Report: Eastern Sierra ETa Dataset Development Using Remote-Sensing-Based Energy Balance Algorithm

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1 Executive Summary

In 2016, Formation Environmental LLC (Formation), collaboratively with the Los Angeles Department of Water and Power (LADWP) and Stantec, initiated a pilot study to validate remote-sensing-based actual evapotranspiration (ETa) estimates for the unique climate and vegetation communities of the Eastern Sierra region in California. This was followed by a successful comparison of ETa estimates to Eddy Covariance evapotranspiration (ET) data collected by Inyo County from 2000 through 2003 for specific upland and groundwater-dependent plant communities. In 2018, the ETa dataset was expanded to support water balance studies within the Long Valley region. This expansion added 34 years of daily ETa records (1985 through 2018) covering Mono Lake, Crowley Lake, and the Long Valley region (encompassed within a single Landsat scene: Path 42, Row 34). In 2019, the area of coverage for this ETa dataset was further expanded to include Owens Lake and remaining portions of the Owens Valley. With the last expansion, the ETa dataset now encompasses the complete Owens Valley area, including the 1985 to 2019 timespan. The three Landsat scenes (Path-Row 42-34, 41-34, and 41-35) were processed specifically to provide coverage for the Eastern Sierra regions, and this dataset is collectively called the "Eastern Sierra ETa Dataset."

The completion of this time- and data-rich dataset enables a wide array of opportunities for analysis, including use within water balance studies, evaluating plant health, determining impacts on groundwater flux, estimating irrigation on leased lands, calculating consumptive use by native and riparian vegetation, identifying lakebed vegetation establishment, providing inputs to groundwater models, and assessing the impacts of drought and climate change. The purpose of this report is to provide a detailed description of the approach used to develop the Eastern Sierra ETa Dataset, statistical analyses of this dataset, and tabular data summaries.

2 Introduction

Vegetation monitoring within the Owens Valley is conducted by both LADWP and the Inyo County Water Department (ICWD) as a component of the Inyo/LA Water Agreement. An established "Green Book" (Inyo County and City of Los Angeles 1990) provides the protocols and monitoring procedures to guide vegetation and groundwater management. Monitoring consistent with these procedures began in 1985 and has continued to present day. The goal of these monitoring activities is to assign vegetation classes by first calculating the average ET of each plant community. The relationship between Transpiration and Leaf Area Index (LAI) was developed for each species as a function of day of the year. Annual field measurements of LAI (one-time measurement) are used for calculating plant water requirements using the developed relationship. Every year since 1985, LADWP and ICWD conduct field campaigns to establish line-point transects to monitor the vegetation across the Owens Valley. The vegetation monitoring results are translated into ET estimates, used for comparison to available soil water, then ultimately to projected plant-soil water balance. The Green Book classifies the five vegetation classes according to water consumptive use (Table 1).

TABLE 1. GREEN BOOK VEGETATION CLASSES

A	Average ET less than or equal to 5.76 inches
B	Scrub communities with annual ET greater than estimated average precipitation
C	Grass-dominant vegetation with estimated annual ET greater than quadrangle-average precipitation. The quadrangle-average precipitation was computed from maps of isohyetal contours
D	Riparian vegetation with annual average ET greater than precipitation
E	All vegetation whose ET requirement is fulfilled by irrigation water

The Green Book recommends development of a remote-sensing-based technique for mapping and monitoring vegetation in the Owens Valley.

The purpose of the remote sensing pilot project initiated in 2016 was to evaluate the applicability of remote sensing tools for improving existing groundwater modeling and vegetation monitoring in the Owens Valley. As part of remote sensing pilot project, LADWP, Formation, and Stantec developed and evaluated datasets on LAI and ETa. Additionally, options were explored to integrate spatial ETa information in groundwater models.

3 METHODOLOGY

This section describes the methodologies used in development of the Eastern Sierra ETa Dataset.

3.1 SATELLITE IMAGERY

The Landsat program provides the world's longest continuously acquired collection of space-based, moderate-resolution satellite imagery. Landsat is a collection of satellites that provides accurate, routine, and repeated measurements of Earth's land cover. The average re-visit interval is approximately 8-16 days, with imagery acquired by two Landsat satellites. Landsat satellites began with Landsat 1 in 1972, progressing with additional satellite implementations, with the most recent Landsat 8 addition launched in 2013. All available imagery from 1985 for Path-Rows 42-34, 41-35, and 41-34 from Landsat satellites 5, 7, and 8 was used to develop the Eastern Sierra ETa Dataset. Figure 1 shows the Landsat scenes and the coverage area of Eastern Sierra ETa Dataset. Each scene undergoes quality assessment/quality control review to identify clouds, cloud shadows, snow, and/or image distortion and image shift. Satellite images that have partial cloud cover undergo cloud delineation to salvage the usable part of the image. Figure 2 shows the number of scenes utilized every year from each Path-Row in the development of Eastern Sierra ETa Dataset (list available in Appendix A).

FIGURE 1. LANDSAT SCENE AND COVERAGE AREA OF EASTERN SIERRA ETA DATASET

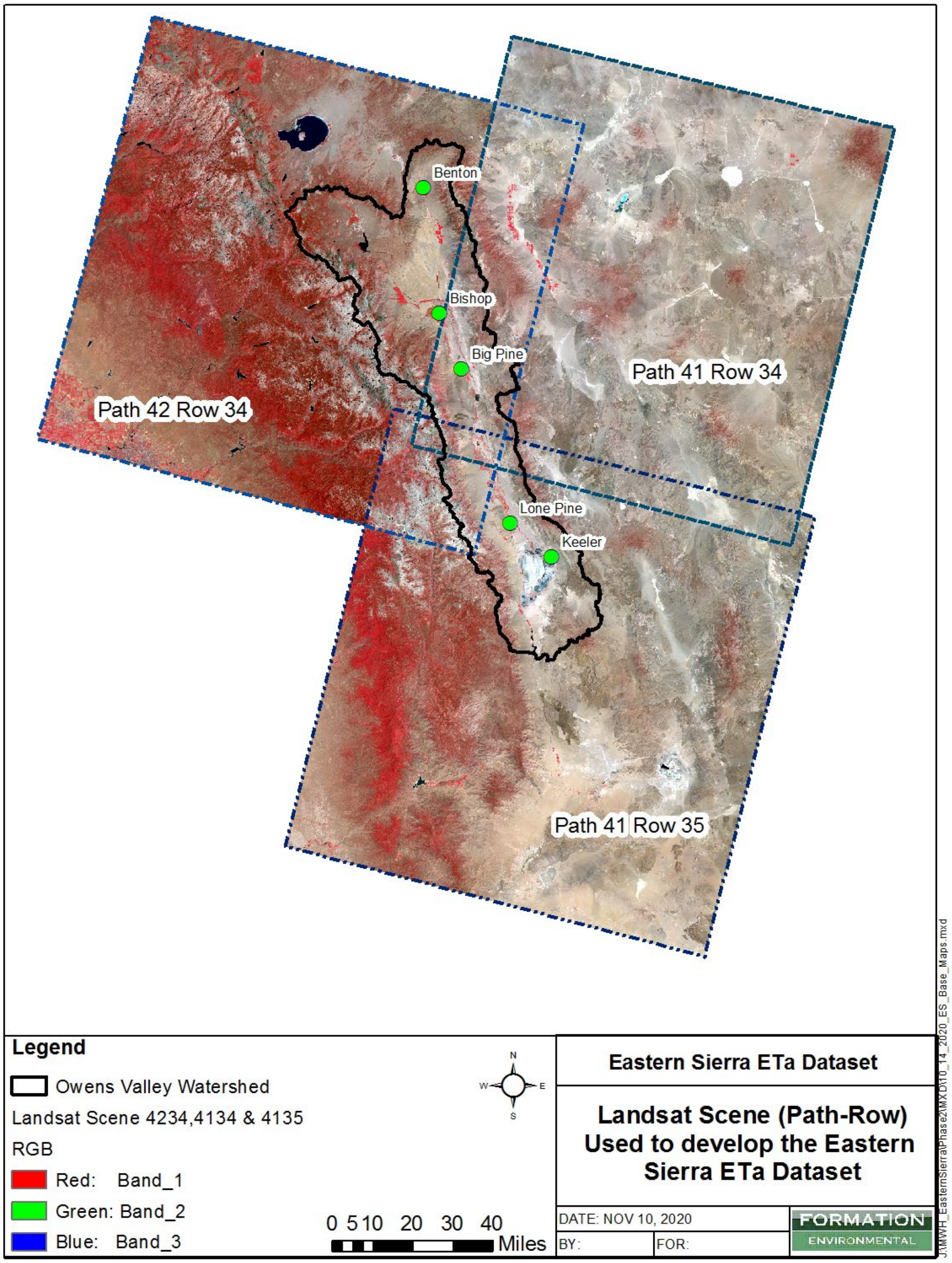
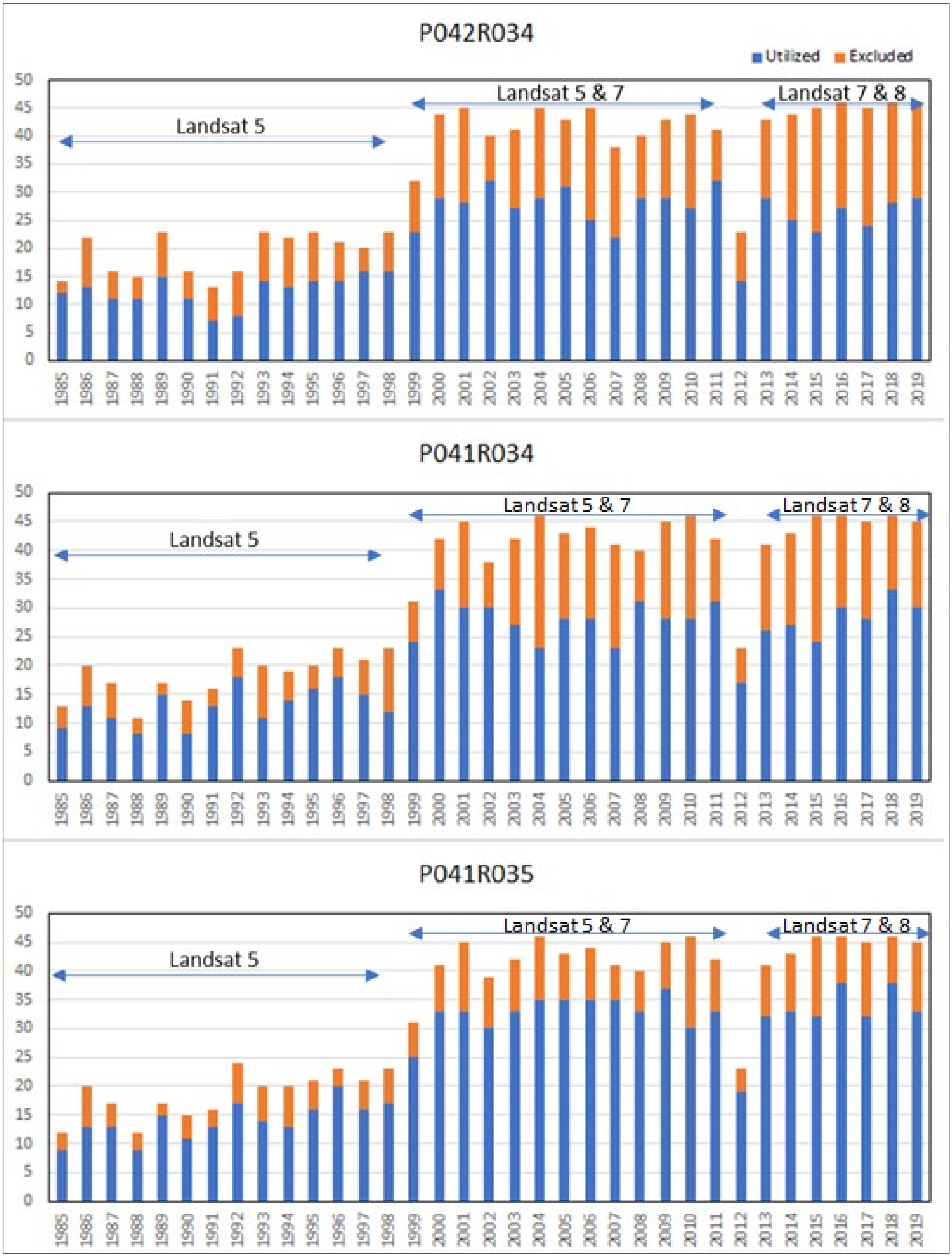


FIGURE 2. LANDSAT IMAGERY USED TO DEVELOP THE EASTERN SIERRA ETA DATASET



3.2 CalETa Framework

The Eastern Sierra ETa Dataset was developed using Formation's California Actual Evapotranspiration (CalETa) Mapping Program. CalETa was initiated to assist water agencies in planning and developing water management strategies through actionable ETa datasets. This framework generates 30-meter, daily ETa data, covering the state of California. To develop the Eastern Sierra ETa Dataset, the CalETa framework was used with additional weather stations to capture the larger variation of mountainous terrain.

Remote sensing algorithms based on the equilibrium between the radiation balance and energy balance at the surface of the earth are recognized as the only viable means to map regional- and meso-scale patterns of ETa. Over the past three decades, numerous remote-sensing-based ETa mapping algorithms were developed (Chen and Liu 2020). These algorithms provided robust, economical, and efficient tools for ETa estimations over a wide range of ecosystem and plant communities.

Remote-sensing-based ET models make use of the visible, near-infrared (NIR), shortwave infrared (SWIR), and thermal infrared data acquired by sensors onboard satellite platforms. These are used in combination with weather data to simulate the energy balance at the soil-vegetation-atmosphere interface. In its simplest form, this energy balance can be given as:

$$R_n = G_o + H + LE \qquad \text{Eq.1}$$

where R_n is the net radiation, G_o is the soil heat flux, H is the sensible heat flux, and LE is the latent heat flux, with all units expressed in Wm^{-2} (Watts per meter square). All energy balance algorithms solve for R_n, G_o, and H, and LE is calculated as the residual of the other three components (LE=R_n-H-G_0). LE is expressed as hourly ET (mm) by dividing the latent heat of vaporization (Lv; 2.47 *10^6 J kg^{-1}) and the density of water (ρ; 1,000 kg m^{-3}). The net radiation constitutes the key driver for heating the atmosphere and ground and is expressed as an electromagnetic balance of all incoming and outgoing fluxes. The net radiation formulation is based on well-established principles of atmospheric physics. The relatively accurate albedo, improved emissivity estimations, and cloudiness factor from remote sensing data have helped to constrain the uncertainty in R_n computation to within a range of 5-10%. The soil heat flux is a small component of the energy balance in a vegetated ecosystem, and it is usually parametrized using an empirical relationship involving a vegetation index and R_n. This leaves sensible heat flux (H) as the most critical and most difficult variable in the estimation of LE (or ET). The mathematical formulation of H is based on a source resistance scheme of mass transport of heat and momentum between the surface and the overlying atmosphere. H is directly related to the difference between the surface aerodynamic temperature (T_o) and above canopy air temperature (T_a):

$$H = \rho_a C_p \frac{T_o - T_a}{r_{ah}} \qquad \text{Eq. 2}$$

where ρ_a is the density of air (~1.17 kg m^{-3}), Cp is the air specific heat at constant pressure (~1,005 $Jkg^{-1} K^{-1}$), and r_{ah} is the aerodynamic resistance to heat between the surface and the reference level (s m^{-1}). Because T_o cannot be measured directly at source height, the radiometric surface temperature (T_s)

measured by the remote sensing thermal sensors is used as a surrogate. With the introduction of SEBAL (Surface Energy Balance Algorithm for Land) (Bastiaanssen 1995; Bastiaanssen et al. 1998) in the mid-1990s, there was a surge in use and adoption of RS-ET models. Around the same period, a two-layer energy balance approach was introduced (Norman et al. 1995), and in the early 2000s another algorithm called SEBS (Surface Energy Balance System) (Su 2002) gained popularity. The main differentiating feature among these three algorithms was in their approach to circumvent the T_s and T_o differences, and effectively use T_s to estimate ET. Over the years, several researchers modified portions of the SEBAL, TSM, and SEBS algorithms and developed numerous variants; nevertheless, the underlying formulation remained the same. The CalETa framework utilizes the SEBS algorithm, which is described below.

3.3 Surface Energy Balance System (SEBS) Algorithm

SEBS is an extensively applied remote-sensing surface energy balance algorithm used in regional and field-scale mapping of ETa (Zhao et al. 2019; Bhattarai et al. 2019). The SEBS model has a detailed parameterization for estimation of surface heat fluxes, producing robust ETa estimates over a wide range of land cover. A recent study conducted in California (Xue et al. 2020) compared SEBS, SEBAL, and METRIC (Mapping EvapoTranspiration at high Resolution with Internalized Calibration) algorithms on almond, tomato, and maize crops. The findings of this study concluded that SEBS performed the best among the three models in estimating daily ETa. SEBS uses an excess resistance parameter (kB^{-1}) as a correction factor to resolve the difference between T_o and T_s. In the formulation of sensible heat flux, the aerodynamic temperature T_o is defined as the extrapolation of air temperature down to an effective height within the canopy at which the vegetation component of H and LE fluxes arise, given by d_o+z_{oh}. From the Monin-Obukhov (M-O) similarity theory, the aerodynamic resistance, r_{ah}, is defined as the resistance from height d_o+z_{oh} having an aerodynamic temperature, to the height z_{ref}, given by:

$$r_{ah} = r_a + r_r = \frac{1}{ku_*}\left[ln\left(\frac{z-d_o}{z_{om}}\right) - \psi_h\right] + \frac{1}{ku_*}ln\left(\frac{z_{om}}{z_{oh}}\right) \quad \text{Eq.3}$$

where r_a (s m^{-1}) is the aerodynamic resistance to momentum transfer between height d_o + z_{om} (d_o is zero plane displacement height, and z_{om} [m] is roughness length for momentum transport), and z_{ref} (m) is the reference height. The other terms in Eq.3 are the Von Karman constant k, friction velocity u_*, and buoyancy correction factor ψ. The formulation of H using the definition of T_o requires an additional resistance called the excess resistance and is denoted by r_r in the above equation. The excess resistance (r_r) is an integral part of the aerodynamic resistance formulation, which drives the difference in the mechanism determining heat and momentum transfer. The excess resistance (r_r) formulation from the above equation can be written as:

$$r_r = \frac{1}{ku_*}ln\left(\frac{z_{om}}{z_{oh}}\right) \quad \text{Eq.4}$$

And is commonly expressed as a function of the dimensionless bulk parameter B^{-1} (inverse Stanton number):

$$kB^{-1} = ln\left[\frac{z_{om}}{z_{oh}}\right] \quad \text{Eq.5}$$

When using radiometric surface temperature, T_s (acquired by satellite sensor), the kB^{-1} becomes a fitting parameter, no longer connected to its theoretical background and largely empirical. SEBS has a detailed parameterization for kB^{-1} applicable over a wide range of land cover. Su et al. (2001) used analytical and experimental approaches to develop a relationship based on environmental variables, vegetation structural characteristics, multi-layer approach, and simulation results, and provided the formulation for excess resistance to the heat transfer parameter (kB^{-1}). This is the most important aspect of SEBS, which differentiates it from SEBAL and TSM, and which makes it the most appropriate algorithm to use in the CalETa framework.

3.4 METEOROLOGICAL DATA

Hourly and daily weather data are required for execution of the SEBS algorithm. Only the 11th hour weather information, corresponding to the overpass time of the satellite, is used in the SEBS algorithm. The daily weather data are used for developing reference ET information, which is used to scale the instantaneous ET to daily ET, and used for interpolation between image acquisition dates. The weather variables used in the ETa framework are wind speed, solar radiation, air temperature, relative humidity, and barometric pressure. Grass reference ET is computed using the Penman-Monteith model. To capture the spatial variations in the weather across the Eastern Sierra region, a large weather station dataset (Table 2) is collected and used to create the Eastern Sierra ETa Dataset. Table 2 identifies the complete list of weather stations. In general, fewer stations are available in the earlier years, and the duration and amount of data (weather variables) varies with time. The weather data from 1985 are downloaded or acquired from different agencies and undergo a detailed QA/QC process before being used in the SEBS algorithm. Weather data are critical; the comprehensive QA/QC process is followed for creation of "clean" weather input information.

TABLE 2. WEATHER STATIONS USED TO DEVELOP THE EASTERN SIERRA ETA DATASET

NAME	STATION_ID	DATA_SOURC	LATITUDE	LONGITUDE	ELEV (ft)
Mammoth - June Lakes	5322	CARB	37.62	-118.83	7099
Big Sandy	505	CDEC	37.47	-119.59	5757
Dana Meadows	503	CDEC	37.90	-119.26	9799
Ellery Lake	501	CDEC	37.93	-119.23	9645
Fresno Dome	507	CDEC	37.46	-119.54	7142
Friant Dam	506	CDEC	37.00	-119.69	577
Gin Flat	511	CDEC	37.77	-119.77	7050
North Fork R S	508	CDEC	37.23	-119.50	2631
Ostrander Lake	509	CDEC	37.64	-119.55	8198
South Lake	513	CDEC	37.18	-118.56	9599
Arvin-Edison	125	CIMIS	35.21	-118.78	508
Bishop	35	CIMIS	37.36	-118.41	4170
Delano	182	CIMIS	35.83	-119.26	300

NAME	STATION_ID	DATA_SOURC	LATITUDE	LONGITUDE	ELEV (ft)
Fresno State	80	CIMIS	36.82	-119.74	339
Lindcove	86	CIMIS	36.36	-119.06	474
Merced	148	CIMIS	37.31	-120.39	200
Orange Cove	142	CIMIS	36.72	-119.39	470
Owens Lake North	183	CIMIS	36.49	-117.92	3558
Owens Lake South	189	CIMIS	36.36	-117.94	3564
Parlier	39	CIMIS	36.60	-119.50	337
Porterville	169	CIMIS	36.08	-119.09	400
Shafter/Usda	5	CIMIS	35.53	-119.28	360
Bakersfield/Meadows	KBFL	faa	35.43	-119.05	488
Bishop Airport	KBIH	faa	37.37	-118.36	4101
China Lake (Naf)	KNID	faa	35.69	-117.69	2230
Fresno - Chandler	KFCH	faa	36.73	-119.82	278
Fresno Air Terminal	KFAT	faa	36.78	-119.72	334
Hawthorne	KHTH	faa	38.54	-118.63	4209
Madera	KMAE	faa	36.98	-120.11	252
Porterville (Awos)	KPTV	faa	36.03	-119.06	442
Tonopah Airport	KTPH	faa	38.05	-117.09	5426
Usmc Mtn Warfare Tra	KBAN	faa	38.36	-119.52	6748
A-Tower	GB17	GBUAPCD	36.52	-117.94	-
Bill Stanley	GB8	GBUAPCD	36.36	-118.01	3622
B-Tower	GB18	GBUAPCD	36.42	-117.89	-
Cottonwood	GB19	GBUAPCD	36.40	-117.98	-
Flat Rock	GB6	GBUAPCD	36.42	-117.84	3717
Keeler	GB13	GBUAPCD	36.49	-117.87	3599
Kirkwood	GB1	GBUAPCD	38.69	-120.07	7762
Lee Vining	GB15	GBUAPCD	37.96	-119.12	6781
Lizard Tail	GB9	GBUAPCD	36.54	-117.94	3602
Lone Pine Met	GB3	GBUAPCD	36.61	-118.05	-
Mill Site	GB11	GBUAPCD	36.46	-117.85	3618
Mono Shore	GB16	GBUAPCD	38.07	-118.95	6420
North Beach	GB10	GBUAPCD	36.54	-117.99	5288
Olancha	GB4	GBUAPCD	36.27	-117.99	3678
Shell Cut	GB7	GBUAPCD	36.37	-117.90	3622
White Mountain	GB2	GBUAPCD	37.36	-118.33	4124
Ash Meadows Nevada	261711	RAWS	36.41	-116.34	2090
Ash Mountain	44701	RAWS	36.49	-118.82	1699
Batterson	44207	RAWS	37.38	-119.63	3100
Bear Peak	44730	RAWS	35.88	-118.05	8228
Benton	43708	RAWS	37.84	-118.48	5377
Bird Spring Pass	45023	RAWS	35.54	-118.14	7644
Blackrock	44722	RAWS	36.09	-118.26	8199

NAME	STATION_ID	DATA_SOURC	LATITUDE	LONGITUDE	ELEV (ft)
Breckenridge	45009	RAWS	35.45	-118.58	7549
Bridgeport	43702	RAWS	38.25	-119.22	6558
Buddy Adams Nevada	261408	RAWS	37.02	-116.61	4593
Case Mountain	44733	RAWS	36.41	-118.81	6450
Catheys Valley	44114	RAWS	37.38	-120.08	1234
Cedar Grove	44719	RAWS	36.79	-118.66	4721
Crane Raws	44195	RAWS	37.76	-119.83	6644
Crestview	43709	RAWS	37.74	-119.00	7562
Democrat	45002	RAWS	35.53	-118.63	2356
Dexter	43711	RAWS	37.84	-118.77	7982
Dinkey	44521	RAWS	37.07	-119.17	5669
El Portal Raws	44112	RAWS	37.68	-119.78	2100
Fancher Creek	44516	RAWS	36.88	-119.47	915
Fence Mdw	44503	RAWS	36.97	-119.18	5256
Fountain Springs	44731	RAWS	35.89	-118.92	794
Ft Springs	44704	RAWS	35.89	-118.92	791
Hart Flat	45018	RAWS	35.25	-118.60	2684
High Sierra	44520	RAWS	37.31	-119.04	7402
Hunter Mountain	44809	RAWS	36.55	-117.47	6880
Hurley	44517	RAWS	37.02	-119.57	1201
Indian Wells Canyon	45015	RAWS	35.69	-117.89	3999
Jawbone	45013	RAWS	35.29	-118.23	4301
Jerseydale	44105	RAWS	37.54	-119.84	3599
Johnsondale	44707	RAWS	35.97	-118.55	4701
Laural Mtn	45022	RAWS	35.48	-117.70	4390
Mariposa	44106	RAWS	37.50	-119.99	2228
Metcalf Gap	44209	RAWS	37.41	-119.77	3077
Miami	44110	RAWS	37.42	-119.74	4327
Milo	44708	RAWS	36.23	-118.87	1965
Minarets	44203	RAWS	37.41	-119.35	5180
Mt Tom	44511	RAWS	37.38	-119.17	9019
Mtrest	44505	RAWS	37.05	-119.37	4101
Northfork	44204	RAWS	37.23	-119.51	2733
Oak Creek	44804	RAWS	36.83	-118.25	4281
Oak Opening	44717	RAWS	36.18	-118.70	3241
Opal Mountain	45127	RAWS	35.16	-117.18	3241
Owens Valley	44803	RAWS	37.39	-118.55	4649
Park Ridge	44713	RAWS	36.72	-118.94	7539
Peppermint	44726	RAWS	36.07	-118.54	7169
Pinecrest 2	43615	RAWS	38.19	-120.01	5699
Pinehurst	44508	RAWS	36.69	-119.00	4058
Piute	45017	RAWS	35.45	-118.28	6401

NAME	STATION_ID	DATA_SOURC	LATITUDE	LONGITUDE	ELEV (ft)
Quima Peak Nevada	260810	RAWS	38.49	-117.10	7986
River Kern	45016	RAWS	35.78	-118.43	3041
Rock Creek	43710	RAWS	37.56	-118.68	7096
Shadequarter	44724	RAWS	36.57	-118.96	4360
Shaver	44522	RAWS	37.14	-119.26	5614
Smith Peak (Stf)	44115	RAWS	37.80	-120.10	3871
Trimmer	44510	RAWS	36.90	-119.30	1539
Twisselman	45019	RAWS	35.35	-118.82	3232
Uhl/Hot Springs	44712	RAWS	35.89	-118.63	3720
Walker Pass	45014	RAWS	35.66	-118.06	5571
Wawona Raws	44109	RAWS	37.54	-119.65	3960
Wofford Heights	44190	RAWS	35.72	-118.50	3150
Wolverton	44732	RAWS	36.44	-118.70	5240
Woody	45020	RAWS	35.71	-118.82	1591
Wolf Raws	43612	RAWS	37.85	-119.65	7999

3.5 Validation

In the Inyo/LA Cooperative Study (Harrington et al. 2004) conducted from 2000 to 2003, evapotranspiration was measured extensively using Eddy Covariance (EC) meteorological stations. EC measurements were collected at seven sites over four years, providing 12 site-year combinations (Table 3). This dataset provides an independent measurement of ETa that can be compared to estimates from the remote-sensing-based ETa dataset developed for the Eastern Sierra region.

Figure 3 shows the correlation between monthly observed and remote sensing estimates of ETa, combined for all station-years. The remote-sensing-based ETa estimate from the SEBS algorithm captures the variance in the monthly measured data with a high coefficient of determination (R^2) of 0.93. Other performance statistics computed at a monthly scale for the pooled data from all stations are MAE (mean absolute error) at 0.24 inches/month (18%), MBE (mean bias error) at 0.09 inches/month (7.0%), and NSE (Nash-Sutcliffe efficiency) at 0.91. All the performance statistics indicated very good agreement of the remote-sensing-based measurement of ETa to the EC observation of ETa. The annual ET observed values of the different vegetation types monitored in the study compared well with the remote sensing measurements of ETa (Figure 4).

TABLE 3. DETAILS OF EDDY COVARIANCE METEOROLOGICAL STATION USED FOR ET MEASUREMENT

Station Code	Veg Code and Type		Latitude	Longitude	YEAR			
					2000	2001	2002	2003
FSL138	AM2	Alkali Meadow	37.41	-118.42			Available	
PLC018	RBS	Rabbitbrush Scrub	37.36	-118.35			Available	
PLC074	SBM	Nevada Saltbush Meadow	37.32	-118.36			Available	Available
PLC045	SBS	Nevada Saltbush Scrub	37.33	-118.35		Available		
PLC185	DSS	Desert Sink Scrub	37.27	-118.33			Available	Available
BLK009	RBM	Rabbitbrush Meadow	36.98	-118.22		Available		
BLK100	AM1	Alkali Meadow	36.89	-118.23	Available	Available	Available	Available

FIGURE 3. MONTHLY OBSERVED VERSUS SEBS MEASURED ETA FOR ALL AVAILABLE STATION-YEARS

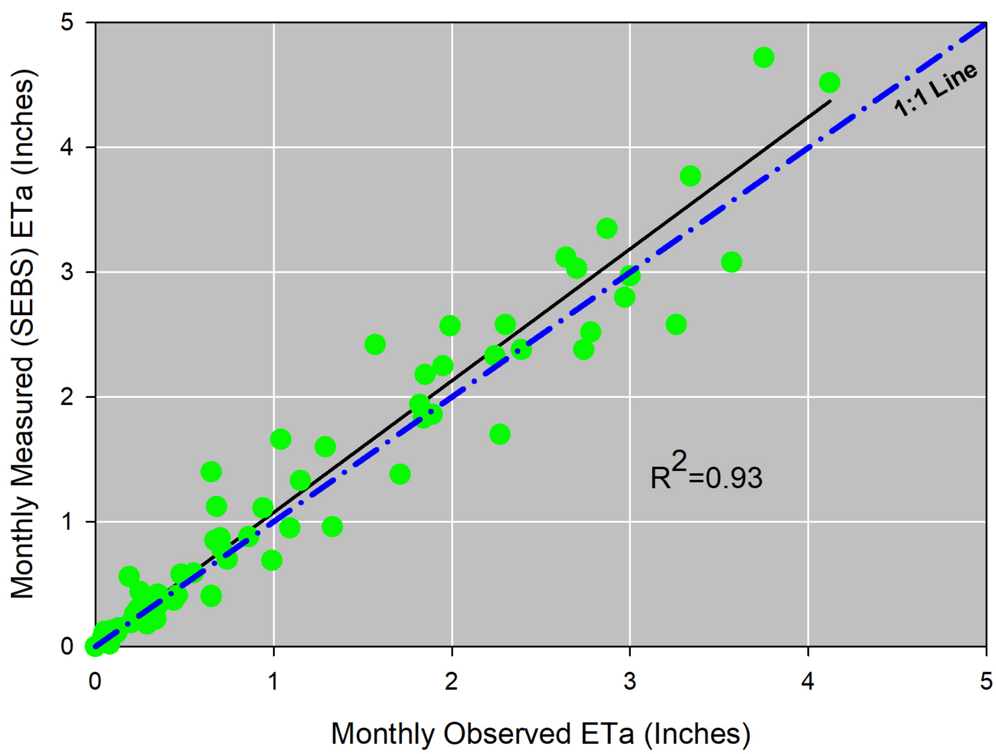
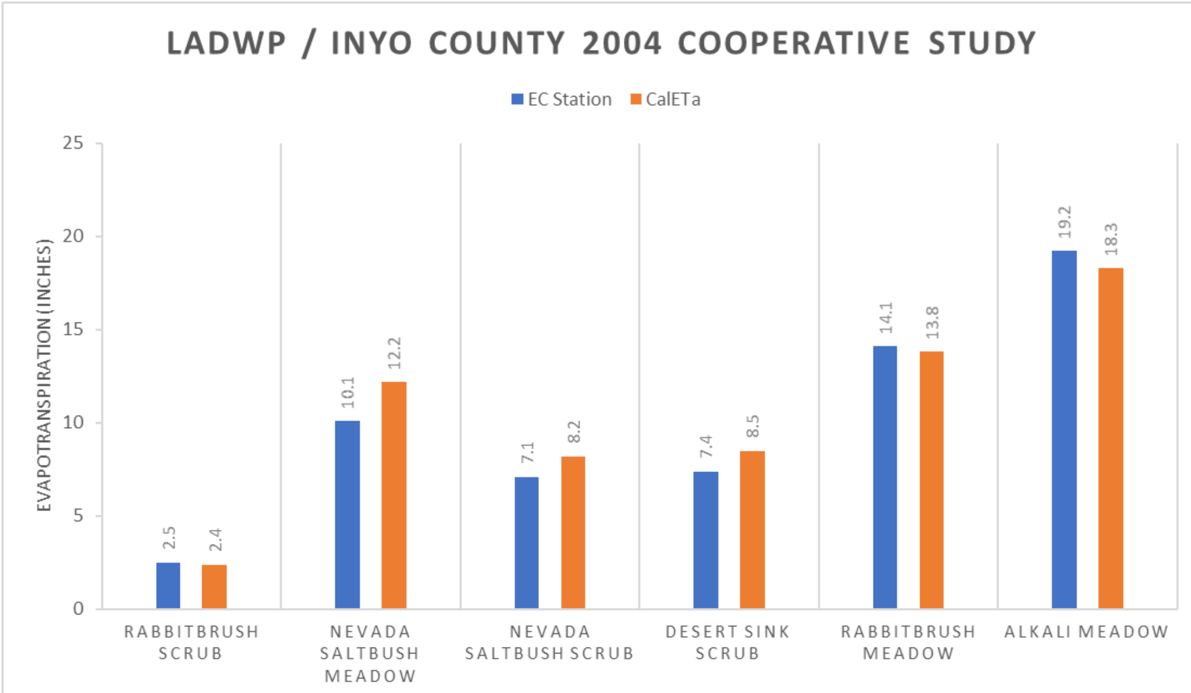


FIGURE 4. ANNUAL ETA COMPARISON FOR DIFFERENT VEGETATION COMMUNITIES MONITORED IN THE 2004 COOPERATIVE STUDY



4 ANALYSIS

This section describes the study of the spatial and temporal distribution of ETa across the Eastern Sierra Valley. Three specific studies were carried out to determine: (1) long-term ETa and precipitation dynamics across different regions of Eastern Sierra, (2) relationship of ETa to other hydrological components in the Owens Valley watershed, and (3) change in ETa flux in different year types. For the purpose of analysis, the runoff year is defined from April to March and the water year is defined from October to September. The April-to-September timeframe is considered the summer period, and the October-to-March timeframe is considered the winter period.

4.1 EXTRACTING ETA FOR (1) MODEL DOMAINS AND (2) WELLFIELDS

ETA AND PRECIPITATION ANALYSIS FOR GROUNDWATER MODEL DOMAINS

Spatially averaged monthly ETa was extracted from the Eastern Sierra ETa Dataset for each groundwater model domain (Figure 5) and compared with monthly precipitation extracted from the PRISM (Parameter-elevation Regressions on Independent Slopes Model) dataset. PRISM gridded climate data products are USDA's (United States Department of Agriculture) official climatological data and commonly used for research and applied studies related to ecology (Ackerly et al. 2010) and hydrology (Huntington and McEvoy 2011). The PRISM products use a weighted regression scheme to account for complex climate regimes associated with orography, rain shadows, temperature inversions, slope aspect, coastal proximity, and other factors. A monthly precipitation PRISM product at 4-km resolution was used in this study. The monthly data were aggregated into summer (April to September) and winter (October to March) months for analysis. Table 4 shows the 35-year average ETa and precipitation value for each of the model domains, for the summer and winter months. From Table 4, it is evident that most ET is occurring during the summer period, while the precipitation is occurring during the winter months. The long-term average annual value aggregated for the runoff year (April to March) was found to be the same as that of the water year (October to September). The ET minus precipitation value for each domain is tabulated in Table 4. Figure 6 shows the long-term ETa for summer months and long-term precipitation for winter months, for each model domain.

FIGURE 5. GROUNDWATER MODEL DOMAIN USED FOR STUDYING SPATIAL ETA AND PRECIPITATION

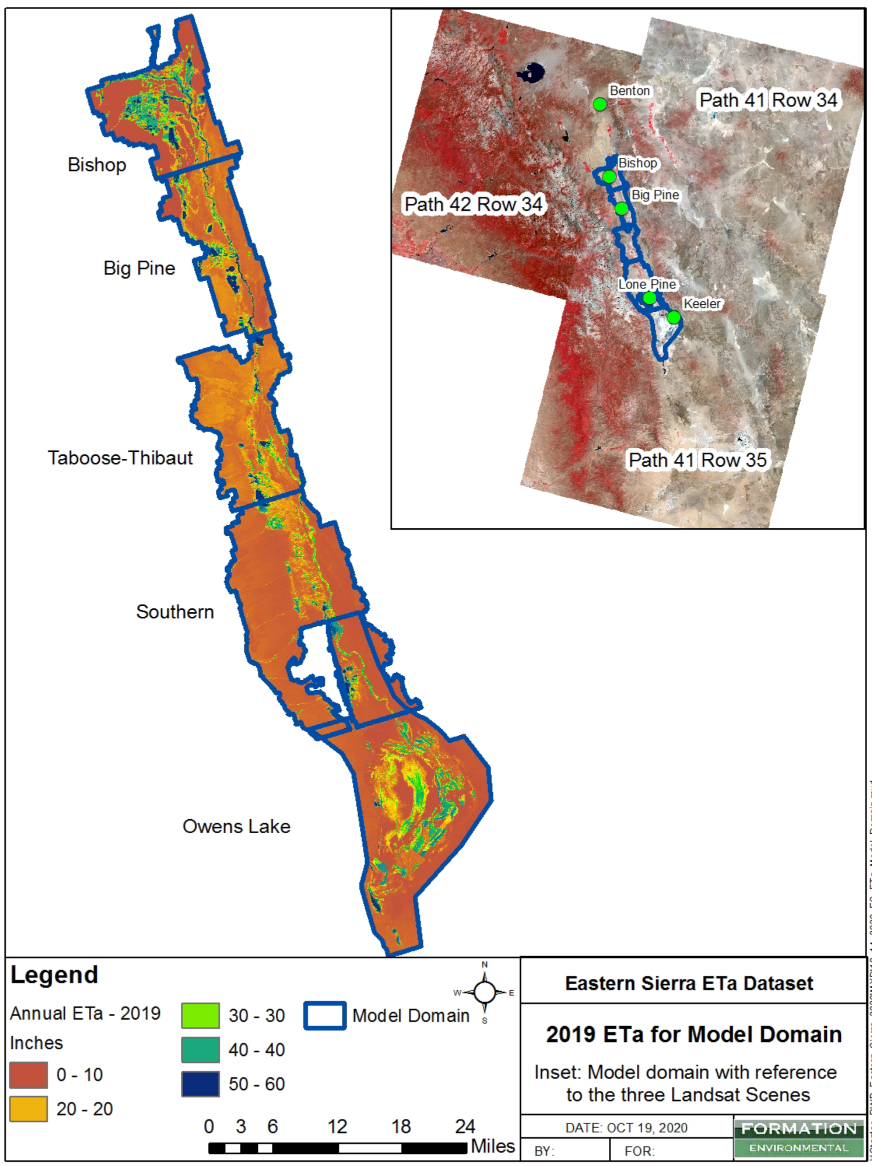


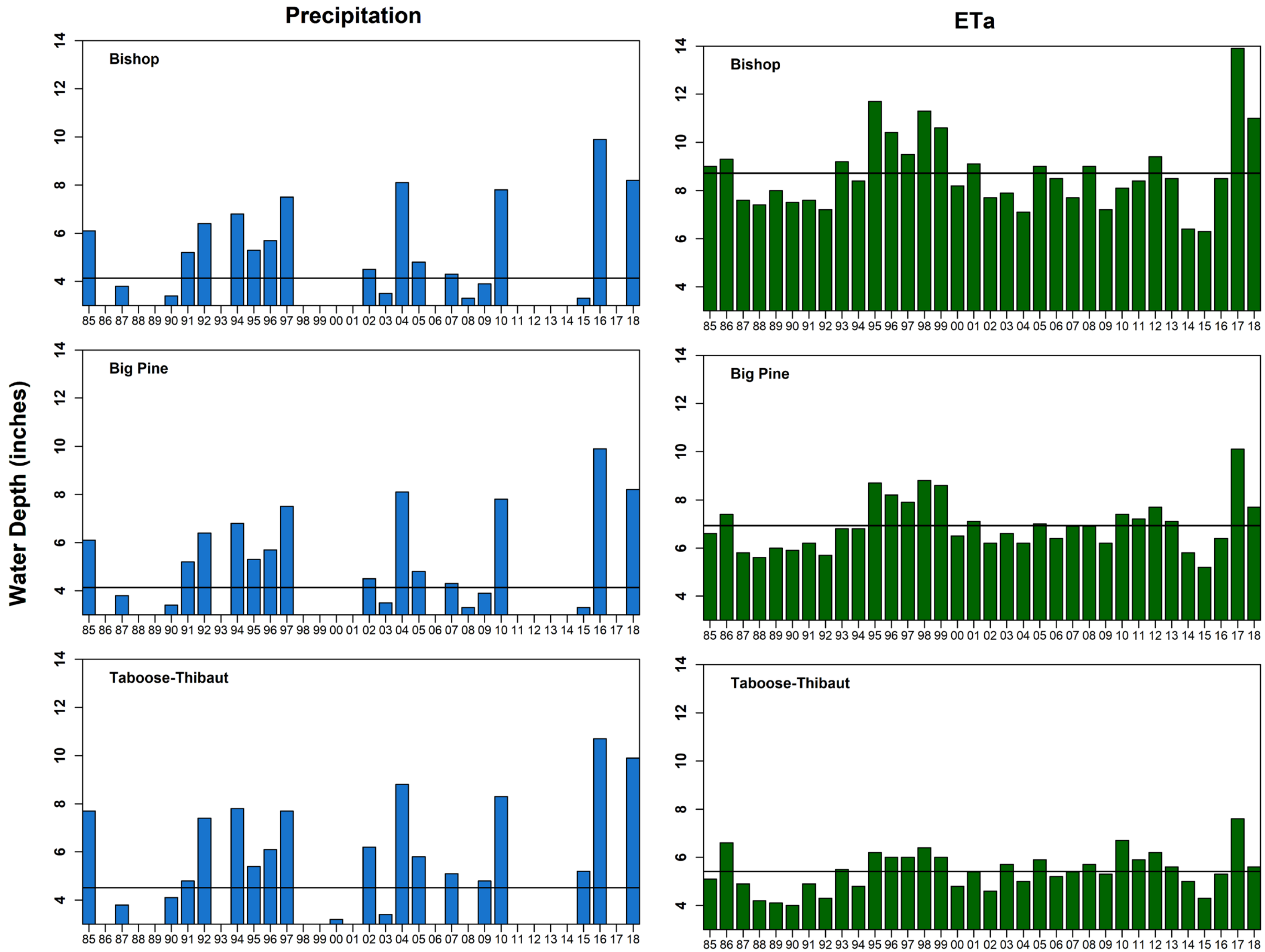
TABLE 4. LONG-TERM (1985-2019) AVERAGE VALUE OF ETA AND PRECIPITATION FOR GROUNDWATER MODEL DOMAINS IN INCHES AND THOUSAND ACRE FEET (TAF)

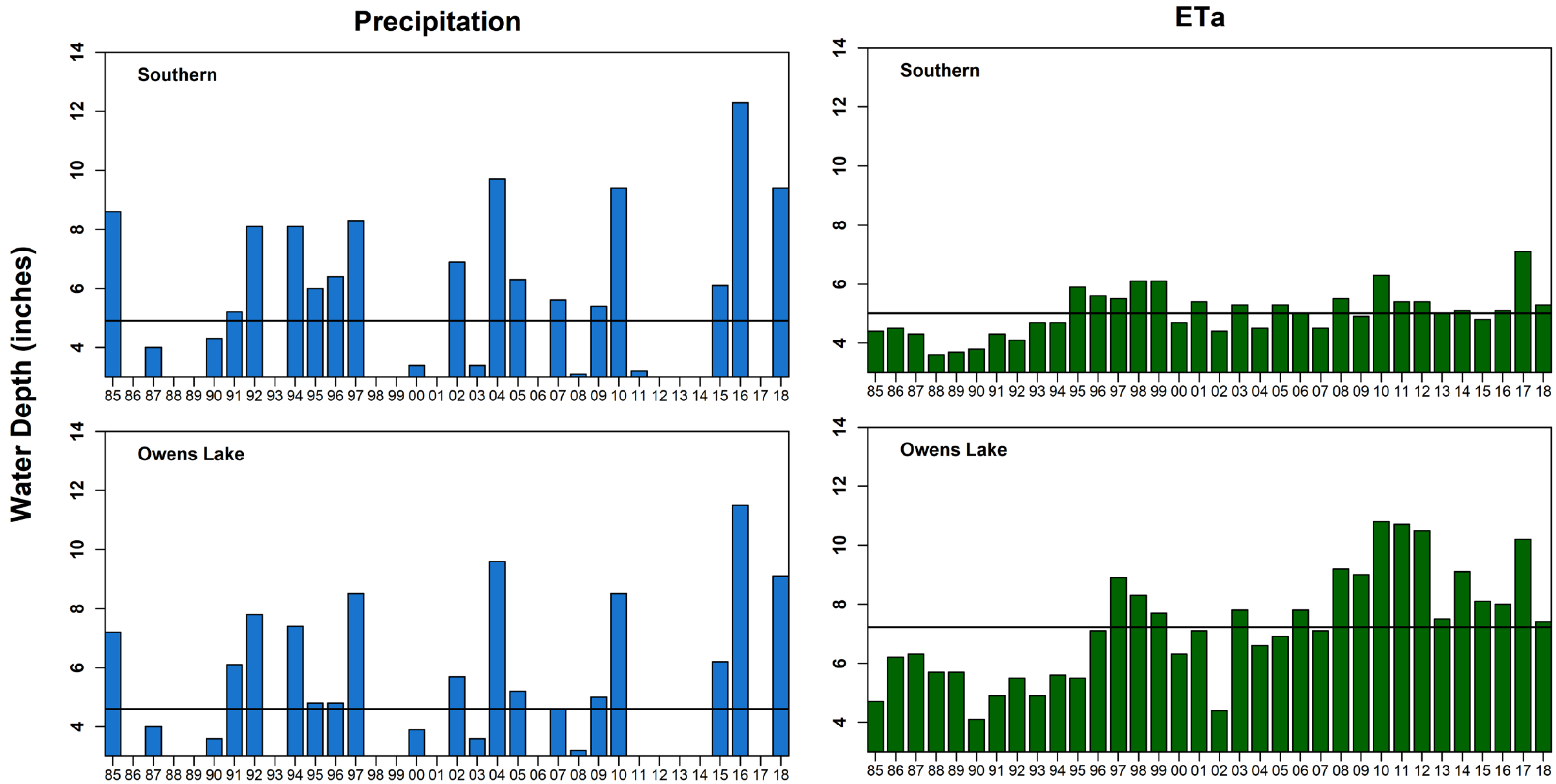
MODEL DOMAIN	ETA (INCHES)			PRECIPITATION (INCHES)			ET-PRECIP
	Summer April - Sep	Winter Oct - March	Annual April-March	Summer April - Sep	Winter Oct - March	Annual April-March	Annual April-March
BISHOP	8.8	3.1	11.8	1.3	4.1	5.4	6.4
BIG PINE	7.0	2.7	9.7	1.3	4.1	5.4	4.3
TABOOSE-THIBAUT	5.5	2.5	7.9	1.1	4.5	5.6	2.3
SOUTHERN	5.1	2.1	7.2	1.1	4.9	6.0	1.2
OWENS LAKE	7.3	2.6	9.8	1.1	4.6	5.7	4.1

MODEL DOMAIN	ETA (TAF)			PRECIPITATION (TAF)			ET-PRECIP
	Summer April - Sep	Winter Oct - March	Annual April-March	Summer April - Sep	Winter Oct - March	Annual April-March	Annual April-March
BISHOP	48	17	64	7	22	29	35
BIG PINE	34	13	47	6	20	26	21
TABOOSE-THIBAUT	32	15	47	6	27	33	14
SOUTHERN	58	24	82	12	56	68	14
OWENS LAKE	91	32	122	14	57	71	51

FIGURE 6. OWENS VALLEY ETA AND PRECIPITATION FOR MODEL DOMAINS

ETa is shown for summer months (April to September), and precipitation is shown for winter months (October to March). Note that the ETa is positively correlated (R^2=0.50) to 6-month lagged precipitation. The horizontal black line is the historic average.




Precipitation
ETa
Southern
Owens Lake
Water Depth (inches)
85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18
4
6
8
10
12
14

ETa and Precipitation Analysis for Wellfields and Other Regions

Spatially averaged monthly ETa was extracted from the Eastern Sierra ETa Dataset for the wellfields and other areas (Figure 7) and compared with monthly precipitation extracted from the PRISM dataset. Table 5 shows the 35-year average ETa and precipitation values for each region, aggregated to summer and winter months. The long-term average annual value aggregated for the runoff year (April to March) was found to be the same as that of the water year (October to September). Figure 8 shows the long-term ET for summer months and long-term precipitation for winter months, for the wellfields and other areas.

Figure 7. Wellfields Used for Studying Spatial ETa and Precipitation

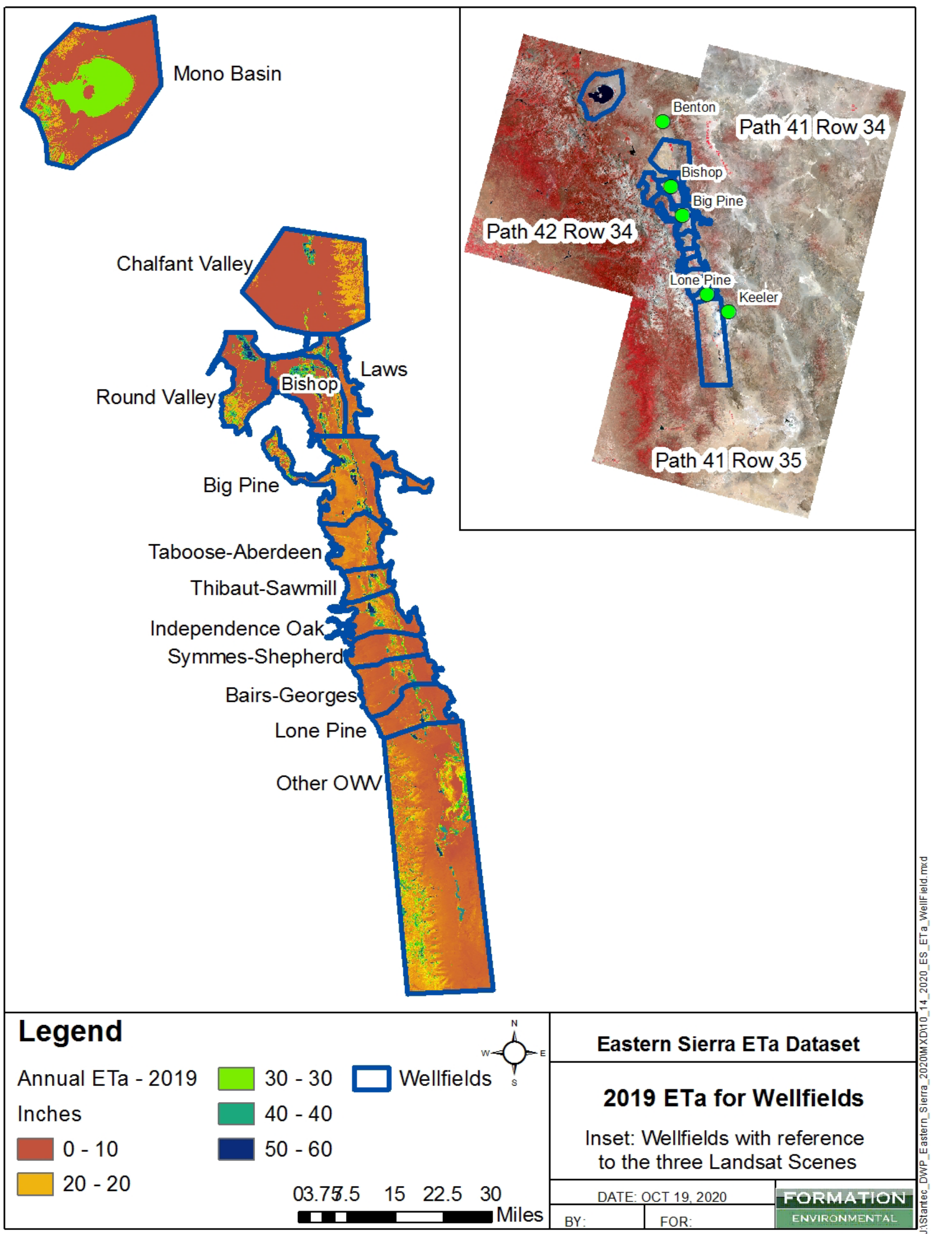


TABLE 5. LONG-TERM (1985-2019) AVERAGE VALUE OF ET AND PRECIPITATION FOR WELLFIELDS AND OTHER AREAS IN INCHES AND THOUSAND ACRE FEET (TAF)

WELL FIELDS	ETA (INCHES)			PRECIPITATION (INCHES)		
	Summer April - Sep	Winter Oct - March	Annual April - March	Summer April - Sep	Winter Oct - March	Annual April - March
BAIRS-GEORGES	4.8	2.2	7.0	1.2	5.3	6.5
BISHOP	9.1	3.2	12.2	1.3	4.3	5.6
BIG PINE	7.0	3.0	9.9	1.8	6.6	8.3
INDEPENDENCE OAK	6.4	2.5	8.8	0.9	4.5	5.4
LONE PINE	5.0	2.2	7.1	1.1	4.9	6.0
LAWS	5.3	2.4	7.6	1.5	4.1	5.6
SYMMES-SHEPHERD	4.4	2.0	6.3	1.1	5.3	6.4
TABOOSE-ABERDEEN	4.8	2.4	7.1	1.3	5.0	6.2
THIBAUT-SAWMILL	5.5	2.4	7.7	1.1	4.8	5.8
MONO BASIN*	14.0	7.0	21.1	3.1	10.2	13.3
ROUND VALLEY*	9.4	5.0	14.3	2.0	6.9	8.8
CHALFANT VALLEY*	5.3	2.9	8.2	2.7	6.4	9.1
OTHER OWV*	8.0	3.3	11.2	1.6	7.5	9.1

*OTHER AREA AND NOT A WELLFIELD

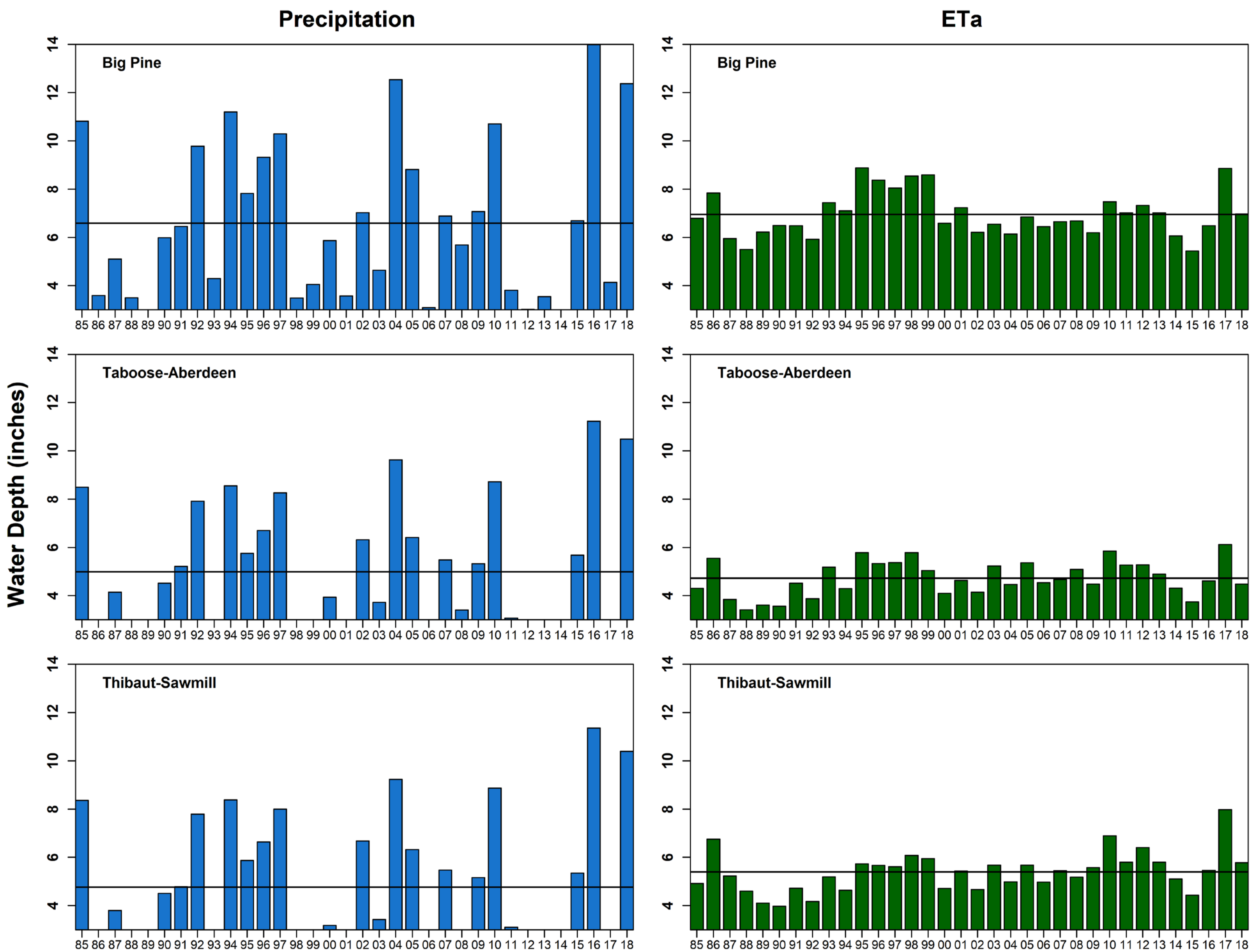
WELL FIELDS	ETA (TAF)			PRECIPITATION (TAF)		
	Summer April - Sep	Winter Oct - March	Annual April - March	Summer April - Sep	Winter Oct - March	Annual April - March
BAIRS-GEORGES	38	17	55	9	42	51
BISHOP	30	10	40	4	14	18
BIG PINE	12	5	17	3	11	14
INDEPENDENCE OAK	20	8	28	3	14	17
LONE PINE	13	6	19	3	13	16
LAWS	20	9	29	6	16	21
SYMMES-SHEPHERD	15	7	21	4	18	22
TABOOSE-ABERDEEN	22	11	33	6	23	29
THIBAUT-SAWMILL	13	6	19	3	12	14
MONO BASIN*	73	37	111	16	53	70

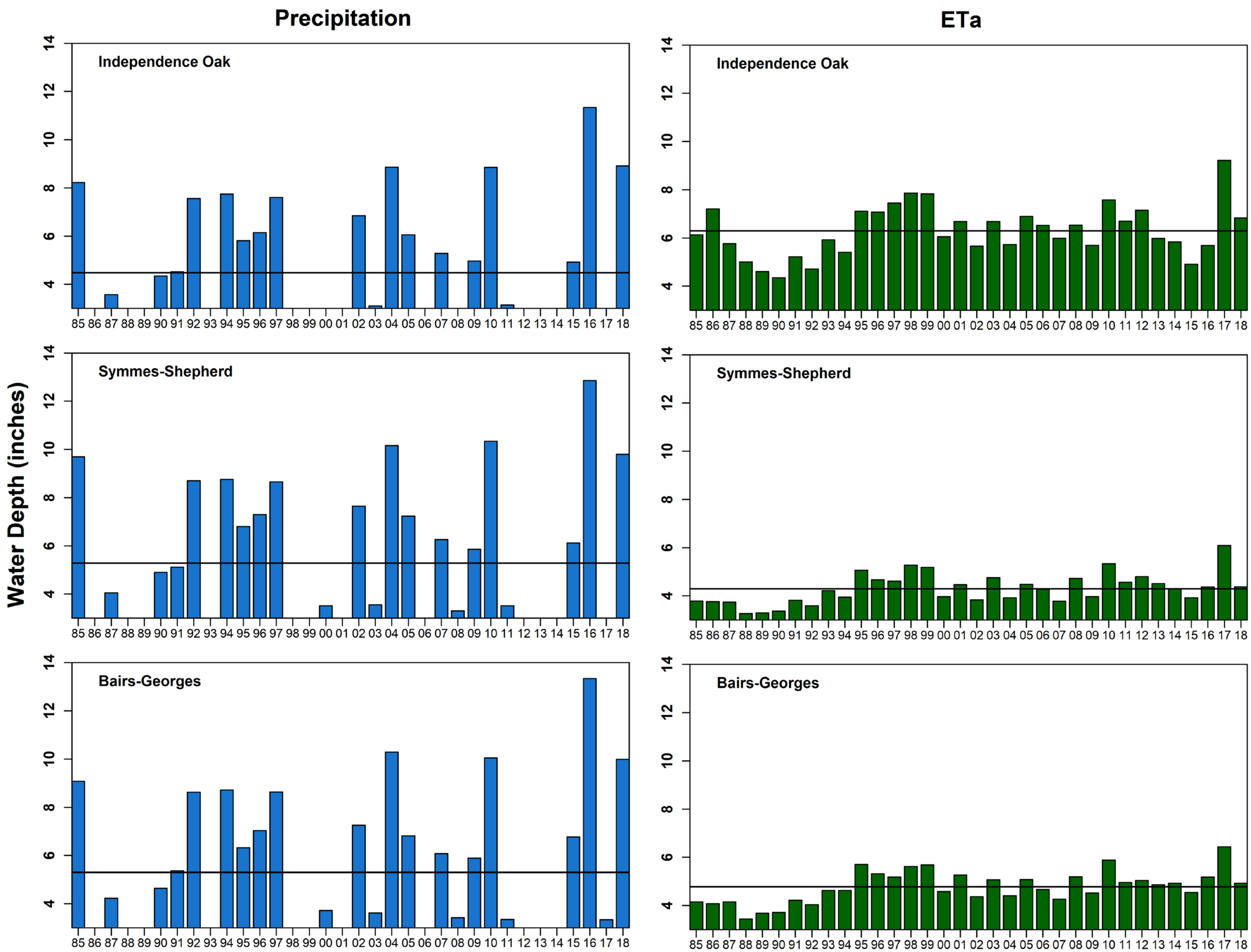
WELL FIELDS	ETA (TAF)			PRECIPITATION (TAF)		
	Summer April - Sep	Winter Oct - March	Annual April - March	Summer April - Sep	Winter Oct - March	Annual April - March
ROUND VALLEY*	168	89	256	35	123	158
CHALFANT VALLEY*	70	38	108	36	84	120
OTHER OWV*	228	95	320	46	215	260

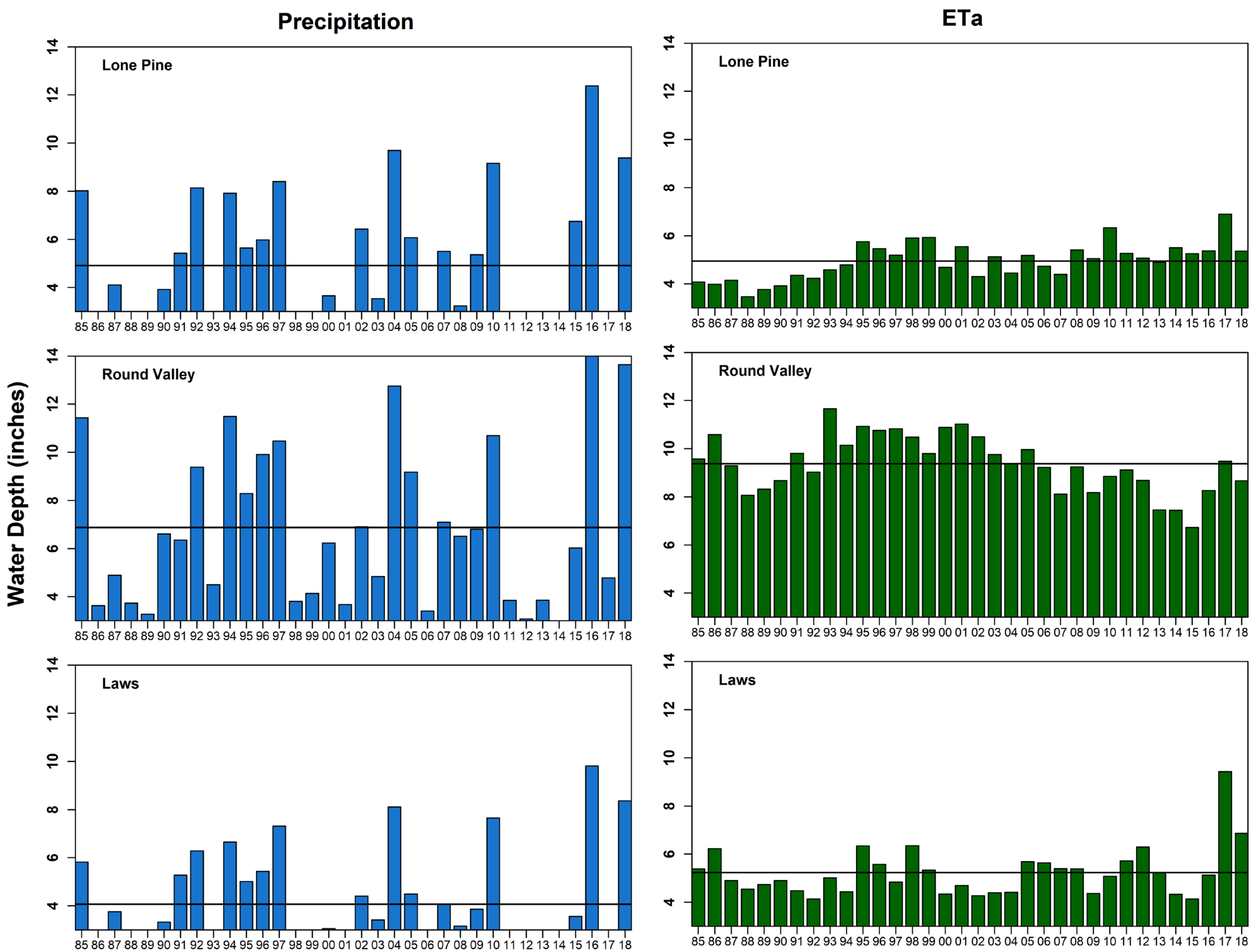
***OTHER AREA AND NOT A WELLFIELD**

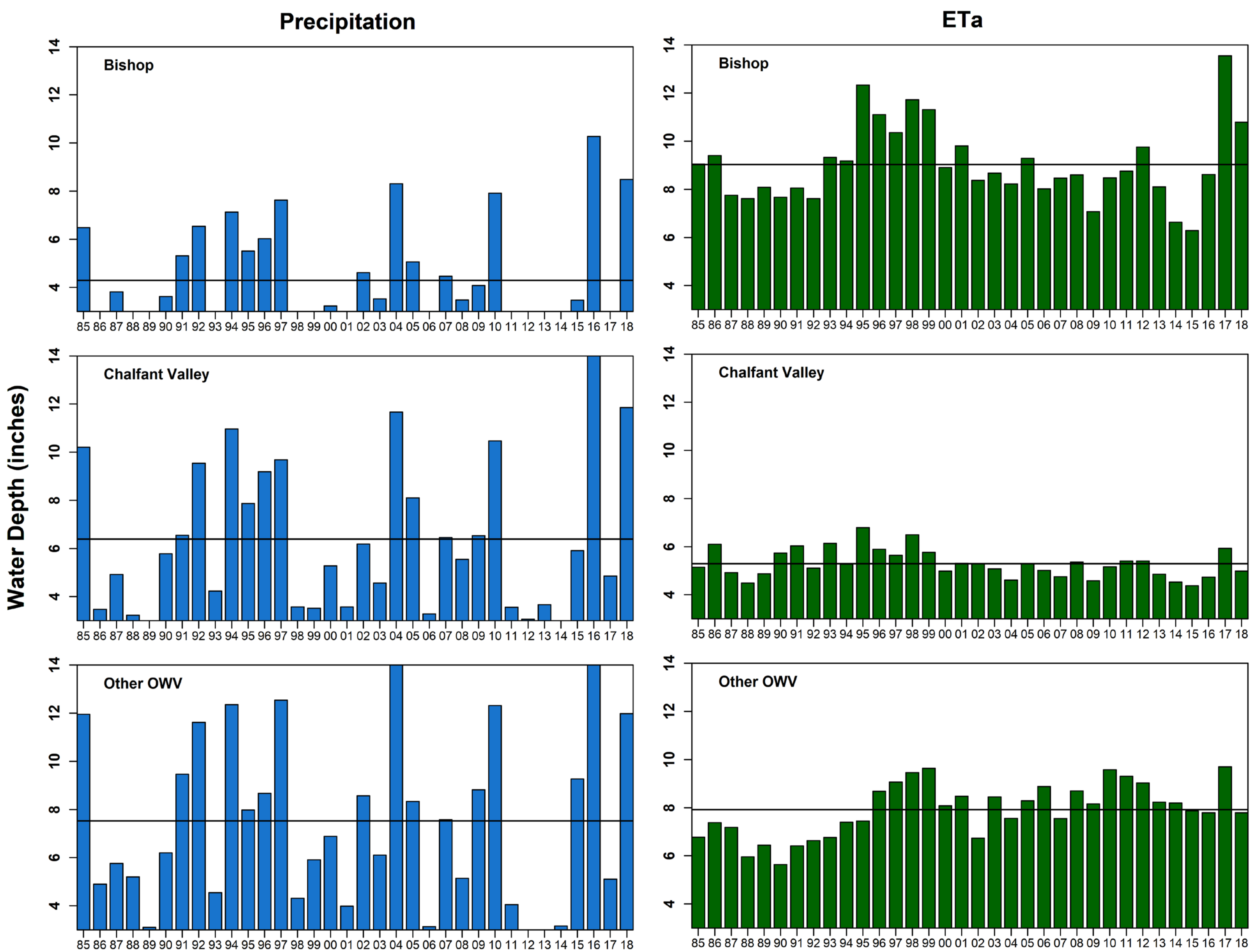
Figure 8. Owens Valley ETa and Precipitation for Wellfield Areas

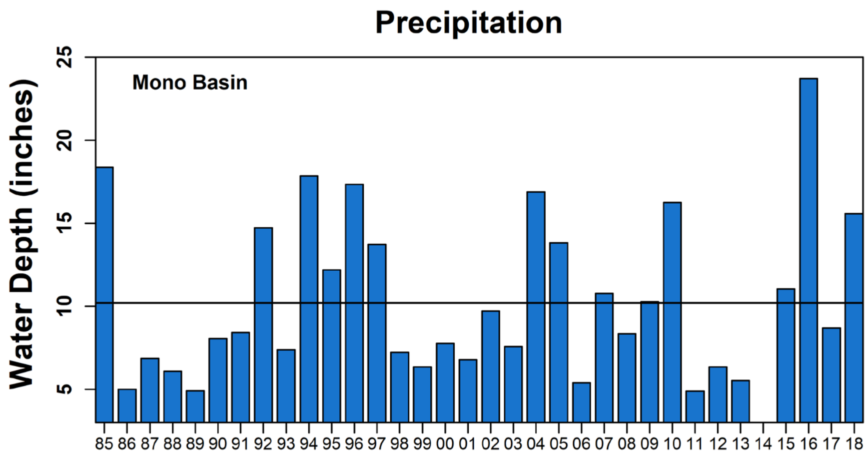
ETa is shown for summer months (April to September), and precipitation is shown for winter months (October to March). Note that the ETa is positively correlated (R^2=0.50) to 6-month lagged precipitation. The horizontal black line is the historic average.

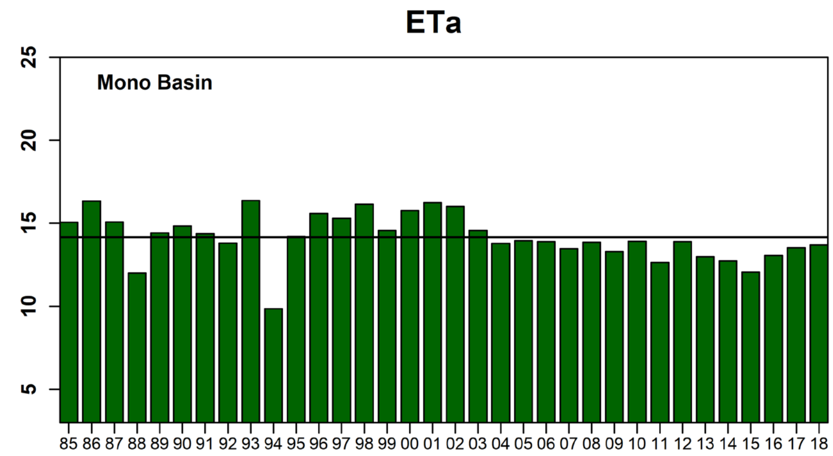



Precipitation
ETa
Water Depth (inches)
Independence Oak
Symmes-Shepherd
Bairs-Georges
4 6 8 10 12 14
85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18


Precipitation
ETa
Water Depth (inches)
Lone Pine
Round Valley
Laws
4
6
8
10
12
14
85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18


Precipitation
ETa
Water Depth (inches)
Bishop
Chalfant Valley
Other OWV
85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18
4 6 8 10 12 14


Precipitation
Mono Basin
Water Depth (inches)
5
10
15
20
25
85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18


ETa
Mono Basin
5
10
15
20
25
85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18

4.2 Comparing Extracted ET Data to (a) Precipitation, (b) Runoff, and (c) Snowpack

Monthly ETa and precipitation data from 1985 to 2019 were extracted for the Owens Valley Watershed and aggregated to the summer and winter periods. Monthly runoff data for the Owens Valley were also aggregated to the summer and winter periods. Figure 9 shows the relationship between summer ETa and runoff in the Owens Valley Watershed. This relationship could be further studied by classifying the 35 years of data into dry, normal, and wet year types. The year type classification based on runoff year values (April 1 to March 31) is shown in Table 6. ETa response to runoff during dry, normal, and wet years (Figure 9) is evident here and explains the vegetation dynamics to water availability. The precipitation response to runoff is lagged by a 6-month period (Figure 10); therefore, ETa also shows a 6-month lagged response to precipitation (Figure 11). The annual snowpack at Mammoth Pass is highly correlated to the annual runoff at Owens Valley (Figure 12). The large variance between annual snowpack and ETa shown in Figure 13 could be partially explained by the lagged response time of these two processes, but the R^2 of 0.44 indicates some degree of collinearity between the two variables.

Figure 9. 1985 to 2018 Summer ETa and Runoff Relationship for Owens Valley Watershed

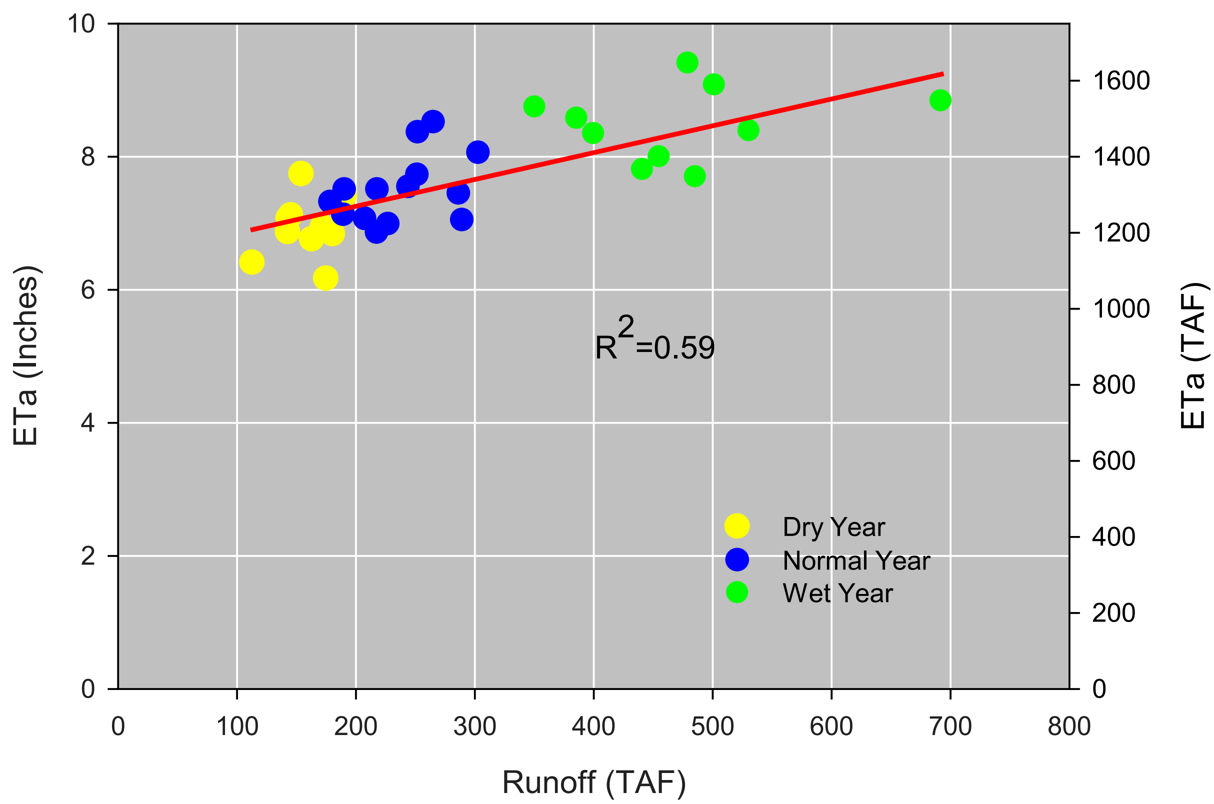


FIGURE 10. 1985 TO 2018 BI-ANNUAL PRECIPITATION AND RUNOFF RELATIONSHIP FOR OWENS VALLEY WATERSHED

Precipitation and runoff aggregated to summer and winter periods: April to September and October to March.

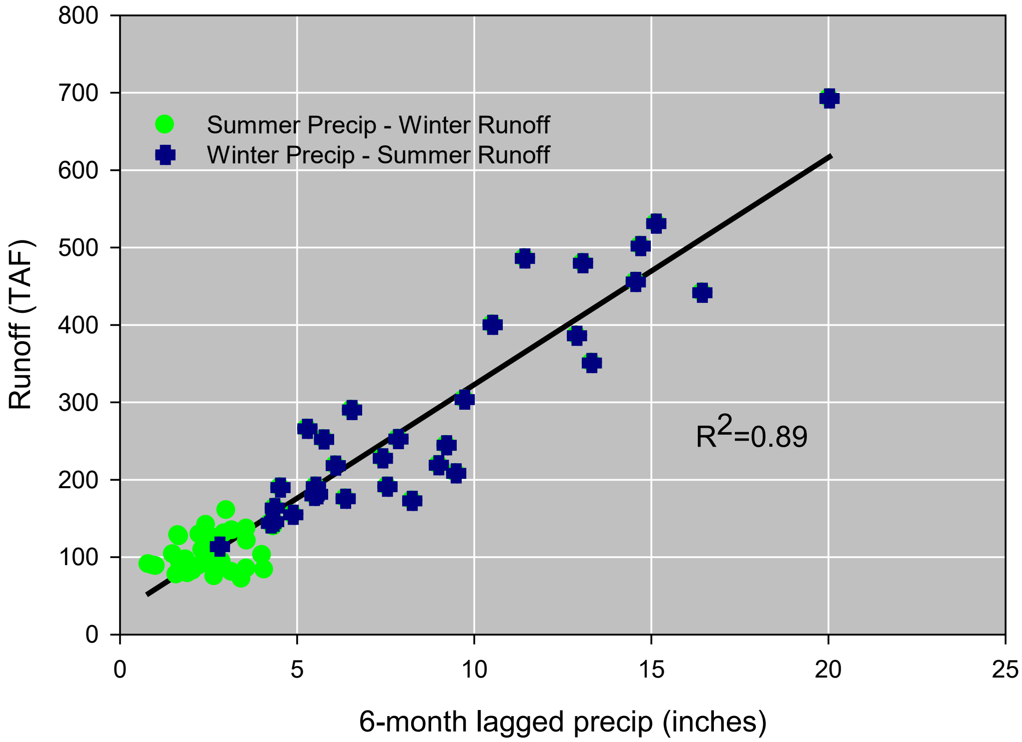


FIGURE 11. 1985 TO 2018 BI-ANNUAL PRECIPITATION AND ETA RELATIONSHIP FOR OWENS VALLEY WATERSHED

Precipitation and ETa aggregated to summer and winter periods: April to September and October to March.

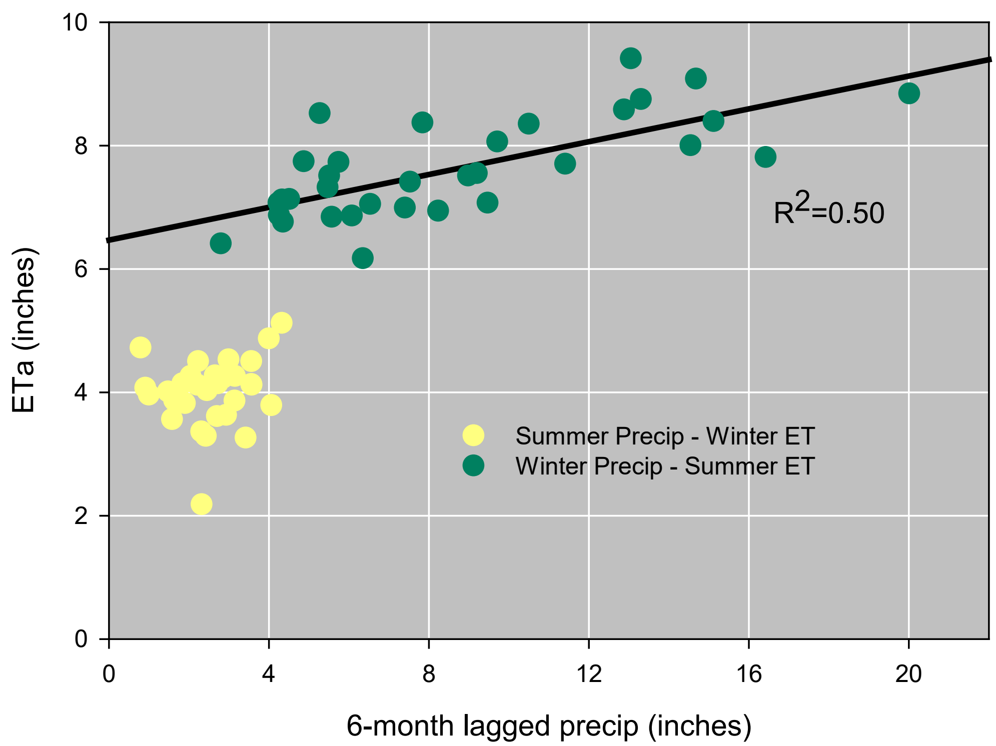


FIGURE 12. 1990 TO 2018 ANNUAL SNOWPACK AT MAMMOTH PASS AND OVR RUNOFF RELATIONSHIP

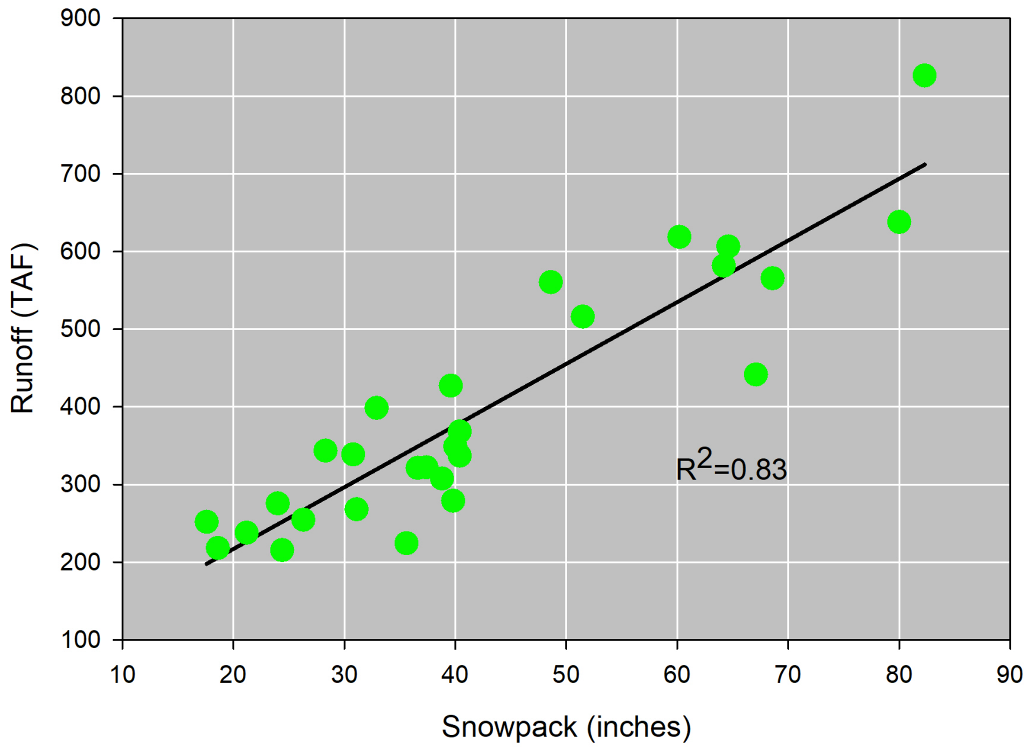
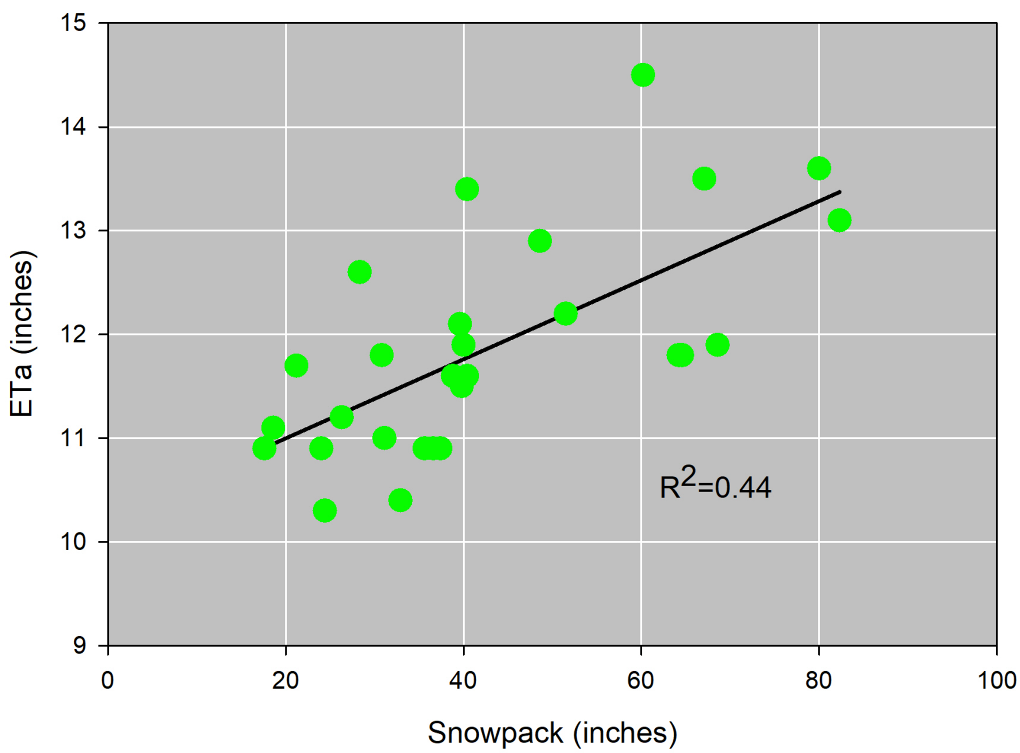


FIGURE 13. 1990 TO 2018 ANNUAL SNOWPACK AT MAMMOTH PASS AND ETA RELATIONSHIP



4.3 Seasonal Variability and Year Type Analysis

The ETa analysis for different water-year type is presented in this section. Mean annual runoff was used to derive percentage deviation, which was used to classify the years (Table 6). Average annual ETa maps for model domains were generated for dry, wet, and normal years (Appendix E). Heat maps of ETa minus precipitation for average dry, normal, and wet years for the Bishop groundwater modeling domain are shown in Figure 14 through Figure 16. Appendix F shows the ETa minus precipitation maps for other modeling domains.

Table 6. Classification of Dry, Normal, and Wet Years Based on Runoff Year Value (April 1 to March 31)

Year	*Runoff (Acre-ft)*	*RO%*	*Year type*
2015	198193	51.1	DRY
1990	215375	55.6	
2014	217982	56.3	
2013	224298	57.9	
2012	237719	61.3	
2007	251628	64.9	
1992	254358	65.6	
1988	258845	66.8	
1989	261425	67.5	
1991	267858	69.1	
1994	275497	71.1	NORMAL
2002	278750	71.9	
1987	280785	72.5	
2008	307425	79.3	
2004	321253	82.9	
2009	321786	83.0	
2016	336985	86.9	
2003	338416	87.3	
2001	343340	88.6	
2000	348698	89.9	
1999	368000	94.9	
2018	398492	102.8	
2010	426874	110.2	
1985	428046	110.5	
1993	441306	113.9	WET
1997	516225	133.2	
1996	560366	144.6	
2005	565593	145.9	
2011	581758	150.1	
2006	606508	156.5	
1998	618668	159.6	
1995	638036	164.6	

Year	*Runoff (Acre-ft)*	*RO%*	*Year type*
1986	658839	170.0	
2017	826446	213.3	

FIGURE 14. BISHOP MODELING DOMAIN: AVERAGE ANNUAL ETA OF DRY YEARS MINUS AVERAGE ANNUAL PRECIPITATION OF DRY YEARS

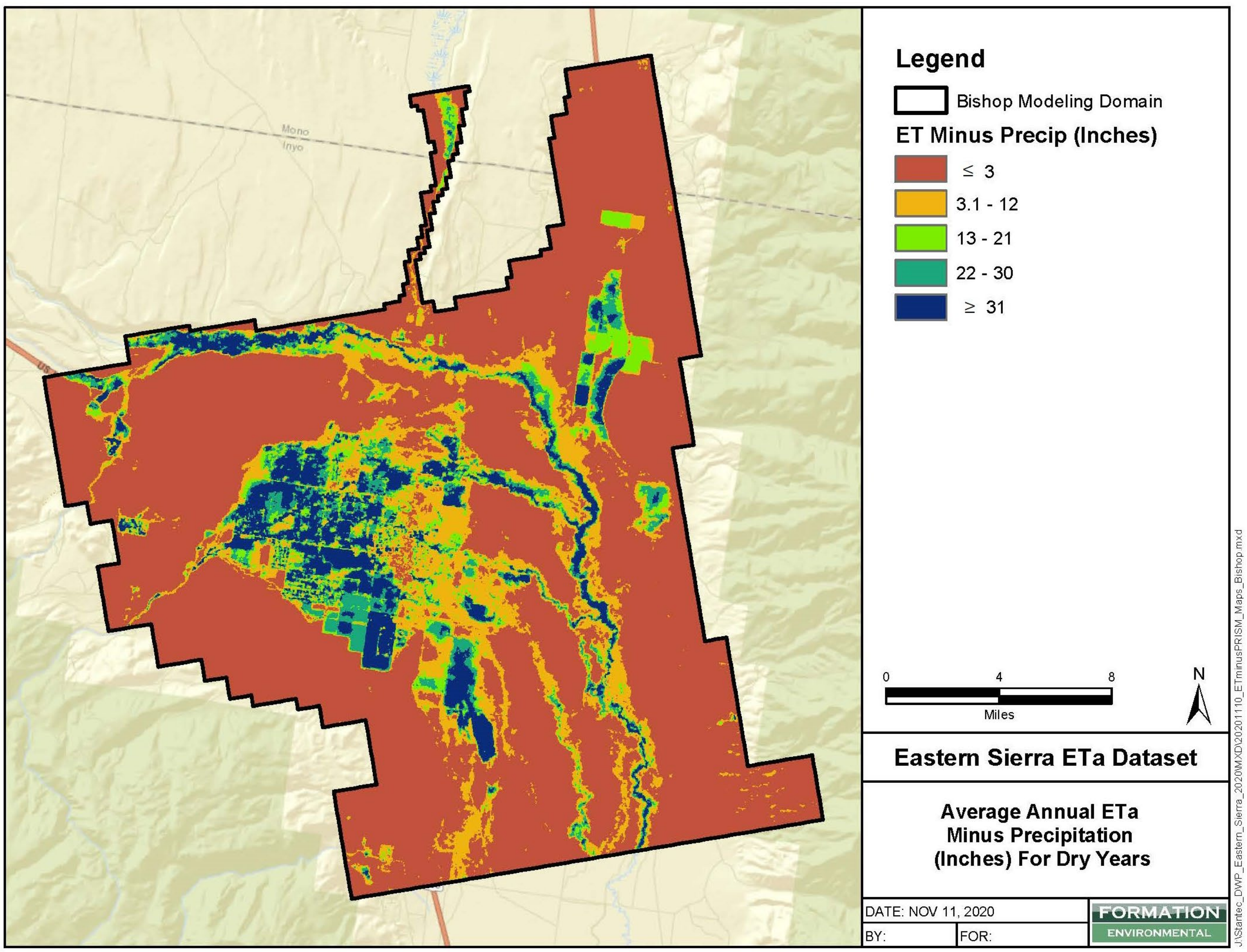


Figure 15. Bishop Modeling Domain: Average Annual ETa of Normal Years Minus Average Annual Precipitation of Normal Year

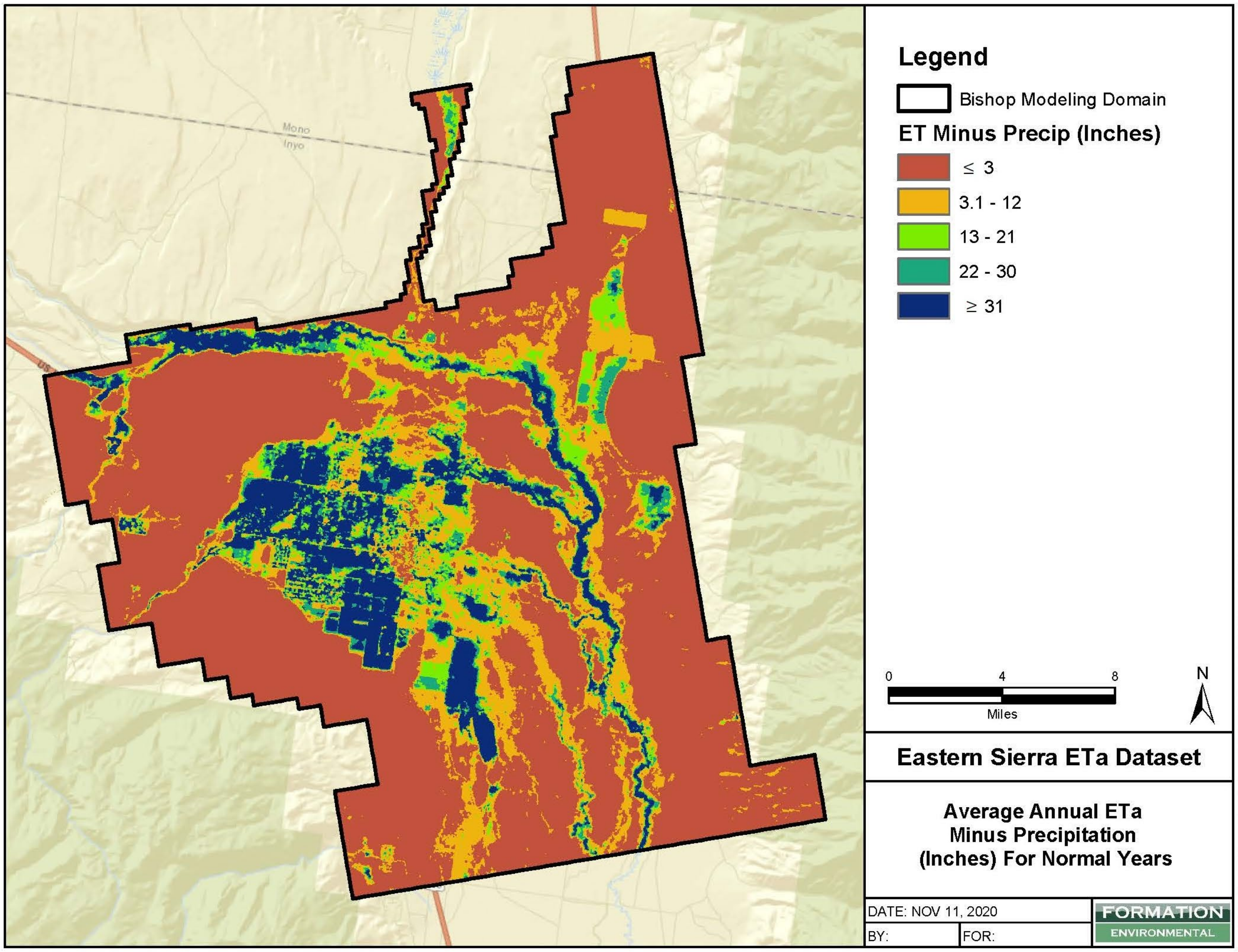
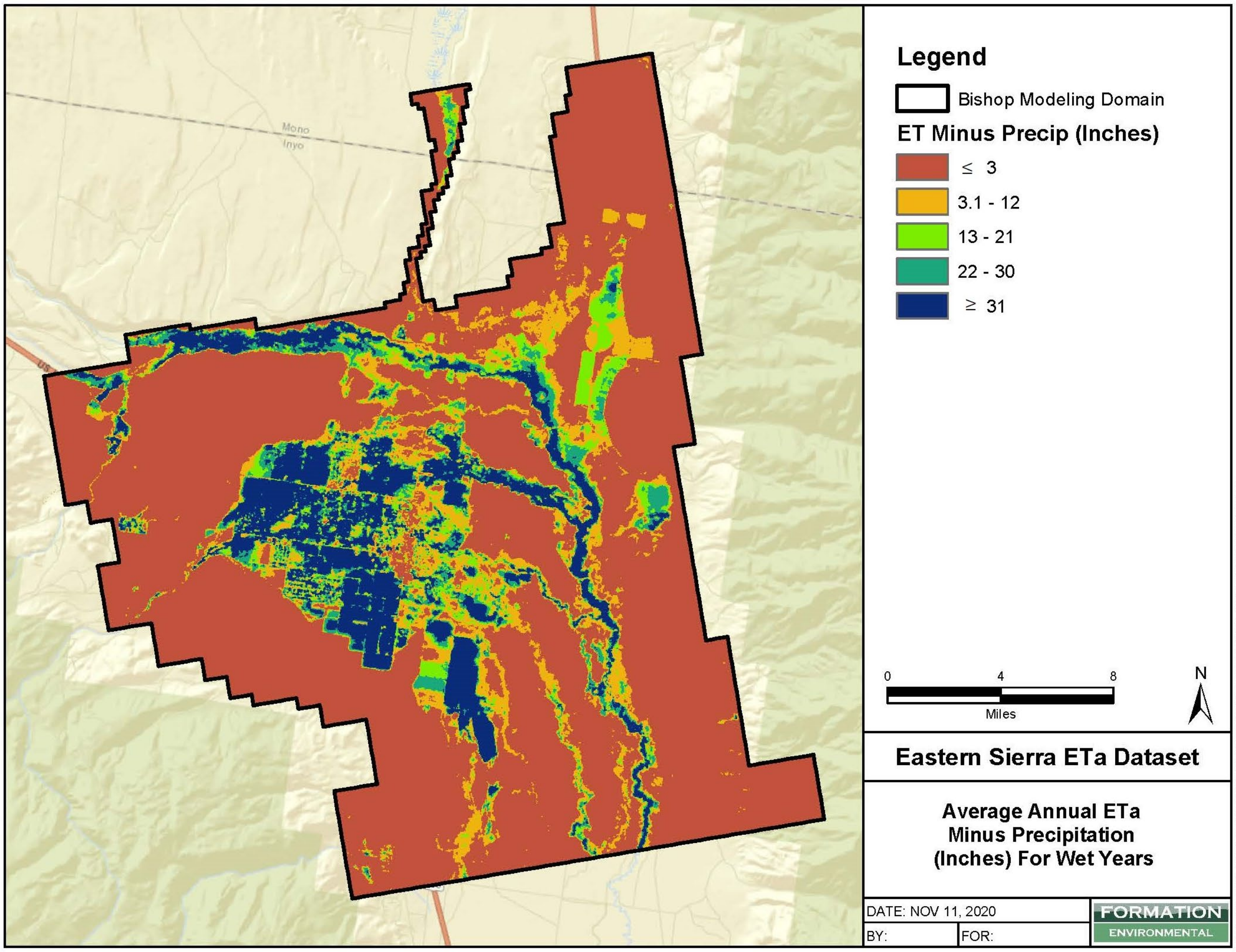


FIGURE 16. BISHOP MODELING DOMAIN: AVERAGE ANNUAL ETA OF WET YEARS MINUS AVERAGE ANNUAL PRECIPITATION OF WET YEARS



5 RECOMMENDATIONS FOR USAGE OF THIS DATASET

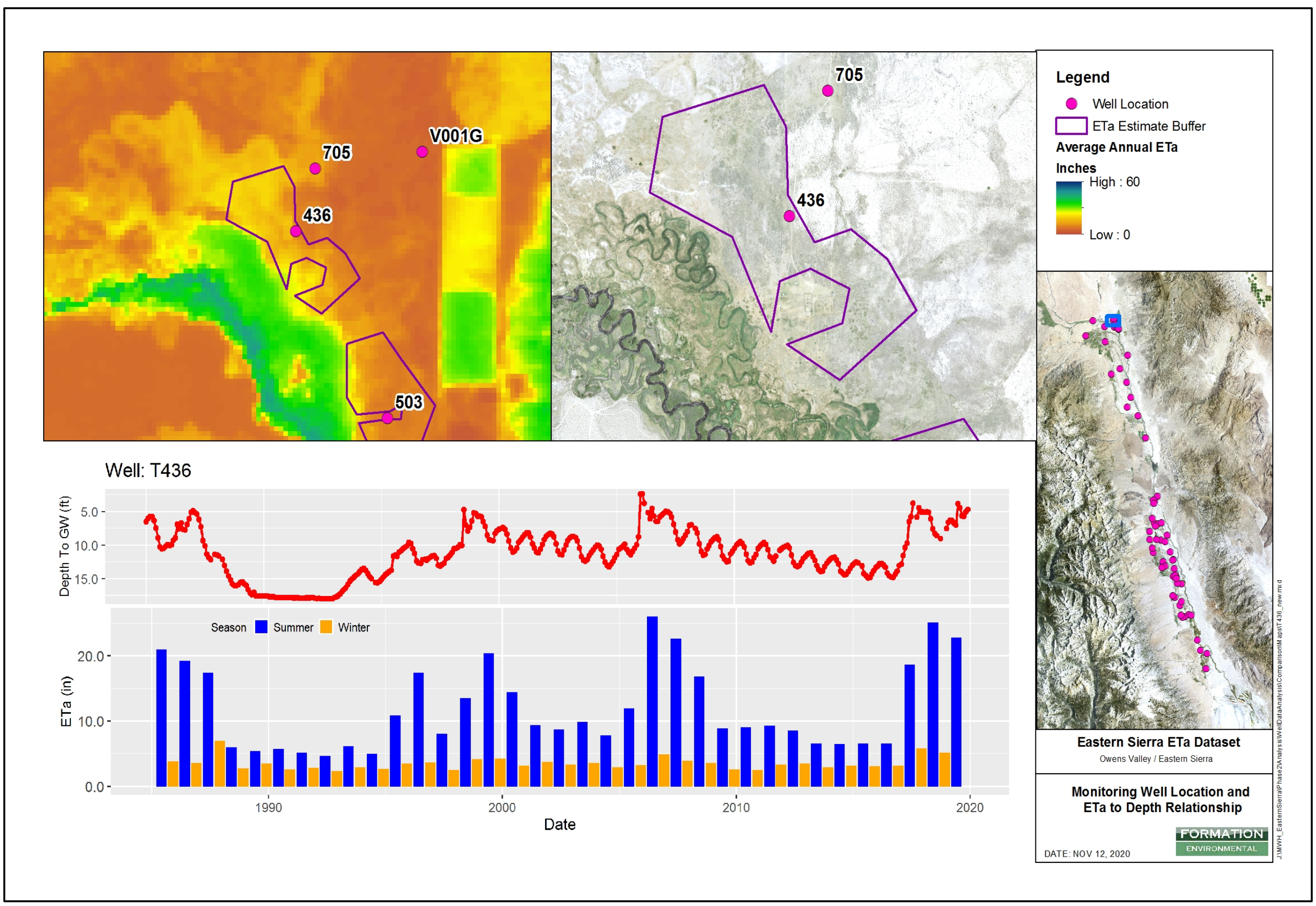
5.1 ET AND DEPTH TO GROUNDWATER RELATIONSHIP

The relationship between ETa and depth to groundwater (DTW) is important for regions with phreatophytes. Vegetation community (vegetation structure) and the water table elevation may directly determine this relationship; however, there are several other factors that drive the strength of this relationship. The long-term ETa data developed for Eastern Sierra are being used to study this relationship for shallow wells in the Owens Valley. ETa and DTW relationships may be developed to determine distribution of ET extinction depths that may also be correlated to biological habitat. Also, this enables observation of areas where groundwater level is only dependent on surface waters and irrigation management are uncorrelatable with ET (e.g., Bishop Cone). Figure 17 shows an example of DTW and ETa relationship for well T-436. The strength and behavior of this relationship depends on complex interactions of components including (but not limited to) well location and depth, plant community, soils profile, and adjacency to water features. Nevertheless, annual correspondence is evident, so it seems promising to develop the ET/DTW relationship. The definitions of the variables (e.g., average DTW vs. peak DTW vs. starting depth at spring or fall) need to be determined as well as generalization of data from several sites to see what works. Based on the strength and trend of the relationship, the wells can be grouped under three classes:

- **Connected Trends:** A connected trend is defined as a consistent qualitative relationship where ETa was connected to summer DTW measurements.
- **Disconnected Trends:** A disconnected trend was defined as a relationship where ETa was inversely related to summer DTW measurements. Specifically, as groundwater depth increased, there was a corresponding increase or stabilization of ETa and plant biomass. This relationship is prevalent for wells near irrigated agriculture or in urban regions.
- **No Trends:** Wells that exhibit no relationship between DTW and ETa. Upland regions with sparse vegetation and low summer ETa show no interaction with surrounding wells.

FIGURE 17. HYDROGRAPH AND ETA COMPARISON FOR WELL NUMBER T-436

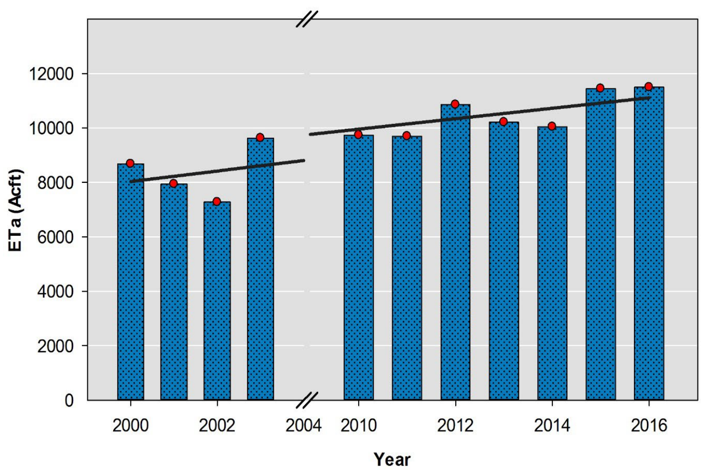
The plots reveal the seasonal cycles of DTW and the qualitative relationship to ETa. The top left panel shows the spatial ETa, and the top right shows the location of the well in high-resolution imagery.



5.2 AGRICULTURAL WATER DEMAND

ETa represents the total evapotranspiration from an area from all sources (precipitation, applied water, or vegetation). Because groundwater pumping information is not readily available, the ETa dataset could be used to study the trend of agricultural water demand in the valley. Fish Slough, located to the north of the Bishop/Laws model boundary, southwest of Chalfant Valley, and east of Hammil Valley (Figure 18), is an area of groundwater discharge with sensitive habitat and critical environmental concern. There has been a long-term reduction in flow at Fish Slough from 6,000 to 7,000 acre-feet per year (AF/yr) in the 1960s to 3,000 AF/yr currently. As a result, there is a need to identify the reason for reduced flows (pumping from the Bishop/Laws area, pumping in the Chalfant area, or some other factor). Figure 18 and Figure 19 show the long-term agricultural consumptive use in the Chalfant, Benton, and Hammil Valleys. Additionally, the ETa information could be used to support new irrigation techniques to meet water conservation metrics. The high variability in the seasonal runoff increases the need to conserve water while improving irrigation and grazing practices. The Eastern Sierra ETa data would guide land managers and stakeholders in achieving goals pertaining to water conservation.

FIGURE 18. ANNUAL ETA FROM AGRICULTURAL FIELDS IN CHALFANT-BENTON VALLEY



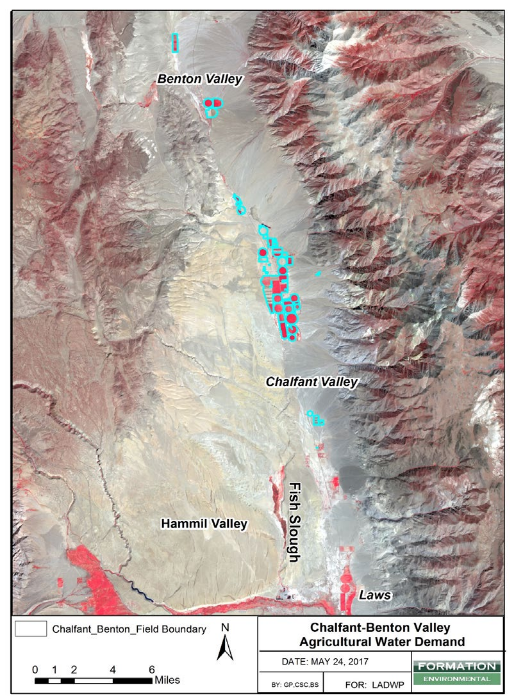
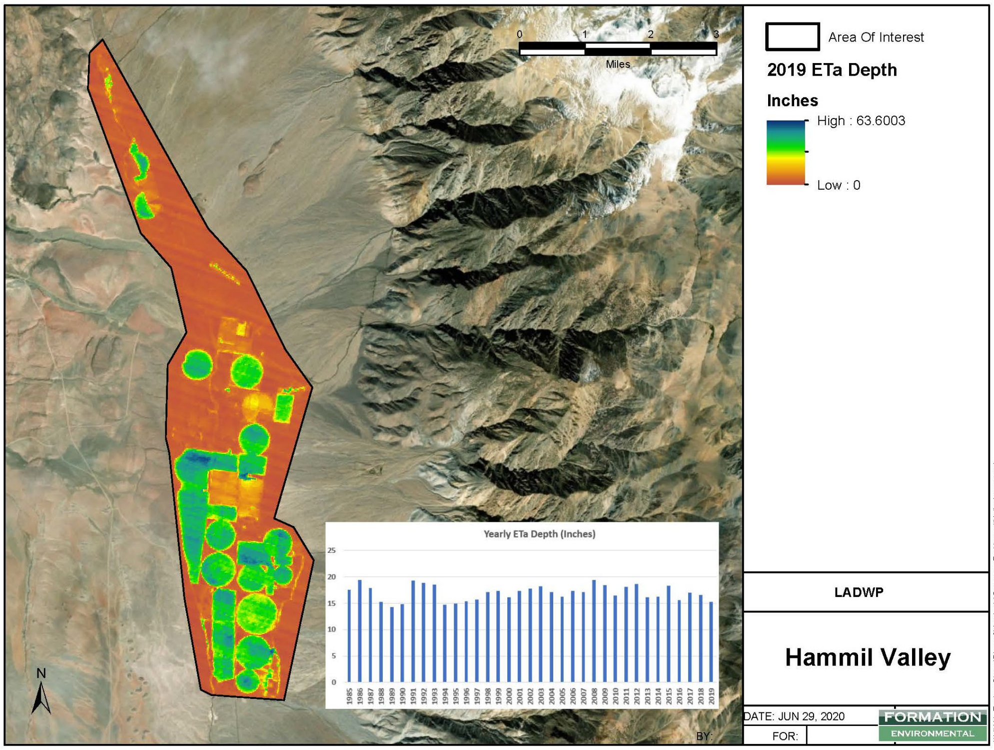


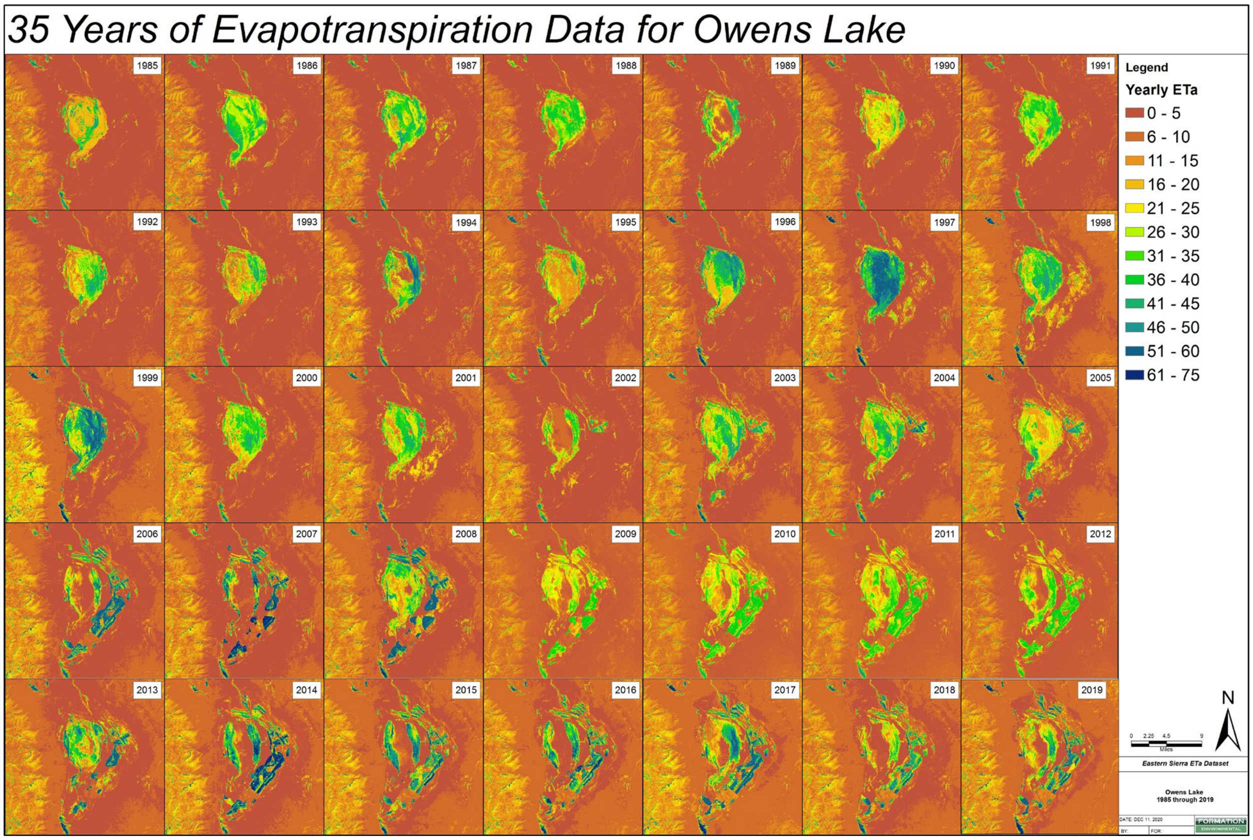
FIGURE 19. ANNUAL ETA FROM AGRICULTURAL FIELDS IN HAMMIL VALLEY



5.3 WATER BUDGET OF EASTERN SIERRA

ETa is a landscape-scale process that influences hydrology and is also a major component of water budgets. Recharge to Owens Valley occurs principally as runoff, while the consumptive use of water is driven by evaporation and transpiration processes. The groundwater production at the different wellfields and water available for export and other purposes are informed by the annual water budget and as directed in the Water Agreement (County of Inyo and the City of Los Angeles, dated October 18, 1991). The Eastern Sierra ETa dataset would help in better modeling of the surface and groundwater resources across the Owens Valley. Refinement and calibration of the groundwater model using the ETa dataset would improve the simulation of annual water budgets. Additionally, the ETa dataset could be utilized in groundwater budgets by providing a new approach to determining ET sourced from groundwater (ETg). Volumetric estimates, histories, and summary statistics can also be developed for specific areas of interest in the Owens Valley. Figure 20 shows the long-term ETa dataset of Owens Lake, which is being used to answer various questions related to water budget and consumptive use of water for various operations.

FIGURE 20. LONG-TERM ETA DATASET FOR OWENS LAKE



5.4 VEGETATION MONITORING

The Green Book (Inyo County and City of Los Angeles 1990) assigns vegetation classes A to E based on the ET of each plant community (Table 1). This classification is central to tracking any undesirable transition from one vegetation class to another. However, the pump turn-off/on trigger is based on soil moisture availability and vegetation water requirements. Monitoring of vegetation and ET is critical to both pumping operations and vegetation health. The ET dataset could be directly used as an operational tool for managing water resources and monitoring vegetation in the phreatophytic ecosystem of Owens Valley. It can also address factors affecting long-term trends in ET such as increase/decrease in LAI, as well as drought effects.

6 CONCLUSIONS AND RECOMMENDATIONS

The Eastern Sierra ETa dataset covers the entire Owens Valley and is available at a daily time-step for the past 35 years (1985-2019). It is a rich dataset with a wide array of applications. Apart from the few applications listed in Section 5, this information can be used in the Owens Valley for improving water balance computation, developing drought plans, monitoring vegetation, improving irrigation, informing surface and groundwater models, supporting the SGMA (Sustainable Groundwater Management Act) program, and adapting to climate change, to name a few. Integration of the Eastern Sierra ETa dataset for managing water resources in Owens Valley is underway; however, a more widespread adoption of this dataset is needed. ETa is used as an indicator in the Green Book (Inyo County and City of Los Angeles 1990) for assessing vegetation type, which leads to larger decisions on pump operations. The Eastern Sierra ETa dataset should be used to compliment other vegetation monitoring efforts and should be adopted as a tool for decision-making. Specific recommendations are as follows:

1. Integration of the ETa dataset for different applications, including but not limited to monitoring vegetation, informing groundwater models, supporting Owens Lake operations, and supporting SGMA programs.

2. State-of-art technology to be used for continuous improvement of this dataset. For example, improved inputs from the new Weather Research and Forecasting (WRF) model would better capture the spatial distribution of weather variables. Another advancement is inclusion of newer satellite imagery for more datapoints and improved interpolations between overpass dates.

3. Training and support for adoption of this dataset and engagement with stakeholders. Hands-on training on the SEBS approach and training on using codes for working with this dataset would facilitate its use.

4. Continued development of this dataset on a near real-time basis.

5. Building a secure platform for easy access and querying of this dataset.

6. Developing a validation program. It is important to understand that validation is not a one-time process but a continuous process, which would generate required data for quality checking and calibration, if required. Establishing an Eddy Covariance station, which could be moved annually to areas with different vegetation types, would generate observation data required for building confidence (validation) and improving the dataset in the event of any gaps.

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APPENDIX A – SATELLITE DATA USED TO DEVELOP THE OWENS VALLEY ETA DATASET

TABLE A-1. SATELLITE DATA USED TO DEVELOP THE OWENS VALLEY ETA DATASET

Year	Total Number of Scenes Available/ Processed			Total Number of Scenes Used in the SEBS Algorithm		
	PR – 4234	PR – 4134	PR – 4135	PR – 4234	PR – 4134	PR – 4135
1985	14	13	12	12	9	9
1986	22	20	20	13	13	13
1987	16	17	17	11	11	13
1988	15	11	12	11	8	9
1989	23	17	17	15	15	15
1990	16	14	15	11	8	11
1991	13	16	16	7	13	13
1992	16	23	24	8	18	17
1993	23	20	20	14	11	14
1994	22	19	20	13	14	13
1995	23	20	21	14	16	16
1996	21	23	23	14	18	20
1997	20	21	21	16	15	16
1998	23	23	23	16	12	17
1999	32	31	31	23	24	25
2000	44	42	41	29	33	33
2001	45	45	45	28	30	33
2002	40	38	39	32	30	30
2003	41	42	42	27	27	33
2004	45	46	46	29	23	35
2005	43	43	43	31	28	35
2006	45	44	44	25	28	35
2007	38	41	41	22	23	35
2008	40	40	40	29	31	33
2009	43	45	45	29	28	37
2010	44	46	46	27	28	30
2011	41	42	42	32	31	33
2012	23	23	23	14	17	19
2013	43	41	41	29	26	32
2014	44	43	43	25	27	33
2015	45	46	46	23	24	32
2016	46	46	46	27	30	38
2017	45	45	45	24	28	32
2018	46	46	46	28	33	38
2019	46	45	45	29	30	33

APPENDIX B – ETA AND PRECIPITATION FOR GROUNDWATER MODEL DOMAINS

TABLE B-1. MODEL DOMAIN: BISHOP

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	9.0	2.6	1.5	6.1
1986	9.3	2.8	0.4	2.4
1987	7.6	3.3	1.1	3.8
1988	7.4	2.9	2.7	1.8
1989	8.0	2.6	2.1	1.7
1990	7.5	2.8	2.5	3.4
1991	7.6	1.6	0.9	5.2
1992	7.2	2.4	0.8	6.4
1993	9.2	3.2	0.5	2.8
1994	8.4	2.2	1.5	6.8
1995	11.7	3.4	2.7	5.3
1996	10.4	3.2	0.8	5.7
1997	9.5	2.2	1.3	7.5
1998	11.3	3.7	2.7	1.9
1999	10.6	3.9	1.6	2.0
2000	8.2	3.1	0.7	3.0
2001	9.1	2.9	0.7	1.6
2002	7.7	3.6	0.1	4.5
2003	7.9	3.0	0.7	3.5
2004	7.1	3.1	0.8	8.1
2005	9.0	2.7	1.2	4.8
2006	8.5	3.3	1.0	2.0
2007	7.7	3.1	0.7	4.3
2008	9.0	3.4	0.6	3.3
2009	7.2	2.8	0.7	3.9
2010	8.1	2.6	0.8	7.8
2011	8.4	2.8	0.7	2.6
2012	9.4	3.4	0.8	1.4
2013	8.5	3.0	1.2	2.4
2014	6.4	3.2	1.3	1.0
2015	6.3	2.9	2.3	3.3
2016	8.5	3.8	2.5	9.9
2017	13.9	4.3	2.1	2.3
2018	11.0	3.9	2.3	8.2
2019	11.4		1.3	
Average	8.8	3.1	1.3	4.1

TABLE B-2. MODEL DOMAIN: BIG PINE

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	6.6	2.2	1.5	6.1
1986	7.4	1.9	0.4	2.4
1987	5.8	0.9	1.1	3.8
1988	5.6	2.3	2.7	1.8
1989	6.0	2.2	2.1	1.7
1990	5.9	2.5	2.5	3.4
1991	6.2	1.9	0.9	5.2
1992	5.7	2.0	0.8	6.4
1993	6.8	2.9	0.5	2.8
1994	6.8	1.9	1.5	6.8
1995	8.7	2.8	2.7	5.3
1996	8.2	3.1	0.8	5.7
1997	7.9	2.1	1.3	7.5
1998	8.8	3.7	2.7	1.9
1999	8.6	3.6	1.6	2.0
2000	6.5	2.9	0.7	3.0
2001	7.1	2.5	0.7	1.6
2002	6.2	3.3	0.1	4.5
2003	6.6	2.8	0.7	3.5
2004	6.2	3.1	0.8	8.1
2005	7.0	2.5	1.2	4.8
2006	6.4	3.3	1.0	2.0
2007	6.9	3.0	0.7	4.3
2008	6.9	3.0	0.6	3.3
2009	6.2	3.0	0.7	3.9
2010	7.4	2.6	0.8	7.8
2011	7.2	2.4	0.7	2.6
2012	7.7	2.9	0.8	1.4
2013	7.1	2.8	1.2	2.4
2014	5.8	3.2	1.3	1.0
2015	5.2	2.8	2.3	3.3
2016	6.4	3.6	2.5	9.9
2017	10.1	3.7	2.1	2.3
2018	7.7	3.5	2.3	8.2
2019	9.4		1.3	
Average	7.0	2.7	1.3	4.1

TABLE B-3. MODEL DOMAIN: TABOOSE-THIBAUT

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	5.1	1.8	1.2	7.7
1986	6.6	1.8	0.6	2.2
1987	4.9	0.9	0.8	3.8
1988	4.2	1.7	2.4	1.7
1989	4.1	1.7	1.2	1.2
1990	4.0	1.8	1.7	4.1
1991	4.9	1.6	0.6	4.8
1992	4.3	1.9	0.8	7.4
1993	5.5	2.5	0.3	2.1
1994	4.8	1.4	1.0	7.8
1995	6.2	2.3	1.4	5.4
1996	6.0	2.4	0.5	6.1
1997	6.0	1.8	1.9	7.7
1998	6.4	3.5	2.9	1.8
1999	6.0	3.0	1.9	2.2
2000	4.8	2.4	0.7	3.2
2001	5.4	2.1	1.0	1.8
2002	4.6	2.6	0.1	6.2
2003	5.7	2.6	0.9	3.4
2004	5.0	2.9	0.5	8.8
2005	5.9	2.5	1.1	5.8
2006	5.2	3.3	0.9	1.6
2007	5.4	2.8	0.4	5.1
2008	5.7	2.8	0.4	2.8
2009	5.3	3.1	0.6	4.8
2010	6.7	2.4	0.6	8.3
2011	5.9	2.6	0.4	2.9
2012	6.2	2.7	0.6	1.5
2013	5.6	2.8	1.4	2.1
2014	5.0	3.2	1.5	1.3
2015	4.3	2.9	1.6	5.2
2016	5.3	3.3	1.3	10.7
2017	7.6	3.4	1.8	2.2
2018	5.6	3.2	1.5	9.9
2019	7.9		1.2	
Average	5.5	2.5	1.1	4.5

TABLE B-4. MODEL DOMAIN: SOUTHERN

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	4.4	1.0	1.3	8.6
1986	4.5	1.3	0.7	2.2
1987	4.3	0.9	0.8	4.0
1988	3.6	1.4	2.3	2.0
1989	3.7	1.3	1.0	1.4
1990	3.8	1.6	1.5	4.3
1991	4.3	1.4	0.5	5.2
1992	4.1	1.5	0.7	8.1
1993	4.7	2.2	0.2	2.3
1994	4.7	1.4	0.9	8.1
1995	5.9	1.9	1.1	6.0
1996	5.6	2.0	0.6	6.4
1997	5.5	1.7	2.2	8.3
1998	6.1	2.9	2.7	2.0
1999	6.1	2.8	2.0	2.4
2000	4.7	2.1	0.7	3.4
2001	5.4	1.9	1.1	1.9
2002	4.4	2.0	0.1	6.9
2003	5.3	2.3	1.2	3.4
2004	4.5	2.3	0.4	9.7
2005	5.3	2.3	1.1	6.3
2006	5.0	2.7	0.9	1.8
2007	4.5	2.3	0.6	5.6
2008	5.5	2.5	0.3	3.1
2009	4.9	2.4	0.6	5.4
2010	6.3	2.5	0.6	9.4
2011	5.4	2.4	0.5	3.2
2012	5.4	2.4	0.5	1.6
2013	5.0	2.5	1.4	2.0
2014	5.1	2.9	1.5	1.5
2015	4.8	2.8	2.3	6.1
2016	5.1	3.1	1.0	12.3
2017	7.1	3.2	1.7	2.8
2018	5.3	3.0	1.2	9.4
2019	7.4		1.5	
Average	5.1	2.1	1.1	4.9

TABLE B-5. MODEL DOMAIN: OWENS LAKE

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	4.7	1.4	1.0	7.2
1986	6.2	1.8	0.5	2.7
1987	6.3	1.1	0.8	4.0
1988	5.7	1.7	2.9	1.9
1989	5.7	1.3	0.8	1.4
1990	4.1	2.1	1.9	3.6
1991	4.9	1.4	0.7	6.1
1992	5.5	1.6	0.8	7.8
1993	4.9	1.8	0.3	2.4
1994	5.6	1.7	0.7	7.4
1995	5.5	1.9	1.0	4.8
1996	7.1	2.4	0.4	4.8
1997	8.9	2.4	2.1	8.5
1998	8.3	3.3	2.6	1.8
1999	7.7	3.0	2.6	2.7
2000	6.3	2.3	0.8	3.9
2001	7.1	1.9	1.0	1.6
2002	4.4	2.2	0.1	5.7
2003	7.8	2.8	1.3	3.6
2004	6.6	2.7	0.4	9.6
2005	6.9	3.1	1.1	5.2
2006	7.8	2.9	1.0	1.7
2007	7.1	3.0	1.0	4.6
2008	9.2	3.4	0.4	3.2
2009	9.0	3.3	0.6	5.0
2010	10.8	3.8	0.7	8.5
2011	10.7	3.6	0.5	2.5
2012	10.5	3.4	0.5	1.6
2013	7.5	3.0	1.2	2.0
2014	9.1	3.6	1.4	1.6
2015	8.1	3.4	2.0	6.2
2016	8.0	4.0	0.9	11.5
2017	10.2	3.7	1.3	2.4
2018	7.4	3.2	0.9	9.1
2019	9.3		1.5	
Average	7.3	2.6	1.1	4.6

APPENDIX C – ETA AND PRECIPITATION FOR WELLFIELDS AND OTHER AREAS

TABLE C-1. BIG PINE WELLFIELD

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	6.79	2.47	1.79	10.82
1986	7.84	2.29	0.87	3.59
1987	5.95	1.03	1.60	5.10
1988	5.50	2.79	3.17	3.50
1989	6.22	2.79	2.32	3.00
1990	6.49	2.54	2.88	5.99
1991	6.48	2.22	1.18	6.46
1992	5.92	2.41	1.40	9.78
1993	7.44	3.32	0.60	4.29
1994	7.10	2.37	2.06	11.20
1995	8.88	3.25	2.77	7.82
1996	8.37	3.63	1.72	9.32
1997	8.05	2.66	2.00	10.29
1998	8.54	4.24	3.75	3.49
1999	8.59	4.07	2.85	4.05
2000	6.59	3.33	1.27	5.87
2001	7.23	2.82	1.65	3.57
2002	6.21	3.26	0.62	7.03
2003	6.55	3.04	1.62	4.64
2004	6.14	3.18	1.18	12.54
2005	6.85	2.72	1.52	8.81
2006	6.45	3.58	2.19	3.09
2007	6.65	3.15	1.33	6.89
2008	6.68	3.19	0.76	5.69
2009	6.19	3.20	1.05	7.07
2010	7.48	2.62	1.79	10.70
2011	7.02	2.62	0.99	3.81
2012	7.33	2.93	1.20	3.02
2013	7.02	3.09	1.69	3.55
2014	6.06	3.48	2.10	1.76
2015	5.44	3.03	2.56	6.69
2016	6.48	3.48	1.98	13.99
2017	8.86	3.71	2.34	4.14
2018	6.97	3.17	2.35	12.37
2019	8.78		2.10	
Average	7.00	2.99	1.81	6.59

TABLE C-2. TABOOSE-ABERDEEN WELLFIELD

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	4.30	1.79	1.30	8.49
1986	5.55	1.71	0.58	2.61
1987	3.84	0.69	0.98	4.14
1988	3.41	1.63	2.81	2.13
1989	3.61	1.67	1.44	1.71
1990	3.56	1.74	2.05	4.52
1991	4.52	1.56	0.78	5.21
1992	3.87	1.80	1.03	7.91
1993	5.18	2.49	0.40	2.69
1994	4.29	1.40	1.28	8.55
1995	5.78	2.28	1.74	5.75
1996	5.33	2.46	0.68	6.70
1997	5.37	1.76	1.87	8.26
1998	5.78	3.55	3.11	2.18
1999	5.04	2.93	2.30	2.73
2000	4.10	2.34	0.82	3.94
2001	4.63	2.01	1.07	2.16
2002	4.14	2.68	0.16	6.31
2003	5.23	2.57	1.05	3.72
2004	4.46	3.01	0.67	9.63
2005	5.36	2.47	1.24	6.41
2006	4.54	3.18	1.17	1.95
2007	4.67	2.76	0.69	5.48
2008	5.09	2.79	0.47	3.40
2009	4.48	3.05	0.73	5.32
2010	5.85	2.26	0.83	8.72
2011	5.27	2.52	0.51	3.07
2012	5.28	2.51	0.73	1.79
2013	4.89	2.65	1.44	2.40
2014	4.31	3.13	1.57	1.41
2015	3.74	2.69	1.91	5.68
2016	4.61	3.06	1.50	11.23
2017	6.12	3.23	1.82	2.66
2018	4.48	2.93	1.76	10.49
2019	6.74		1.31	
Average	4.78	2.39	1.25	4.98

TABLE C-3. THIBAUT-SAWMILL WELLFIELD

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	4.92	1.67	1.28	8.36
1986	6.75	1.75	0.70	2.10
1987	5.23	1.03	0.83	3.80
1988	4.60	1.62	2.32	1.81
1989	4.10	1.49	1.07	1.23
1990	3.97	1.79	1.52	4.51
1991	4.72	1.49	0.54	4.79
1992	4.17	1.80	0.80	7.79
1993	5.19	2.31	0.18	2.17
1994	4.64	1.22	0.96	8.38
1995	5.73	2.10	1.20	5.87
1996	5.67	2.17	0.53	6.64
1997	5.61	1.57	2.08	8.00
1998	6.08	3.18	2.72	1.99
1999	5.95	2.80	1.77	2.30
2000	4.71	2.26	0.71	3.18
2001	5.43	1.97	1.10	1.83
2002	4.67	2.41	0.12	6.68
2003	5.68	2.56	0.97	3.42
2004	4.98	2.67	0.45	9.23
2005	5.68	2.29	1.18	6.32
2006	4.97	3.17	1.01	1.68
2007	5.45	2.57	0.43	5.47
2008	5.18	2.51	0.32	2.88
2009	5.57	3.05	0.59	5.16
2010	6.89	2.29	0.59	8.87
2011	5.80	2.48	0.34	3.10
2012	6.41	2.75	0.56	1.50
2013	5.80	2.70	1.41	2.09
2014	5.11	3.21	1.57	1.41
2015	4.43	2.92	1.45	5.35
2016	5.46	3.44	1.14	11.36
2017	7.98	3.38	1.88	2.34
2018	5.78	3.23	1.35	10.39
2019	8.23		1.23	
Average	5.47	2.35	1.05	4.76

TABLE C-4. INDEPENDENCE OAK WELLFIELD

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	6.13	1.58	1.30	8.22
1986	7.20	1.78	0.76	1.76
1987	5.76	1.10	0.70	3.57
1988	5.01	1.76	1.80	1.62
1989	4.60	1.60	0.92	0.92
1990	4.35	1.95	1.03	4.35
1991	5.22	1.63	0.27	4.52
1992	4.72	1.88	0.57	7.56
1993	5.92	2.52	0.11	1.81
1994	5.41	1.54	0.80	7.75
1995	7.11	2.37	0.90	5.81
1996	7.07	2.40	0.61	6.15
1997	7.45	2.01	2.28	7.61
1998	7.86	3.44	2.59	1.72
1999	7.83	3.23	1.31	1.87
2000	6.05	2.43	0.48	2.73
2001	6.68	2.09	0.92	1.56
2002	5.66	2.52	0.14	6.85
2003	6.68	2.76	1.03	3.11
2004	5.73	2.86	0.36	8.86
2005	6.90	2.70	1.05	6.05
2006	6.52	3.40	0.66	1.41
2007	5.99	2.72	0.33	5.29
2008	6.53	2.79	0.20	2.48
2009	5.70	2.87	0.48	4.97
2010	7.58	2.62	0.42	8.85
2011	6.70	2.85	0.35	3.14
2012	7.15	2.82	0.40	1.25
2013	5.98	2.96	1.46	1.88
2014	5.84	3.33	1.50	1.35
2015	4.91	2.97	1.60	4.92
2016	5.69	3.39	1.05	11.34
2017	9.22	3.59	1.83	2.18
2018	6.83	3.63	1.22	8.92
2019	9.16		1.15	
Average	6.38	2.53	0.93	4.48

TABLE C-5. SYMMES-SHEPHERD WELLFIELD

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	3.79	0.86	1.38	9.69
1986	3.76	1.17	0.84	2.12
1987	3.74	0.82	0.86	4.05
1988	3.26	1.34	2.14	2.27
1989	3.29	1.23	1.08	1.43
1990	3.37	1.53	1.34	4.90
1991	3.82	1.29	0.42	5.12
1992	3.59	1.49	0.77	8.70
1993	4.22	2.04	0.17	2.50
1994	3.95	1.25	0.94	8.76
1995	5.06	1.69	1.23	6.80
1996	4.67	1.79	0.74	7.30
1997	4.61	1.58	2.33	8.65
1998	5.28	2.71	2.72	2.25
1999	5.18	2.64	1.76	2.51
2000	3.97	1.97	0.64	3.52
2001	4.46	1.75	1.13	2.14
2002	3.83	2.01	0.17	7.64
2003	4.75	2.30	1.26	3.55
2004	3.92	2.36	0.46	10.16
2005	4.48	2.18	1.18	7.23
2006	4.27	2.66	0.93	1.94
2007	3.78	2.24	0.58	6.26
2008	4.72	2.38	0.26	3.30
2009	3.97	2.30	0.58	5.86
2010	5.33	2.27	0.63	10.34
2011	4.56	2.32	0.46	3.52
2012	4.80	2.36	0.60	1.61
2013	4.51	2.45	1.46	2.13
2014	4.29	2.69	1.60	1.61
2015	3.92	2.52	2.17	6.12
2016	4.37	2.77	1.05	12.85
2017	6.09	2.95	1.88	2.97
2018	4.38	2.76	1.21	9.79
2019	6.17		1.49	
Average	4.35	2.02	1.10	5.28

TABLE C-6. BAIRS-GEORGES WELLFIELD

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	4.15	1.09	1.34	9.08
1986	4.08	1.36	0.77	2.33
1987	4.15	0.90	0.93	4.23
1988	3.44	1.59	2.48	2.25
1989	3.68	1.37	1.13	1.61
1990	3.71	1.62	1.63	4.64
1991	4.22	1.43	0.60	5.37
1992	4.04	1.56	0.85	8.62
1993	4.63	2.27	0.28	2.53
1994	4.63	1.42	0.94	8.72
1995	5.70	1.94	1.38	6.32
1996	5.32	2.02	0.66	7.03
1997	5.18	1.77	2.25	8.63
1998	5.62	3.08	2.79	2.29
1999	5.69	2.87	2.23	2.73
2000	4.58	2.17	0.78	3.72
2001	5.26	1.88	1.17	2.22
2002	4.37	2.08	0.14	7.26
2003	5.07	2.32	1.33	3.62
2004	4.40	2.41	0.50	10.29
2005	5.08	2.31	1.22	6.82
2006	4.67	2.75	1.04	2.03
2007	4.26	2.36	0.66	6.08
2008	5.19	2.51	0.36	3.42
2009	4.52	2.36	0.65	5.89
2010	5.88	2.40	0.72	10.05
2011	4.96	2.40	0.53	3.35
2012	5.04	2.40	0.61	1.79
2013	4.86	2.54	1.37	2.15
2014	4.93	2.95	1.61	1.65
2015	4.54	2.81	2.62	6.77
2016	5.18	3.09	1.05	13.34
2017	6.43	3.19	1.81	3.34
2018	4.93	2.78	1.17	9.99
2019	6.74		1.64	
Average	4.83	2.18	1.18	5.30

Table C-7. Lone Pine Wellfield

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	4.08	1.02	1.25	8.02
1986	3.99	1.33	0.62	2.43
1987	4.15	0.90	0.82	4.11
1988	3.47	1.44	2.64	1.98
1989	3.77	1.39	1.05	1.54
1990	3.92	1.72	1.82	3.92
1991	4.36	1.51	0.70	5.43
1992	4.23	1.53	0.78	8.14
1993	4.58	2.19	0.34	2.49
1994	4.79	1.55	0.89	7.92
1995	5.75	1.88	1.18	5.64
1996	5.46	2.01	0.52	5.98
1997	5.19	1.79	2.16	8.40
1998	5.90	3.04	2.67	2.09
1999	5.93	2.78	2.36	2.66
2000	4.69	2.12	0.73	3.66
2001	5.55	1.93	1.08	1.96
2002	4.30	2.02	0.11	6.43
2003	5.13	2.19	1.21	3.54
2004	4.45	2.17	0.48	9.69
2005	5.18	2.28	1.11	6.07
2006	4.73	2.57	0.93	1.86
2007	4.40	2.29	0.71	5.50
2008	5.41	2.56	0.41	3.24
2009	5.05	2.40	0.65	5.36
2010	6.33	2.57	0.68	9.16
2011	5.27	2.31	0.54	3.00
2012	5.07	2.30	0.60	1.72
2013	4.90	2.43	1.29	2.05
2014	5.50	3.01	1.52	1.56
2015	5.26	2.82	2.57	6.75
2016	5.37	3.24	1.01	12.38
2017	6.90	3.12	1.66	2.82
2018	5.36	2.89	1.16	9.38
2019	7.41		1.56	
Average	5.02	2.16	1.14	4.91

TABLE C-8. ROUND VALLEY WELLFIELD

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	9.57	4.63	2.25	11.43
1986	10.58	5.03	1.04	3.63
1987	9.29	4.36	1.71	4.89
1988	8.06	5.41	3.44	3.73
1989	8.32	4.98	2.83	3.27
1990	8.67	3.93	3.06	6.60
1991	9.80	5.18	1.09	6.35
1992	9.03	7.98	1.45	9.38
1993	11.66	6.30	0.47	4.50
1994	10.14	5.49	2.68	11.49
1995	10.93	6.26	3.35	8.29
1996	10.76	6.00	2.16	9.91
1997	10.82	5.65	2.08	10.47
1998	10.48	5.58	3.40	3.81
1999	9.79	5.85	2.52	4.13
2000	10.88	5.53	1.22	6.23
2001	11.02	5.33	1.73	3.68
2002	10.49	4.97	0.61	6.90
2003	9.76	5.86	1.79	4.84
2004	9.38	5.12	1.26	12.75
2005	9.96	5.27	1.89	9.18
2006	9.22	4.15	2.54	3.40
2007	8.11	4.71	1.62	7.09
2008	9.24	4.00	0.83	6.51
2009	8.18	4.11	1.08	6.80
2010	8.85	5.14	1.96	10.69
2011	9.11	4.44	1.12	3.84
2012	8.68	4.16	1.13	3.08
2013	7.46	3.51	1.51	3.85
2014	7.44	3.86	2.18	1.60
2015	6.73	4.09	3.07	6.02
2016	8.26	4.45	2.68	16.87
2017	9.48	3.85	2.78	4.78
2018	8.66	3.53	2.58	13.64
2019	8.89		2.19	
Average	9.36	4.96	1.98	6.87

TABLE C-9. LAWS WELLFIELD

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	5.39	2.14	1.43	5.82
1986	6.23	2.01	0.55	2.44
1987	4.90	0.77	1.32	3.76
1988	4.54	2.31	2.89	1.75
1989	4.73	2.31	2.24	1.63
1990	4.90	2.09	2.66	3.33
1991	4.48	1.86	1.10	5.27
1992	4.13	1.73	1.04	6.28
1993	5.01	2.74	0.55	2.70
1994	4.43	2.03	1.71	6.65
1995	6.34	2.63	2.91	5.01
1996	5.57	2.54	1.15	5.43
1997	4.83	1.82	1.51	7.31
1998	6.35	2.94	3.14	1.83
1999	5.33	2.92	2.12	2.00
2000	4.34	2.44	0.84	3.06
2001	4.69	2.14	0.90	1.59
2002	4.27	2.59	0.23	4.40
2003	4.39	2.28	0.91	3.41
2004	4.41	2.56	0.94	8.11
2005	5.69	2.34	1.33	4.49
2006	5.64	2.86	1.41	1.92
2007	5.40	2.69	0.82	4.08
2008	5.39	2.71	0.65	3.16
2009	4.37	2.31	0.85	3.86
2010	5.08	2.16	1.02	7.65
2011	5.71	2.21	0.82	2.55
2012	6.29	2.75	0.99	1.45
2013	5.24	2.40	1.34	2.34
2014	4.33	2.59	1.50	0.98
2015	4.13	2.39	2.46	3.56
2016	5.12	2.95	2.48	9.81
2017	9.43	3.43	2.16	2.30
2018	6.86	3.25	2.47	8.36
2019	8.11		1.77	
Average	5.32	2.41	1.49	4.07

TABLE C-10. BISHOP WELLFIELD

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	9.05	2.86	1.58	6.48
1986	9.40	2.36	0.36	2.54
1987	7.76	1.50	1.06	3.82
1988	7.62	3.09	2.60	1.98
1989	8.08	2.79	2.01	1.78
1990	7.67	3.01	2.46	3.62
1991	8.06	2.03	0.86	5.31
1992	7.62	2.37	0.77	6.54
1993	9.33	3.47	0.43	2.92
1994	9.18	2.24	1.52	7.13
1995	12.33	3.48	2.69	5.51
1996	11.11	3.57	0.75	6.03
1997	10.36	2.51	1.27	7.63
1998	11.72	3.97	2.66	2.04
1999	11.31	4.22	1.68	2.17
2000	8.91	3.38	0.68	3.23
2001	9.81	2.96	0.63	1.73
2002	8.37	3.92	0.12	4.61
2003	8.67	3.26	0.66	3.53
2004	8.22	3.56	0.78	8.31
2005	9.29	2.83	1.13	5.06
2006	8.02	3.53	0.94	2.02
2007	8.47	3.38	0.66	4.46
2008	8.60	3.42	0.53	3.48
2009	7.07	3.02	0.71	4.08
2010	8.48	2.82	0.70	7.92
2011	8.76	2.70	0.63	2.69
2012	9.76	3.46	0.84	1.50
2013	8.10	3.08	1.15	2.42
2014	6.63	3.28	1.25	1.01
2015	6.29	3.03	2.18	3.47
2016	8.62	3.81	2.41	10.27
2017	13.55	4.24	2.12	2.35
2018	10.79	3.90	2.25	8.49
2019	11.29		1.11	
Average	9.09	3.15	1.26	4.30

TABLE C-11. MONO BASIN

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	15.05	5.84	3.66	18.37
1986	16.33	8.24	1.89	5.00
1987	15.07	4.61	2.44	6.86
1988	12.00	7.27	3.71	6.09
1989	14.43	7.44	4.59	4.91
1990	14.83	5.63	4.01	8.06
1991	14.37	6.53	1.88	8.44
1992	13.80	10.71	2.64	14.72
1993	16.37	7.35	0.61	7.39
1994	9.86	6.17	3.54	17.85
1995	14.19	7.60	4.06	12.19
1996	15.59	6.69	3.35	17.34
1997	15.30	6.52	3.36	13.72
1998	16.15	7.32	4.48	7.23
1999	14.57	7.21	3.16	6.36
2000	15.76	7.83	2.10	7.78
2001	16.24	7.16	2.96	6.79
2002	16.02	6.83	1.61	9.73
2003	14.57	8.40	3.31	7.57
2004	13.79	8.09	2.56	16.89
2005	13.95	6.92	2.81	13.83
2006	13.89	6.25	3.26	5.40
2007	13.46	8.32	2.64	10.78
2008	13.86	6.64	1.17	8.35
2009	13.29	8.64	2.52	10.29
2010	13.91	7.85	2.39	16.26
2011	12.64	6.26	2.44	4.89
2012	13.89	6.71	1.84	6.35
2013	12.98	6.39	2.75	5.53
2014	12.74	6.47	3.83	2.87
2015	12.06	6.52	6.88	11.05
2016	13.05	6.10	4.57	23.71
2017	13.52	6.49	5.02	8.69
2018	13.70	4.46	4.27	15.59
2019	9.28		3.10	
Average	14.01	6.98	3.13	10.20

Table C-12. Chalfant Valley

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	5.14	2.84	2.46	10.21
1986	6.10	2.73	1.71	3.47
1987	4.92	1.64	2.41	4.92
1988	4.49	2.72	4.25	3.23
1989	4.87	3.01	3.87	2.83
1990	5.73	2.77	3.79	5.78
1991	6.03	2.71	1.91	6.55
1992	5.11	2.87	2.27	9.54
1993	6.14	3.34	0.74	4.23
1994	5.28	2.88	3.08	10.96
1995	6.79	3.60	4.41	7.87
1996	5.89	3.45	2.98	9.19
1997	5.64	2.55	2.95	9.68
1998	6.49	3.46	4.95	3.57
1999	5.76	3.41	3.98	3.52
2000	4.99	2.80	1.79	5.28
2001	5.31	3.19	2.44	3.57
2002	5.29	3.05	1.18	6.18
2003	5.08	3.06	2.70	4.56
2004	4.61	2.92	2.01	11.67
2005	5.29	2.87	2.36	8.10
2006	5.01	2.95	3.22	3.28
2007	4.75	2.88	2.47	6.45
2008	5.36	3.08	1.18	5.55
2009	4.58	2.73	1.71	6.53
2010	5.16	2.62	2.39	10.47
2011	5.41	2.81	1.54	3.55
2012	5.41	3.15	2.23	3.06
2013	4.85	2.90	2.13	3.67
2014	4.53	3.17	3.11	1.58
2015	4.38	2.65	4.20	5.91
2016	4.73	2.98	3.34	15.66
2017	5.93	3.18	3.18	4.85
2018	4.99	2.64	3.05	11.85
2019	5.50		3.02	
Average	5.30	2.93	2.71	6.39

TABLE C-13. OTHER OWV

Year	April-Sep ET in Inches	October-March ET in Inches	April-Sep Precip in Inches	October-March Precip in Inches
1985	6.77	2.17	1.36	11.95
1986	7.38	2.58	1.43	4.90
1987	7.18	1.50	1.35	5.76
1988	5.96	2.19	3.92	5.20
1989	6.44	2.03	1.51	3.10
1990	5.64	2.47	2.28	6.20
1991	6.42	2.12	0.95	9.47
1992	6.63	2.13	1.32	11.62
1993	6.76	3.23	0.87	4.54
1994	7.40	2.12	1.38	12.36
1995	7.44	3.04	2.23	7.98
1996	8.68	3.56	1.06	8.67
1997	9.06	3.05	2.74	12.54
1998	9.46	5.16	3.59	4.31
1999	9.63	4.53	3.18	5.91
2000	8.08	3.22	1.04	6.88
2001	8.47	3.20	1.67	3.98
2002	6.73	3.31	0.32	8.57
2003	8.45	3.40	2.28	6.11
2004	7.56	3.25	0.56	14.69
2005	8.29	4.04	2.27	8.33
2006	8.88	4.27	2.19	3.13
2007	7.55	3.53	1.28	7.58
2008	8.70	3.86	0.70	5.14
2009	8.16	3.54	0.95	8.82
2010	9.58	3.70	1.15	12.32
2011	9.31	3.86	0.84	4.05
2012	9.03	3.75	0.85	2.33
2013	8.23	3.62	1.30	2.99
2014	8.19	4.38	1.41	3.16
2015	7.87	4.04	2.02	9.27
2016	7.79	4.16	1.06	16.98
2017	9.70	4.56	1.73	5.11
2018	7.79	3.55	1.14	11.98
2019	9.82		2.17	
Average	7.97	3.33	1.60	7.53

APPENDIX D – 35-YEAR AVERAGE ANNUAL ETA MAPS FOR MODEL DOMAINS

FIGURE D-1. BISHOP MODELING DOMAIN: 35-YEAR AVERAGE ANNUAL ETA (1985-2019)

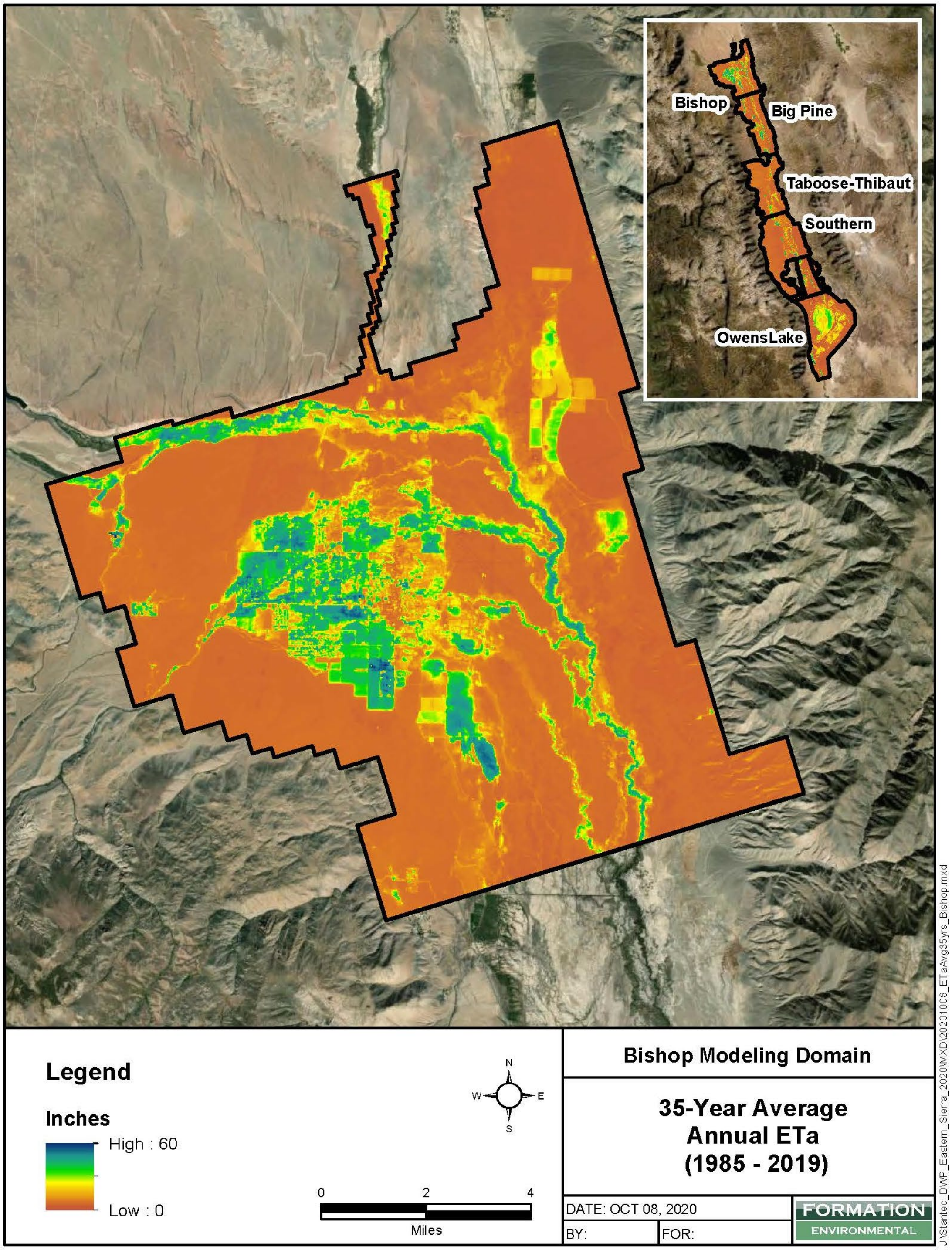


FIGURE D-2. BIG PINE MODELING DOMAIN: 35-YEAR AVERAGE ANNUAL ETA (1985-2019)

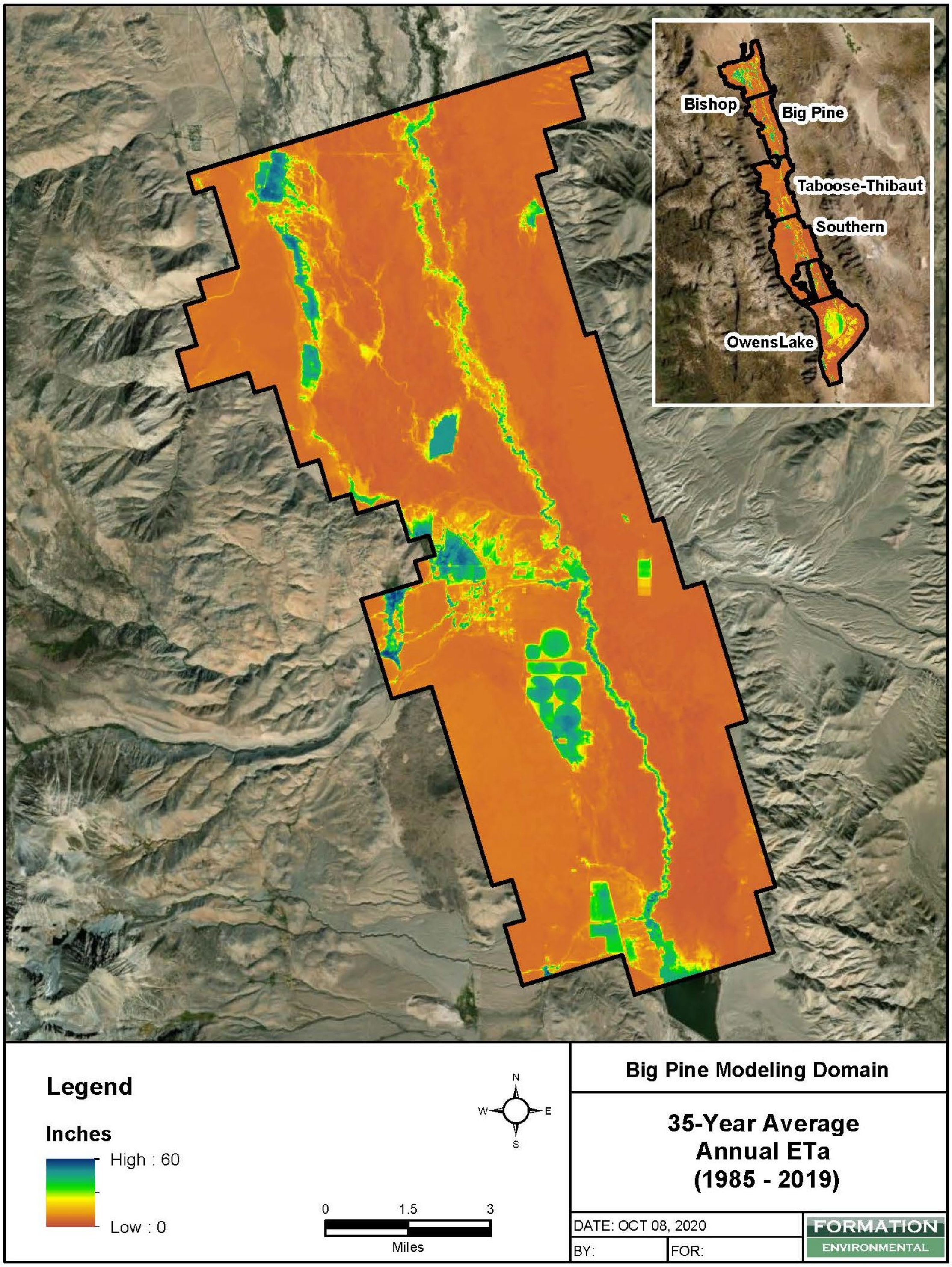


FIGURE D-3. TABOOSE-THIBAUT MODELING DOMAIN: 35-YEAR AVERAGE ANNUAL ETA (1985-2019)

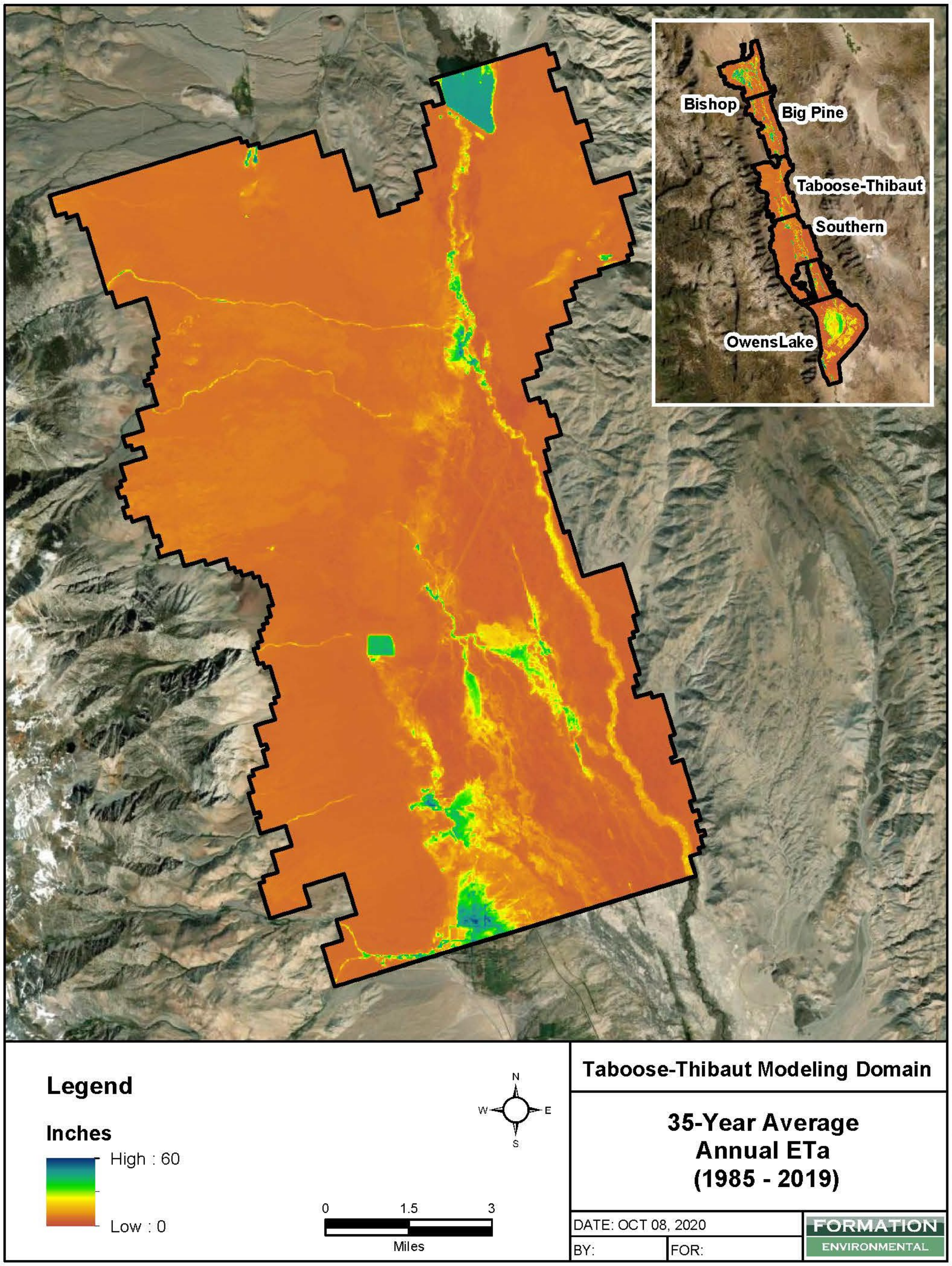


FIGURE D-4. SOUTHERN MODELING DOMAIN: 35-YEAR AVERAGE ANNUAL ETA (1985-2019)

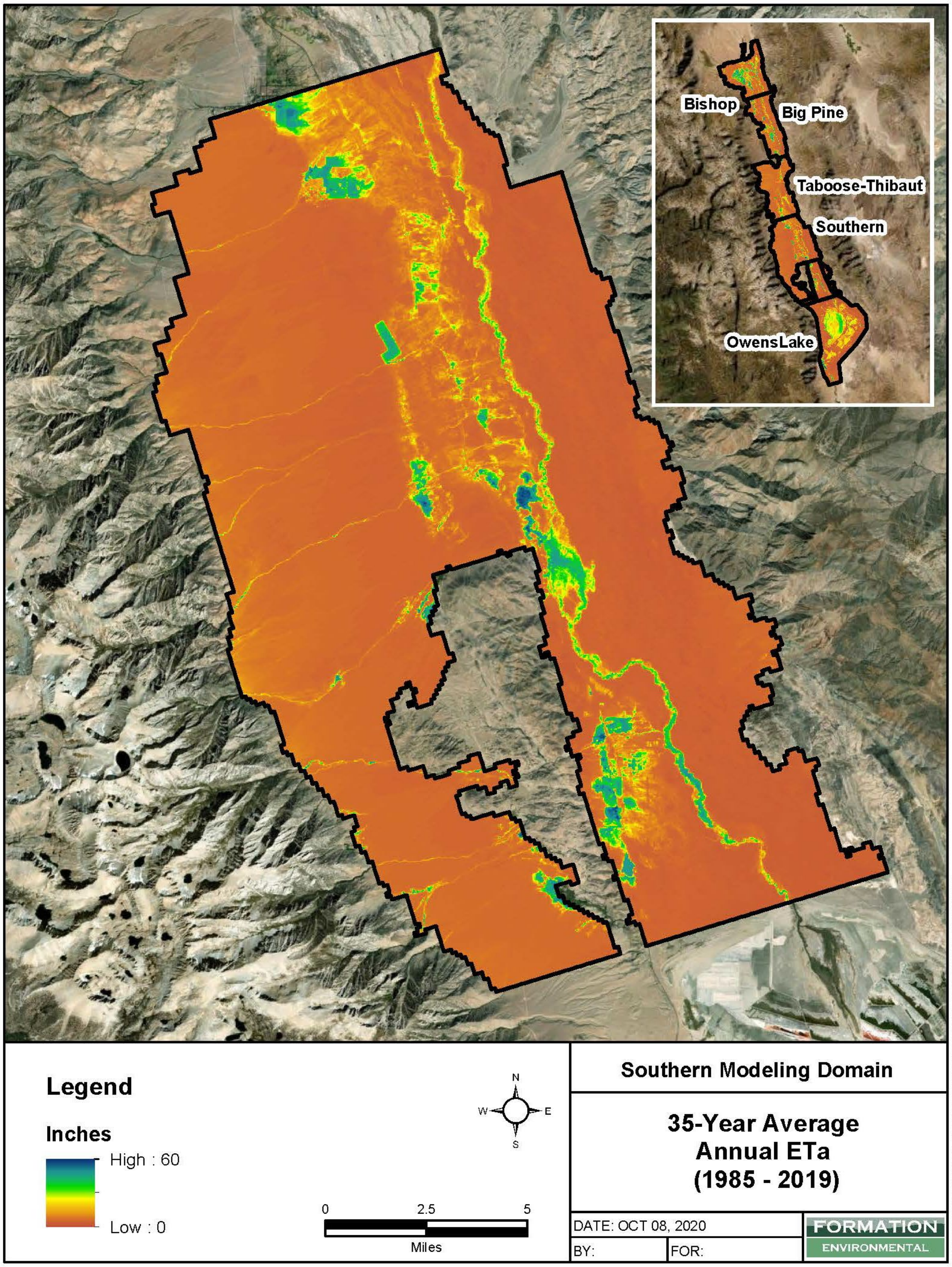
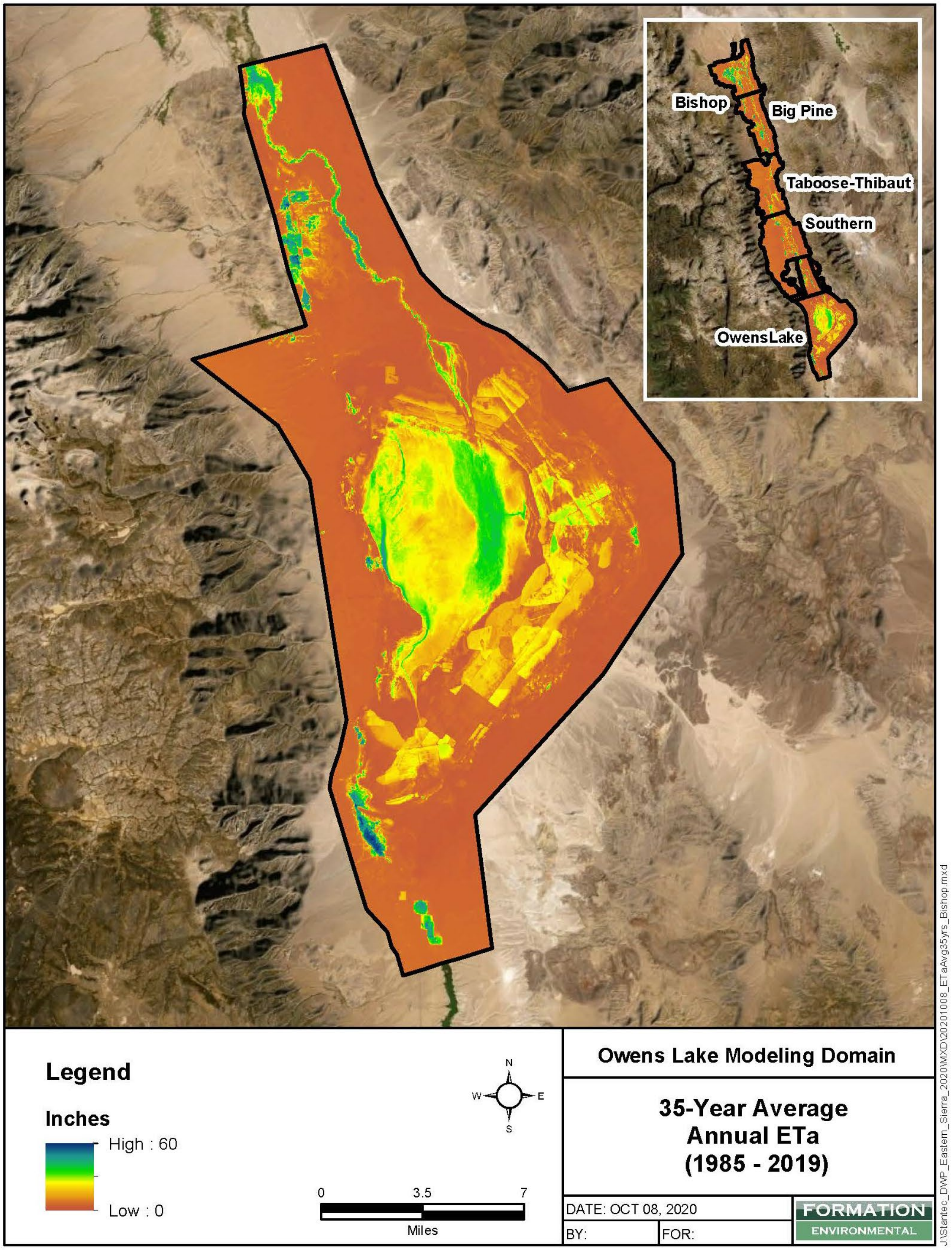
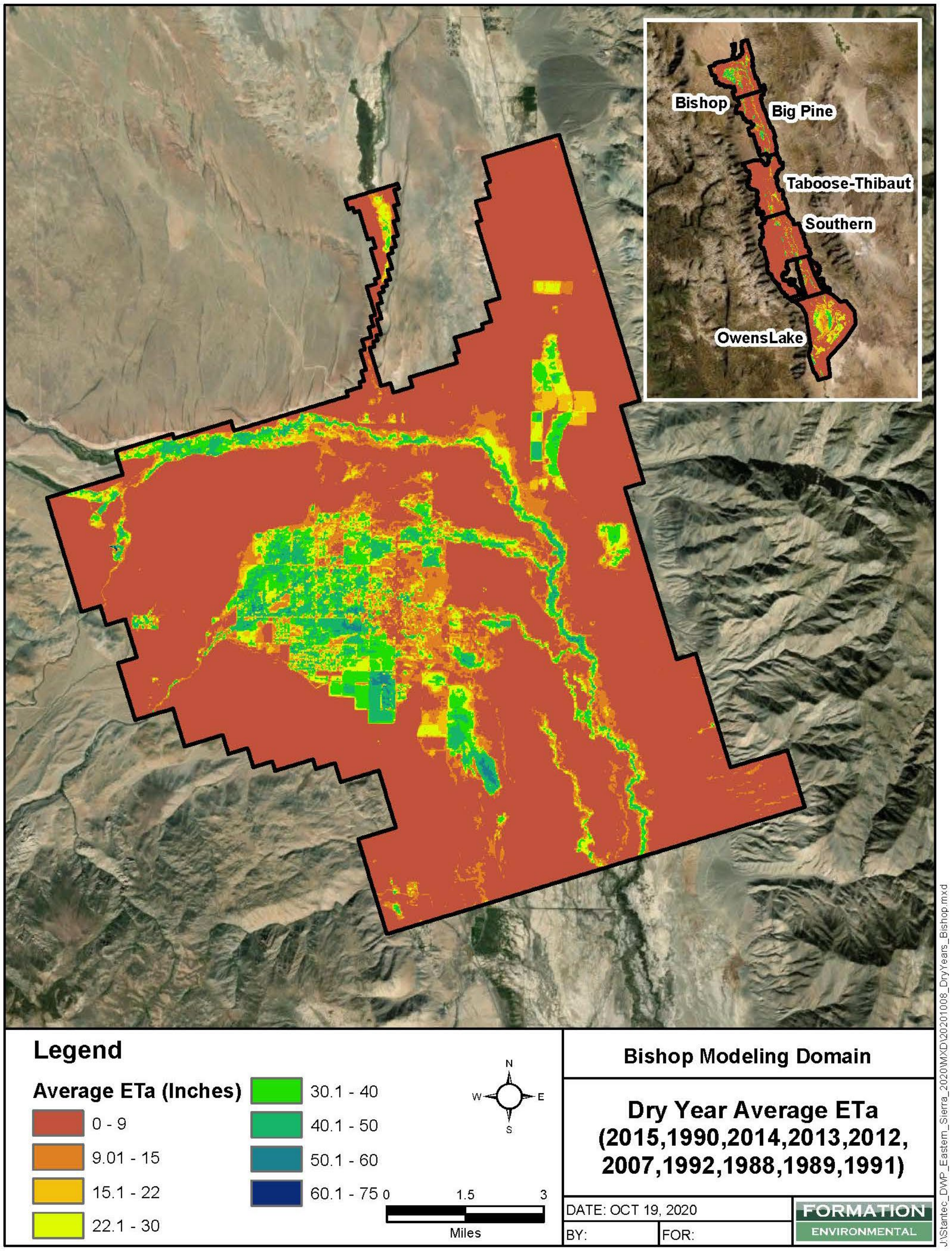


FIGURE D-5. OWENS LAKE MODELING DOMAIN: 35-YEAR AVERAGE ANNUAL ETA (1985-2019)



APPENDIX E – DRY, WET, AND NORMAL YEAR AVERAGE ETA MAPS FOR MODEL DOMAINS

FIGURE E-1. BISHOP MODELING DOMAIN: AVERAGE ANNUAL ETA FOR DRY YEARS



APPENDIX F – ETA MINUS PRECIPITATION MAPS FOR MODEL DOMAINS

FIGURE F-1. BIG PINE MODELING DOMAIN: ETA MINUS PRECIPITATION FOR AVERAGE DRY YEAR

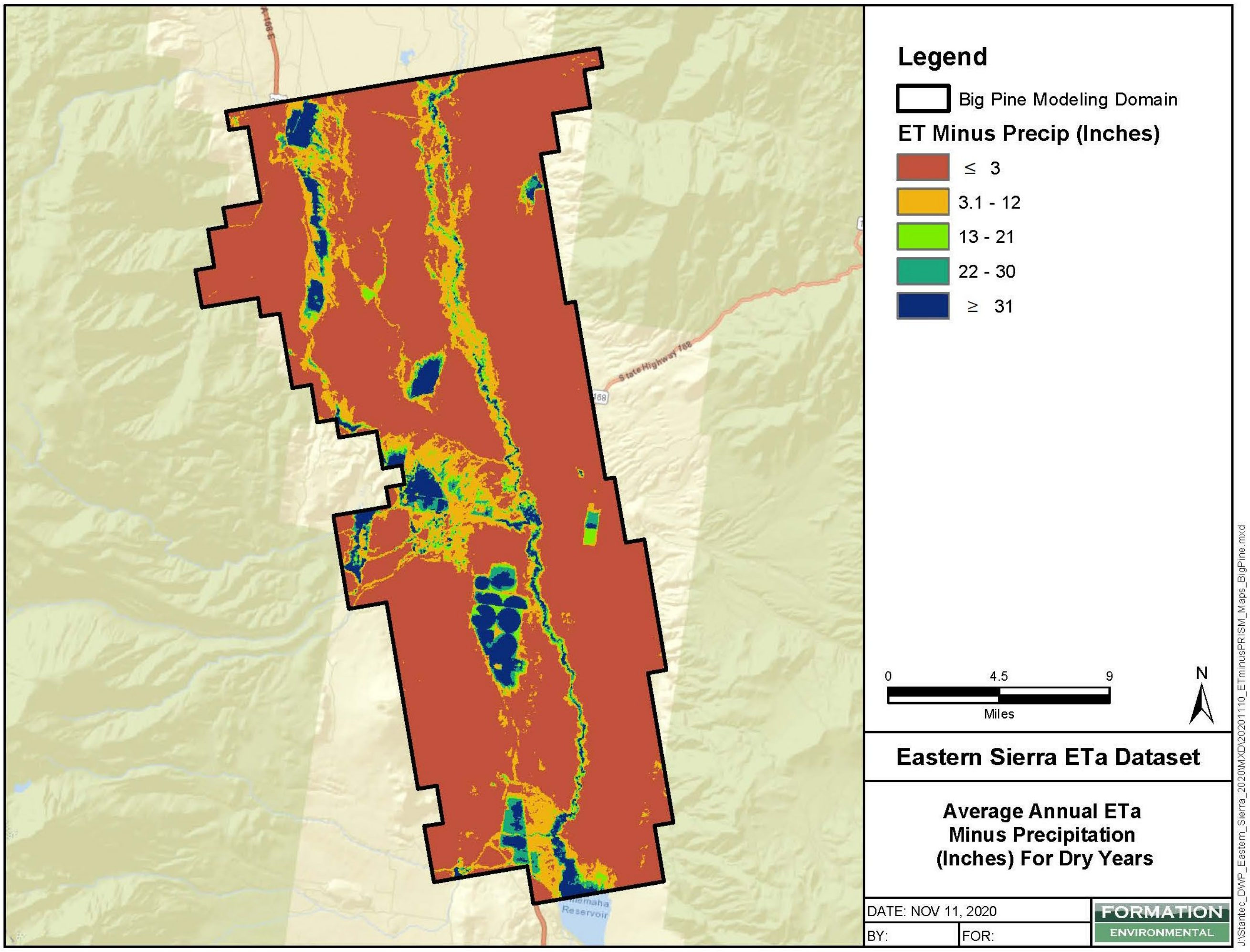


FIGURE F-2. TABOOSE-THIBAUT MODELING DOMAIN: ETA MINUS PRECIPITATION FOR AVERAGE DRY YEAR

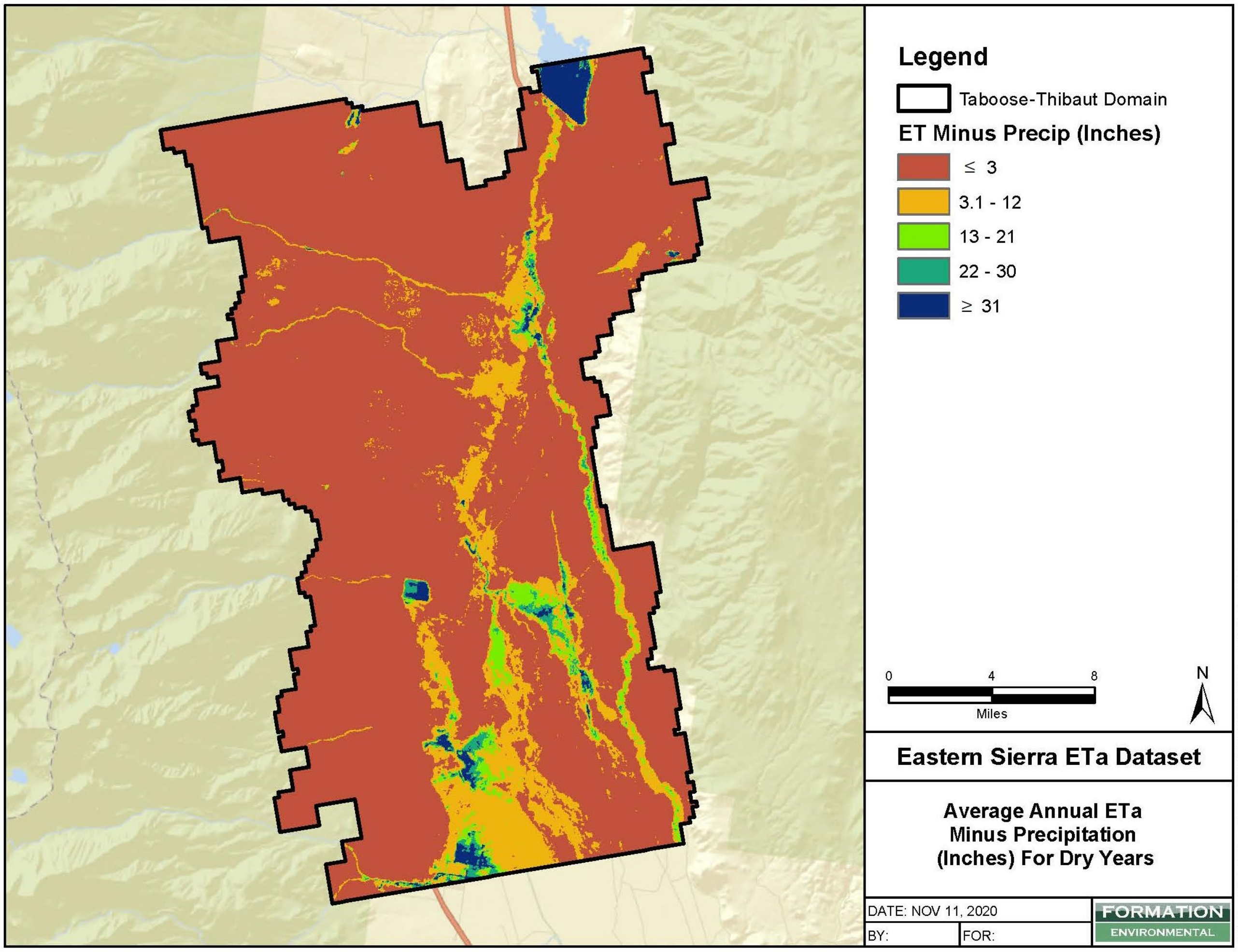


FIGURE F-3. SOUTHERN MODELING DOMAIN: ETA MINUS PRECIPITATION FOR AVERAGE DRY YEAR

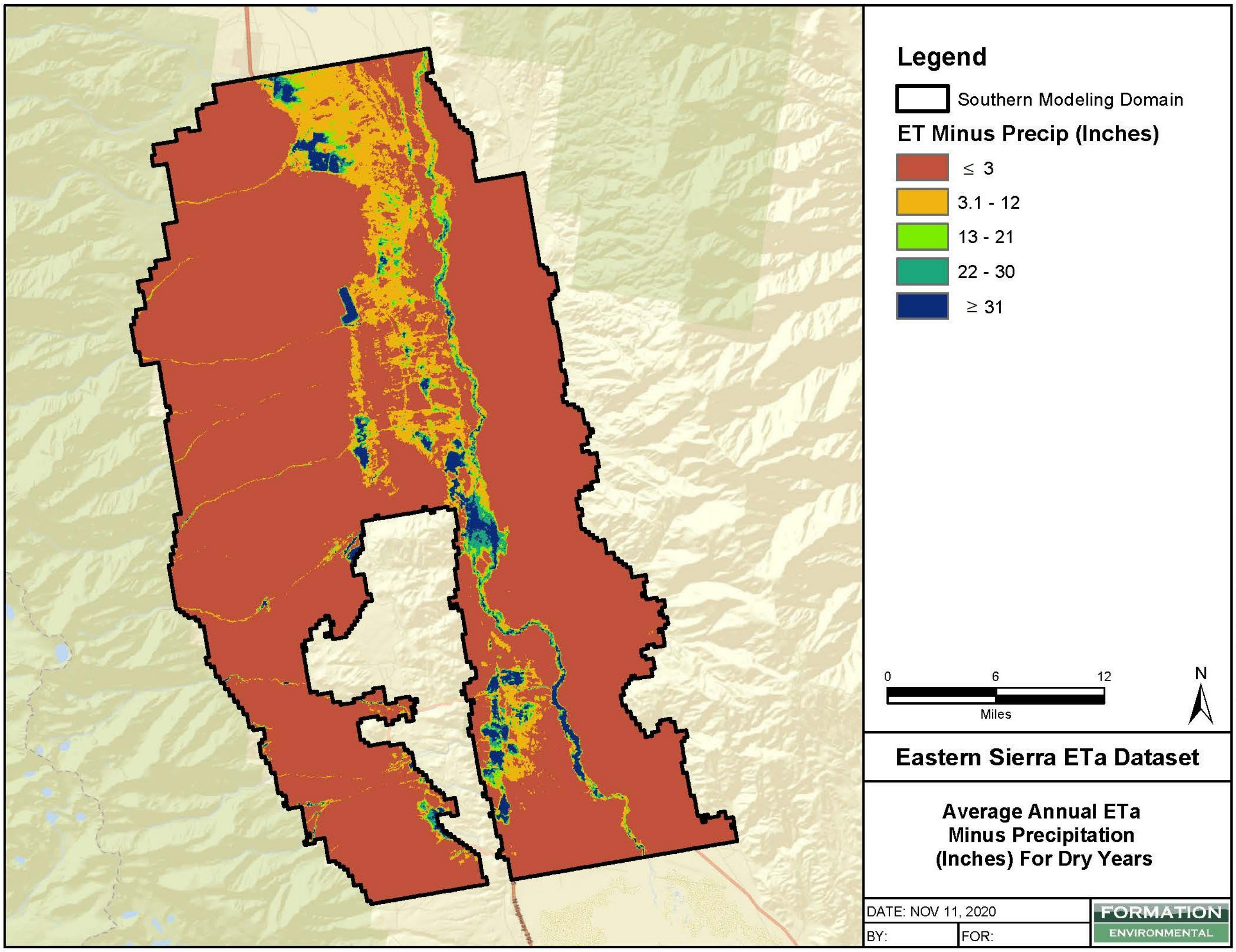


FIGURE F-4. OWENS LAKE MODELING DOMAIN: ETA MINUS PRECIPITATION FOR AVERAGE DRY YEAR