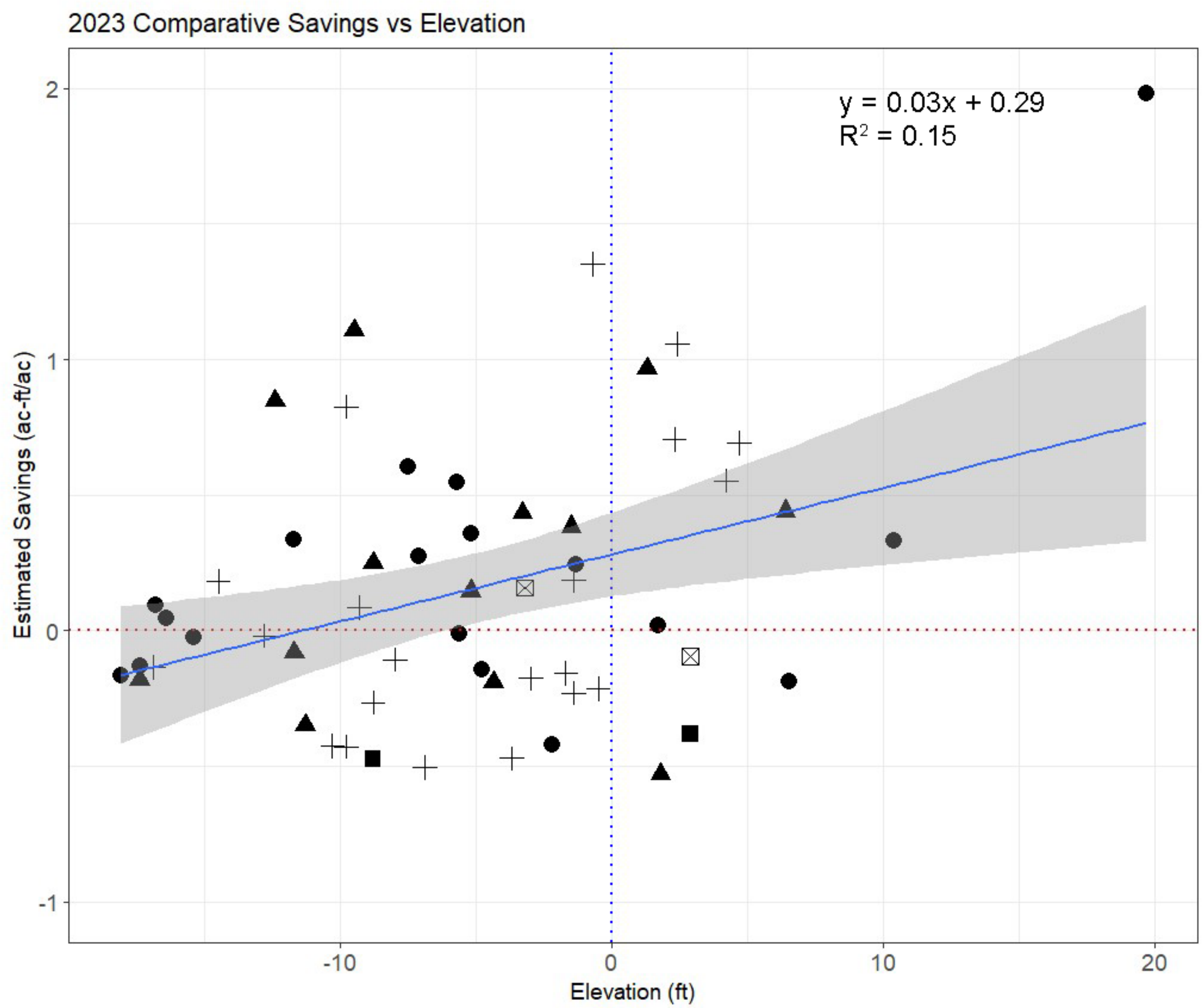

Figure 11. Comparative savings estimate (ac-ft/ac) vs elevation (ft) without outliers. Deficit Irrigation is symbolized as a circle, Forgo Cash Crop is symbolized as a triangle, Shift Crop Type is symbolized as a cross, Other Annual is symbolized as a square, and Other Perennial is symbolized as a box with an x. The blue dashed line represents sea level, and the red dashed line shows the zero water savings estimate. The solid blue line represents the linear model for elevation and comparative savings estimates pooled across water conservation practice types and excluding outliers, and the grey represents a 95% confidence interval.

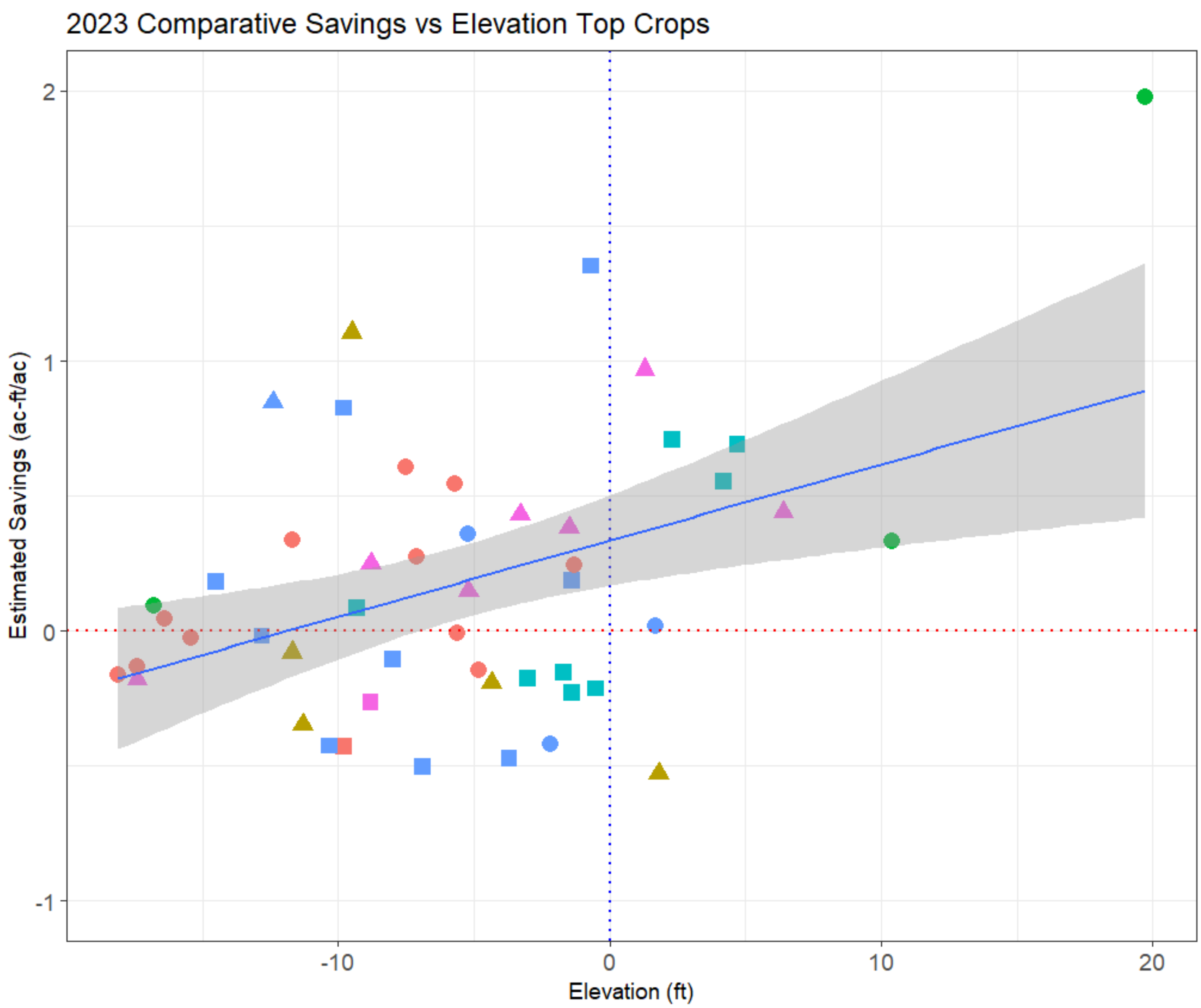

Figure 12. Comparative savings estimates vs elevation showing top 6 crops without outliers. Deficit Irrigation is symbolized by a circle, Forgo Cash Crop is symbolized by a triangle, and Shift Crop Type is symbolized by a square. Corn is shown in red, fallow fields are gold, pasture is green, safflower is blue-green, triticale is blue, and wheat is pink. The blue dashed line represents sea level, and the red dashed line shows the zero water savings estimate. The linear trend line is shown only to assist in graphic interpretation.

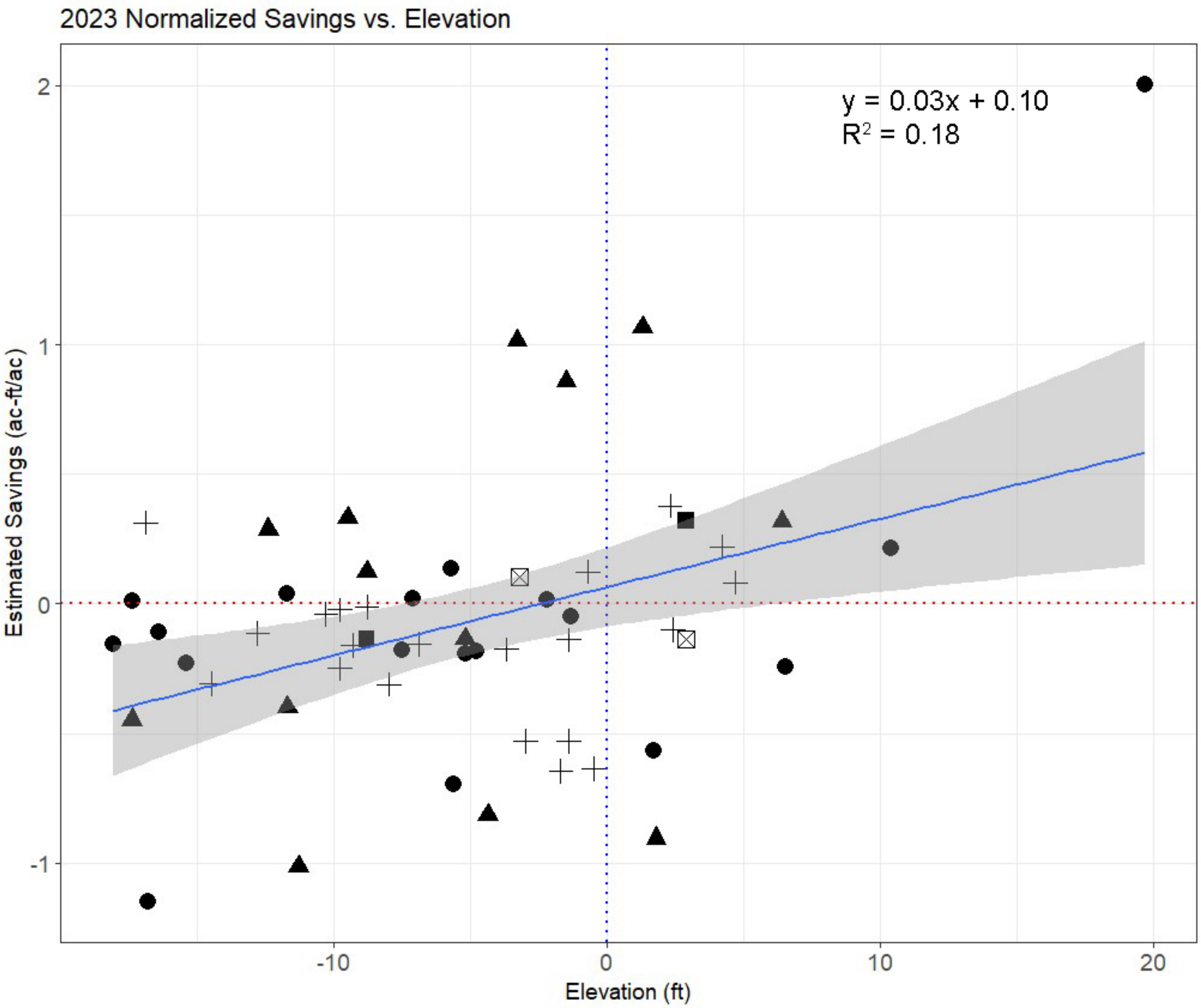

Figure 13. Normalized savings estimate (ac-ft/ac) vs elevation (ft) without outliers. Deficit Irrigation is symbolized as a circle, Forgo Cash Crop is symbolized as a triangle, Shift Crop Type is symbolized as a cross, Other Annual is symbolized as a square, and Other Perennial is symbolized as a box with an x. The blue dashed line represents sea level, and the red dashed line shows the zero water savings estimate. The solid blue line represents the linear model for elevation and normalized savings estimates pooled across water conservation practice types and excluding outliers, and the grey represents a 95% confidence interval.

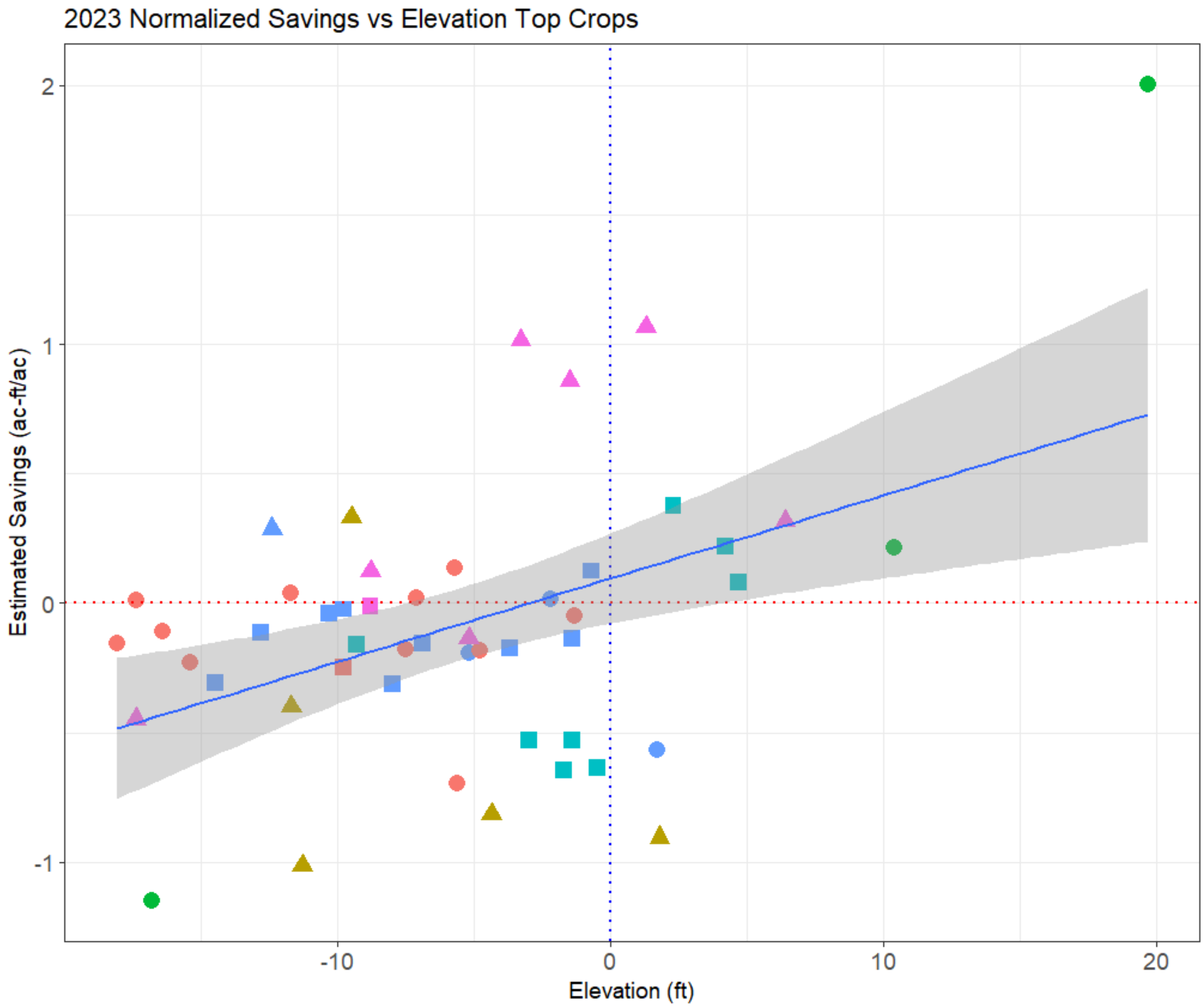

Figure 14. Normalized savings estimate (ac-ft/ac) vs elevation (ft) top six crops shown without outliers. Deficit Irrigation is symbolized by a circle, Forgo Cash Crop is symbolized by a triangle, and Shift Crop Type is symbolized by a square. Corn is shown in red, fallow fields are gold, pasture is green, safflower is blue-green, triticale is blue, and wheat is pink. The blue dashed line represents sea level, and the red dashed line shows the zero water savings estimate. The blue line represents the linear model for elevation and normalized savings estimates pooled across water conservation practice types and excluding outliers, and the grey represents a 95% confidence interval. The linear trend line is shown only to assist in graphic interpretation.

Cost of Water Savings

Overall, water savings estimated for the Program were low, thus cost per ac-ft of water saved was high (Table 17). This was true across water conservation practice types (Table 18). Fields above sea level more efficiently saved water and costs were less for each ac-ft estimated to have been saved (Table 19).

Table 17. Cost per acre-foot of water saved.

Water Savings Estimation Method	Count*	Total Cost ($)	Total Savings (ac-ft)	Cost per ac-ft ($)
Comparative Savings	58	9,819,590	1,890	5,194
Normalized Savings	58	9,819,590	-2,507	-

*Does not include areas where only beneficial bird habitat practices were performed.

Table 18. Cost per acre-foot of water saved by water conservation practice.

Response Variable	Water Conservation Practice	Count*	Total Area (ac)*	Total Cost ($)	Total Savings (ac-ft)	Cost per ac-ft
Comparative Savings	Shift Crop Type	22	5,048	2,786,505	547	5,095
Comparative Savings	Deficit Irrigate	18	4,769	3,189,144	1,160	2,749
Comparative Savings	Forgo Cash Crop	14	4,362	2,855,482	150	19,053
Comparative Savings	Other Annual	2	209	62,700	-90	-
Comparative Savings	Other Perennial	2	1,370	924,750	123	7,505
Normalized Savings	Shift Crop Type	22	5,048	2,786,505	-674	-
Normalized Savings	Deficit Irrigate	18	4,769	3,189,144	-427	-
Normalized Savings	Forgo Cash Crop	14	4,362	2,855,482	-1,474	-
Normalized Savings	Other Annual	2	209	62,700	17	3,759
Normalized Savings	Other Perennial	2	1,370	924,750	52	17,893

*Does not include areas where only beneficial bird habitat practices were performed.

Table 19. Cost per ac-ft of water saved by elevation.

Response Variable	Count	Area (ac)	Total Cost ($)	Total Savings (ac-ft)	Cost per ac-ft ($)
Comparative Savings: above sea level	15	3,226	2,068,425	1,433	1,443
Comparative Savings: below sea level	43	12,532	7,750,155	458	16,942
Normalized Savings: above sea level	15	3,226	2,068,425	671	3,082
Normalized Savings: below sea level	43	12,532	7,750,155	-3,178	-

Beneficial Bird Habitat Practices

Beneficial bird habitat practices were performed on a total of 5,103 acres. On average, bird benefit fields were 365 acres, ranging from 30 to 1,076 acres. 2,334 acres had only beneficial bird habitat practices performed. 2,769 acres had beneficial bird habitat practices and additional water conservation practices implemented. One field of 1,000 acres implemented both Spring Flood-up and Fall Flood-up, and it was not double counted in the proceeding summary statistics. Five fields had beneficial bird habitat practices being performed on all or part of a field also implementing Shift Crop Type (713 acres). Three fields had beneficial bird habitat practices being performed on all or part of a field that implemented Deficit Irrigation (436 acres). Two fields had beneficial bird habitat practices being performed on all or part of a field implementing Forgo a Cash Crop (1,620 acres). All but one of the bird benefit fields were below sea level, and average field elevation was -11.92 feet below sea level. Table 4 summarizes the field characteristics of fields implementing beneficial bird habitat practices.

The two Fall Flood-up implemented practices outside of the 2023 water year and Nesting habitat was equivalent in field management to many of the Shift Crop Type fields, and, thus, only Spring Flood-up fields (n = 56) were evaluated for their potential impacts on consumptive use. Seven fields totaling 3,740 acres implemented Spring Flood-up. During the implementation period for Spring Flood-up (January-April 2023), monthly consumptive use was similar among fields with beneficial bird habitat flooding, weather related flooding, and no flooding, except in January when Spring Flood-up fields had higher consumptive use than the other fields (Table 20). We compared average annual consumptive use for fields with Spring Flood-up, fields that experienced weather related flooding during at least one month, and fields that experienced no flooding. Spring Flood-up fields had slightly higher consumptive use than the other two groups, but these fields are also positioned at lower average elevation than the other two groups (Table 21).

Table 20. Consumptive use (ac-ft/ac) during months where spring flooding for beneficial bird habitat was being implemented, where no beneficial bird habitat practices were performed, and where weather-related flooding was reported.

Practice	Month	Count	Mean Consumptive Use (ac-ft/ac)
Spring Flood-up	Jan	7	0.106± 0.01
No Beneficial Bird Habitat (flooding)	Jan	32	0.083 ± 0.00
No Beneficial Bird Habitat (no flooding)	Jan	17	0.08 ± 0.00
Spring Flood-up	Feb	7	0.144 ± 0.01
No Beneficial Bird Habitat (flooding)	Feb	30	0.111 ± 0.00
No Beneficial Bird Habitat (no flooding)	Feb	19	0.103 ± 0.00

Practice	Month	Count	Mean Consumptive Use (ac-ft/ac)
Spring Flood-up	March	7	0.23 ± 0.01
No Beneficial Bird Habitat (flooding)	March	17	0.207 ± 0.01
No Beneficial Bird Habitat (no flooding)	March	32	0.209 ± 0.01
Spring Flood-up	April	7	0.308 ± 0.04
No Beneficial Bird Habitat (flooding)	April	5	0.344 ± 0.014
No Beneficial Bird Habitat (no flooding)	April	44	0.342 ± 0.014

Table 21. Annual consumptive use in water year 2023 on fields performing Spring Flood-up and fields where no beneficial bird habitat practices were performed.

Practice	Count	Mean Consumptive Use (ac-ft/ac)	Median Consumptive Use (ac-ft/ac)	Max Consumptive Use (ac-ft/ac)	Min Consumptive Use (ac-ft/ac)	Average Elevation (ft)
Spring Flood-up	7	3.23 ± 0.05	3.28	3.35	3.05	-13.21
No Beneficial Bird Habitat, Weather Flooding Reported	34	2.78 ± 0.07	2.82	4.01	2.00	-5.59
No Beneficial Bird Habitat, No Weather Flooding Reported	15	2.37 ± 0.13	2.43	3.14	1.43	2.43

Comparing the 2022 and 2023 Program

A total of 13 DDRPP 2023 project fields had some portion of their area enrolled in the 2022 DDRPP (Table 22). The areas enrolled in both years totaled 3,717 acres. The average elevation of the fields enrolled in both years was -4.25 ft below sea level. Average annual consumptive use for these areas was 2.50 ± 0.14 in water year 2022 and 2.77 ± 0.13 in water year 2023, but there was a considerable variation among fields in both years (Figure 16 and Table 19). Site K was enrolled in both 2022 and 2023 and was further explored in Appendix B: Case Studies.

Table 22. Summary of consumptive use (ac-ft/ac) for areas enrolled in 2022 and 2023 DDRPP.

Site ID	Area (ac)	2022 Water Conservation Practice	2022 Crop	2023 Water Conservation Practice	2023 Crop	2022 Consumptive Use (ac-ft/ac)	2023 Consumptive Use (ac-ft/ac)
A	141.98	Non-Irrigated Crop	Barley	Deficit Irrigation	Triticale	1.87	2.52
B	83.17	Non-Irrigated Crop	Corn	Deficit Irrigation	Corn	2.57	2.92
D	114.27	Non-Irrigated Crop	NA	Deficit Irrigation	Triticale	2.61	2.71
F*	166.99	Deficit Irrigation	Corn	Deficit Irrigation	Corn	3.22	3.05
K*	403.85	Managed Lands	Cattle Grazing	Deficit Irrigation	Pasture	1.70	1.58
M	104.9	Non-Irrigated Crop	Safflower	Deficit Irrigation	Corn	2.82	3.02
H	270.05	Non-Irrigated Crop	Wheat	Forgo Cash Crop	Wheat	2.85	3.32
I	293.06	Non-Irrigated Crop	Wheat	Forgo Cash Crop	Wheat	1.87	2.25
C	275.53	Non-Irrigated Crop	Barley	Shift Crop Type	Triticale	2.58	2.63
E	137.99	Deficit Irrigation	Alfalfa	Shift Crop Type	Triticale	2.82	3.09
G	100.36	Deficit Irrigation	Alfalfa	Shift Crop Type	Safflower	1.94	3.02
J	164.94	Managed Lands	NA	Shift Crop Type	Triticale	2.48	2.90
L*	148.24	Non-Irrigated Crop	Sorghum	Shift Crop Type	Corn	3.14	3.04

*Areas with higher consumptive use in the 2022 water year.

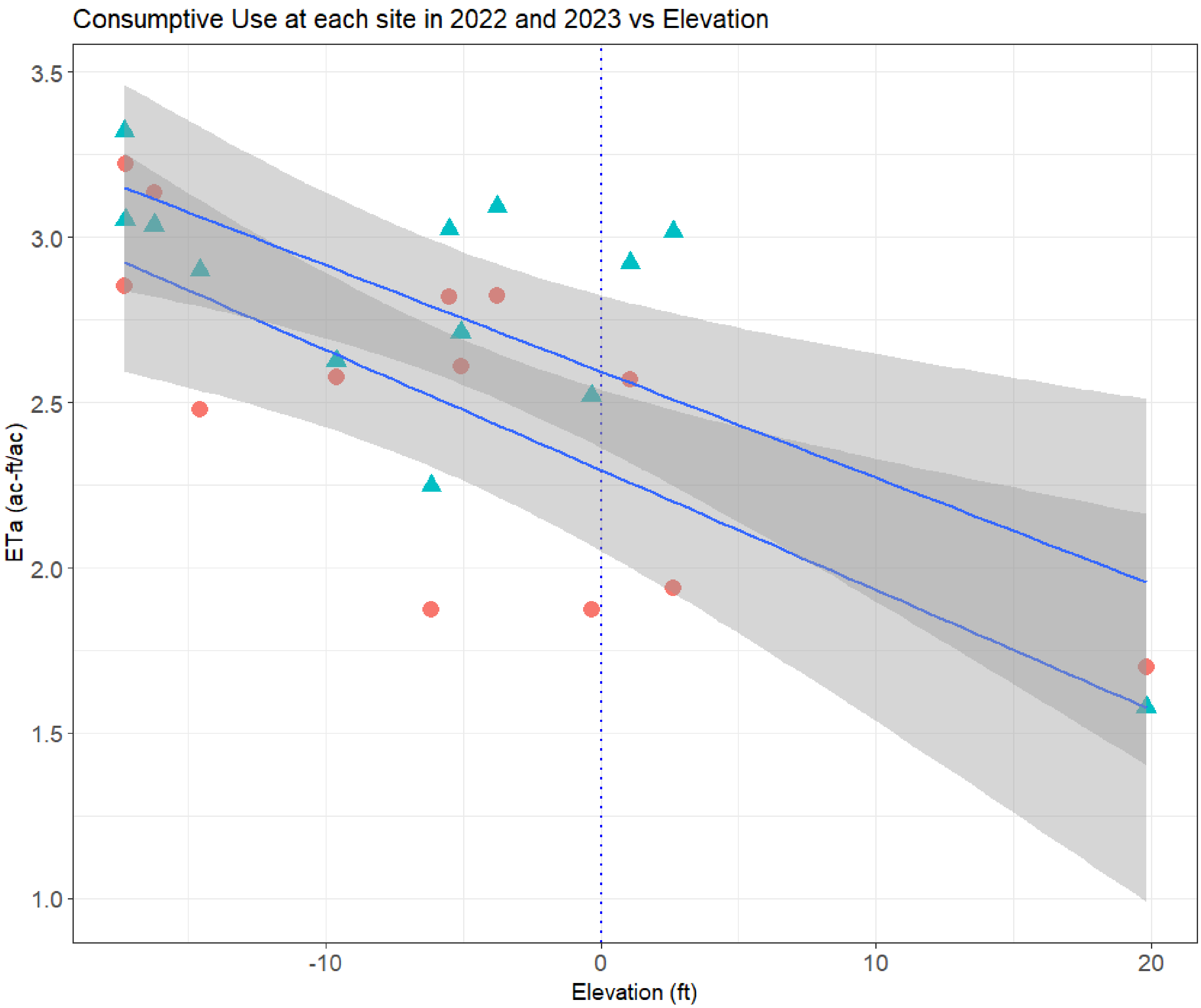

Figure 15. Estimated consumptive water use (ac-ft/ac) vs elevation (ft) for areas enrolled in both the 2022 and 2023 DDRPP. Fields in water year 2022 are shown as red circles and fields in water year 2023 are shown as blue triangles. The linear trend line is shown only to assist in graphic interpretation.

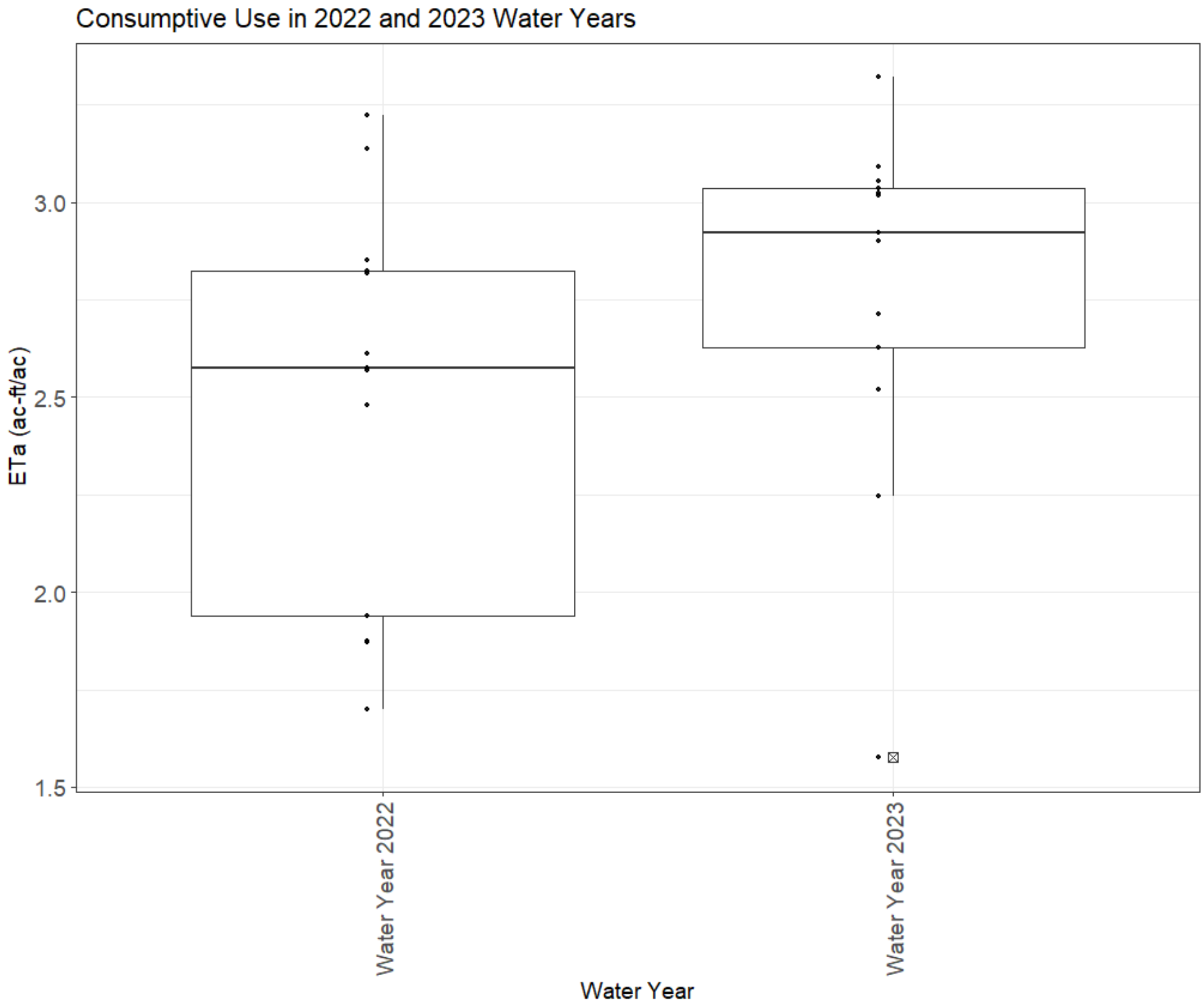

Figure 16. Boxplot of consumptive use (ac-ft/ac) for areas enrolled in both the 2022 and 2023 DDRPP. Median values are indicated by the horizontal bar in each box. The lower and upper ends of the box correspond to the first and third quartiles (the 25th and 75th percentiles). The upper whisker extends from the box to the largest value no further than 1.5 times the interquartile range from the top of the box. The lower whisker extends from the box to the smallest value, at most 1.5 times the interquartile range of the box. Outliers are shown as x in a square. Points represent ETa values of individual fields.

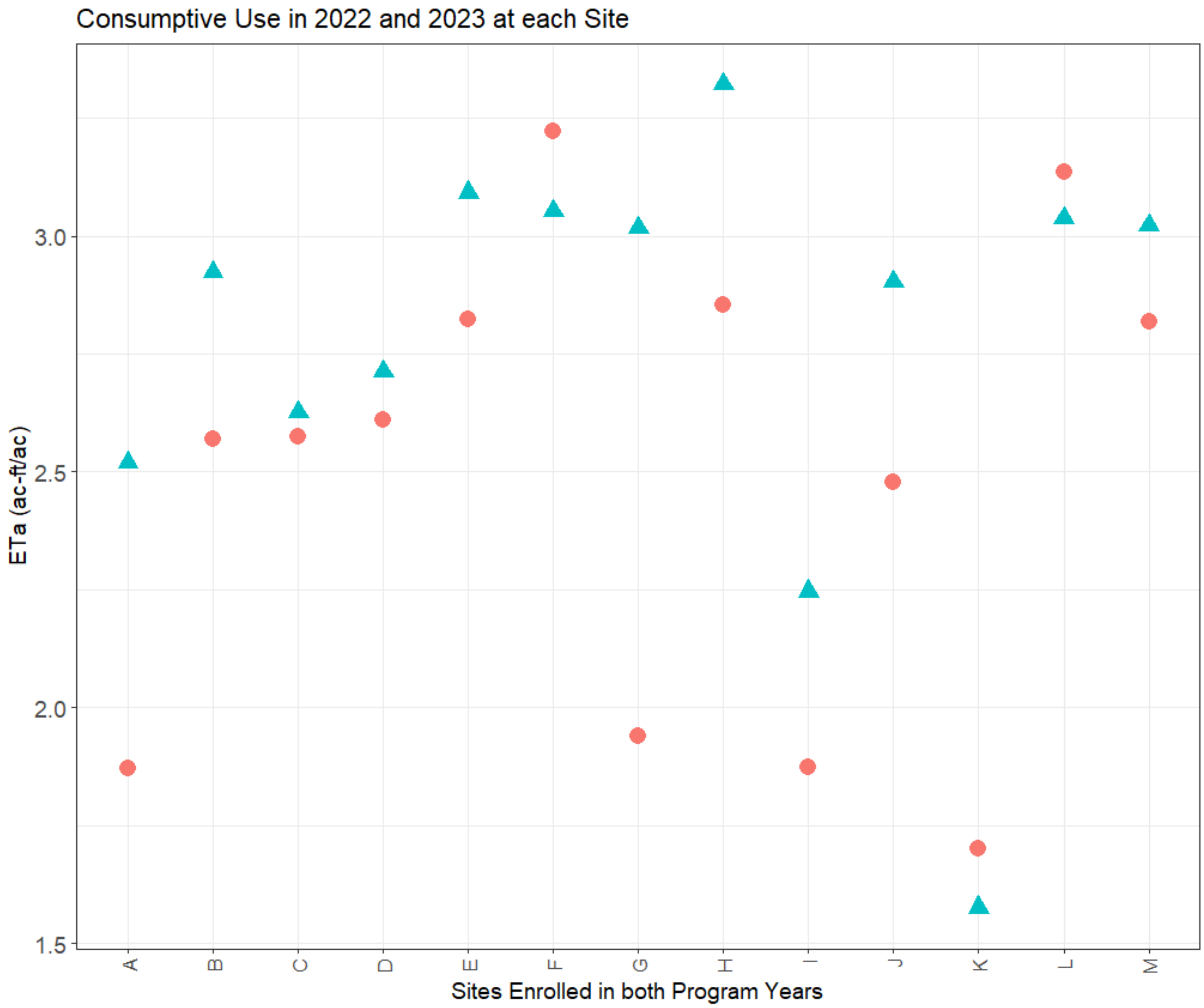

Figure 17. Consumptive use (ac-ft/ac) for areas enrolled in both the 2022 and 2023 DDRPP. Fields in water year 2022 are shown as red circles and fields in water year 2023 are shown as blue triangles.

Beyond the small number of fields enrolled in both the 2022 and 2023 DDRPP, the two water years were quite different. Figure 18, Figure 19, and Figure 20 show data from three CIMIS stations from across the Delta (California Department of Water Resources, 2024). Though there are regional differences, all three show substantially higher precipitation, lower average daily temperatures, and slightly lower cumulative ETo in water year 2023.

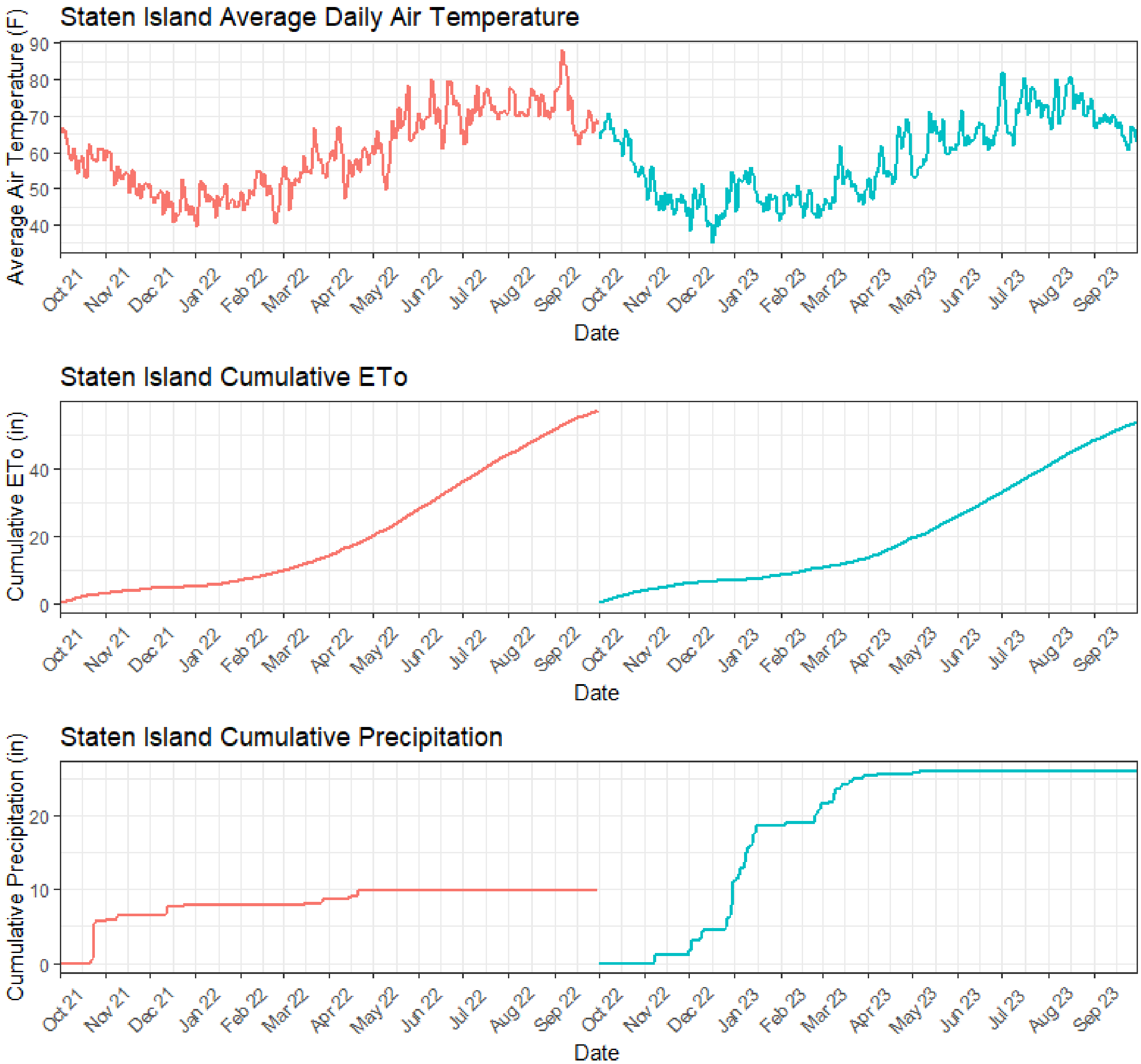

Figure 18. Average daily air temperature (F), cumulative ETo (in) and cumulative precipitation (in) for the 2022 and 2023 water years at the Staten Island CIMIS station. Water year 2022 is shown in red and water year 2023 is shown in blue.

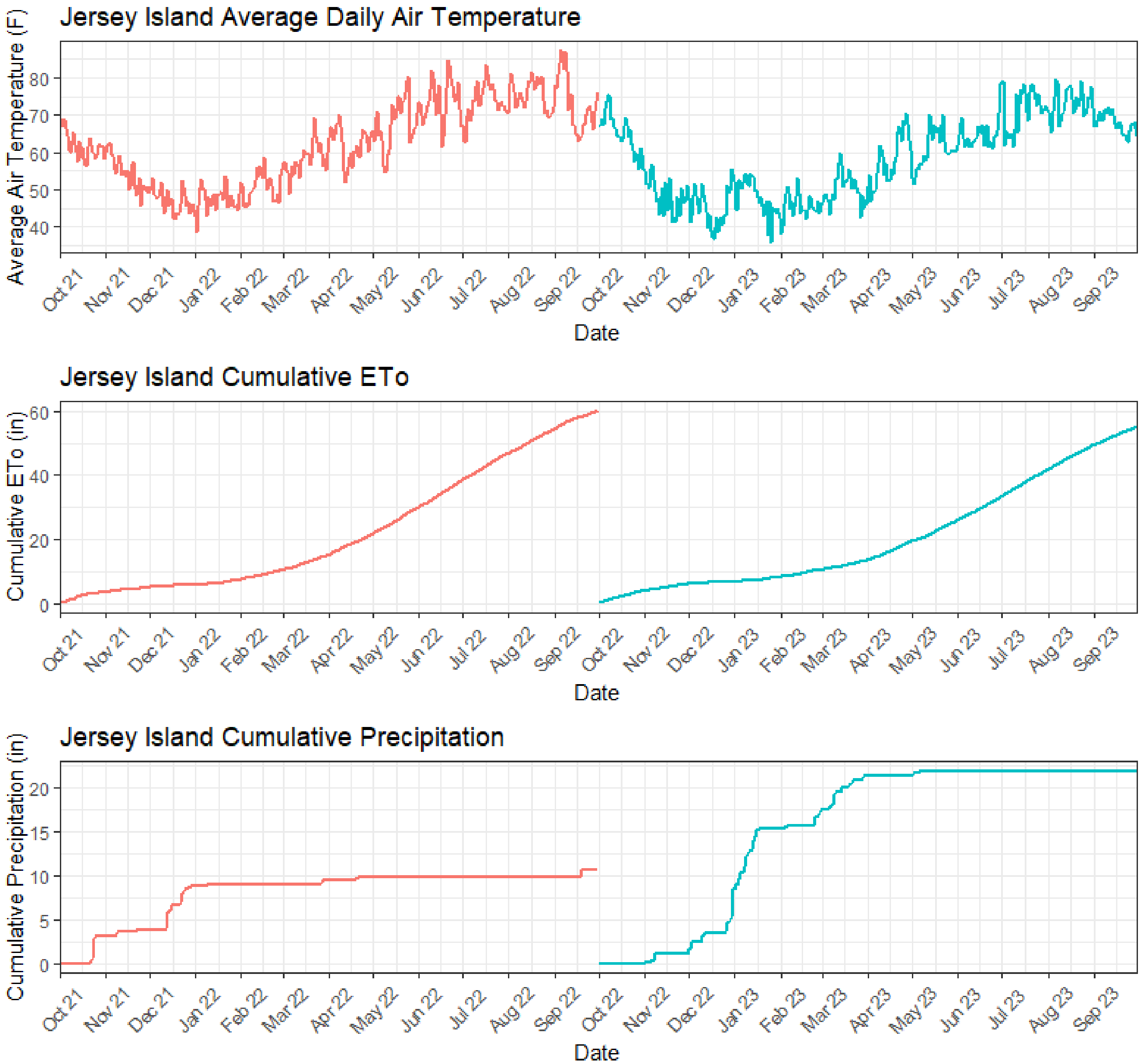

Figure 19. Average daily air temperature (F), cumulative ETo (in) and cumulative precipitation (in) for the 2022 and 2023 water years at the Jersey Island CIMIS station. Water year 2022 is shown in red and water year 2023 is shown in blue.

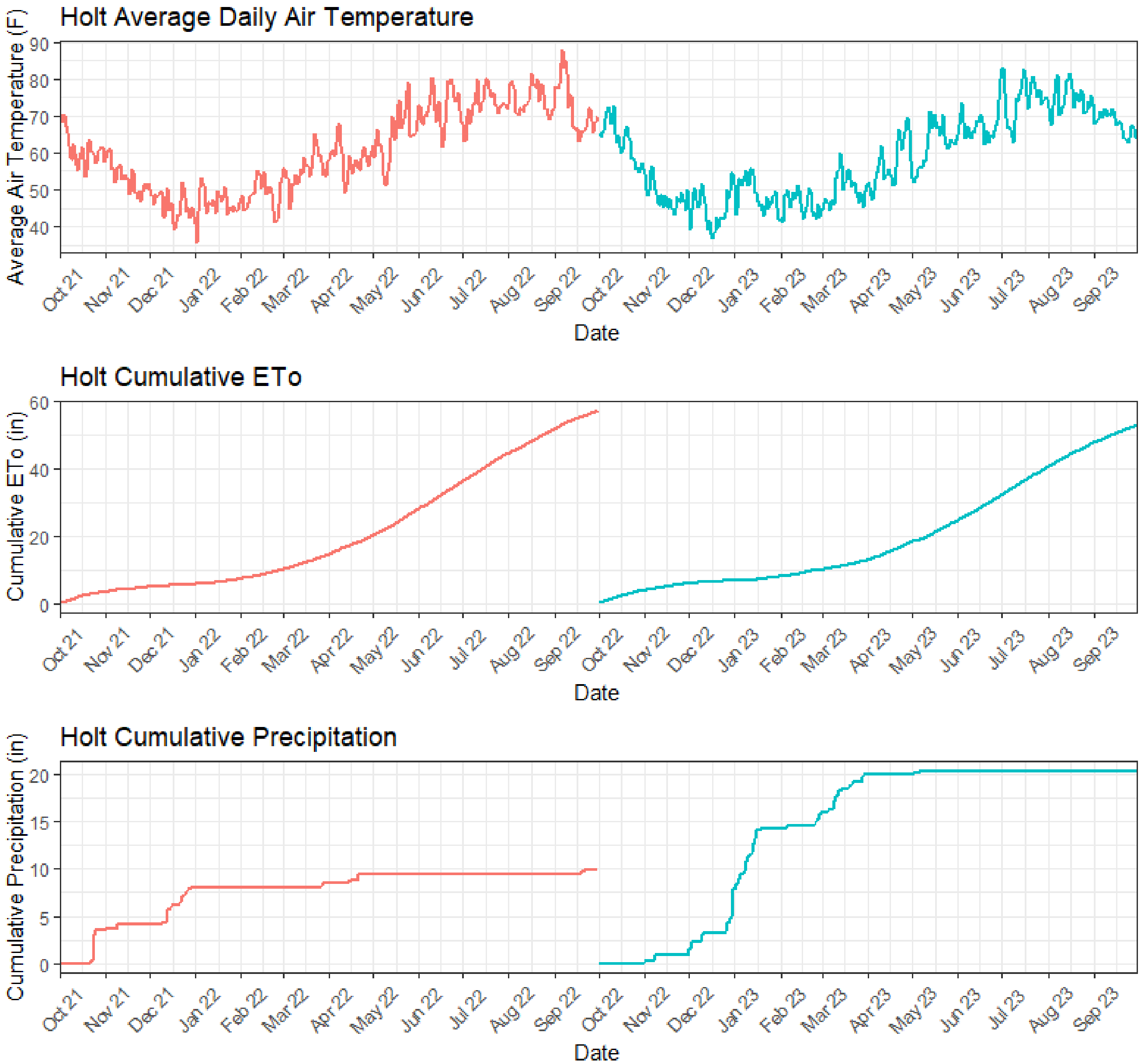

Figure 20. Average daily air temperature (F), cumulative ETo (in) and cumulative precipitation (in) for the 2022 and 2023 water years at the Holt CIMIS station. Water year 2022 is shown in red and water year 2023 is shown in blue.

Conclusions

Reductions in applied water did not consistently result in reductions in ETa for fields enrolled in the Program during water year 2023. It is likely soil moisture levels remained high, particularly in the spring of the 2023 water year when there was widespread precipitation and field flooding, which potentially influenced the ETa estimates of the 2023 DDRPP. When soil moisture is high, and conditions are less stressful for plants, plants can tap into the abundant pore water and grow more vigorously compared to when soil moisture is depleted. Both soil moisture and temperature are primary drivers of ET, but neither of these factors were measured directly during this analysis. However, CIMIS data showed greater total precipitation and lower air temperatures in 2023, both of which are likely to result in higher soil moisture.

When comparing fields enrolled in both years of the Program, average consumptive use across both years was similar, but slightly higher in the 2023 water year than in the 2022 water year, likely driven by high soil moisture. Three fields out of the thirteen fields enrolled in both years of the Program had higher consumptive use in the 2022 water year than in the 2023 water year, but the mechanism behind these differences is not clear. ETa can be influenced by crop types, field elevation, and other field management decisions, all of which varied across this small sample size. The UC Davis study (Appendix D: UC Davis Study Update) includes several fields enrolled in both years of the Program and may ultimately provide more clarity about the interannual differences present on these fields, as well as the overall patterns of water use on the fields.

There were differences in water savings estimates based on the calculation method used. The comparative savings estimate found minimal annual water use savings, while the normalized savings estimate found a net increase in water use compared to the baseline (i.e. negative savings). The comparative savings estimate method calculated water savings by comparing the ETa on the project site during the 2023 water year to ETa on a comparison field located nearby and performing business-as-usual practices during the 2023 water year. Although comparison fields are useful for estimating savings, selecting suitable comparison fields was difficult and time consuming, and comparison field selection had a large influence on the accuracy of this savings estimate.

The normalized savings estimate method normalizes for ETa by dividing it by ETo (ETa/ETo=EToF) and tries to compare ETa in the project field in 2023 to ETa on the same field in water years 2017-2021 while negating the impacts of previous atmospheric water demands (ETo) on ETa. Again, the ETa of well-watered crops is generally higher than the ETa of crops experiencing drought stress, and crops in the Delta likely experienced less water stress in the 2023 water year than during several of the water years between 2017 and 2021. Thus, water year 2023 likely had higher EToF values than many water years 2017-2021, so the normalized savings estimate value was more likely to be negative. Utilizing additional tools alongside OpenET (e.g., the UC Davis study or closed ground station ET) could facilitate a more accurate assessment of savings.

In both years of the Program, the estimated reductions in consumptive use were less than anticipated. Additional refinement of estimated water savings could improve the accuracy of the data but is not expected to change the overall conclusions of this analysis. To put these results in context, consumptive use for several crops commonly grown in the Delta was estimated at 2.9 ac-ft/ac for corn, and 3.5 ac-ft/ac for pasture during 2015 (a critically dry year) (Medellín-Azuara, et al., 2018). Compared to these estimates, consumptive use was reduced by 7-20% on average for fields enrolled in the 2023 DDRPP. Additionally, even the maximum estimated 2023 DDRPP savings of up to 1,890 ac-ft is a small fraction of estimated in-Delta water use—which includes all agricultural water use in the legal Delta, plus riparian use and channel evaporation. In-Delta water use was estimated at 1.8 million ac-ft in 2021 (Gartrell, Mount, & Hanak, 2022). The ability to measure the effects of marginal increases in localized flows that would have remained in Delta channels is difficult to calculate, and the relatively small amounts of conserved water would be overwhelmed by predictable tidal conditions in the Delta. Consequently, it is unlikely the volume of water saved by this Program significantly impacted water quality. Compared to the overall volume of water flowing into the Delta during the same water year, daily tidal volumes, and proportion of estimated in-Delta use, savings were not substantial.

Field elevation may impact water conservation potential. On some fields in the legal Delta, especially in areas below sea level, crop water use is likely supplemented by shallow groundwater and channel surface water that percolates under levees (seepage). These areas are likely sub-irrigated by high water tables, resulting in crop growth and high ET even without applied irrigation. In both years of the Program there was variability around the relationship between elevation and estimated water savings, with some fields below sea level showing some water savings. To better understand sources of variation in relation to water use/savings future studies should select fields across a more even distribution of elevations in the Delta to better understand the relationship between elevation and water savings within the legal Delta. Low estimated water savings may also have been driven by shallow groundwater and seepage of surface water from channels onto Delta fields, and a future study could directly measure applied water and seepage across a range of elevations. Elevation only partially explained the patterns of water savings/use among 2023 DDRPP fields, and several fields below sea level showed some water savings. Variation in water saved/used on fields may also have been driven by vegetation management, crop type, soil type, and local flooding. More study is needed to fully understand how specific field characteristics impact patterns of water savings/use in the Delta.

Fields above sea level accounted for a disproportionate amount of estimated water savings. Fields above sea level made up 20% of the total acreage analyzed, but they accounted for 76% of estimated annual water savings using the comparative savings estimate. Fields above sea level showed some savings using the normalized savings estimate, while fields below sea level showed negative annual savings. In 2022, when savings were estimated using the comparative savings estimate method, only one of the 15 project fields above sea level showed no water savings. In 2023, when savings were estimated using the comparative savings estimate method, four of the 15 project fields above sea level showed no water savings. Twenty-nine percent of the legal Delta is below sea level (California Department of Water Resources, 2017), which leaves much upland area to potentially explore for water conservation.

The voluntary enrollment process may have impacted the types of fields enrolled in the Program, potentially biasing the sample to fields below sea level. A reverse auction process was used to gain more information from bidders about appropriate water conservation practices for the region and the cost of implementing those practices. This process allowed applicants to voluntarily select project locations and to propose their own water conservation practices, which were then approved, or negotiated and approved by the Selection Committee and/or during the grant agreement process. When selecting fields to apply for the Program, some growers reported enrolling fields that were less likely to experience crop yield losses when decreasing applied water through deficit irrigating or shifting to a lower water-use crop. These voluntarily selected fields may not have had the highest water saving potential relative to other fields in the region, and more enrolled projects were below sea level than above sea level.

There was variability in consumptive use and savings estimates among and within crop types. Shifting away from alfalfa had estimated water savings across water conservation practices in water year 2023; only shifting from alfalfa to sorghum-sudangrass calculated by the normalized savings estimate method did not show savings. A three-year old almond orchard had the lowest consumptive use of any crop type, but also had low estimated savings. Using the comparative savings estimate, deficit irrigated pasture saved water across varying elevations. Alternatively, some fields deficit irrigating corn showed water savings while others showed increases in ETa in the 2023 water year. The variability among enrolled fields is explored further in Appendix B: Case Studies.

This analysis found no differences in average annual consumptive use or water savings among water conservation practice types. Flexibility within different water conservation practices was useful in the pilot program stage, but variation in how water conservation practices were implemented may have resulted in more variable ET within practice types. To recruit farmers during the drought emergency, and since this was a pilot program, the Program provided flexibility within each water conservation practice for growers to respond to changing environmental and market conditions while still complying with grant requirements. For example, in water year 2023, the Program did not specify vegetation/weed management practices for the Forgo Cash Crop practice—such as maintaining crop stubble to a specific height—and this likely led to wide variation in vegetation density, height, and rates of ETa on fields that reported growing no crop.

Due to low estimated water savings, the cost per acre-foot of water saved was correspondingly high. Determining which practices and field conditions are associated with consistent savings could allow future programs to focus on these field types and potentially save much more water for less money. For example, fields above sea level had more cost-effective savings than fields below sea level, and deficit irrigating pasture showed estimated savings across a range of elevations.

In most months during the practice implementation time frame (January-April), fields performing Spring Flood-Up for bird habitat and Program fields that only carried out water conservation practices had similar consumptive use rates. This similarity could be driven by widespread weather-related flooding on non-beneficial bird habitat fields during the same period. At the annual level, mean consumptive use was higher and estimated savings were lower for the 43 fields that experienced flooding for either beneficial bird habitat or weather-related flooding than for the 15 fields that did not experience any flooding. On average, the 15 fields that did not experience any flooding were all above sea level. Whereas, the 34 fields that experienced weather-related flooding were below sea level on average. The seven fields that carried out Spring Flood-Up practices were further below sea level on average than either the fields with no flooding or the fields with weather related flooding. The beneficial bird habitat practices provided valuable bird habitat but were challenging to integrate into the Program and analysis of the 2023 DDRPP. Due to high costs of mosquito abatement in the late summer and early fall, the timing of Fall Flood-Up implementation was delayed outside of the water year that was studied for this analysis.

Recommendations

Improving Program Implementation:

The data suggest fields above sea level more consistently save water, but to understand if there is a relationship between field elevation and the ability to save water using field management practices, field elevation would need to be used as a selection factor to enroll fields across the range of elevations present in the Delta and achieve sufficient replication for rigorous statistical testing.

Applicants should be equipped with complete information upfront to decide whether to participate in the Program. Future programs should provide detailed water conservation practice guidelines—such as vegetation/weed management practices, fallow periods, specific crop types, and limitations on planting/harvest windows—prior to the bidding process to decrease the variability in field management across the sample. It is possible that more prescriptive practices might lead to decreased yields or higher implementation costs for growers, which could decrease growers' willingness and ability to participate in the Program. Alternatively, growers may still participate, but bid prices may increase to account for the decreased yield or increased cost, resulting in fewer acres enrolled in the Program for the same dollar amount. Future implementation would need to balance costs with enrolling areas implementing the practices estimated to save the most water, and any prescriptive farming guidelines should be developed in consultation with regional agricultural experts—including UC Cooperative Extension personnel, certified crop consultants, and water users.

Using a calculation method that does not rely on comparison fields would likely result in significant time savings and more transparency with growers about how savings will be estimated. However, comparison fields are useful for providing a baseline for measuring water conservation and eliminating interannual sources of variability. If comparison fields are used to estimate water savings they should be selected and verified prior to the start of the Program, which would require significant upfront lead time. To obtain accurate results, these comparison fields should be operated by the same land manager as the project fields. Baseline field management practices and reporting requirements should be agreed upon ahead of time. Future programs should consider providing compensation for growers to manage comparison fields as experimental controls, which could result in greater administrative and reporting costs for growers.

Site visits would be more productive earlier in the water year. Due to planning and scheduling constraints, some site visits for water year 2023 were conducted later in the water year after crops had been harvested. Future programs should consider offering time slots for site visits immediately following grant execution so visits can be scheduled at mutually agreeable times during the peak growing season.

Beneficial bird habitat flood-up practices may be better suited as a separate program. Future implementation of beneficial bird habitat could identify areas with low potential for consumptive use savings and target those for implementation of Spring and Fall Flood-up practices. For the Fall Flood-Up practice, proactive coordination with Vector Control Districts will reduce upfront grower costs and allow for optimal flood-up timing.

Future project iterations should consider which baseline is most useful when estimating water savings. Comparisons to the business-as-usual practice will give an estimate of short-term potential savings on specific fields, based on individual field management practices. Fields with higher consumptive use business-as-usual practices may have a higher potential for water savings. For example, in this study, not growing alfalfa generally led to high short-term water savings. If long-term reductions in consumptive use are desired, consumptive use is likely a more meaningful metric than estimated water savings. Focusing on practices with lower consumptive use against the background of all regional practices could allow program managers to choose practices that lower consumptive use across the Delta in the long-term.

Future Analysis:

As part of the DDRPP, the Delta Conservancy entered into an agreement with UC Davis to carry out field-level analysis on six DDRPP project sites, representing a range of locations, soil types, and field management practices. This study, led by Dr. Kosana Suvočarev and her team, will continue to collect micrometeorological and soil data from these six DDRPP sites through September 2026. The six project sites involved in the ongoing study, encompassing a total of 395 acres, will continue to carry out water conservation practices throughout the study period. This experiment will provide valuable insights about ET in the Delta and provide further ground-truthing for remote-sensing ET accounting methods.

Analyses like the ones in this study using remote-sensing ET accounting methods, like OpenET, could be carried out comprehensively across California and compiled to identify the most effective practice types and locations to most effectively reduce consumptive water use. Analyzing changes in ET from previously performed water conservation practices and/or changes in land use stemming from programs like The California Department of Conservation’s Multibenefit Land Repurposing Program and DWR’s Landflex Program, or from irrigation curtailments, like the remote-sensing analysis done in the Scott and Shasta valleys could improve the efficiency of targeted water conservation efforts in future drought emergencies (Asarian, 2023).

The insights derived from the 2022 and 2023 DDRPP, as well as forthcoming research from the DDRPP/UC Davis study, are likely to be applicable beyond the Delta region— including the relationship between elevation, biodiversity, water conservation strategies, and their resulting water savings. The approach used by the Program can be adapted in other regions of California to identify the most effective agricultural conservation measures for drought contingency planning. However, the impact of topographical variations on water conservation effectiveness underscores the importance of customizing these strategies to the unique attributes of each region. Such adaptations must consider local soil composition, crop types, and climatic conditions and biodiversity for effective and environmentally sustainable region-specific drought mitigation.

Combining landscape-level estimates of naturally occurring ET with region-specific findings from the DDRPP can support water managers in protecting water quality and mitigating drought impacts in the Delta during future droughts. Recently published research carried out at UC Santa Barbara used remote-sensing ET accounting to estimate future savings (Boser, et al., 2024). This study examines the differences between agricultural ET and naturally occurring ET. Identifying naturally occurring ET can help target the implementation of water conservation practices to maximize water savings and cost efficiency by estimating the ability of regions and specific fields to conserve water.

Appendix B: Case Studies

Each case study presented in this appendix provides a more detailed look at an individual project, highlighting field management actions and unique characteristics. These three DDRPP projects include a range of practices, crops, elevations, and field conditions. The selection of projects demonstrates the variability of fields enrolled in the DDRPP and were chosen to illustrate a variety of practices and scenarios.

Case Study: Non-Irrigated Triticale with Weather-related Flooding in San Joaquin County

Figure 21. Map of case study: non-irrigated triticale with weather-related flooding in San Joaquin County.

Acreage: 98
Region: Central Delta; San Joaquin County
Business-as-usual Crop: Corn
2023 Water Year Crop: Non-irrigated triticale
Water Conservation Practice: Shift Crop Type (as categorized in grant agreement); recategorized as Forgo Cash Crop (as categorized for analysis, due to crop loss)
Soil Type: silty loam
Elevation: -12.4 feet

Consumptive Use: 2.21 ac-ft/ac
Estimated Savings – Comparative Savings Estimate: 0.85 ac-ft/ac
Estimated Savings – Normalized Savings Estimate: 0.29 ac-ft/ac

Overview:

This project was initially categorized under the Shift Crop Type water conservation practice, as the grantee planted triticale instead of corn, with no planned irrigation. However, weather-related flooding damaged the newly planted triticale crop. Since ultimately, no crop was grown during the summer months, the project was recategorized under the Forgo Cash Crop water conservation practice for analysis purposes. This project field is notable for having greater estimated ET savings when calculated using both the comparative savings estimate and normalized savings estimate methods as compared to other Forgo Cash Crop projects below sea level. The unexpected savings, relative to other Forgo Cash Crop fields below sea level, may be related to the discing of weeds in March and August; this field saw its highest savings occur during the months of June through September.

Timeline:

Prior to planting, the fields were disced. Triticale was planted on the project site on December 5, 2022. During January and February 2023, the project site experienced weather-related flooding. The fields were disced in March 2023 to incorporate the flood-damaged triticale and weeds. The fields were disced again in August 2023 to manage weeds. There was no harvest in water year 2023 because of the flood damage. See Figure 22 for a visualization of this project’s timeline, monthly water use, and estimated water savings.

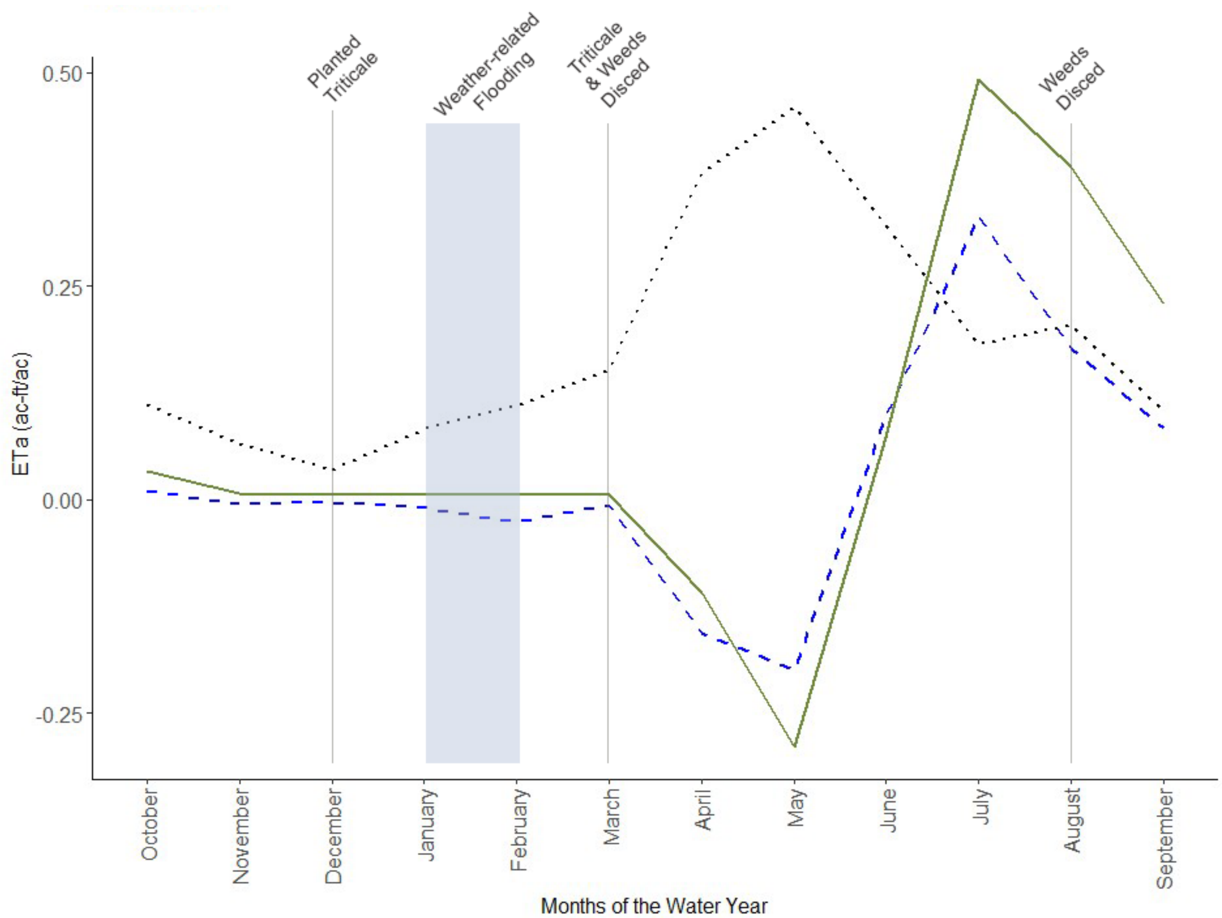

Figure 22. Non-Irrigated triticale with weather-related flooding in San Joaquin County consumptive use and savings estimates by months of the year. Normalized savings estimate is shown as a blue dashed line. The comparative savings estimate is shown as a green solid line. Consumptive use is shown as a black dotted line.

Case Study: Young Almond Orchard in San Joaquin County

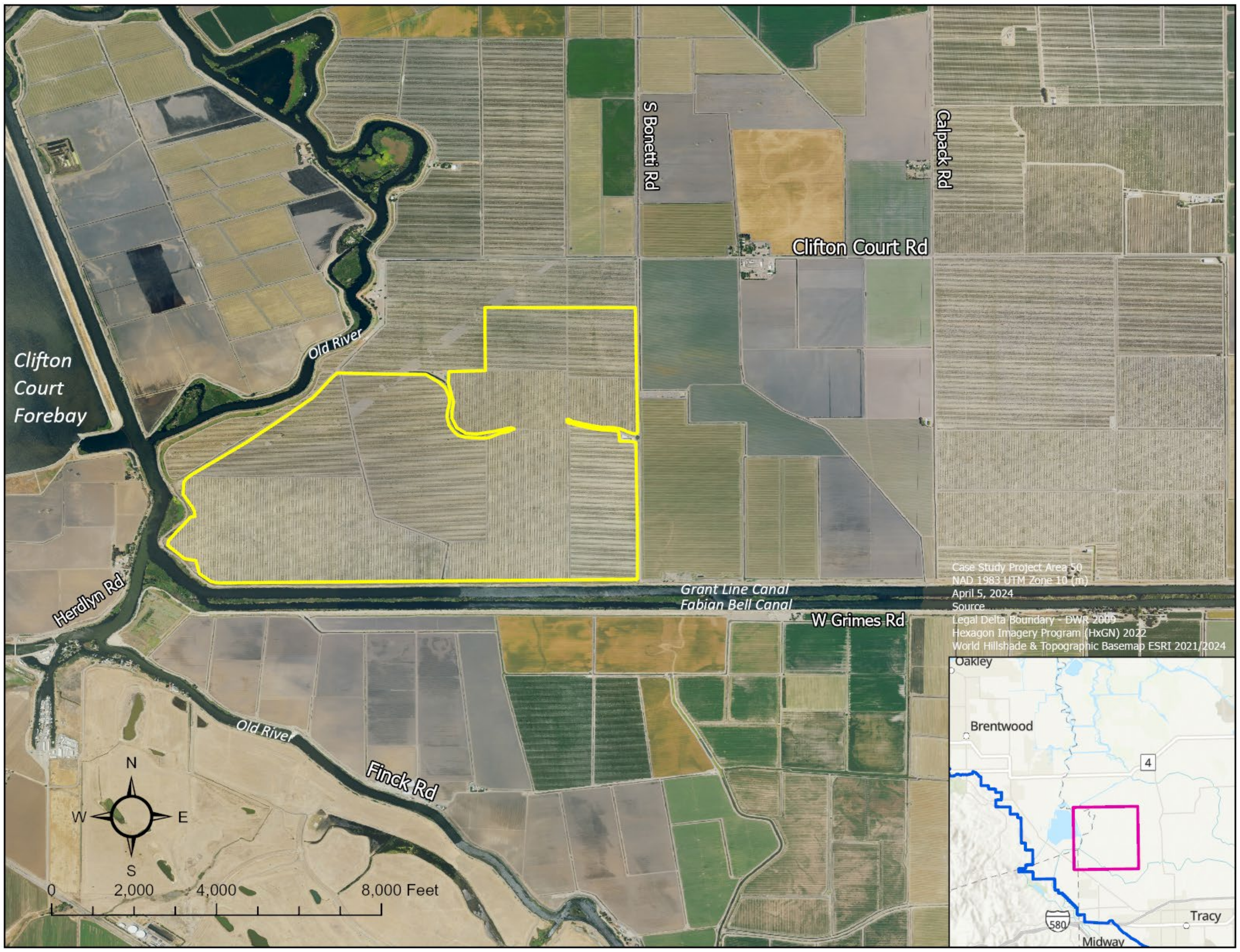

Figure 23. Map of case study: young almond orchard in San Joaquin County.

Acreage: 1,000
Region: San Joaquin County
Business-as-usual Crop: Almonds
2023 Water Year Crop: Almonds, planted September 2020
Water Conservation Practice: Other (Perennial), reduce irrigation by 20%
Soil Type: Silty Clay Loam
Elevation: -3.2ft
Consumptive Use: 1.765 ac-ft/ac
Estimated Savings – Comparative Savings Estimate: 0.16 ac-ft/ac
Estimated Savings – Normalized Savings Estimate: 0.10 ac-ft/ac
Overview: This project consists of a 1,000-acre almond orchard that was planted in September 2020. The orchard is irrigated using a micro-sprinkler system. Flooding is rarely an issue at this site because the orchard has tile drains that deter standing water by preventing groundwater from seeping up. The

orchard was categorized as Other (Perennial). Notably, the almond orchard used as the comparison field for this project was planted in December 2019, about a year prior to the project field.
This project reduced applied water by calculating the evapotranspiration rate of their almond orchard and reducing irrigation by 20% of the crop water need. The crop water need for this calculation was determined using the local CIMIS station, in addition to a Semios (crop management data analytics platform) Delta weather station. The total water applied for water year 2023 was 1452 acre-ft across the whole project or 1.452 ac-ft applied per acre.
With consumptive use measured at 1.765 ac-ft/ac, this project had the third lowest consumptive use among all the water year 2023 DDRPP projects. One likely reason for this is the young age of the orchard. Generally, the evapotranspiration rate of young orchards is less than that of mature orchards because younger orchards have a smaller canopy than mature orchards (Schwankl, Prichard, Hanson, & Elkins). Estimated water savings using the comparative savings estimate and the normalized savings estimate methods were calculated at 0.16 ac-ft/ac and 0/10 ac-ft/ac, respectively. This is equivalent to savings of between 100 and 160 ac-ft for the entire project. Based on the water savings from carrying out this practice, the landowners of this project site reported that they plan to take what they have learned from this Program and apply water conservation measures across more of their almond orchards in the Delta.

Timeline:

The orchard was planted in September 2020. Herbicide was applied on the project site in December 2022, May 2023, and July 2023. Irrigation was applied on a regular basis beginning in April 2023 and ending in September 2023. The almond harvest began on September 18 and ended on October 27, 2023. There was no weather-related flooding reported during the 2023 water year. See Figure 24 for a visualization of this project’s timeline, monthly water use, and estimated water savings.

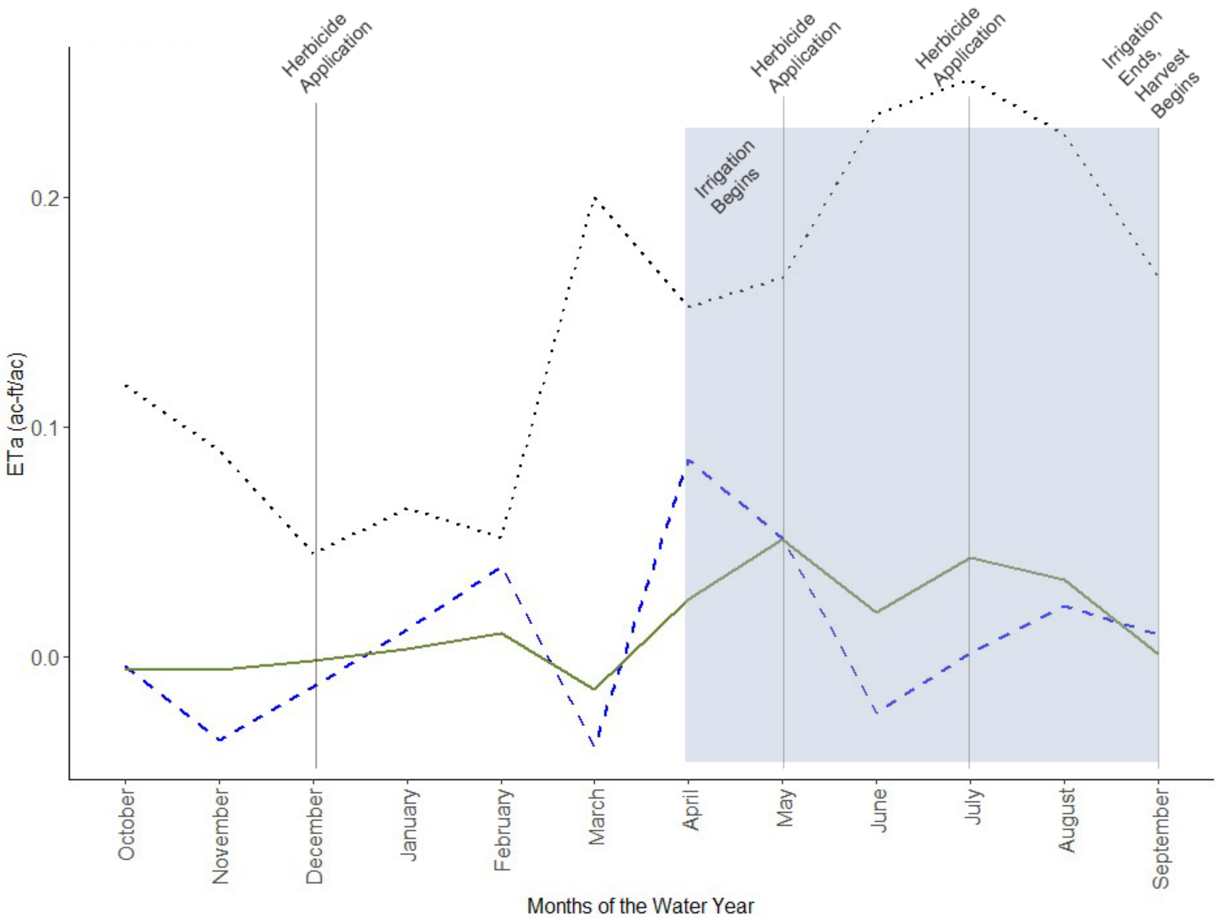

Figure 24. Young almond orchard in San Joaquin County consumptive use and savings estimates by months of the 2023 year. Normalized savings estimate is shown as a blue dashed line. The comparative savings estimate is shown as a green solid line. Consumptive use is shown as a black dotted line.

Case Study: Non-irrigated Pasture in Yolo County

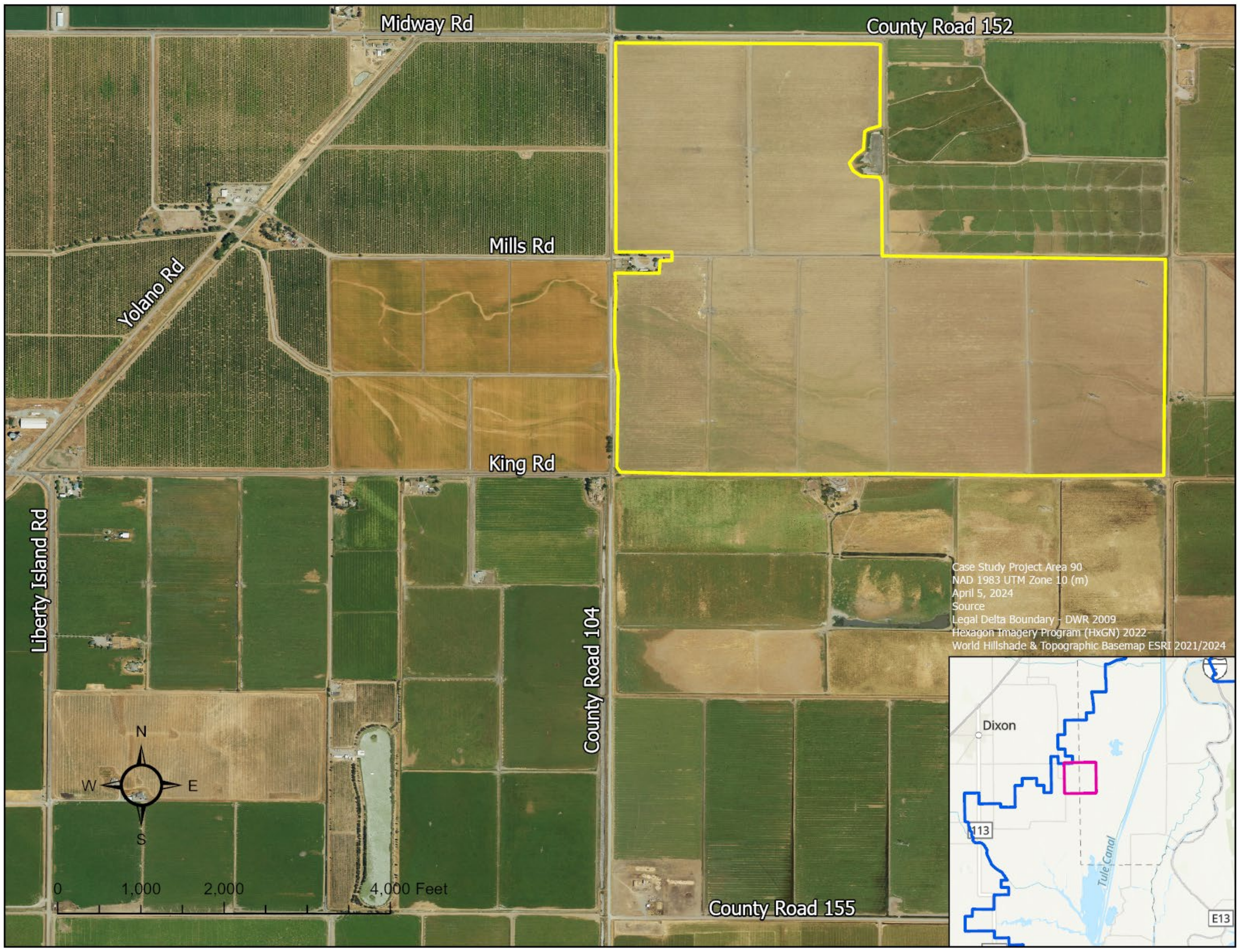

Figure 25. Map of case study: non-irrigated pasture in Yolo County.

Acreage: 450 acres
Region: Yolo County
Business-as-usual Crop: Irrigated Pasture
2023 Water Year Crop: Pasture
Water Conservation Practice: Deficit Irrigation
Soil Type: Silty Clay
Elevation: 19.7 ft
Consumptive Use: 1.58 ac-ft/ac
Estimated Savings – Comparative Savings Estimate: 1.98 ac-ft/ac
Estimated Savings – Normalized Savings Estimate: 2.00 ac-ft/ac
Overview:

This project site was enrolled in DDRPP for 2022 performing a similar conservation practice, discontinuing irrigation of the 450 acres of the same annual crop, pasture, and managing the idled lands. The site consists of multiple fields with a small unlined canal at the drain side of each field and project site elevation varies from 14.1 ft to 24.3 ft, giving it one of the highest mean elevations of all the DDRPP 2023 project sites, 19.7 ft. This site has been a pasture since 1994 and hasn't been tilled since. Furthermore, this site is among six research sites with UC Davis's micrometeorological equipment installed for data collection over the next three years.

Among all DDRPP 2023 project sites, this site had the highest estimated savings, utilizing both the comparative savings estimate and the normalized savings estimate methods, while having the second lowest consumptive use, 1.58 ac-ft/ac. The conservation practice type of Deficit Irrigation proved most successful over both DDRPP 2022 and 2023, as evidenced by this site having the highest estimated savings. Unique to this project site, the estimated savings by both methods exceeded its consumptive use, a distinction not observed elsewhere. Most of the estimated savings, calculated at 0.40 ac-ft/ac by both methods, were realized in July of 2023, whereas the peak consumptive use occurred in May of 2023, at 0.35 ac-ft/ac.

Timeline:

Prior to December 2022, this project site was already part of DDRPP for the year 2022, which means no crops were grown on the project site. Although, the permanent pasture did exist until it dried out during the summer due to the absence of irrigation. Prior to planting an annual crop for water year 2023, while no perennial crops were planted, multiple varieties of clover grow every year, accompanied by grazing cattle for weed control. Between December 22nd and 24th, 2022, and from January 25th to February 1st, 2023, annual rye grass was sown across the site.

On January 5th, 2023, the project site experienced weather-related flooding, affecting the drainage areas of most fields for around 24 hours. However, no management was necessary other than cleaning one of the field’s drainpipes. The grant was executed for the project site on February 17th, 2023. Weed control began on March 7th, 2023, by moving cattle onto the project site to graze. The grantee emphasized that it is crucial to start weed control early in the year otherwise the cattle are unable to eat all the weed which would allow sour dock to grow. Later, on September 25th, 2023, about an acre on the eastern part of the site may have gotten wet due to the main drain ditch on that side of the ranch filling up. One challenge the grantee faced was that bull thistle grew in certain areas, so mowing of those areas was necessary. Overall, during water year 2023, no harvesting or irrigation occurred on the project site and minimal flooding developed. See Figure 26 for a visualization of this project’s timeline, monthly water use, and estimated water savings.

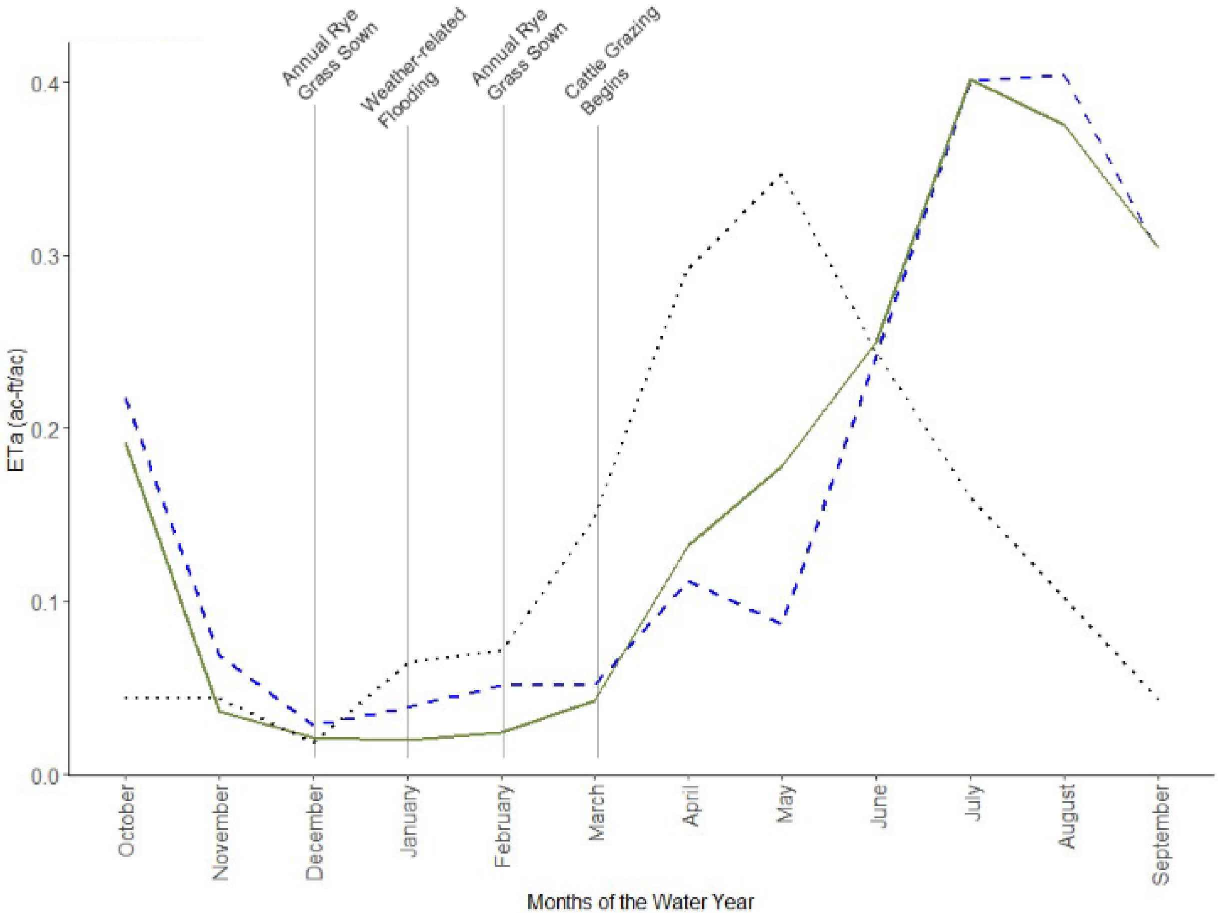

Figure 26. Non-irrigated pasture in Yolo County consumptive use and savings estimates by months of the year. Normalized savings estimate is shown as a blue dashed line. The comparative savings estimate is shown as a green solid line. Consumptive use is shown as a black dotted line.

Appendix C: Beneficial Bird Habitat Practices Monitoring

Summary of Bird Response in DDRPP fields with Beneficial Bird Habitat Practices: Flooded Waterbird Habitat

Some of the fields that were enrolled in the DDRPP were flooded to provide waterbird habitat. This was done to help offset reductions in flooding that occurred in the region that resulted from drought conditions. In total 4,879 acres were enrolled in the flooded waterbird habitat practice: 3,740 acres were enrolled during the spring and 1,139 acres were enrolled during the fall. Some fields were flooded in both the fall and the spring, and some fields overlapped with implementation of other water conservation practice types; see Table 4 for detailed descriptions of field characteristics. Growers were paid $75 per acre to provide flooded waterbird habitat, for a total of $365,925 for all enrolled flooded waterbird habitat fields. Prior to flooding, enrolled fields were required to incorporate straw and other vegetation into the soil. While enrolled they were required to maintain ≥75% of the field area flooded to an average depth of four inches.

Spring-enrolled fields were flooded between 1/3/23 and 4/11/23. Fall-enrolled fields were targeted to flood from 9/1/2023 through 9/30/2023, but flooding was ultimately delayed to 10/1/2023-11/9/2023 due to complications with vector control. A subset of the spring-enrolled fields was monitored for waterbird response. This amounted to eight fields in which 20 survey points were established. Over the course of the spring flooding period, 229 fixed radius (200 meter) waterbird surveys were conducted.

Results of the monitoring demonstrate that these fields supported a wide diversity of waterbirds. They were used by waterfowl, shorebirds, and long-legged waders in order of decreasing abundance (Table 23). Shorebirds were the main conservation target of the Program due to their declining populations across North America. In the rice fields that were enrolled in the DDRPP, shorebird densities were like those observed in conventionally managed winter flooded rice fields in the Sacramento Valley (Golet, et al., 2018). The corn fields that were enrolled in the DDRPP flood practice had much lower densities than was observed in the rice fields, consistent with what has been noted in previously published work conducted in the Delta (Shuford, et al., 2019).

Table 23. DDRPP flood-up bird response by species group and abundance.

Species Group	Abundance	Density (birds/hectare)
Waterfowl	8,551	5
Shorebirds	1,358	0.69
Long-legged Waders	115	-

Species Group	Abundance	Density (birds/hectare)
Other Waterbirds	27	-
Raptors/Corvids	14	-
Total Birds	10,065	-

Future flood-up programs in the Delta could be more impactful by flooding to shallower depths, and most importantly by focusing on creating habitat in the “shoulder seasons”, specifically mid-July to September 30, and April. According to recent bioenergetic studies, these are the time periods when migratory shorebirds in the Central Valley are in greatest need of additional habitat (Dybala, et al., 2017; Golet G. H., et al., 2022).

Summary of Bird Response in DDRPP fields with Bird Benefit Practices: Nesting Habitat

Other fields that were enrolled in the DDRPP were managed for nesting cover to provide habitat for breeding waterfowl and land birds. In the case of waterfowl, this was done to provide a habitat type that is thought to be limiting waterfowl production in the Delta, and the Central Valley more generally. The practice is also expected to provide breeding and foraging habitat for grassland birds, which are one of the fastest declining groups of birds in North America. Fields enrolled in this practice were required to maintain ≥ 60% of the enrolled acreage undisturbed with vegetative cover of ≥ eight inches from April 15 - July 1. In total 1,224 acres were enrolled in the practice. Some fields overlapped with implementation of other water conservation practice types; see Table 4 for detailed descriptions of field characteristics. Growers were paid $40 per acre to provide nesting habitat, for a total of $48,960 for all enrolled nesting habitat fields.

To evaluate bird response to this practice, 11 strip transect surveys were conducted (five in June and six in July). These fields showed evidence of use by many species including many songbirds and a few waterbirds. Evidence of breeding by some species was found including nests, and observations were made of adults performing territorial displays and carrying food in their bills. Hatch year birds were also observed. Aerial foragers were active above some of the fields suggesting that there was on-site invertebrate production. Elevated field edges on levees and roadsides provided a 3-dimensional structure that was often where birds were observed. Although some California grassland birds were observed, many were not. In total 187 birds were counted during the surveys (96 in June, 91 in July). The average number of birds observed per survey was 17 ± 7.7 SD, and the average number of species per survey was 6.1 ± 2.9 SD. As shown in Table 24, 27 species were observed in June and July. 16 species were observed in only one month and 11 species were observed in both months.

Table 24. DDRPP nesting bird response observations in June and July.

Common Name	Observed in June	Observed in July
American Goldfinch	June	July
Bank Swallow	June	-
Barn Swallow	-	July
Brown-headed Cowbird	June	July
Blue Grosbeak	June	-
Black Phoebe	-	July
Bullocks Oriel	-	July
Cliff Swallow	-	July
Common Yellowthroat	June	July
Great Egret	June	-
House Finch	June	July
Horned Lark	June	-
Killdeer	June	-
Lesser Goldfinch	-	July
Mallard	June	July
Marsh Wren	June	July
Mourning Dove	June	July
Northern Harrier	-	July
Northern Mockingbird	-	July
Red-necked Phalarope	June	-
Red-winged Blackbird	June	July
Savanah Sparrow	June	July
Song Sparrow	June	July
Spotted Towhee	-	July
Turkey Vulture	June	-
Western Kingbird	June	July
Western Meadowlark	-	July

Overall, it appeared that these sites provided some valuable habitat even though abundances of birds were relatively low. Habitat value could likely be enhanced by introducing more heterogeneity to the fields which were often quite uniform in terms of species composition, density, and height of the plants. Many of the fields had very dense cover crop and weed communities, and while this is attractive to some species, others would have been more likely to use the sites if there were some gaps in the vegetation.

Appendix D: UC Davis Study Update

This appendix summarizes the progress made on the grant agreement between the Delta Conservancy and UC Davis on the study titled, “Micrometeorological Measurements and Water Budget Calculations to Evaluate Conservation Practices in the Annual Delta Crops.” The UC Davis research team includes Principal Investigators Dr. Kosana Suvočarev, Dr. Kyaw Tha Paw U, Dr. Samuel Sandoval, Dr. Dave Pyles, and Dr. Michelle Leinfelder-Miles, as well as graduate students Olmo Guerrero Medina and Emma Ware, and undergraduate students Ellie Park and Emma Falk.

The goals of the study are to (1) measure and estimate water budgets for up to six fields in the Sacramento-San Joaquin Delta and (2) assess the application of OpenET to estimate consumptive water use of these six fields, recommend improvements to OpenET, and recommend improvements to the calculation of the OpenET ensemble value as applicable.

In the spring of 2023, the UC Davis research team worked with the DDRPP Oversight Committee to choose the six fields for study. At the time of bid, growers were asked to state if they would be willing to host the study, and the UC Davis research team met with the DDRPP Oversight Committee and other interested parties to discuss which of the available sites would be most useful to study. Potential sites would need to meet the requirements of hosting the micrometeorological stations and represent a variety of field management practices, crop types, and elevations. The UC Davis team and Delta Conservancy staff performed eight site visits to create a proposed list of study sites. The UC Davis team then met again with the DDRPP Oversight Committee to confirm the site choices.

By the end of September 2023, the UC Davis research team installed all the sites (DDRPP23-034, DDRPP23-055, DDRPP23-065, DDRPP23-090, DDRPP23-104, DDRPP23-113), each consisting of two micrometeorological stations (Figure 27). All sites have two micrometeorological stations: primary, or main (Figure 28), and secondary. The main stations have research-grade micrometeorological sensors (e.g., sonic anemometer and infrared gas analyzer) and a denser array of soil sensors to better consider atmosphere-soil exchange processes. The secondary stations have less precise instruments (e.g., wind propeller) but have an independent energy supply, which will reduce data loss should the main station fail. Both stations have three soil humidity profilers that monitor water movement in the first meter of the soil. The stations are in different field corners to capture the soil’s spatial variability. The corner of the main stations was chosen based on micrometeorological conditions to ensure that the measurement footprint lies within the field of interest, which is ±180° to the local prevailing wind direction.

To determine the wind direction, the UC Davis research team used data from the closest CIMIS stations for each field, and when two stations showed contradictory prevailing wind directions, the UC Davis research team installed a wind vane on a temporary deployment tower to capture data for several days to see which of the CIMIS stations is more representative of field conditions to consider long-term wind patterns. After analyzing the data, the UC Davis research team selected the best corner for installing both the main station and the secondary station. The corner of the secondary station was chosen as the point of opposite slope than the main station, aiming to monitor water movement in the soil across the field. In some cases, the UC Davis research team had to sacrifice this design to gain safe winter access to the secondary station, which will be necessary for the long-term maintenance of the stations. Simultaneously to the installation, vegetation measurements (e.g., Leaf Area Index, height) were taken that will be very useful to understand the flux trends through the seasonal development of the crops and annual changes in management.

The following is a description of each of the fields where measurements are being taken.

DDRPP23-034 was rain-fed winter wheat during the 2023 DDRPP. The 2023 wheat crop was already in the field and would be harvested in July 2023. The stations were installed after harvest in summer 2023. After the harvest they tilled the field and prepared it for starting a winter crop. The site is an excellent size for the study, with three winter wheat plots (around 50-60 acres each), one after the other (approximately 170 acres). Some relatively small ditches separate the fields. The farmer pointed out on a site visit that the delimitation of the fields is more related to differences in soil texture. The terrain is flat, with no perceivable slope and with no obstacles. The site has good size and fetch. The wheat was very clean, meaning that there were not many invasive grasses in the field; the farmer has good weed management, which will provide more homogeneous fields.

DDRPP23-055 grew safflower during the 2023 DDRPP. All the plots are separated by big ditches. They use sprinkler irrigation. The field is flat, with no obstacles inside the farm, but it is surrounded by vineyards and in all directions it has tree rows as wind breakers. The initial site visit day was very windy, and the farmer said it is usually like that. The winds are predominantly southwest, with some northwest, as stated by the farmer. The soil does not have a lot of clay and is sandier than other sites. The farmers live on site, which makes it very safe for hosting the equipment. They have had no vandalism on their property in the past. This is a well-managed farm, and the farmers have a lot of knowledge and experience with this site.

DDRPP23-065 was fallow during the 2023 DDRPP. Historically the fields were corn, but the farmer is trying to convert to rice in his long-term plan. The field is well below sea level. There is good access from the levee road, although the roads between the fields may get muddy during the winter. There is a public marina/harbor on the road at the southeast corner of the property, but the levee road on the east side of the property is private, and there didn’t seem to be any security concerns. The soil is sandy towards the south and gets peaty on the northern part of the field, with sand strata throughout. The site has very heterogeneous soil. There are irrigation ditches between fields, but the fetch is large enough for the equipment. There are plans for sheep/cattle grazing the site, so it’s a particularly interesting fallowing practice with some vegetation that might be maintained according to the healthy soils practices.

DDRPP23-090 was a rain-fed pasture with cows present throughout the 2023 DDRPP. Wild geese are also present when the site has clover. This site has been a pasture since 1994 and hasn't been tilled since. The plot hosting the experiment is around 80 acres. The dimensions of the field are excellent, with almost no obstacles. The farmers seed the field with regular grass seeds and allow the growth of any other weed species. They are particularly interested in clovers. The soil has a lot of organic matter.

DDRPP23-104 was a low irrigation maize field during the 2023 DDRPP. The farm has 165 acres separated into two plots. The plot hosting the experiment is 72 acres. The field is below sea level, as can be seen by the close-by pond that is, approximately, 6 meters higher than the field. The plots are divided by local ditches, and the land is delimited by state ditches that are bigger in size and are in the northwest-northeast direction, possibly negatively affecting the fluxes. During the previous year, the farmer planted sorghum, but the field also has a lot of Johnsongrass. The farmer now plans to grow corn, a variety that reaches around 10 feet tall. The farming is conventional, with herbicides. Historically, the farm has been used to grow asparagus, and in the last years they have mainly transitioned to tomatoes, peppers, and corn, but they have also tried other crops. The soil has a lot of clay and organic matter.

DDRPP23-113 was a low irrigation maize plot during the 2023 DDRPP. Previously the farmer planted safflower, and in 2023 they planted corn. Corn has been planted in this site since the 1940s. The grower is hosting other scientific projects related to migratory birds. The site is flat, with no slopes or obstacles. The site is surrounded by organic pear orchards and vineyards. The orchards are far enough away that they will not distort the wind flow. The soil seemed to have a lot of clay, it showed cracks in the surface, but 5 cm deep it still felt very wet. The farmer commented that it has taken two months to dry, which was the reason the disking had been delayed in 2023.

Initial Findings

The UC Davis research team processed 2023 soil samples to obtain soil humidity content, real and apparent densities, and porosity of the soil. Data gathered by sensors thus far has been collected, processed, cleaned, and preliminarily analyzed. These preliminary findings underscore the necessity of resolving large mean vertical temperature and moisture gradients that can occur within intensive crops in a semiarid environment. For example, the UC Davis research team has noticed routinely large amounts of ET and carbon uptake that present challenges to common theoretical assumptions behind ET estimation methods that rely on surface temperature estimates from remotely sensed satellite data. One issue is related to intense levels of ET that can occur amid warm, windy daytime conditions with low humidity. During the day, H values can approach < -200 Wm^2, while LE can be well over 500 W m^2; NEE > 50 µmol m^2 s^1. Although these observed values are very high, the UC Davis team is taking them into account, and after collecting the full range of data under the annual and multi-annual changes in management, they will have better sense if some of those data might be identified in the future as spikes that need to be removed and gap filled. Whether or not the soil is wet, dry, and/or is directly exposed to sunlight plays a large role in the variations of temperature and humidity within the canopy, and thus the total ET that is estimated.

The UC Davis research team has also been exploring strategies to interpolate remotely sensed vegetation timeseries for the regions closest to each site. Intensely managed farmlands exhibit ranges of vegetation density that change rapidly. Large differences between 30-m pixels can heavily influence estimates of ET, as models are commonly sensitive to this crucial parameter, and the total LAI of croplands varies considerably amid rapid growing conditions, harvesting, and management schedules.

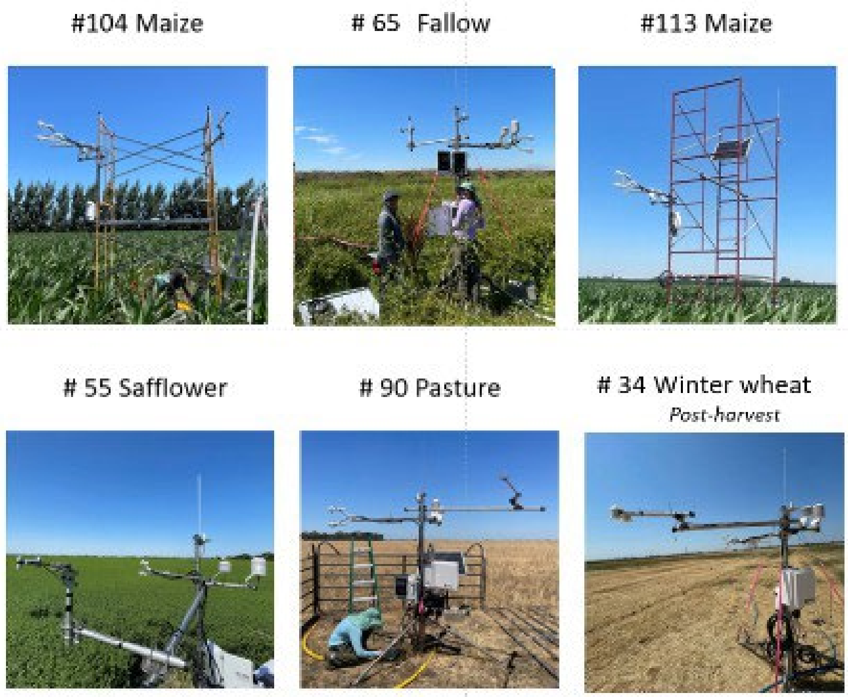

Figure 27. Micrometeorological equipment installed on six sites.

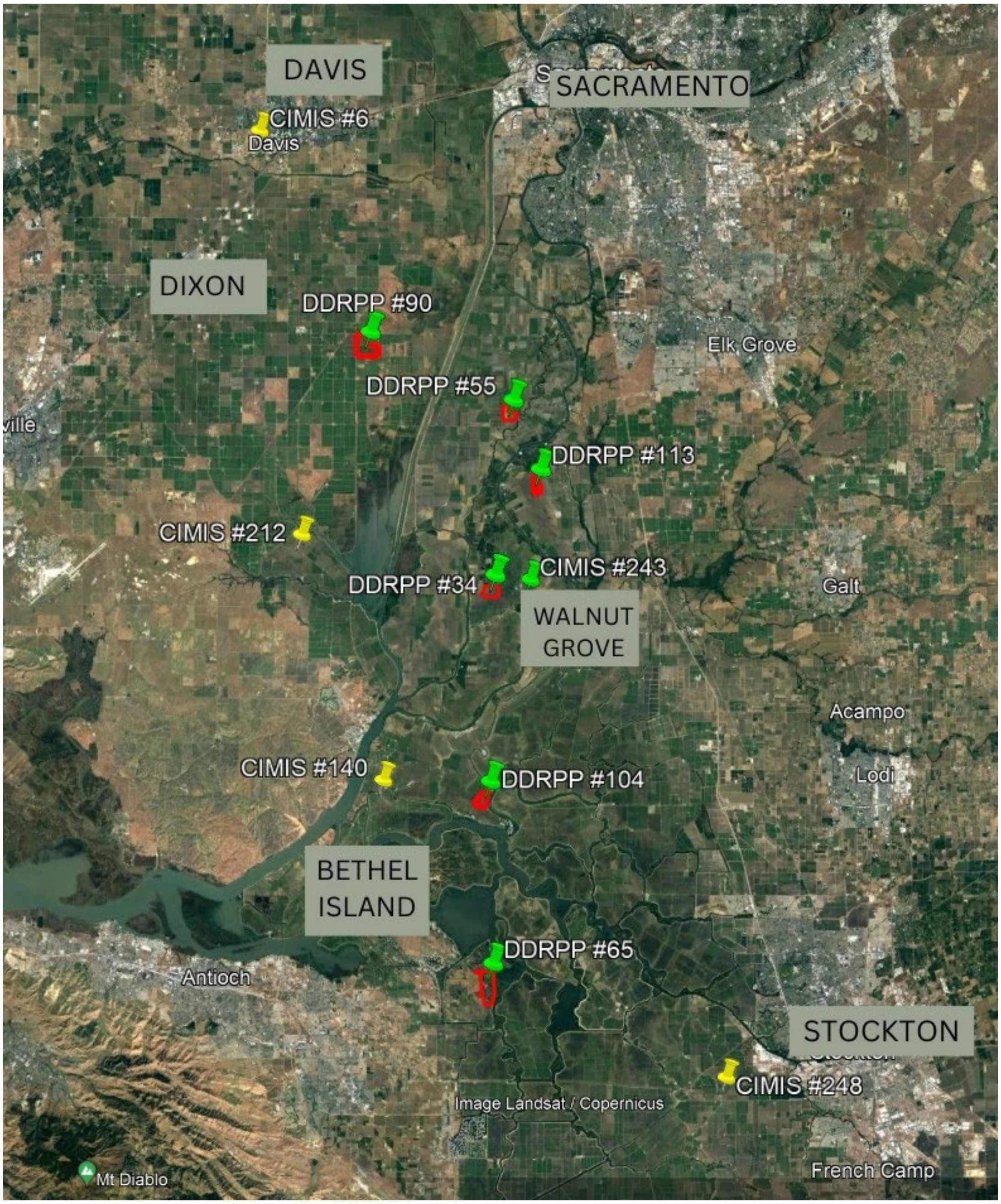

Figure 28. Locations of UC Davis study sites.

Appendix E: Solicitation of Applicants

The following is the text of the solicitation posted on the Delta Conservancy website.

Program Goals

The goals of the 2023 Delta Drought Response Pilot Program (Program) are to reduce drought stress in the Sacramento-San Joaquin Delta (Delta) watershed by incentivizing agricultural water users to incorporate practices into their operations that:

1. Conserve water on a net basis during the 2023 water year versus business-as-usual;
2. Protect Delta water quality by providing an added buffer against salinity intrusion;
3. Promote soil health; and
4. Mitigate potential drought impacts on fish and migratory birds.

Deadline and Eligibility

Participation in the Program requires interested individual agricultural water users to submit bids. Bids for the Program are due on October 18, 2022. Bid submission through The Delta Conservancy's website must be fully completed by 5 p.m. on the due date. Individual agricultural water users with points of diversion located within the legal Delta are eligible to apply. See below the Program background and bidding details.

Background

This Program is a response to consecutive dry years, low combined storage in Project reservoirs, heightened risk of salinity intrusion, and drought-constrained water deliveries to Project contractors. Funds are available to incentivize agricultural water users in the legal Delta to incorporate practices expected to reduce crop consumptive water use and thereby protect water quality. Water conserved through these incentivized practices will be allocated to protect Delta water quality and will not be available for diversion within the Delta or export out of the legal Delta.

The Delta Conservancy (Conservancy) has received extensive feedback from participants in the 2022 Delta Drought Response Pilot Program. Based on that feedback, and to improve efficiency, transparency, and fairness of the grant selection process, the Conservancy will conduct this year's Program through a reverse auction process.

Reverse Auction

A reverse auction is essentially the mirror image of a typical auction in which there is one seller and multiple competing buyers. For the 2023 Program, many farmers across the Delta are anticipated to submit bids for incentive payments to undertake one or more water conservation practices. The reverse auction will be used to select the combination of bids that maximize the benefit to the Delta within the limited budget, while fairly compensating grantees. To incentivize bidding that is both competitive and fair, all accepted bids will be offered grants at the highest price accepted for similar practices. This price is called a market clearing price[1] and will be paid to the accepted bidders even if their original bid was lower than that price.

This means that all accepted bids will be paid at least as much as their own bid and up to any higher bid accepted into the Program for similar practices. To increase the chance of getting an accepted bid, the best strategy is to bid the cost of implementing a water conservation practice into the 2023 farming plan plus any forgone profits expected from business-as-usual. Bidding higher than cost and forgone profits reduces the chances of selection without increasing the amount paid if selected. Bidding below cost could lead to being offered a grant that does not provide any incentive for the farmer.

Selection Criteria

Criteria used to establish a clearing price and select eligible bids include:

- Estimated water savings at the cost per acre bid, and
- Diversity of locations and of proposed water conservation practices.

The Program will fund a variety of water conservation practices across the Delta to inform both farmers and state agencies about the efficacy of diverse practices and locations for potential response to future droughts. A selection committee including representatives from the Conservancy, Department of Water Resources, Office of the Delta Watermaster, Department of Food and Agriculture, University of California Cooperative Extension as well as Davis and Merced campuses, and The Nature Conservancy will evaluate the bids.

Bid Qualifications

For the 2023 Program, farmers are asked to bid a price per acre for implementing specific water conservation practices on their farms between January 1, 2023, and the end of the water year on September 30, 2023. Proposed practices must be reasonably expected to reduce net consumptive water use in the applicants' agricultural operations at the project site across the entire grant period. Bidders are encouraged to propose practices that (1) maximize the Program's goals and (2) are appropriate for the applicant's locations and agricultural circumstances. Common practices from the 2022 Program included:

1. Deficit irrigate to conserve water (e.g., forgo a portion of the normal irrigation cycle);

[1] We define a market clearing price as a single, uniform price paid to all selected bids for similar practices that, combined with the prices paid for other practices, allows total awards to best fit Program goals and objectives within the available budget.

2. Shift Crop Type to reduce water consumptive use (e.g., substituting small grains, safflower, or other crop that consumes less water than a more water-intensive crop like corn or tomatoes); and
3. Forgo a cash crop to reduce consumptive water use (e.g., maintain idled farmland with appropriate drainage and soil protections).

The 2023 Program encourages applicants to propose other innovative practices designed to accomplish one or more of the Program's goals.

Reverse Auction Process Example

While the market clearing prices cannot be known in advance of receiving the bids, suppose twenty farmers provide bids for a particular practice, such as forgoing a summer crop, and the bids range from $100 per acre to $900 per acre. The Program evaluates the bids based on the amount of water expected to be saved per dollar spent and then establishes the highest bid (market clearing price) that maximizes water savings within the limited budget.[2] For this example, say, the Program reaches optimum water conservation for this practice by selecting bids as high as $500 per acre. All selected bids for similar practices at or below $500 will be offered a grant at $500/enrolled acre; those who bid over $500 will not be offered a grant.

Bird Benefit Practices

Applicants are encouraged, but not obligated, to incorporate bird benefit practices, which provide crucial habitat for waterbirds and other wildlife. Migrating waterbird populations have declined dramatically in North America; shorebirds have experienced a ~40% population drop in the last 50 years; some waterfowl, including mallards and pintail, show similar declines compared to the long-term averages.

The Program anticipates providing waterbird habitat improvements through short-term shallow flooding of fields and delaying harvest of non-irrigated small grains to protect nesting cover. In exchange, accepted applicants will receive a bonus of $75 per acre for shallow flooding and/or $40/acre for Nesting habitat through delayed harvest. Program requirements for the flooding practice include minor field preparation to incorporate leftover vegetation into soil and shallow flooding for at least four weeks with an average depth of 4 inches on a minimum of 30 contiguous acres. For Nesting habitat, participants agree to leave non-irrigated small grain crops and cover crops in the field until at least July 1, 2023. Each applicant's combination of

[2] Although the bids will set the market clearing price, grant applications will be evaluated and selected to achieve the overall best fit with Program goals, not just best water savings/dollar.

water conservation practices and bird benefit practices must achieve a significant overall water savings for the water year compared to business-as-usual.

Bid Process

The following link takes a prospective bidder to an electronic bid form. Please use the form to electronically submit your bid by the deadline of 5:00 p.m. on Tuesday, October 18.

1. Applicants may submit multiple bids that specify different practices at different sites by submitting multiple bid forms, but the same site cannot be included in more than one bid.
2. Bids must be a minimum of 100 contiguous acres in each site with a single proposed practice for each bid.
3. There is no limit on total acres bid by any applicant, but individual and closely related bidders will be capped at 1,000 acres enrolled in the Program.
4. Applicants must propose a comparison field against which to compare water savings attributable to proposed practices at the project site versus business-as-usual at the comparison field (see **Baselines for Measuring Conservation** below).
5. Only responsible bids that seek reasonable compensation for proposed practices will be considered.

Grant Offers Timeline

Grant awards will be announced following Conservancy approval, which is expected by November 30, 2022. Results will be posted with the final selection and ranking. Grant agreements are expected to be executed by December 31, 2022.

Payment Terms

Twenty five percent (25%) of the grant is payable six weeks after the grant agreement has been executed. Up to fifty percent (50%) is payable for satisfactorily completing key project milestones specified in the grant agreement. The balance of the grant is payable upon completion of all tasks specified in the grant agreement, after the end of the water year (September 30, 2023). Payments will be made based on submission of a proper invoice, as described in the grant agreement.

Baselines for Measuring Conservation

Bidders will include with their applications a proposed comparison field(s), which will be used in an evaluation of the water savings attributable to different water conservation practices across the Program. By measuring crop evapotranspiration (ET) on the comparison fields versus fields enrolled in the Program, crop consumptive water use savings attributable to the incentivized water conservation practice can be estimated. The bidder should propose a comparison field based on characteristics that make it comparable to the field enrolled in the Program.

The comparison field should reflect the business-as-usual practices that would otherwise be applied at the project site if it were not enrolled in the Program. The comparison field should have the same (1) crop type, (2) field management, and (3) irrigation methods that would have been used on the project site but for the incentive grant.

Additional characteristics of a good comparison field are:

1. Near enrolled site,
2. Has same or similar soil type(s) as enrolled site,
3. Is farmed by the applicant or an affiliate,
4. Has similar elevation to the enrolled site, and
5. Has a similar size/area as the enrolled site.

The Conservancy will review the proposed comparison field and work with the bidder to choose a final comparison field that is an appropriate baseline for comparison.

Measurement of Crop ET

For purposes of the Program, crop ET will be measured by the state agencies using OpenET (https://openetdata.org/) and evaluated by an oversight committee.

Monitoring and Evaluation

Monitoring and evaluation of the Program will be as transparent and objective as available data allow. In cooperation with grantees, an oversight committee will gather and share all data related to the Program. To augment measurement of crop ET through OpenET, state agencies will organize a monitoring team, comprising academic researchers, to assist with data gathering, monitoring, and synthesis of data from the Program. The Conservancy and other collaborators will meet regularly to assess the Program. The Conservancy will prepare a written draft evaluation of the Program for public review and comment prior to finalization.

Access for Monitoring and Verification

Grant agreements will include permission from the grantee for representatives of the Conservancy (including collaborators, selection committee, oversight committee, and the monitoring team) to access the project site for monitoring and verification purposes. Such representatives will provide at least a 24-hour advance notice to the grantee and follow appropriate safety protocols while on site. Site visits will be at the sole risk of the representatives; the grantee will have no liability for the safety of the representatives related to site visits. In addition, a limited number of grantees (up to six) may be asked to host field measurement equipment. Conditions for the field equipment will be specified in the applicable grant agreements.

Equipment Hosting

The 2023 Program will include data collection on water conservation/water quality practices and how they are affected by soil type, proximity to channels, crop selection, irrigation strategies, etc. The selection committee will give extra consideration to bidders with suitable locations willing to host equipment for three years.

Program Costs

All costs associated with implementing proposed practices on their project site are to be borne by grantees. All costs for monitoring and administering the Program will be borne by the state agencies.

For more information: http://deltaconservancy.ca.gov/grant-program/delta-drought-response-pilot-program/

If you have questions, please contact the Conservancy at Contact@DeltaConservancy.ca.gov or (916) 375-2084.

Appendix F: 2023 Grant Summaries

This Appendix lists the grants as awarded. Some grants were not carried out as awarded, (see Execution of Grant Agreements).

Grant #	Grantee Name	Amount Awarded	County	Water Saving Acres	Proposed Action
DDRPP23-010	Nuss Farms, Inc.	$29,700	San Joaquin	99	Other
DDRPP23-011	Willow Springs Ag LLC	$103,555	Solano	149	Forgo a Cash Crop
DDRPP23-012	Willow Springs Ag LLC	$130,660	Solano	188	Forgo a Cash Crop
DDRPP23-014	Willow Springs Ag LLC	$125,100	Solano	180	Forgo a Cash Crop
DDRPP23-015	Willow Springs Ag LLC	$186,955	Solano	269	Forgo a Cash Crop
DDRPP23-016	Willow Springs Ag LLC	$72,280	Solano	104	Forgo a Cash Crop
DDRPP23-019	Willow Springs Ag LLC	$73,670	Solano	106	Forgo a Cash Crop
DDRPP23-025	Nuss Farms, Inc.	$33,000	San Joaquin	110	Other
DDRPP23-026a	Hubert Denis VanDeMaele	$140,400	Sacramento	208	Deficit Irrigation
DDRPP23-026b	Hubert Denis VanDeMaele	$97,875	Sacramento	145	Deficit Irrigation
DDRPP23-027	Linda Katsuki	$181,500	Sacramento	363	Shift Crop Type

Grant #	Grantee Name	Amount Awarded	County	Water Saving Acres	Proposed Action
DDRPP23-029	Doug Chan Farms	$65,475	Sacramento	97	Deficit Irrigation
DDRPP23-030	Doug Chan Farms	$164,700	Sacramento	244	Deficit Irrigation
DDRPP23-032	Doug Chan Farms	$166,050	Sacramento	246	Deficit Irrigation
DDRPP23-034	Wallace Chan Farms, Inc.	$103,500	Sacramento	207	Shift Crop Type
DDRPP23-037	Garrett Esperson	$65,000	Solano	130	Shift Crop Type
DDRPP23-038	Garrett Esperson	$68,000	Solano	136	Shift Crop Type
DDRPP23-039	Garrett Esperson	$80,000	Solano	160	Shift Crop Type
DDRPP23-040	Garrett Esperson	$71,000	Solano	142	Shift Crop Type
DDRPP23-041	Richard Silva	$518,400	Contra Costa	768	Deficit Irrigation
DDRPP23-042	Mello Farms, Inc.	$174,420	Sacramento	323	Shift Crop Type
DDRPP23-043	Mello Locke Ranch	$89,500	Sacramento	179	Shift Crop Type
DDRPP23-045	J & L Mello Farm Equipment Company	$313,200	Sacramento	464	Deficit Irrigation

Grant #	Grantee Name	Amount Awarded	County	Water Saving Acres	Proposed Action
DDRPP23-046	Steven Dinelli	$141,375	Sacramento	190	Deficit Irrigation
DDRPP23-047	Steven Dinelli	$49,000	San Joaquin	98	Shift Crop Type
DDRPP23-048	Steven Dinelli	$154,575	San Joaquin	229	Deficit Irrigation
DDRPP23-049	Wallace Chan Farms, Inc.	$63,500	Sacramento	127	Shift Crop Type
DDRPP23-050	Lund Ranch LLC	$675,000	San Joaquin	1000	Other
DDRPP23-051	Gardiner Company	$62,775	Sacramento	93	Deficit Irrigation
DDRPP23-052	Gardiner Company	$87,750	Sacramento	130	Deficit Irrigation
DDRPP23-054	Daniel Yarbrough	$69,525	Sacramento	103	Deficit Irrigation
DDRPP23-055	Dutra Hay & Grain	$93,960	Yolo	174	Shift Crop Type
DDRPP23-057	Ernest J Pombo Jr	$71,585	San Joaquin	103	Forgo a Cash Crop
DDRPP23-060	Ernest J Pombo Jr	$81,315	San Joaquin	117	Forgo a Cash Crop
DDRPP23-065	Lemhi Land & Cattle, LLC	$845,000	Contra Costa	1000	Forgo a Cash Crop

Grant #	Grantee Name	Amount Awarded	County	Water Saving Acres	Proposed Action
DDRPP23-071	Sutter Home Winery, Inc. – Trinchero Family Estates	$249,750	Yolo	370	Other
DDRPP23-074	Ewing Farms LP	$84,790	Sacramento	122	Forgo a Cash Crop
DDRPP23-076	VKR FARMS LLC	$108,500	Yolo	150	Forgo a Cash Crop
DDRPP23-077	D&L Farms, Inc.	$93,825	San Joaquin	135	Forgo a Cash Crop
DDRPP23-078	Steven Dinelli	$83,250	San Joaquin	111	Deficit Irrigation
DDRPP23-081	D&L Farms, Inc.	$250,000	San Joaquin	500	Shift Crop Type
DDRPP23-084	Jackson Land & Cattle, LP	$420,475	Contra Costa	605	Forgo a Cash Crop
DDRPP23-085	Richard J. Carli	$391,435	Sacramento	542	Forgo a Cash Crop
DDRPP23-087	Richard J. Carli	$190,695	Sacramento	360	Forgo a Cash Crop
DDRPP23-090	Ross Rasmussen	$303,750	Yolo	450	Deficit Irrigation
DDRPP23-092	Celli Ranches, Inc.	$68,925	San Joaquin	0	Bird Benefits Only

Grant #	Grantee Name	Amount Awarded	County	Water Saving Acres	Proposed Action
DDRPP23-094	Meirinho Land & Cattle, LP	$202,500	San Joaquin	300	Deficit Irrigation
DDRPP23-095	Raymond Lagorio	$23,175	San Joaquin	0	Bird Benefits Only
DDRPP23-096	LMT Investments, LLC	$357,750	San Joaquin	530	Deficit Irrigation
DDRPP23-098	Zuckerman Family Farms, Inc.	$84,000	San Joaquin	168	Shift Crop Type
DDRPP23-103	Coleman M. Foley, Jr.	$455,700	Contra Costa	620	Forgo a Cash Crop
DDRPP23-104	Louis Biagioni	$97,250	Sacramento	172	Shift Crop Type
DDRPP23-105	Coleman M. Foley, Jr.	$183,500	San Joaquin	367	Shift Crop Type
DDRPP23-109	3D Farms, LLC	$100,500	San Joaquin	201	Shift Crop Type
DDRPP23-110	Wallace Chan Farms, Inc.	$68,000	Sacramento	136	Shift Crop Type
DDRPP23-113	John C. Backer Estate	$86,925	Sacramento	127	Deficit Irrigation

Grant #	Grantee Name	Amount Awarded	County	Water Saving Acres	Proposed Action
DDRPP23-116	Zuckerman Family Farms, Inc.	$80,700	San Joaquin	0	Bird Benefits Only
DDRPP23-117	Victoria Island LP	$260,000	San Joaquin	520	Shift Crop Type
DDRPP23-118	Victoria Island LP	$173,055	San Joaquin	249	Forgo a Cash Crop
DDRPP23-120	Knob Hill Mines, Inc. dba Hastings Island Land Company	$135,500	Solano	271	Shift Crop Type
DDRPP23-122	Knob Hill Mines, Inc. dba Hastings Island Land Company	$492,075	Solano	729	Deficit Irrigation

Appendix G: Optimization and Reverse Auction

Model Description

For a given water conservation practice, the indices in Table 25 were used to define the model data and variables.

Table 25. Optimization model indices

Index	Description
a	practice
i	bid
k	bidder

Each bid consisted of the following data:

1. Water conserving practice to be performed
2. Number of acres
3. Price per acre
4. Average water savings per acre for each practice estimated by the selection committee

The optimization problem was to choose the acres to fund (x_{aik}) at the bid price for each practice (p_a) to maximize estimated water saving in Equation 1 subject to the constraints given by Equation 2, Equation 3, Equation 4, and Equation 5.

Equation 1

$$\mathrm{Max}_{x_{aik}} \quad \sum_{a,i,k} w_{aik} \cdot x_{aik}$$

w_{aik} is estimated water savings (ac-ft per acre) from bid i submitted by bidder k for practice a. Therefore, the product (w · x) in the summation above represents ac-ft of water saved.

Equation 2 ensures the bid price (p_a) is greater than or equal to the price for each funded bid (p_{aik}^b).

Equation 2

$$(p_a - p_{aik}^b)x_{aik} \geq 0$$

The accepted acreage per bid is constrained by Equation 3 where $\underline{x}$ is the minimum allowed acreage in the Program (set to 100 acres) and x_{aik}^b is the acreage submitted in the bid. This inequality implies that Equation 2 is equal to zero for all unfunded bids and is strictly greater than zero for all funded bids.

Equation 3

$$\underline{x} \leq x_{aik} \leq x_{aik}^{b}$$

In Equation 4, the total acres funded for each bidder k must not exceed the allowed acreage per bidder ($\bar{x}$), which was set to 1,000 acres.

Equation 4

$$\sum_{a,i} x_{aik} \leq \bar{x}$$

Equation 5 indicates that at the bid price for each practice (p_a) the total cost of the acres funded must not exceed the budget ($\bar{y}_a$).

Equation 5

$$\sum_{i,k} p_a \cdot x_{aik} \leq \bar{y_a}$$

Implementation

The model was solved in GAMS (GAMS, 2022) using the CONOPT solver (Drud, 1985). The model was solved as a linear programming (LP) model. Because the market-clearing price represents a uniform payment per acre, the cost curve for each practice is discontinuous, increasing stepwise in acreage. The price paid for each successful bid corresponds to the highest price of the accepted bids for that practice, which caused the price per acre to jump as more expensive bids were accepted. Due to this discontinuity, the program is solved for a given set of prices corresponding to the different water conservation practices. Once the model is solved for all unique combinations of prices submitted, the optimal set of prices is selected based on total potential water savings (ac-ft) for each water conservation practice. The algorithm is summarized as:

1. Select bid prices for each of the water conservation practices
2. Run the optimization model
3. Given the model solutions from step 2, choose the set of prices that maximizes benefits

Auction Performance

The weighted price paid across the three water conservation practices was $638.75 per acre, which is 29% lower than the fixed price offered in the 2022 Program. The competitive aspect of the auction combined with heterogeneity of costs across different farmers and locations allowed for the selection of lower-cost bids than would have otherwise been possible. However, because the objectives of the Program included considerations such as collecting information from a diversity of locations and water-saving practices, the prices paid were not as low as they could have been had cost-effectiveness been the sole basis for bid selection. In particular, allocating a pre-specified percentage of the Program budget to the three practices meant some bids that would have saved more water at a lower cost were not selected. This may be thought of as the cost of learning what is the most effective means of conserving water. Given what has been learned over the two years of the Program, it is very likely that the use of a reverse auction in future water-savings programs would result in much lower costs than would be expected under a fixed price scheme.

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Glossary

Term or Acronym	Definition
ac-ft	Acre-foot or acre-feet. A measure of volume commonly used in water supply planning. One acre-foot is the volume of water required to cover one acre (43,560 square feet) of surface area to a depth of one foot. Equivalent to 325,851 gallons.
ac-ft/ac	The number of acre-feet per acre. Calculated by dividing the volume (ETa) by area (acres). Used to compare ETa across areas of varying sizes.
Beneficial Bird Habitat	Practices in the 2023 DDRPP, including Nesting habitat, Spring Flood-up, and Fall Flood-up, that provide crucial habitat for waterbirds and other wildlife. Referred to as “bird benefits” in the solicitation materials.
business-as-usual	The crop type, irrigation practices, and field management practices for the project site if the site had not been awarded a DDRPP grant, as self-defined by DDRPP applicants. Used as a baseline for measuring water conservation.
cash crop	A crop produced for its commercial value.
CDFA	California Department of Food and Agriculture
CIMIS	California Irrigation Management Information System. A California Department of Water Resources (DWR) unit that manages a network of over 145 automated weather stations—or CIMIS stations—in California.
comparative savings estimate	One method to estimate consumptive use savings for DDRPP 2023. Compares actual evapotranspiration (ET) on the project field to actual ET on a comparison field performing business-as-usual field management. Calculated as: 2023 Comparison Field ETa – 2023 Project Field ETa. Positive savings values indicate that consumptive use on the project field for water year 2023 was less than the baseline. Negative estimated savings values indicate that consumptive use on the project field for water year 2023 was greater than the baseline.
consumptive use	Water that is removed from a watershed via evapotranspiration and is not available for other uses. Consumptive use and evapotranspiration are often used interchangeably.

Deficit Irrigation	A water conservation practice from the 2023 DDRPP in which the crop type in 2023 and the business-as-usual crop were the same. Project sites went without a portion of the business-as-usual irrigation cycle. Most projects had no irrigation events but were allowed a maximum of two irrigation events on the project site during the water year.
DDRPP or Program	Delta Drought Response Pilot Program
Delta Conservancy	Sacramento-San Joaquin Delta Conservancy
DWR	California Department of Water Resources
ETa	Actual crop evapotranspiration. An estimate of the amount of ET that occurred under actual conditions.
ETo	Reference evapotranspiration. Based on the ET of a well-watered short reference crop surface with full canopy coverage, typically sod.
EToF	Reference evapotranspiration fraction. Calculates the ratio of actual evapotranspiration (ETa) to reference evapotranspiration. EToF = ETa/ETo
evapotranspiration or ET	The combination of water vaporization from soil (i.e. evaporation) and plants (i.e. transpiration). Measured in linear units over time (for example, millimeters per day, mm/d), which can then be multiplied by land area and time period to calculate a volume.
Fall Flood-up	A beneficial bird habitat practice from the 2023 DDRPP that entails minor post-harvest field preparation to incorporate leftover vegetation into the soil and shallow flooding during fall 2023 for at least four weeks with an average depth of four inches on a minimum of 30 contiguous acres.
Forgo Cash Crop	A water conservation practice from the 2023 DDRPP in which there was no crop grown on the project site during the months of June, July, August, and September 2023. Some projects had no crop grown for the entire water year, and there was wide variation in vegetation management on these idle fields. Combines two 2022 DDRPP practices: Not Double Cropped and Managed Idle Lands.
Managed Idle Lands	A water conservation practice from the 2022 DDRPP in which the project site was neither irrigated nor planted with a cash crop.
Nesting Habitat	A beneficial bird habitat practice from the 2023 DDRPP that entails delaying harvest to protect nesting cover by leaving

	non-irrigated small grains and cover crops in the field until at least July 1, 2023.
Non-irrigated Crop	A water conservation practice from the 2022 DDRPP in which the project site was planted with crops that were not actively irrigated during the grant period (roughly March to September of 2022).
normalized savings estimate	One method to estimate consumptive use savings for DDRPP 2023. Calculated as: [(Average EToF 2017-2021) - (2023 EToF)] * 2023 ETo. This normalizes the savings estimate by accounting for atmospheric demand and comparing the project year (water year 2023) to the baseline, which is an average of five previous years (water year 2017 through 2021). This is comparing the project field to a historical average of itself, thus eliminating variables introduced by using a comparison field (e.g. soil type, proximity to a water course, owner, etc.) Positive savings values indicate that consumptive use on the project field for water year 2023 was less than the baseline. Negative estimated savings values indicate that consumptive use on the project field for water year 2023 was greater than the baseline.
Not Double Cropped	A water conservation practice from the 2022 DDRPP in which project sites that would normally have a winter and a summer crop grew only a winter small grain crop. The project site was left fallow during the summer, and residual stubble was retained after harvest to protect the soil.
ODWM	The California State Water Resources Control Board's Office of the Delta Watermaster
Other Annual	A water conservation practice from the 2023 DDRPP in which annual crops (peppers and tomatoes) were grown and more efficient drip irrigation systems were installed.
Other Perennial	A water conservation practice from the 2023 DDRPP in which perennial crops (young almonds and mature grapes) were deficit irrigated by 20%.
reverse auction	An auction with one buyer and many potential sellers. Sellers place bids for the prices at which they are willing to sell their goods and services.
Shift Crop Type	A water conservation practice from the 2023 DDRPP in which the crop grown on the project site shifted from a more water-intensive crop (such as corn, tomatoes, or alfalfa) to a crop that uses less water, such as safflower or small grains.

Spring Flood-up	A beneficial bird habitat practice from the 2023 DDRPP that entails minor field preparation to incorporate leftover vegetation into the soil and shallow flooding during spring 2023 for at least four weeks with an average depth of four inches on a minimum of 30 contiguous acres.
SWB or State Water Board	The California State Water Resources Control Board
TNC	The Nature Conservancy
UC Cooperative Extension	University of California Cooperative Extension
UC Davis	University of California, Davis
UC Merced	University of California, Merced
UC Santa Barbara	University of California, Santa Barbara
water year	The 12-month period from October 1 through September 30 of the following year. The water year is designated by the calendar year in which it ends, and which includes nine of the 12 months. For example, the 2023 water year would span the period from October 1, 2022 to September 30, 2023.