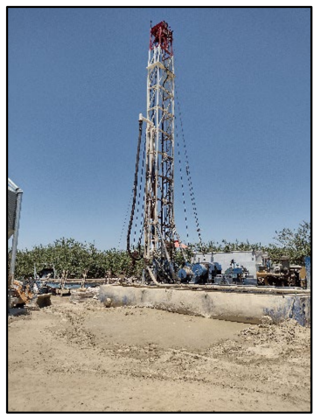
Kern Subbasin

1993-2022 ITRC-METRIC ETc for Kern County - DRAFT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ITRC moving water in new directions

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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 Kern Subbasin. The area of interest is shown in Figure 1 with a "natural color" image in the background. This report is an update to the Kern Groundwater Authority 1993-2021 ITRC-METRIC report prepared in February of 2022. The figures and analysis have been modified based on current parcels and GSA boundaries. The previous irrigation/water district level analysis has been removed to focus on the GSAs in the subbasin. All annual results are presented as calendar year.

ITRC uses a modified Mapping of EvapoTranspiration with Internal Calibration (METRIC^{TM}) 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.

ITRC- METRIC Procedures

This *Procedures* section will discuss the information that was gathered and used to compute the actual crop evapotranspiration (ET) in the Kern 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 5, 7, 8, and 9 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 and 9. 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

<u>A critical benefit of using ITRC-METRIC to determine actual evapotranspiration is that land use/crop type information is not needed</u>. Therefore, inaccuracies of determining land use are <u>not</u> 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, 7, 8, and 9 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	LandSAT 9
Nov 1982 - Oct 2011	Jun 1999 - Apr 2022	Apr 2013 - Present	Feb 2022- 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.

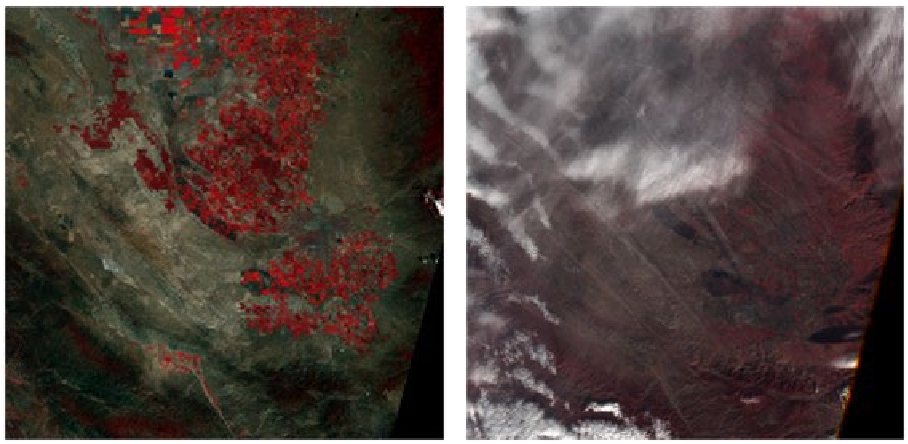


Figure 2. Cloud free LandSAT image (left) and LandSAT image with clouds (right)

All relatively cloud-free available images were used for the modeling process.

Table 2 lists the images processed from late 1992 through 2022. A total of 385 individual 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 1993-2022 Kern County METRIC process

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
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	3/16/2004*	1/30/2005*	38742
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	4/9/2004	4/12/2005	2/10/2006
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	5/11/2004	5/14/2005	4/7/2006*
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	6/12/2004	6/15/2005	5/7/2006*
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	7/14/2004	7/1/2005	5/17/2006
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	7/30/2004	7/17/2005	6/18/2006
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	8/31/2004	8/18/2005	7/20/2006
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	9/16/2004	9/19/2005	8/5/2006
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*	10/2/2004	10/5/2005	8/21/2006
9/2/1993					11/19/1998	10/5/1999	10/7/2000	9/16/2001*	10/21/2002*			11/14/2005*	38982
10/20/1993					12/5/1998	11/22/1999	11/16/2000*	10/18/2016*	12/8/2002*				38998
11/5/1993						12/24/1999	12/26/2000	11/3/2001*					39030
								12/13/2001					12/19/2006*

2007	2008	2009	2010	2011	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1/12/2007	2/16/2008	1/17/2009	2/13/2010*	2/8/2011	4/18/2013**	12/14/2013**	1/2/2015**	2/6/2016**	1/31/2017*	1/26/2018**	1/13/2019**	1/16/2020**	1/18/2021**	2/6/2022**
2/21/2007*	3/19/2008	2/2/2009	4/26/2010	3/4/2011*	5/20/2013**	12/30/2013**	2/27/2015*	2/22/2016**	2/24/2017**	2/3/2018*	2/6/2019*	2/1/2020**	1/26/2021*	3/10/2022**
3/17/2007	4/20/2008	3/30/2009*	5/12/2010	4/29/2011	6/5/2013**	1/15/2014**	3/7/2015**	3/9/2016**	2/12/2017**	2/11/2018**	2/22/2019*	2/25/2020*	2/19/2021**	3/18/2022*
4/10/2007*	5/30/2008*	4/23/2009	6/29/2010	5/7/2011*	7/7/2013**	2/24/2014*	4/16/2015*	3/17/2016*	3/28/2017**	2/19/2018*	3/18/2019**	3/4/2020**	2/27/2021*	4/19/2022+
5/20/2007	6/23/2008	5/25/2009	7/15/2010	6/16/2011	8/8/2013**	4/13/2014*	5/10/2015**	5/12/2016**	4/21/2017*	3/15/2018**	4/27/2019**	3/20/2020**	3/31/2021*	5/13/2022**
6/21/2007	7/25/2008	6/26/2009	7/31/2010	7/2/2011	9/9/2013**	4/29/2014*	6/11/2015**	6/13/2016**	4/29/2017*	3/31/2018**	5/5/2019**	4/21/2020**	4/8/2021**	5/21/2022+
7/7/2007	8/10/2008	7/12/2019	8/16/2010	8/3/2011	10/11/2013**	5/23/2014**	7/13/2015**	6/29/2016**	5/15/2017**	4/8/2018*	5/13/2019*	5/7/2020**	4/16/2021*	6/14/2022**
8/8/2007	8/26/2008	7/28/2009	9/17/2010	9/4/2011	12/14/2013**	6/24/2014**	7/29/2015**	7/15/2016**	5/23/2017*	4/24/2018*	5/29/2019*	5/15/2020*	5/2/2021*	6/30/2022**
8/24/2007	9/27/2008	8/29/2009	10/3/2010	10/22/2011	12/30/2013**	7/10/2014**	8/14/2015**	7/31/2016**	6/16/2017**	5/18/2018**	6/6/2019**	5/23/2020**	5/10/2021**	7/16/2022+
9/25/2007	10/13/2008	9/30/2009	11/12/2010*	11/15/2011*		8/27/2014**	9/23/2015 *	8/16/2016**	7/2/2017**	6/3/2018**	6/14/2019*	6/16/2020*	5/26/2021**	7/24/2022+
10/19/2007*	11/14/2008	10/24/2009*	12/6/2010	12/1/2011*		9/12/2014**	10/09/2015*	9/1/2016**	7/18/2017**	6/19/2018**	6/22/2019**	6/24/2020**	6/11/2021**	8/25/2022+
11/4/2007*		11/17/2009		1/18/2012*		10/14/2014**	11/18/2015**	9/17/2016**	8/11/2017*	7/5/2018**	6/30/2019*	7/2/2020*	6/27/2021**	9/2/2022**
		12/3/2009		2/3/2012*		11/7/2014*		10/19/2016**	8/19/2017**	7/21/2018**	7/8/2019**	7/18/2020*	7/5/2021*	10/4/2022**
								12/14/2016*	8/27/2017*	8/6/2018**	7/24/2019**	7/26/2020**	7/21/2021*	11/29/2022+
									9/20/2017**	8/22/2018**	8/1/2019*	8/11/2020**	8/14/2021**	1/23/2023**
									9/28/2017*	9/7/2018**	8/9/2019**	8/27/2020**	8/30/2021**	
									10/6/2017**	9/23/2018**	8/25/2019**	9/4/2020*	9/7/2021*	
									10/22/2017**	10/9/2018**	9/10/2019**	9/20/2020*	10/9/2021*	
									11/7/2017**	10/25/2019**	9/18/2019*	10/14/2020**	11/2/2021**	
									11/23/2017**	11/2/2018*	9/26/2019**	10/22/2020*	12/12/2021*	
									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*			
											10/28/2019**			
											11/5/2019*			
											11/21/2019*			
											12/15/2019**			
											12/31/2019**			

Note: * indicates LandSAT 7, ** indicates LandSAT 8, + indicates LandSAT 9, 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. 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. 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, Famoso, and Delano CIMIS stations were utilized as the "primary" weather stations for different years. These stations were selected because of their centralized locations within the primary area of interest. Shafter was used from 1992-1997, Famoso was used from 1998-2015, and Delano was used from 2016-2022. 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 the primary CIMIS station. 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)

<u>All collected **hourly** weather data from the stations went through a quality control check and correction procedure</u>. A detailed procedure on the quality control conducted can be found in FAO Irrigation and Drainage Paper No. 56[1] 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.

[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 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, post-2016 ITRC no longer corrects the Spatial CIMIS raster images. The only corrections being conducted are on the hourly weather data at the primary weather station.

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. Shafter (#5) was used as a primary station for the years 1993 through 1997, Famoso (#138) was used as a primary station for 1998-2015 and Delano (#182) was used as a primary station for the remainder of the study period. These stations 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
- The switch from Famoso to Delano was due to inactivation of the Famoso station in early 2016

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 3 shows the calibration AOI for the Delano CIMIS station.

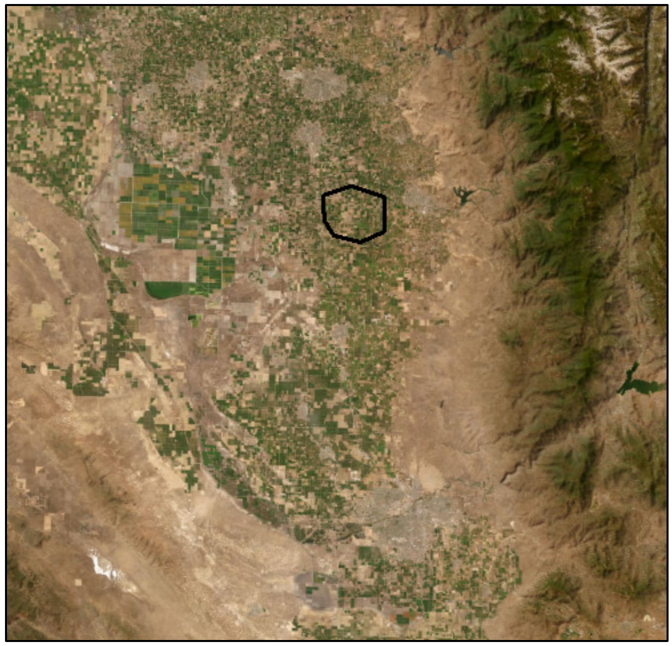


Figure 3. Delano CIMIS station calibration area of interest (AOI)

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. An updated DWR parcel shapefile was available in 2021 as part of the Statewide Crop Mapping Service. The field boundaries provided in this shapefile were used in 2021 to present.

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 4 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.

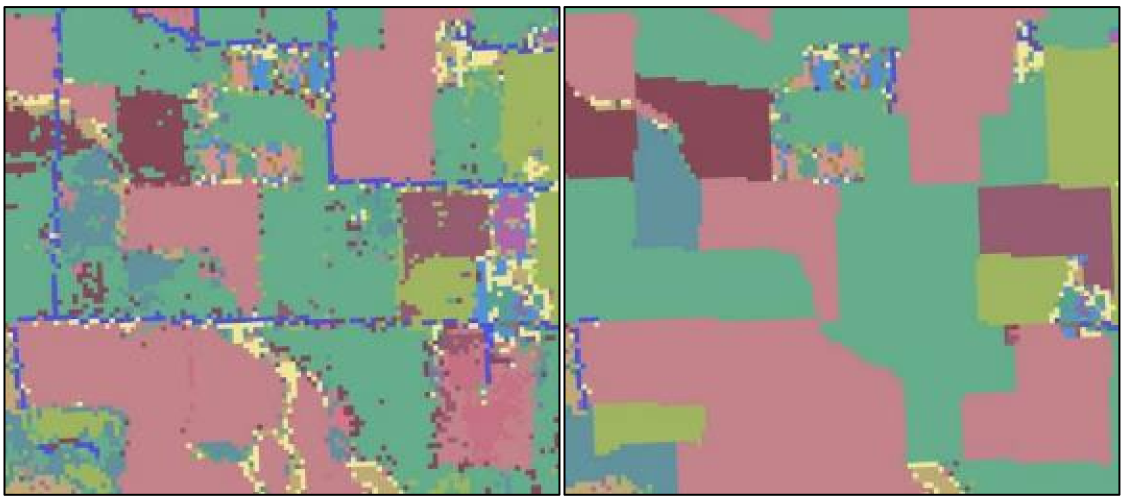


Figure 4. Example original NASS land use (left) compared to corrected land use based on the majority crop type within each agricultural field (right). Each color identifies a different land use type (i.e., almonds, alfalfa, developed, etc.)

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.

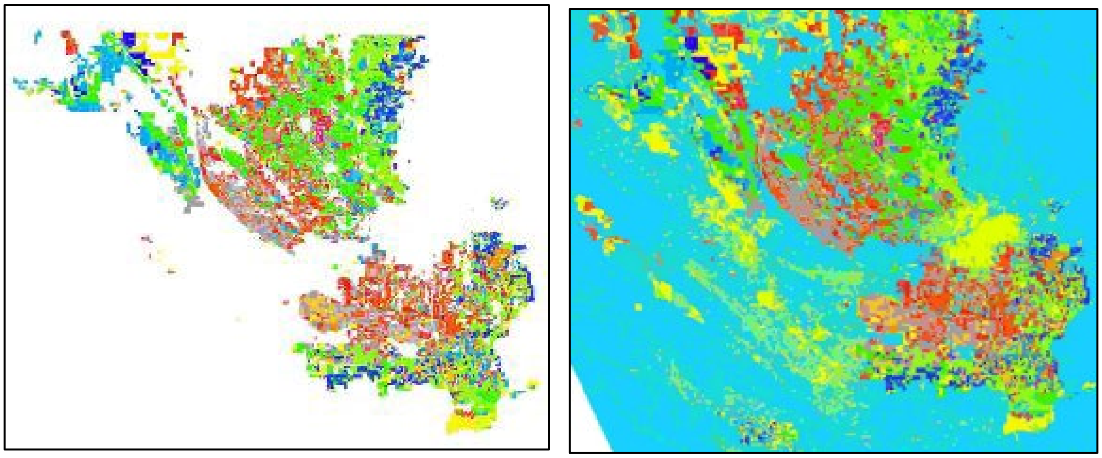


Figure 5. County of Kern agricultural land use fields (left). Combined County of Kern and NASS land use image (right)

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 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 Kc and actual ETc results for Kern County for the period 1993-2022 (excluding 2012) 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 vegetative health. Spatial variation in ETc throughout a field and between fields is taken into accounted. 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 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 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 Kern Subbasin and the field boundaries within the subbasin. Figure 6 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 30-year period, the field boundaries and overall boundary were the same.

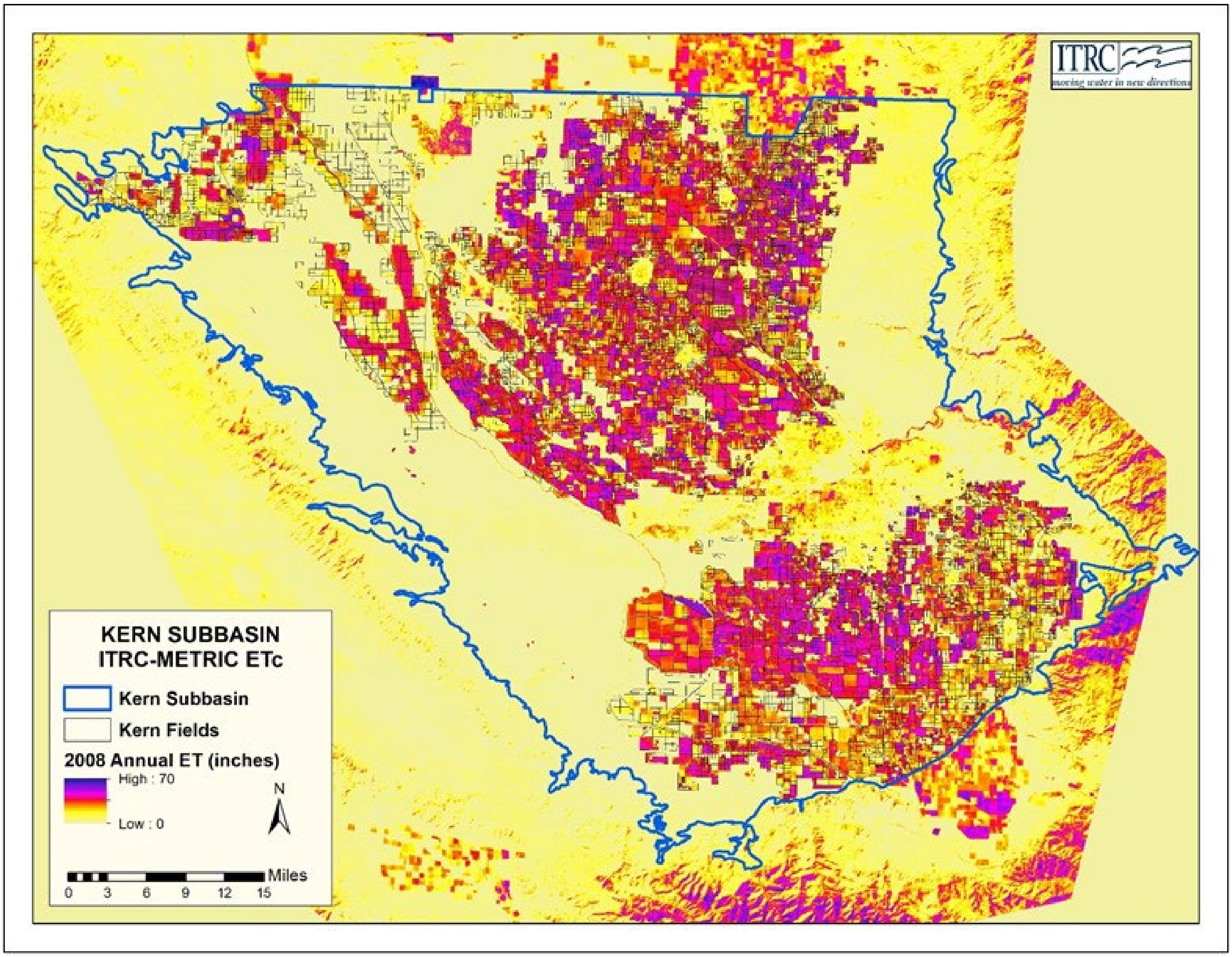


Figure 6. 2008 ETc image with Kern Subbasin and field boundaries used for the summary analysis

The volume of actual ETc for the overall area of the subbasin and only within fields is shown in Figure 7. For reference, the grass reference evapotranspiration (ETo) and precipitation are also shown. ETo provides an idea of the weather conditions that drive evapotranspiration. Hotter, drier years have a higher ETo.

Figure 8 and 12 show the volume and depth of ETc for all GSAs within the Kern Subbasin.

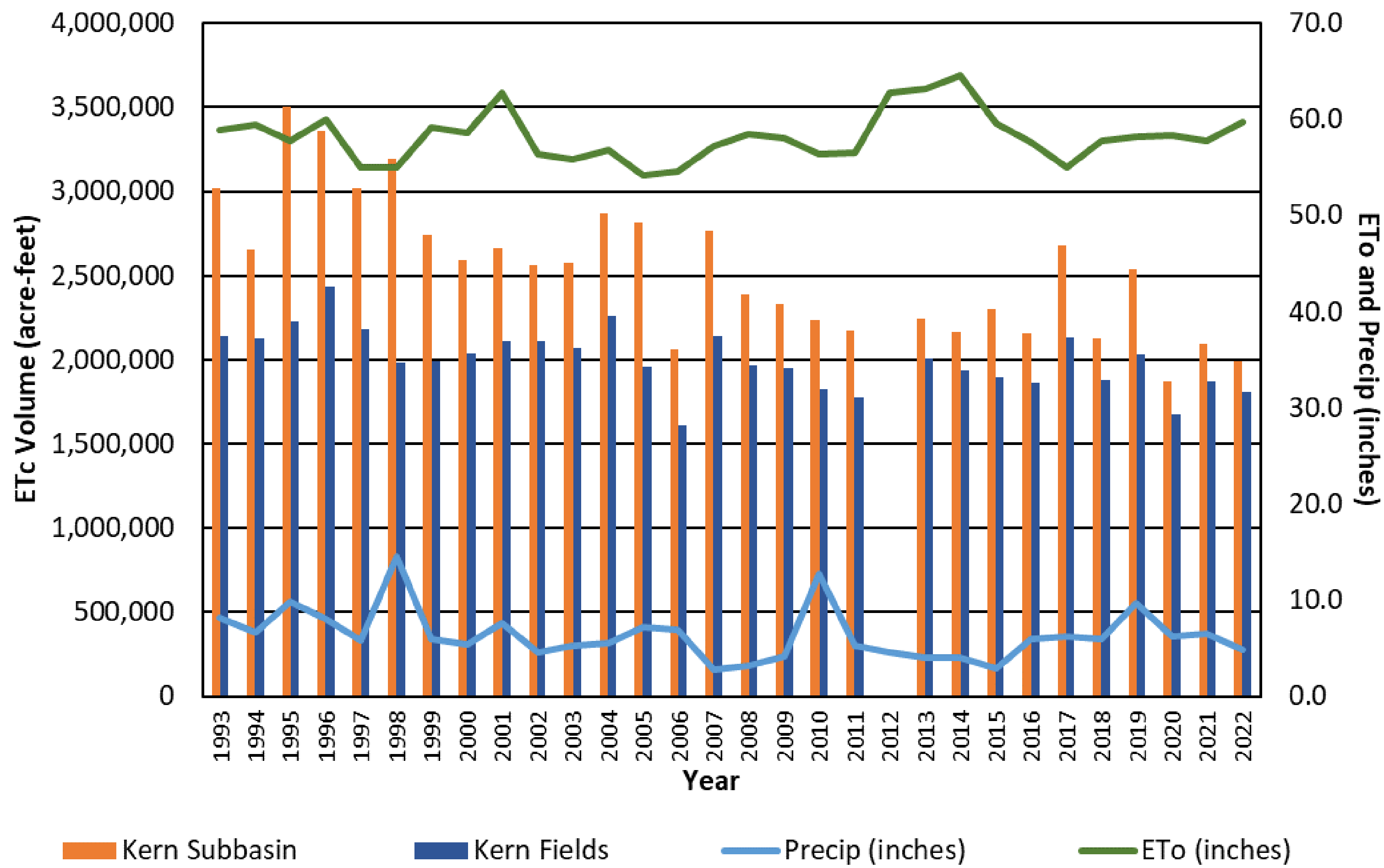


Figure 7. Annual volume of ETc for the Kern Subbasin and within fields in Kern County. Grass reference ETo and precipitation depths are shown as a reference.

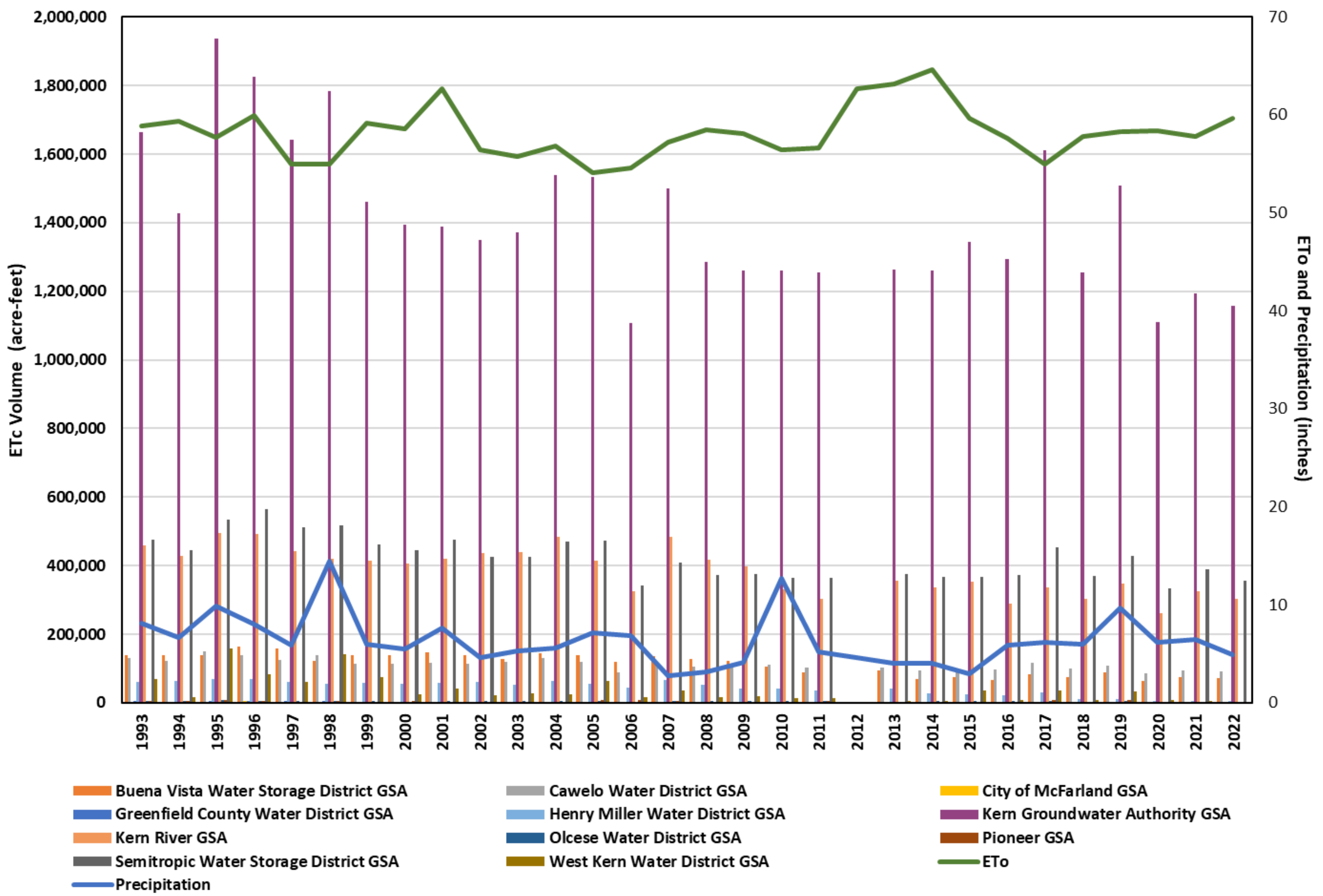


Figure 8. Annual ETc volume (acre-feet) by GSA within the Kern Subbasin

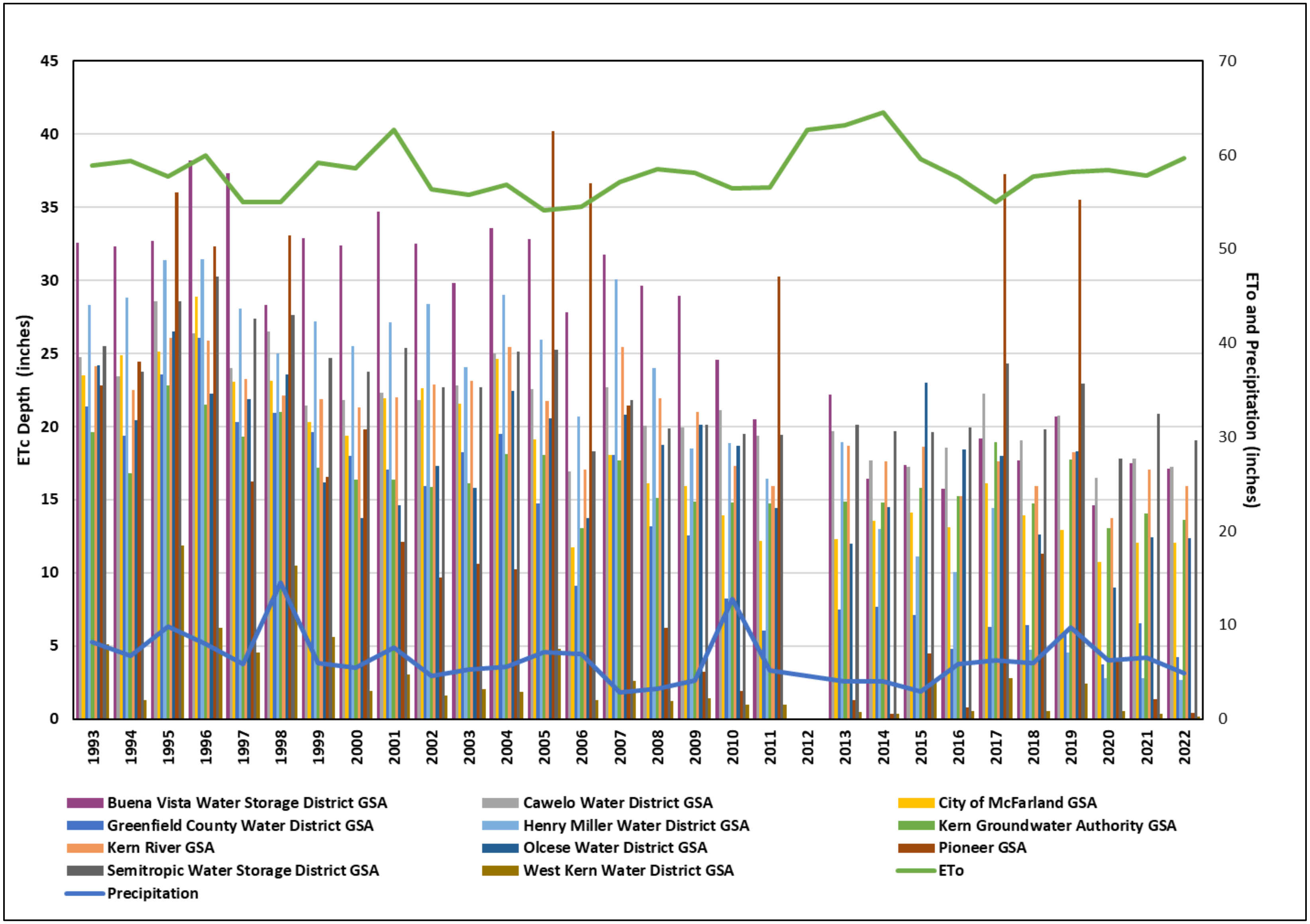


Figure 9. Annual ETc depth (inches) by GSA within the Kern Subbasin

Evaluation of ETc Variation

In general, there is an overall decline in ETc volume from the Kern Subbasin over the 30 years that the ET analysis covers. The field ETc decline is not as significant but does trend downward. 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 10 for the study period for the entire Kern Subbasin area (includes urban, streets, undeveloped areas, etc.) and within fields only (only agricultural fields in the same area).

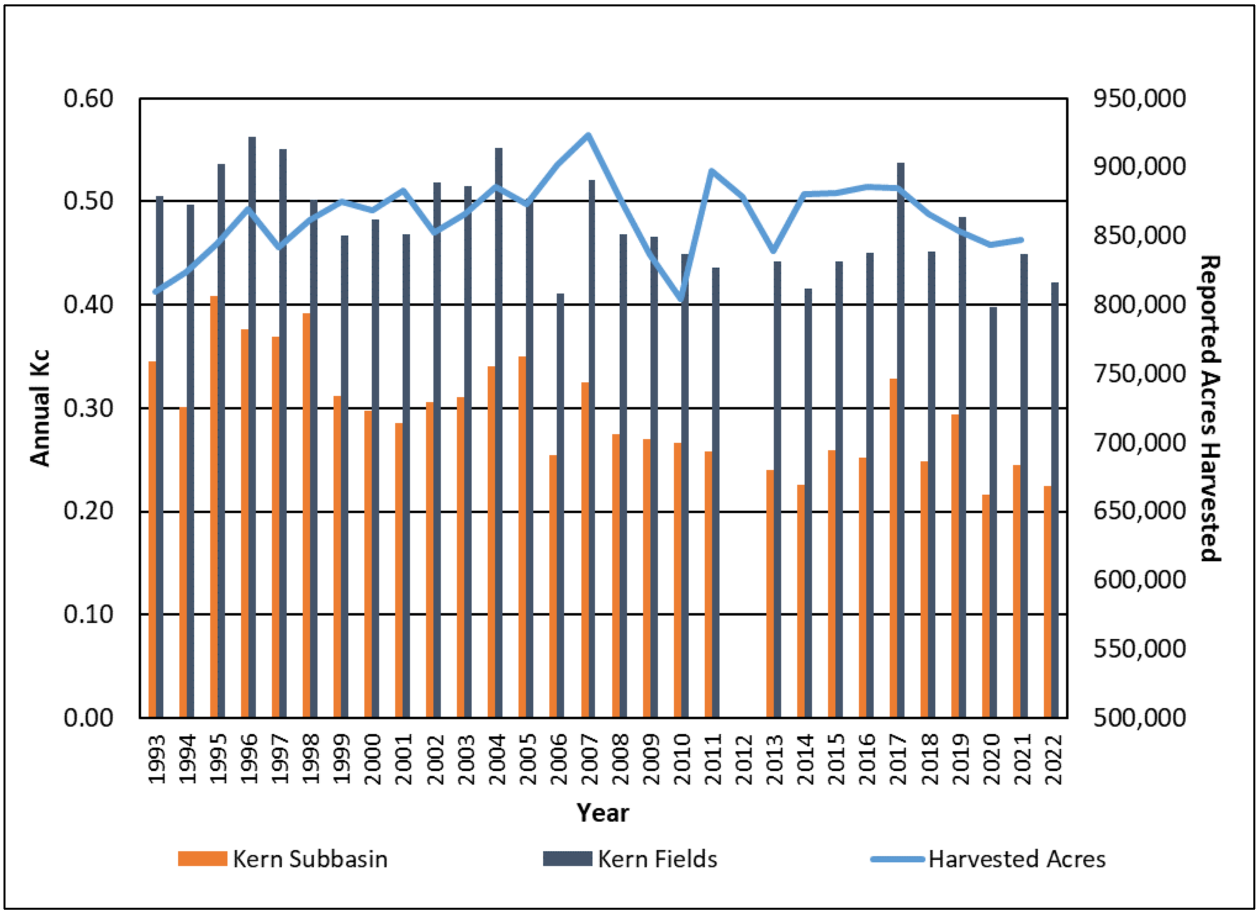


Figure 10. Annual crop coefficient (Kc) for the Kern Subbasin and within fields. Reported Ag Commissioner total harvested acres per year on the right axis of the graph

As expected, the Kc is higher when only looking within field boundaries compared to 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. As with the volume, there seems to be a general decline in overall Kc over the years. There is a spike in 2017 for an unknown reason. There was more area planted in the Buena Vista Lake than recent years. There is also substantial recharge along the Kern River in 2017 and 2019 that would increase the overall ETc. Water supplies were higher, which may have led to more complete irrigations compared to prior years as well.

In the mid-2000s the Kc increases. Figure 10 also includes the Kern County Ag Commissioners total harvested acres over the 30-year period for reference and to possibly explain some of the variation. Interestingly, the Ag Commissioners' total harvested acreage increases from 1993 to 2021. 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. 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.

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 11. 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. 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 often include double cropping, such as corn and grain hay, which are not shown.

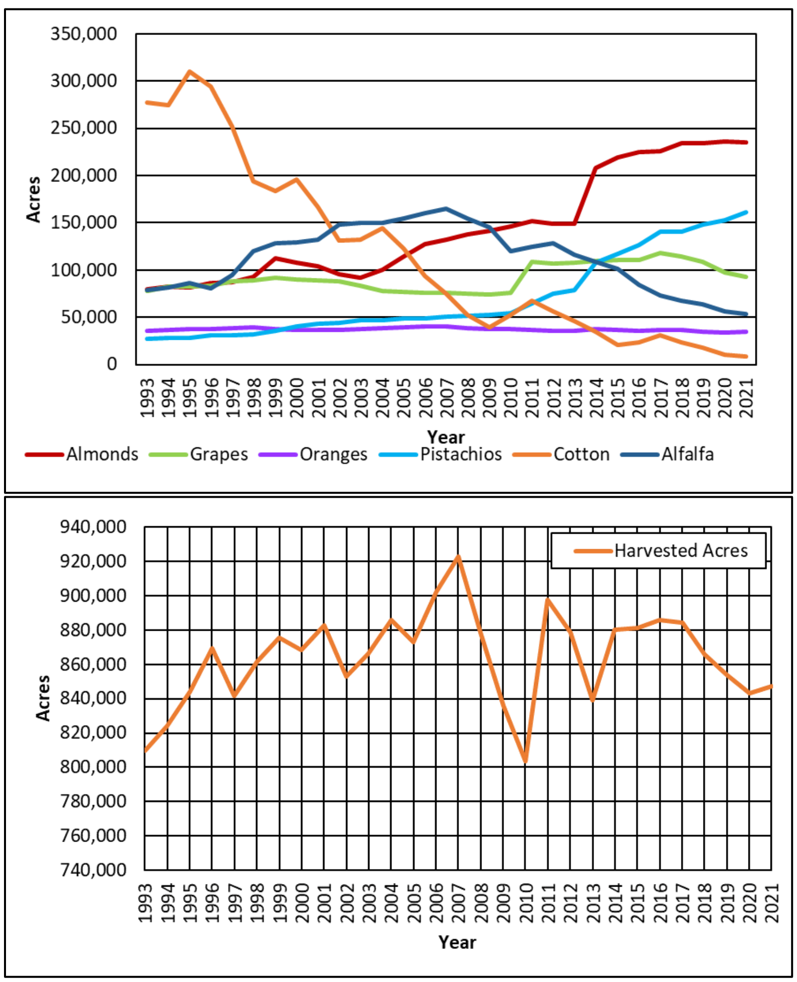


Figure 11. Crop acreage for major crops in Kern County from 1993-2021 (top) and total harvested acres (bottom) from Ag Commissioner Reports

As previously discussed, the Kern County Ag Commissioner reports presented an overall increase in harvested acreage from 1993 to 2021. The Ag Commissioner reports indicated that the 1993 total harvested acres was approximately 809,700, and the 2021 harvested acreage was 847,383. It should be mentioned that the harvested acreage accuracy is not known and likely includes immature orchards and vineyards that are below maximum water use. Year-to-year variations are shown in Figure 11.

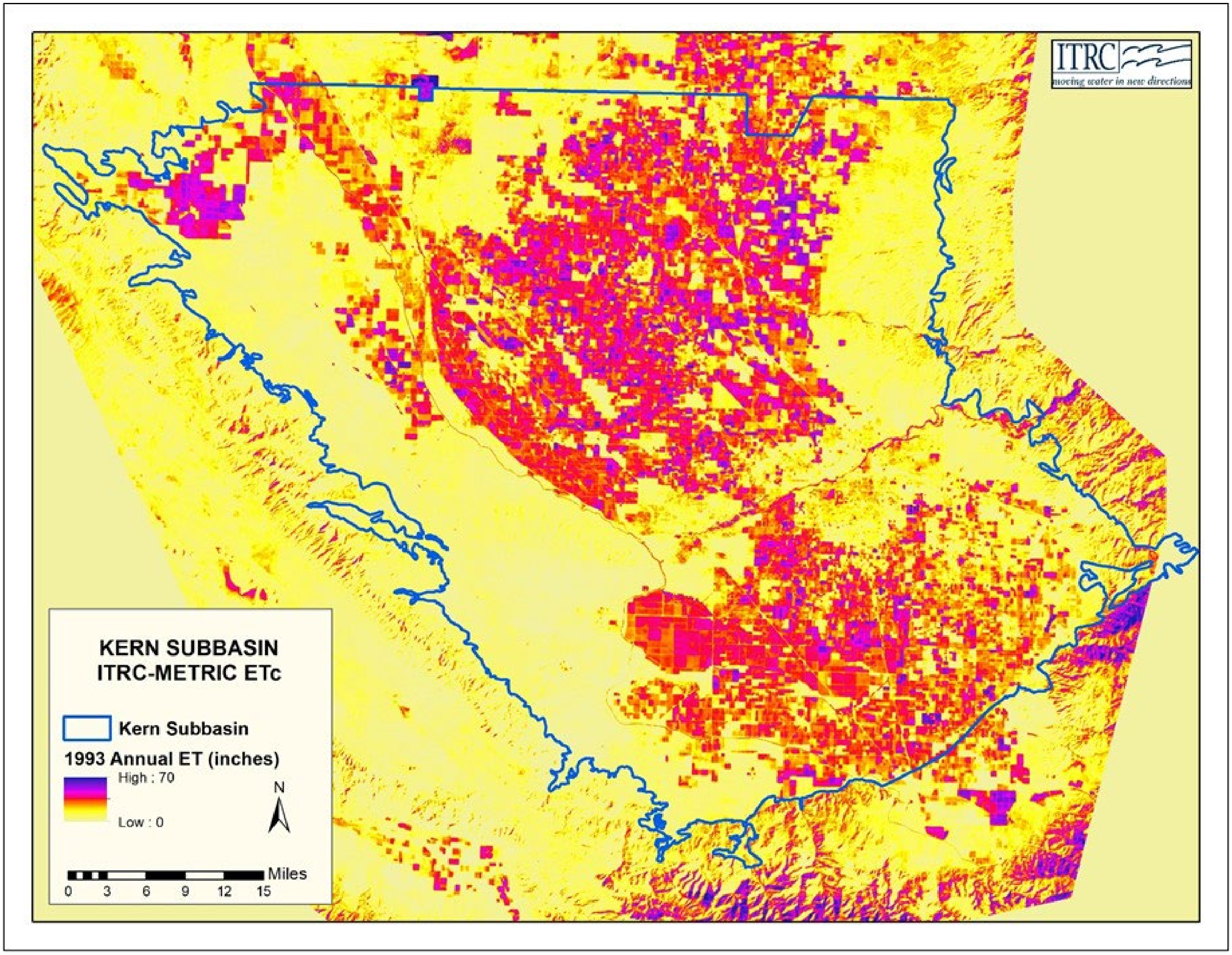
Conclusion

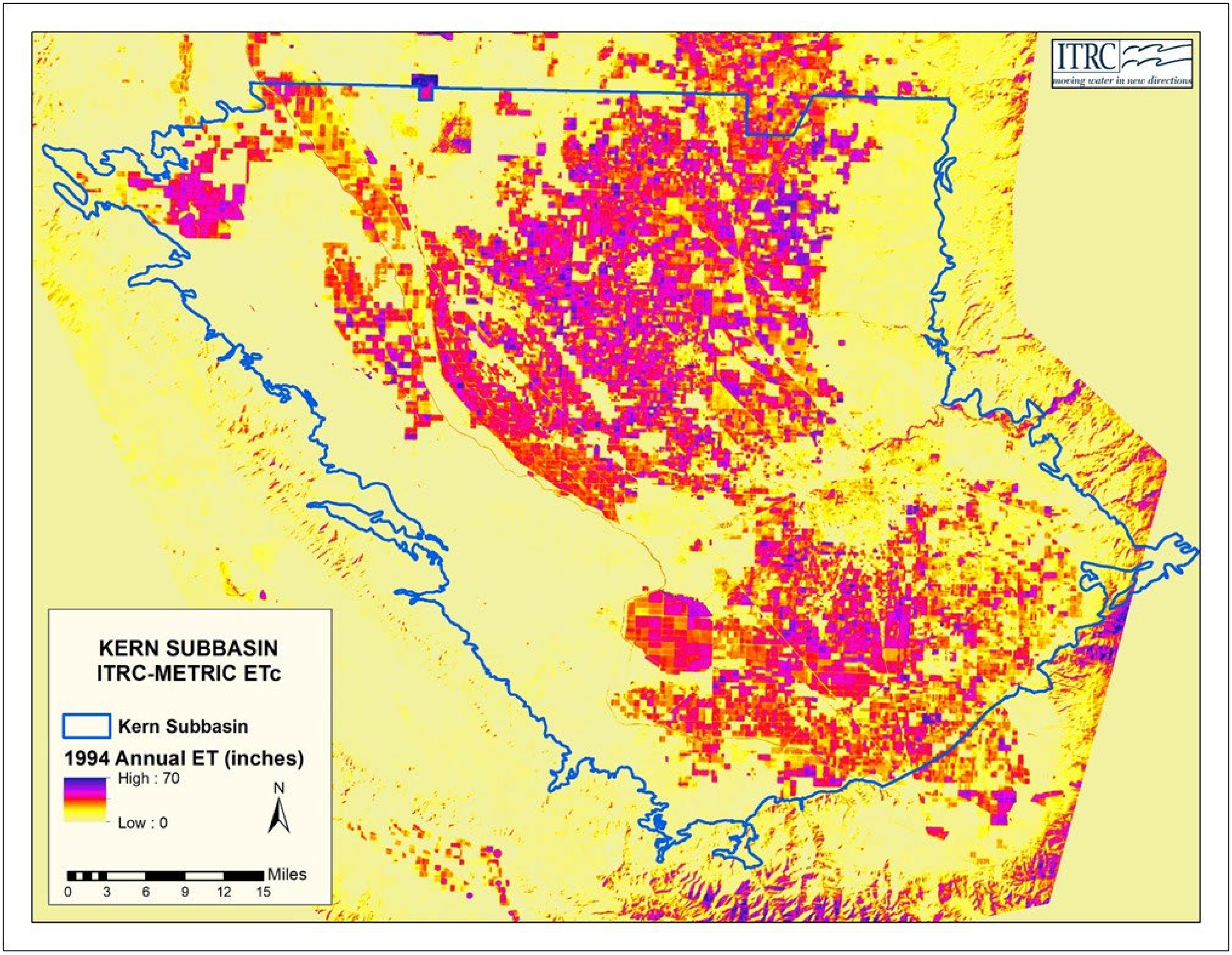
Over the 1993-2022 period, the volume of evapotranspiration from fields within the Kern Subbasin ranged from approximately 2-2.5 million acre-feet. Evapotranspiration varies year to year in the Kern Subbasin. This is caused by several factors including weather, crop mix/age, water availability, precipitation, and land fallowing.

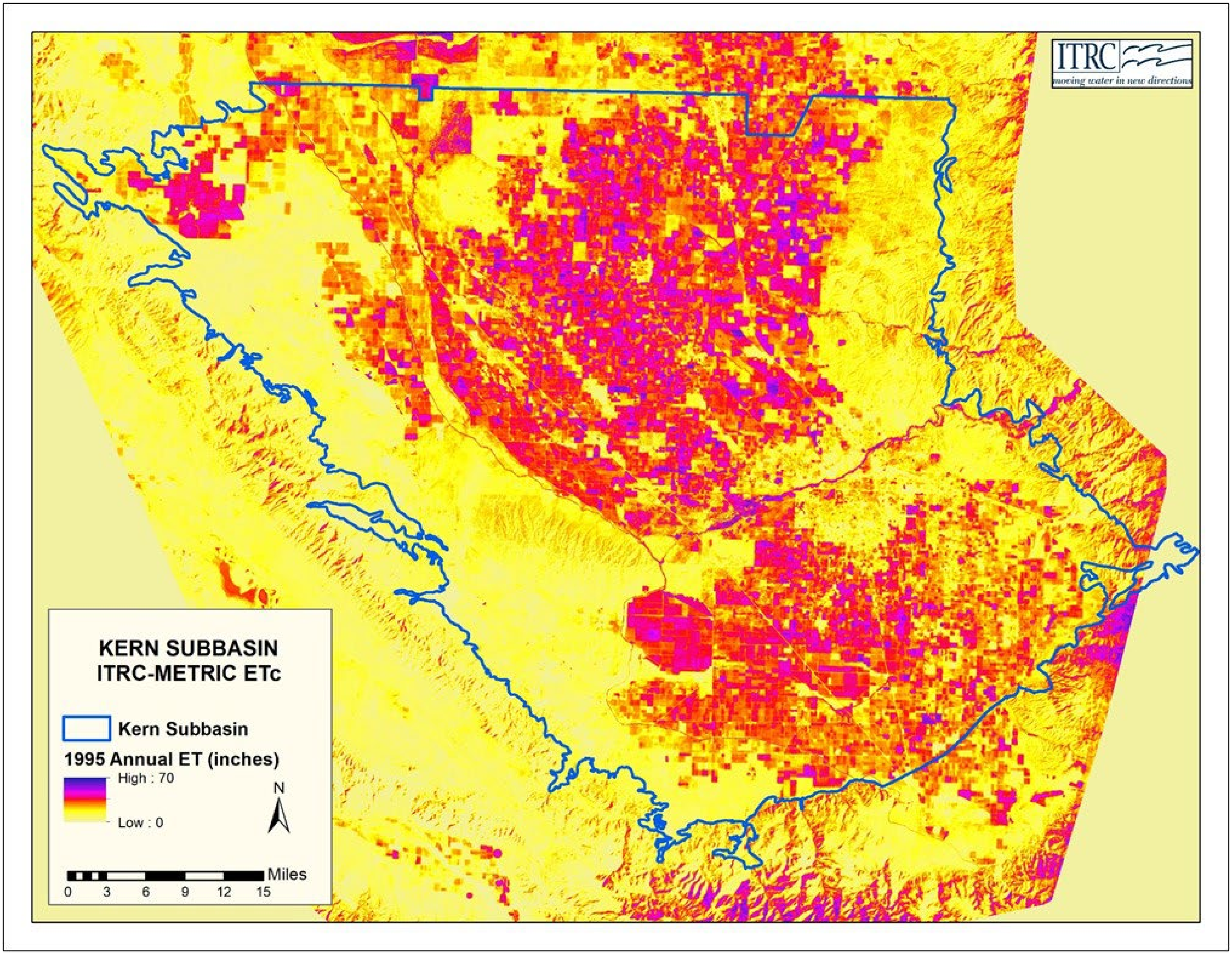
The monthly and annual evapotranspiration imagery in GIS format has been transmitted to Kern Groundwater Authority.

Attachment A

Annual ITRC-METRIC ETc




ITRC
moving water in new directions
KERN SUBBASIN
ITRC-METRIC ETc
Kern Subbasin
1994 Annual ET (inches)
High : 70
Low : 0
N
Miles
0 3 6 9 12 15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Kern Subbasin
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Low : 0
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Miles
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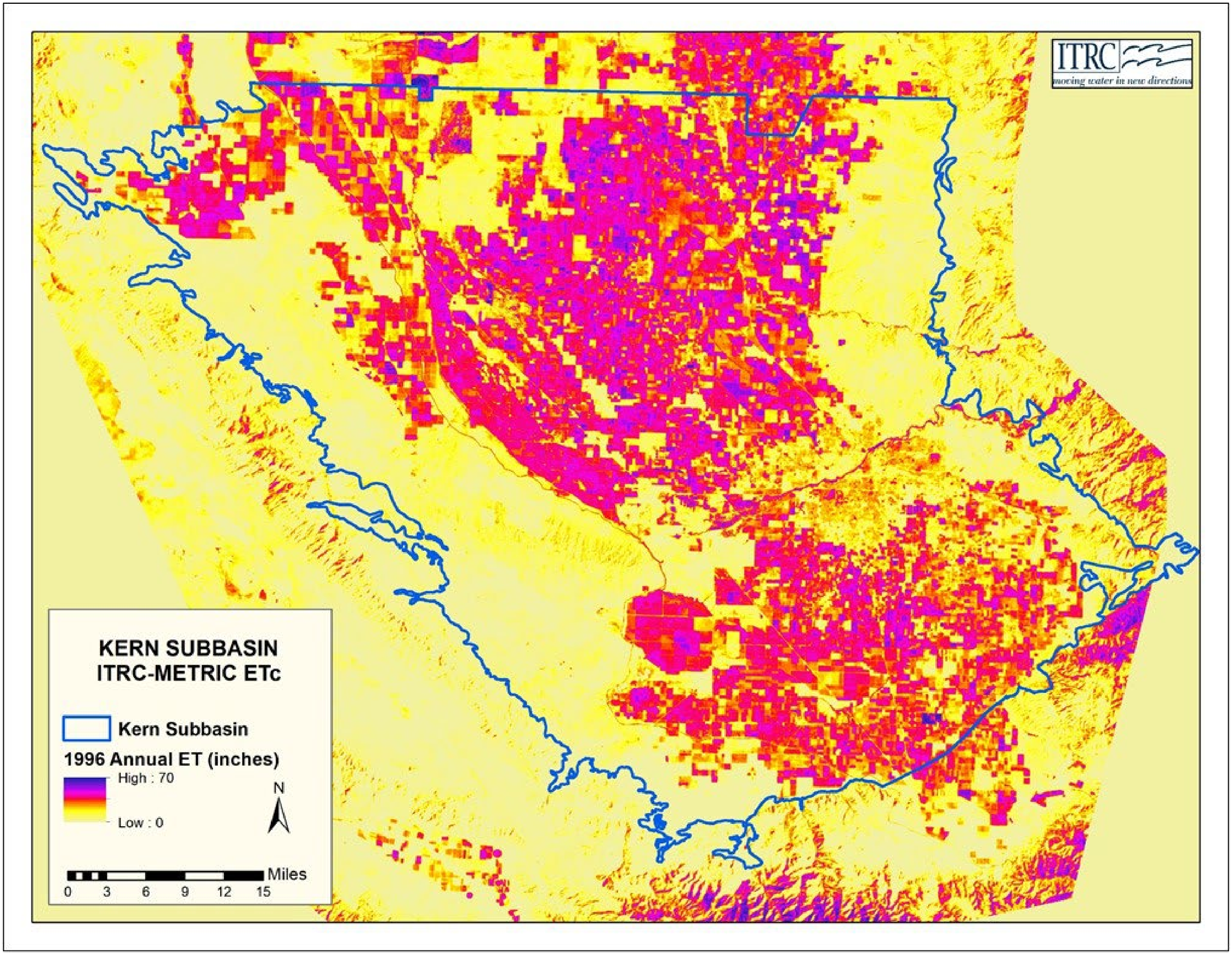
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Kern Subbasin
1996 Annual ET (inches)
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Low : 0
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Miles
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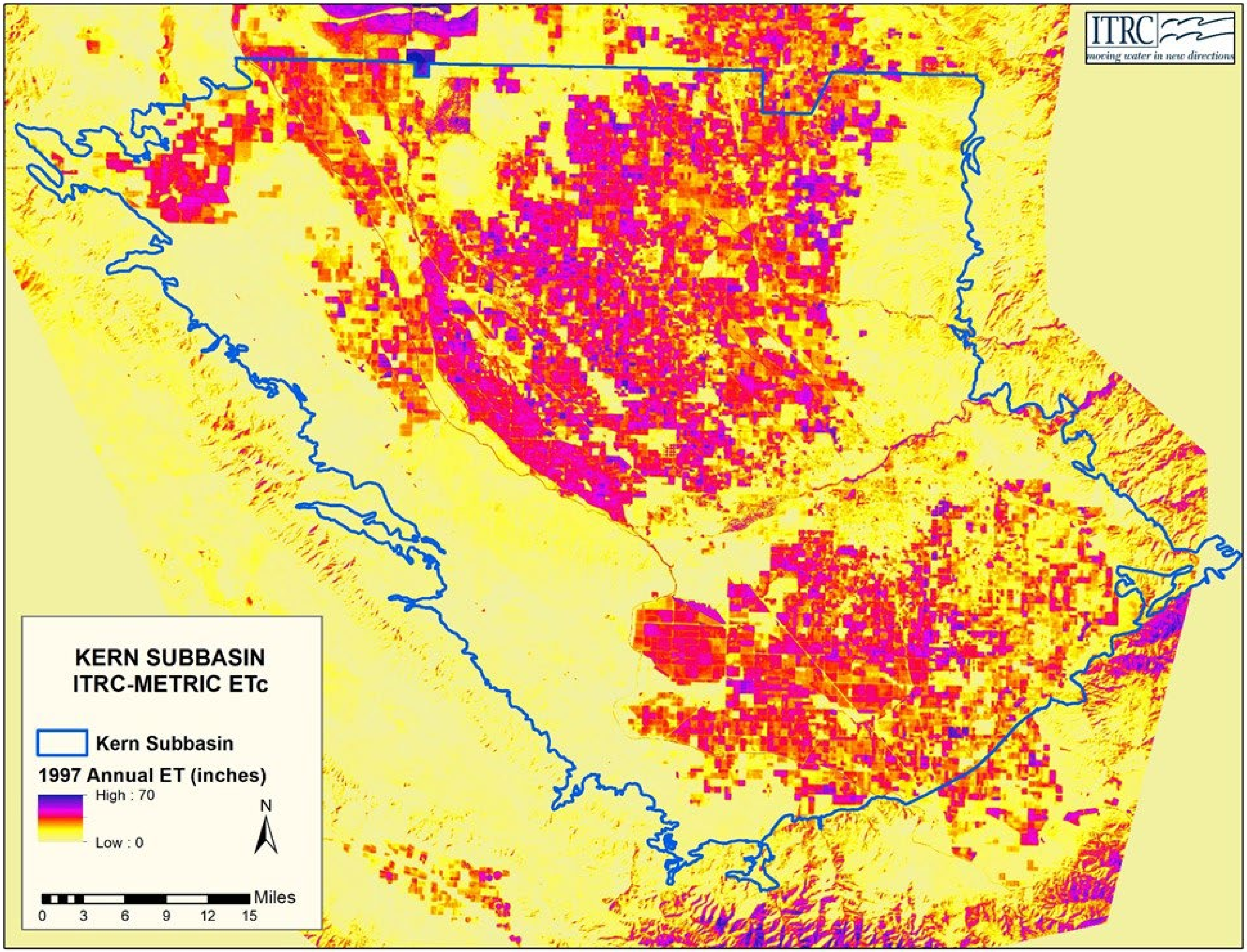
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Low : 0
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Miles
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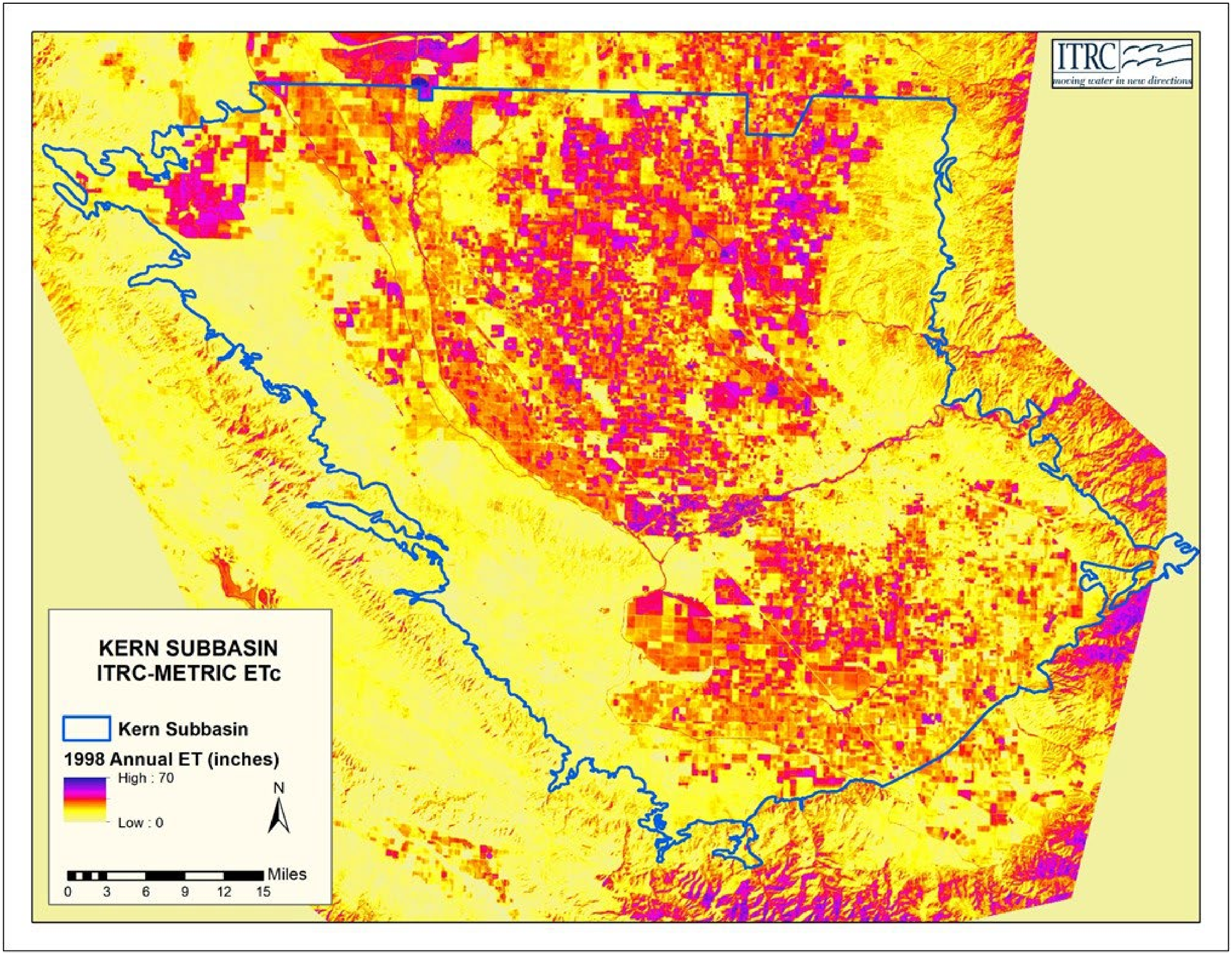
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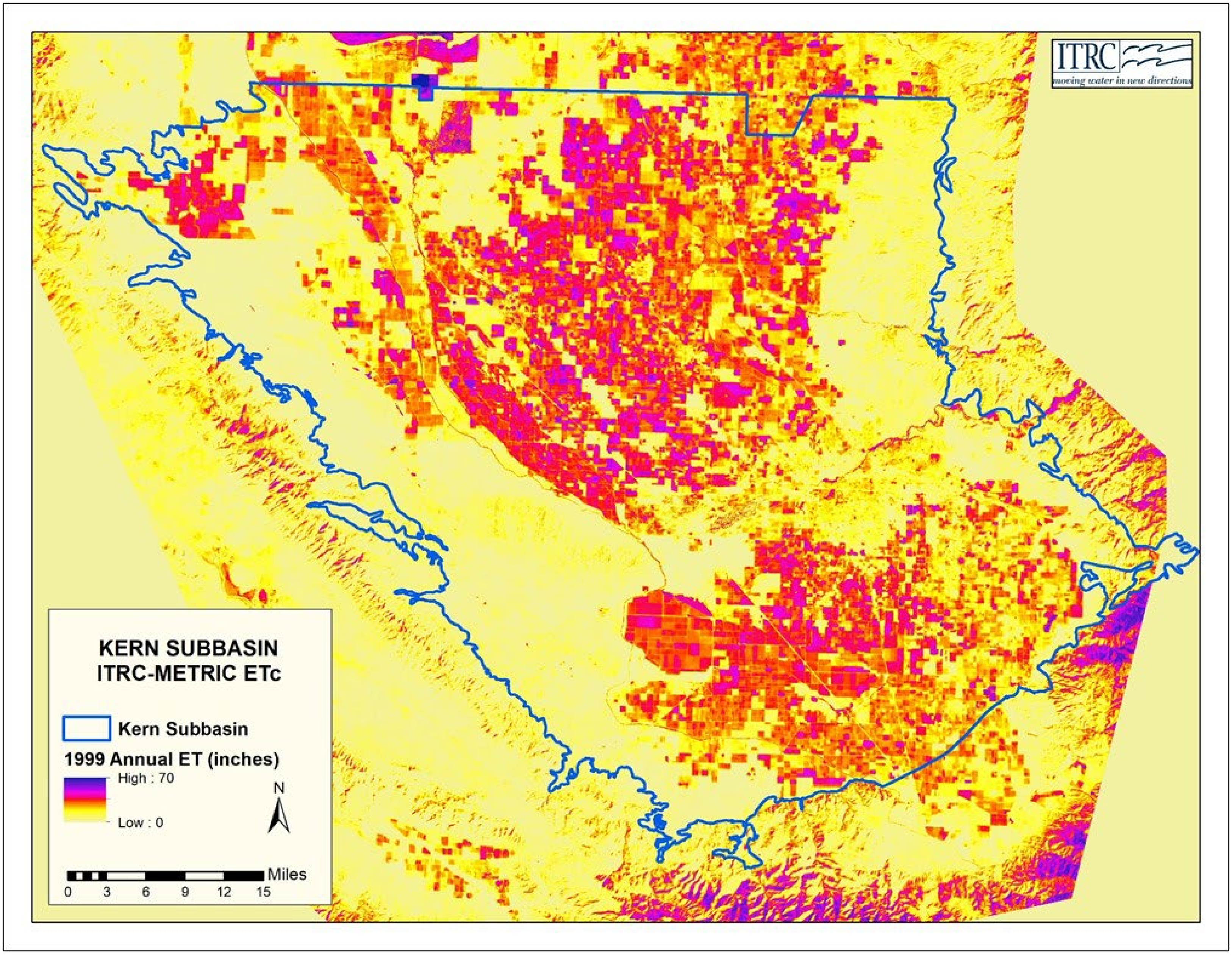
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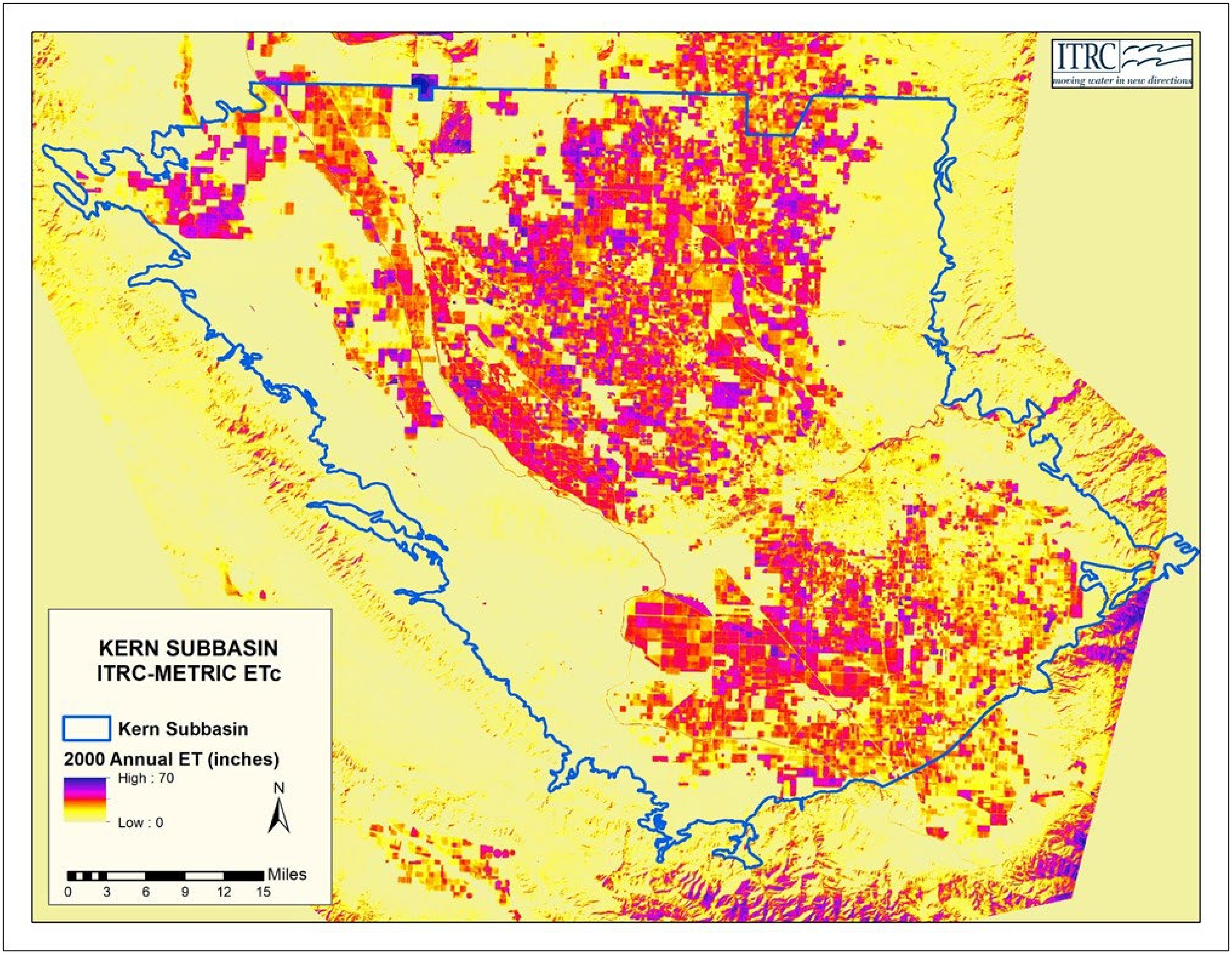
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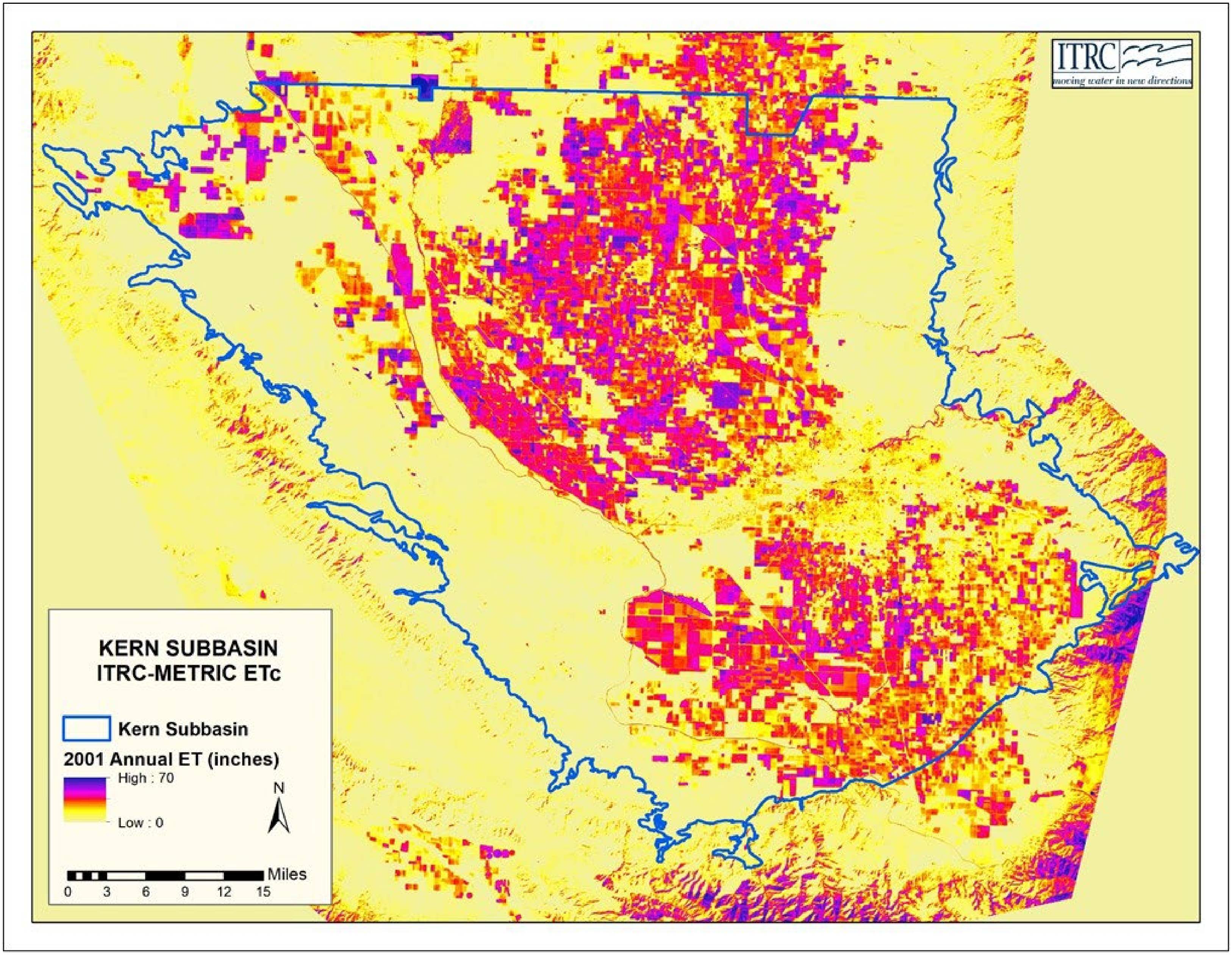
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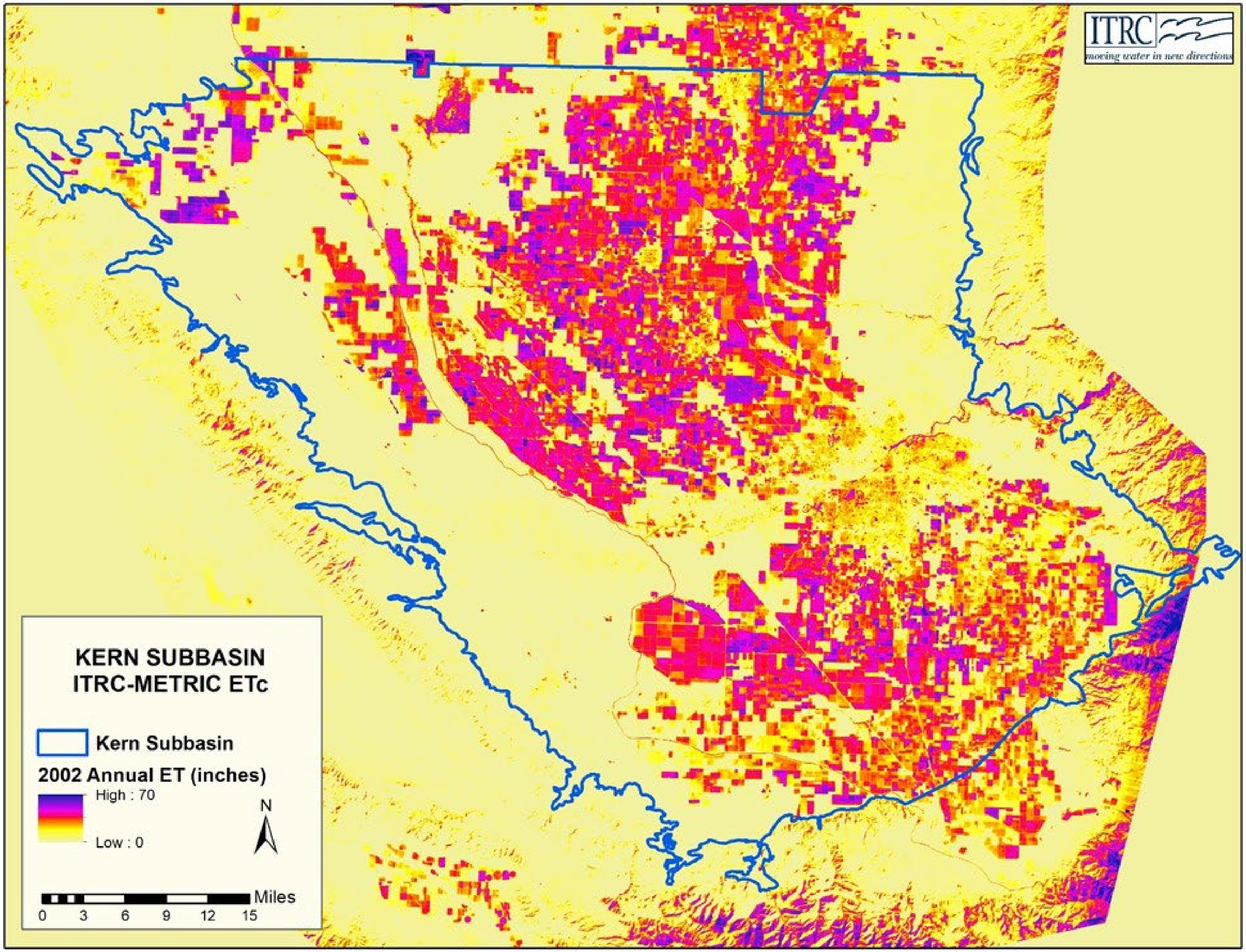

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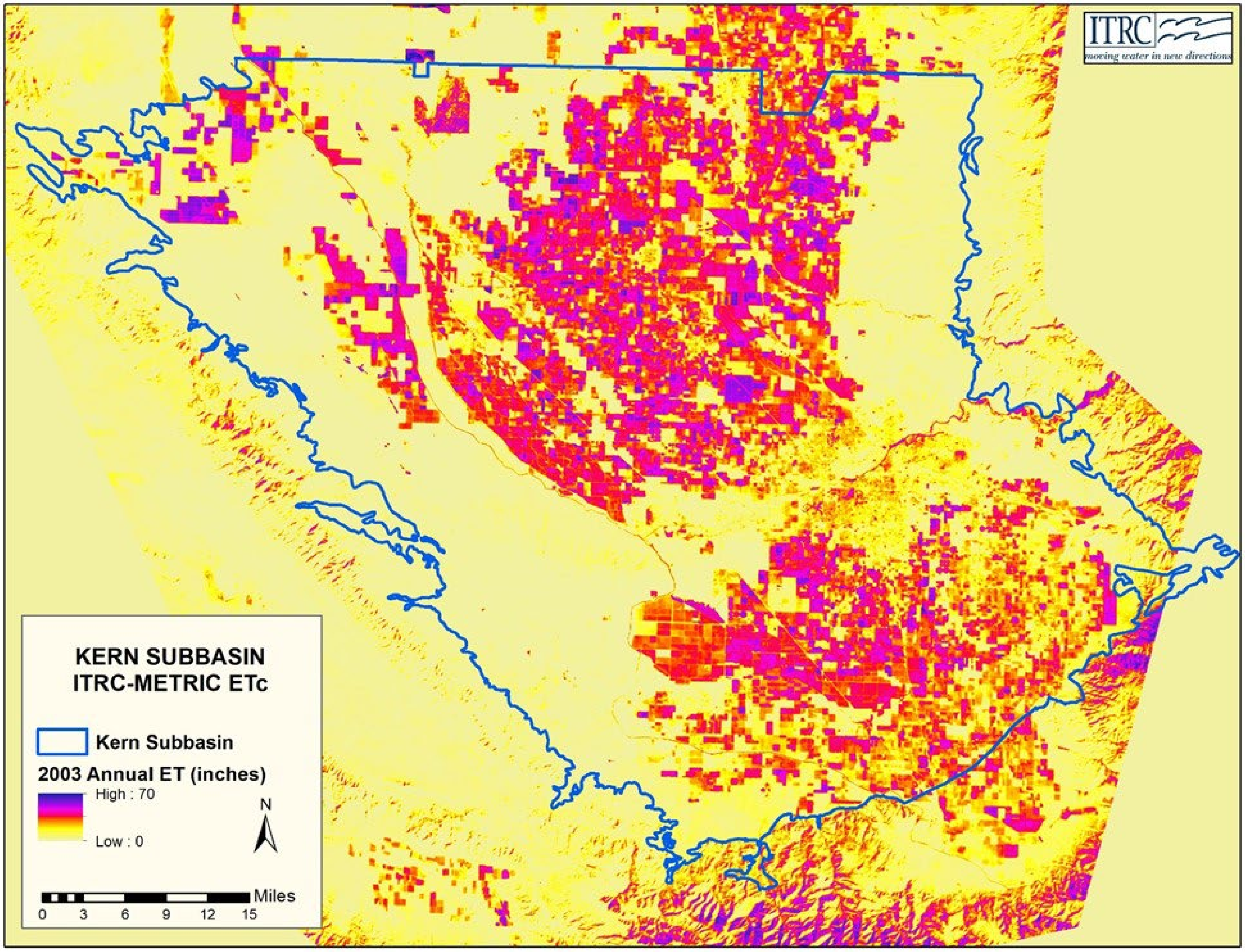
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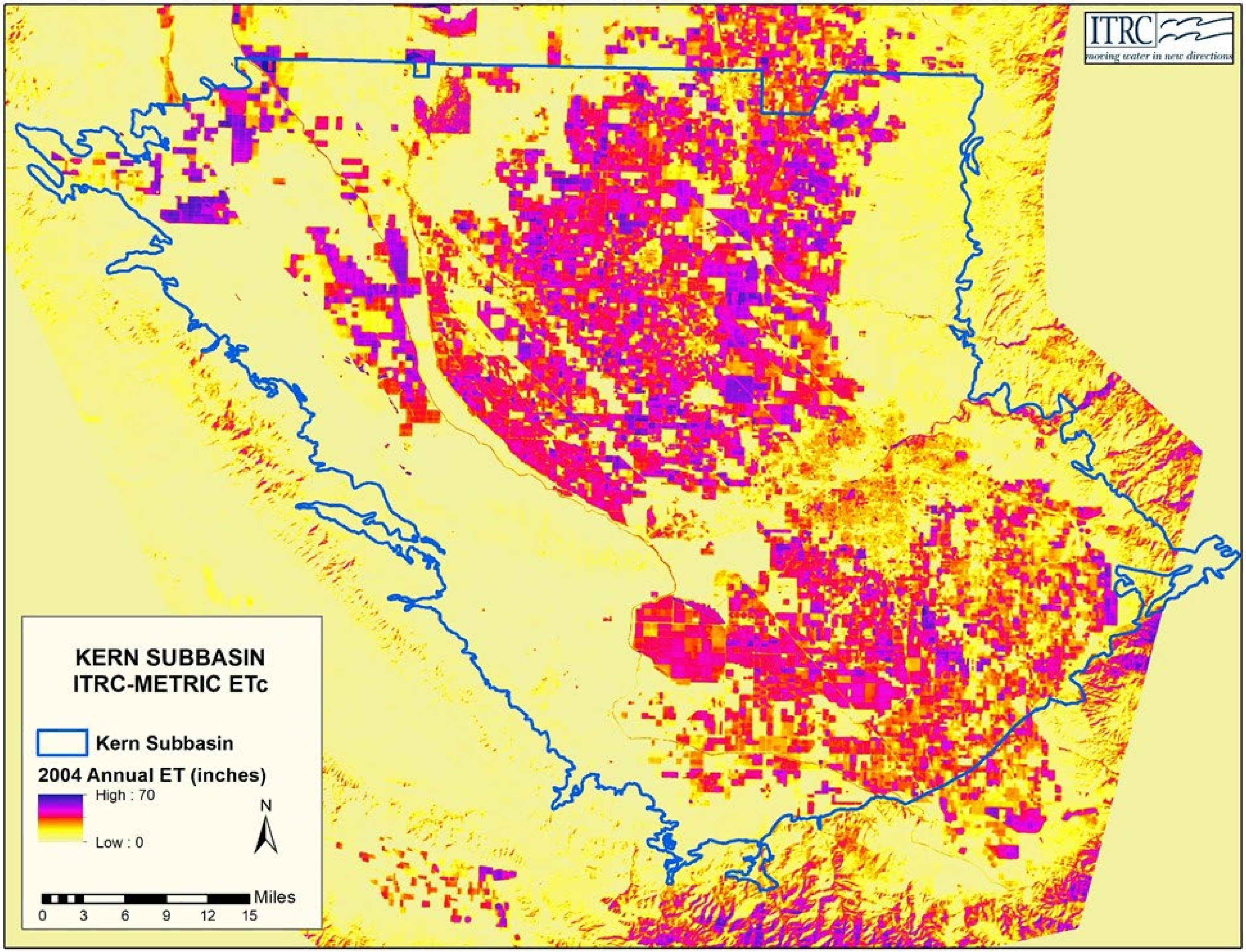
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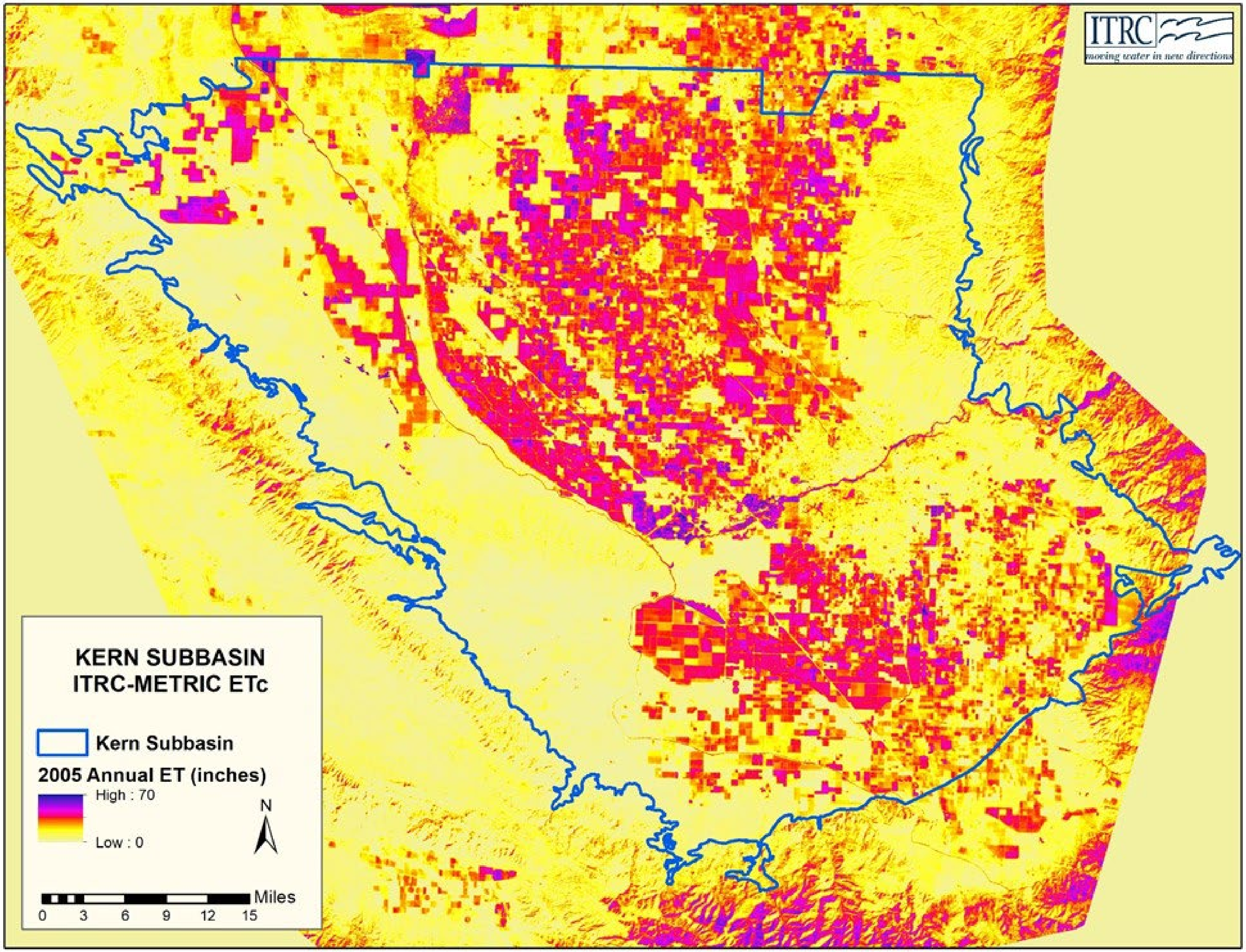
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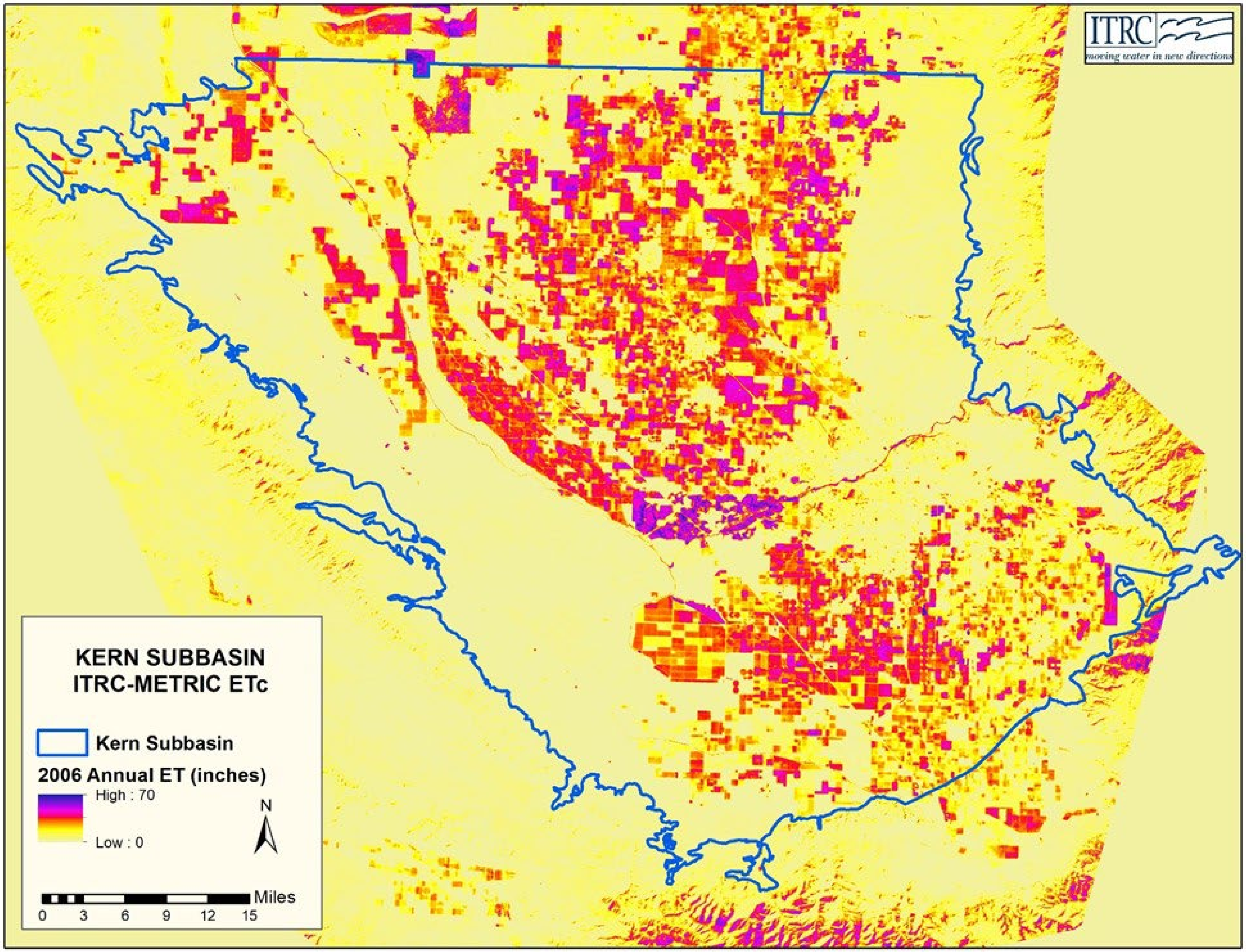
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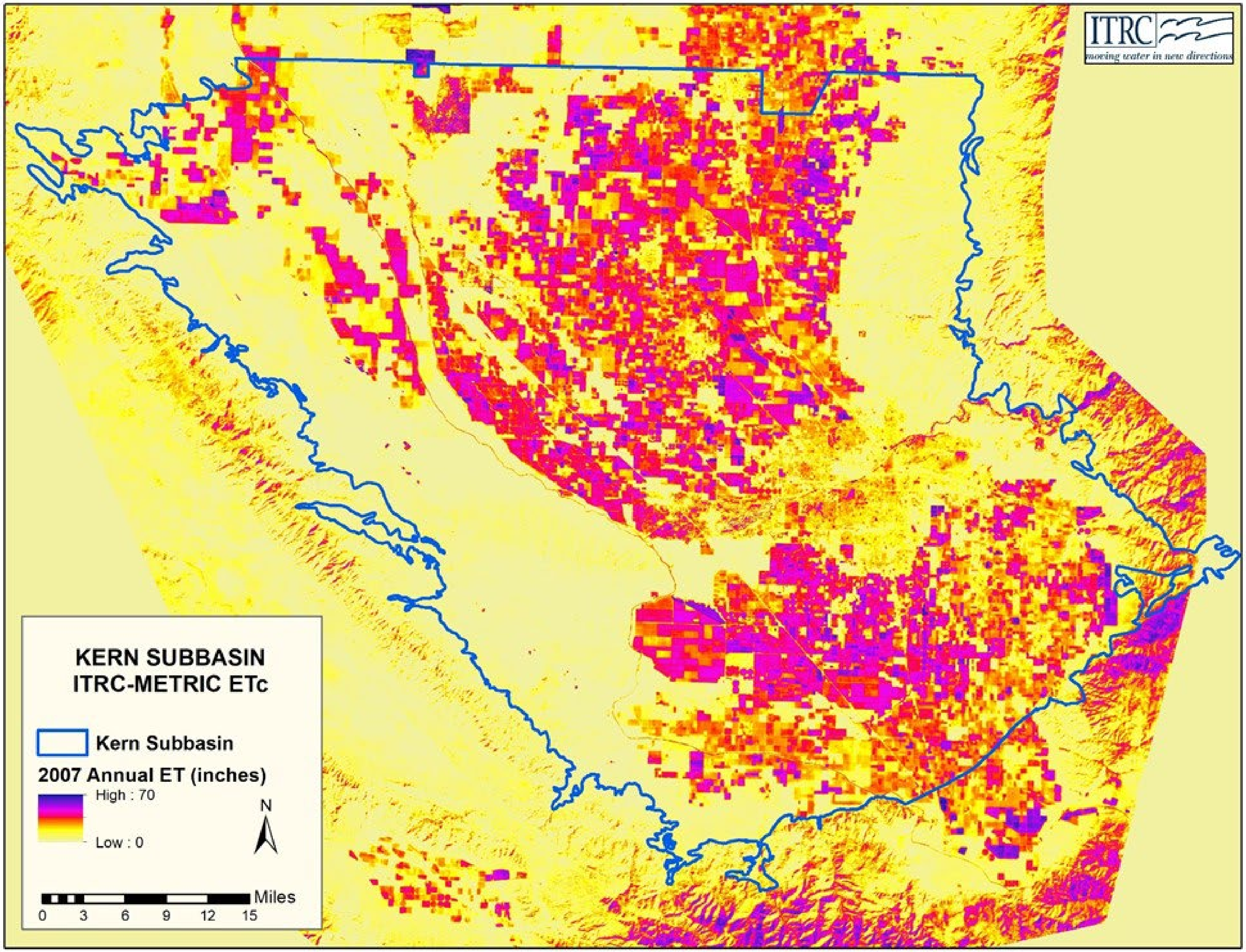
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Kern Subbasin
2007 Annual ET (inches)
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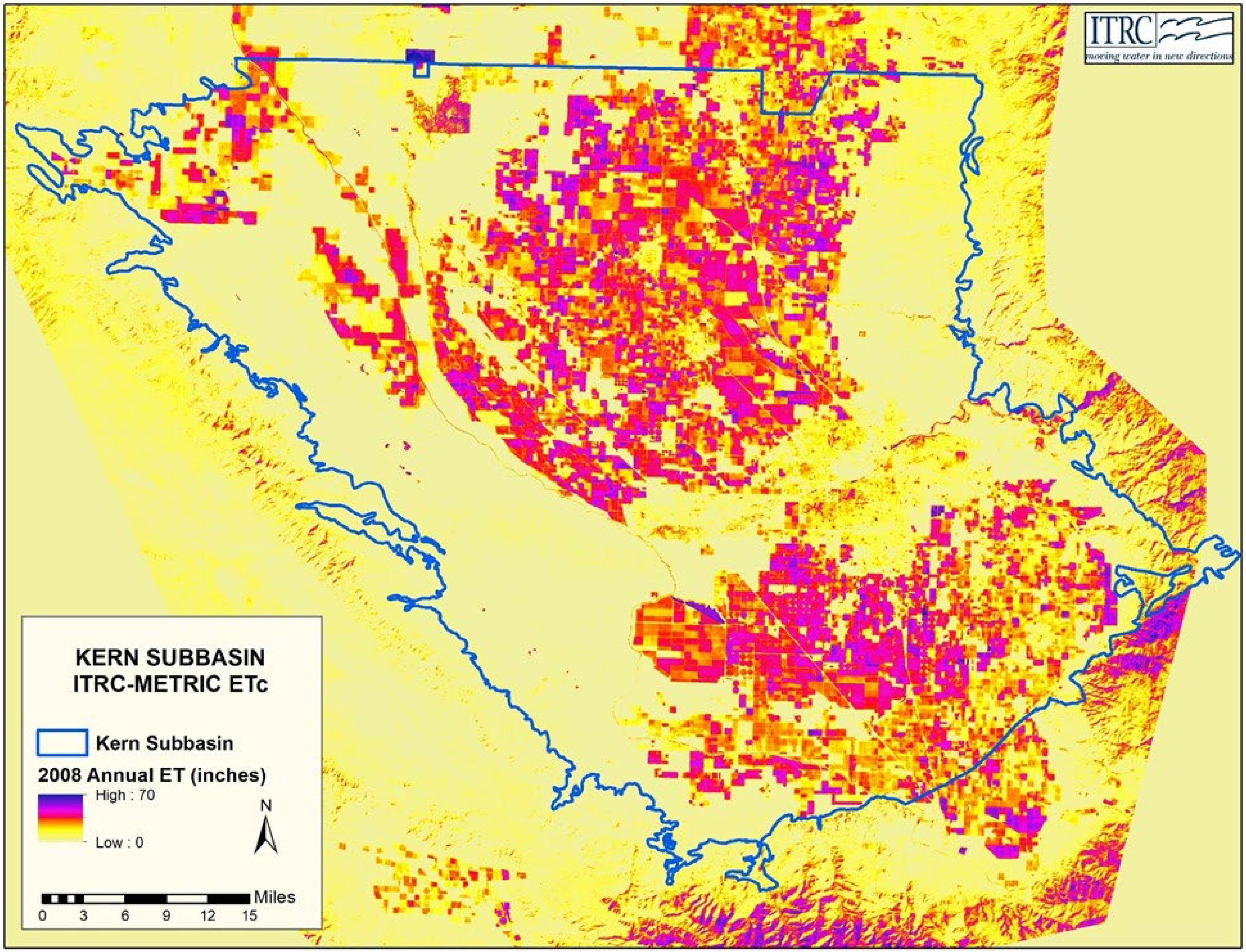
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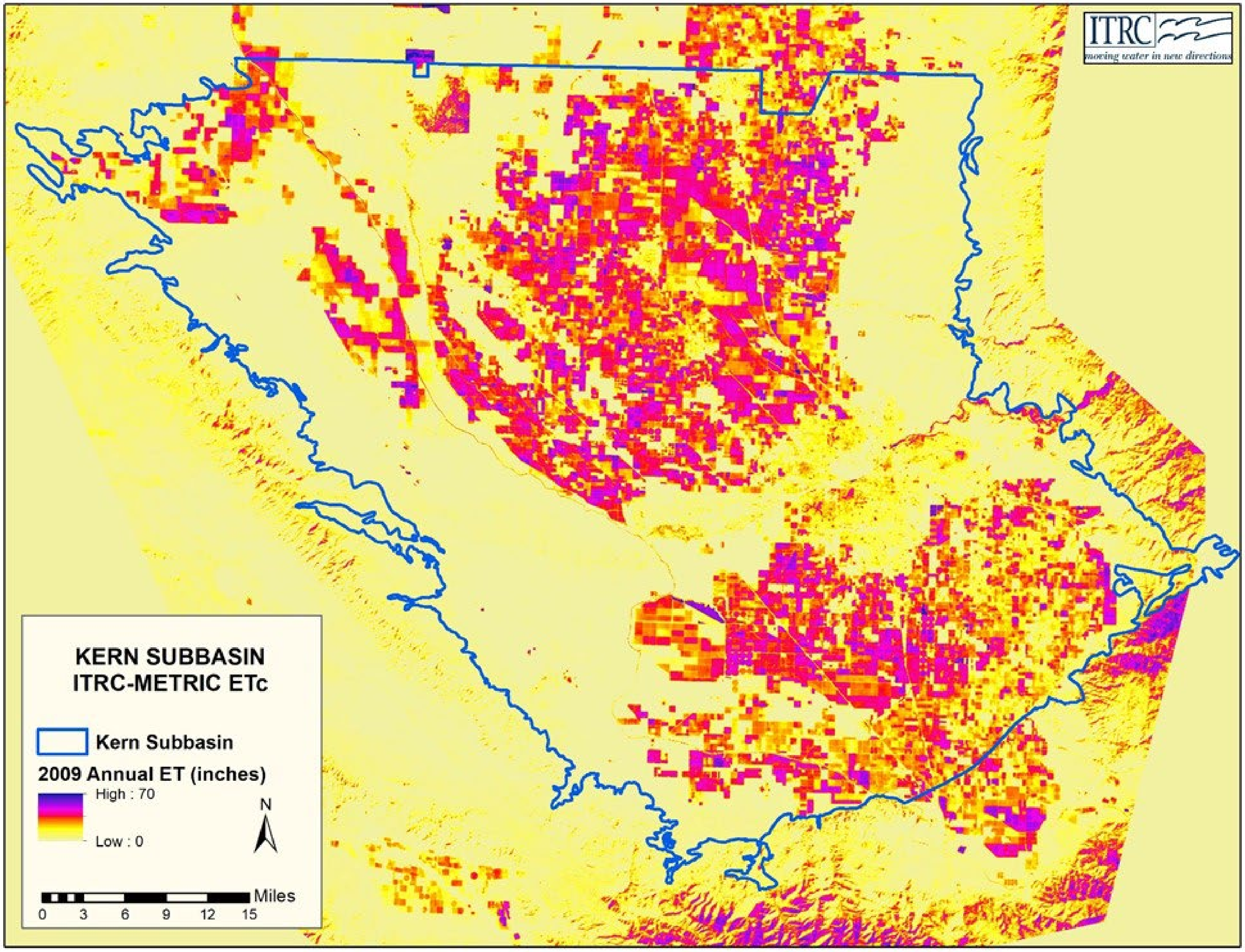
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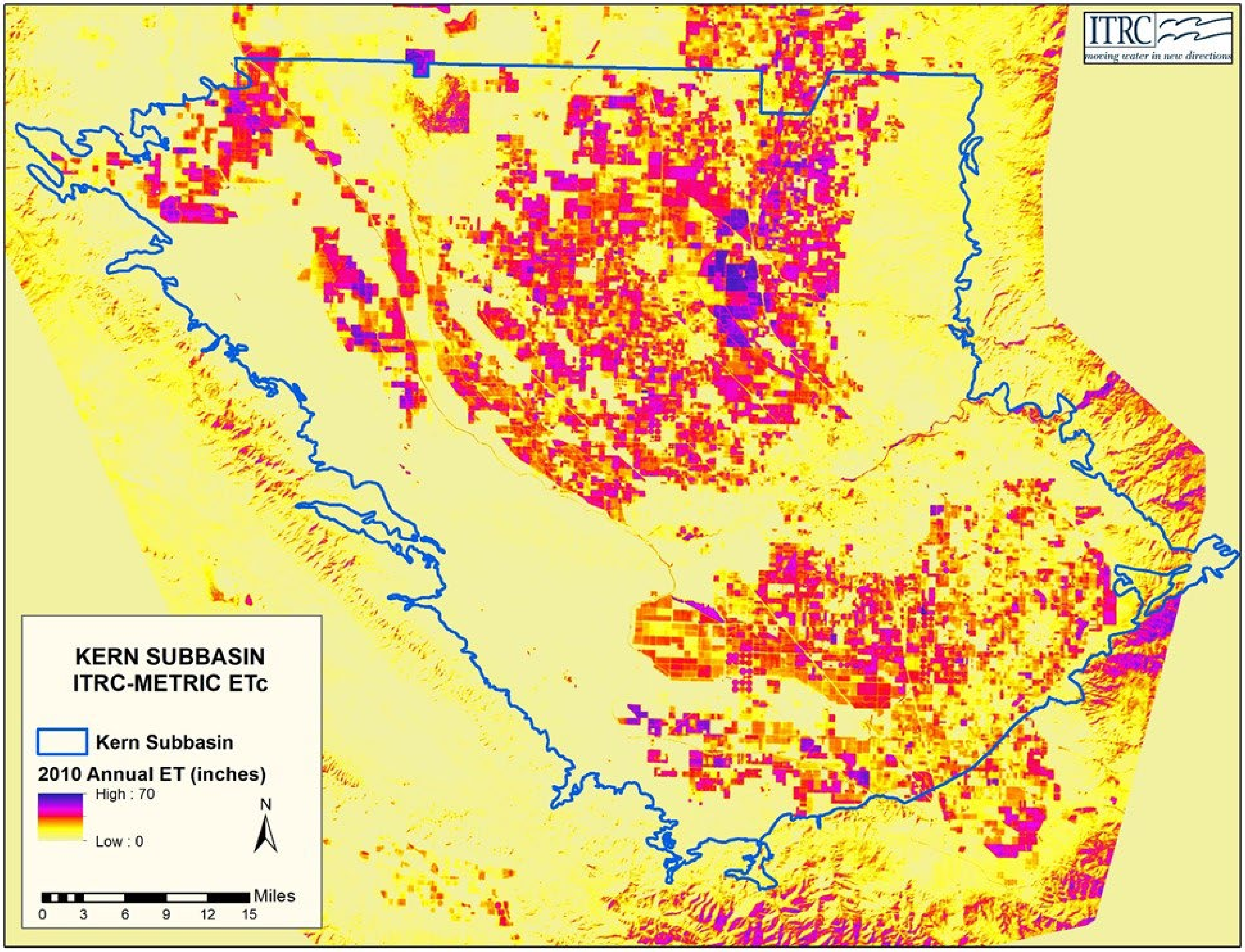

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Kern Subbasin
2010 Annual ET (inches)
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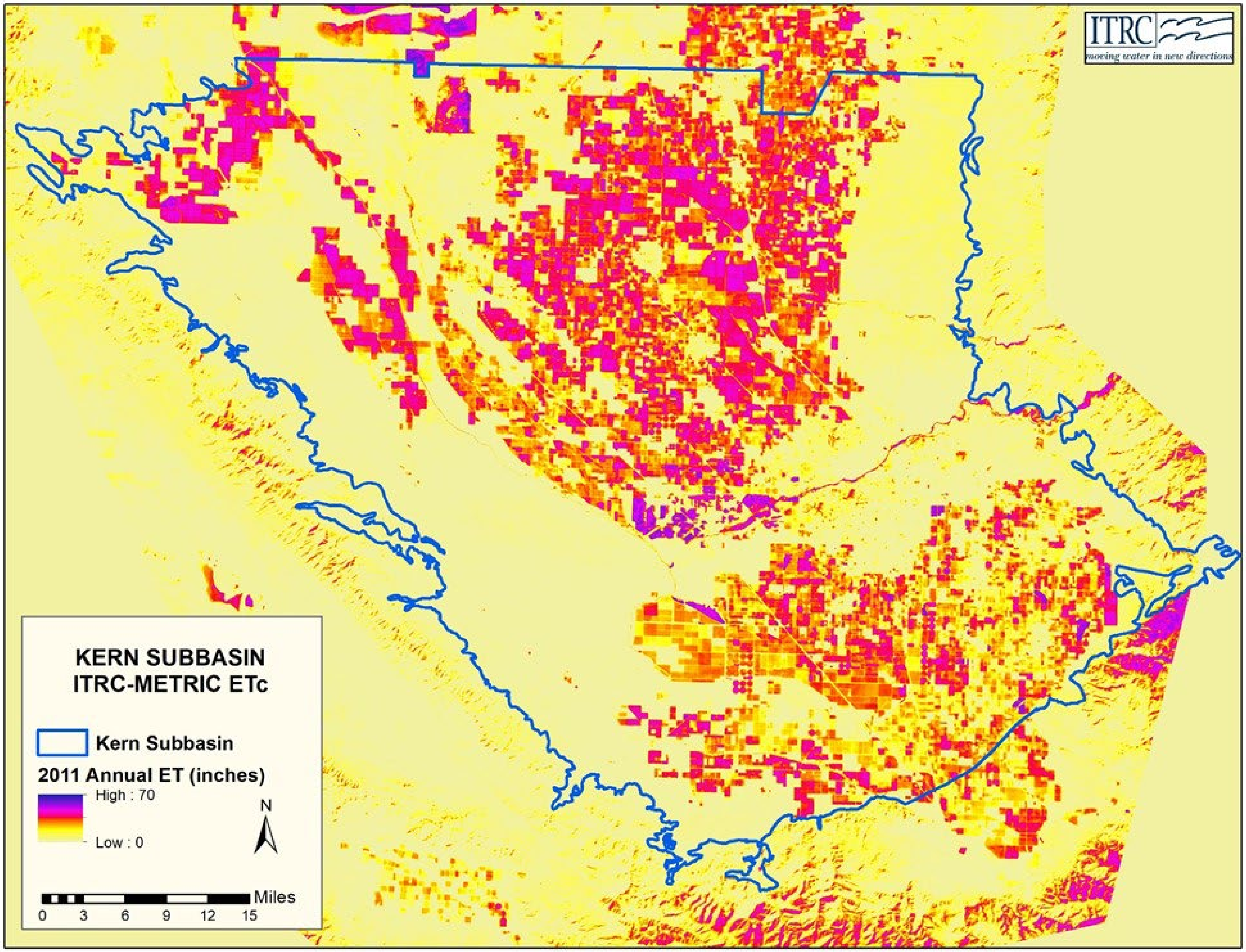
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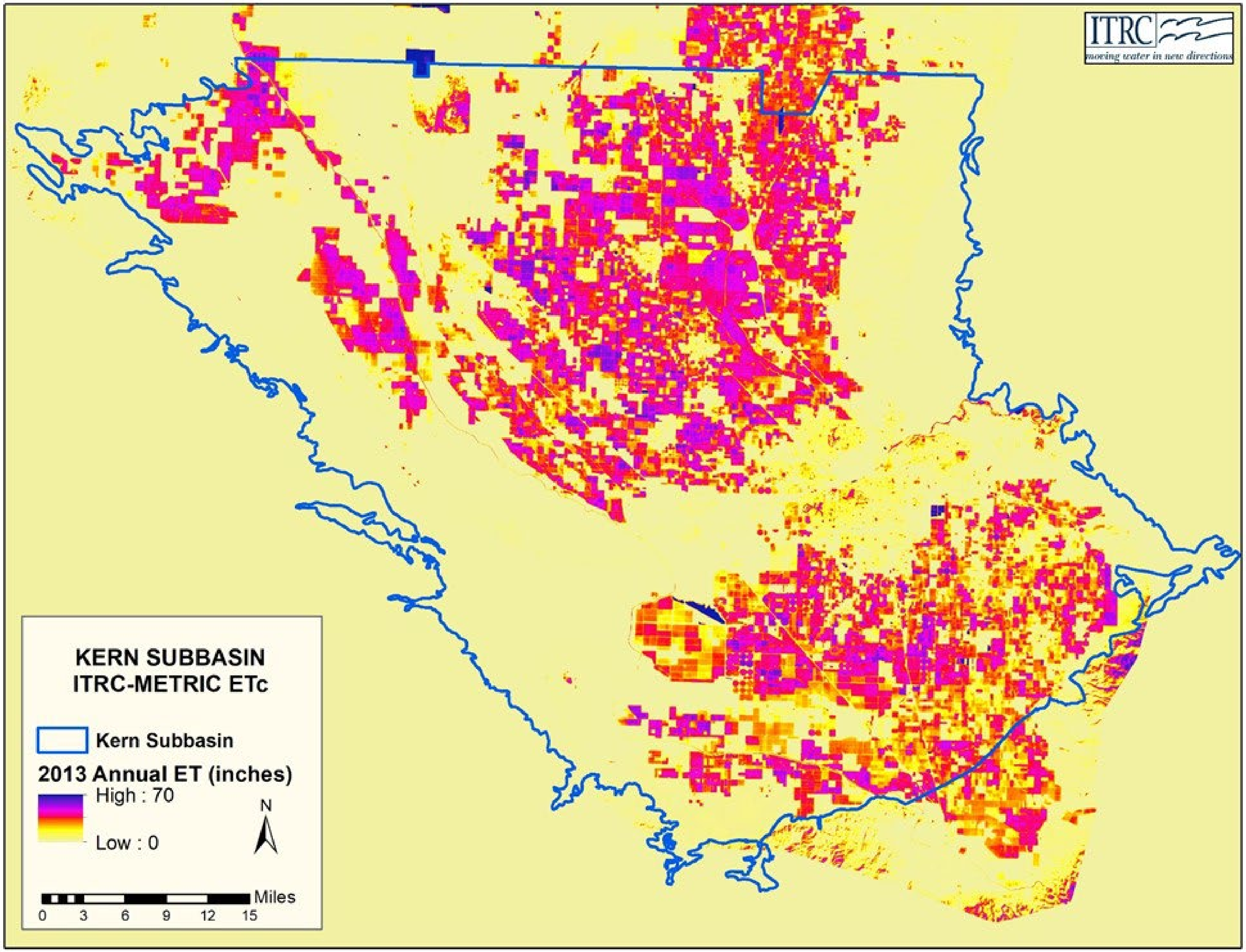
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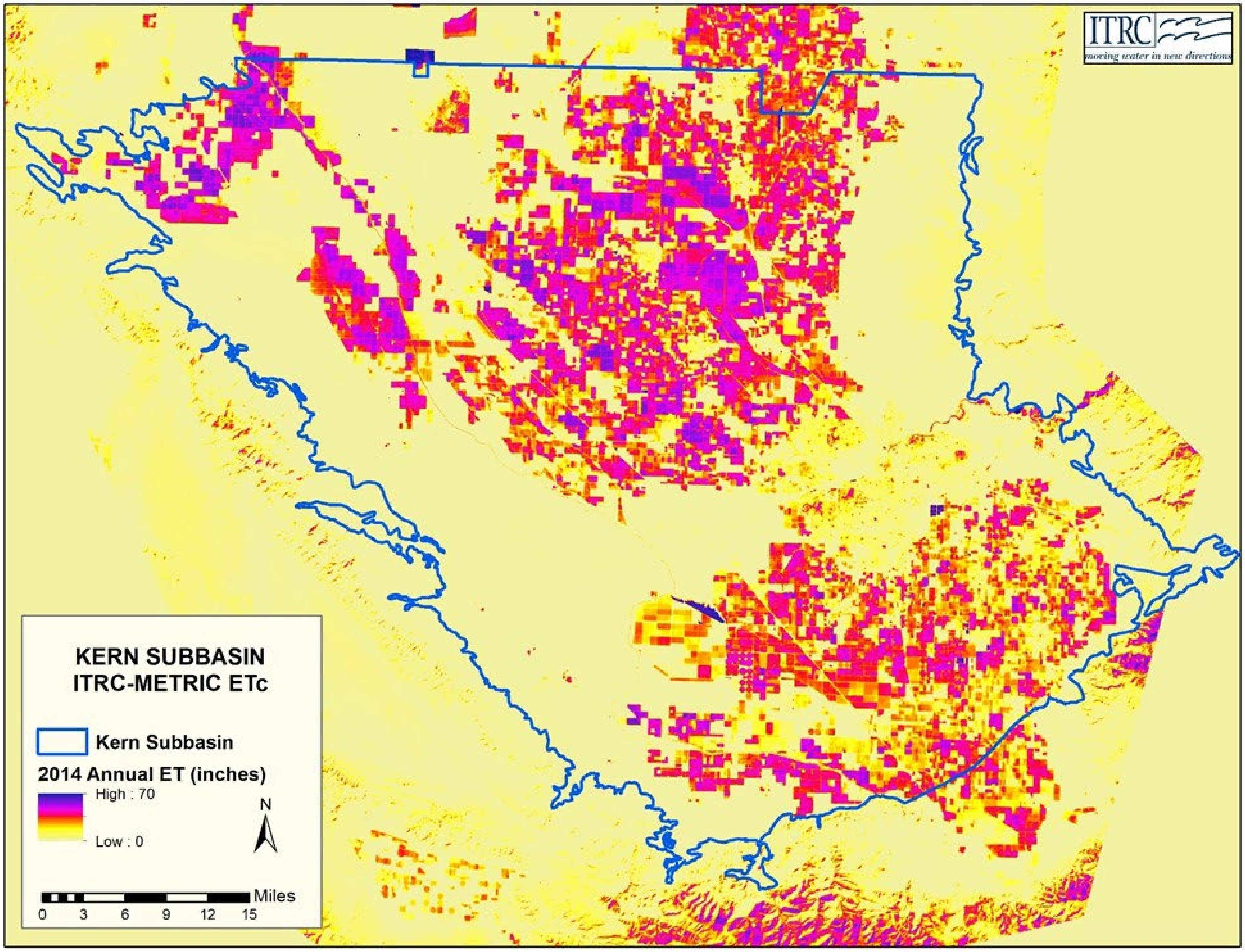
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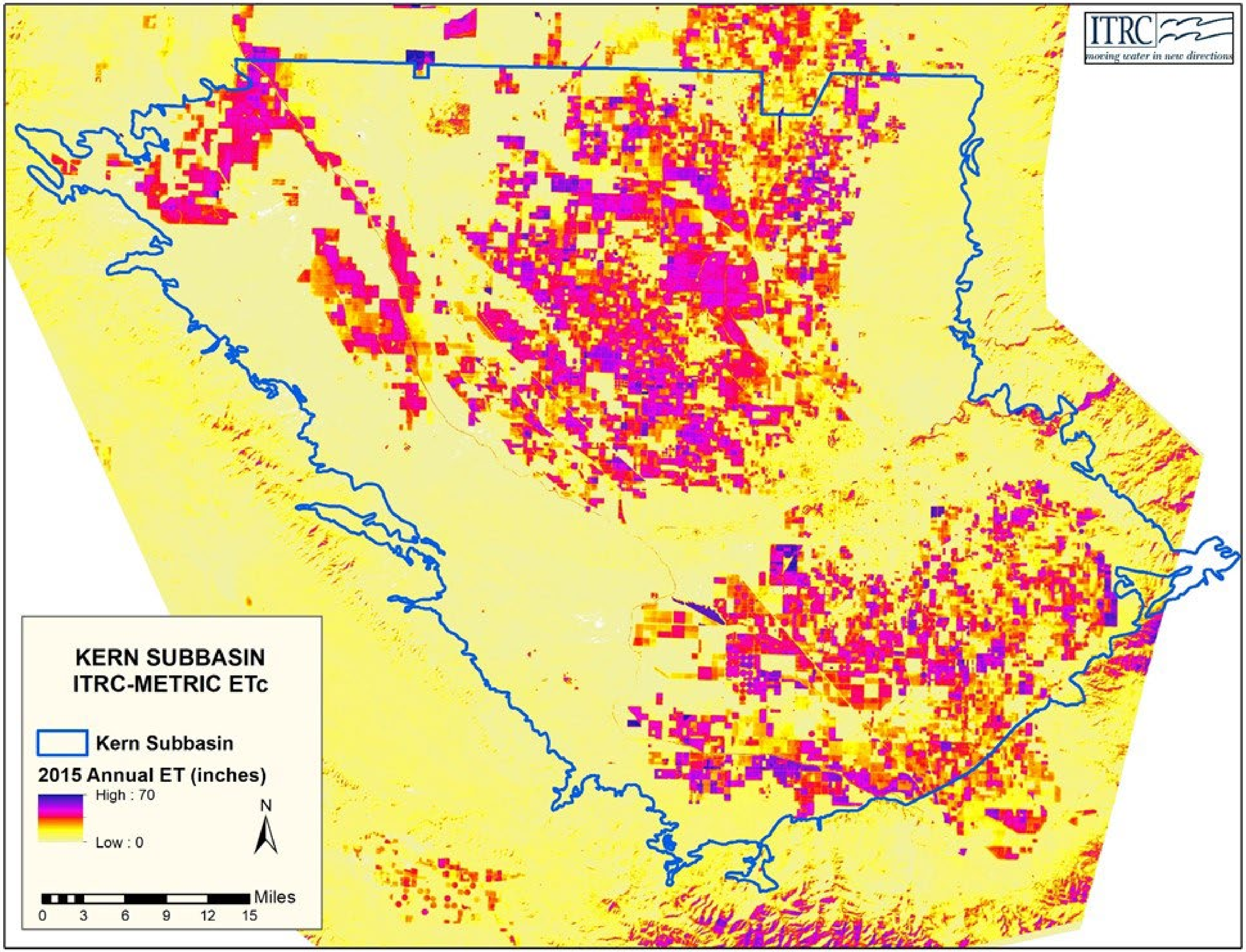

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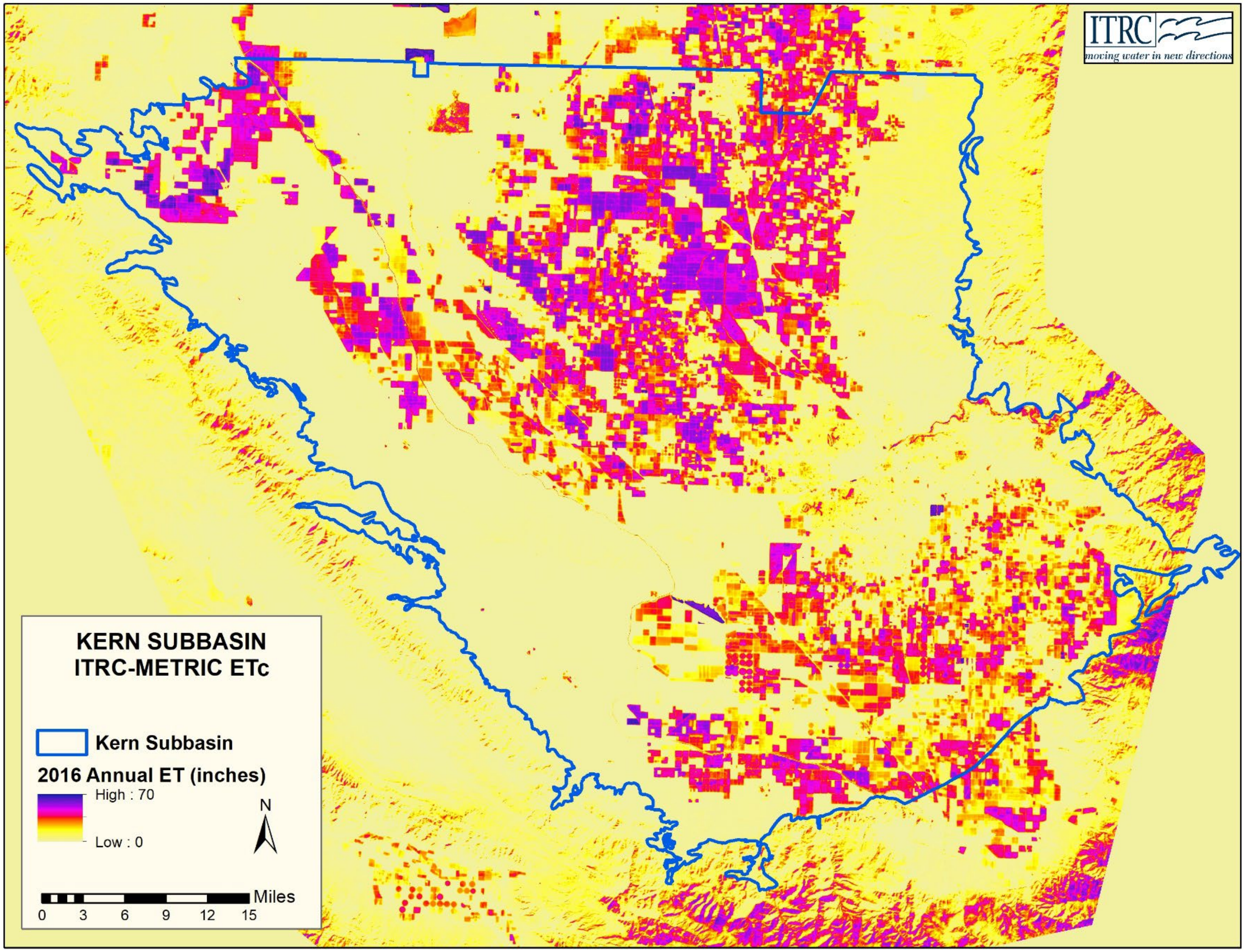
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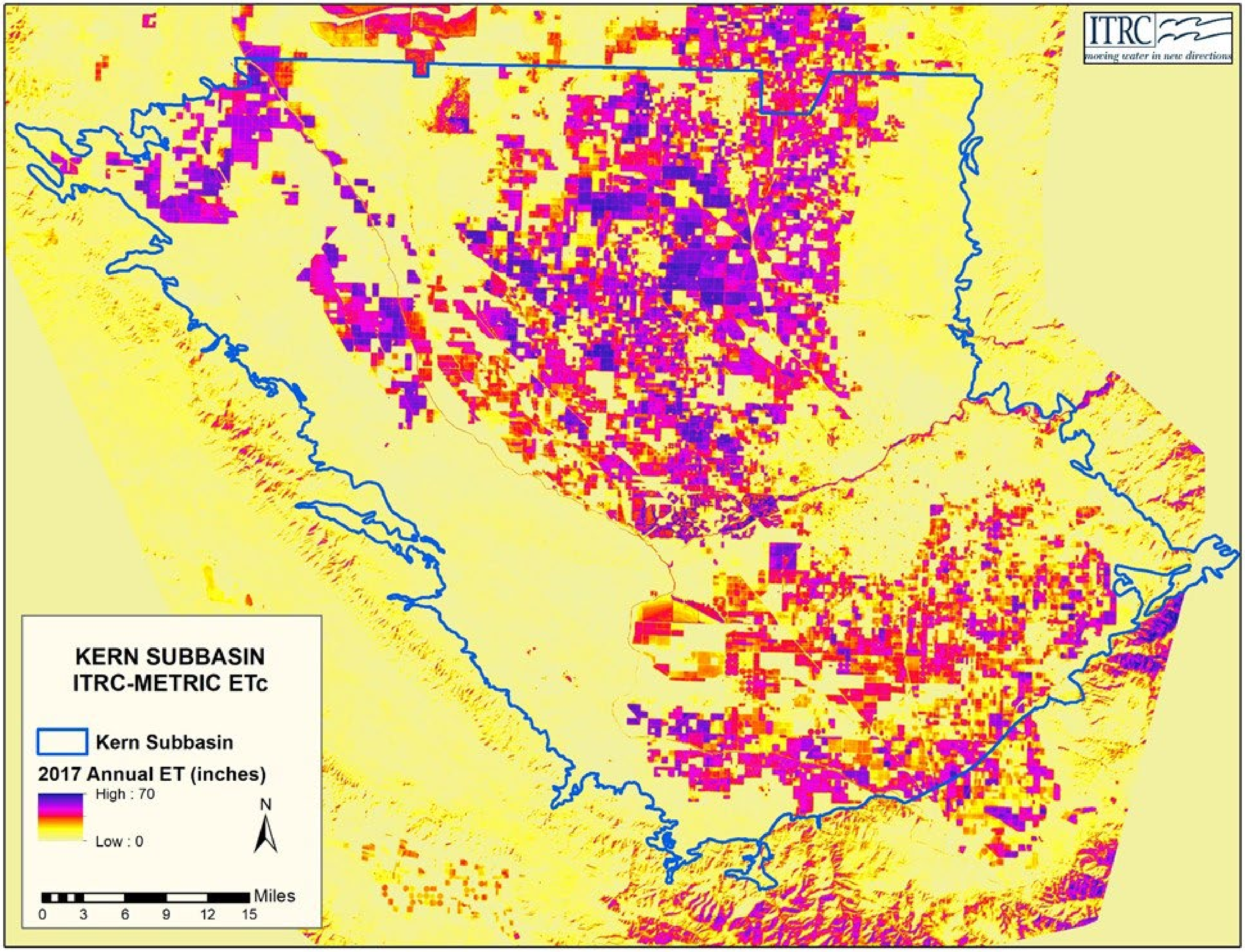
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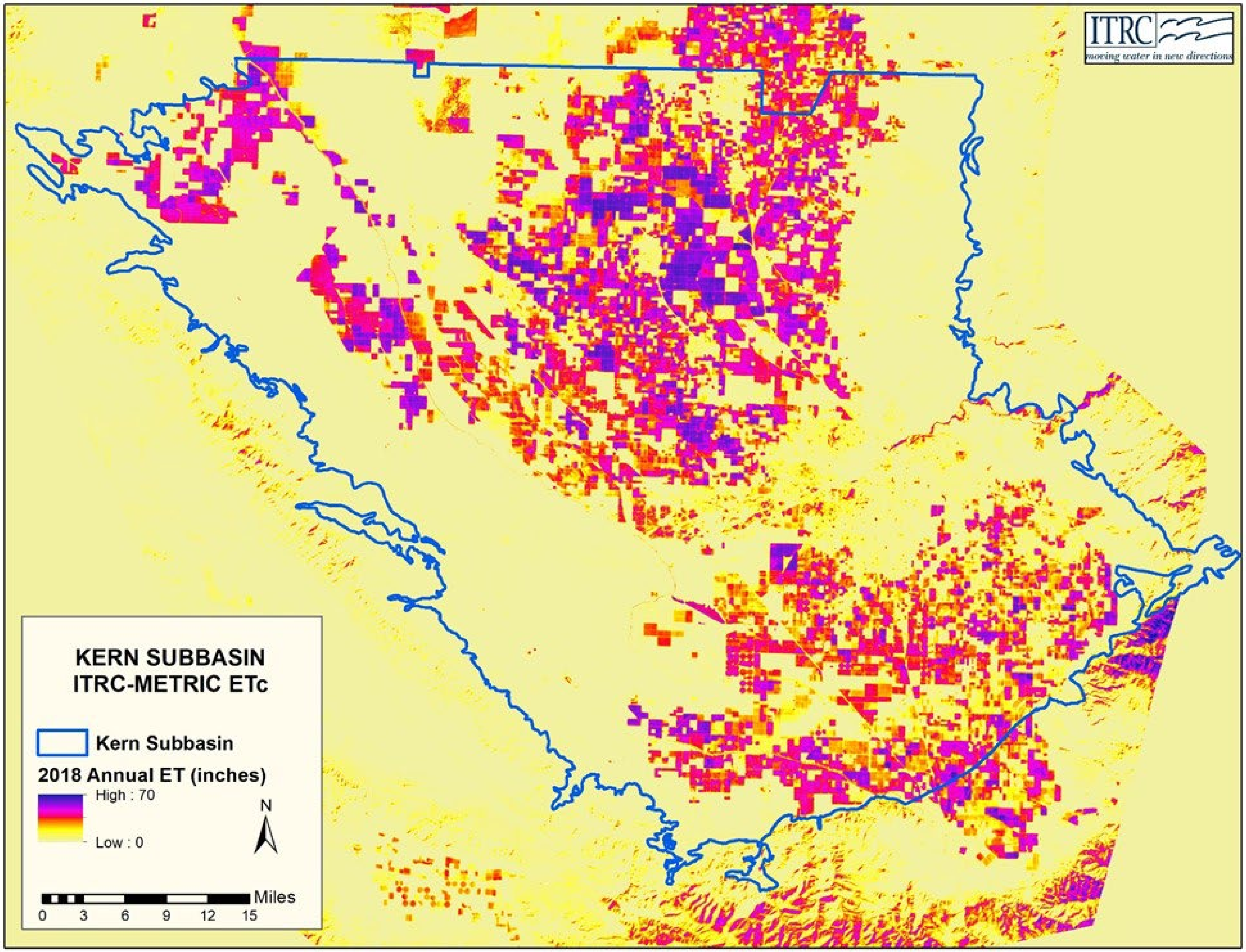
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Kern Subbasin
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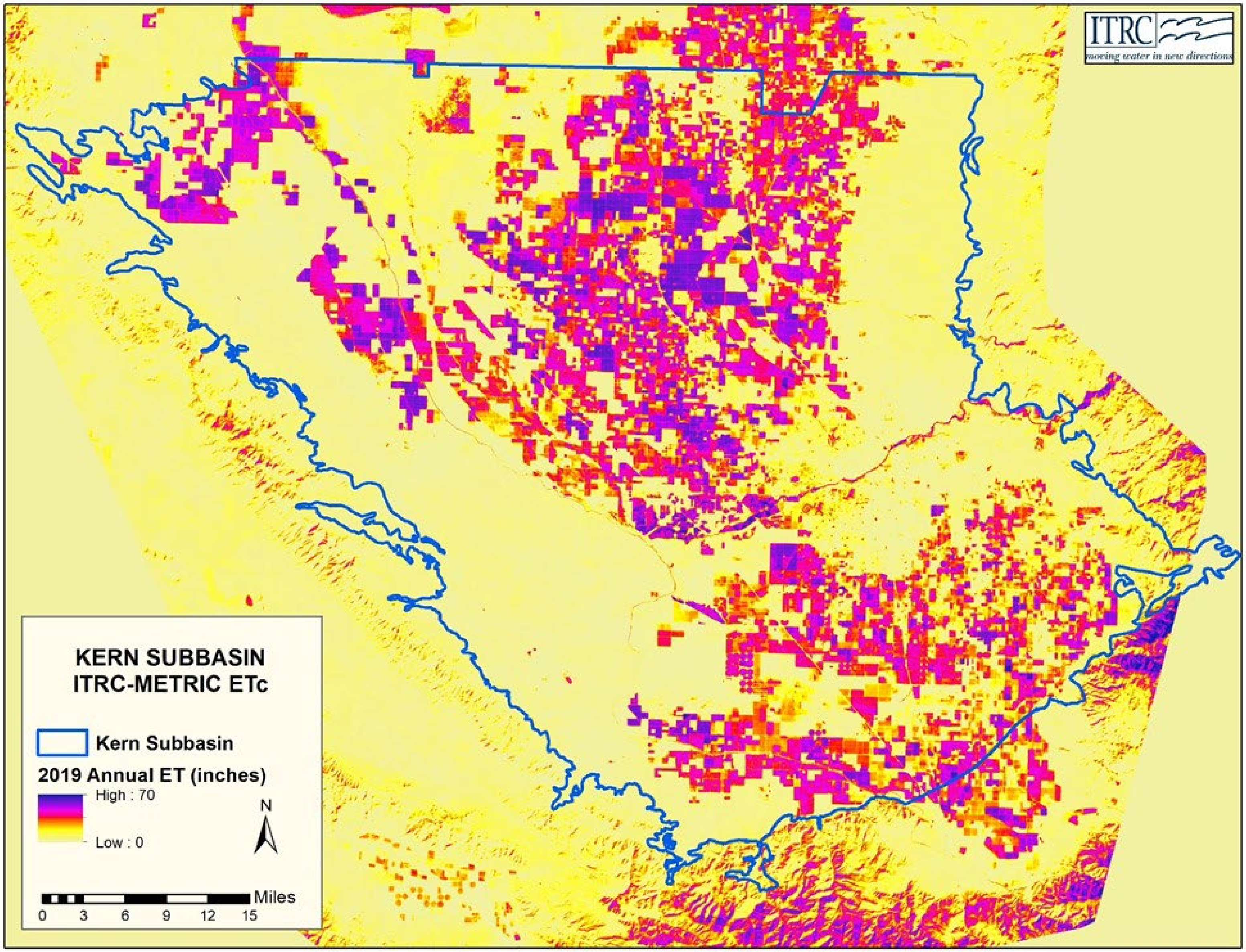
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ITRC-METRIC ETc
Kern Subbasin
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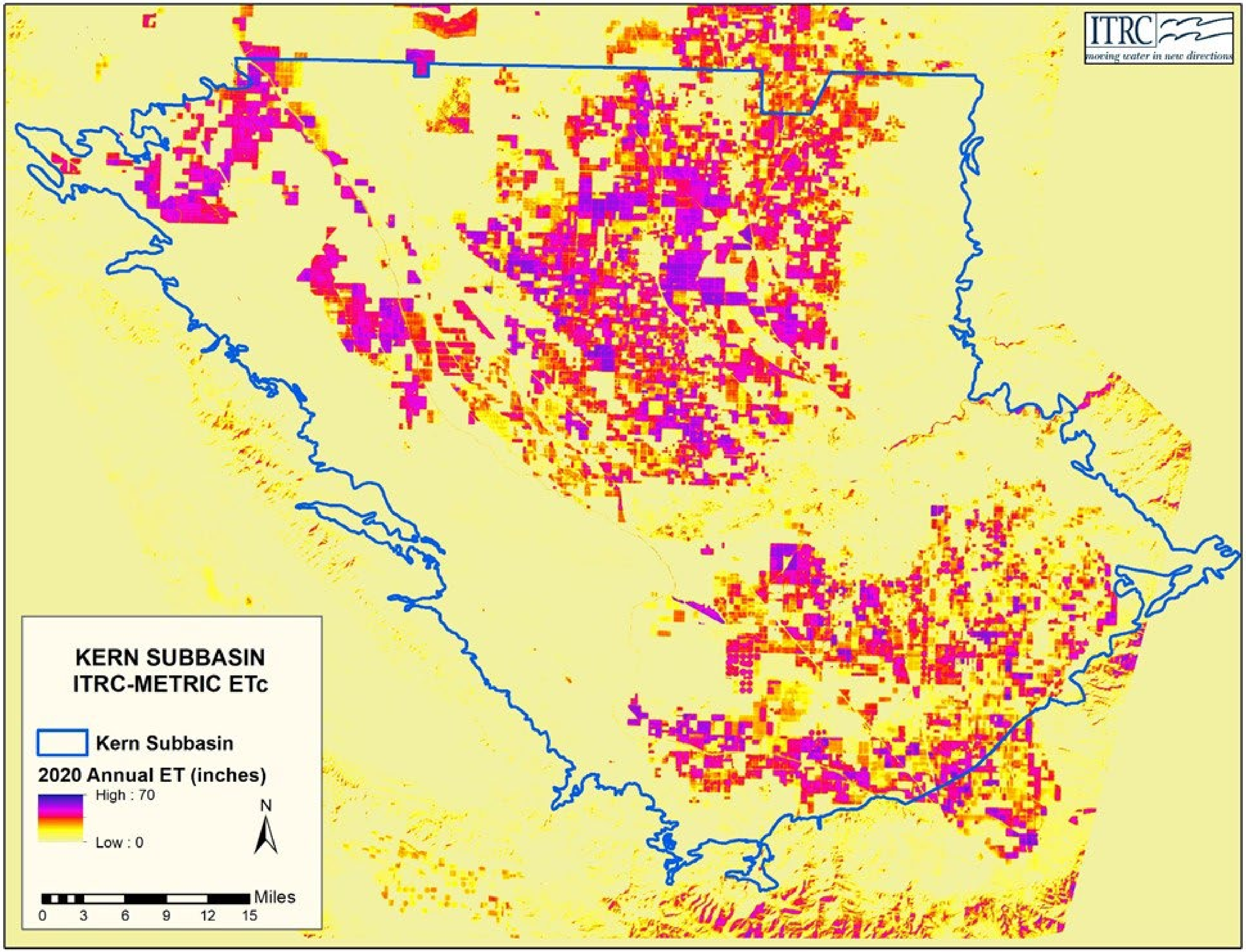
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ITRC-METRIC ETc
Kern Subbasin
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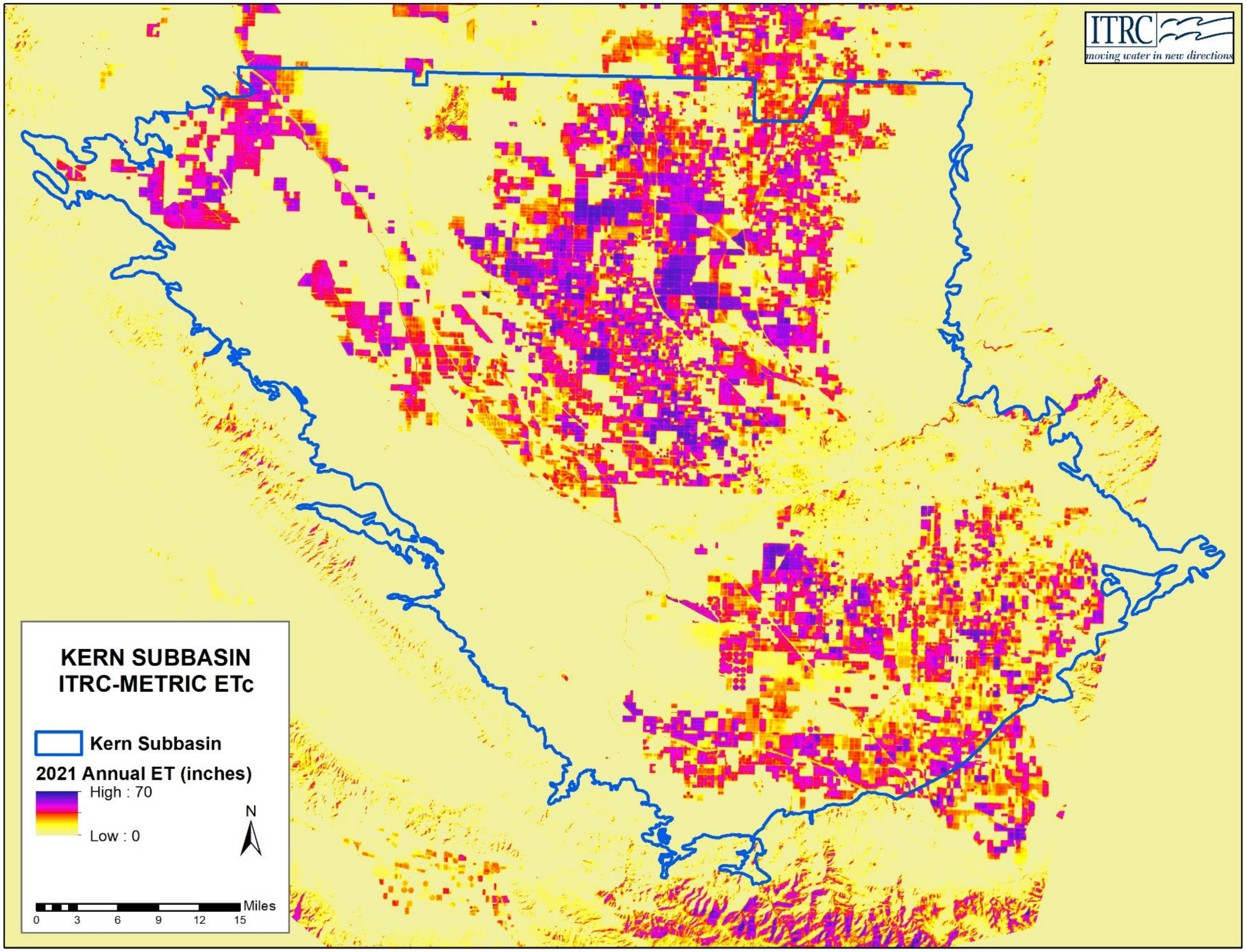
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moving water in new directions
KERN SUBBASIN
ITRC-METRIC ETc
Kern Subbasin
2021 Annual ET (inches)
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Low : 0
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Miles
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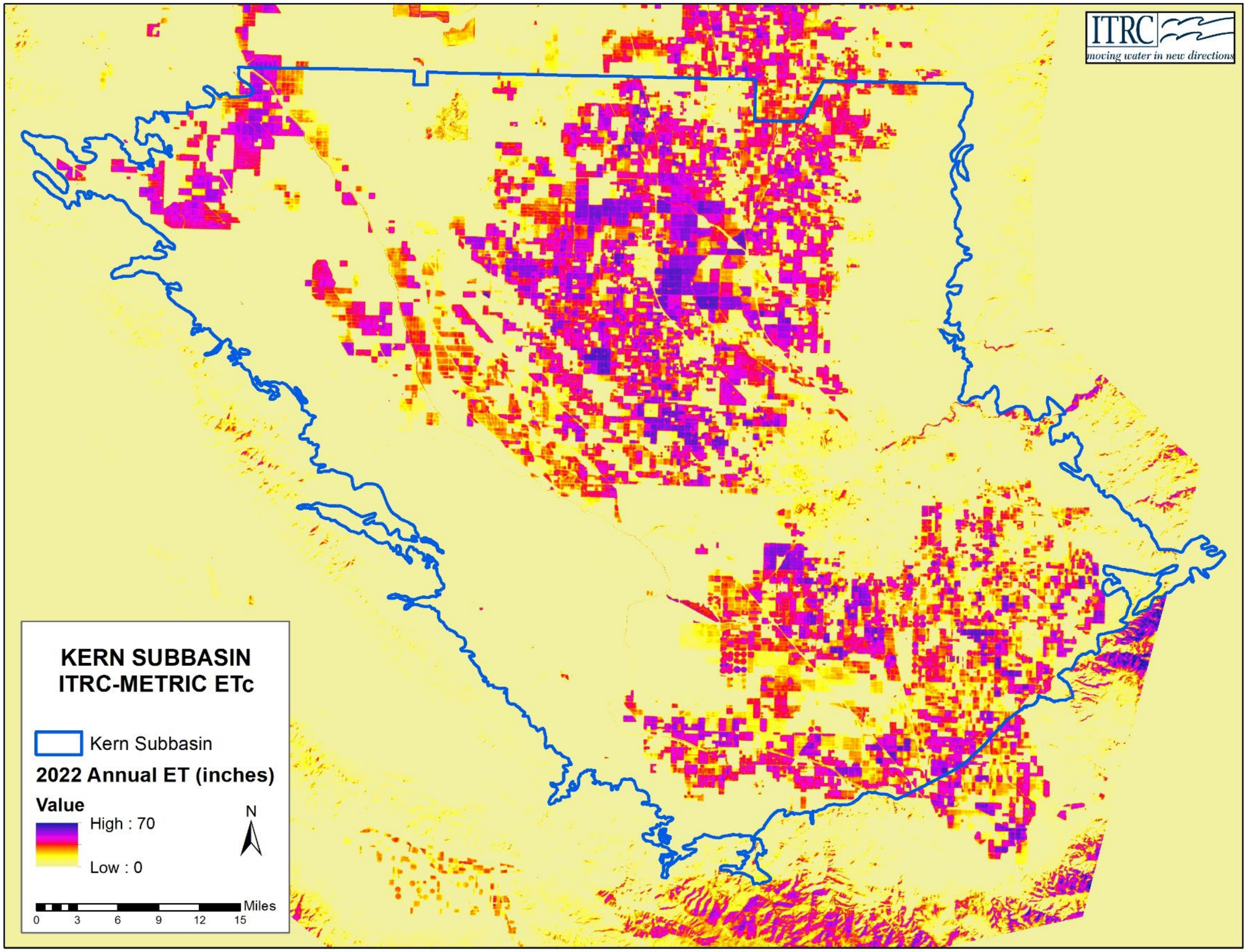
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Kern Subbasin
2022 Annual ET (inches)
Value
High : 70
Low : 0
N
Miles
0 3 6 9 12 15