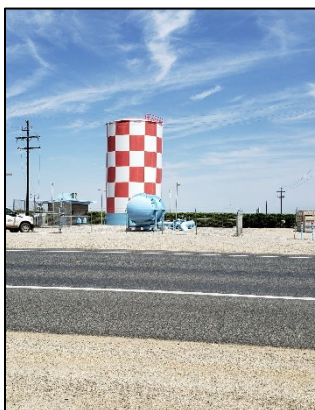
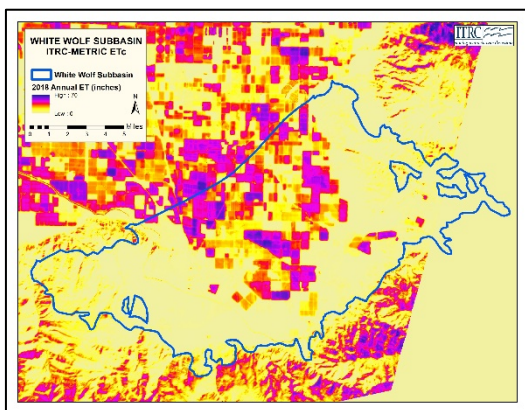


2017-2020 ITRC-METRIC ETc for White Wolf Subbasin

FINAL



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White Wolf Subbasin GSA 2017-2020 ITRC-METRIC ET_c

Introduction

The Irrigation Training & Research Center (ITRC) at California Polytechnic State University, San Luis Obispo was contracted by the White Wolf Subbasin GSA (WWSGSA) to compute actual evapotranspiration (ET_c) from the White Wolf Subbasin. The area of interest is shown in Figure 1 with a “natural color” image in the background. All annual results are presented based on a calendar year.

ITRC uses a modified Mapping of EvapoTranspiration with Internal Calibration (METRIC™) procedure to compute actual evapotranspiration using LandsAT Thematic Mapper (LandsAT) data. The original METRIC procedure was developed by Dr. Richard Allen (University of Idaho). ITRC has made a number of modifications to the original procedures including using a grass reference evapotranspiration instead of alfalfa, a semi-automated calibration procedure, spatially interpolated ET_o, modifications to the aerodynamic resistance and albedo computations for certain crops, improved open water evaporation algorithm, etc.

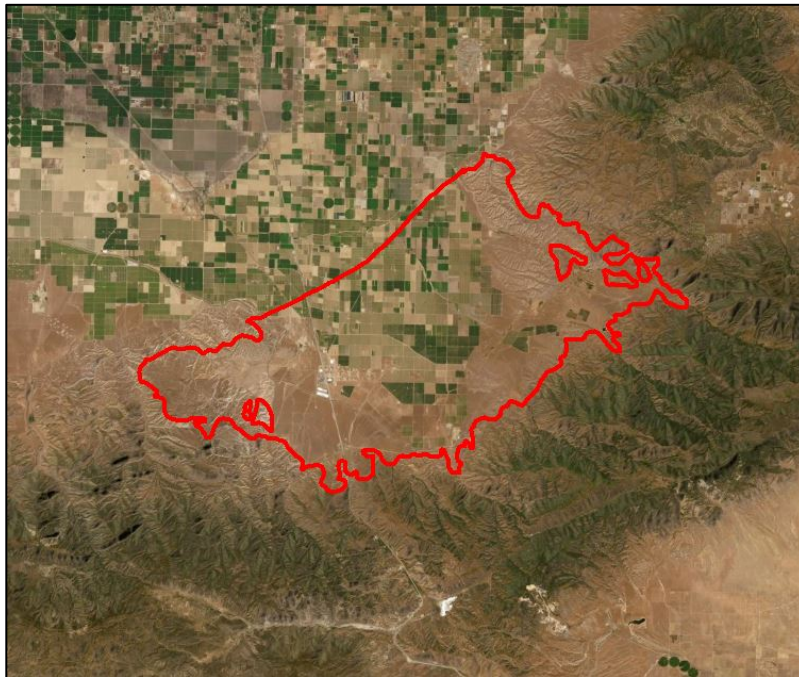


Figure 1. Aerial image of the area of interest within which actual evapotranspiration was provided to WWSGSA

This report will describe the general process and some results of the modeling over the timeframe. The monthly and annual results of ITRC-METRIC for this project have been transmitted to WWSGSA.

ITRC-METRIC Procedures

This *Procedures* section will discuss the information that was gathered and used to compute the actual crop evapotranspiration (ET) in the White Wolf Subbasin. The ITRC-METRIC process is based on a surface energy balance and includes corrections for aerodynamic resistance. It depends upon both accurate and frequent LandSAT satellite thermal images and understanding of the cropping systems within a region. The METRIC programs have gradually evolved from research in the US and other countries with the objective of being able to directly estimate actual ET over large areas with limited data availability (such as crop type, irrigation method, irrigation practices, etc.). The image processing is relatively fast; however, the collection of significant background data (besides the satellite images) that are necessary to start the processing in a new area can be somewhat time-consuming. Proper use of METRIC also requires expert input/interpretation by those who run the program.

LandSAT 7 and 8 image pixel resolution is 30 meters by 30 meters for all but the thermal band. The thermal band pixel resolution is 60 meters by 60 meters for LandSAT 7 and 100 meters by 100 meters for LandSAT 8. For this project, the thermal band was sharpened to 30 meter by 30 meter resolution using the nominal cubic spline that is provided in the raw images by USGS. ITRC has a more advanced thermal sharpening process, but that was not used because of time and budget constraints for this project. Inputs into the ITRC-METRIC model included:

- LandSAT imagery
- Digital elevation maps
- NASS CropScape data
- Corrected weather station data (hourly and daily)
- Corrected spatial grass reference evapotranspiration (ET_o) maps (daily)
- Spreadsheet calculated values
- Tabulated constants

A critical benefit of using ITRC-METRIC to determine actual evapotranspiration is that land use/crop type information is not needed. Therefore, inaccuracies of determining land use are not part of the uncertainty in ET_c output. General land use information (row crop, orchard, etc.) is used to correct for aerodynamic influences on ET_c. The information provided through the NASS CropScape is of sufficient accuracy for this piece of the process.

Satellite Images

LandSAT 7 and LandSAT 8 images available from the United States Geological Survey (USGS) on sixteen-day intervals were used for the METRIC process. Table 1 shows the time frame of available images from each satellite. ITRC has not processed ET_c data for 2012 since only LandSAT 7 imagery is available, which is incomplete due to the bandgaps¹.

Table 1. Time frame of available images for LandSAT 7 and 8

LandSAT 7	LandSAT 8
June 1999 – Present	April 2013 – Present

¹ After May 2003, LandSAT 7 began producing images with missing data, or “bandgaps” because of a defective sensor/mirror. LandSAT 7 is only used as a backup if other LandSAT data is missing. Bandgaps are filled using interpolation techniques in GIS as described in the METRIC Application Manual Version 2.0.7 (Allen et al. 2010)

The area of interest is covered by the LandsAT image path 42, row 36. Each path identifies a path, or single trip the LandsAT takes, and the rows are different portions of that path. The rows along the same path are taken on the same day and the center of the row image is taken at approximately the same time of the day (approximately 11 a.m. Pacific Standard Time).

The METRIC modeling process relies on surface temperature data from the LandsAT thermal band. Actual ET_c cannot be computed for the regions covered by clouds or fog. Figure 2 compares a non-clouded image with a cloud-covered LandsAT image. The best quality (minimal clouds and fog) LandsAT images were selected for processing. Every LandsAT image available throughout the study period was evaluated manually. All relatively cloud-free available images were used for the modeling process.

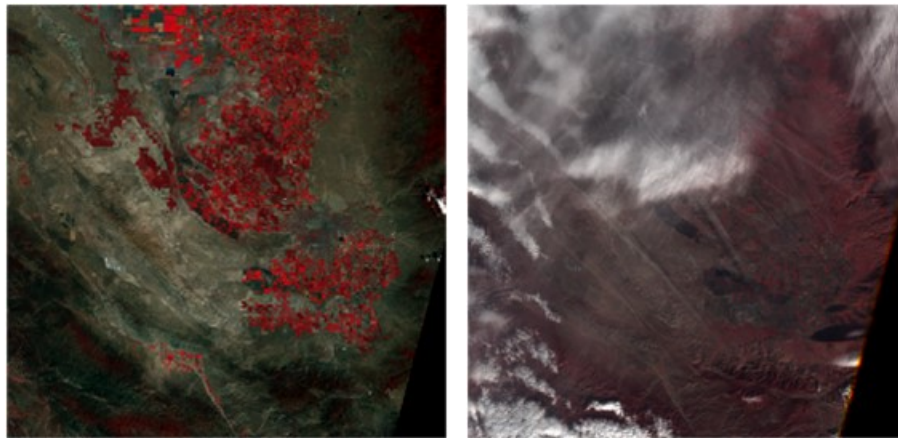


Figure 2. Cloud free LandsAT image (left) and LandsAT image with clouds (right)

Table 2 lists the images processed from late 2016 through 2020. A total of 103 individual images were used to cover the study period.

If a cloud-free LandsAT 8 image was not available during a month, the image with the fewest clouds was selected or cloud-free LandsAT 7 imagery was used. If an image with clouds had to be used, the clouds were masked out of the results and replaced with interpolated results from images processed before and after the image date. For the cloud masking interpolation, the two previous and three subsequent processed images were used to estimate the actual crop coefficient for the cloudy region. Cloud masking is most common during the winter months due to rain and fog. The potential error due to cloud masking is highest in these months. Overall, the uncertainty due to cloud masking and bandgap interpolation is relatively low since the ET_c is lowest during these winter months.

Table 2. Chosen image dates for 2017-2020 Kern County METRIC process

2016	2017	2018	2019	2020
9/1/2016	1/31/2017*	1/26/2018	1/13/2019	1/16/2020
9/17/2016	2/24/2017	2/3/2018*	2/6/2019*	2/1/2020
10/19/2016	2/12/2017	2/11/2018	2/22/2019*	2/25/2020*
12/14/2016*	3/28/2017	2/19/2018*	3/18/2019	3/4/2020
	4/21/2017*	3/15/2018	4/27/2019	3/20/2020
	4/29/2017*	3/31/2018	5/5/2019	4/21/2020
	5/15/2017	4/8/2018*	5/13/2019*	5/7/2020
	5/23/2017*	4/24/2018*	5/29/2019*	5/15/2020*
	6/16/2017	5/18/2018	6/6/2019	5/23/2020
	7/2/2017	6/3/2018	6/14/2019*	6/16/2020*
	7/18/2017	6/19/2018	6/22/2019	6/24/2020
	8/11/2017*	7/5/2018	6/30/2019*	7/2/2020*
	8/19/2017	7/21/2018	7/8/2019	7/18/2020*
	8/27/2017*	8/6/2018	7/24/2019	7/26/2020
	9/20/2017	8/22/2018	8/1/2019*	8/11/2020
	9/28/2017*	9/7/2018	8/9/2019	8/27/2020
	10/6/2017	9/23/2018	8/25/2019	9/4/2020*
	10/22/2017	10/9/2018	9/10/2019	9/20/2020*
	11/7/2017	10/25/2019	9/18/2019*	10/14/2020
	11/23/2017	11/2/2018*	9/26/2019	10/22/2020*
	12/17/2017*	11/26/2018	10/4/2019*	10/30/2020
		12/12/2018	10/12/2019	11/23/2020*
		12/28/2018	10/20/2019*	12/1/2020
			10/28/2019	12/9/2020*
			11/5/2019*	1/18/2021
			11/21/2019*	2/19/2021
			12/15/2019	
			12/31/2019	

Note: * indicates LandSAT 7, and no asterisk indicates LandSAT 8 images

Weather Data

ITRC-METRIC utilizes daily spatially varied grass reference ETo for interpolation between image dates. Spatial CIMIS is a product provided by the California Irrigation Management Information System (CIMIS) maintained by the California Department of Water Resources (DWR). Spatially varied ETo is developed by interpolating ETo between CIMIS weather stations, which measure and compute the ETo on an hourly basis. Spatial CIMIS interpolation in mountainous terrain is a known issue and is not considered a problem in the data provided since the terrain is relatively flat with some foothills. All ETc data provided as part of this project that happens to be in mountainous terrain should be considered suspect. ITRC has the capabilities of providing more accurate ETc in mountainous terrain with a special set of mountain correction models that were not used as part of this project.

ITRC-METRIC also relies on hourly weather data from a station within the area of interest for processing the instantaneous images (prior to interpolation). The Delano CIMIS station was utilized as the “primary” weather station. This station was selected because of its central location within the image.

Hourly weather data for the project time frame was collected from the primary CIMIS station. The weather component data collected from the weather stations included:

1. Solar radiation (W/m²)
2. Vapor pressure (kPa)
3. Air temperature (°C)
4. Wind speed (m/s)
5. Precipitation (mm)

6. Relative humidity (%)
7. Dew point temperature (°C)
8. PM ETo (mm)

All collected **hourly** weather data from the station went through a quality control check and correction procedure. A detailed procedure on the quality control conducted can be found in FAO Irrigation and Drainage Paper No. 56² along with correction procedures. For missing data, or if an error was flagged on the CIMIS station signifying missing, incomplete, or odd data results, data were examined for general consistency. Missing data and data believed to be in error were corrected. The correction procedure used in this analysis replaced the missing or flawed data with the averages from nearby weather stations. Once all hourly data was corrected, the data was input into REF-ET™ (Dr. Richard Allen, University of Idaho) to compute the corrected hourly ASCE Standardized ETo that was used in this study.

ETo and individual weather data are used within the ITRC-METRIC process to compute inputs into the software. METRIC computes the instantaneous ETc for every pixel within the LandSAT image at the instant the image is taken. Knowing the ETo at that instant from the local weather station, a **crop coefficient (Kc)** can be computed ($Kc = ETc/ETo$). It has been shown that this instantaneous actual Kc at the time of image acquisition (approximately 11 a.m.) is a very good representation of the Kc for that entire day. These instantaneous Kc results are interpolated using a cubic spline procedure between image dates. The interpolated pixel Kc for each day is then multiplied by the daily corrected spatial ETo discussed in the next section.

If the image used is after a precipitation event, ITRC manually reduces the Kc for bare soil in the instantaneous image. This is so that during interpolation between images, the evaporation from bare soil is not overestimated when interpolated over the month.

Spatial ETo

Spatial CIMIS ETo is a relatively new resource available through the DWR. A specialized algorithm uses weather station data, elevations and other inputs to interpolate ETo between stations. However, Spatial CIMIS ETo rasters rely on CIMIS weather data that could have errors. In order to improve accuracy, ITRC incorporated the corrected CIMIS weather data into the Spatial CIMIS ETo raster images using a model we developed for ArcGIS 10.1 for Spatial CIMIS up through 2016. Recently, ITRC conducted a study of the corrected versus uncorrected Spatial CIMIS and the results indicated less than a 1% difference in the results. Therefore, since 2017 ITRC has no longer corrected the Spatial CIMIS raster images. The only corrections being conducted are on the hourly weather data at the primary weather station.

Elevation Data

A Digital Elevation Model (DEM) obtained from the USGS was used to adjust the model outputs based on the surface elevation throughout the area of interest. The DEM used had a resolution of 10m (1/3 arc second) which was then re-projected into a 30m × 30m pixel size to match the resolution of the LandSAT images.

² Allen, R.G.; Pereira, L.S.; Raes, D. & Smith, M. (1998). Crop evapotranspiration – Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper, No. 56, FAO, Rome

Land Use Map

As previously mentioned, accurate land use/crop types are not necessary for ITRC-METRIC. General information on whether land is natural vegetation, row/field crops, orchards, or vineyards is used to adjust for aerodynamic resistance of the canopy, and is also a function of leaf area index. NASS CropScape provides sufficient accuracy for this information.

Land Use Data 2017 to Present

For years 2017 to present, only the land use data from the NASS annual rasters were used. While this information is sufficient for METRIC, there are issues with consistency within fields. Land use surveys were conducted by the California DWR on a field-by-field basis for all of the counties located in the Central Valley. DWR land use survey shapefiles were downloaded for each county, some of which may have last been surveyed in the 1990s. The shapefiles contain field boundaries or in some cases boundaries of the same crop that cover multiple fields. All non-agricultural areas in the DWR land use surveys were removed from the shapefile. Using the zonal statistics tool in ArcGIS, the NASS land use was summarized for each DWR agricultural field boundary in the Central Valley. The crop that made up the majority of the field area was assumed to cover the entire field area.

The final corrected land use maps went through a quality control check to ensure that a single land use value was uniform across an entire field. Figure 3 shows an example of the original uncorrected NASS land use compared to the land use used in this analysis, which is much more consistent. The inconsistent “pixelated” areas in the corrected land use were identified as non-cropped areas in the DWR land use survey. Therefore, these non-ag areas use the original NASS data.



Figure 3. Example original NASS land use (left) compared to corrected land use based on the majority crop type within each agricultural field (right). Each color identifies a different land use type (i.e., almonds, alfalfa, developed, etc.)

Interpolation between Image Dates

The selected images were processed, resulting in instantaneous actual crop coefficients (Actual Kc) on those dates for each pixel. The crop coefficient has been shown to remain constant during the majority of the daylight hours. Therefore, the instantaneous actual Kc was used as a surrogate for the daily actual Kc. In order to estimate the actual ETc between dates that images are available, actual Kc values are interpolated between image dates. A modified cubic spline approach is used to examine images within the month to be computed, prior to that month, and after that month. For example, to interpolate the ETc in the month of July, the July image(s) would be used along with May and June, and August and September. Cubic spline interpolation provides a smooth, non-linear interpolation between image dates. The interpolation takes place for every pixel in the image and the results are temporary Kc images for every day in the month. The daily pixel actual Kc values are then multiplied by the daily corrected Spatial ETo previously discussed to compute the daily actual ETc for each pixel. These daily ETc images are summed together for each month. Finally, the corrected Spatial ETo is summed for each month and the monthly ETc is divided by the ETo to generate the final monthly Kc image.

Monthly actual ETc results for White Wolf Subbasin for the period 2017-2020 have been provided to the WWSGSA in GIS raster (image) format.

Accuracy of ITRC-METRIC ETc Estimates

Uncertainty is the quantification of accuracy in measurements and estimates. The most accurate method to estimate ETc is using a weighing lysimeter (correctly) but this is not feasible except in research situations. There are various methods that can be used to estimate ETc, each with different levels of uncertainty:

1. Traditional crop coefficient models (not used here but common in groundwater modeling) have uncertainty due to the assumptions that ETc is constant within a field and between fields in a region. Additionally, errors in land use determination (acreage of each crop), planting and harvest dates (or budbreak and dormancy for permanent crops), and crop management (irrigation, pruning, etc.) all impact the ETc uncertainty. Errors in weather data collection to determine grass reference ETo also impact the uncertainty. As a reference, uncertainties with crop coefficient methods are in the range of 20-25%.
2. Sensor-based measurements such as eddy covariance and surface renewal only measure a small footprint in a field and have potential for sensor errors due to improper calibration, loss of calibration over time, or sensor fouling. Additionally, the sensors must be adjusted, installed correctly, and some (e.g., surface renewal) depend on assumptions that may not hold. Data management and technical support make these infeasible when examining ETc over many fields.
3. NDVI-based ETc estimates have some advantages over (1) and (2) in that they provide spatial variation over a field and field-to-field. However, these still rely on accurate crop surveys. Additionally, this method does not account for crop stress, unless that stress is so severe that it impacts the vegetative index. As with (1) above, the ETo errors translate to ETc uncertainty.
4. ITRC-METRIC ETc overcomes many of the issues with other methods, which is why it was developed. This method does not rely on accurate crop surveys. It also accounts for crop stress before it impacts the vegetative health. Spatial variation in ETc throughout a field and between fields is taken into account. ETo continues to be an important part of ITRC-METRIC, which is why quality control of the data is important. In order to limit errors in ETo, ITRC conducts an extensive quality control of the weather station data and utilizes spatially varied ETo to account for different climates within a region. As with other methods, it is imperative that the person doing the processing understands

agronomic aspects within the region being evaluated. Errors in processing will generate errors in ETc estimation. All ITRC-METRIC images are reviewed by project managers with many years of experience in farming, irrigation, and crop water use estimation to ensure that the outputs are correct. This overcomes potential errors in LandSAT sensor data since each image is calibrated independently.

ITRC-METRIC uncertainty is estimated to be +/-7 to 10% in this study. On a large scale (GSA or county-wide ETc volumes) the error is on the lower end of this range. On a field scale, it may currently be on the upper end. We have continued to make improvements to our methodology and feel that in the future, field-scale ETc will be on the lower end of the uncertainty range provided. There are no other ETc computational methods available with uncertainties on both a large scale and field scale within these ranges.

Summary of Results

The annual results have been summarized for the White Wolf Subbasin and the field boundaries within the subbasin. Figure 4 shows the boundaries (overall and field boundaries) used for the data extraction for the summaries discussed in this section. Average annual ITRC-METRIC ETc was extracted using the Zonal Statistics tool in ArcGIS. The average ETc from the extracted area was multiplied by the area within the boundaries (overall boundary or each field boundary for the fields) to compute volumes. Over the 4-year period, the field boundaries and overall boundary were the same. The field boundaries focus on the agricultural/cropped and irrigated fields. Some fields may be fallow but there is a clear field location. The difference between the field and overall boundary ET is areas that are generally non-irrigated pasture, residential, or native vegetation regions.

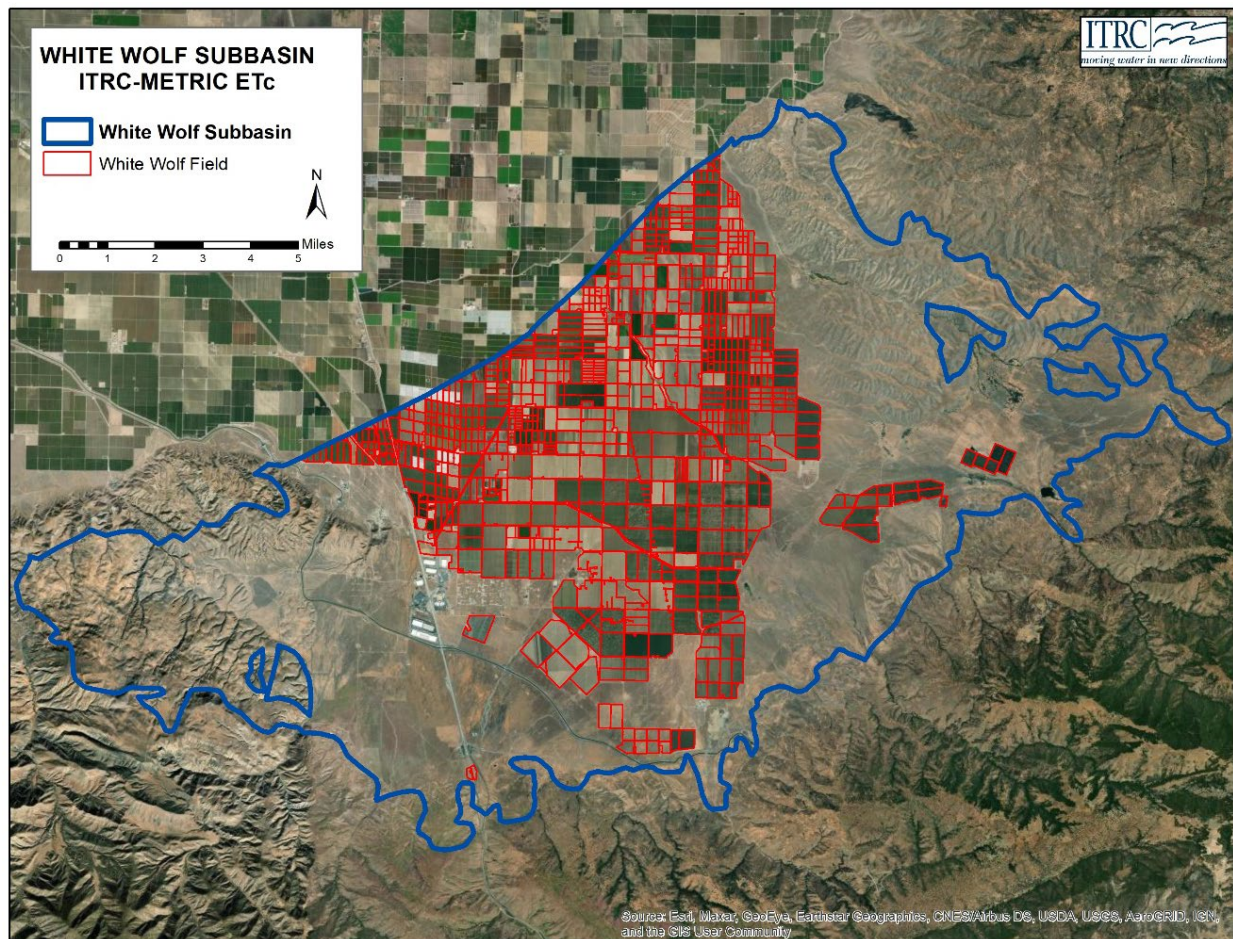


Figure 4. White Wolf Subbasin and field boundaries used for the summary analysis

The ETc was also extracted by district within the subbasin. There is some overlapping between the districts within the subbasin. Figure 5 shows the portions of Tejon-Castaic W.D., Wheeler Ridge-Maricopa W.S.D. and Arvin Edison W.S.D. within White Wolf Subbasin GSA.

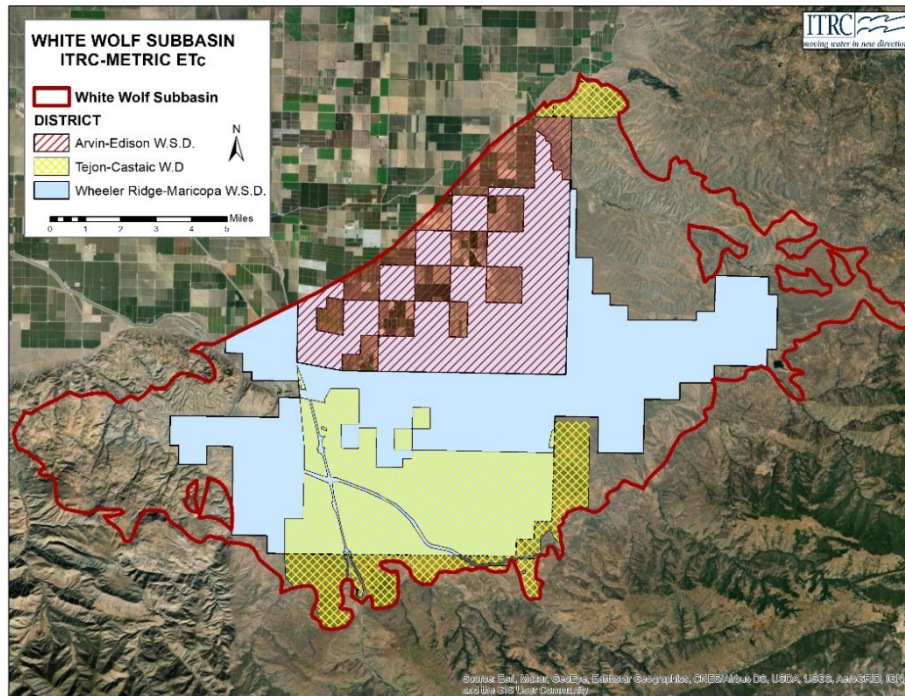


Figure 5. Districts within the White Wolf Subbasin

The volume of actual ETc for the overall area of the subbasin and only within fields is shown in Figure 6. For reference, the grass reference evapotranspiration (ETo) and precipitation for CIMIS Station #125 (Arvin-Edison) are also shown. ETo provides an idea of the weather conditions that drive evapotranspiration. Hotter, drier years have a higher ETo. Figure 7 and Figure 8 show the volume and depth of ETc for the overall boundary of the districts within the White Wolf Subbasin. The volumes in overlapping areas were attributed to both overlapping districts (double counted), so the user should NOT sum the volumes of the districts' ETc together. Instead, use the subbasin total as the correct volume. Figure 7 and Figure 8 show the volume and depth of ETc for ag fields, summarized for the districts within the subbasin.

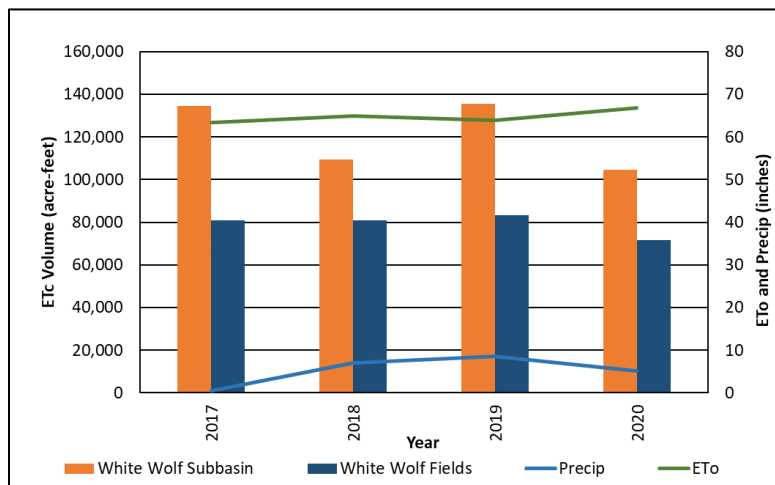


Figure 6. Annual volume of ETc for the White Wolf Subbasin and within fields in the subbasin. Grass reference ETo and precipitation depths are shown as a reference.

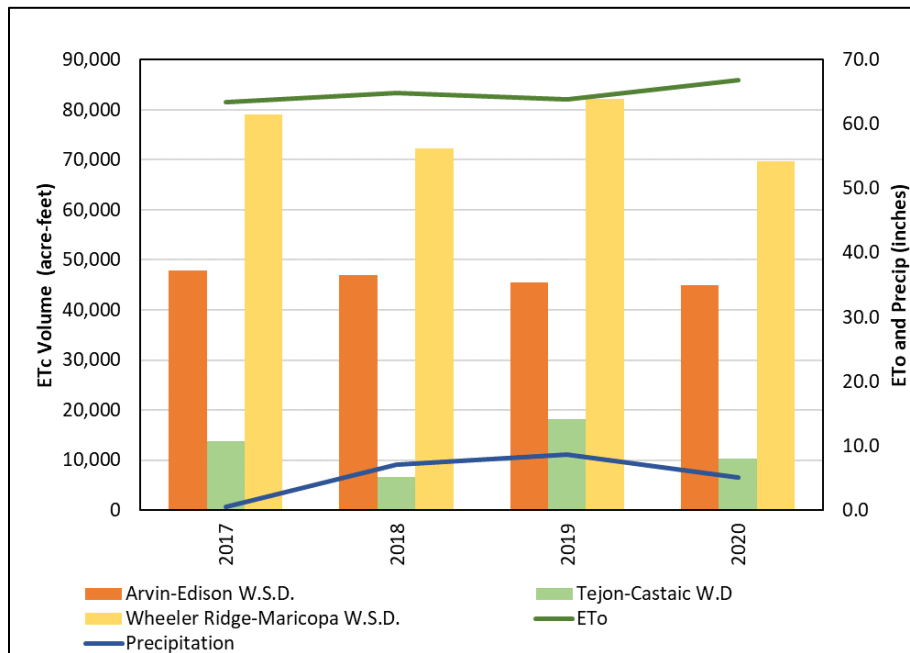


Figure 7. Annual ETc volume (acre-feet) by district within the White Wolf Subbasin

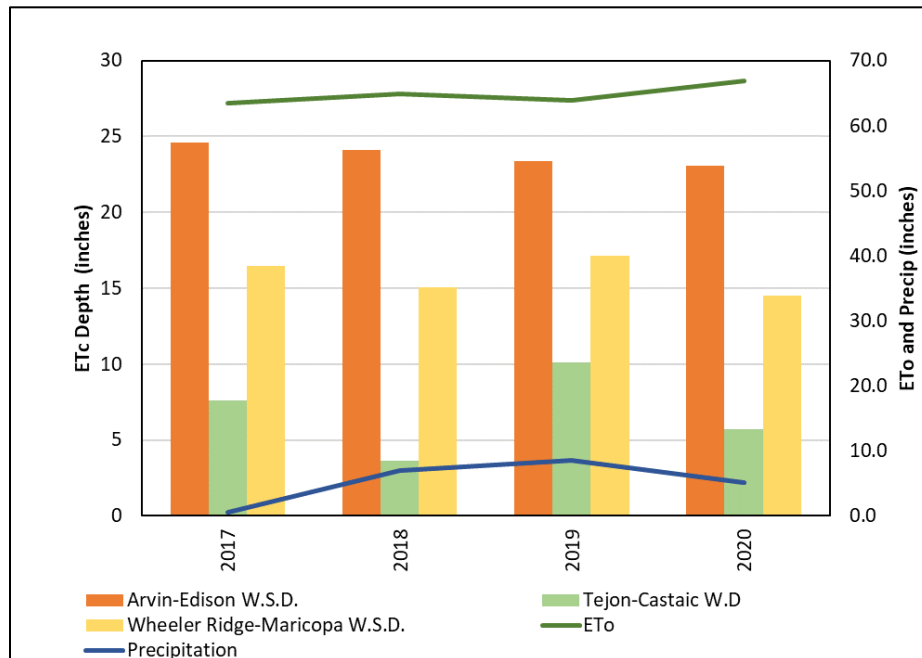


Figure 8. Annual ETc depth (inches) by district within the White Wolf Subbasin

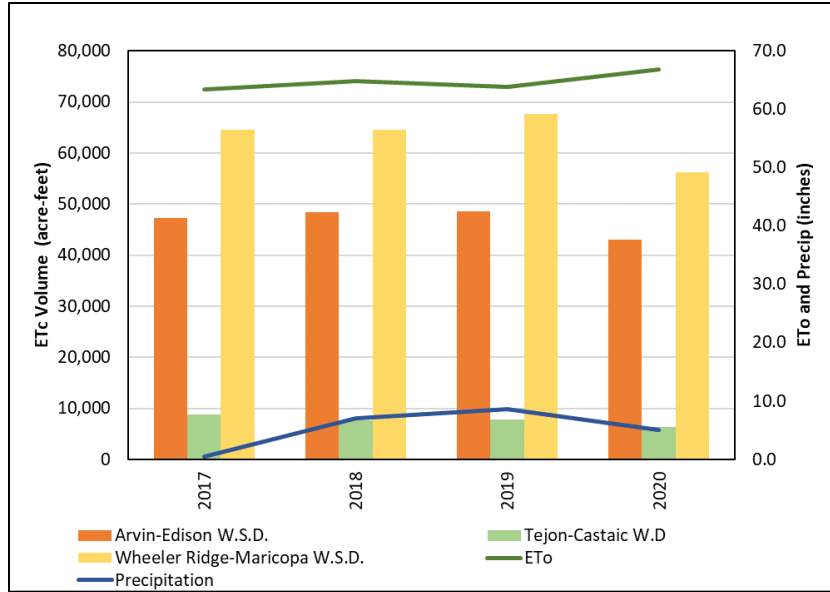


Figure 9. Ag fields' annual ETc volume (acre-feet) by district

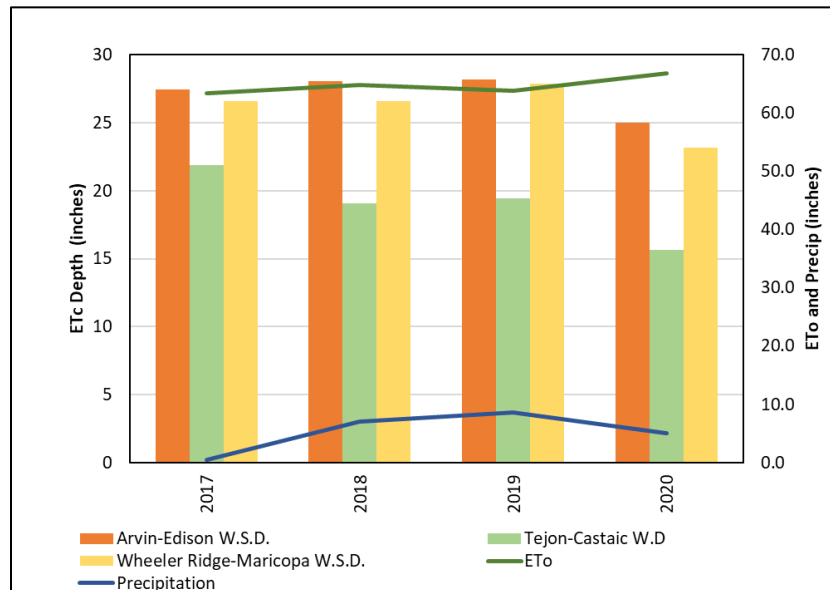


Figure 10. Ag fields' annual ETc depth (inches) by district

Evaluation of ETc Variation

In general, the variation is not significant from year to year and can likely be attributed to weather variation. The difference between the subbasin and field ETc is due to ET and evaporation occurring outside of field boundaries. Year-to-year variability in ETc volume might be explained by weather differences between years. To examine this, the data was normalized to exclude weather variation by examining the annual crop coefficient (Kc), computed as the actual ETc divided by ETo (ETo is computed based on weather data, not including precipitation). Annual Kc values are shown in Figure 11 for the study period for the entire White Wolf Subbasin area (includes urban, streets, undeveloped areas, etc.) and within fields only (only agricultural fields in the same area).

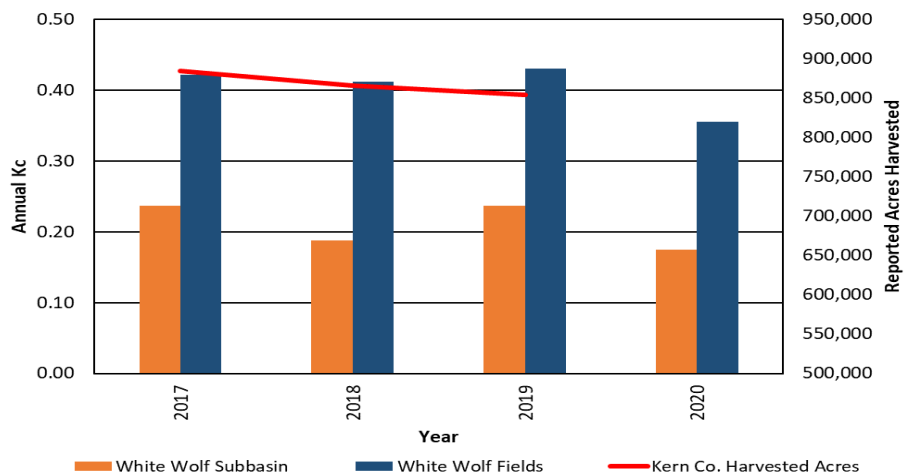


Figure 11. Annual crop coefficient (Kc) for the White Wolf Subbasin and within fields. Reported Ag Commissioner total harvested acres per year on the right axis of the graph

As expected, the Kc is higher when only looking within field boundaries rather than the subbasin. Areas outside of the fields are in large part reliant on precipitation or are a mix of landscape and residential areas. Urban areas and open water are also included.

Kc by Crop Type Categories

Field crop information was obtained from County of Kern Agriculture and Measurement Standards Kern Spatial Data website (<http://www.kernag.com/gis/gis-data.asp>). This data was overlaid on the field boundaries used to extract the monthly evapotranspiration data and used to assign land use to each field. The area weighted ETc was developed for each crop category and divided by the monthly ETo to compute the monthly area weighted crop coefficients. The results for trees and vines are shown in Figure 12 and for other crops such as vegetable rotations (carrots, potatoes, etc.), berries, and melons in Figure 13.

It should be noted that the crop coefficients include fields that may have immature permanent crops or crops misclassified. The “Nuts” category has a lower Kc than anticipated likely the overall ETc for that category is driven down by immature orchards. We anticipate that Citrus and Grapes would have an overall Kc within the ranges shown indicating that over the last four years there likely was not a significant increase in plantings of these crops in the GSA. It was beyond the scope of this study to estimate fields that may have been immature.

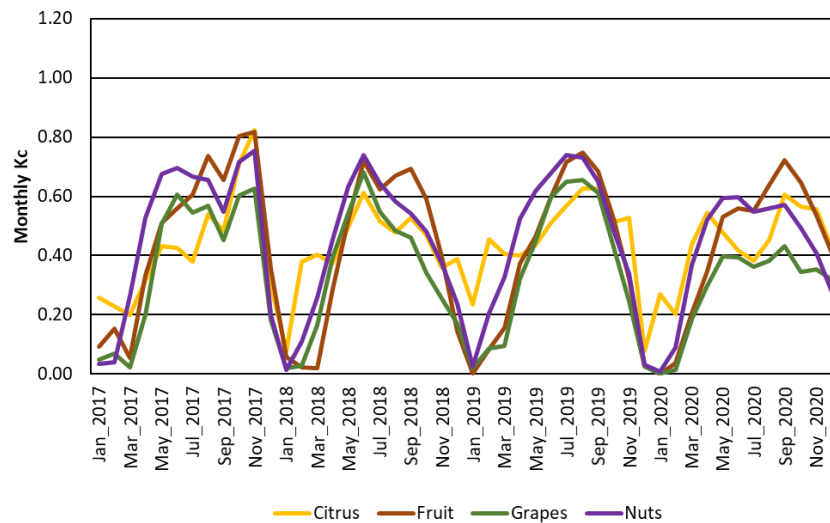


Figure 12. Monthly area weighted crop coefficients for orchards and vineyards

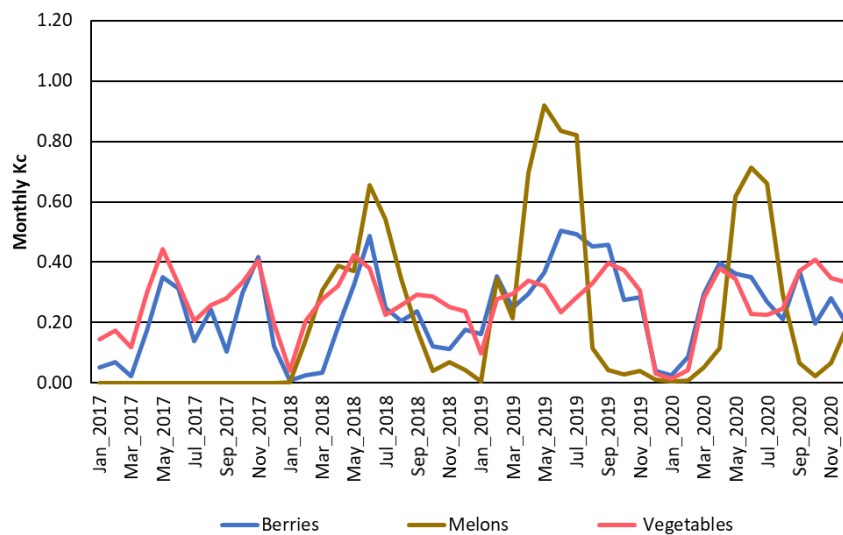


Figure 13. Monthly area weighted crop coefficients for other crops

Conclusion

Over the 2017-2020 period, the volume of evapotranspiration from fields within the White Wolf Subbasin ranged from approximately 71,000 to 83,000 acre-feet. Evapotranspiration varies year to year in the White Wolf Subbasin. This is caused by several factors including weather, crop mix/age, water availability, precipitation, and land fallowing.

The monthly and annual evapotranspiration and Kc imagery in GIS format has been transmitted to White Wolf Subbasin.

Attachment A

Annual ITRC-METRIC ETc

