River Partners

Evapotranspiration at the Grayson Property

Prepared by
Daniel J. Howes, Ph.D., P.E.
Office: 805-756-2347
Mobile: 858-354-0504
djhowes@calpoly.edu

Prepared for
Julie Rentner, President
River Partners
Office: 530-894-5401 x226
Mobile: 209-639-2012
jrentner@riverpartners.org

Final 1/23/2020

January 2020

IRRIGATION TRAINING & RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Office Phone: (805) 756-2434 FAX: (805) 756-2433
www.itrc.org

Table of Contents

List of Figures

List of Tables

River Partners
Evapotranspiration at the Grayson Ranch

Background

This report was prepared at the request of River Partners to examine historical and predicted future vegetation evapotranspiration on Grayson Ranch. Evapotranspiration is the water that evaporates from the soil and plant surfaces plus the water that moves through the plants into the atmosphere (transpiration).

The Grayson property is in Stanislaus County. River Partners is replacing the agricultural fields with native vegetation. This vegetation will be irrigated for approximately three years and then it will rely on rainfall and shallow groundwater into the future. The objectives of this study were to:

1. Determine, using remote sensing, the historic actual evapotranspiration from the fields and existing natural areas in Grayson.
2. Predict future evapotranspiration demands once the native areas mature in 10-20 years.

The process to measure the actual consumptive use in Grayson is called ITRC-METRIC (Irrigation Training and Research Center modified Mapping EvapoTRanspiration with Internal Calibration). This methodology has been used extensively throughout California (and worldwide) to determine actual evapotranspiration from vegetation.

The basic strategy for estimating future water requirements leverages ITRC-METRIC and the fact that this project borders rehabilitated areas in the San Joaquin National Wildlife Refuge (SJNWR). This area has been restored over time with various plantings that will be similar to those used in Grayson. Older restored sites were planted in 2002 and younger plantings in 2012. The fields in SJNWR will be used to predict the evapotranspiration in the Grayson post restoration. The fields in Grayson, SJNWR, and another River Partners' project (Dos Rios) are shown in Figure 1.

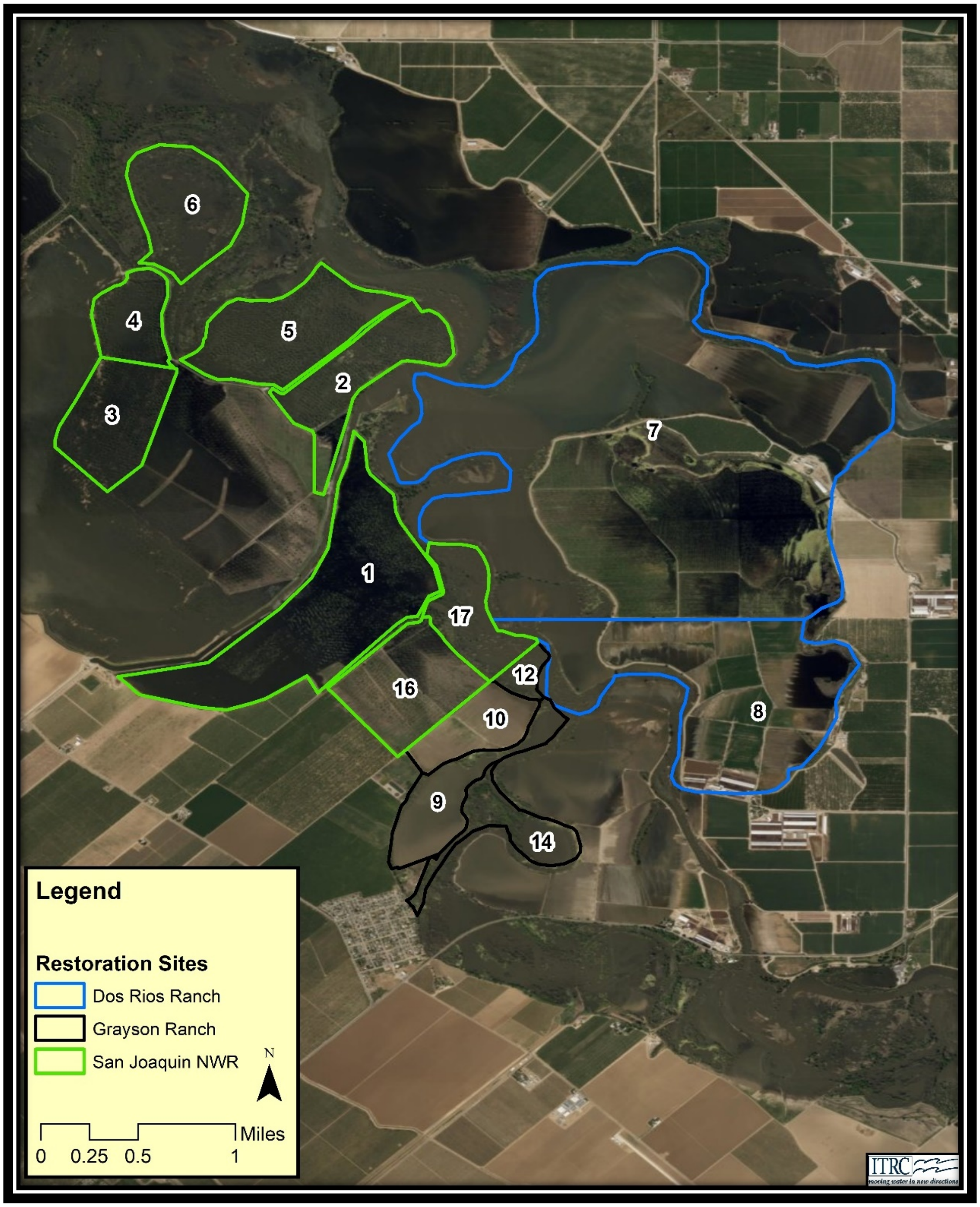


Figure 1. Grayson fields and nearby fields in Dos Rios and SJNWR

ITRC- METRIC Procedures

This *Procedures* section will discuss the information that was gathered and used to compute the actual crop evapotranspiration (ET). 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

Satellite Images

LandSAT 5, 7 and 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
June 1982 – Oct. 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 43, rows 34 and 35. 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.

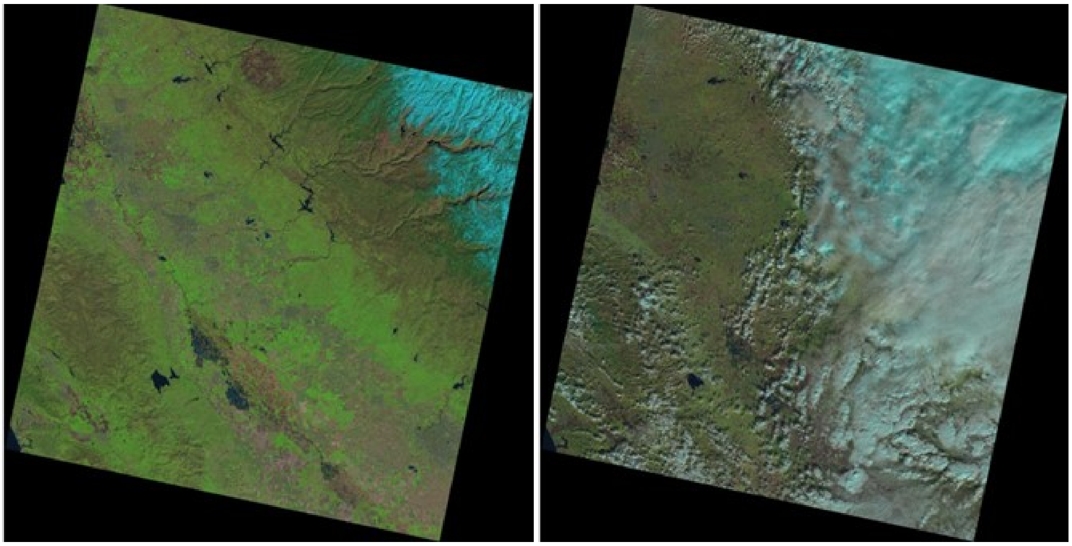


Figure 2. Cloud-free LandSAT image (left) and LandSAT image with clouds (right)

All relatively cloud-free available images were used for the modeling process. Table 2 shows the images processed for the study period. A total of 29 images were used to cover the newly processed 2015 to 2016 time frame. The images utilized from the previous years are also shown as a reference.

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 pixel 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.

Table 2. Chosen image dates for METRIC processing

2008	2009	2010	2011	2013	2014	2015	2016
2/7/2008	1/16/2009*	2/12/2010	2/7/2011*	4/25/2013	1/22/2014	1/1/2015*	2/5/2016*
3/26/2008	2/1/2009*	4/1/2010	3/11/2011*	5/11/2013	2/23/2014	2/26/2015	2/29/2016
4/11/2008	3/13/2009	5/1/1935	4/4/2011	6/12/2013	3/11/2014	3/14/2015	3/16/2016
4/27/2008	4/30/2009	5/19/2010	5/6/2011	6/28/2013	3/19/2014*	4/15/2015	4/17/2016
5/13/2008	5/16/2009	6/20/2010	6/23/2011	7/14/2013	4/28/2014	5/1/2015	5/27/2016*
5/29/2008	6/17/2009	7/6/2010	7/9/2011	7/30/2013	5/14/2014	6/2/2015	6/28/2016*
6/14/2008	7/3/2009	7/22/2010	8/10/2011	8/15/2013	6/15/2014	6/18/2015	7/6/2016
6/30/2008	8/4/2009	8/7/2010	9/27/2011	8/31/2013	7/1/2014	7/4/2015	7/22/2016
7/16/2008	9/21/2009	8/23/2010	10/29/2011	9/16/2013	8/18/2014	8/21/2015	8/7/2016
8/1/2008	10/7/2009	9/24/2010	12/24/2011*	10/18/2013	9/3/2014	9/6/2015	8/23/2016
8/17/2008	11/16/2009*	10/10/2010	1/9/2012*	12/25/2013	10/5/2014	9/22/2015	9/8/2016
9/2/2008	12/2/2009*	11/11/2010	2/26/2012*	12/21/2013	11/14/2014*	10/16/2015*	9/24/2016
9/18/2008						11/1/2015*	10/26/2016
10/20/2008							11/3/2016*
							12/19/2016

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

Weather Data

Hourly weather data for the project time frame was collected from California Irrigation Management Information System (CIMIS) weather stations located throughout the project area. Dozens of individual weather stations were used for the METRIC modeling process. Figure 3 shows the approximate locations of weather stations used in this project. Each station is listed in Table 3 showing the approximate range of time that the station was utilized. A station may have become active or inactive within this time frame.

The Los Banos #56 CIMIS station was utilized as the “primary” weather station. This station was selected because of its centralized location within the primary area of interest (see Figure 3). The same quality control procedure was used at all weather stations as will be described.

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)

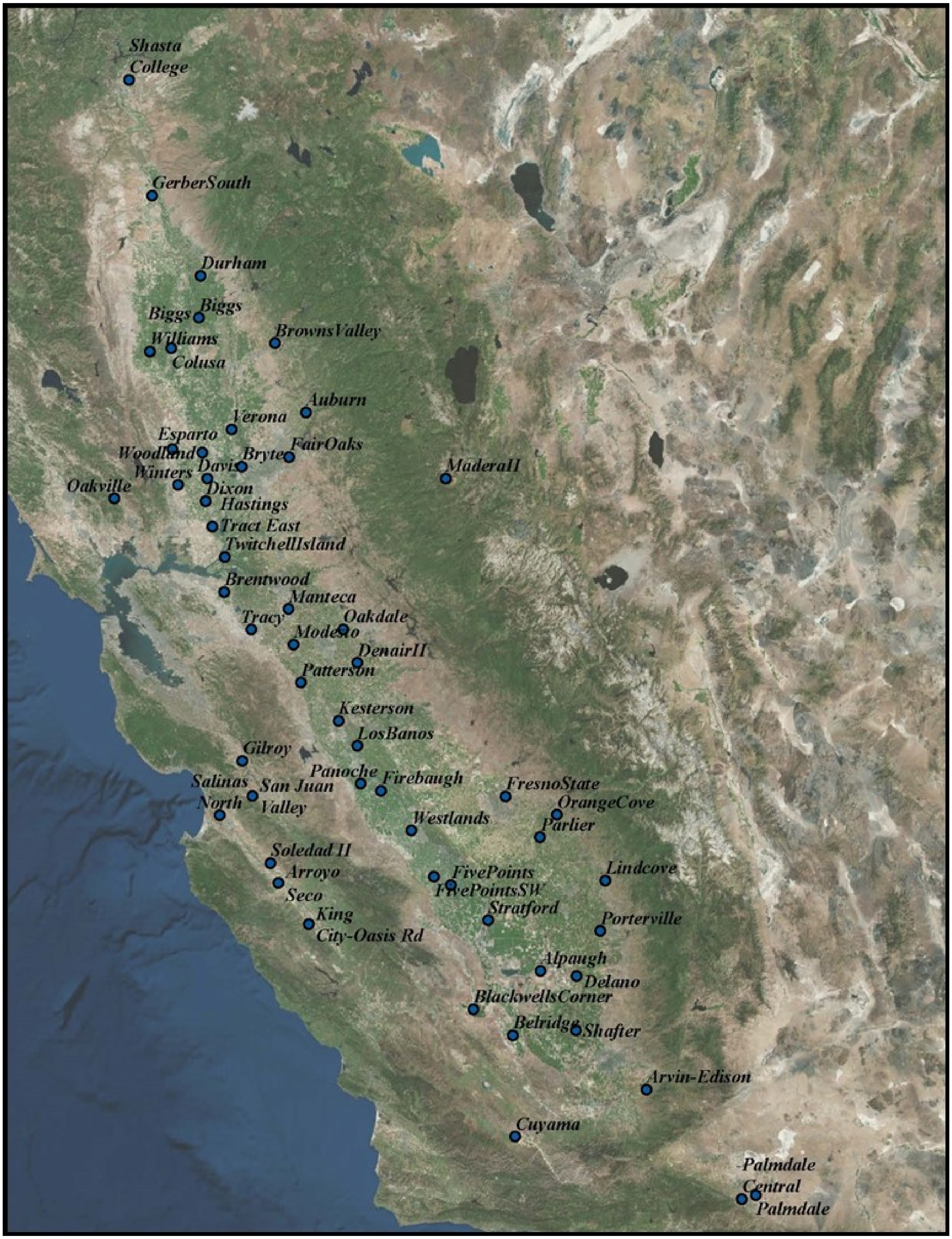


Figure 3. Locations of the CIMIS weather stations used in this evaluation

Table 3. Weather stations used for the METRIC modeling process

2008-2015 CIMIS Station		2016-2017 CIMIS Station	
Alpaugh	Kettleman	Alpaugh	Los Banos
Arvin-Edison	Lindcove	Arroyo Seco	Madera II
Auburn	Lodi West	Arvin-Edison	Manteca
Belridge	Los Banos	Auburn	Meloland
Blackwells Corner	Madera	Belridge	Merced
Brentwood	Madera II	Biggs	Modesto
Browns Valley	Manteca	Blackwells Corner	Oakdale
Bryte	Merced	Brentwood	Oakville
Colusa	Modesto	Browns Valley	Oasis
Davis	Oakdale	Bryte	Orange Cove
Delano	Orange Cove	Calipatria Mulberry	Palmdale
Denair II	Panoche	Colusa	Palmdale II
Dixon	Parlier	Cuyama	Panoche
Durham	Patterson	Davis	Parlier
Esparto	Porterville	Delano	Patterson
Fair Oaks	Shafter	Denair II	Porterville
Famoso*	Shasta College	Dixon	Ripley
Firebaugh	Stratford	Durham	Salinas North
Five Points	Tracy	Esparto	San Juan Valley
Five Points SW	Twitchell Island	Fair Oaks	Seeley
Fresno State	Verona	Firebaugh	Shafter
Gerber	Westlands	Five Points	Shasta College
Gerber South	Winters	Five Points SW	Stratford
Hastings Tract East	Woodland	Fresno State	Thermal South
Kesterson		Gerber South	Tracy
		Gilroy	Twitchell Island
		Hastings Tract East	Verona
		Indio II	Westlands
		Kesterson	Westmorland North
		King City-Oasis Rd	Williams
		La Quinta II	Winters
		Lindcove	Woodland
		Lodi West	

Hourly weather data from the primary station went through a quality control check and correction procedure. A detailed procedure on the quality control conducted can be found in FAO Irrigation and Drainage Paper No. 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 Los Banos CIMIS station for 2015 through half of 2017. 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.

[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

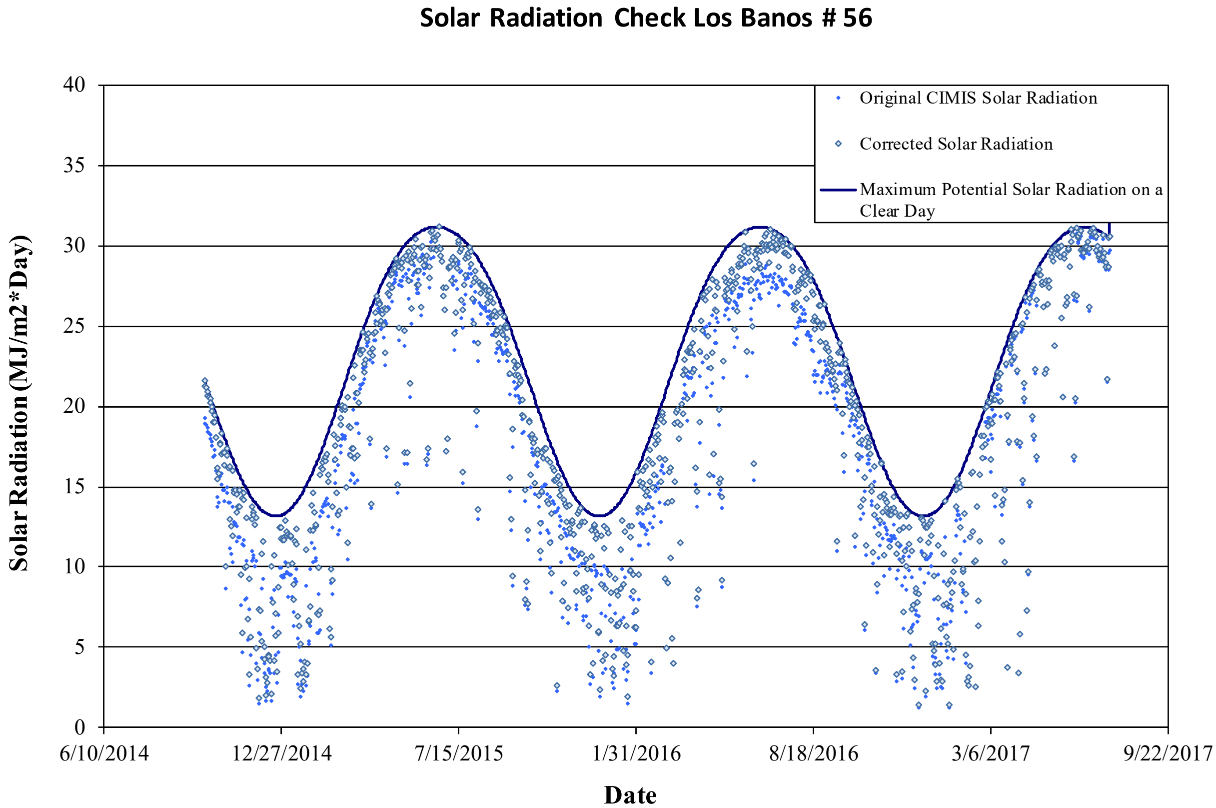


Figure 4. Example of solar adjustments made on Los Banos CIMIS Station for 2015-2017. The same analysis was conducted for all weather stations in the project area.

For missing data, or if an error was flagged on the CIMIS station signifying missing, incomplete, or odd data results, data were examined for general consistency. Missing data and data believed to be in error were corrected. The correction procedure used in this analysis replaced the missing or flawed data with the averages from nearby weather stations. Once all hourly data was corrected, the data was input into REF-ET™ (Dr. Richard Allen, University of Idaho) to compute the corrected hourly ASCE Standardized ETo that was used in this study.

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

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 the CIMIS stations listed in Table 3 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.

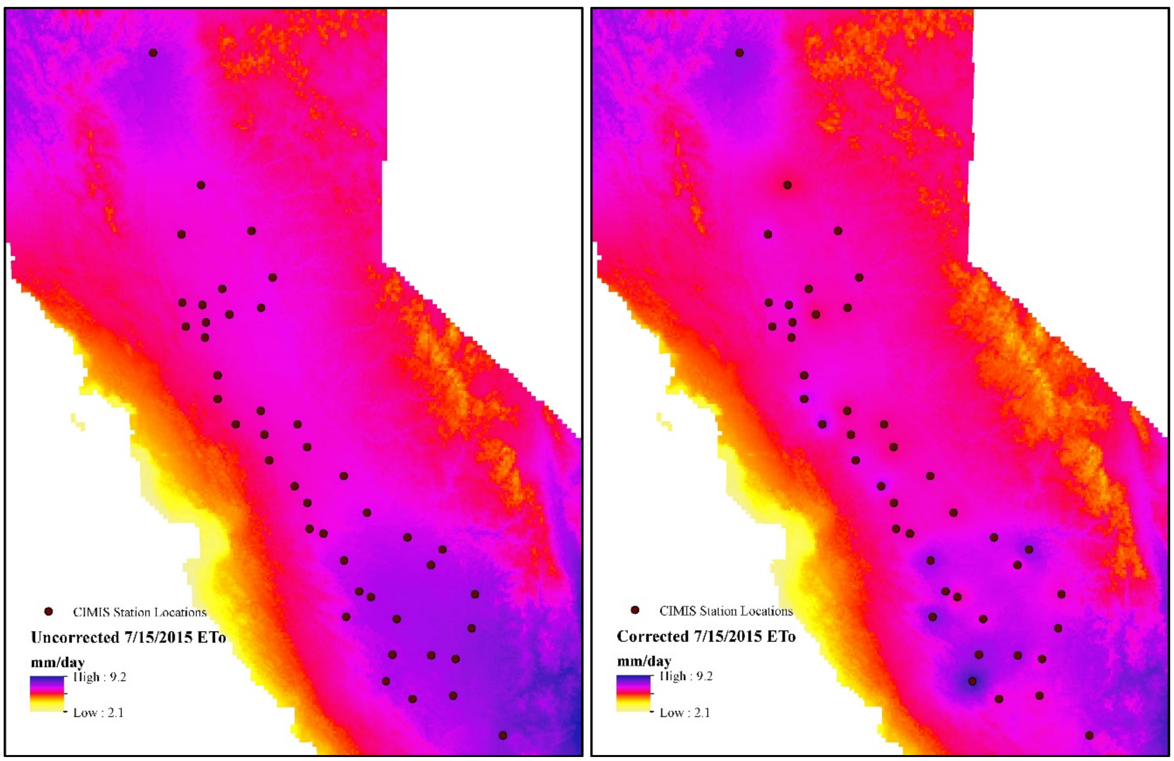


Figure 5. Example of uncorrected Spatial CIMIS ETo compared to corrected Spatial ETo for July 15, 2015

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

The ITRC-METRIC process requires land use information to help estimate ETc. Annual land use rasters were created from data provided from the National Agricultural Statistics Service (NASS). Figure 6 shows an example of the 2016 land use raster used in the modeling process. Each color identifies a different land use type (i.e., almonds, alfalfa, developed, etc.). The land use data provided by NASS underwent a control process so that only one land use type was uniform across the entire designated agricultural field. The agricultural field boundaries were provided by shapefiles produces by the DWR's land use surveys of the counties in California. 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.

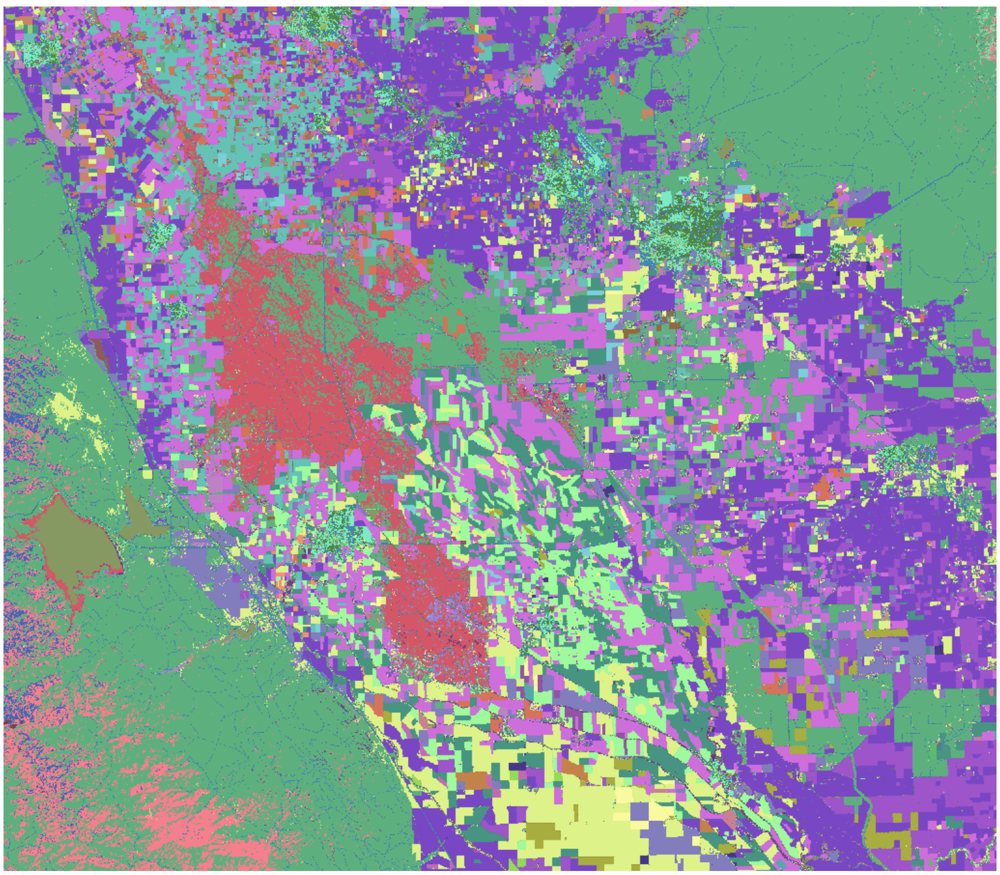


Figure 6. Example of the 2016 NASS land use raster used for this project. Each color identifies a different land use type (i.e., almonds, alfalfa, developed, etc.)

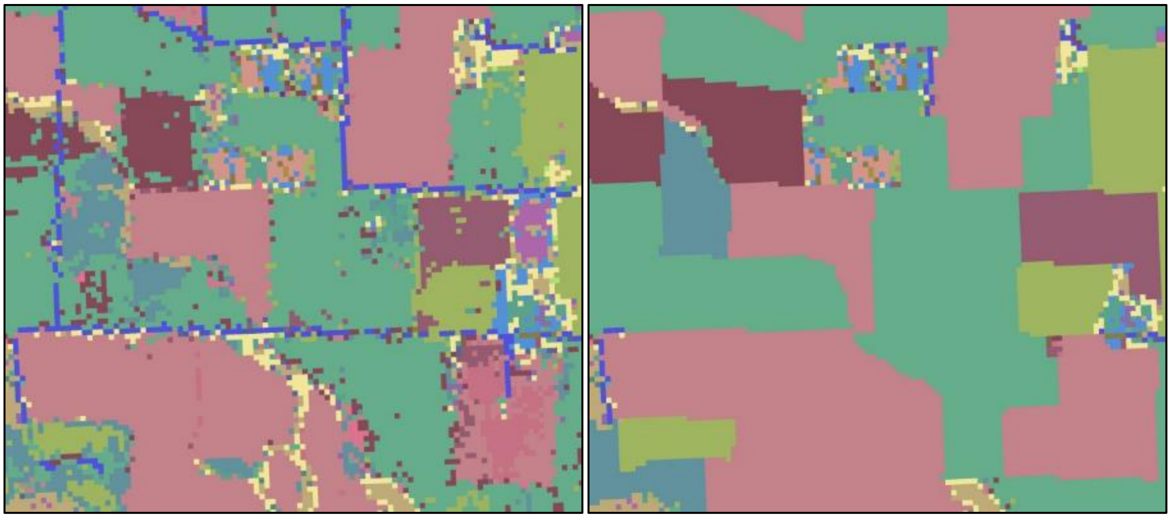


Figure 7. Example original NASS land use (left) compared to corrected land use based on the majority crop type within each agricultural field (right). Each color identifies a different land use type.

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.

Results

The results will be first discussed by field and year. Fields in Figure 8 have been numbered and colored to identify the property (color) and specific field (number). Fields 16 and 17 will not be utilized, because information from these fields was not provided. The Dos Rios fields are shown for reference purposes, tabular ETc for fields 7 and 8 will not be included unless requested by River Partners.

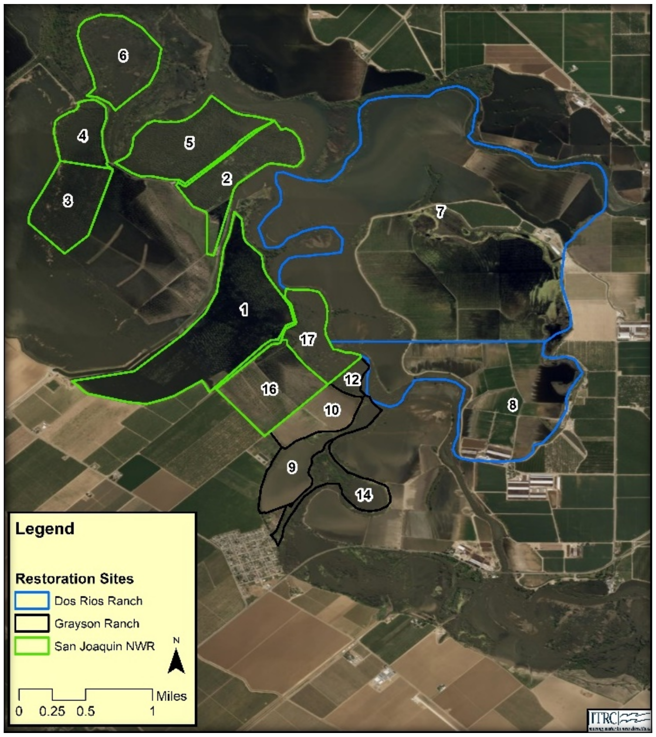


Figure 8. Map identifying field locations

Example evapotranspiration maps are shown in Figure 9 for 2009 and 2016 calendar years. The maps for all years can be found in **Appendix A**. The ETc variability is shown as color variation, where blues and reds have higher ET and yellow is lower. Low vegetative areas have lower ETc than open water and dense vegetation. Annual ETc variability will be influenced by several factors. In the agricultural fields on Grayson, the crop types will have the most significant influence, while in the natural vegetation areas (Grayson and SJNWR), precipitation and vegetation maturity will have the most significant influence. Figure 10 shows the annual precipitation for the study years.

Table 4 shows the annual ITRC-METRIC ETc depth averaged over each field. The Field ID's at the top coincide with Figure 8. Clearly there are some areas that consistently have higher ETc than others, especially in the non-irrigated areas. The irrigated Grayson fields (9, 10) tend to have consistent ETc during the same years but variations between years, which is common when different crops are grown.

To simplify the analysis, the fields were grouped by vegetation type and the ETc was averaged (weighted based on field acreage) within those groups. It is clear that the ETc is lower in the SJNWR and Native areas compared to the irrigated and non-ag areas in Grayson. The difference is even greater if we eliminate 2011 from the analysis. The fall 2010 to winter 2011 was very wet. It is likely that crop plantings were delayed or a different crop was chosen in the ag areas, which resulted in the lower ETc value. The high ET in SJNWR and Native is due to the heavy rains causing flooding and heavy weed grown, which resulted in unusually high ET. The 2011 data was not used for the prediction of future ETc.

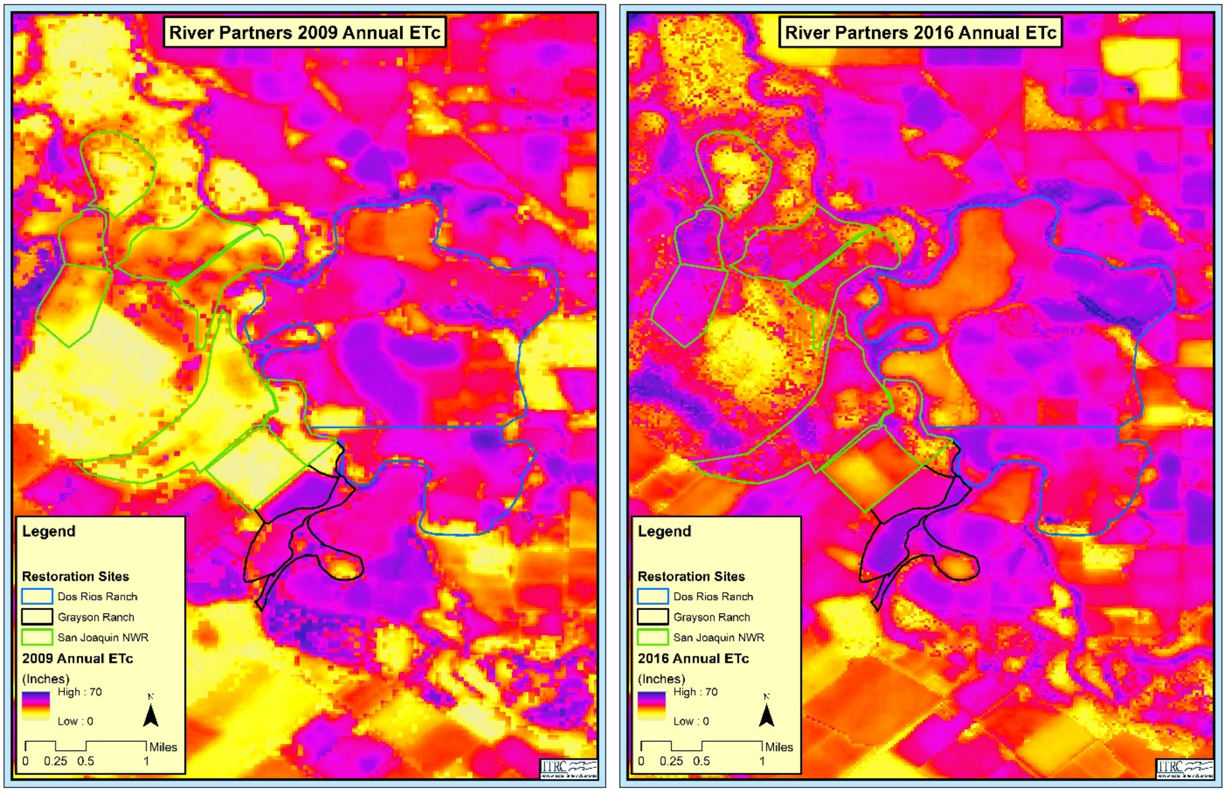


Figure 9. Example ITRC-METRIC ETc maps for 2009 and 2016

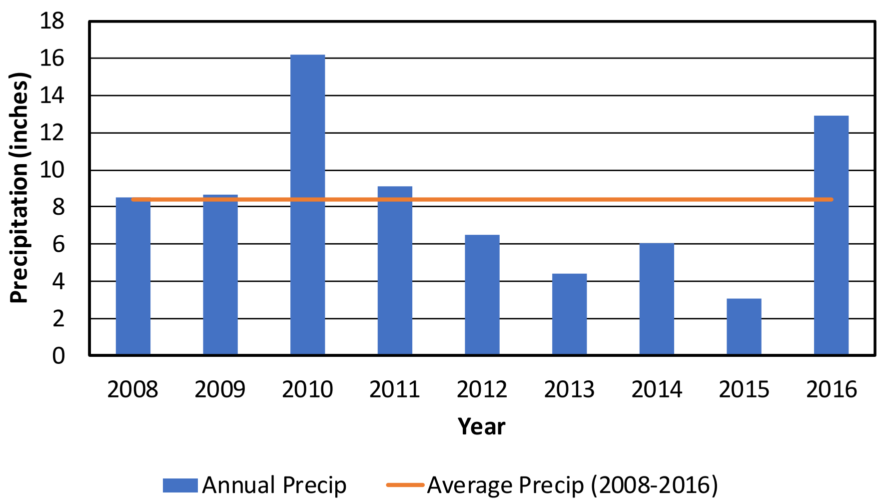


Figure 10. Local annual precipitation from Modesto CIMIS station

Table 4. Annual ITRC-METRIC ETc depth (inches) for evaluated fields

	ETc (inches/year)									
Field ID Acreage	**1** 366	**2** 144	**3** 134	**4** 78	**5** 184	**6** 152	**9** 105	**10** 81	**12** 22	**14** 77
Year	SJNWR	SJNWR	SJNWR	SJNWR	SJNWR	Native	Grayson	Grayson	Grayson	Grayson
2009	16.8	26.3	22.5	30.2	26.9	20.5	41.9	45.5	14.4	39.4
2010	26.2	32.9	25.2	35.9	35.1	28.4	41.9	39.4	34.9	38.5
2011	46.9	49.0	49.3	50.9	52.3	50.3	34.6	38.3	44.7	48.4
2013	44.6	38.5	41.4	50.6	43.9	34.7	54.8	50.6	44.5	50.7
2014	36.3	32.9	36.4	42.3	37.0	27.3	51.6	48.3	33.9	42.0
2015	35.1	32.1	34.4	40.7	35.8	22.5	47.3	44.5	31.0	36.2
2016	39.0	35.2	45.3	47.0	38.6	29.0	50.4	41.7	31.1	40.0

Table 5. Summary of average ETc depth weighted by field acreage shown for different land use category

Field IDs *Acreage*	**1-5** *905*	**6** *152*	**9, 10** *186*	**12, 14** *100*
Year	SJNWR	Native	Grayson Ag	Grayson Non-Ag
2009	22.3	20.5	43.5	33.8
2010	29.8	28.4	40.8	37.7
2011	49.0	50.3	36.2	47.6
2013	43.5	34.7	53.0	49.3
2014	36.4	27.3	50.2	40.2
2015	35.1	22.5	46.1	35.0
2016	39.9	29.0	46.6	38.0
Average	**36.6**	**30.4**	**45.2**	**40.2**

To develop the 10- to 15-year prediction, the ITRC-METRIC data was examined in the SJNWR restored habitat (Hagemann and Lara Tracts specifically). The ETc depths in SJNWR Fields 1, 2, 3, 4, and 5 were used to predict the future water use in the next 10-20 years by transposing this water use into the Grayson agricultural fields. The ETc depths for each year were converted to feet and multiplied by the Grayson ag field acreage to compute the volume of ETc in acre-feet. Table 6 shows the predicted water use 10-20 years into the future in the table on the left.

Just north of the Hagemann and Lara Tracts is an area that has never been developed (identified as Field 6). The area has been subject to flooding, fires, regrowth, etc. In the distant future, it is probable that vegetation in restored areas would be similar to the area that was never developed. The ETc is lower in the non-developed location because of vegetation missing in areas that are prone to flooding and fires. The long-term predicted ETc volume on the Grayson ag fields is shown in the right table of Table 6. The volume ETc in the future is computed as the depth of Native field ETc converted to feet and multiplied by the Grayson ag field acreages.

Table 6. Predicted future ETc on Grayson ag fields in 10-20 years after restoration (left) and in the predicted long-term (right), compared to current ETc

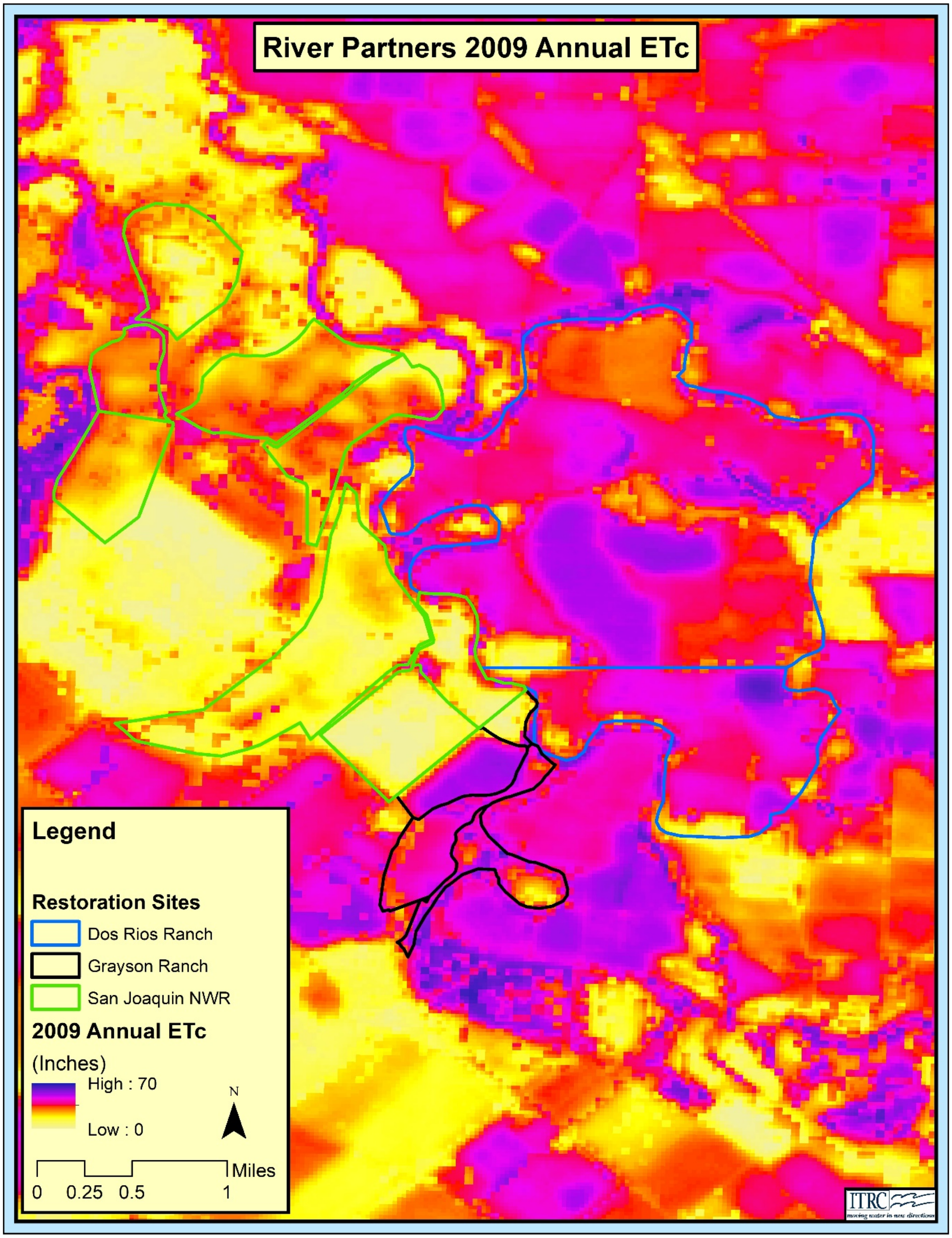
	Grayson Ag Fields ETc (Acre-Feet)	
Year	**Predicted 10-20 years in Future**	**Current**
2009	347	676
2010	462	634
2013	676	823
2014	566	779
2015	546	716
2016	620	723
Average	**536**	**725**
	Difference	**189**

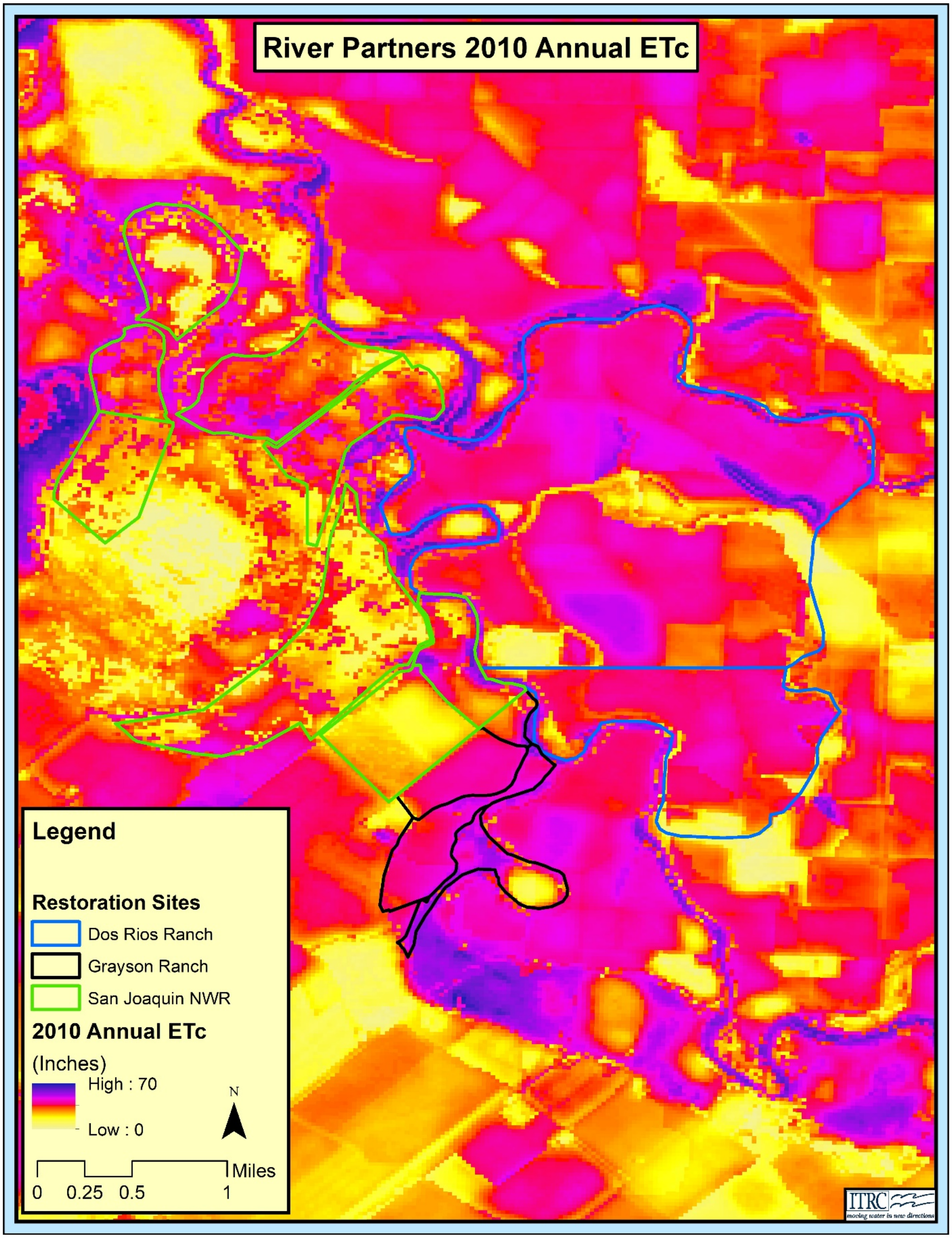
	Grayson Ag Fields ETc (Acre-Feet)	
Year	**Predicted Long-Term Future**	**Current**
2009	318	676
2010	442	634
2013	539	823
2014	424	779
2015	350	716
2016	450	723
Average	**421**	**725**
	Difference	**305**

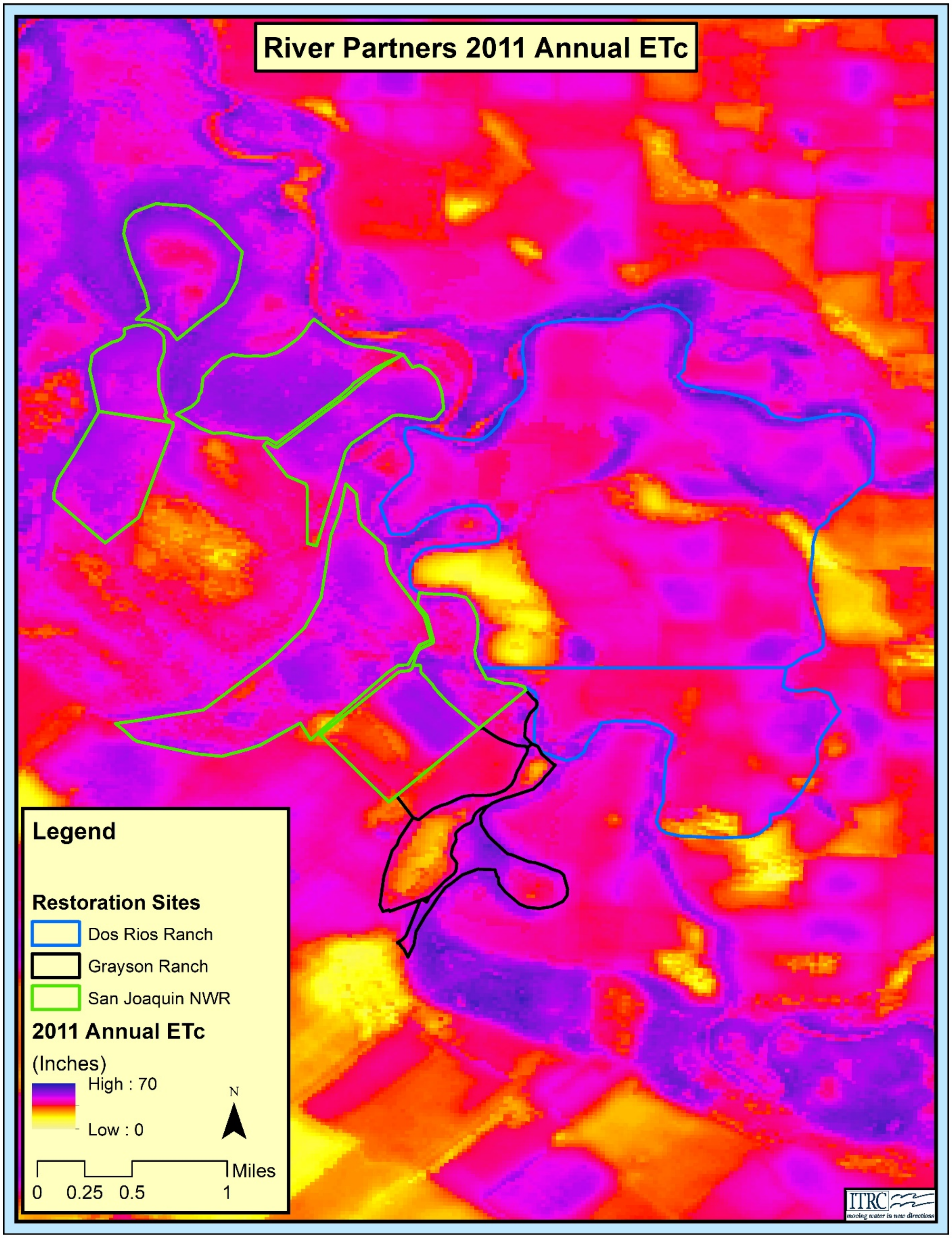
The difference between the current and future ETc in both scenarios (10-20 years and long-term) is significantly different. In reality, the long-term ETc is likely between these values. However, in 10-20 years it will likely be between 180-200 AF. The Grayson non-ag areas (fields 12 and 14) are assumed to stay the same, so the ETc will likely remain consistent.

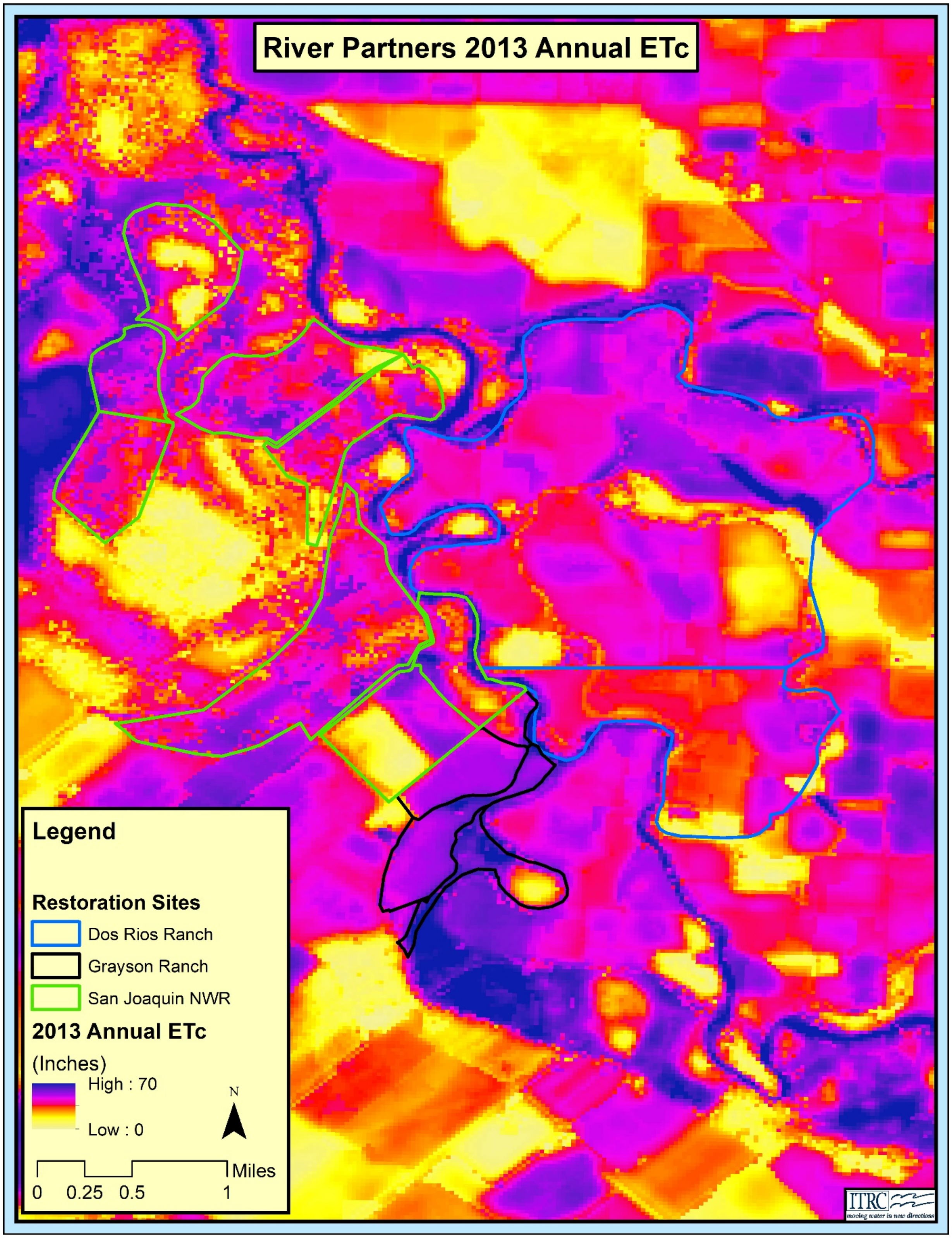
Attachment A

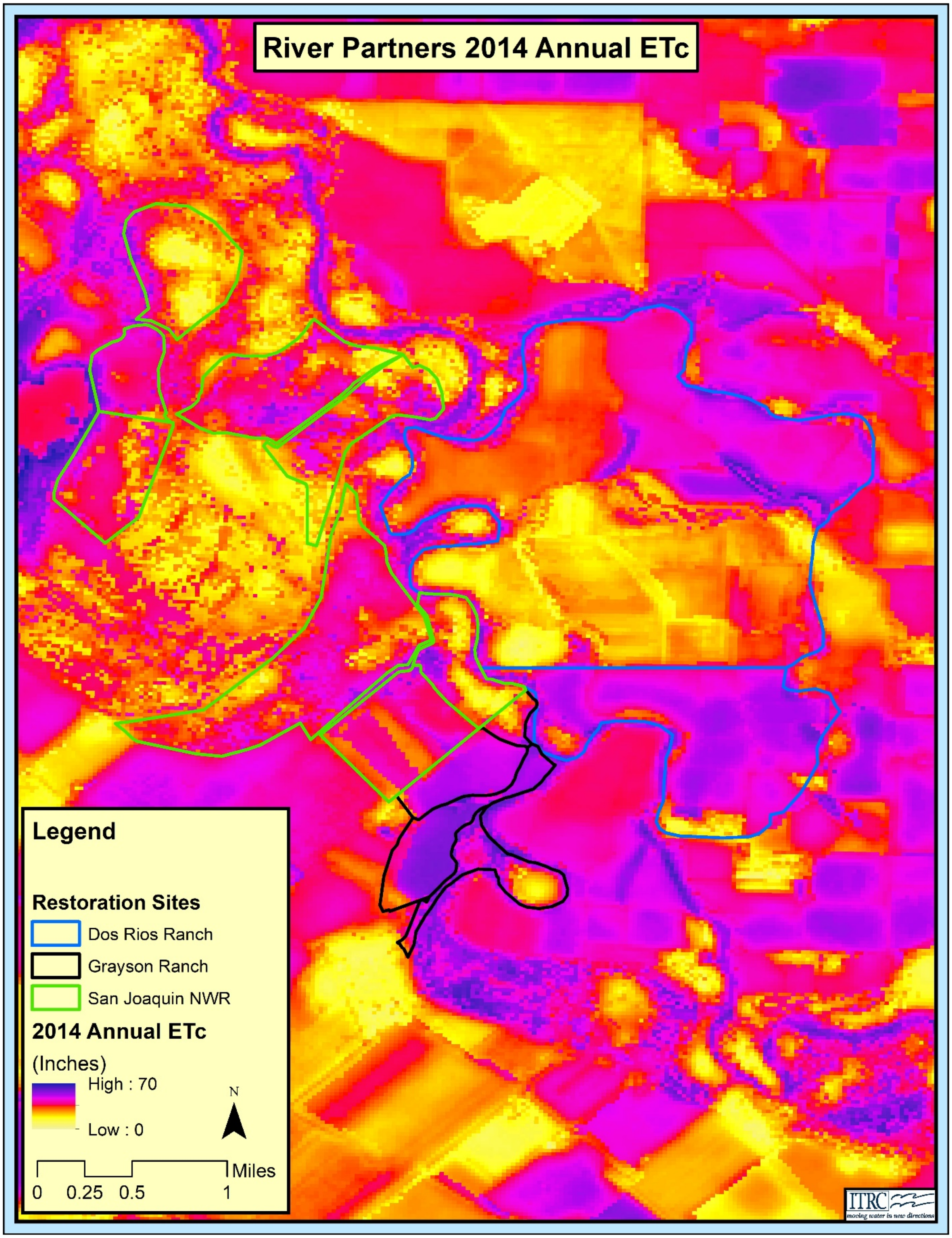
Annual ITRC-METRIC ETc Maps

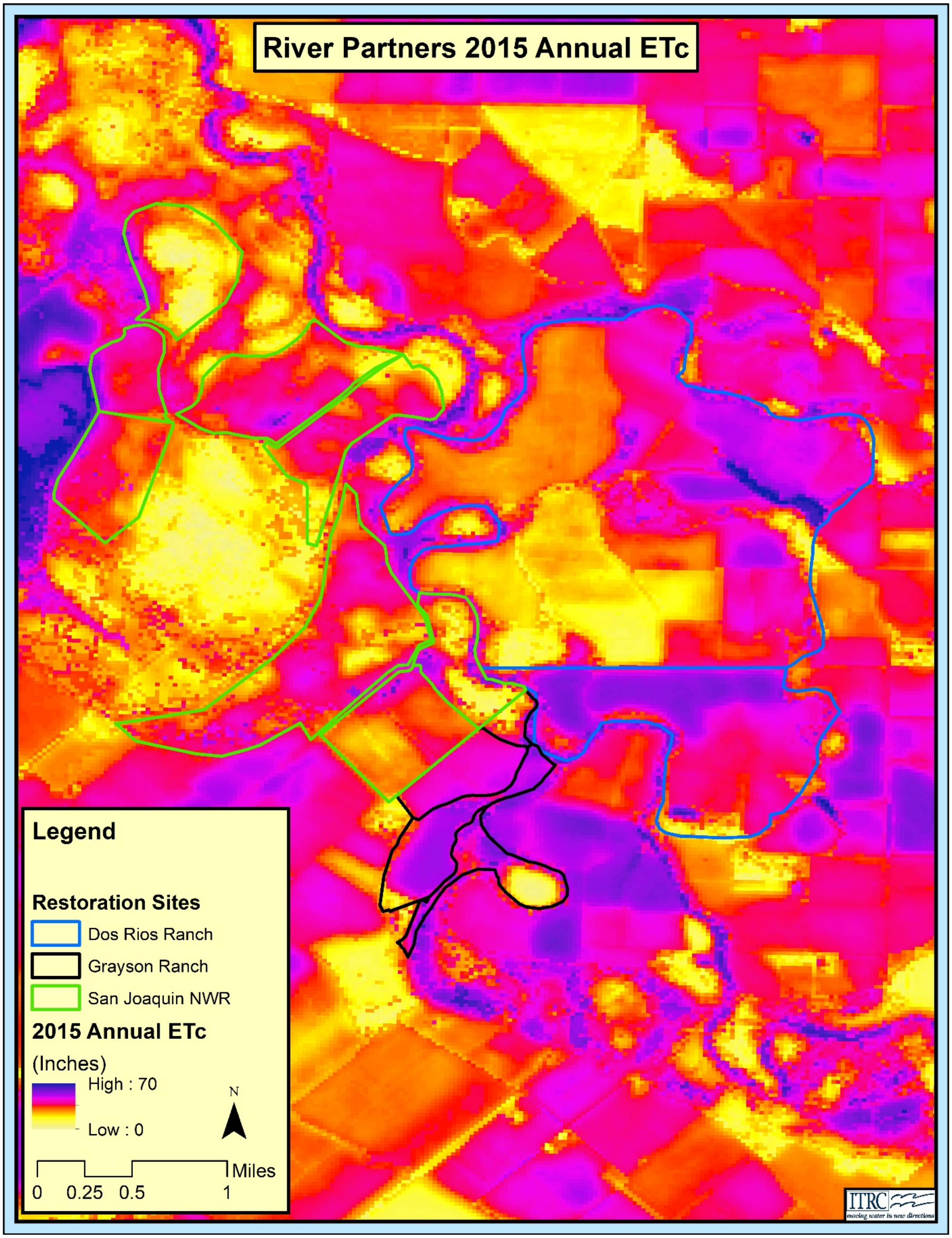


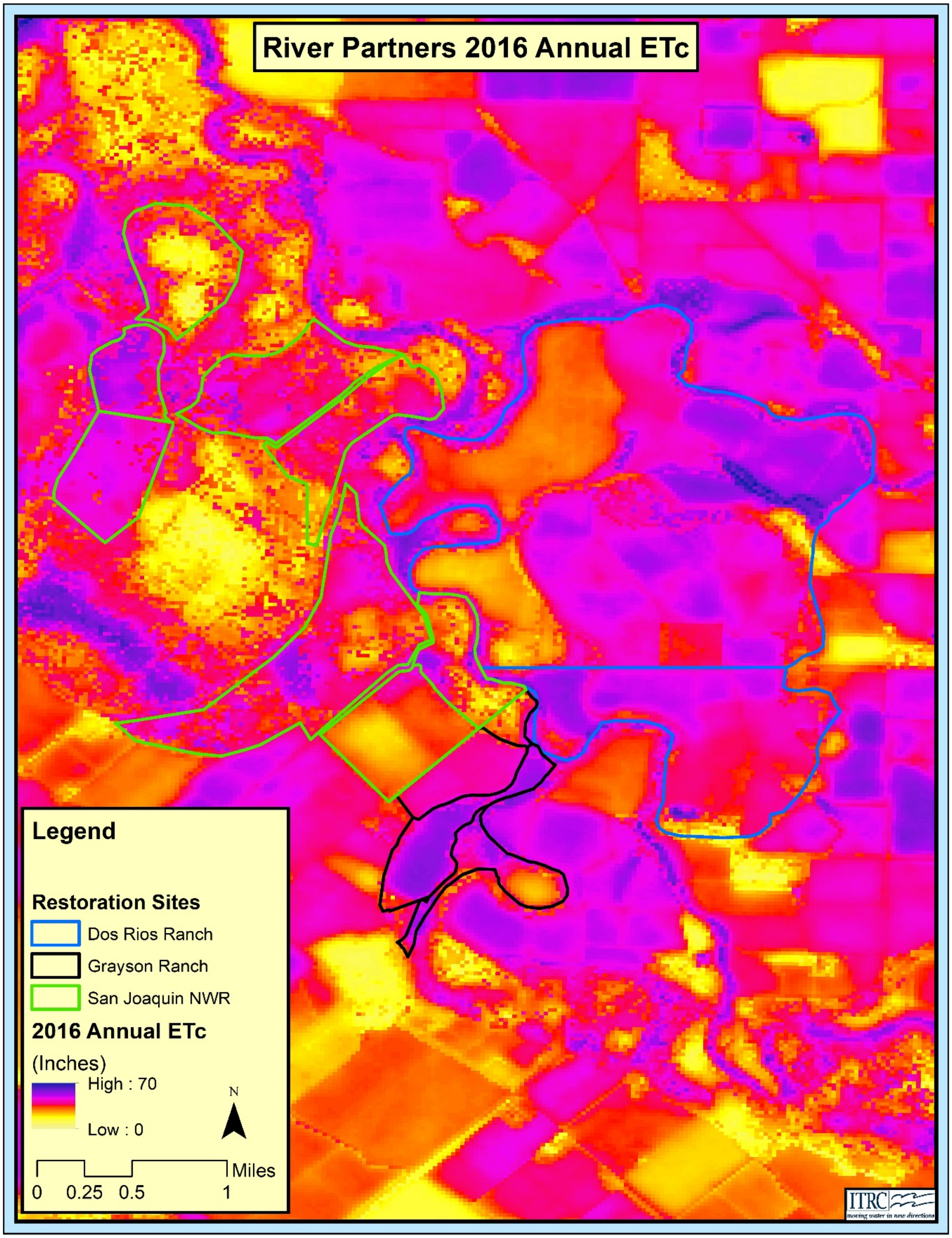

River Partners 2010 Annual ETc
Legend
Restoration Sites
Dos Rios Ranch
Grayson Ranch
San Joaquin NWR
2010 Annual ETc
(Inches)
High : 70
Low : 0
N
0 0.25 0.5 1 Miles
ITRC
moving water in new directions


River Partners 2011 Annual ETc
Legend
Restoration Sites
Dos Rios Ranch
Grayson Ranch
San Joaquin NWR
2011 Annual ETc
(Inches)
High : 70
Low : 0
N
0
0.25
0.5
1
Miles
ITRC
moving water in new directions


River Partners 2013 Annual ETc
Legend
Restoration Sites
Dos Rios Ranch
Grayson Ranch
San Joaquin NWR
2013 Annual ETc
(Inches)
High : 70
Low : 0
N
0
0.25
0.5
1
Miles
ITRC
moving water in new directions


River Partners 2014 Annual ETc
Legend
Restoration Sites
Dos Rios Ranch
Grayson Ranch
San Joaquin NWR
2014 Annual ETc
(Inches)
High : 70
Low : 0
N
0
0.25
0.5
1
Miles
ITRC
moving water in new directions


River Partners 2015 Annual ETc
Legend
Restoration Sites
Dos Rios Ranch
Grayson Ranch
San Joaquin NWR
2015 Annual ETc
(Inches)
High : 70
Low : 0
N
0
0.25
0.5
1
Miles
ITRC
moving water in new directions


River Partners 2016 Annual ETc
Legend
Restoration Sites
Dos Rios Ranch
Grayson Ranch
San Joaquin NWR
2016 Annual ETc
(Inches)
High : 70
Low : 0
N
0
0.25
0.5
1
Miles
ITRC
moving water in new directions