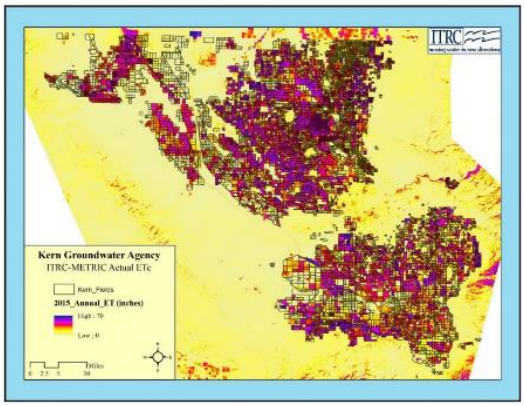
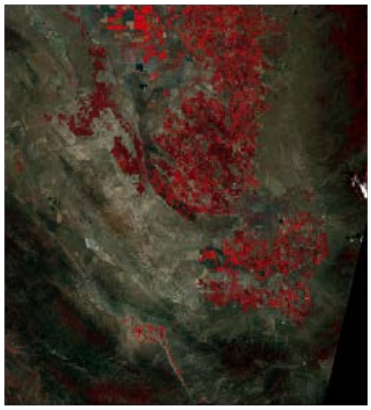
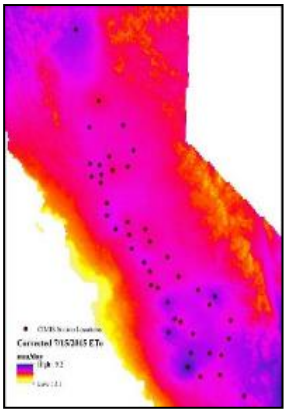
Kern Groundwater Authority

1993-2016 ITRC-METRIC ETc for Kern County







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ITRC moving water in new directions

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Kern Groundwater Authority
1993-2016 ITRC-METRIC

Introduction

The Irrigation Training & Research Center (ITRC) at California Polytechnic State University, San Luis Obispo was contracted by the Kern Groundwater Authority (KGA) to compute actual evapotranspiration (ETc) from the Southern San Joaquin Valley within and near the Kern Groundwater Basin. The area of interest is shown in Figure 1 with a "natural color" image in the background.

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 ETo, 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 KGA

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 KGA (care of Eric Averett, General Manager, Rosedale-Rio Bravo WSD).

ITRC- METRIC Procedures

This *Procedures* section will discuss the information that was gathered and used to compute the actual crop evapotranspiration (ET) in the Delta. 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 5, 7, and 8 image pixel resolution is 30 meters by 30 meters for all but the thermal band. The thermal band pixel resolution is 120 meters by 120 meters for LandSAT 5, 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 (ETo) 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 ETc output. General land use information (row crop, orchard, etc.) is used to correct for aerodynamic influences on ETc. The information provided through the NASS CropScape is of sufficient accuracy for this piece of the process.

Satellite Images

LandSAT 5, 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.

Table 1. Time frame of available images for LandSAT 5, 7, and 8

LandSAT 5	LandSAT 7**	LandSAT 8
November 1982 – October 2011	June 1999 – Present	April 2013 – Present

***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, rows 35 and 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 ETc 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.

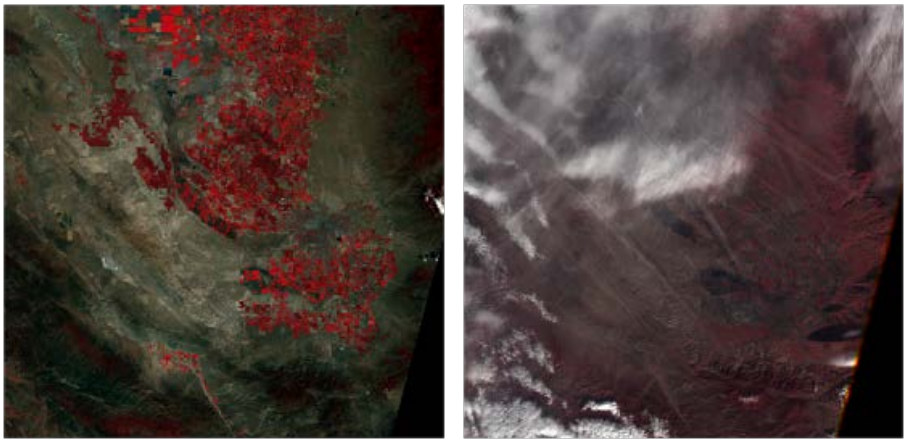


Figure 2. Cloud free LandSAT image (left) and LandSAT image with clouds (right)

All relatively cloud-free available images were used for the modeling process. Table 2 lists the images processed from late 1992 through early 2016. A total of 234 images were used to cover the study period.

If a cloud-free image was not available during a month, the image with the fewest clouds was selected or 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.

Some months (generally during winter) had no usable images because of significant cloud cover. Available images, before and after the month with no data, were selected to be used to interpolate the missing image.

For those cases when three or more consecutive months did not have usable images, the closest available image was used in combination with a correction factor, to get an average estimated Kc map for the missing month. Those correction factors were established based on data from years with usable winter images. Because this process was used only for winter months, which have low ET, the overall accuracy should not be influenced significantly. However, users should understand that the uncertainty of the data for these months is greater than if LandSAT images were available. The months when this process was used can be seen in Table 3.

Table 2. Chosen image dates for 1993-2016 Kern County METRIC process

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
10/1/1992	2/25/1994	4/1/1995	4/3/1996	3/5/1997	3/8/1998	1/22/1999	2/2/2000*	1/3/2001*	2/7/2002*	3/6/2003
12/20/1992	3/13/1994	5/3/1995	5/21/1996	4/6/1997	4/9/1998	2/23/1999	3/21/2000*	2/4/2001*	3/3/2002	4/7/2003
3/10/1993	6/1/1994	6/3/1995	6/22/1996	5/8/1997	5/27/1998	3/27/1999	4/30/2000	3/24/200*	4/12/2002*	6/10/2003
4/27/1993	6/17/1994	7/6/1995	7/8/1996	6/9/1997	6/28/1998	5/14/1999	5/24/2000	4/17/2001	5/14/2002*	7/12/2003
5/29/1993	7/3/1994	7/22/1995	7/24/1996	7/11/1997	7/14/1998	6/15/1999	6/17/2000	5/11/2001*	6/15/2002	8/13/2003
6/30/1993	8/4/1994	8/7/1995	8/9/1996	7/27/1997	7/30/1998	7/17/1999	7/3/2000	6/20/2001	7/9/2002	8/29/2003
7/16/1993	9/5/1994	9/8/1995	9/10/1996	8/28/1997	8/31/1998	7/25/1999*	7/19/2000	7/14/2001*	7/25/2002	9/14/2003
8/1/1993	9/21/1993	10/10/1995	9/26/1996	9/29/1997	9/16/1998	8/2/1999	8/12/2000*	7/30/2001*	8/18/2002*	10/16/2003
8/17/1993	10/23/1993	11/11/1995	11/29/1996	10/15/1997	10/18/1998	9/3/1999	9/29/2000*	8/23/2001	9/19/2002*	11/25/2003*
9/2/1993					11/19/1998	10/5/1999	10/7/2000	9/16/2001*	10/21/2002*	
10/20/1993					12/5/1998	11/22/1999	11/16/2000*	10/18/2016*	12/8/2002*	
11/5/1993						12/24/1999	12/26/2000	11/3/2001*		
								12/13/2001		

2004	2005	2006	2007	2008	2009	2010	2011	2014	2015
3/16/2004*	1/30/2005*	1/25/2006	1/12/2007	2/16/2008	1/17/2009	2/13/2010*	2/8/2011	12/14/2013**	1/2/2015**
4/9/2004	4/12/2005	2/10/2006	2/21/2007*	3/19/2008	2/2/2009	4/26/2010	3/4/2011*	12/30/2013**	2/27/2015*
5/11/2004	5/14/2005	4/7/2006*	3/17/2007	4/20/2008	3/30/2009*	5/12/2010	4/29/2011	1/15/2014**	3/7/2015**
6/12/2004	6/15/2005	5/7/2006*	4/10/2007*	5/30/2008*	4/23/2009	6/29/2010	5/7/2011*	2/24/2014*	4/16/2015*
7/14/2004	7/1/2005	5/17/2006	5/20/2007	6/23/2008	5/25/2009	7/15/2010	6/16/2011	4/13/2014*	5/10/2015**
7/30/2004	7/17/2005	6/18/2006	6/21/2007	7/25/2008	6/26/2009	7/31/2010	7/2/2011	4/29/2014*	6/11/2015**
8/31/2004	8/18/2005	7/20/2006	7/7/2007	8/10/2008	7/12/2019	8/16/2010	8/3/2011	5/23/2014**	7/13/2015**
9/16/2004	9/19/2005	8/5/2006	8/8/2007	8/26/2008	7/28/2009	9/17/2010	9/4/2011	6/24/2014**	7/29/2015**
10/2/2004	10/5/2005	8/21/2006	8/24/2007	9/27/2008	8/29/2009	10/3/2010	10/22/2011	7/10/2014**	8/14/2015**
	11/14/2005*	9/22/2006	9/25/2007	10/13/2008	9/30/2009	11/12/2010*	11/15/2011*	8/27/2014**	9/23/2015 *
		10/8/2006	10/19/2007*	11/14/2008	10/24/2009*	12/6/2010	12/1/2011*	9/12/2014**	10/09/2015*
		11/9/2006	11/4/2007*		11/17/2009		1/18/2012*	10/14/2014**	11/18/2015**
		12/19/2006*			12/3/2009		2/3/2012*	11/7/2014*	2/6/2016**

Note: * indicates LandSAT 7, ** indicates LandSAT 8, and no asterisk indicates LandSAT 5 images

Table 3. Months with data estimated by the factor process

1994	1995	1996	1997	1998	2003	2004
November **December**	**January** **February** **March** **December**	**January** **February** **March** **December**	**January** **February** **November** **December**	**January** **February**	**December**	**January** **February**

Weather Data

ITRC-METRIC utilizes daily spatially varied grass reference ETo for interpolation between image dates. SpatialCIMIS 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. However, the collected data could have errors. Therefore, ITRC quality controls the hourly weather data at each weather station in the Central Valley (Redding to south of Bakersfield) and corrects the daily Spatial CIMIS data.

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 Shafter and Famoso CIMIS stations were utilized as the "primary" weather stations. These stations were selected because of their centralized locations within the primary area of interest. Shafter was used from 1992-1997 and Famoso was used from 1998-2015. The same quality control procedure was used at all weather stations, as will be described.

Hourly weather data for the project time frame was collected from CIMIS weather stations located throughout the project area. Forty-nine weather stations were used for the METRIC modeling process. Figure 3 shows the majority of weather stations used in this project. Not all stations were available during the entire analysis period. Each station is listed in Table 4 showing the approximate range of time that the station was utilized. A station may have become active or inactive within this timeframe.

The weather component data collected from the weather stations included:

1. Solar radiation (W/m^2)
2. Vapor pressure (kPa)
3. Air temperature (ºC)
4. Wind speed (m/s)
5. Precipitation (mm)
6. Relative humidity (%)
7. Dew point temperature (ºC)
8. PM ETo (mm)

Figure 3. Locations of the CIMIS weather stations used in this evaluation

Table 4. Weather stations used for the METRIC modeling process

1993-2004 CIMIS Station	2005-2015 CIMIS Station
Arvin-Edison	Alpaugh
Auburn	Arvin-Edison
Belridge	Auburn
Blackwells Corner	Belridge
Brentwood	Blackwells Corner
Browns Valley	Brentwood
Bryte	Browns Valley
Colusa	Bryte
Davis	Colusa
Dixon	Davis
Durham	Delano
Esparto	Denair II
Fair Oaks	Dixon
Famoso	Durham
Firebaugh-Telles	Esparto
FivePoints	Fair Oaks
FresnoState	Famoso*
Gerber	Firebaugh
Gerber South	Five Points
Hastings Tract East	Five Points SW
Kesterson	Fresno State
Kettleman	Gerber
Lindcove	Gerber South
Los Banos	Hastings Tract East
Madera	Kesterson
Manteca	Kettleman
Merced	Lindcove
Modesto	Lodi West
Orange Cove	Los Banos
Panoche	Madera
Parlier	Madera II
Shafter*	Manteca
Shasta College	Merced
Stratford	Modesto
Twitchell Island	Oakdale
Verona	Orange Cove
Westlands	Panoche
Winters	Parlier
Woodland	Patterson
	Porterville
	Shafter
	Shasta College
	Stratford
	Tracy
	Twitchell Island
	Verona
	Westlands
	Winters
	Woodland

* “Primary” stations

All collected **hourly** weather data from the stations 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. 56[1] along with correction procedures. The main variable needing correction to accurately compute the hourly ETo is solar radiation. However, relative humidity was also examined using the procedures described in Allen et al. (1998). Figure 4 contains a graph of the corrected solar radiation for the Famoso CIMIS station for 2010-2014. This weather parameter is often in error if a pyranometer becomes covered with dust or debris, or if it loses calibration. This can be identified by comparing the daily incoming solar radiation with the maximum potential solar radiation (computed based on elevation, latitude, and time of year). If the measured value does not approach or become equal to the maximum potential over a time frame of several weeks, this could indicate an error in the measurement. Day-to-day variability is expected, but during a clear day, the measured should approach the potential. High values of solar radiation can be caused by incorrect sensor calibration.

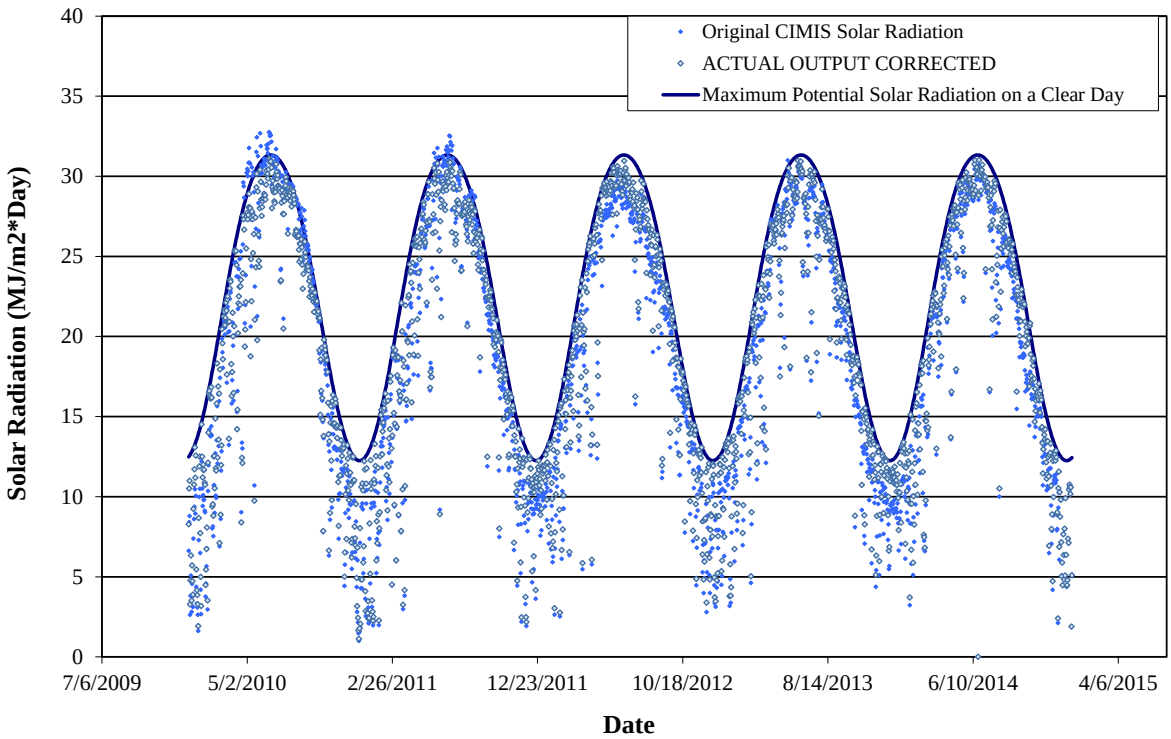


Figure 4. Example of solar adjustments made on Famoso CIMIS Station for 2010-2014. The same analysis was conducted for all weather stations in the Central Valley.

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.

[1] 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

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.

Corrected 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.

The basic correction procedure first included adding the locations of all 49 stations into GIS. The uncorrected Spatial ETo at the weather station location was extracted for each day over the time frame investigated. The difference between the corrected daily ETo for each station and the uncorrected Spatial ETo was computed. These differences were used to generate a difference raster using Inverse Distance Weighting (IDW) interpolation. The difference raster was combined with the uncorrected Spatial ETo to generate the corrected Spatial ETo image.

Figure 5 shows a comparison of the uncorrected Spatial CIMIS ETo and the corrected Spatial ETo for July 15, 2015. The corrected Spatial ETo represents the combination of our corrected ETo data blended with the original Spatial CIMIS ETo.

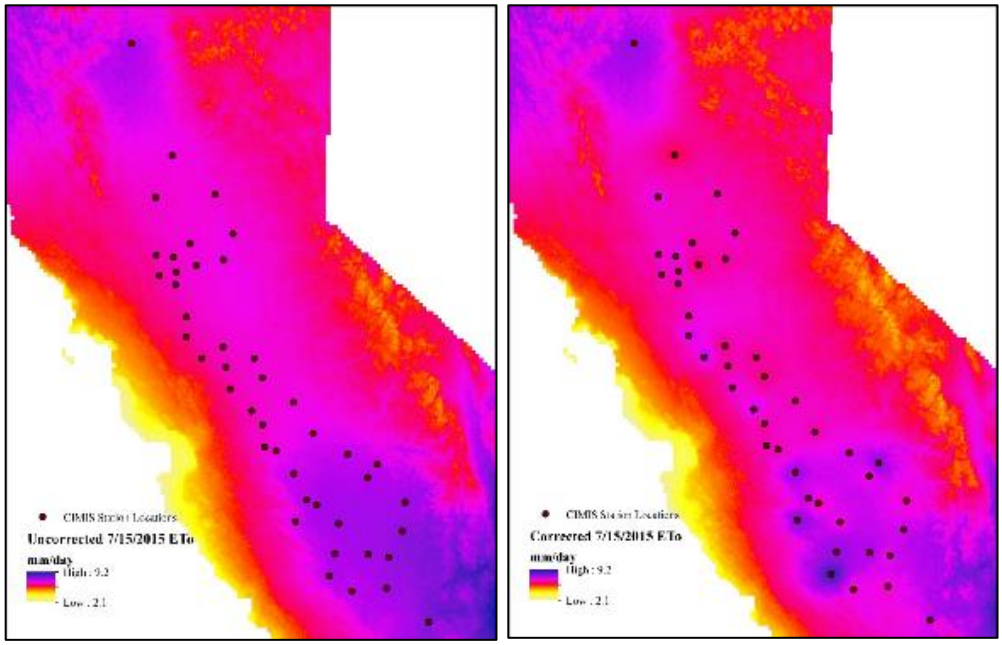


Figure 5. Example of uncorrected Spatial CIMIS ETo compared to corrected Spatial ETo for July 15, 2015

Calibration near Primary Weather Station

The METRIC process requires calibration of the hot and cold pixel for each image processed. The calibration should be conducted near a primary weather station within the image. Therefore, a primary weather station was selected for each image path. The stations selected (Shafter (1993-1997) and Famoso (1998-2015)) were chosen on the basis of the stations' history of reliable, relatively error-free data. Other reasons for choosing primary stations included:

- The location within intensive agricultural areas.
- Relatively representative of weather throughout the agricultural regions in the path.

Shafter was used as a primary station for the years 1993 through 1997. Famoso was used as a primary station for the remainder of the study period.

For the semi-automated calibration process, an area of interest (AOI) is created around the primary weather station. This AOI is generally within a 5 to 10 mile radius of the primary station and urban areas, or large non-agricultural areas are avoided. Figure 6 shows the calibration AOI for the Famoso CIMIS station.

Figure 6. Famoso CIMIS station calibration area of interest (AOI)

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.

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 2007 to Present

For years 2007 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 7 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.

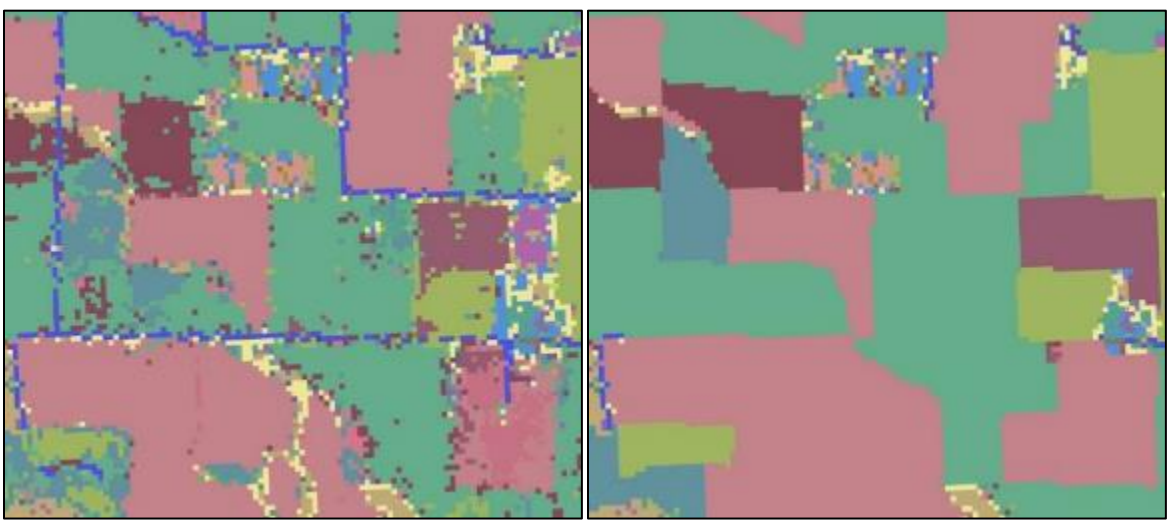


Figure 7. Example original NASS land use (left) compared to corrected land use based on the majority crop type within each agricultural field (right). Each color identifies a different land use type (i.e., almonds, alfalfa, developed, etc.)

Land Use Data 1997 to 2006

The earliest NASS land use raster available for California is from 2007. The County of Kern Agriculture and Measurement Standards provides land use shapefiles only for agricultural fields in the county from 1997 to present. The shapefiles did not provide land use data outside of the agricultural fields. Therefore, information from the last available NASS land use raster (2007) was used to fill in the missing background. The following process was used to combine the two sources to create land use maps for 1997 through 2006:

1. The crop data for each individual field from the Kern County data was converted to a specific value to match the crop identification value used by NASS. For example, a field containing alfalfa in the Kern County data was converted to the NASS crop value of 16.
2. The Kern County shapefile, with the added NASS crop value, was then converted to a raster image to represent the crop value.
3. The DWR survey shapefile was used to quality control the 2007 NASS land use raster so that the raster values within the field boundaries were all uniform.
4. The new Kern County raster was then mosaicked with the corrected 2007 NASS raster. The land use values from the Kern County raster had top priority over the 2007 NASS values and therefore were utilized in the final land use raster. Then 2007 NASS values were used in the non-agricultural areas as well as the background portion of the image.

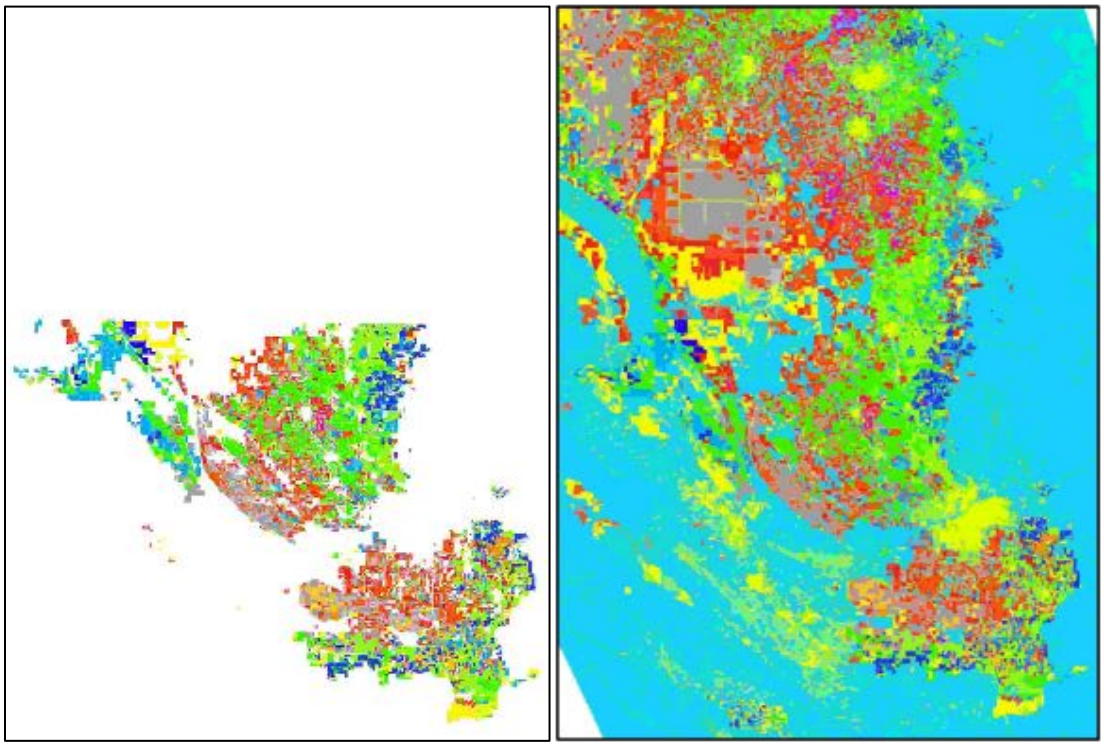


Figure 8. County of Kern agricultural land use fields (left). Combined County of Kern and NASS land use image (right)

Land Use Data 1993-1996

No land use data was available prior to 1997. Therefore, the final quality controlled 1997 land map was used for 1993 through 1996.

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's 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 Kc and actual ETc results for Kern County for the period 1993-2016 have been provided to the Kern Groundwater Authority 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. But 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 vegetation. Spatial variation in ETc throughout a field and between fields is accounted for. 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 utilize 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 be on the upper end currently. 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 range provided. Additionally, the launch of LandSAT 9 (planned for December 2020) will improve the temporal resolution, providing images every 16 days, offset by 8 days from LandSAT 8 (potential for images on an 8 day interval). 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 Kern County Valley floor and the field boundaries (majority) within the Valley floor of Kern County. Figure 9 shows the 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 23-year period, the field boundaries and overall boundary were the same.

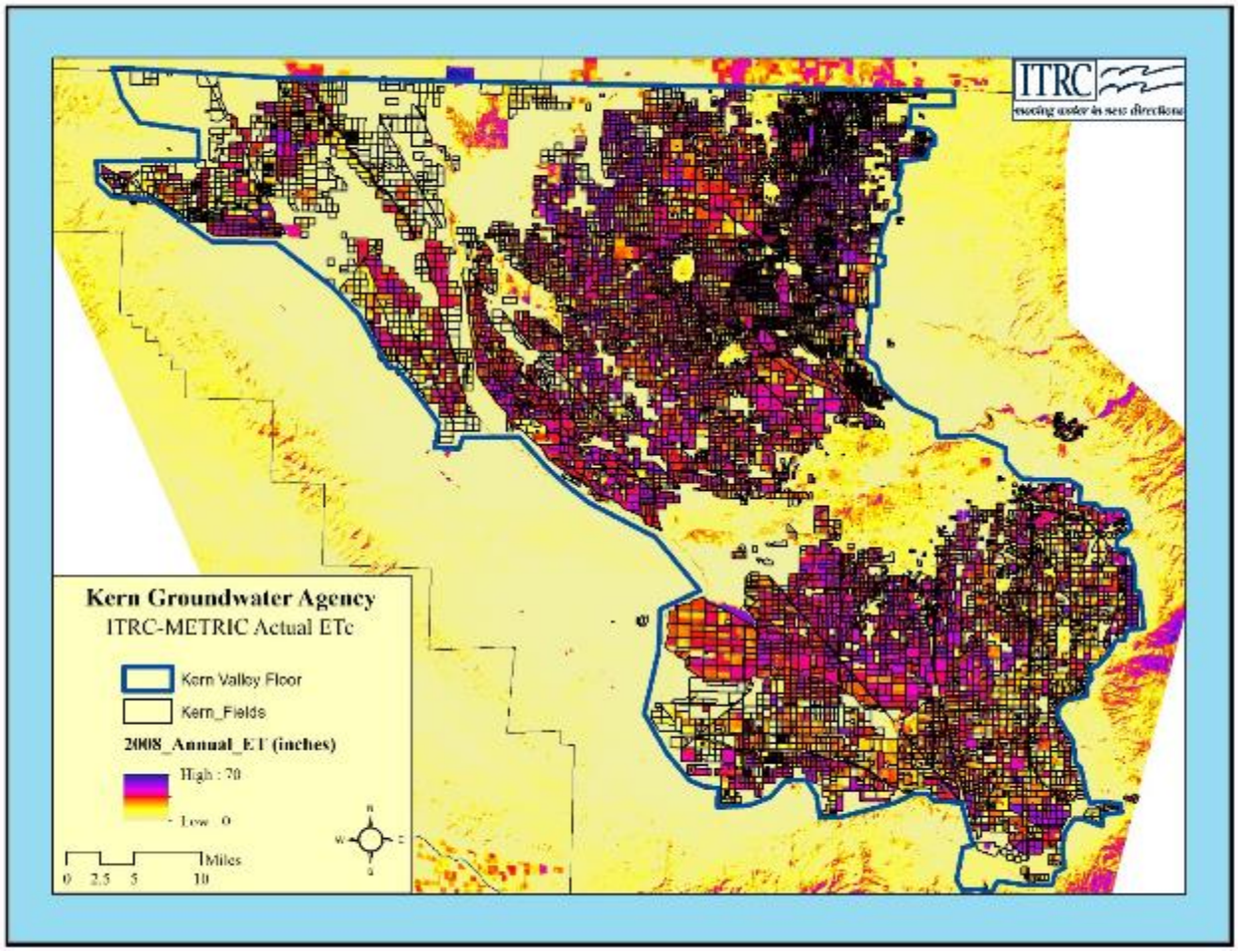


Figure 9. 2008 ETc image with Valley floor and field boundaries used for the summary analysis

The volume of actual ETc for the overall area and only within fields is shown in Figure 10. For reference, the grass reference evapotranspiration (ETo) and precipitation from the Shafter CIMIS station (1992-1997) and Famoso CIMIS (1998-2015) are also shown. ETo provides an idea of the weather conditions that drive evapotranspiration. Hotter, drier years have a higher ETo.

Figure 11 shows the volume of ETc for all water districts in Kern County and Kern Groundwater Authority members. The acreage of all districts is greater than the "Valley Floor Area" because of district boundaries covering areas outside of the valley floor (e.g., West Kern W.D.). Some districts with

substantial overlap of other districts were removed from the evaluation to limit double counting. However, some minor overlap may cause the estimates to be slightly higher than the actual volume of ETc.

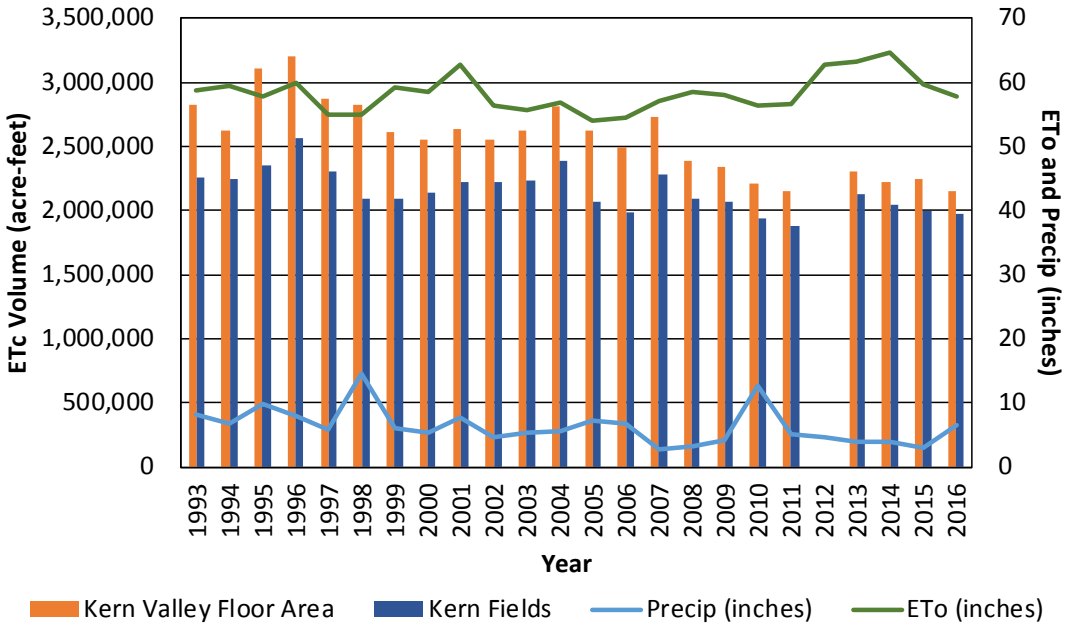


Figure 10. Annual volume of ETc for the Kern County Valley floor and within fields in Kern County. Grass reference ETo and precipitation depths are shown for each year as a reference.

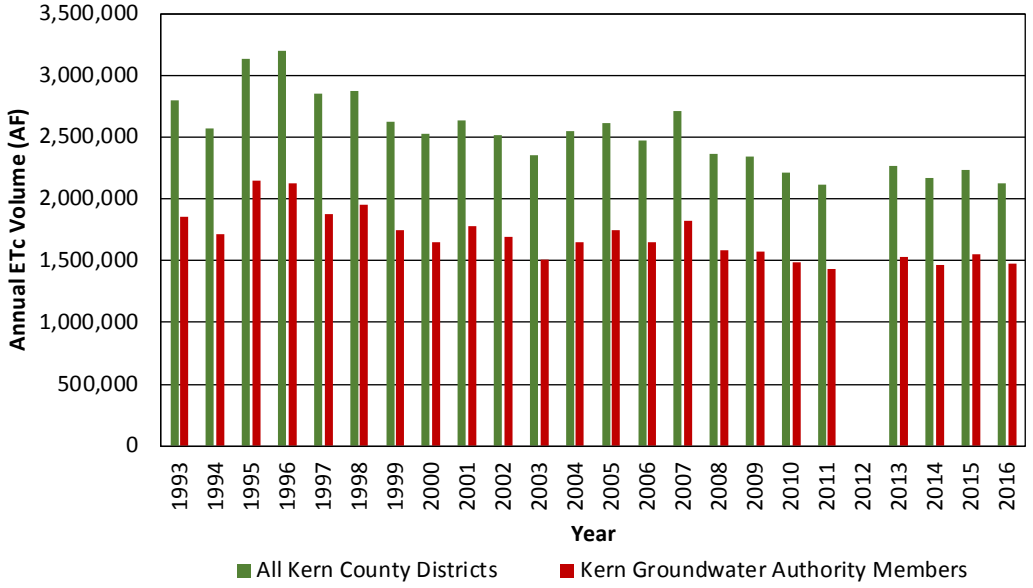


Figure 11. Annual volume of ETc for irrigation/water districts in Kern County and just Kern Groundwater Authority member districts

Evaluation of ETc Variation

In general, there is an overall decline in ETc volume from the Valley floor starting over the 23 years that the ET analysis covers. The field ETc decline is not as significant but does trend downward. The difference between the Valley floor 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 12 for the study period (bar graphs) for the entire Kern valley floor area (includes urban, streets, undeveloped areas, etc.) and within fields only (only agricultural fields in the same area).

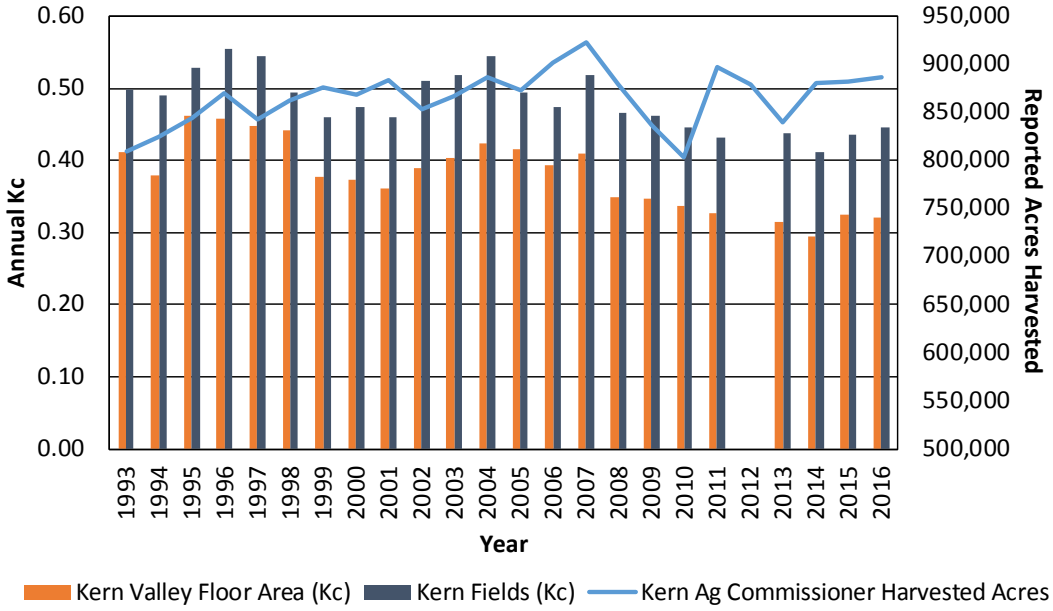


Figure 12. Annual crop coefficient (Kc) for the Kern County Valley floor and within fields in Kern County. Reported Ag Commissioner total harvested acres per year on the right axis of the graph.

As expected, the Kc is higher when only looking within field boundaries compared to the entire Valley floor of Kern County. 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. As with the volume, there seems to be a general decline in overall Kc over the 23 years.

In the mid-2000s the Kc increases. Figure 12 also includes the Kern County Ag Commissioners total harvested acres over the 23 year period for reference and to possibly explain some of the variation. Interestingly, the Ag Commissioners' total harvested acreage increases from 1993 to 2016. While there are some general trends indicating that the annual Kc increases as the acreage increases, the trends do not follow as closely as one might expect. This could be due to the types of crops harvested over the period or the age of permanent crops being grown. <u>It is important to restate that crop types are not used to determine ETc using ITRC-METRIC. They are only shown here as a reference to potentially explain the variation in ETc.</u>

To delve further into the theory that crop type shifts may explain ETc variation, crop acreages of the major crops in Kern County (Kern County Agricultural Commissioner Reports) are shown in Figure 13. The higher ETc and Kc values in the mid-2000s are likely due to the increase in alfalfa acreage during this period in combination with the higher almond acreage. However, the higher ETc and Kc values in the mid-1990s are more challenging to explain. Obviously there is more cotton acreage and likely more double cropping of different row crops (although cotton is not commonly double cropped). Other crops in the cotton rotations likely include double cropping, such as corn and grain hay, which are not shown.

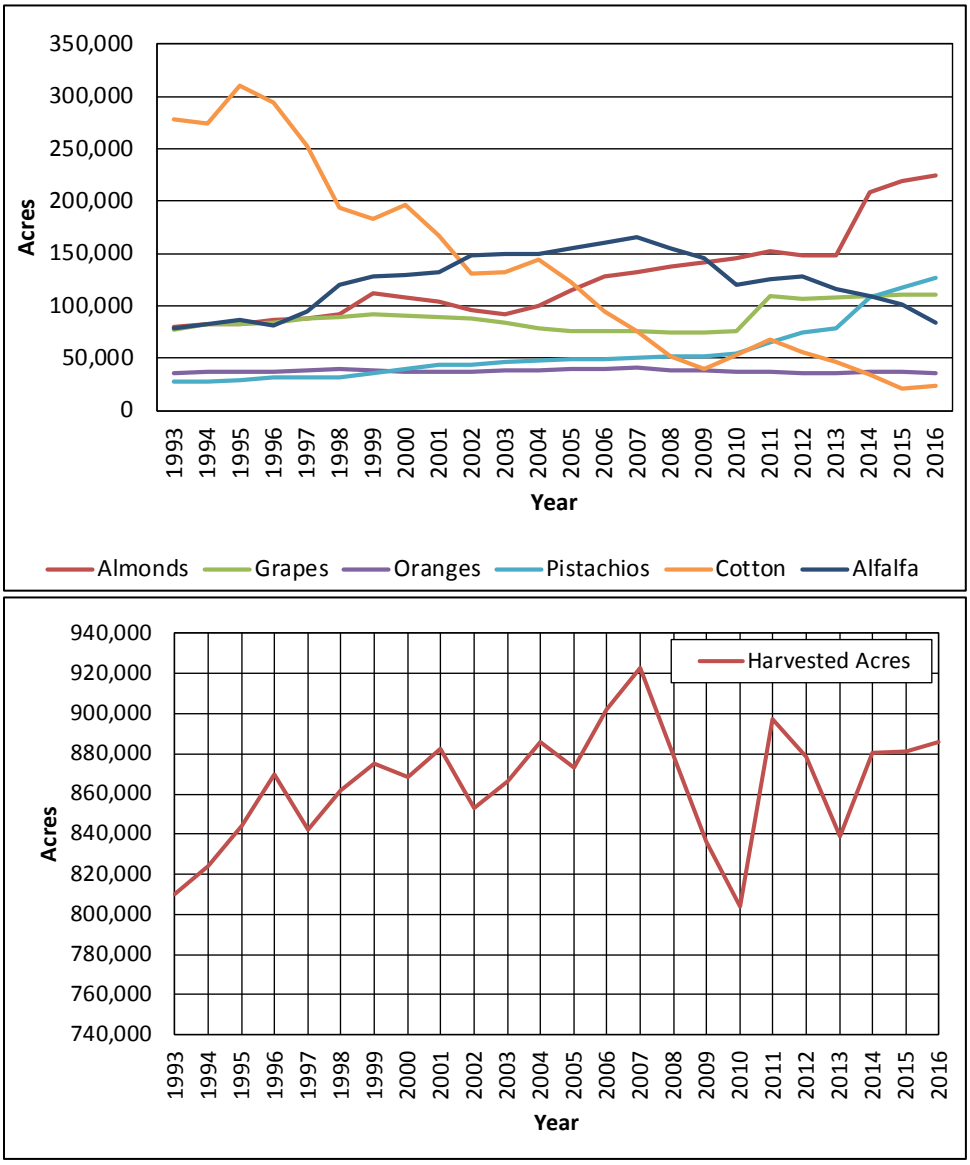


Figure 13. Crop acreage for major crops in Kern County from 1993-2016 (top) and total harvested acres (bottom) from Ag Commissioner Reports

As previously discussed, the Kern County Ag Commissioner reports showed an overall increase in harvested acreage from 1993 to 2015. The Ag Commissioner reports showed the 1993 total harvested acres at approximately 809,700 compared to the 2015 harvested acreage of 881,000. Year-to-year variations are shown in Figure 12.

There are also some unexplainable anomalies in the Ag Commissioner data, such as the increase in almond acreage from 2013 to 2014. Figure 13 shows that total acres (bearing and non-bearing) for almonds increased by over 50,000 acres from 2013-2014. The bearing acreage showed the most significant increase from 2013 to 2014 even though only 1,600 acres of non-bearing trees were reported for 2013. The bottom line is that over 50,000 acres of bearing almonds showed up in 2014 without explanation. This could be due to an error in the Ag Commissioner's reporting or a shifting methodology of accounting for certain crops.

The annual Kc by field in Kern County from ITRC-METRIC was plotted from lowest to highest Kc for four selected years (Figure 14). The fields with the lowest Kc would be fallow or young orchards/vineyards. Notice that there are more fields with Kc values below 0.2 in 2008 and 2015 than in 1993 or 1996. Of these, 1996 has the fewest low Kc fields while 2015 has the most. Different fields have different Kc values each of these years. The key point is that the lower Kc values in 2014 and 2015 (Figure 12) are likely driven down by increased fallowing or young orchards. Additionally, Figure 14 indicates that the overall field acreage was probably lower in 2015 than in 1993. While field acreage is not the same as harvested acreage because it does not account for double-cropping, it is unlikely that double cropping accounts for the full difference in reported acreage.

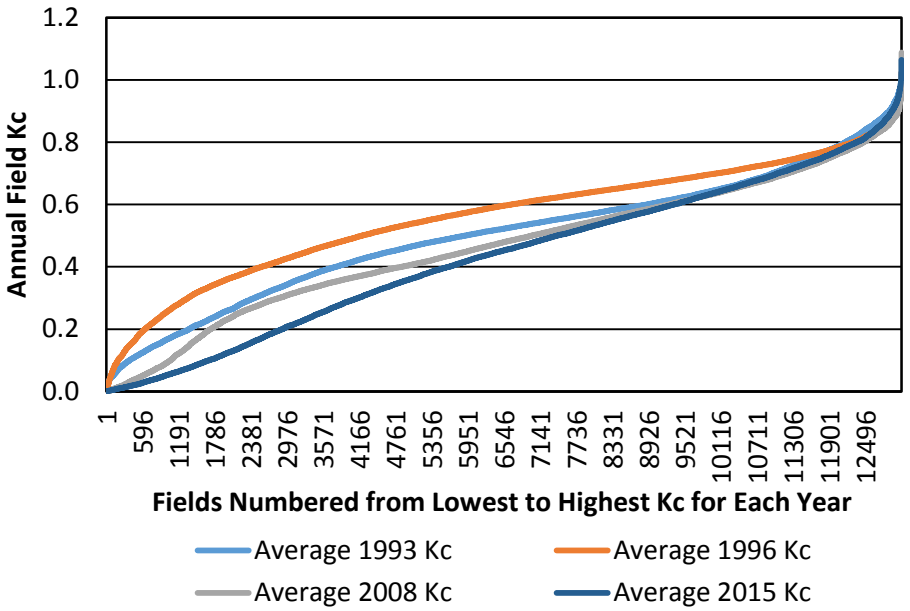


Figure 14. Annual Kc by field sorted from lowest to highest for four different years

Visually, significantly more non-cropped fields can be seen in 2015 than in 1993 (Figure 15). Portions of Kern County (red circles which include portions of Lost Hills Water District, Buena Vista WSD, and Henry Miller WD) show much lower ET in 2015 than 1993. These areas were fallowed or not cropped during the drought. In other areas, new permanent crop plantings may be the cause of lower ET. Additionally, the Kern Lake and areas south of Bakersfield have much lower ET values indicating new permanent crops or fallowing.

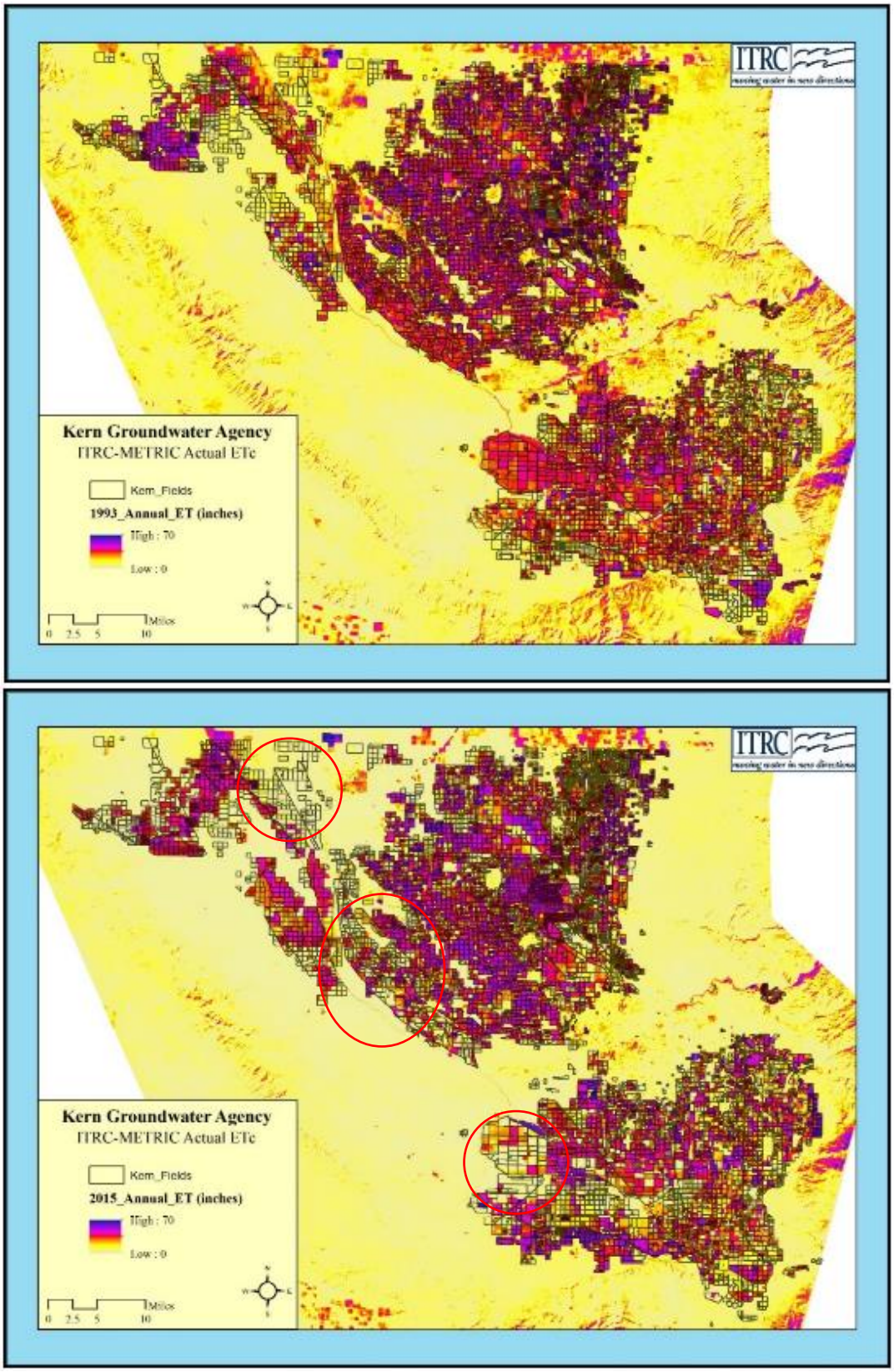


Figure 15. Annual ITRC METRIC ET in 1993 (top) and 2015 (bottom) with field boundaries

Conclusion

Over the 1993-2016 period, the volume of evapotranspiration from fields within the valley floor of Kern County ranged from approximately 2-2.5 million acre-feet. Evapotranspiration varies year to year in the valley floor portion of Kern County. This is caused by several factors including weather, crop mix, water availability, precipitation, and land fallowing. It was beyond the scope of this study to investigate exactly why evapotranspiration varied. However, the previous figures indicate that there seems to be increased fallowing or young orchards and vineyards planted in more recent years, resulting in lower evapotranspiration in this period. This acreage reduction does not coincide with Kern County Ag Commissioner's reported harvest acreage changes over the period.

The monthly and annual evapotranspiration and Kc imagery in GIS format has been transmitted to Kern Groundwater Authority.

Future Work

Net To/From Groundwater (NTFGW)

ITRC has developed a process to examine net groundwater use without the need to monitor groundwater pumping. This process is called the Net To and From Groundwater (NTFGW) and can be conducted at various scales from the farm/field, GSA, and Basin. This method incorporates surface water diversions, turnout deliveries (for farm/field scale), surface outflows, and precipitation with the monthly ETc to determine net groundwater use. Basically, if precipitation and surface water deliveries exceed ETc, the excess water would be stored in the root zone or moves to the groundwater (net to groundwater). If ETc exceed surface supplies, there is a net extraction from the groundwater to make up the difference. Results are provided spatially at the 30 meter pixel resolution. NTFGW is being used for two purposes:

1. Using historical data, to assist in calibration/verification of groundwater models. Equally important, the results provide a directly computed future ETc with net zero extraction.
2. For future management and regulation of groundwater use within the GSA. Monthly results will be provided to each GSA participant in near real-time (approximately 15 days after surface delivery information is provided to ITRC). Some GSAs are planning on providing this to farmers via a web mapping portal.

The benefits of NTFGW include:

- No groundwater metering program with meters at each well is needed. DWR has approved the method as a best-available science alternative.
- No estimates on irrigation efficiency are needed. Irrigation efficiency estimates have a high level of uncertainty, vary from field to field, and will change over time. NTFGW simplifies the evaluation of sustainable yield because inherently sustainable yield is a net value of how much groundwater can be consumed in a GSA. There is no need to estimate leaching requirements or other non-consumptive uses of groundwater. Comparing net values eliminates many uncertainties.
- It offers the ability to track net canal seepage and net recharge basin recharge by basin.
- It offers the ability to continuously track banked or over-drafted groundwater on a farm, district, and GSA level.
- It is cost-effective: the anticipated cost will be $30,000-$50,000 per year per district/GSA. Actual cost will depend on the district/GSA size and the level of evaluation.

ITRC-METRIC ETc

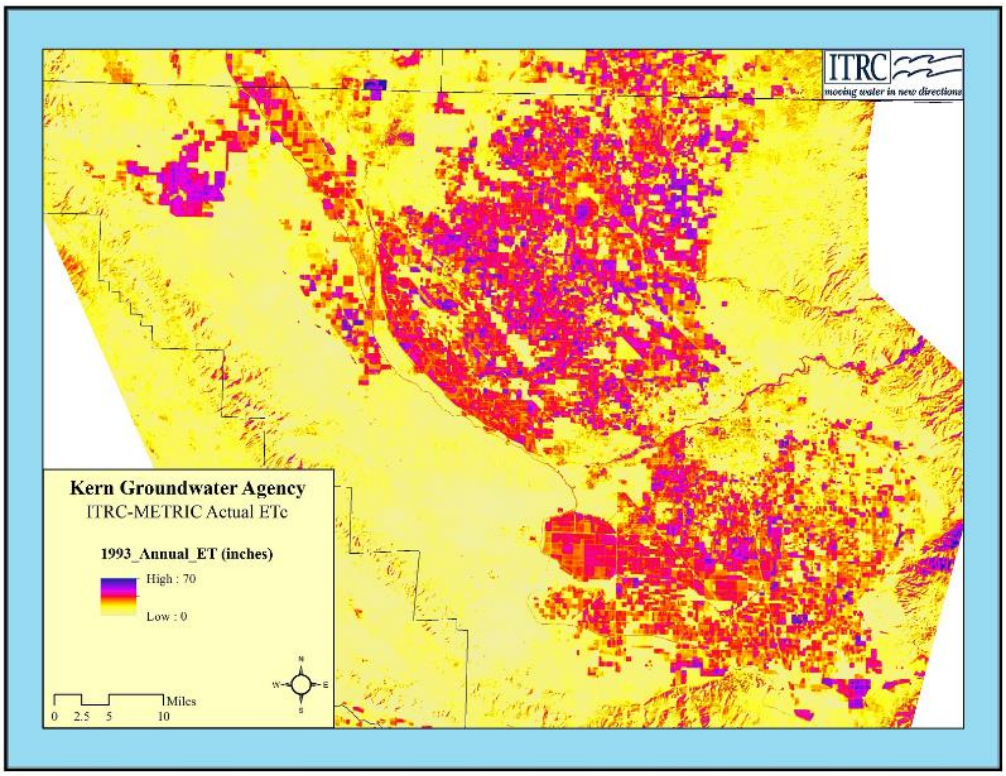
There are several options moving forward. ITRC-METRIC ETc will be an important tool. Over the past several years there have been lessons learned which will impact the process in the future:

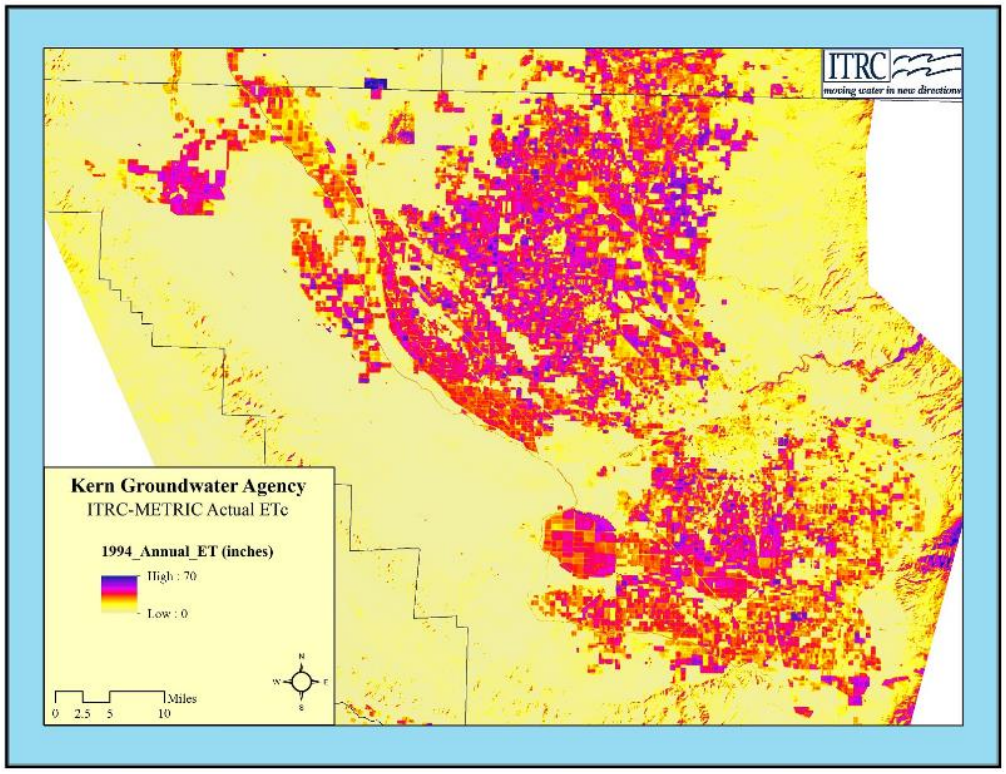
1. Thermal sharpening has not been extensively used because it is time-consuming. However, ITRC is working on expediting this process. Currently, the thermal sharpening process increases the overall processing cost by a factor of 50%. It is expected that this cost will be reduced in the future. On a larger scale it is not important because the overall ETc is not increased or decreased. On a field level, it may be more important.
2. In the past we used at least 1 image per month to compute ETc. ITRC now uses all available good-quality images (mostly cloud/fog free, some cloud coverage is okay). Again, on a large scale (over a district for example) it is not as critical, but for individual fields, especially for row and field crops, it is critical to have images at least on a 16-day interval to capture harvests appropriately.

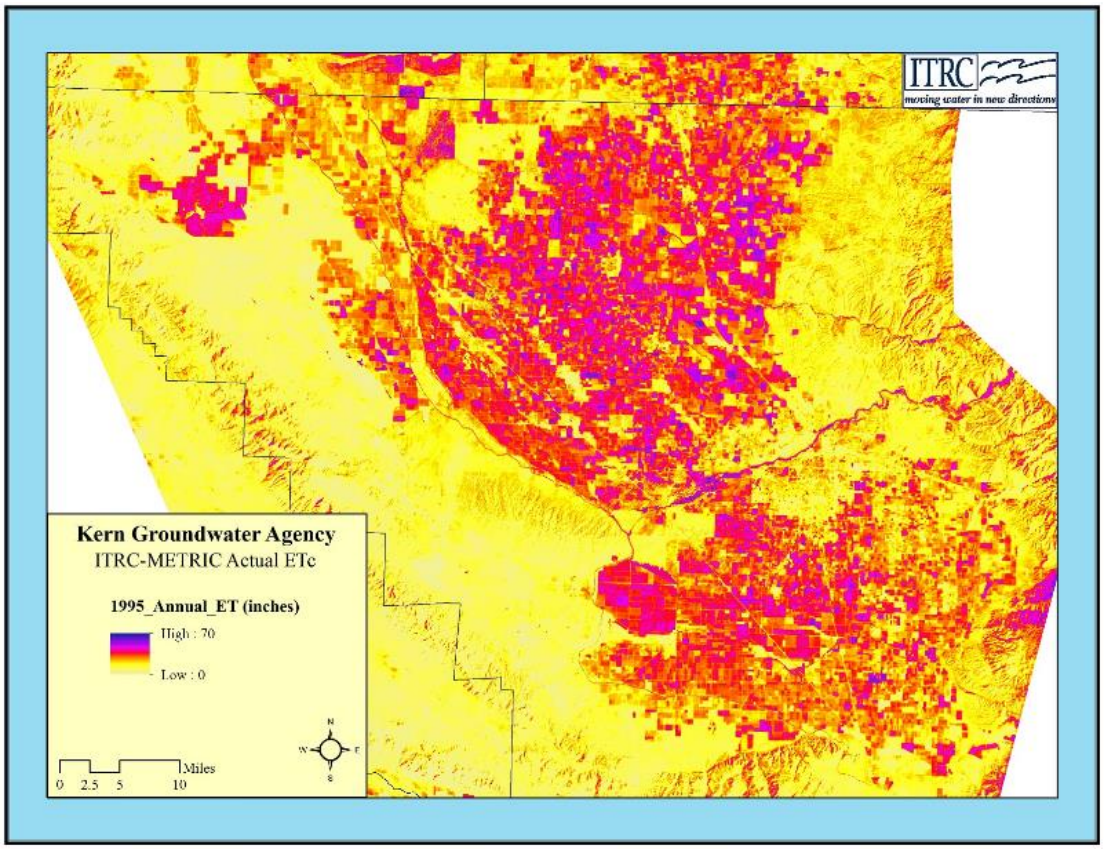
Future implementation of continuous ETc will be important for groundwater management in the Kern subbasin. The historical data generated as part of this project is being implemented in the groundwater modeling efforts in the subbasin. The next steps are towards monitoring sustainable use of the groundwater into the future. ITRC believes that NTFGW is the best methodology to monitor groundwater use since net groundwater use is more important than gross groundwater pumping. Pilot projects using NTFGW compared to groundwater pumping have been successfully implemented in a subbasin just north of Kern. ITRC would be pleased to share these results with interested parties.

Attachment A

Annual ITRC-METRIC ETc



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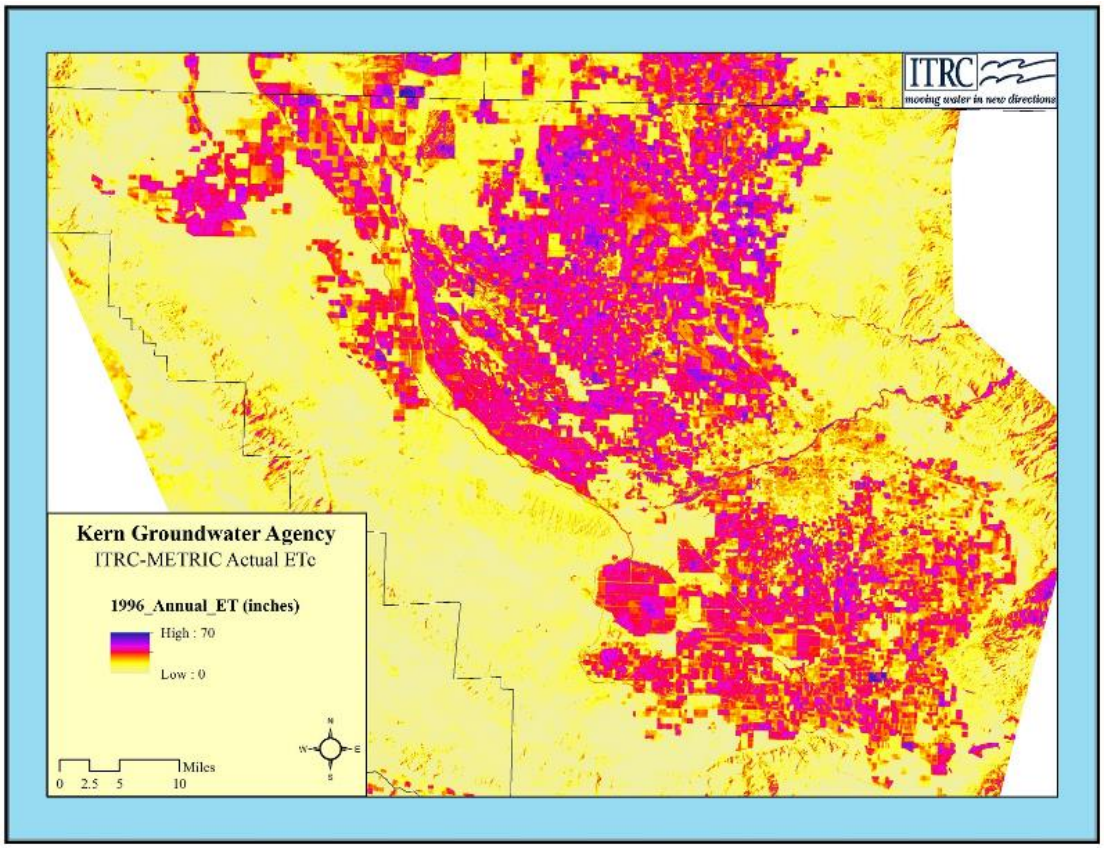
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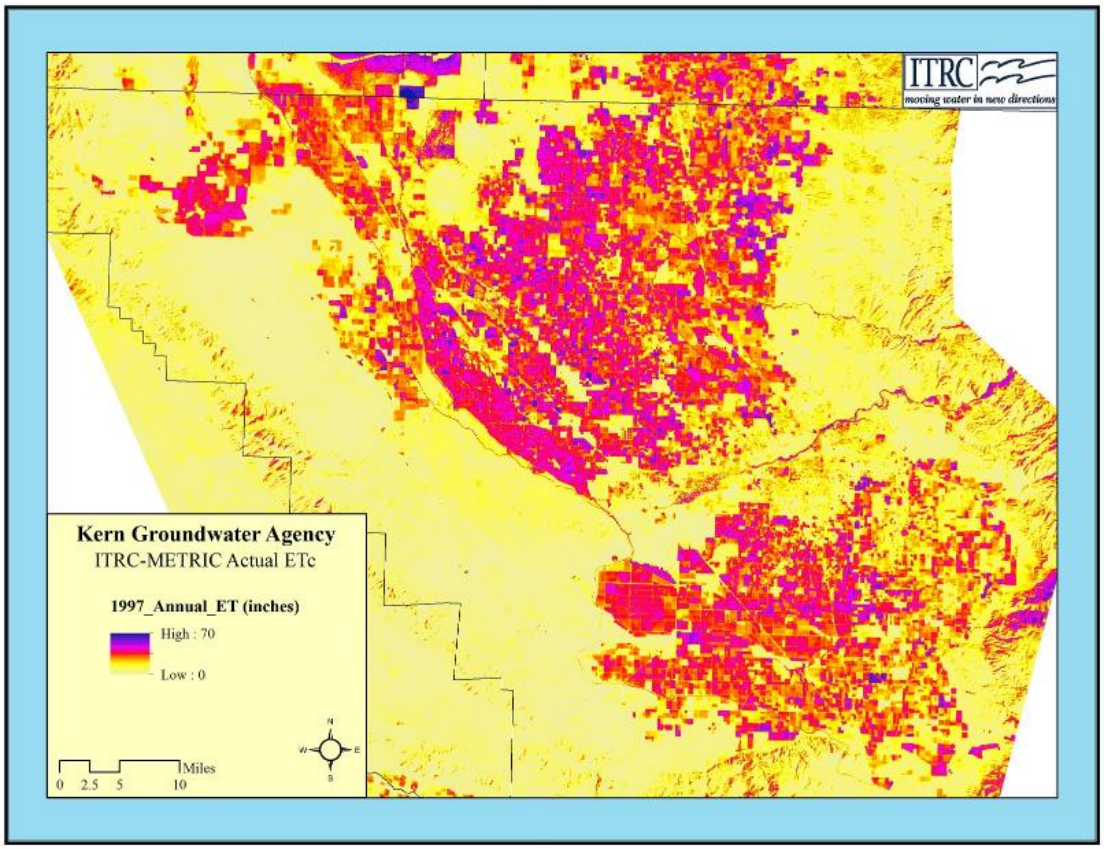
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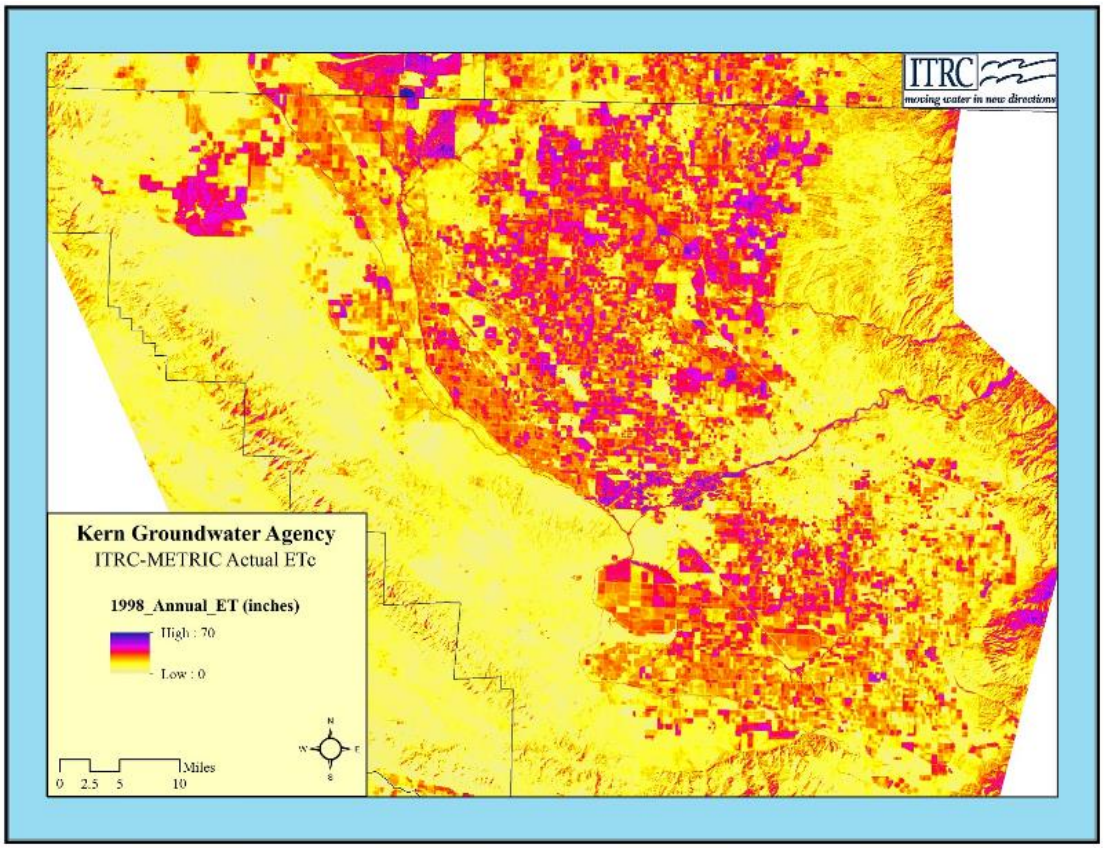
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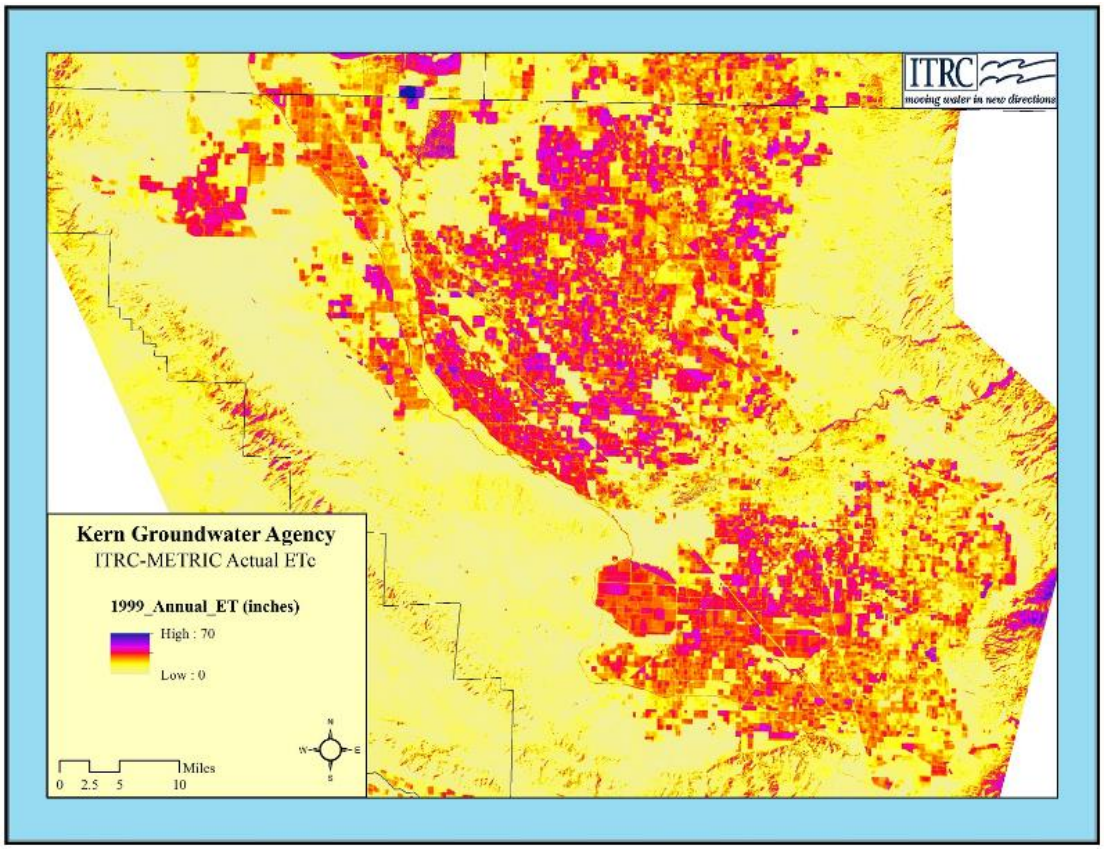
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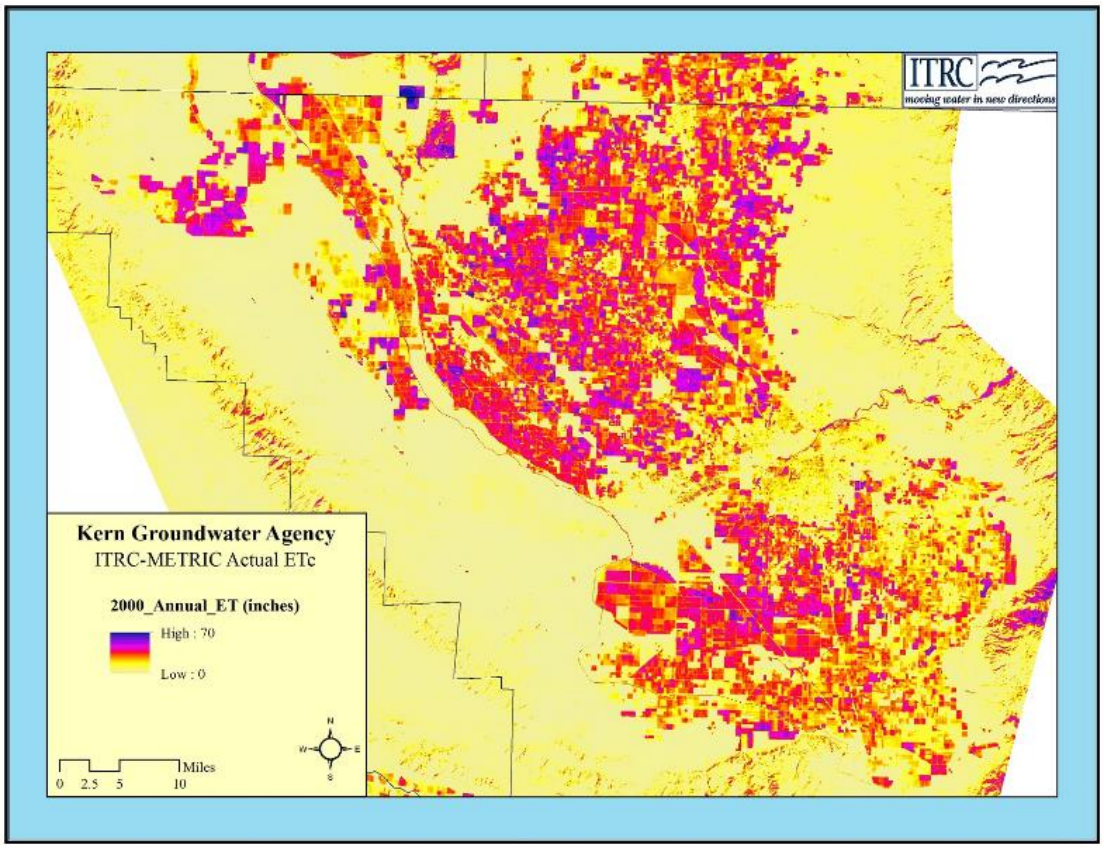
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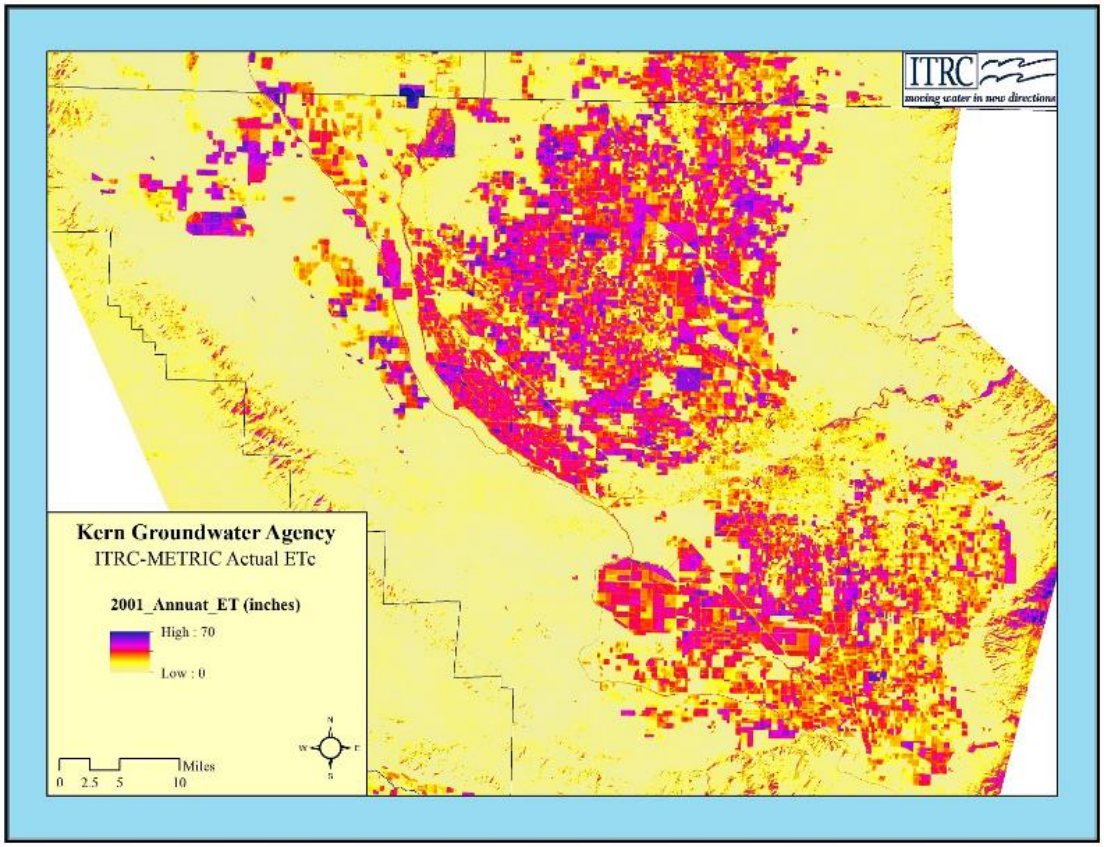
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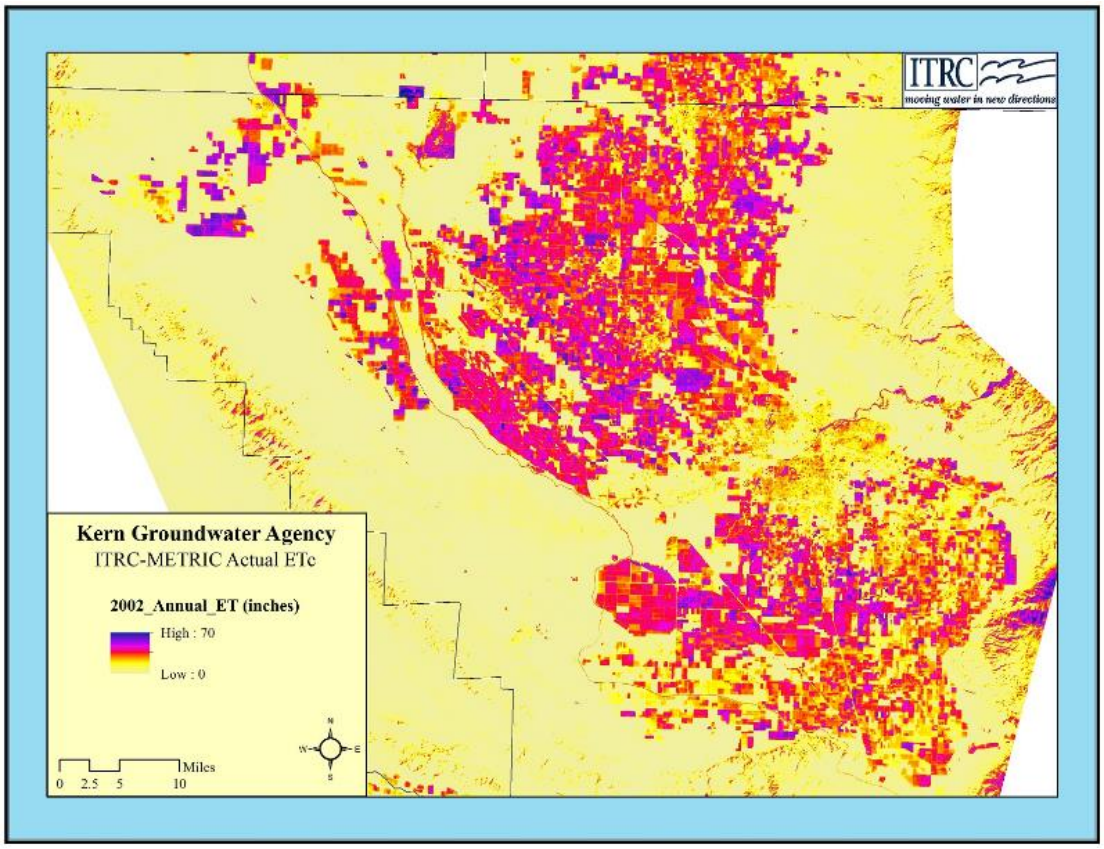
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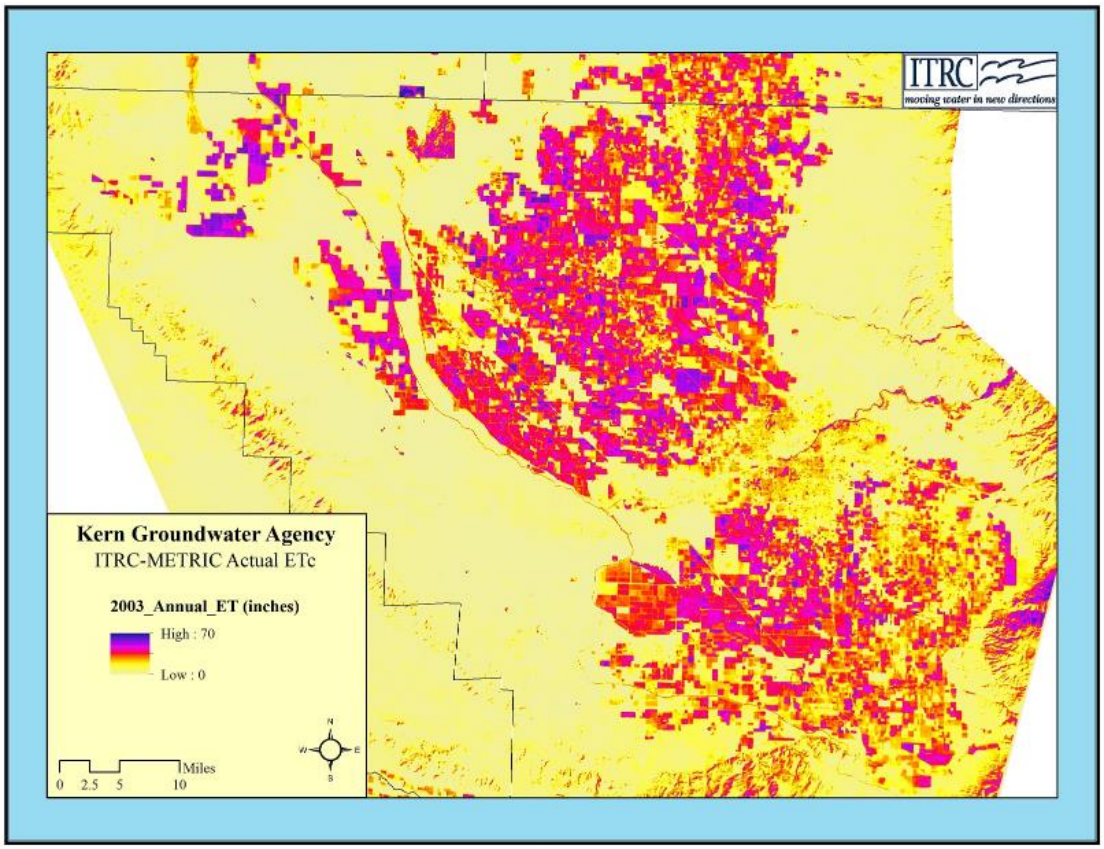
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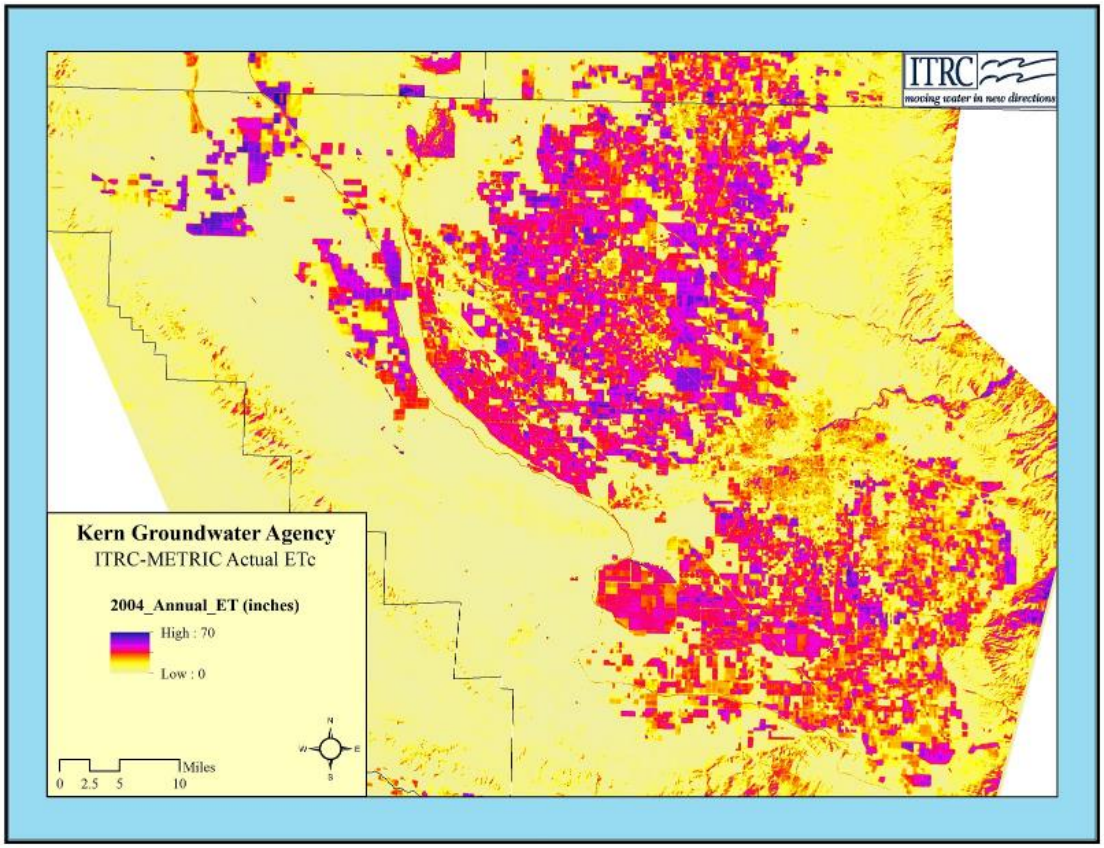
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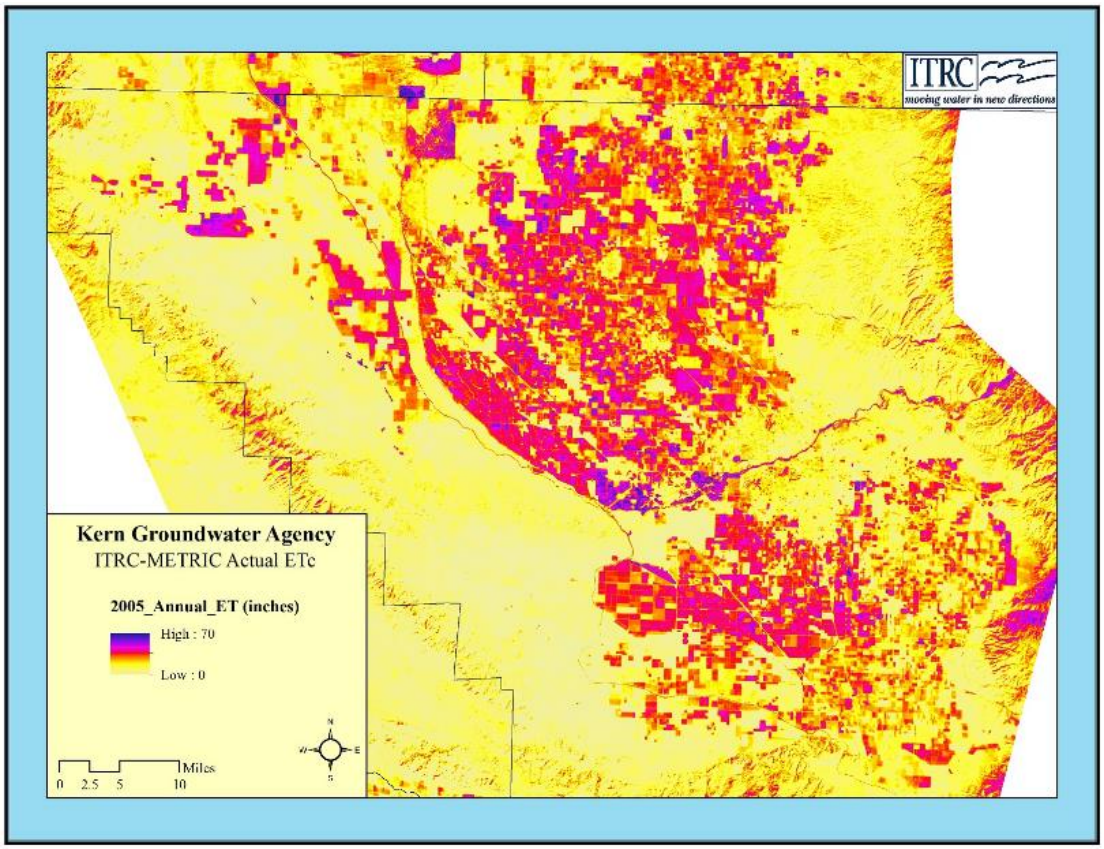
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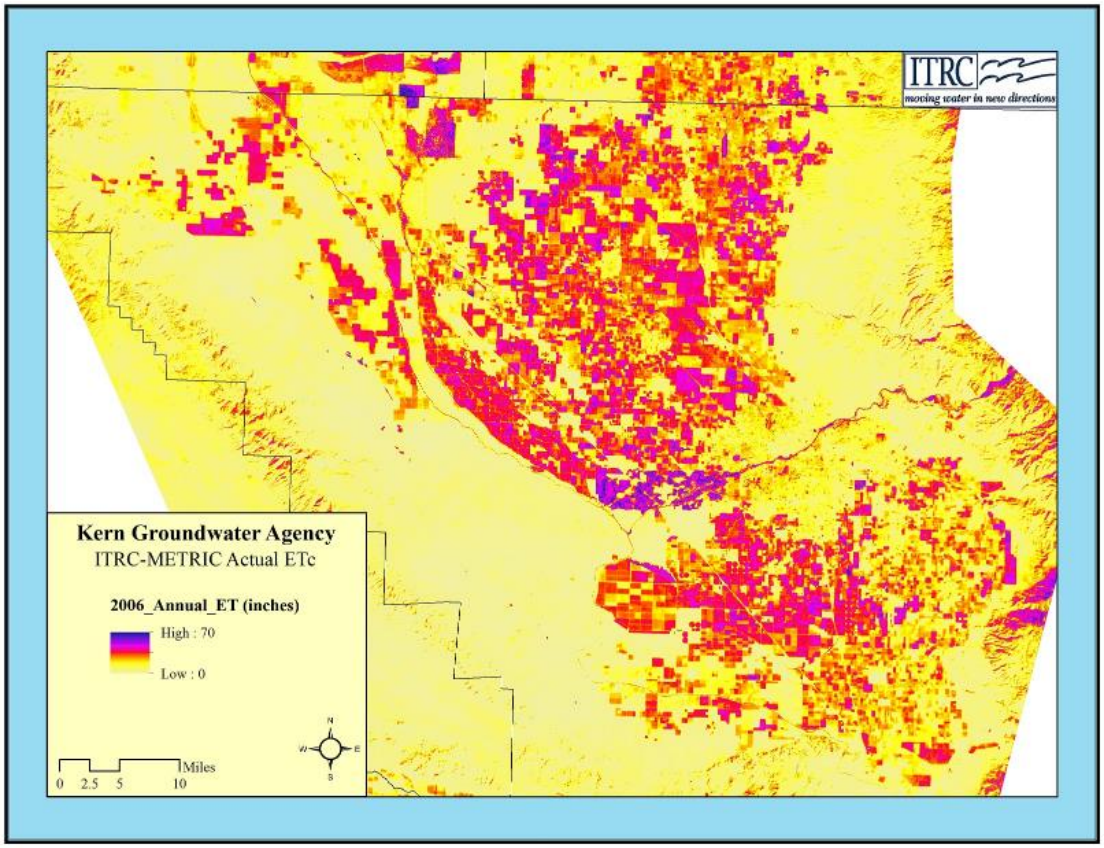
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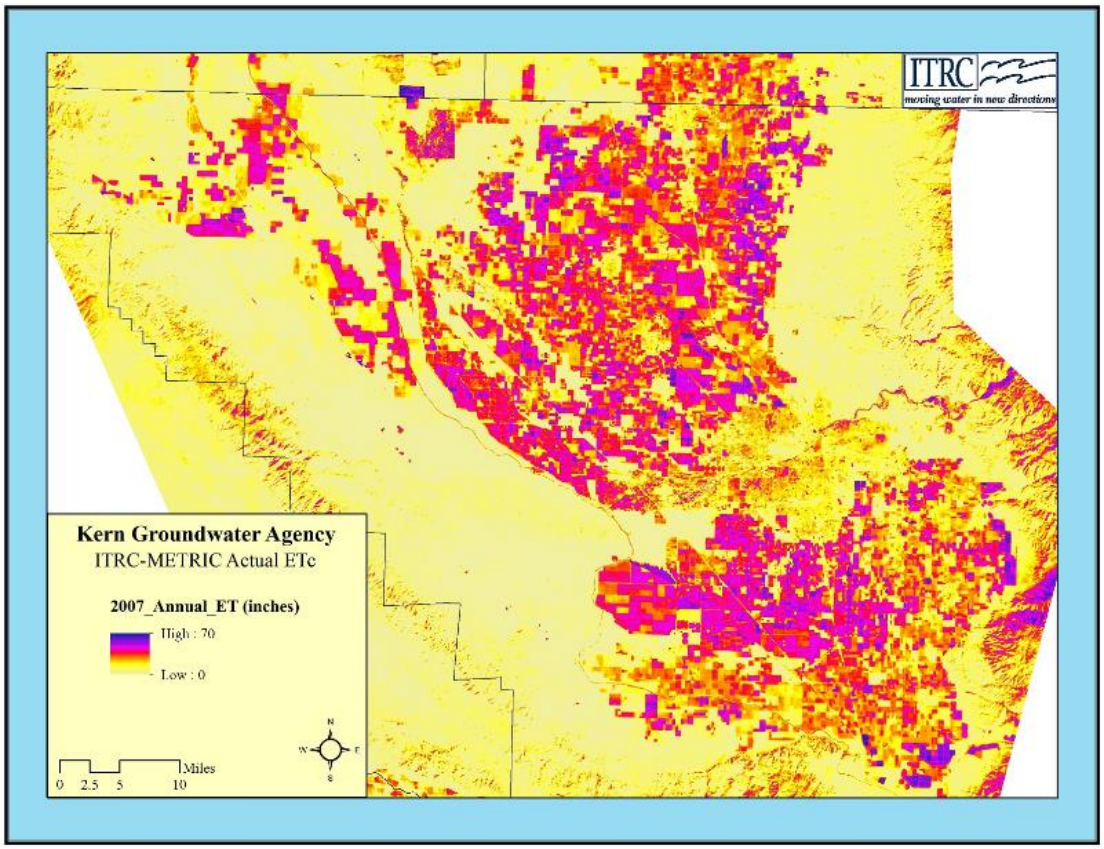
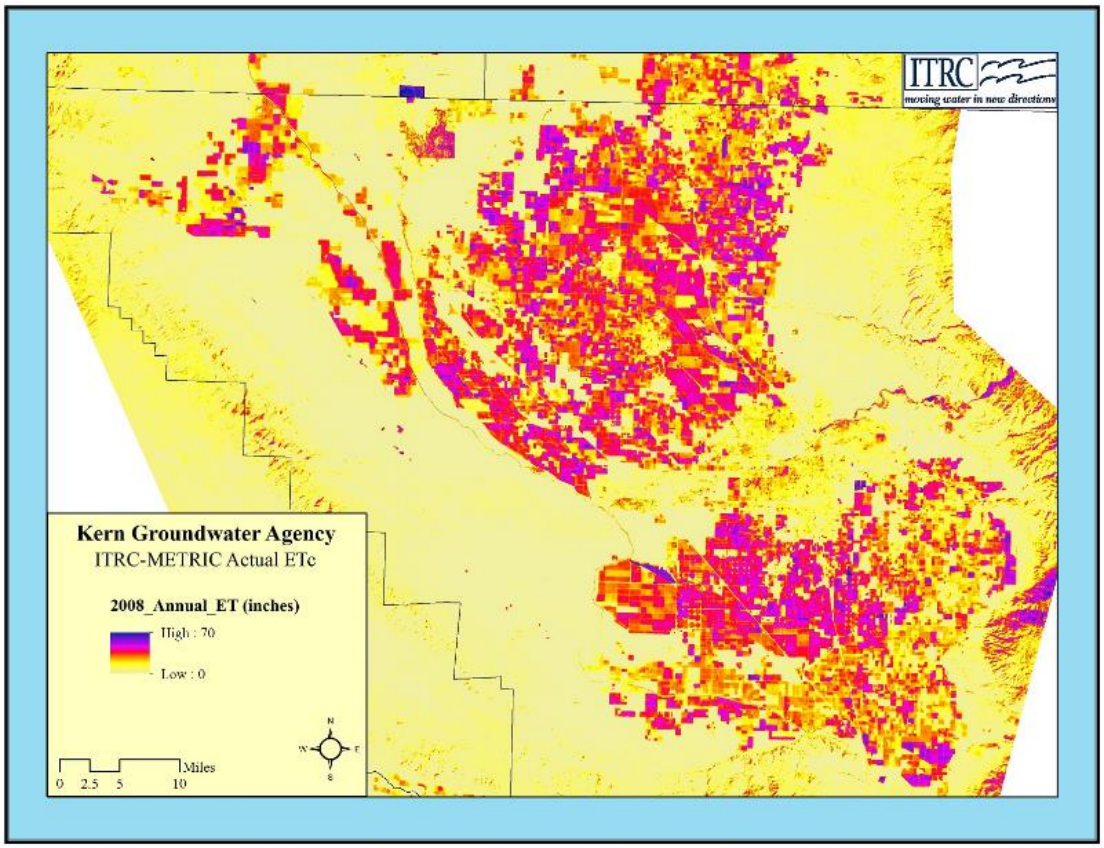
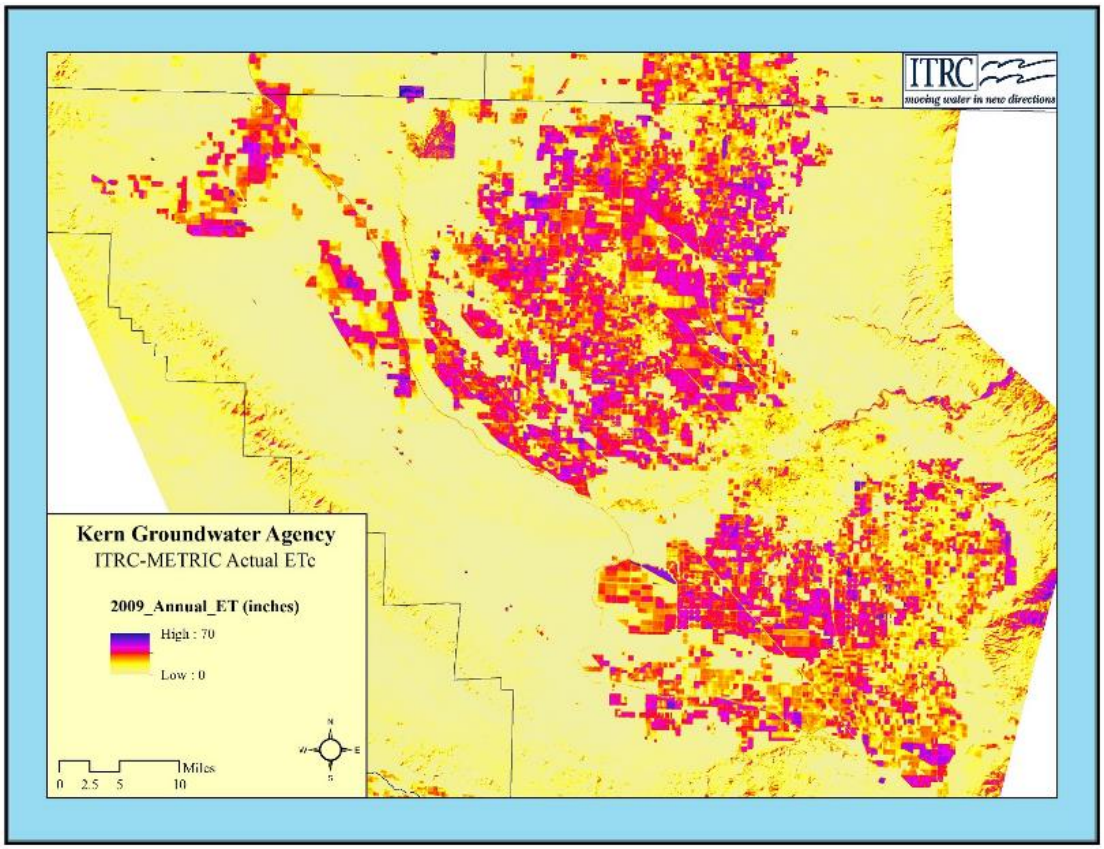
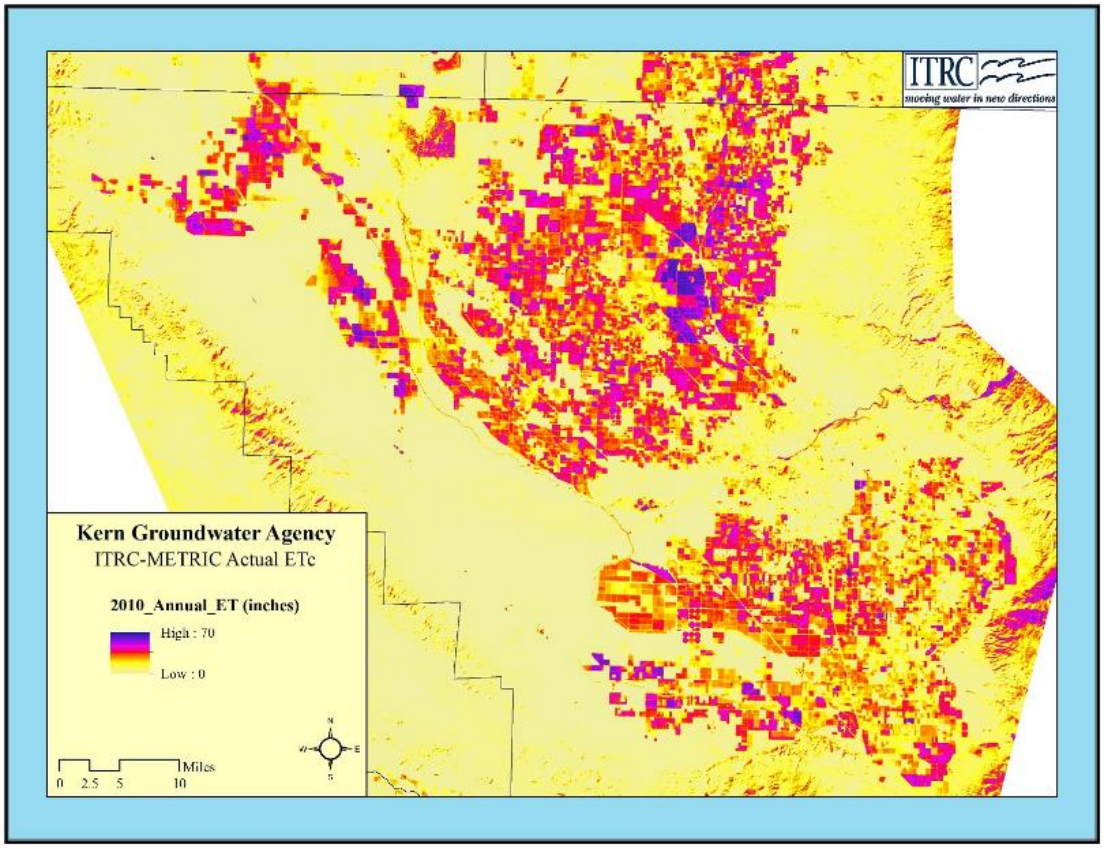
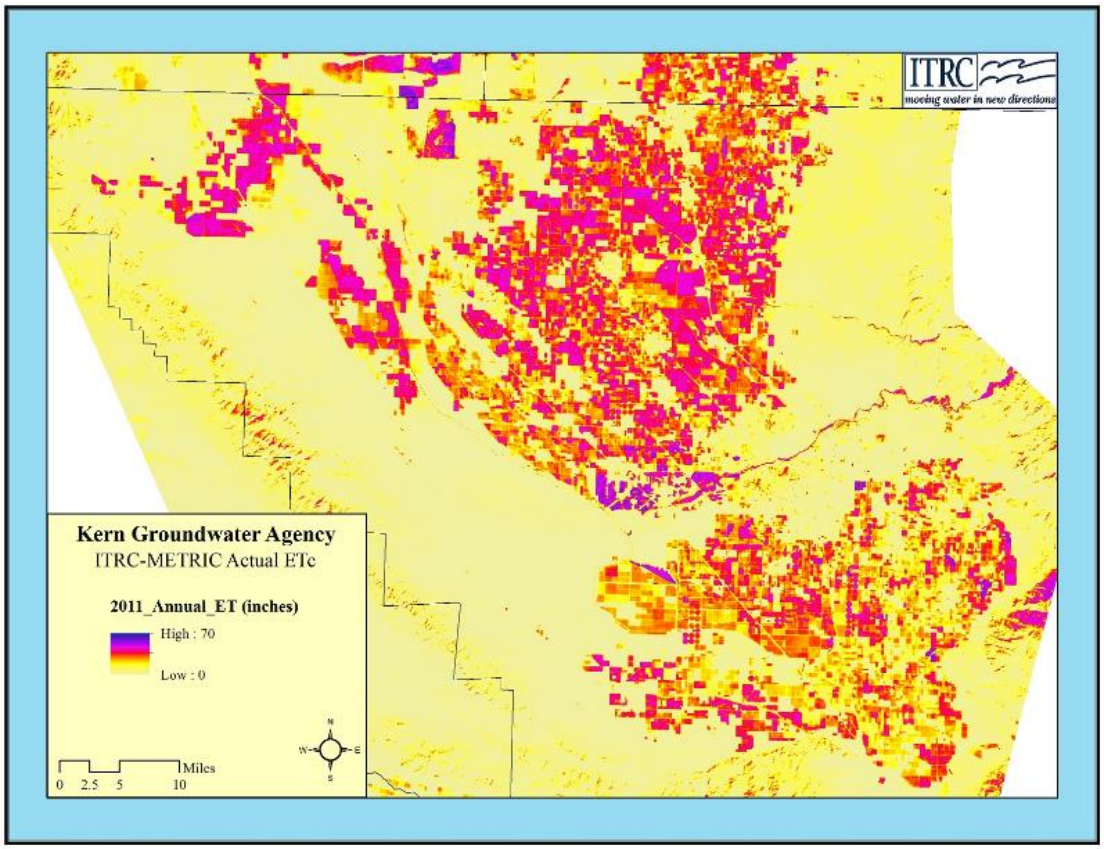
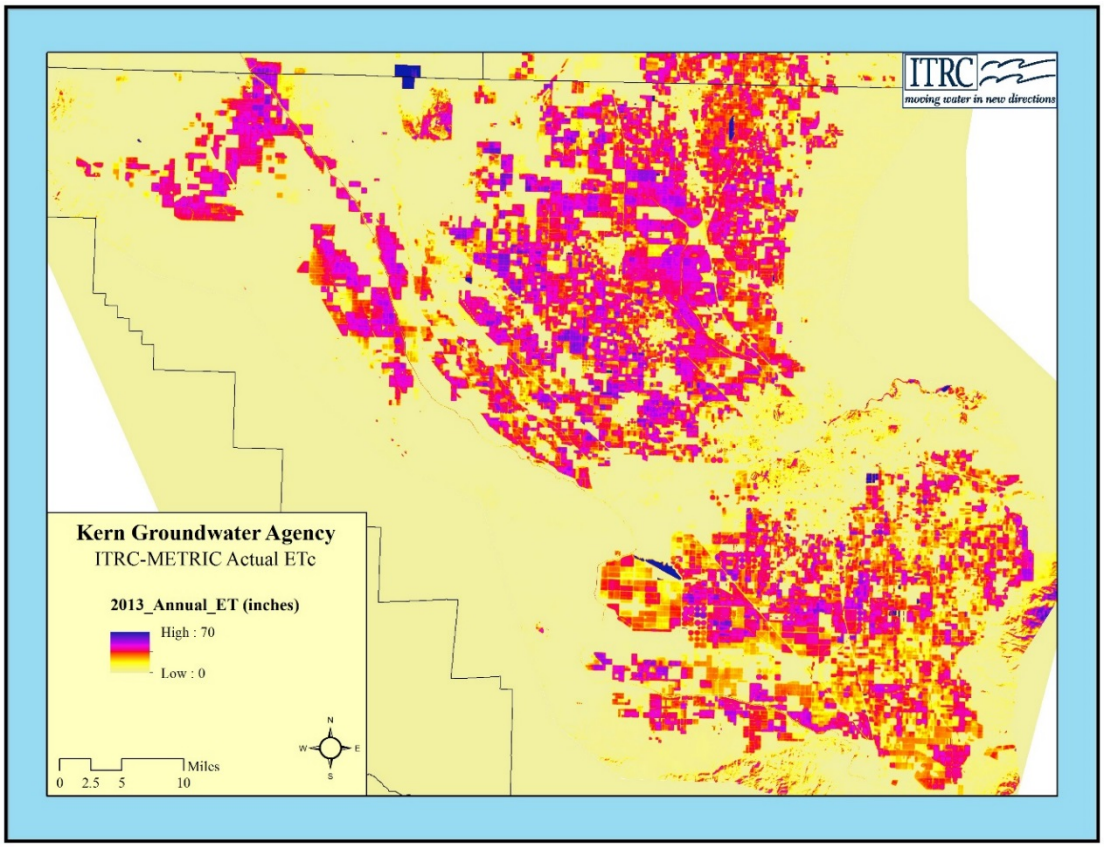

ITRC
moving water in new directions
Kern Groundwater Agency
ITRC-METRIC Actual ETc
2007_Annual_ET (inches)
High : 70
Low : 0
Miles
0 2.5 5 10

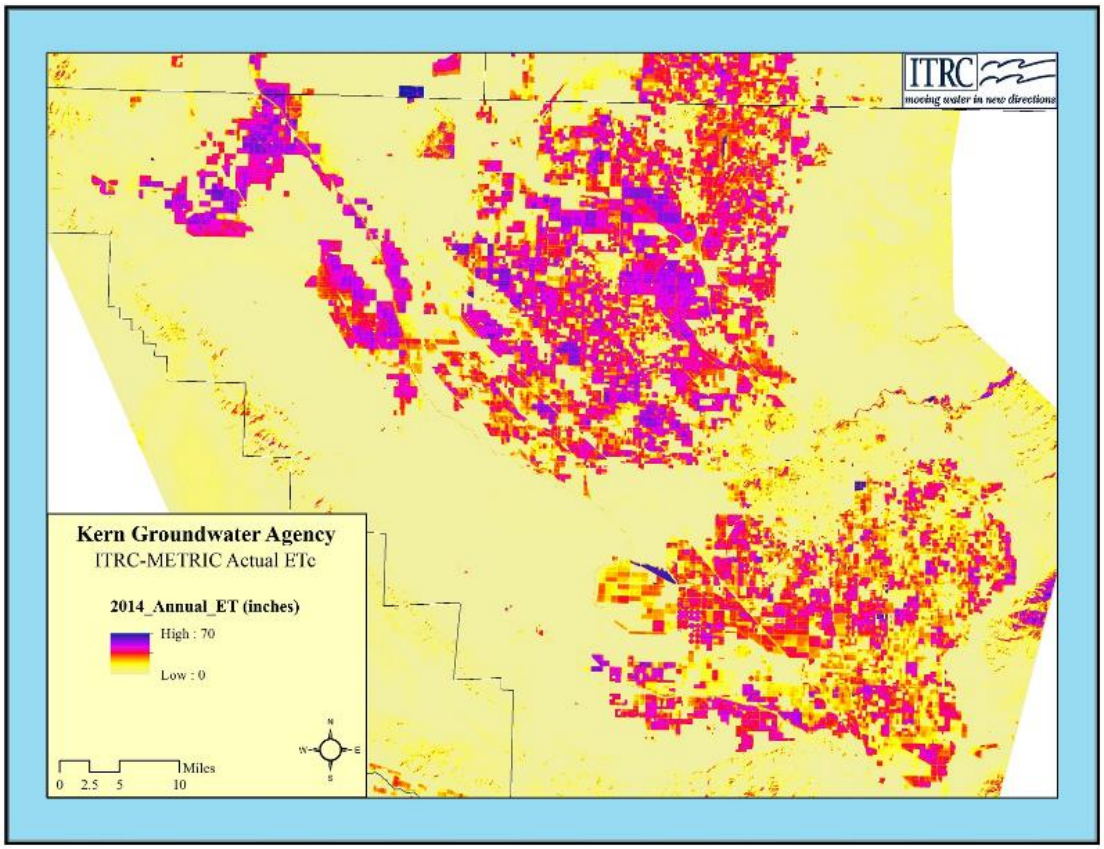

ITRC
moving water in new directions
Kern Groundwater Agency
ITRC-METRIC Actual ETc
2008_Annual_ET (inches)
High : 70
Low : 0
Miles
0 2.5 5 10

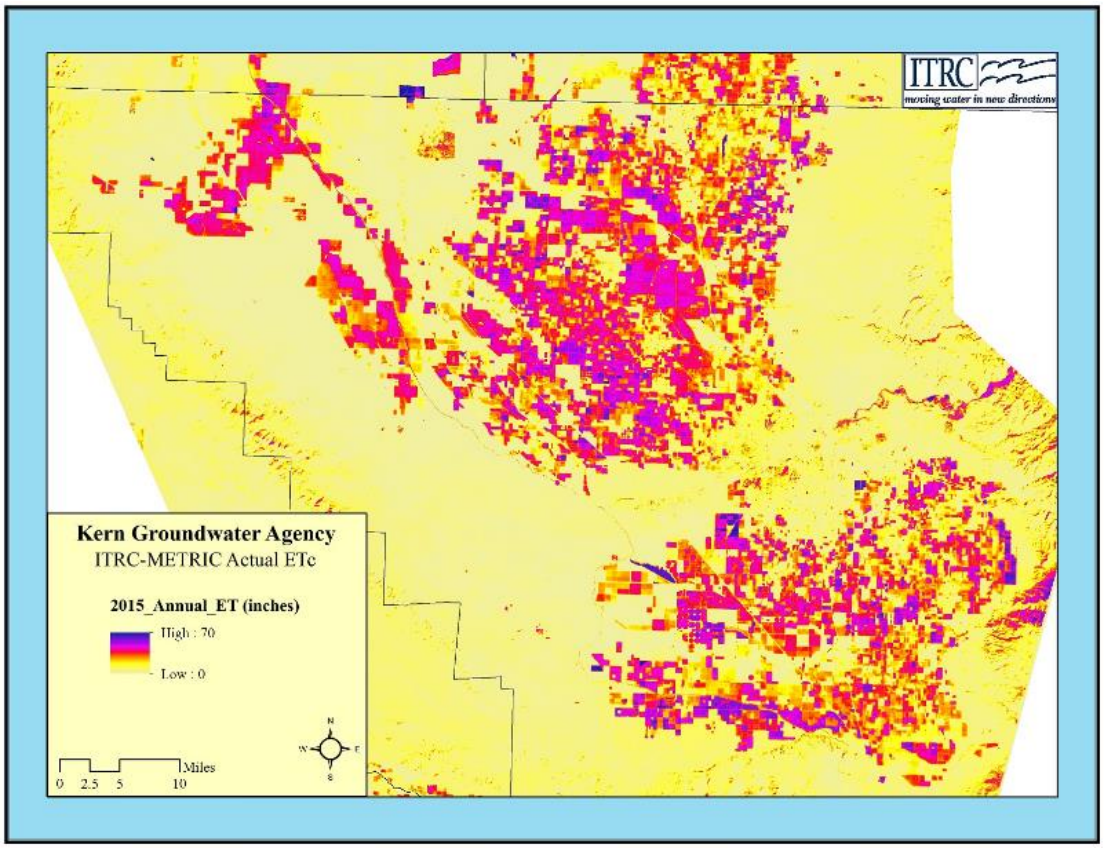

ITRC
moving water in new directions
Kern Groundwater Agency
ITRC-METRIC Actual ETc
2009_Annual_ET (inches)
High : 70
Low : 0
Miles
0 2.5 5 10

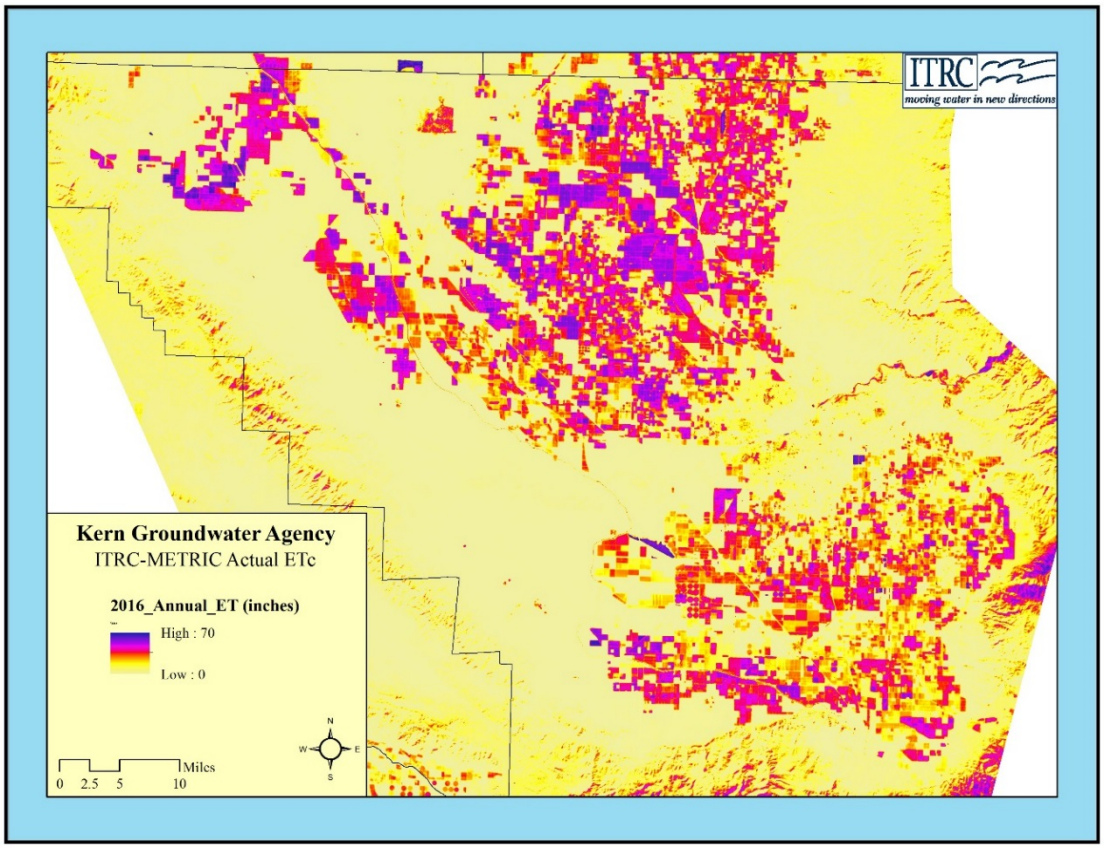

ITRC
moving water in new directions
Kern Groundwater Agency
ITRC-METRIC Actual ETc
2010_Annual_ET (inches)
High : 70
Low : 0
Miles
0 2.5 5 10


ITRC
moving water in new directions
Kern Groundwater Agency
ITRC-METRIC Actual ETc
2011_Annual_ET (inches)
High : 70
Low : 0
N
W
E
S
Miles
0 2.5 5 10


ITRC
moving water in new directions
Kern Groundwater Agency
ITRC-METRIC Actual ETc
2013_Annual_ET (inches)
High : 70
Low : 0
N
W
E
S
Miles
0 2.5 5 10


ITRC
moving water in new directions
Kern Groundwater Agency
ITRC-METRIC Actual ETc
2014_Annual_ET (inches)
High : 70
Low : 0
Miles
0 2.5 5 10


ITRC
moving water in new directions
Kern Groundwater Agency
ITRC-METRIC Actual ETc
2015_Annual_ET (inches)
High : 70
Low : 0
Miles
0 2.5 5 10


ITRC
moving water in new directions
Kern Groundwater Agency
ITRC-METRIC Actual ETc
2016_Annual_ET (inches)
High : 70
Low : 0
N
W
E
S
0 2.5 5 10
Miles