EVAPOTRANSPIRATION OF FALLOW FIELDS IN THE SACRAMENTO-SAN JOAQUIN DELTA 2018

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LIST OF ABBREVIATIONS

CIMIS: California Irrigation Management Information System

dT: Near Surface Temperature Difference

ET: Evapotranspiration

ETa: Actual Evapotranspiration

ETo: Reference Evapotranspiration

ET_{of}: $\frac{ET_a(fallow)}{ET_o}$; conceptually similar to crop coefficient but for fallow field ET

K_c: $\frac{ET_a(crop)}{ET_o}$; crop coefficient for crops

K_f : $\frac{ET_a(fallow)}{ET_o}$; crop coefficient for fallow fields

ST: Surface Temperature

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1 INTRODUCTION

Consumptive use (CU) in water systems is defined as the quantity of water use that is not returned for reuse via surface runoff or deep percolation into groundwater (Womach 2005). Evapotranspiration (ET), the combination of water evaporated from the soil and transpired from plants, is the predominant consumptive use from agriculture or natural vegetation and represents a substantial portion of the water budget for the Sacramento-San Joaquin Delta (hereafter referred to as 'Delta') region of California and for the State at large.

1.1 STUDY BACKGROUND

Estimating and measuring ET accurately is critical to water rights administration, irrigation management, consumptive use calculation, water distribution, and environmental and water quality protection. Specifically, water transfer policies need to be informed and guided by information about the amount of water savings resulting from fallowed field conditions and management practices.

Calculation of ET can be done fairly accurately using weighing lysimeters and various micrometeorological techniques, including eddy covariance. These methods are limited, however, because they provide values of ET for local areas ranging from a few meters (lysimeters) to a few hundred meters (micrometeorological techniques) but not for a regional scale. In regions such as the Delta, with significantly elevated water tables, lysimeters are difficult to use accurately. When regional scale estimates of ET are needed, various methods have been used with remotely sensed (RS) data from satellites to evaluate ET over broad areas. Satellite data are ideally suited for deriving spatially continuous ET surfaces spanning domains ranging from global, continental scales, and statewide scales, and also can be pared down to the field scale because of their temporal and spatial characteristics. However, RS data also have limitations because they can only measure electromagnetic radiation (light, near-infrared, thermal infrared, microwave) that traverse the atmosphere. Therefore, the most accurate use of RS models requires calibration to in situ ET measurements. The approach used in this study includes a combination of Delta island-specific ground micrometeorological ET measurements and RS modeling, calibrated with those measurements.

1.2 STUDY PURPOSE

San Luis Delta Mendota Water Authority, along with State Water Contractors and stakeholders, desired specific information on the amount of water used by fallow fields to inform their knowledge about how much water could be saved, and in turn, transferred, by fallowing fields instead of cropping them. This information is also valuable to the California Department of Water Resources and the State Water Resources Control Board, both of whom play key roles in Delta water management. A stakeholder process was initiated to develop a Delta Fallow ET Study strategy that was implemented in partnership between San Luis Delta Mendota, State Water Contractors, and the State Water Resources Control Board Delta Watermaster. This resulted in separate funding to the University of California, Davis (UC Davis), and Land IQ for a collaborative study. UC Davis was responsible for field data collection at specific locations on multiple Delta Islands, and Land IQ was responsible for spatial Delta ET assessment based on UC Davis field data; Land IQ managed remotely sensed satellite data and supplemental Tule Technologies (Tule) ET station data, meant to provide additional context in the study.

This research project was the last in a series of three projects, in which the first two, convened by the Center for Watershed Sciences at UC Davis with funding from some of the previously mentioned agencies, to study ET from fallow and cropped fields. The previous projects resulted in an interim report for a 2015 study on fallow fields by Medellín-Azuara et al. (2016) and a report on the 2017 study of selected crop ET, Medellín-Azuara et al. (2018).

The main focus of the study documented in this report, the Delta Fallow ET Study, was to establish the basis for water savings if fields were left fallow during the growing season instead of cropped. It mainly focused on measuring and estimating fallow field ET and measuring or documenting specific field conditions to determine if they were influential on ET. In addition, ET measurements and estimates were made in some active alfalfa, tomato, and pasture fields that represent a range of ET conditions. A remote sensing method was employed to leverage measured ET data points and develop a complete spatial assessment of consumptive use by fallow and cropped areas in the Delta.

1.3 Site Description

The Delta's area can be defined by either the Legal Delta boundaries, as specified by the 1959 Delta Protection Act, or the Delta Service Area (DSA), which is defined by the California Department of Water Resources (DWR) as areas that are irrigated by channels in the Delta. The Legal Delta area covers 737,625 acres, while the DSA covers 679,594 acres of generally congruent land and water surface. The Delta Service Area boundary was used to both identify potential station locations and perform imagery analysis.

2 Summary of Methodology

The Delta Fallow ET Study took place in the 2018 water year (October 1, 2017- September 30, 2018). This study focused on monitoring and assessment of ET under fallow and cropped land conditions on selected fields in the Sacramento-San-Joaquin Delta (Delta). In this study, approximately 166 acres of cropland (based on 2018 Land IQ delineated field boundaries) were fallowed to evaluate the effect on net reduction of water consumption, contemporaneous with matched neighboring crop fields at some sites. Water consumption was measured at selected locations using a variety of micrometeorological instrumentation managed by UC Davis and Land IQ to calculate site-specific evapotranspiration rates. These in-situ measurements were used by Land IQ, along with available satellite imagery data, to calibrate a remote sensing ET modeling approach and generate evapotranspiration (ET) calculations for the entire fallowed area for the duration of the pilot growing season.

2.1 Field Measurements of ET

During the study period, specific fields were instrumented with field data collection stations so that ET could be measured and estimated in multiple ways. These sites with ET measurements were also used to calibrate a Delta-specific, remotely sensed ET model for all fields in the Delta. Appendix B and Medellín-Azuara et al. (2016;2018) provide details of the UC Davis-led field methodology and a discussion of measurement and estimate uncertainties. UC Davis installed and operated all meteorological instruments and collected and processed data from field stations, while Land IQ supported site selection and instrumentation, acquired remotely sensed imagery, and performed remotely sensed ET calibration and analysis.

Four types of field stations were installed for ET measurements:

1. Surface renewal energy budget residual (UCD)
2. Modified surface renewal (Tule – managed by Land IQ)
3. Eddy covariance energy budget residual (UCD)
4. Direct eddy covariance of evapotranspiration (UCD)

Field Stations

UC Davis installed 18 field data collection stations and Land IQ installed four stations (Figure 1; Table 1), all located in fallow fields and in nearby alfalfa, pasture, and tomato fields to assess fallow field ET and compare with cropped field ET. Because of operational difficulties related to battery and datalogger problems, data from only 16 of the UC Davis stations were used in the analysis.

Field station locations were chosen if they met minimum size requirements, had a relatively homogenous surface nature, and were uninhibited by the presence of large buildings, trees, or levees within the station footprint that could interrupt airflow and related measurements. Fallow fields with nearby cropped fields of alfalfa or tomato were given priority to enable ET comparisons of the fallow field with that of a cropped field experiencing similar meteorological, soil, and water table conditions. Site selection efforts sought to identify fields in different areas within the Delta to reflect an assortment of these conditions. After landowner and university approval (for the sites run by UC Davis), ET stations were installed beginning in May 2018, around one month after irrigation needs typically begin for the Delta summer crops.

Some fallow fields chosen for the study were previously planted with winter wheat, oats, or triticale. Upon the harvest of those crops and after any post-harvest field operations such as tillage, flooding, and spraying of herbicides, the ET stations were installed. In total, eighteen fields were chosen for this study: seven fallow fields, seven alfalfa fields, one pasture field, and three tomato fields. Two of the fields (one fallow and one alfalfa) contained two different stations with different ET measuring methodologies.

Three potential factors – water table, site elevation, and weediness – in fallow field ET were assessed using measurements, field observations, and remotely sensed data. Details are provided in Appendix B. Water table levels were measured with manual sampling along with some supplemental automated sensor data. Field elevation was taken from the USGS 3D Elevation Dataset (Archuleta et al. 2017). The degree of weed growth was evaluated using the Normalized Difference Vegetation Index (NDVI) product from Landsat 8 datasets, as well as visual and photo observations. Appendix B includes additional siting, station, and sensor details.

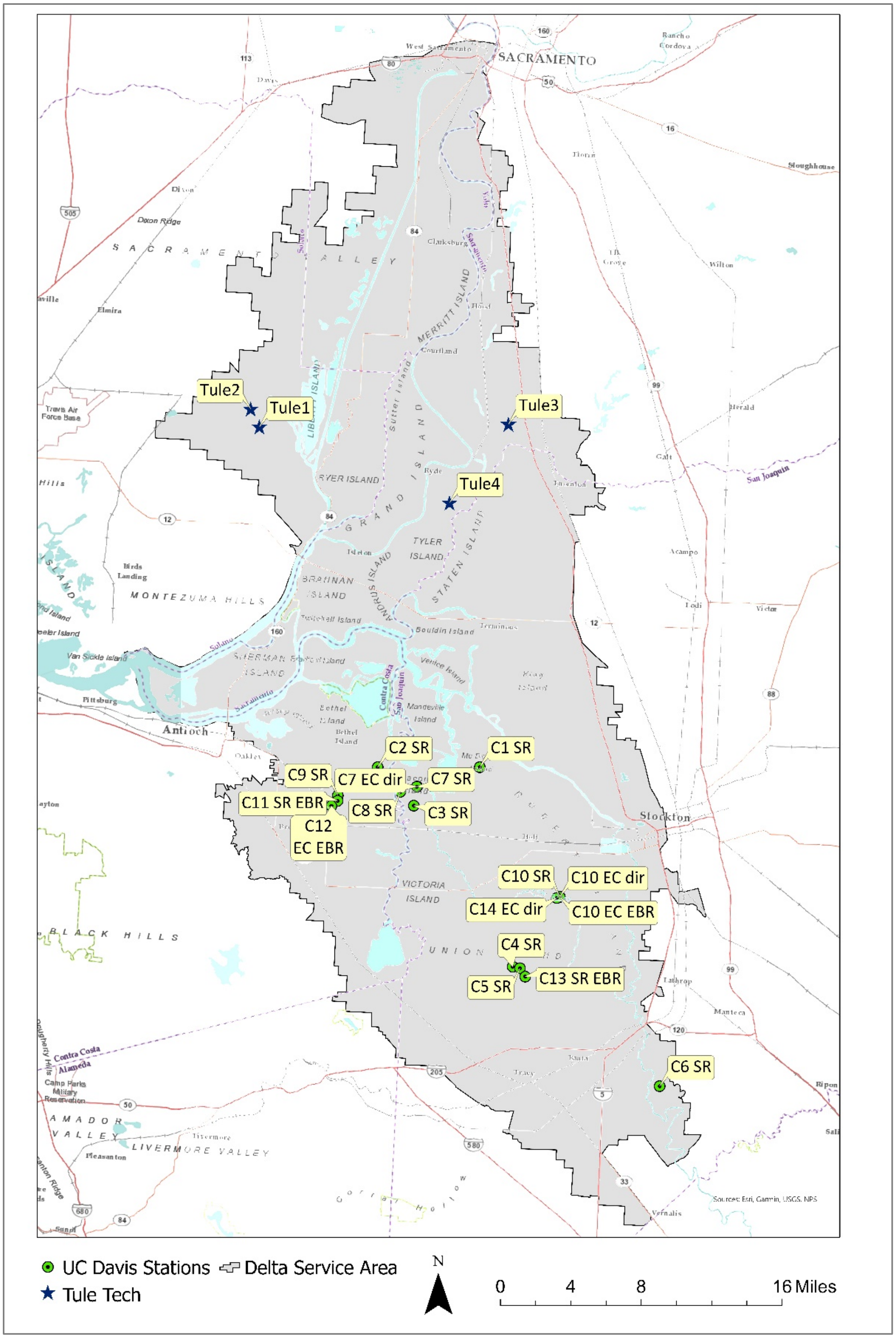

Figure 1. Field Stations in the Study Area

Table 1. Field Station Information

Station ID	General Measurement Methodology	Island	Land Use	Elevation (m)	Start Date	End Date
C1 SR	Surface Renewal	McDonald	Fallow	-4.81	05/24/18	09/30/18
C3 SR	Surface Renewal	Bacon Island	Old Alfalfa	-3.54	6/11/2018	10/25/2018
C4 SR	Surface Renewal	Union Island	New Alfalfa	1.36	9/1/18	11/6/18
C5 SR	Surface Renewal	Union Island	Tomato	1.45	6/27/2018	9/6/2018
C6 SR	Surface Renewal	Tracy	Fallow	6.65	05/24/18	09/17/18
C7 SR	Surface Renewal	Bacon Island	New Alfalfa	-4.87	5/11/18	10/25/18
C7 EC_{dir}	Eddy Covariance	Bacon Island	New Alfalfa	-5.00	5/12/18	10/25/18
C8 SR	Surface Renewal	Bacon Island	Fallow	-4.44	06/20/18	09/30/18
C9 SR	Surface Renewal	Veale Tract	Fallow	1.73	06/16/18	09/27/18
C10 SR	Surface Renewal	Roberts Island	Fallow	0.82	5/25/18	10/9/18
C10 EC_{EBR}	Energy Balance Residual	Roberts Island	Fallow	0.78	7/10/18	9/18/18
C10 EC_{dir}	Eddy Covariance	Roberts Island	Fallow	0.80	8/11/18	9/18/18
C11 SR_{EBR}	Energy Balance Residual	Veale Tract	New Alfalfa	2.67	6/12/18	10/15/18
C11 EC_{EBR}	Energy Balance Residual	Veale Tract	New Alfalfa	2.67	6/12/18	10/15/18
C12	Energy Balance Residual	Veale Tract	Tomato	4.71	6/14/2018	8/11/2018
C13 SR_{EBR}	Energy Balance Residual	Union Island	Fallow	1.58	08/25/18	09/30/18
C14 EC_{dir}	Eddy Covariance	Roberts Island	Tomato	0.97	8/10/2018	8/20/2018
Tule1	Surface Renewal	Hastings	3-year-old Alfalfa	-0.30	7/19/18	11/5/18
Tule2	Surface Renewal	Hastings	Pasture	1.83	7/19/18	11/5/18
Tule3	Surface Renewal	Twin Cities	New Alfalfa	0.61	7/19/18	11/5/18
Tule4	Surface Renewal	Tyler	New Alfalfa	-1.83	7/19/18	11/5/18

Note: "C" IDs are for UC Davis stations; "Tule" are for Land IQ stations

The stations described above in Table 1 employ various methods to calculate actual ET. Tule stations directly measure high-frequency air temperature (and thus sensible heat flux) via a fine wire thermocouple. They use an assumed ground heat flux of zero over 24 hours and estimate net radiation from satellite data. In the direct eddy-covariance method, high frequency (10 -20 Hz) measurements of humidity are statistically covaried with high-frequency measurements of vertical wind velocity, but this method and the sensors involved are computationally and monetarily expensive. In contrast, the cost-saving option of the energy budget residual methods are based on the surface energy balance theory which is defined by the following equation (see Appendix B and Medellín-Azuara et al. (2016; 2018) for more detailed information):

$$Rnet - G - H - LE = 0 \qquad \text{Eq. 1}$$

Where:

- Rnet is the net radiation (W m^{-2}) that accounts for both incoming and outgoing solar and terrestrial radiation and is measured with a net radiometer (UC Davis stations) or estimated from remote sensing (Land IQ model & Tule stations).
- G is the surface soil heat flux (W m^{-2}) and is derived from changes in soil temperature, soil moisture, and soil characteristics, and can be measured with soil heat flux sensors, estimated from Rnet, or assumed to be zero for a daily energy balance.
- H is the sensible heat flux (W m^{-2}) measured or estimated as the exchange of heat between the plant canopy and surrounding atmosphere either with eddy covariance, surface renewal, or remotely sensed techniques.
- LE is the latent heat flux (W m^{-2}), where L is the latent heat of vaporization (in J kg^{-1} K^{-1}) and E is the evapotranspiration flux (kg $m^{-2}s^{-1}$) in plant systems or evaporation in open water or bare soil surfaces. E can be directly measured with eddy covariance independently from the energy budget residual method, as noted earlier.

Theoretically, the terms are considered balanced and equal to zero because energy quantified by the Rnet term is distributed among the other three terms. This equation can be used in two main ways: (1) when Rnet, G, and H are either measured or estimated, then LE can be calculated, and (2), when H and LE are independently measured with eddy covariance (EC), then the quality of the EC method can be assessed by checking if Equation 1 is approximately satisfied with the use of Rnet and G measurements or estimates.

In the energy balance residual (EBR) methods, H is obtained by either surface renewal (SR), EC, or remotely sensed methods. Equation 1 is rearranged such that LE is the residual component, and the Rnet, G, and H terms are directly measured with on-site instrumentation in the EBR and estimated in remotely sensed methods:

$$LE = Rnet - G - H \qquad \text{Eq. 2}$$

The main advantage of this approach is that it reduces the overall cost by not having to measure LE directly. Research has also shown that directly measuring LE can introduce large errors over irrigated systems, if not properly corrected (Lindquist et al., 2015).

In the EBR methods used in this study, the H term was either directly quantified with a 3-dimensional sonic anemometer or was estimated through the implementation of the surface renewal theory (Paw U et al., 1995; Paw U et al., 2005). The surface renewal methods used a coefficient (alpha-factor or H_{alpha}) that has been derived from a 3-dimensional sonic anemometer calibration procedure. Uncertainties for the field methods used by UC Davis are in Appendix B (p.6,7). In the EBR approach utilized with Tule instruments used by Land IQ, the G term is assumed to be zero for each day and the Rnet factor is estimated through satellite-based data.

Overall, the accuracies amongst these methodologies are very similar. In previous work performed by Land IQ in the South San Joaquin Valley, Tule sensors generally varied from eddy covariance energy budget residual stations by 2-4% on a monthly timestep in alfalfa from late May through early July, during the irrigation season. Variances are often higher for other crops and outside of the peak growing season. Uncertainties for the UC Davis stations are discussed in Appendix B. The primary difference between them lies in the source of potential error that could be introduced into the measurements and thus the final calculation of LE. Given its balance between various errors introduced from measurements or estimation of the different energy budget terms, numerous studies discussed in Appendix B have shown that the EBR method is relatively accurate and repeatable. Appendix B establishes that in this study, the UCD direct EC measurements for LE and H showed high levels of accuracy with the energy budget test discussed above.

Station Data Processing (Summary)

UCD field stations involved recording complex measurements from a variety of sensors. Accurate meteorological measurements involve extensive data processing in order to convert the raw data from temperature and wind measuring sensors logged at ten times a second into measurements used for further calculations. Data were collected to obtain Rnet, H, LE, and G, and related variables such as air temperature, relative humidity, and water table depth. Sensors used included net radiometers (both 4-stream and single output units), infrared thermometers, 3-directional sonic anemometers, fine wire thermocouples, infrared gas analyzers, ground heat flux plates, soil thermocouples, soil moisture sensors, and water table depth sensors.

Several calibration and data processing techniques were used, depending on the sensor and method. A vast amount of data was gathered, with some data measured and logged 10 times a second over multiple months. All data were examined for anomalies as part of the analysis. Data quality assurance and quality control methods are described in detail in Appendix B. In addition, Appendix B describes the usage of some remotely sensed data to assess the amount of weeds in fallow fields.

2.2 Remote Sensing ET Modeling

Remotely sensed satellite imagery of the Delta area was collected on all available cloud-free overpass dates from May through October 2018. The remote sensing approach to estimating ET in this study included surface energy balance consumptive use analysis coupled with substantial ground truthing.

Actual ET was modeled and estimated using a modified form of Mapping Evapotranspiration with High Resolution and Internalized Calibration (METRIC™ Allen et al. 2007). METRIC™ is a surface energy balance model that uses Landsat imagery to produce high-quality, accurate ET mapping. The main advantage of using an energy balance approach is that estimated actual ET is computed, rather than estimated potential ET, which would have to be paired with a coefficient for fallow land to estimate ET. Land IQ modified traditional METRIC™ methodology by applying actual field ET measurements together with remotely sensed data to estimate sensible heat flux. The Land IQ approach, therefore, requires and benefits from accurate field measurements, as discussed in Section 2.1, from representative site locations. Detailed information on METRIC™ and the modifications that Land IQ used are provided in Appendix A.

Results of fallow ET modeling were dependent on field measurements. The accuracy of field measurements can vary. While some comparison of field instruments were made, independent validation information to assess station measurements were not available.

REMOTELY SENSED IMAGERY

Within the Delta study area, all the suitable Landsat-8 images from the sensor's path 44 row 33 and path 44 row 34 from May to October in 2018 were acquired to model the actual daily ET (Figure 2). However, after QA/QC, the time range was extended to April due to the lack of cloud-free imagery in May. Table 2 lists all the available Landsat-8 images from April to October. For the eight cloud-free dates, Landsat-8 imagery was applied to model the daily map of ETa.

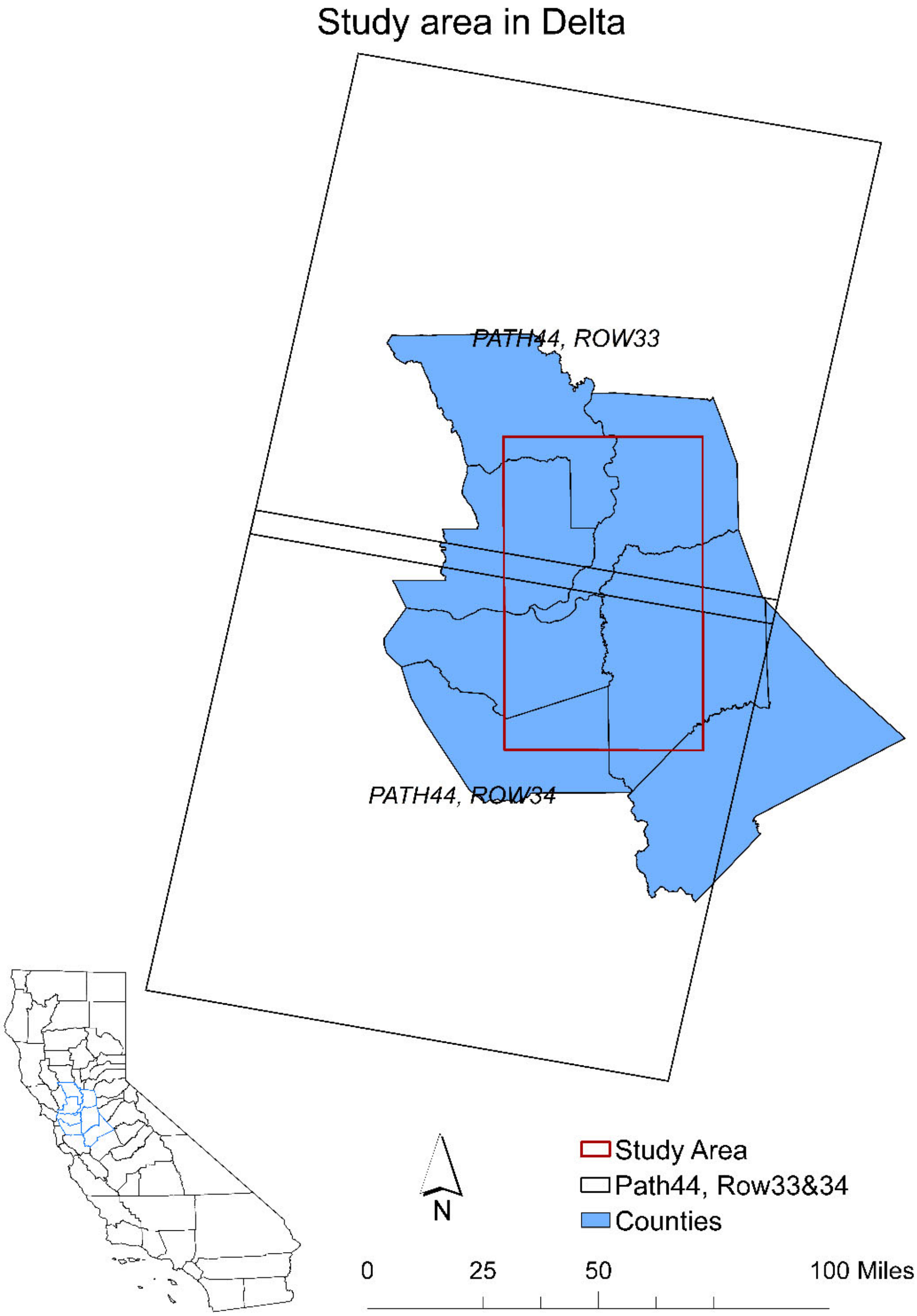

Figure 2. Image Boundary in the Study Area

Table 2. Acquired Landsat-8 Images

Acquired Date	Quality
2018-4-14	cloud-free
2018-4-30	cloudy
2018-5-16	cloudy
2018-6-01	cloud-free
2018-6-17	cloudy
2018-7-03	cloud-free
2018-7-19	cloudy
2018-8-04	cloud-free
2018-8-20	cloud-free
2018-9-05	cloud-free
2018-9-21	cloud-free
2018-10-07	cloud-free
2018-10-23	cloudy

Each acquired daily Landsat-8 imagery set includes data from 11 spectral bands, including visible bands and thermal bands which are used in the model process. These bands were used to create normalized difference vegetation index (NDVI) images, which indicate vegetation vigor, and surface temperature images, which were calculated through the METRIC model (Allen et al. 2007) and do not include corrections for elevation. These NDVI images and surface temperature images were used to calculate daily ET. An example of each type of image is shown in Figure 3.

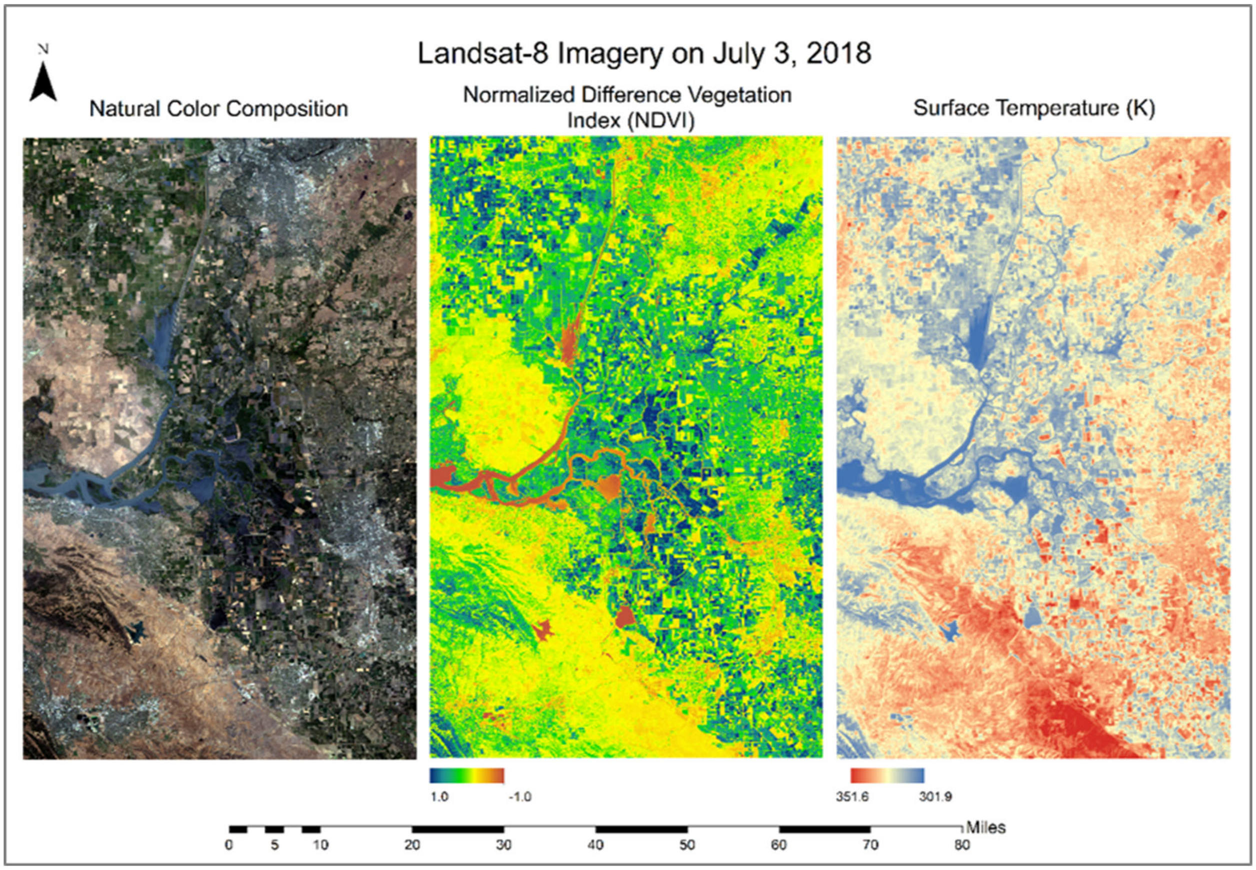

Figure 3. Landsat-8 Imagery on July 3, 2018

3 Results

This section presents the results of ET field site data collected and processed at specific instrumented fields. Both fallow and cropped fields were instrumented to represent a range in ET (from low within fallow fields to higher on cropped fields). These ET measurement locations were then used in a predictive remotely sensed model to assess ET across the full landscape, including all fallow and cropped fields. Detailed uncertainty analysis of these measurements, including energy budget closure, fetch and footprint issues, are in Appendix B (p. 6, 7).

3.1 Field Site Data

Fallow Fields

Table 3 shows site characteristics for each instrumented fallow field. Fields C1 and C8 contained transpiring weeds that were occasionally tilled under to maintain a more homogenous and plant-free surface. Fields C9 and C13 contained the detritus of former crops grown in the field, and this dried plant litter was tilled into the soil. Fields C6 and C10 consisted of no live or dried plant vegetation and the soil surface was completely bare.

Table 3. Site Characteristics of Fallow Fields

Station	Site	Elevation (m)	Avg Water Table Depth (m)	Soil Map Unit Order	Soil Texture	Vegetation Management
C1 SR	McDonald	-4.81	1.361	Histosol	Mucky silt loam	Transpiring weeds
C6 SR	Tracy	6.65	4.1*	Entisol	Fine loamy sand	Bare
C8 SR	Bacon Island	-4.44	0.77*	Histosol	Kingile muck	Transpiring weeds
C9 SR	Veale Tract	1.73	1.454	Vertisol	Clay	Dried crop residue
C10 SR	Roberts Island	0.82	1.216	Mollisol	Silty clay loam	Bare
C10 EC_{EBR}	Roberts Island	0.78	1.216	Mollisol	Silty clay loam	Bare
C10 EC_{dir}	Roberts Island	0.80	1.216	Mollisol	Silty clay loam	Bare
C13 SR_{EBR}	Union Island	1.58	1.098	Mollisol	Mucky clay loam	Dried crop residue

Notes: SR=Surface renewal station; EBR = Energy budget residual; EC_{dir} *= Eddy covariance*
**denotes in-person measurement during a site visit*
Soil information source: USDA SSURGO Database (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/office/ssr12/tr/?cid=nrcs142p2_010596)

Fallow ET differed between stations. The monthly ET and fallow field crop coefficients (K_f) results are shown in Figure 4 and the monthly ET is presented in Table 4.

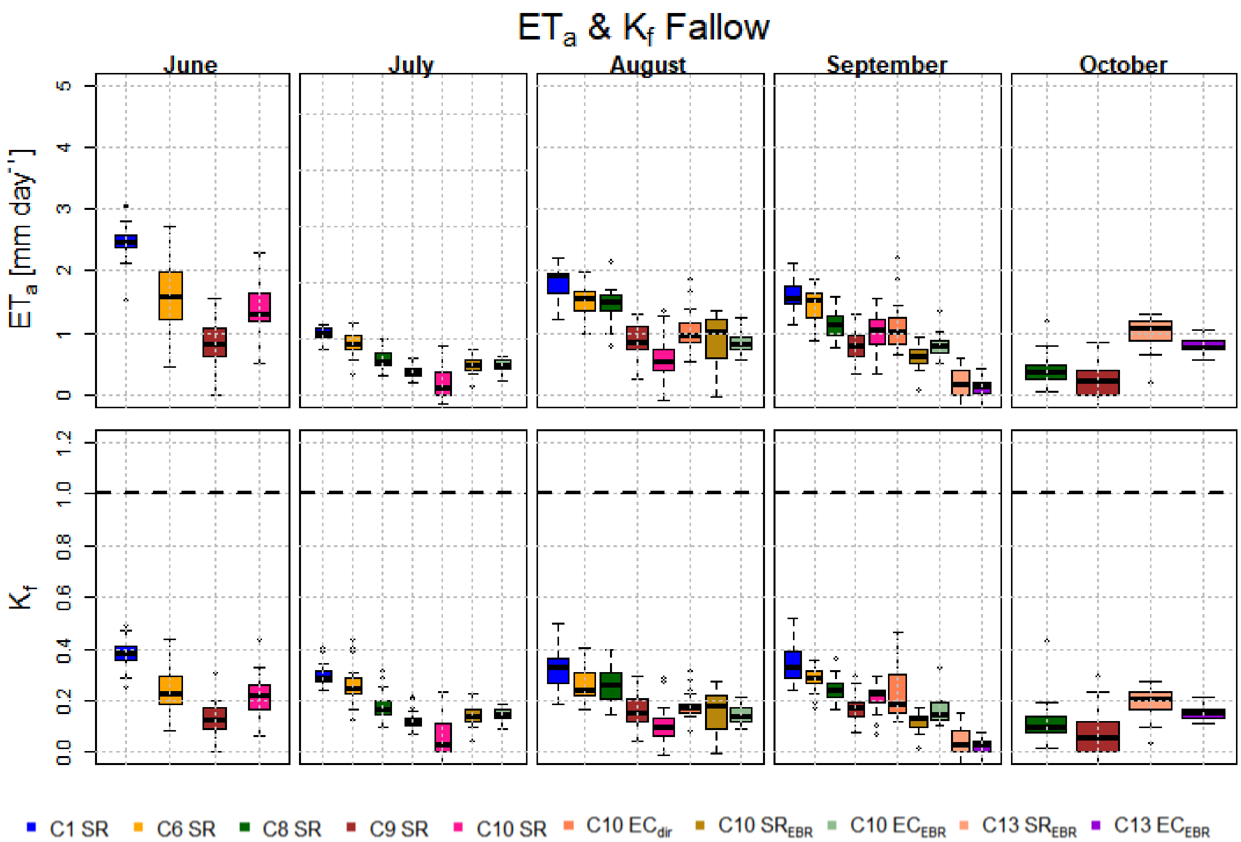

Figure 4. Actual Monthly ET Values and Consumptive Use Coefficients of Fallow Fields

Table 4. Average Daily Evapotranspiration: Fallow (mm/day)

	C1 SR	**C6 SR**	**C8 SR**	**C9 SR**	**C10 SR**	**C10 EC_{EBR}**	**C10 SR_{EBR}**	**C10 EC_{dir}**	**C13 EC_{EBR}**	**C13 SR_{EBR}**
Surface Condition	*Weeds*	*Bare*	*Weeds*	*Dry Crop Residue*	*Bare*	*Bare*	*Bare*	*Bare*	*Dry Crop Residue*	*Dry Crop Residue*
May	2.0	1.7	--	--	0.9	--	--	--	--	--
June	2.5	1.5	1.4	0.8	1.3	--	--	--	--	--
July	2.1	1.9	1.2	0.8	0.4	1.5	1.4	--	--	--
Aug	1.8	1.5	1.5	0.9	0.6	1.3	1.4	1.0	0.6	1.0
Sep	1.6	1.4	1.1	0.8	1.0	1.3	1.1	1.1	0.0	0.1
Oct	1.2	--	0.3	--	0.4	--	--	--	0.6	0.1
Average	**1.9**	**1.6**	**1.1**	**0.8**	**0.8**	**1.4**	**1.3**	**1.1**	**0.4**	**0.4**

The observations show some interesting features, highlighted below, although the differences in the period of data collection needs to be taken into account.

- In all cases, the monthly K_f coefficients were lower than 0.5, in some cases, substantially. However, they were also all greater than zero, meaning ET was occurring even for bare, dry fallow fields without weeds.
- Station C1 SR had the highest actual monthly ET and coefficient for fallow and represented a field with a fair amount of weeds based on field images from cameras and remotely sensed analysis.
- The next highest monthly ET was from Stations C6 SR and C8 SR, compared to the other fallow stations, with C8 representing another field with weed growth apparent.
- The ET from stations C9 SR and C10 SR were comparatively low. The EC-based ET measurements from C10 agreed with each other but were higher than the C10 SR station. The differences in average monthly ET were around 0.1 mm/day, between the C10 SR-derived ET and the direct ET measurements (see Table 8 in Appendix B).
- The lower values of fallow field ET in this study, found in September, were similar to those found in the Delta fallow field studied in 2015 (Medellín-Azuara et al., 2016).

Monthly ranges in fallow ET from the in-situ measurements are summarized in Table 5 below and also in Table 8 in Appendix B. Additional ET and Kc box plots representing station results for their respective data collection periods are provided in Appendix B. Multiple factors can be attributed to differences in fallow ET among stations. Differences in weed growth, elevation, related shallow water table, and localized climate factors all play a role in the bare surface ET. The roles of these factors are discussed further later.

Table 5. Monthly Fallow Daily ET Ranges

Month	**Range in Daily Fallow ET (mm/day)**
May	0.87 – 2.03
June	0.84 – 2.47
July	0.43 – 2.15
August	0.62 – 1.81
September	0.04 – 1.61
October	0.34 – 1.16

Cropped Field Monitoring Sites

Alfalfa and tomato fields were instrumented for ET measurement and estimation, and for comparison with paired fallow fields on the same islands. These fields also represented a range of higher ET values that are necessary for the calibration of remotely sensed modeling efforts. Three of the alfalfa fields instrumented by UCD were considered young alfalfa because they were planted at the beginning of the 2017-2018 water year. The fourth field was considered old because the alfalfa stand had been farmed for four years prior, the sparseness of the canopy, and because the maximum height of the stand was shorter than the young alfalfa fields in the study. Four additional Land IQ sites, two in young alfalfa fields, one in a three-year-old alfalfa field, and one in an established pasture were instrumented with Tule Tech stations to represent ET conditions in the northern Delta region. In both alfalfa and tomato fields, differences in ET results could be the result of methods of measurement or differences in site characteristics. More information on UC Davis ET measurements from each specific cropped field is provided in Appendix B, and additional information for Land IQ sponsored Tule ET measurements are provided in Appendix A.

Alfalfa

Monthly averaged ET_a and K_c values are shown in Figure 5. Average daily ET values of the four alfalfa fields instrumented by UC Davis, three alfalfa fields managed by Land IQ using Tule equipment, and for a Tule-based pasture ET, are shown in Table 6. The daily ET averaged over the UC Davis measurement campaign ranged from 3.2 to 4.9 mm/day and showed a seasonal pattern with maximum values in June, with a consistent drop in subsequent months. This pattern approximately matches that of the available solar radiation for the crops in those given months. The crop coefficient K_c was relatively low for the old alfalfa field, dropping to as low as 0.4 in October. On the other hand, two of the younger alfalfa fields had K_c values greater than one in October. Daily K_c values show variations with maxima close to 1.3 and minima below 0.3, reflecting the effects of irrigation and mowing activities (Figure 6). There was general agreement between the surface renewal station and the direct eddy covariance station at site C7, as shown in Figure 5 and Table 6, although the eddy covariance station averaged approximately 12% greater ET than the surface renewal station. The range of values for the UCD and Tule stations is consistent with a combination of different ages and different times of the season when the stations were operational, coupled with differences in site conditions and the management practices by different growers on different islands. The cluster of Tule stations was also located in different landscape positions within the Northern Delta with differing elevation and soil conditions that also influence ET.

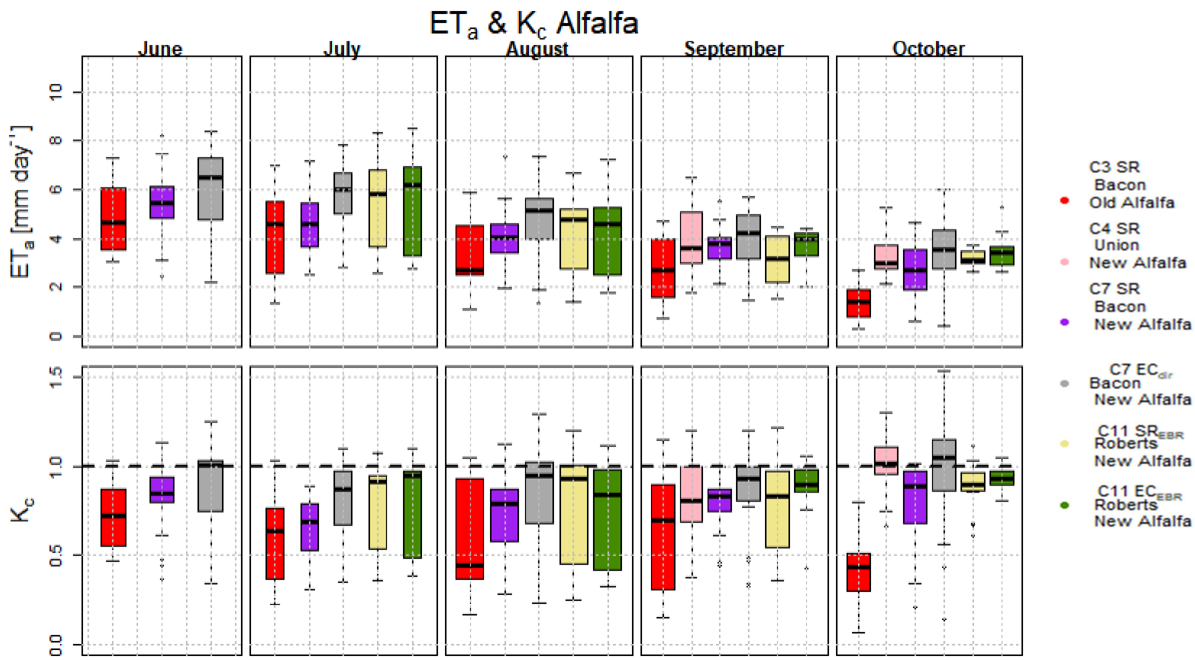

Figure 5. ETa and Kc Values for Alfalfa Fields at the UC Davis Managed Sites

Table 6. Average Daily Evapotranspiration: Alfalfa (mm/day) for both UC Davis Managed Sites and Land IQ Managed Sites

	C3 SR (old alfalfa)	**C4 SR** (new alfalfa)	**C7 SR** (new alfalfa)	**C7 EC_{dir}** (new alfalfa)	**C11 EC_{EBR}** (new alfalfa)	**C11 SR_{EBR}** (new alfalfa)	**Hastings Tule** (3 yr old alfalfa)	**Twin Cities Tule** (new alfalfa)	**Tyler Tule** (new alfalfa)	**Hastings Tule** (Pasture)
May	--	--	5.4	5.5	--	--	--	--	--	--
June	4.7	--	5.4	6.0	6.2	6.5	--	--	--	--
July	4.2	--	4.6	5.6	4.9	4.7	5.7*	2.5*	5.5*	4.5*
Aug	3.1	5.2	4.0	4.7	4.4	4.5	4.9	2.8	4.3	3.9
Sep	2.8	4.0	3.7	4.0	3.4	3.2	3.8	3.8	3.4	2.2
Oct	1.4	3.3	2.7	3.4	3.4	3.2	2.2	2.4	2.2	1.2
Nov	--	2.6	--	--	--	--	1.0	0.9	0.8	0.5
Average	**3.2**	**3.8**	**4.3**	**4.9**	**4.5**	**4.4**	**3.5**	**2.5**	**3.2**	**2.5**

*Partial month of data – indicated by Land IQ

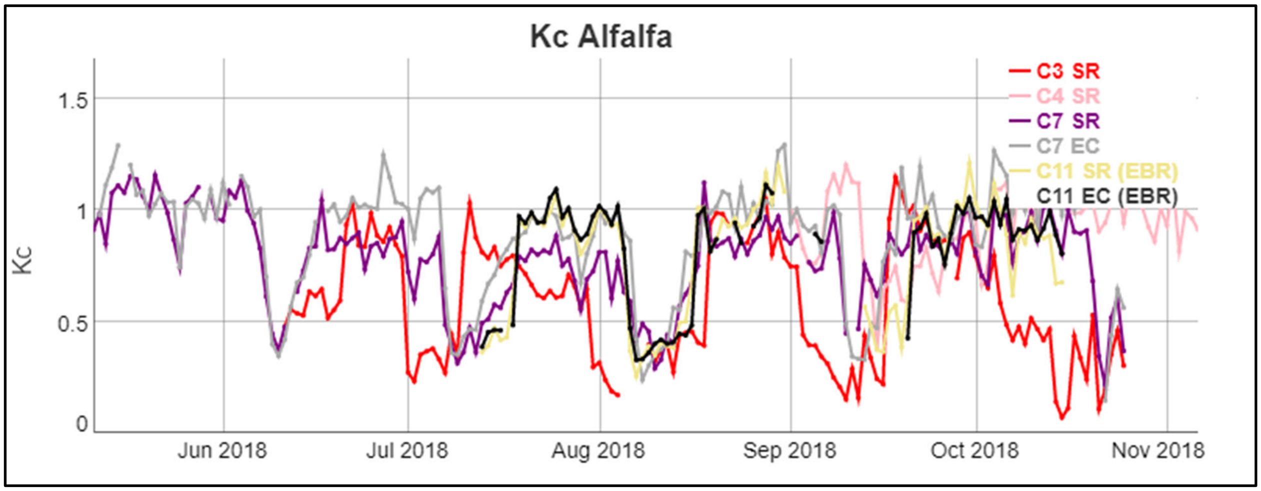

Figure 6. Daily Kc at UCD alfalfa sites

TOMATO

Average daily ET values for the three tomato fields with four stations instrumented by UC Davis are shown in Table 7. Average daily ET from representative stations ranged from 5.21 to 5.43 mm/day. The planting dates for the tomato fields differed from each other by at least seven days, and because the plants were at different phenological stages of their life cycle, differences between the fields are at least in part from these differences in growth stages. The C14 field was already approaching senescence during August, so lower ET values were expected.

Table 7. Average Daily Evapotranspiration for Tomato (mm/day)

	C5 SR	C12 EC_{EBR}	C12 SR_{EBR}	C14 EC_{dir}
June	7.4	7.0	7.0	--
July	6.3	5.1	5.1	--
Aug	4.2	3.8	3.8	2.4
Sep	3.3	--	--	--
Average	**5.3**	**5.3**	**5.3**	**2.4**

TULE STATION MEASUREMENTS IN ALFALFA AND PASTURE

The primary purpose of additional Tule station installation was to establish ET calibration information for spatial mapping in northern regions of the Delta where other instruments had no coverage. Four Tule stations were installed in alfalfa or pasture fields. Data collection at these sites spanned from July 19, 2018, to November 5, 2018. (Figure 7). The month-by-month Tule alfalfa ET values are similar to the UCD field measurements, but because the Tule data do not include values from earlier in the season compared to the field data, the average values differ (Table 6). It should be noted that Tule stations rely on estimated net radiation derived from satellite-based sensors, in contrast to the UCD energy budget residual stations that relied on ground-based net radiation measurements.

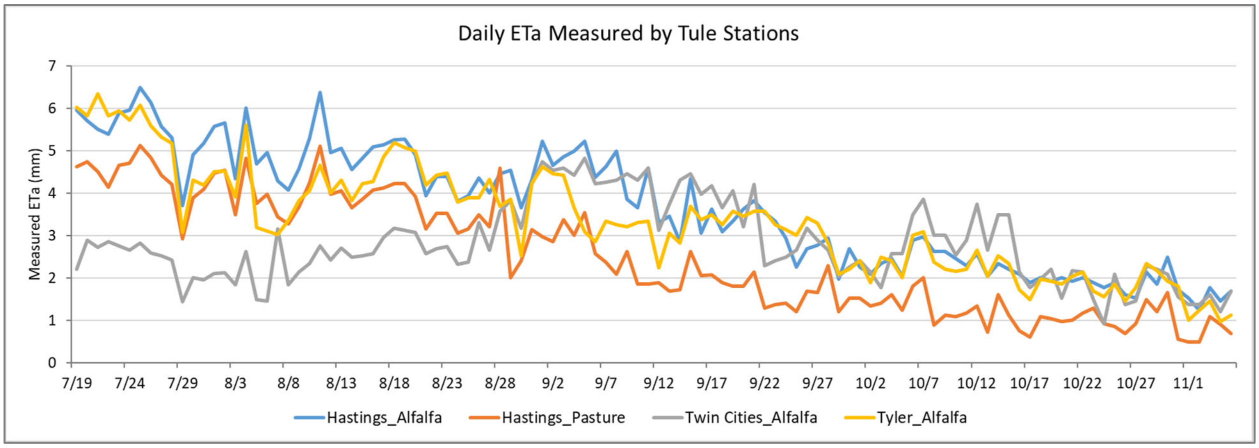

Figure 7. Measured ETa by Tule Stations

3.2 Remote Sensing ET Assessment

All spatial daily estimated ETa images from the Land IQ remote sensing assessment can be found in Figure 8. Comparing daily maps, as a pixel appears more red, its ETa value approaches zero; as a pixel appears more blue, its ETa value increases. Among all the evaluated images, the highest field ETa value occurred in a rice field on the August 4 image, with an ETa of 10.1 mm.

Using the daily ETa maps and nearby CIMIS station reference ET (ETo) data, a total of 169 images from April 14, 2018, to October 7, 2018, were created by applying a linear interpolation method on daily ETof (ETa/ETo) for every pixel in the study area, to represent ETa for each day. ETof is conceptually similar to the crop coefficient, which doesn't change its value rapidly from day to day and therefore is useful for linear interpolation. A monthly ETa map was then created by summing all the daily ETa maps within the month. Each monthly ETa map from May to September within the Delta Service Area is shown in Figure 9.

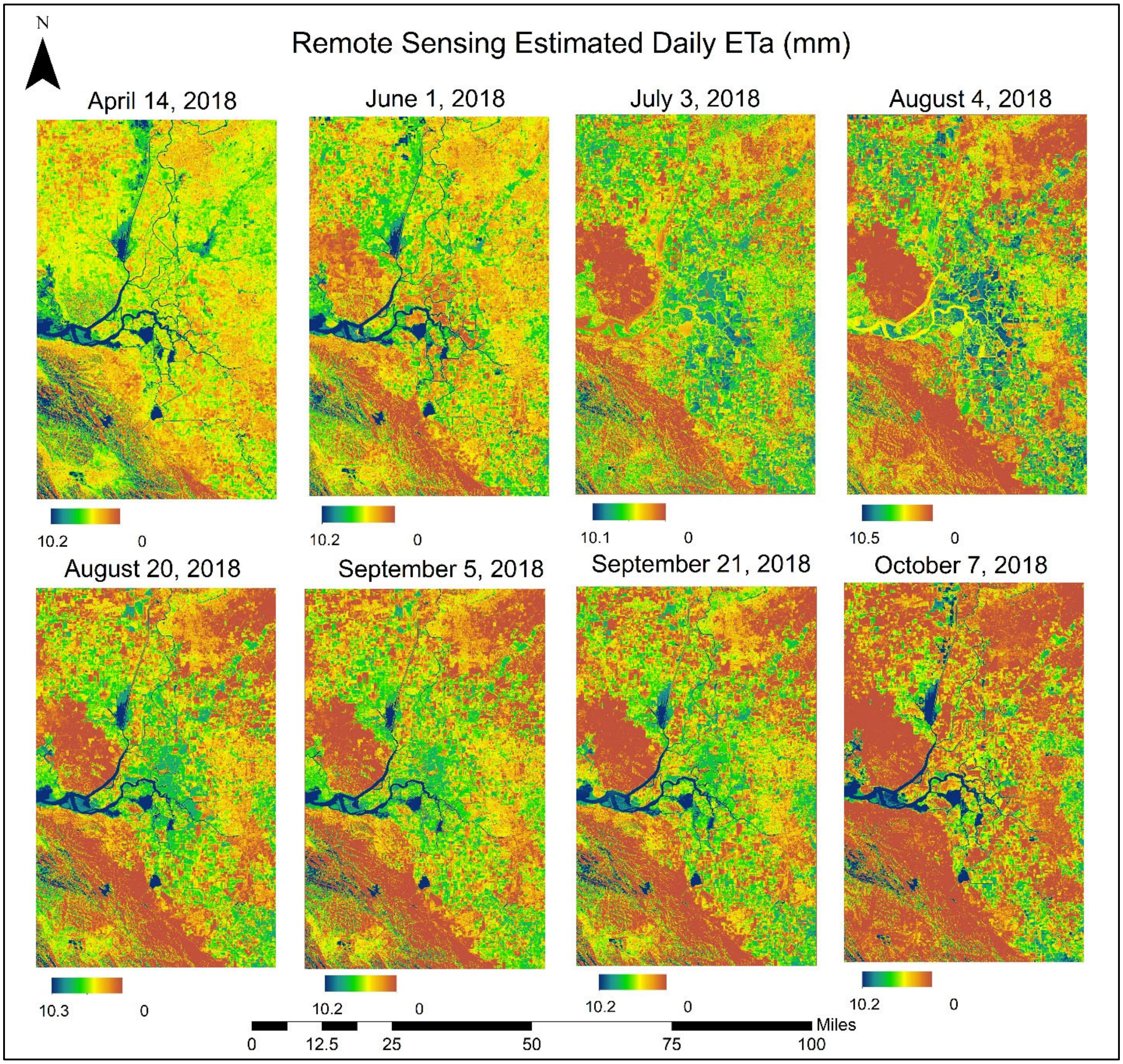

Figure 8. Remote Sensing Estimated Daily ETa Maps for Eight Cloud-Free Satellite Overpass Dates

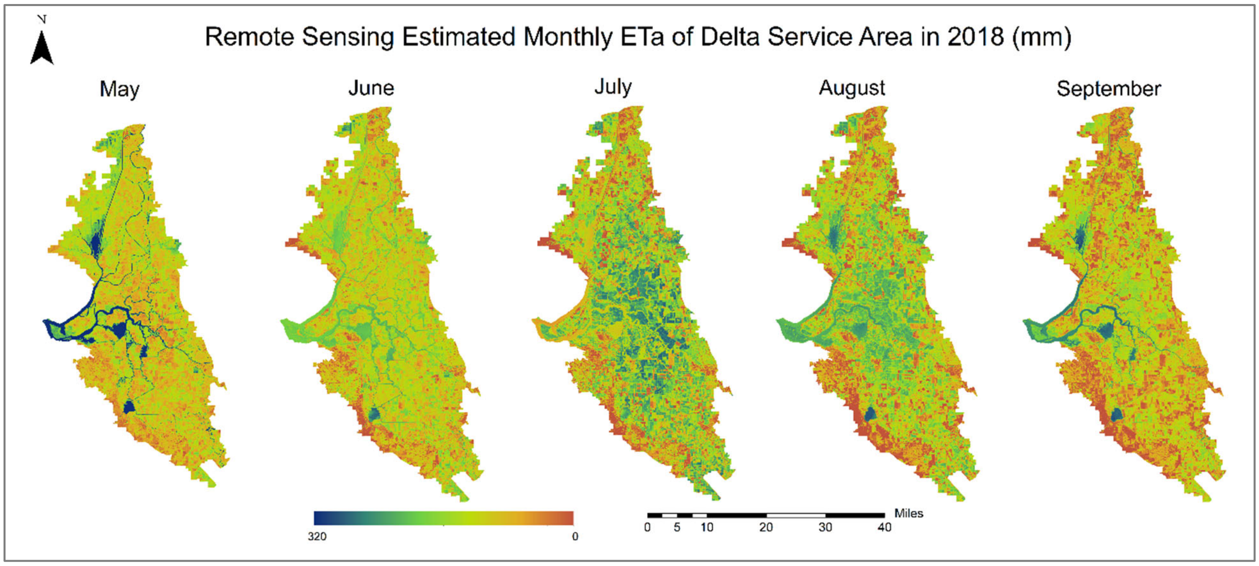

Figure 9. Remote Sensing Estimated Monthly ETa Maps of the Delta Service Area

Accuracy Assessment

The accuracy of the remote sensing methodology was assessed from two perspectives: daily modeling and total actual ET for each active station. R^2, or the coefficient of determination, is a goodness-of-fit measure for linear regression models between two variables, that of the observed data to a predicted result, where a value of 1 indicates a perfect fit. In other words, it represents how close the measured data fits with the modeled (predicted) estimate. For example, an R^2 of 0.75 means that 75% percent of the variability of the real ET data can be explained by the input data. The root mean squared error (RMSE) is a measure of how well the model performed and is calculated by measuring the difference between predicted and actual values. In our case, a value of 0 mm would indicate a perfect model fit to the measurement.

Accuracy results were as follows:

- The R^2 for the daily remote sensing model results was 0.76 and the RMSE of these daily predictions is 1.06 mm, for satellite overpass dates; both metrics indicate a good fit between measured and actual values.
- The R^2 for the total predicted ETa during the measured period (May – September) ETa was 0.92, and the RMSE was 69.4 mm.

Figure 10 shows a scatter plot between predicted daily ETa and observed daily ETa of each active station location for every Landsat modeling date. The black diagonal line represents a perfect fit between measurements and predictions with an R^2 value of 1, and the distribution of points around this line with a 0.76 R^2 value shows how good it is compared to the diagonal line. The term predicted is used to indicate the modeled value.

Figure 11 shows the scatter plot between measured total ETa and predicted ETa for each station's active period. Overall, the total ETa has a better fit compared with the daily ETa result, partly because daily over-and under-estimation errors are balanced out in the summation process.

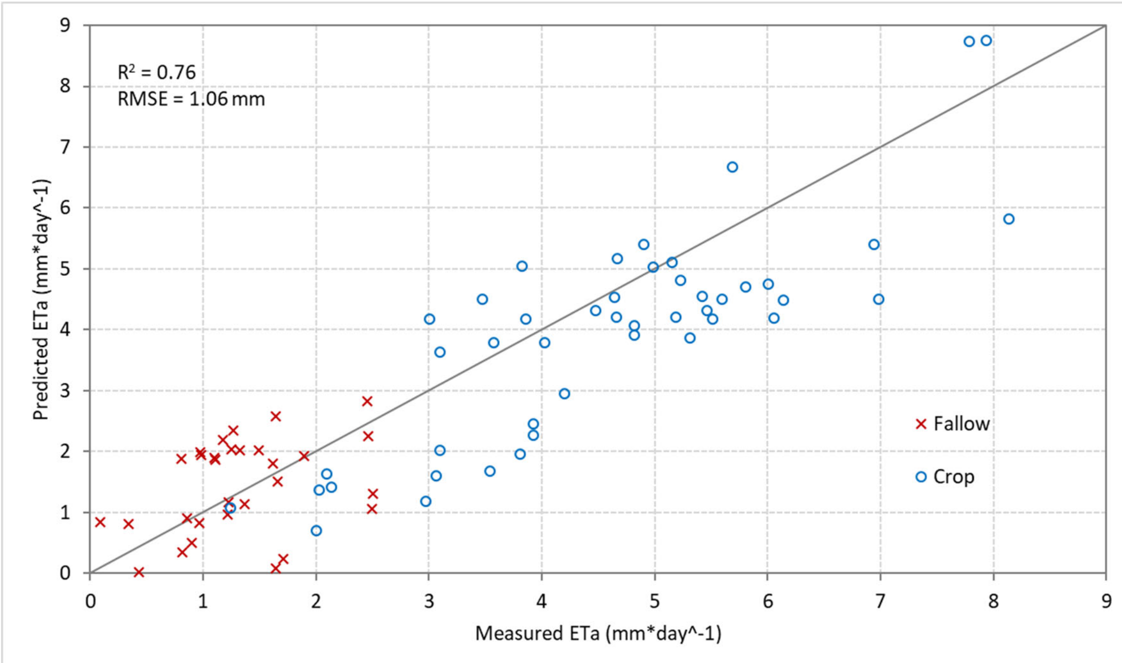

Figure 10. Measured vs. Predicted Daily ETa for Satellite Overpass Dates from May through September 2018

In Figure 10, the red “x” symbols represent fallow stations and the blue circle points represent the crop stations. The active periods were different for the different stations, so all these points represent total measurement and prediction within the active period for each station. Two clusters of values can be observed on the graph: the fallow group with lower ETa values and the crop group with higher values.

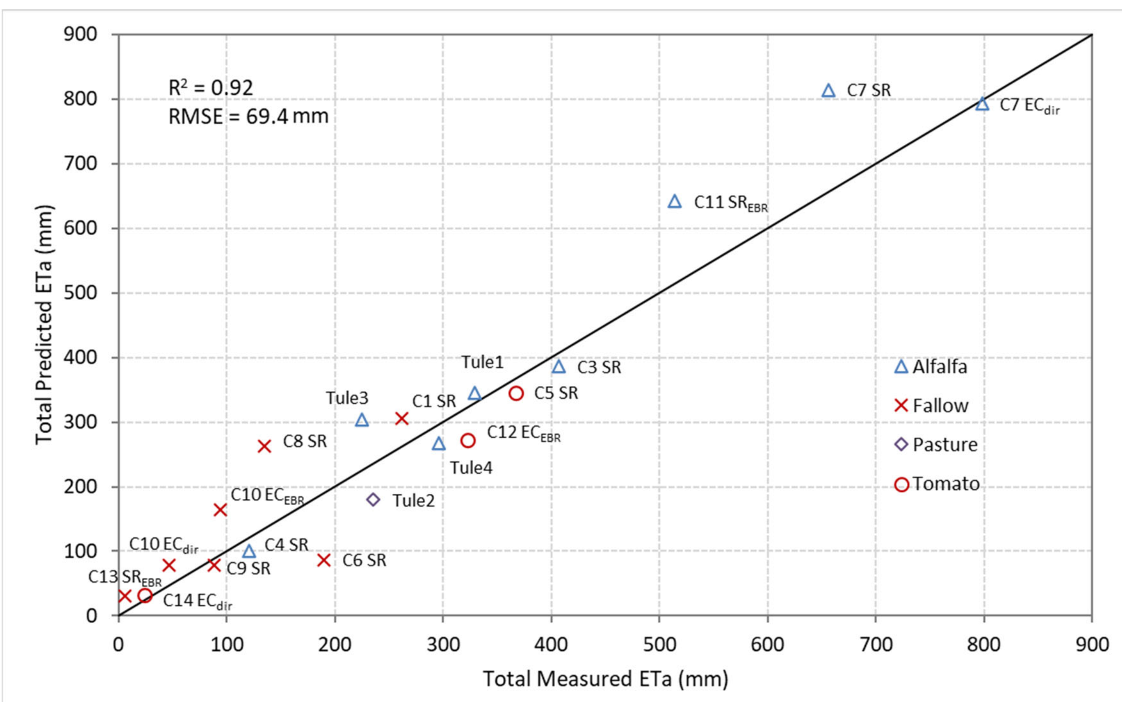

Figure 11. Measured vs. Predicted Total ETa Within Each Instrument’s Active Period, 2018

In Figure 11, the red "x" symbols represent the fallow stations; red circles represent tomato stations; blue triangles represent alfalfa stations, and purple diamonds represent pasture stations. Most stations, especially the ones in fallow fields such as C1 SR, C9 SR, and C13 SR_{EBR}, performed well in estimating daily ETa. For stations in the cropped fields, such as C3 SR, C7 SR, and C11 SR_{EBR}, the prediction is close to the measurement on Landsat overpass dates, but the prediction does not fit the variation of measurement on other dates, which may be a result of the linear interpolation method that was selected for fallow field analysis.

Table 8 shows the total measured and predicted ETa values from remote sensing for fallow fields, as well as the number of days and time period each field's station was actively collecting data. In fields with more active weed growth, the remote sensing prediction of ET was generally higher than those without weeds.

Table 8. Comparison of Total ET Measurement and Prediction by Fallow Stations

Station	Crop	Acres	Active Days	Starting Date	Ending Date	Measurement (mm)	Prediction (mm)	Residual (mm)	Relative Difference (%)
C1 SR	Fallow	78.91	130	05/24/18	09/30/18	261.70	306.35	44.65	14.57
C6 SR	Fallow	32.38	117	05/24/18	09/17/18	189.82	86.71	-103.12	54.32
C8 SR	Fallow	12.11	103	06/20/18	09/30/18	134.40	262.10	127.70	48.72
C9 SR	Fallow	58.459	104	06/16/18	09/27/18	88.42	77.84	-10.58	11.97
C10 EC_{EBR}	Fallow	10.89	69	07/11/18	09/17/18	93.96	164.36	70.40	42.83
C10 EC_{dir}	Fallow	10.89	39	08/11/18	09/18/18	46.26	78.57	32.31	41.12
C13 SR_{EBR}	Fallow	52.55	37	08/25/18	09/30/18	5.76	31.46	25.69	81.69

Accuracy assessment data are provided in Appendix A.

4 DISCUSSION

EVALUATION OF DELTA-WIDE FALLOW AND CROP ET FROM REMOTE SENSING

Based on the 2018 Land IQ crop mapping, there were 1,178 fallow fields within the Delta service area in 2018, totaling 31,876 acres. The distribution of monthly estimated ETa from all fallow fields can be found in Figure 12. It is important to note that unmanaged fallow fields often include significant weed growth or are idle lands that contain substantial vegetation, and the resultant ET is not representative of a managed fallow condition that would be expected in a fallowing program. From June to September, there is a general downward trend in average total monthly estimated ETa in fallow fields from 100 mm to approximately 55 mm throughout the season, however, the range in ETa is larger in July and August which is indicative of varying climate and field conditions among fields (e.g., temperatures, weeds, etc.).

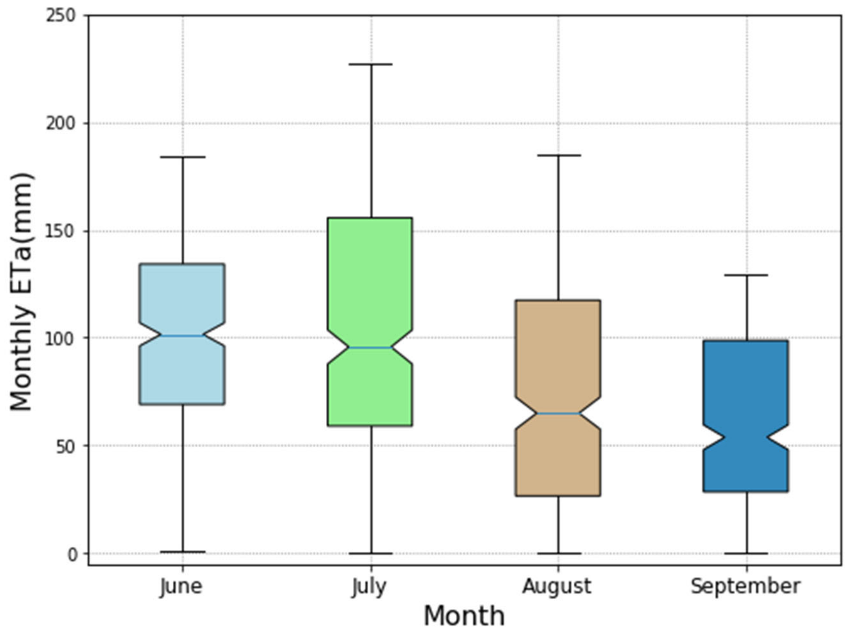

Figure 12. Distribution of Monthly Estimated ETa Across All Unmanaged Fallow Fields, June - September 2018

In comparison, looking at Land IQ 2018 mapped crops in the Delta, safflower, tomatoes, alfalfa, and corn were the predominant annual crop types. Figure 13 shows the distribution of the total estimated ETa from June to September for these most common crop fields, comparing them to the estimated ETa of the fallow sites in the study and all fallow fields in the entire Delta. Fallow ET in the study sites (pink box - where fields were meant to be managed in a fallow condition) is lower than in all fallow sites (red box). The statistical distribution of alfalfa is relatively normal (Gaussian), and the statistical distribution of corn has a longer tail on the lower side although it has the highest median ETa. The varied (skewed) statistical distribution of ETa for corn is likely because of different growing seasons and water usage needs for silage vs. grain corn production. The varied statistical distribution in ETa for safflower and tomatoes is possibly due to different planting dates, different irrigation frequencies and amounts, and different water table depths in the respective fields of the similar crop. The inverted appearance of the fallow study sites (pink box) was caused by the shape of the notch, which displays the lower confidence interval around the median. In this plot, the 1st quartile has a lower value than the confidence of the mean and vice versa.

Table 9 shows a more detailed quantile of estimated ETa for each crop from June to September. The columns represent each crop, the rows are different quantiles, and the resultant content for each crop is a result of linear interpolated ETa distribution. For instance, 10% of total fallow ETa in the Delta service area is 93.0 mm, and 10% of the total studied fallow ETa is 163.30 mm.

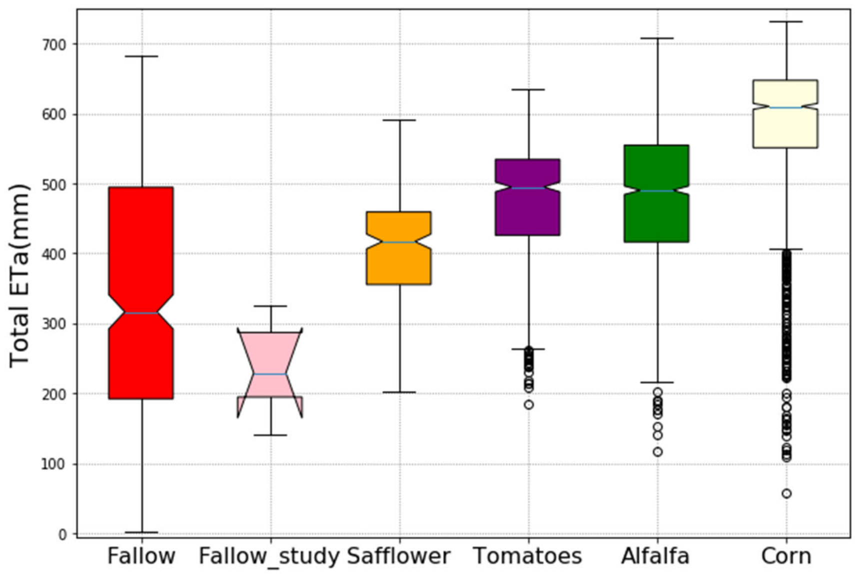

Figure 13. Distribution of Total Estimated Annual Crop ETa Compared with Fallow, June - September 2018

Table 9. Quantile of Total Annual Crop ETa Compared with Fallow, June - September 2018

		Total ETa (mm)					
		Fallow	**Fallow_study**	**Safflower**	**Tomatoes**	**Alfalfa**	**Corn**
Quantile (%)	**5**	59.60	152.48	290.45	280.80	315.41	326.25
	10	93.00	163.03	321.17	325.93	356.93	446.39
	25	192.19	194.66	355.50	425.97	416.41	551.14
	50	316.53	229.27	417.03	495.03	490.28	610.23
	75	494.49	286.97	459.27	534.30	554.75	647.44
	95	633.24	318.61	526.31	588.25	622.67	683.90
	100	682.13	326.53	590.56	634.08	709.01	731.45

POTENTIAL FOR ET REDUCTION FROM CROPPED FIELDS BY IDLING THEM – DERIVED FROM FIELD DATA

The water savings from idling fields can be calculated by using the crop savings coefficient Kcf, where this is defined as:

$$K_{cf} = K_c - K_f \qquad \text{Eq. 3}$$

$$ET_{saved} = K_{cf} * ET_o \qquad \text{Eq. 4}$$

These equations show that by knowing K_{cf}, we can readily estimate the water savings using ET_o from nearby CIMIS stations or Spatial CIMIS.

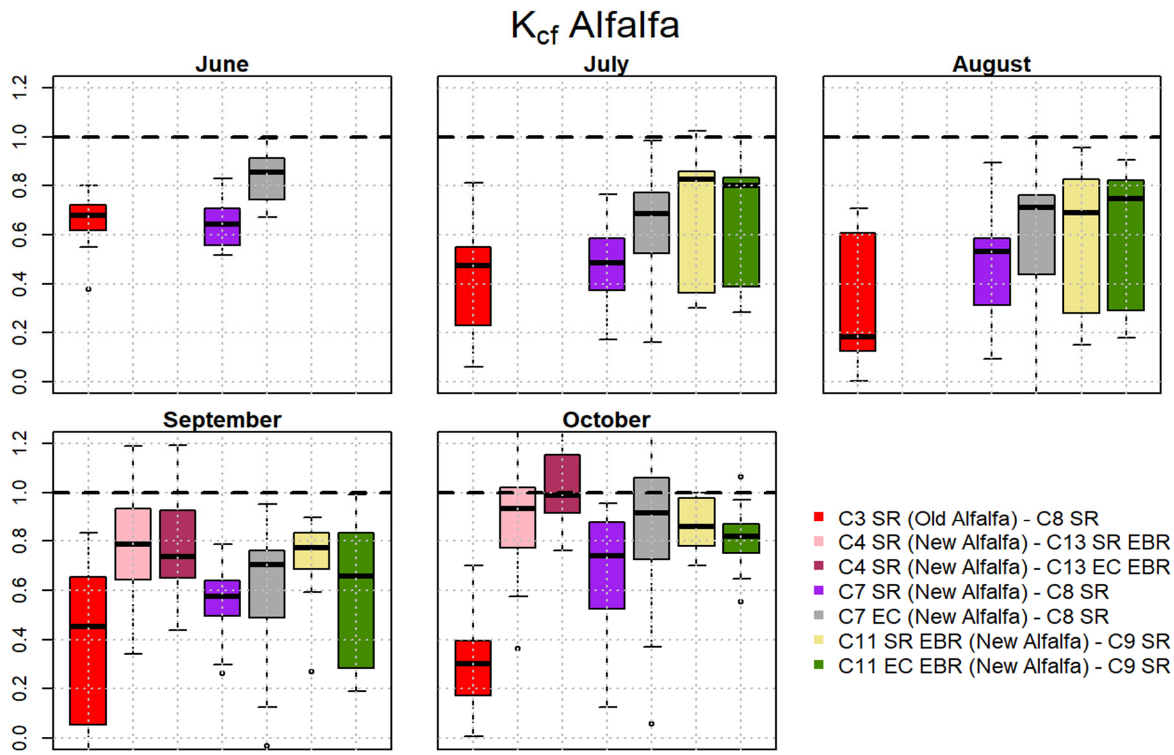

Figure 14. Water Savings Coefficient Kcf for Alfalfa Fields Paired with Nearby Fallow Fields

Figure 14 shows K_{cf} values (June to October) calculated from measurements made at pairs of sites (one fallow, one alfalfa) when both were operating. K_{cf} values varied from approximately 0.2 to 1.0 (Figure 14), associated with variability stemming from different alfalfa fields and fallow field ET. The old alfalfa field with low ET resulted in low K_{cf} values for most months. The new alfalfa fields had higher ET, resulting in high K_{cf} generally, with variations probably based upon the growth cycles of the alfalfa, irrigation frequencies, and other field differences.

A very rough estimate for ET saved from idling alfalfa fields can be made with the calculated K_{cf} and water savings values by extrapolating data to earlier in the season (April and May). For a duration of 127 days, from June to October 2018, the water savings for the C3 old alfalfa field was calculated to be approximately 265 mm, and for 128 days, the water savings for the C7 EC new alfalfa field was calculated to be 460 mm. Extrapolating these data to include the 213 days that span from April to October, the old alfalfa field water savings from April 2018 to October 2018 was approximately 440 mm. For new alfalfa at the UC Davis-instrumented sites, the savings could have been as high as approximately 770 mm for the same time interval. Because of the fallow field variability discussed below, resulting in ET variability, as well as measurement uncertainties, these estimates must be considered approximate and are best considered applicable to the particular Delta regions evaluated in this study. The K_{cf} values could potentially be used along with ET_o maps to estimate larger area water savings. Furthermore, additional detailed studies could narrow down the uncertainty in estimated savings.

Explaining Variation in ET Values from Fallow Fields

Variation in ET from uncropped fields in the Delta is likely influenced by multiple factors. Weed cover, crop residue management, elevation above or below sea level, and depth to shallow groundwater table all play a role in the potential ET on fallow land. Selection of fallow study sites aimed to encompass a range of these conditions. As a result, a range in fallow ET was recorded. While not entirely inclusive of all potential variations within the Delta, these station locations provide a good representation of possible fallow ET in the Delta.

Figure 4 shows that fallow fields differed in their daily and seasonal ETa. Station C1 recorded the highest fallow ET, followed by stations C6 and C8. Both C1 and C8 had transpiring weeds and were also the lowest in elevation (over 4 m below sea level), whereas C6 had 'clean' (very few weeds) bare soil, was surrounded on all borders by a small inlet of water, and was higher in elevation (over 6 m above sea level), relative to the other fallow fields. The remaining fallow fields had bare soil or worked-in dried crop residue, were near sea level in elevation, and recorded moderate ETa compared with other fields.

WEED PRESENCE

This dataset indicates that elevation and weediness are influences on fallow field ETa. Fields with actively growing vegetation are expected to have higher ETa than that of completely bare soil, where no vegetation is consuming and transpiring water. Elevation may have an indirect influence on ETa rates on fallow fields because of relative water table depths in lower and higher elevation sites and increased or decreased demand from weed growth. Where the water table is shallower, increased soil moisture can influence weed development and the soil evaporation component of evapotranspiration. In this study, elevation was roughly correlated with weed growth. The UCD team was able to actively log a limited number of water table measurements due to some technical challenges with the sensors used and is documented in Appendix B. These results indicate that active site management in fallowed fields, through weed control and maintained drainage, are important in maximizing water savings in fallow fields.

CROP RESIDUE

Crop residue cover may have a small but significant role in minimizing potential ET losses from fallow fields as well (van Donk et al., 2010). Site C9 had significant amounts of small grain residue remaining on the soil surface throughout the summer. This resulted in ETa rates during the summer months that were among the lowest. Increased residue cover on the soil surface, especially of highly reflective material such as small grain straw, increases the albedo of the field, which in turn increases the amount of radiation that is reflected into the atmosphere rather than absorbed by the land surface. When compared to the average net radiation of a bare fallow field, the average net radiation for the fallow field with significant crop residue present was 18% lower, reducing evaporative energy at the surface.

OTHER CHARACTERISTICS

Some of the differences between fallow field ET values might also be explained by other site characteristics identified in Table 3. For example, the soil evaporation rate is jointly controlled by atmospheric conditions and by the soil's ability to supply water to meet atmospheric demand. Capillary rise, the ability of water to move upward within a soil, is heavily governed by porosity resulting from the texture of a soil. Finely textured soils (clayey or silty soil) have higher capillary rise potential than more coarse soils that contain larger sand content and larger soil pores. Many of the fallow sites that were included in this study, except for C6, were found on soils classified as silty clay loams. These soils can exhibit capillary rise ranging from a meter to several meters (Keeling, 2004 and Shen et al., 2013). The fraction of potential evapotranspiration lost by surface evaporation is between 5 and 15%, according to Or and Lehmann (2019), who also found that evaporation losses are higher for soils with intermediate textures and smaller for coarse (narrow pore size distribution) and fine-textured soils.

NDVI

To assess the factors influencing fallow ETa by month, Land IQ assessed primary factors affecting estimated fallow ETa in statistical analyses across all fallow fields in the Delta (beyond the study sites) (Appendix A). These factors included NDVI, surface temperature from the METRIC model (Kelvin), elevation, distance to a waterbody, saturated hydraulic conductivity of the soil (Ksat), and available water content of the soil (AWC). For each month, estimated ETa was most strongly related to NDVI (an indication of vegetation vigor). In addition, UC Davis evaluated measured fallow field ET as related to NDVI of the study sites, and results were compatible with Figure 15; details can be found in Appendix B.

Figure 15 shows the relationship between NDVI and remotely sensed monthly estimated ETa in a scatterplot of all four evaluated months for the fallow fields. The NDVI values were interpolated between available overpass dates to yield mean monthly NDVI values.

As an example, all of the black symbols represent the NDVI value and estimated ETa for the fallow fields in July, and the black line is the fitted trend line based on points showing a positive linear relationship between NDVI and estimated ETa for the fallow fields.

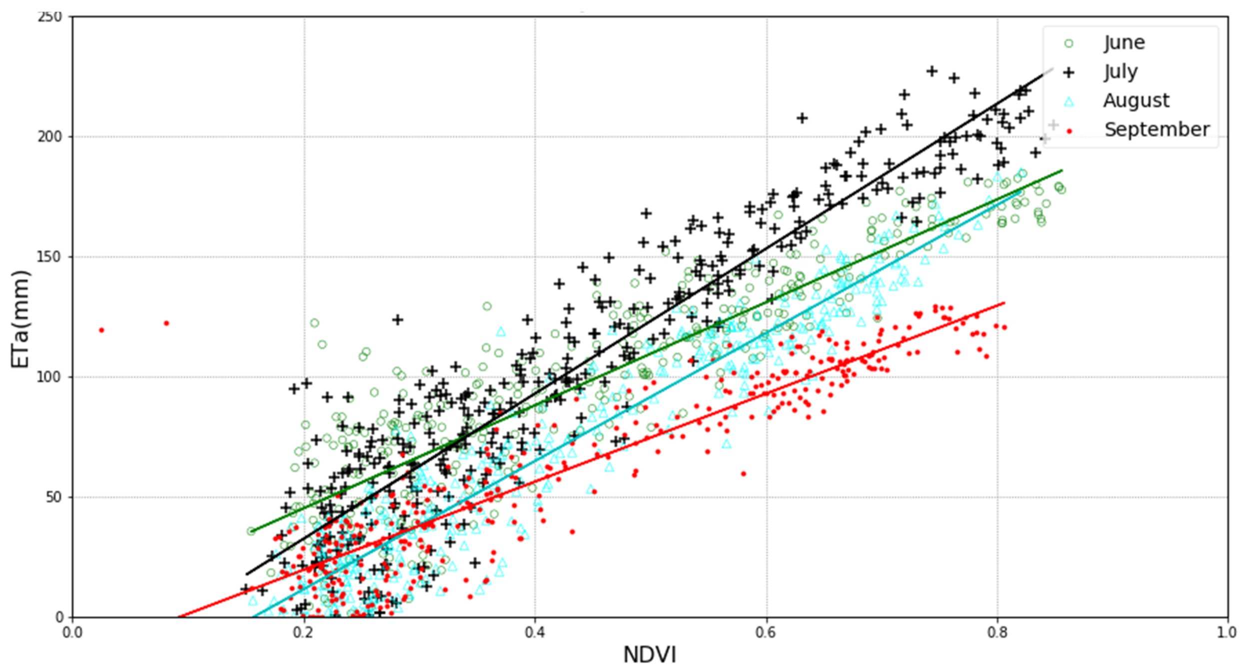

Figure 15. Relationship Between Fallow Fields' NDVI and Remotely Sensed Estimated Monthly ETa, June - September 2018

These results indicate that NDVI could be used to assess the weed presence in fallow fields and assist in the estimation of fallow ET at a given location, considering other factors and ground-based measurements used for calibration. It is important to note that unmanaged fallow fields often include significant weed growth and this substantial vegetation growth might not be representative of managed fallow conditions that could be part of a fallowing program's guidelines. Future research in combining NDVI with estimates of K_f and ET_o measurements or estimates would strengthen the potential ability of remotely sensed NDVI to help with fallow field ET_a estimation.

GUIDANCE FOR FALLOW FIELD ET PREDICTION

Monthly mean NDVI and monthly mean surface temperature are two significant variables for explaining fallow fields' estimated ETa variability and were applied into ordinary least squared regression (OLS) method to model estimated ETa values for the fallow fields for each month. Both variables can be calculated by interpolating daily NDVI and temperature data. Table 10 shows the regression result of remotely sensed modeled estimated fallow ETa in June. Both NDVI and surface temperature were significant variables for the estimated study fallow ETa in June, and they can explain about 80% of modeled fallow ET in that month.

For June, for all the fallow fields, if the surface temperature is held constant when NDVI increases by 0.1, the modeled ETa will increase by about 16 mm. If June's surface temperature is the same for two fallow fields, the one with higher NDVI (indicating probable volunteer weed growth) will likely have more plant transpiration, which increases the ETa. For the fields with the same NDVI, when the surface temperature increases by 1, the modeled ETa will decrease by about 2 mm. If two fields have the same NDVI, the one with a lower temperature will transpire more water since evapotranspiration is the process that consumes energy and cools down the surface at the same time. Both NDVI and surface temperature are used in the METRIC model, so the relationship between surface temperature, NDVI, and modeled ETa is expected.

Table 10. Linear Regression Results for Fallow ETa in June

Parameters	coefficient	std_err (mm)	p	R-squared
NDVI	164. 61	11.99	< 0.0001	0.80
Surface Temperature	-2.14	0.49	< 0.0001	
Constant	716.75	161.94	< 0.0001	

Similar to June, NDVI and surface temperature has a significant influence on remotely sensed modeled ETa in July, August, and September. Therefore, while the regression model is built for each month using the same approach, the resulting regression coefficients for each month are different. The model was built based on that current year's METRIC result, and such a relationship could be used for estimating fallow ETa for other years by applying an adjustment factor. For example, to model the 2020 June fallow ETa, an adjustment factor of the 2020 June ETo divided by the 2018 June ETo would be applied. It is important to note that this is a more coarse approach and does not take into account other factors that may influence ET in different years.

Guidance for predicting fallow ETa based on these monthly models is shown in Table 11. The columns represent NDVI with a step of 0.2 and the rows represent surface temperature with a step of 5 K. These tables can be referenced to find approximate monthly fallow field ETa given its NDVI and surface temperature. For instance, in June of a certain year, if a fallow field has an average monthly NDVI of 0.3 (between 0.2 and 0.4) and average surface temperature of 315 K, referring to the second row and third and fourth columns, then the expected cumulative ETa range for this field in August would be from 76.8 mm to 109.7 mm.

Table 11. Guidance for Modeled Fallow ETa Prediction[1]

Predicted Total ETa in June (mm/month)						
	NDVI					
		0	**0.2**	**0.4**	**0.6**	**0.8**
Surface Temperature (K)	**310**	54.5	87.5	120.4	153.3	186.2
	315	43.9	76.8	109.7	142.6	175.5
	320	33.2	66.1	99.0	131.9	164.9
	325	22.5	55.4	88.3	121.3	154.2
	330	11.8	44.7	77.7	110.6	143.5
	335	1.12	34.05	67.0	99.9	132.8

Predicted Total ETa in July (mm/month)						
	NDVI					
		0	**0.2**	**0.4**	**0.6**	**0.8**
Surface Temperature (K)	**310**	0	19.4	82.7	146.0	209.3
	315	0	22.3	85.6	148.9	212.2
	320	0	25.2	88.5	151.8	215.1
	325	0	28.0	91.3	154.6	217.9
	330	0	30.9	94.2	157.5	220.8
	335	0	33.8	97.1	160.4	223.7

Predicted Total ETa in August (mm/month)						
	NDVI					
		0	**0.2**	**0.4**	**0.6**	**0.8**
Surface Temperature (K)	**310**	36.0	74.4	112.9	151.4	189.8
	315	21.3	59.8	98.2	136.7	175.1
	320	6.7	45.1	83.6	122.0	160.5
	325	0	30.4	68.9	107.3	145.8
	330	0	15.8	54.2	92.7	131.1
	335	0	1.1	39.6	78.0	116.5

Predicted Total ETa in September (mm/month)						
	NDVI					
		0	**0.2**	**0.4**	**0.6**	**0.8**
Surface Temperature (K)	**310**	74.1	93.8	113.4	133.1	152.7
	315	52.2	71.9	91.6	111.2	130.9
	320	30.4	50.0	69.7	89.3	109.0
	325	8.5	28.2	47.8	67.5	87.1
	330	0	6.3	25.9	45.6	65.2
	335	0	0	4.1	23.7	43.4

[1] The inverse relationship between surface temperature and ETa is a result of the energy budget process. As a surface evaporates/transpires more water, it uses more energy for the evaporation of water instead of heating the air, which results in a cooler surface. Conversely, higher surface temps are the result of lower ET from higher H (heating of air) and lower LE (evaporation of water) values in the energy budget. If water is not present and available for evaporation, more energy is instead used in the heating of the air.

5 Conclusions and Recommendations

Fallowing fields reduced ETa by 30% to 85% compared to cropped fields, depending on field conditions and crop type, as shown by the K_{cf} values. For the particular paired alfalfa fields studied, this could result in an ET reduction of 400 mm to 800 mm for alfalfa, over the period from April 2018 to October 2018. The main influences on ET reduction were whether fallow fields had substantial weeds or previous crop residue in the bare soil, crop type, age, and irrigation management. Other possible influencing factors were fallow field elevation, soil type, and water table level. The relationship between measured and modeled ET was strong for the period of site data collection (R^2 of 0.92), however, there are site-specific variations between remote sensing modeled and measured ET. The difference between modeled and measured ET for fallow sites for the period of measurement (period of measurement varied among sites) ranged from 10.6 to 103.1 mm and averaged 59.2 mm. Further discussion of uncertainties for the remote sensing ET and the field data are in Appendices A and B, respectively.

Maximum growing season ET reductions for fallow fields occurred when fields were kept weed-free. Therefore, the costs of fallow field weed control management should be considered in determining the value of consumptive water use saved by fallowing. Pumping and drainage to lower the water table in Delta islands could also decrease fallow field ET. Other site characteristics that cannot be controlled, such as soil type, elevation, and water, may need to be considered in selecting fields to fallow for potential water savings.

6 REFERENCES

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