Appendix B

AMEC's Independent Estimate of PPIW Crop Water Use Using the ASCE Standardized Reference Evapotranspiration via Direct Use of Weather Station Data, and Estimation of Crop Coefficients, and Net Diversions and Depletions

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Overview

The purpose of this Appendix is to provide a detailed summary of AMEC's implementation of the ASCE Standardized Reference Evapotranspiriation equation to provide estimates of crop water use on PPIW lands of the Zuni Tribe. In our independent implementation of the ASCE Penman Monteith (PM) equation, we followed two distinct approaches for developing the required meteorological data set:

- In the first implementation described here in Appendix B, we used data from the same weather stations as NRCE, and followed procedures to fill/extend the missing climate data as described by NRCE (Allen, 2008).
- In the second implementation, described in Appendix C, we obtained Tmin, Tmax, Tdew, and Precp, from available gridded historical weather data, and local and regional weather station data for wind speed.

After introducing the standard ASCE Penman-Monteith (ASCE, 2005) equation and related background, our approaches to implement the equation from available meteorological data are covered in separate subsections below. Appendix C describes our approach to used gridded climatic data to implement the ASCE Standardized Reference ET equation.

The Standardized ASCE Reference ET equation (ASCE, 2005) is:

$$ET_o = \frac{0.408\Delta(Rn - G) + \dfrac{\gamma Cn}{T + 273} u_2 (e_{sat} - e)}{\Delta + \gamma(1 + Cd\, u_2)} \qquad \textbf{(1)}$$

where,

ET_o : Reference evapotranspiration in [mm/day]
Rn = Net solar radiation at the crop surface [MJ/m^2/day]
G = Soil heat flux density at the soil surface [MJ/m^2/day]

T = Mean daily air temperature at 2 m height [^oC]
u_2 = Mean wind speed at 2 m height [m/s]
e_{sat} = Mean saturated vapor pressure at 2 m height [kPa]
e = Mean actual vapor pressure at 2 m height [kPa]
Δ = Slope of the saturated vapor pressure-temperature curve [kPa/^oC]
γ = Psychrometric constant [kPa/^oC]
Cn = Constants for reference type and calculation time step
Cd = Constants for reference type and calculation time step

Following the lead of Allen (2008), we used a short clipped grass reference with daily time steps, which leads to the assignment of Cn = 900 and Cd = 0.34 . The monthly ETo's are calculated as the monthly sum of the daily ETo's.

Calculating ETo from Using Climate Data from Local and Regional Weather Stations

For this implementation, the raw climate data from January 1, 1948, to December 31, 2004, for each pertinent weather station was downloaded from the National Climatic Data Center (NCDC)- Summary of the Day (SD) and Surface Airways (SA) CD's. The raw climate data was then filled/extended by AMEC using the same procedure as described by NRCE (Allen, 2008). The data set was then adjusted first for elevation and then for arid climatic conditions to suit each agricultural unit. The complete data set for the period from July 1, 1948, to December 31, 2004, then was used to calculate ET_o with a daily time-step. The daily *ETo*'s were summed to get the monthly *ETo*'s. Then, we estimated the crop coefficients for each major category of crops grown in each agricultural unit, namely, Nutria, Pecacdo, Tekapo, Ojo Caliente, and Zuni. The final part of this Appendix describes how we calculate the effective precipitation, the net diversion requirement, and the net depletion for an annual period. The independently created estimates are then compared to estimates by others.

Climate data

The following climate parameters are needed to compute ET_o for Nutria, Pescado, Zuni, Tekapo, and Ojo Caliente project areas:

- Daily maximum air temperature (*Tmax*)

- Daily minimum air temperature (*Tmin*)
- Daily dew point temperature (*Tdew*)
- Daily total sky cover (*Tskc*)
- Daily average wind speed (*Wind*)
- Daily precipitation (*Precp*)

To calculate ET_o for each agricultural unit, the climate data from various near-by stations is used. For the Nutria agricultural unit, maximum daily air temperature (Tmax), minimum daily air temperature (Tmin), average daily precipitation (Precp) from McGaffey 5 SE station are used.   For Pescado, Tekapo, Zuni, and Ojo Caliente agricultural units, climate data (Tmax, Tmin, and Precp) from the Zuni-Black Rock station (combined data set) is used. However, these weather stations have many missing climate data. In order to fill the missing data, the available climate data from the near-by stations is used using various procedures (described in the following subsections).

The next subsections briefly describe the procedure(s) used to fill/extend the missing climate data, including how that affects the period of record used in our analysis. Figure 1 shows location of the weather stations used in filling/extending the missing climate data for Zuni-Black Rock, McGaffey 5 SE, Fence Lake, El Morro National Monument, and Gallup municipal airport weather stations, if required. In Figure 1, the numbers represent station ID's. Please see Tables 1, 7, and 10 of this report to see the station name corresponding to the numbers shown in the figure.

Table 1 provides a summary of the missing climate data for five main weather stations, namely, Zuni, Black Rock, McGaffey 5 SE, Fence Lake, El Morro National Monument, Gallup municipal airport, and Albuquerque International airport weather stations from year 1948 to 2004.

Period of Record

NRCE, 2008, report (Appendix E: Climate data, page E-4) has stated that "…the complete set of the climatic inputs can be developed for the period from July 1, 1948 through December 31, 2004". However, in the data set received from the NRCE (in two CD's), the data is filled/extended from January 1, 1948 to December 31, 2004. The NRCE, 2008, report does not point out any procedure to extend the missing climate data for the period from January 1, 1948 to June 30, 1948. Therefore, a sensitivity analysis was performed in which the monthly ET_o was calculated using the two sets of the input climate data. In the first set, Set 1, climate data from January 1, 1948 to June 30, 1948 is include with the data set from July 1, 1948 to December 31, 2004. In the other set, Set 2, data from January 1, 1948 to June 1, 1948 is not included with the data from July 1, 1948 to December 31, 2004. The percentage difference between the annual ET_o's, computed first using the Set 1 date and then computed again using Set 2, is less than 1% (see Figure 2). Because, this difference is relatively small compared to the uncertainty involved in extending/filling the missing climate data and to be consistent with NRCE's narrative description of their data set, we used the climate dataset from July 1, 1948 to December 31, 2004 to compute ET_o with a daily time-step.

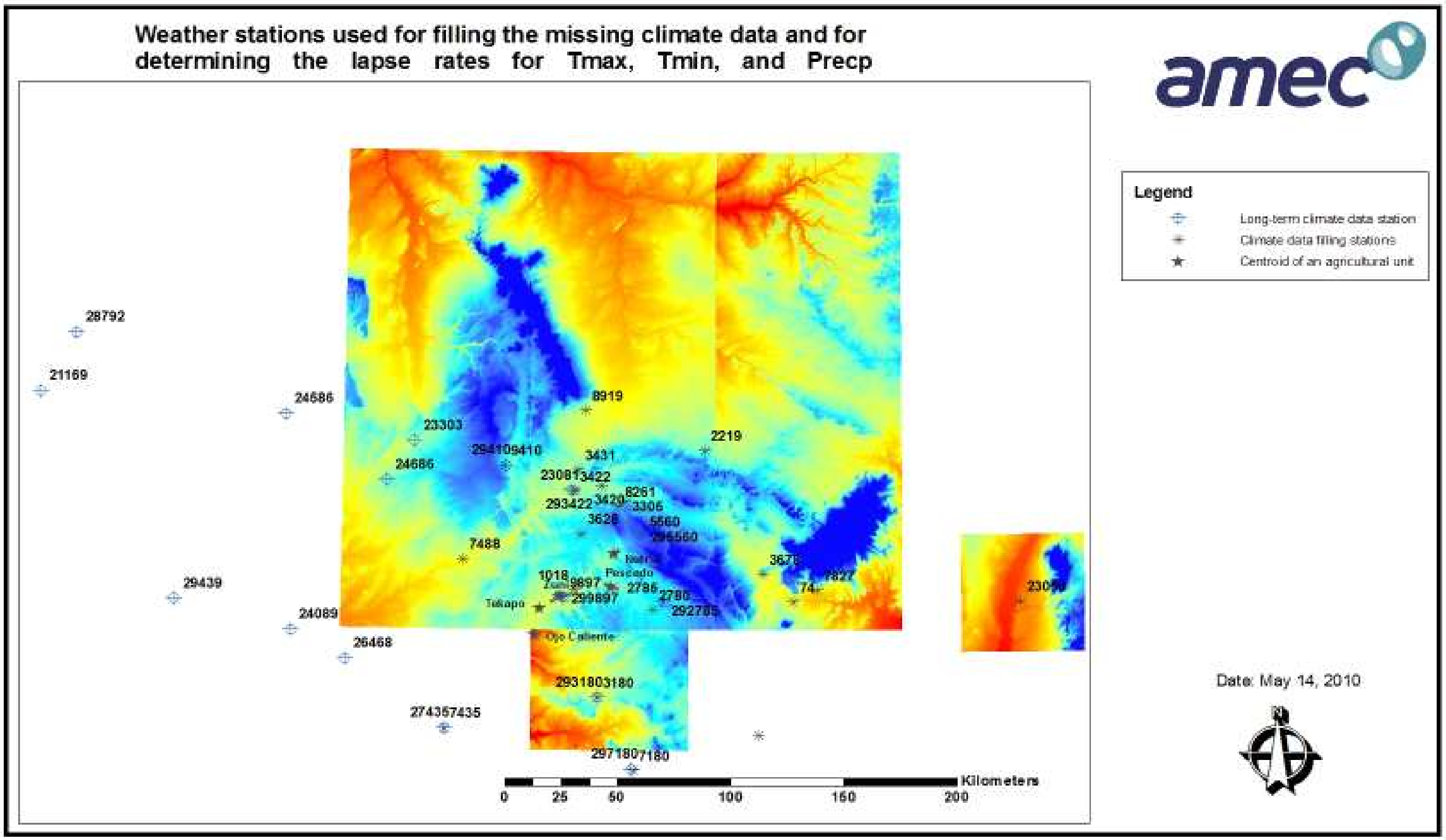

Figure 1. Location of the weather stations used in filling/extension of the climate data for McGaffey 5 SE, Zuni-Black Rock, El Morro National Monument, Fence Lake, and Gallup municipal airport weather stations, and for determining the lapse rates for Tmax, Tmin, and Precp.

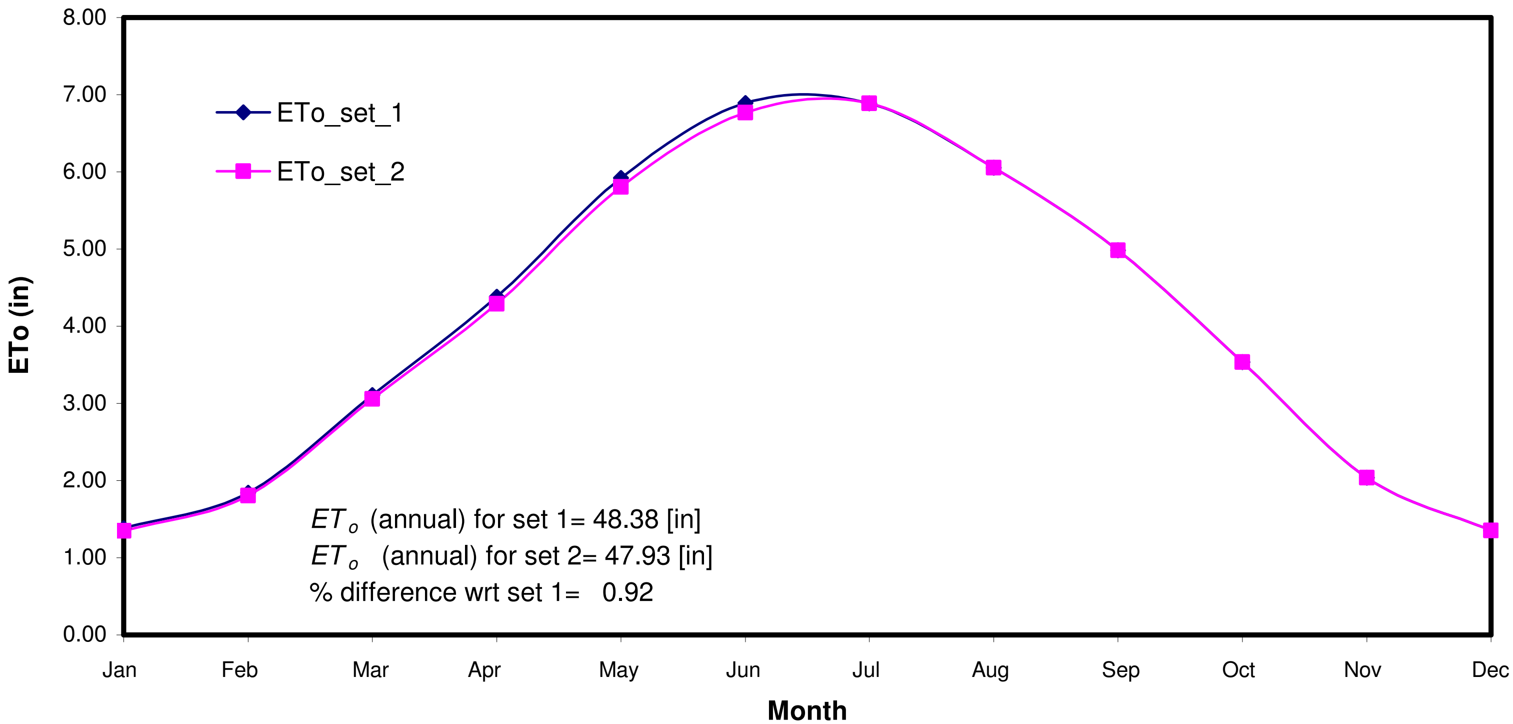

Figure 2. Comparison of the monthly ET_o for the two data sets (set 1 includes January 1, 1948 to June 30, 1948 climate data with the period of record from July 1, 1948 to December 31, 2004, while set 2 does not).

Table 1. Summary of the missing climate data for various weather stations near to the agricultural units (Zuni weather station: 9897, Black Rock weather station: 1018, El Morro National Monument: 2785, Fence Lake weather station: 3180, McGaffey 5 SE weather station: 5560, Gallup municipal airport weather station: 23081, and Albuquerque International airport weather station: 23050).

Year	Precp					Tmax					Tmin					Tdew		Tskc		Wind	
	Station ID					Station ID					Station ID					Station ID		Station ID		Station ID	
	1018	**2785**	**3180**	**5560**	**9897**	**1018**	**2785**	**3180**	**5560**	**9897**	**1018**	**2785**	**3180**	**5560**	**9897**	**23050**	**23081**	**23050**	**23081**	**23050**	**23081**
1948	26	21	366	366	366	50	51	366	366	366	38	51	366	366	366	182	366	182	366	182	366
1949	184	8	365	17	47	189	17	365	26	47	189	27	365	22	47	0	365	0	365	0	365
1950	365	0	365	0	0	365	0	365	0	0	365	4	365	0	0	0	365	0	365	0	365
1951	365	4	365	1	0	365	0	365	1	1	365	0	365	1	0	0	365	0	365	0	365
1952	366	0	366	1	0	366	0	366	2	0	366	16	366	2	0	0	366	0	366	0	366
1953	365	0	365	0	0	365	0	365	1	0	365	0	365	1	0	0	365	0	365	0	365
1954	365	1	365	0	0	365	24	365	1	0	365	24	365	1	0	0	365	0	365	0	365
1955	365	1	365	63	0	365	3	365	62	0	365	10	365	62	0	0	365	0	365	0	365
1956	366	0	366	152	0	366	2	366	178	0	366	1	366	175	0	0	366	0	366	0	366
1957	365	0	365	0	0	365	1	365	0	1	365	1	365	0	0	0	365	0	365	0	365
1958	365	0	365	0	0	365	0	365	0	0	365	0	365	0	0	0	365	0	365	0	365
1959	365	0	365	0	0	365	0	365	0	0	365	0	365	0	0	0	365	0	365	0	365
1960	366	1	366	3	0	366	0	366	17	0	366	0	366	16	0	0	366	0	366	0	366
1961	365	1	365	3	0	365	0	365	9	0	365	0	365	8	0	0	365	0	365	0	365
1962	365	0	365	0	0	365	0	365	10	0	365	0	365	10	0	0	365	0	365	0	365
1963	365	0	365	0	2	365	0	365	7	2	365	0	365	7	2	0	365	0	365	0	365
1964	366	0	121	0	0	366	0	126	2	0	366	0	126	12	0	0	366	0	366	0	366
1965	365	14	0	0	0	365	12	19	1	0	365	12	19	1	0	0	365	0	365	0	365
1966	365	0	62	10	0	365	0	100	11	0	365	0	100	11	0	0	365	0	365	0	365
1967	365	0	0	0	0	365	0	33	16	0	365	0	33	16	0	0	365	0	365	0	365
1968	366	0	61	0	0	366	0	99	25	0	366	2	99	25	0	0	366	1	366	0	366
1969	365	0	181	12	0	365	2	143	47	0	365	1	143	47	0	0	365	0	365	0	365
1970	365	0	0	0	0	365	2	0	39	0	365	2	0	39	0	0	365	0	365	0	365
1971	365	0	15	36	0	365	0	0	45	0	365	0	0	45	0	0	365	0	365	0	365
1972	366	0	0	0	0	366	0	13	32	0	366	0	13	32	0	0	366	0	366	0	366
1973	365	0	0	0	284	365	0	23	17	255	365	0	23	17	314	0	365	0	7	0	365
1974	365	0	0	0	334	365	0	5	38	348	365	0	5	38	349	0	7	0	0	0	7
1975	365	1	0	0	32	365	0	1	27	105	365	0	1	27	164	0	0	0	0	0	0
1976	366	31	0	0	62	366	0	0	23	148	366	0	0	25	189	0	0	0	0	0	0
1977	365	0	2	0	0	365	2	2	19	6	365	0	2	18	7	0	0	0	0	0	0
1978	365	1	1	0	32	365	0	3	17	56	365	0	3	15	55	0	0	0	0	0	0
1979	365	2	0	0	0	365	0	1	15	37	365	0	1	15	36	0	0	0	0	0	0
1980	366	5	0	0	0	366	0	0	13	14	366	0	0	14	12	0	0	0	0	0	0
1981	365	0	0	0	0	365	1	0	18	19	365	2	0	18	82	0	0	0	0	0	0
1982	365	0	0	1	3	365	0	0	0	0	365	0	0	0	0	0	0	0	0	0	0
1983	365	1	0	0	3	365	0	0	0	0	365	0	0	0	0	0	0	0	0	0	0
1984	366	1	0	1	6	366	0	0	0	1	366	0	0	0	0	0	0	0	0	0	0
1985	365	4	0	0	4	365	0	0	0	0	365	0	0	0	0	0	0	0	0	0	0
1986	365	1	0	33	3	365	0	0	31	0	365	0	0	61	0	0	0	0	1	0	0
1987	365	0	0	6	3	365	0	0	0	0	365	0	0	0	0	0	0	1	1	0	0
1988	366	0	0	1	7	366	0	0	0	0	366	0	0	0	0	0	0	0	0	0	0
1989	365	0	0	0	1	365	0	0	0	16	365	0	0	0	20	0	0	0	0	0	0
1990	365	0	0	4	6	365	0	0	0	0	365	0	0	0	0	0	0	0	0	0	0
1991	365	1	1	13	1	365	0	0	0	0	365	0	0	0	0	0	0	0	0	0	0
1992	366	0	0	2	4	366	0	0	0	0	366	0	0	0	0	0	0	0	0	0	0
1993	365	2	0	3	2	365	0	0	0	0	365	0	0	1	0	0	0	0	0	0	0
1994	365	1	0	7	5	365	0	0	0	0	365	0	0	0	1	0	0	0	0	0	0
1995	365	1	0	0	0	365	0	0	0	0	365	1	0	1	0	0	0	0	0	0	0
1996	366	7	0	3	1	366	0	0	0	0	366	0	0	0	0	0	19	306	61	0	0
1997	365	4	2	8	15	365	0	0	0	0	365	0	0	1	0	0	0	365	59	0	0
1998	365	1	0	2	0	365	0	0	1	0	365	0	0	1	0	0	0	365	307	0	0
1999	365	33	0	0	0	365	30	0	2	0	365	31	0	19	1	0	80	365	121	0	31
2000	366	2	0	9	2	366	0	0	0	0	366	0	0	23	0	0	96	366	92	0	0
2001	365	1	1	24	1	365	20	0	0	0	365	25	0	37	0	0	0	365	365	0	0
2002	365	0	0	57	0	365	0	0	39	0	365	0	0	39	0	0	0	365	365	0	0
2003	365	3	0	15	1	365	0	0	14	0	365	0	0	14	0	0	0	365	365	0	0
2004	366	0	5	19	3	366	0	5	20	0	366	0	5	21	0	0	0	366	366	0	0
Total (January 1, 1948 to December 31, 2004)	**20299**	**154**	**6296**	**872**	**1230**	**20328**	**167**	**6417**	**1192**	**1422**	**20316**	**210**	**6417**	**1304**	**1645**	**182**	**9699**	**3412**	**11242**	**182**	**9535**

Tmax and Tmin

Table 1 shows a summary of the missing Tmax and Tmin data for the five main stations, namely: Black Rock weather station (station ID: 1018); Zuni (station ID: 9897); El Morro National Monument (station ID: 2785); McGaffey 5 SE (station ID: 5560); and, Fence Lake (station ID: 3180) weather stations. The missing Tmax and Tmin data for these stations are filled/extended using the following procedures, listed in order of preference for filling/extending the missing Tmax and Tmin data.

i) Linear regression:

Let *y* represents the filled/extended Tmax at a station (filled station), and *x* represents the available Tmax at a near-by station (filling station). *x_mean* and *y_mean* are the average of Tmax at the filling and filled stations, respectively. Let *N* represents the number of days when both the stations have Tmax data available, in other words, it represents the length of the common period of record. Then, *y* at a filled station can be estimated from the available data (*x*) at the near-by filling station using the following relationship:

$$y = A + Bx \tag{1}$$

where,

$$B = \frac{\sum_{i=1}^{i=N} (xi - x\_mean)(yi - y\_mean)}{\sum_{i=1}^{i=N} (xi - x\_mean)^2} \tag{2}$$

$$A = y\_mean - B * x\_mean \tag{3}$$

ii) Linear interpolation:

Let at a particular station of interest temperatures y_1 and y_2 on days d_1 and d_2 are available. The temperature *y* at any other day *d*, between the two days d_1 and d_2, can be estimated from the following relationship:

$$y = y_1 + \frac{y_2 - y_1}{d_2 - d_1}(d - d_1) \tag{4}$$

Tables 2 and 3 list the filled and filling stations, intercept and slope for linear regression method for each filled-filling station combination, total number of days filled by each method (i.e., linear regression and linear interpolation) for Tmax and Tmin, respectively.

Note: A similar procedure is followed for Tmin. Note also that Tmax, Tmin and Precp data for the Zuni weather station are combined with the Black Rock weather station data, as done in the NRCE, 2008 report.

Table 2. A summary of the filling/extension of the Tmax data.

Filled Station	Filling station	Intercept	slope	R^2	Total days filled by Regression	Total days filled by linear interpolation	Total days filled
5560	2785	-1.0816	0.9489	0.9546	975	3	1010
	9897	-3.2174	0.9352	0.9502	32		
9897-1018	2785	4.3288	0.9844	0.9773	1040	3	1043
2785	9897	-1.3057	0.9702	0.9773	142	3	145
3180	2785	2.9171	0.9815	0.9793	6158	3	6235
	9897	0.4954	0.9659	0.9727	74		

Table 3. A summary of the filling/extension of the Tmin data.

Filled Station	Filling station	Intercept	slope	R^2	Total days filled by Regression	Total days filled by linear interpolation	Total days filled
5560	2785	-2.5121	0.9351	0.9339	1088	30	1122
	9897	-5.4215	0.9396	0.9349	4		
9897-1018	2785	4.2868	0.9561	0.9561	1263	3	1267
	3180	4.1683	0.9411	0.9427	1		
2785	9897	-1.4566	0.9576	0.9568	183	3	187
	3180	1.4563	0.9462	0.9485	1		
3180	2785	1.7927	0.9508	0.9485	6146	3	6258
	9897	-0.3665	0.9442	0.9427	109		

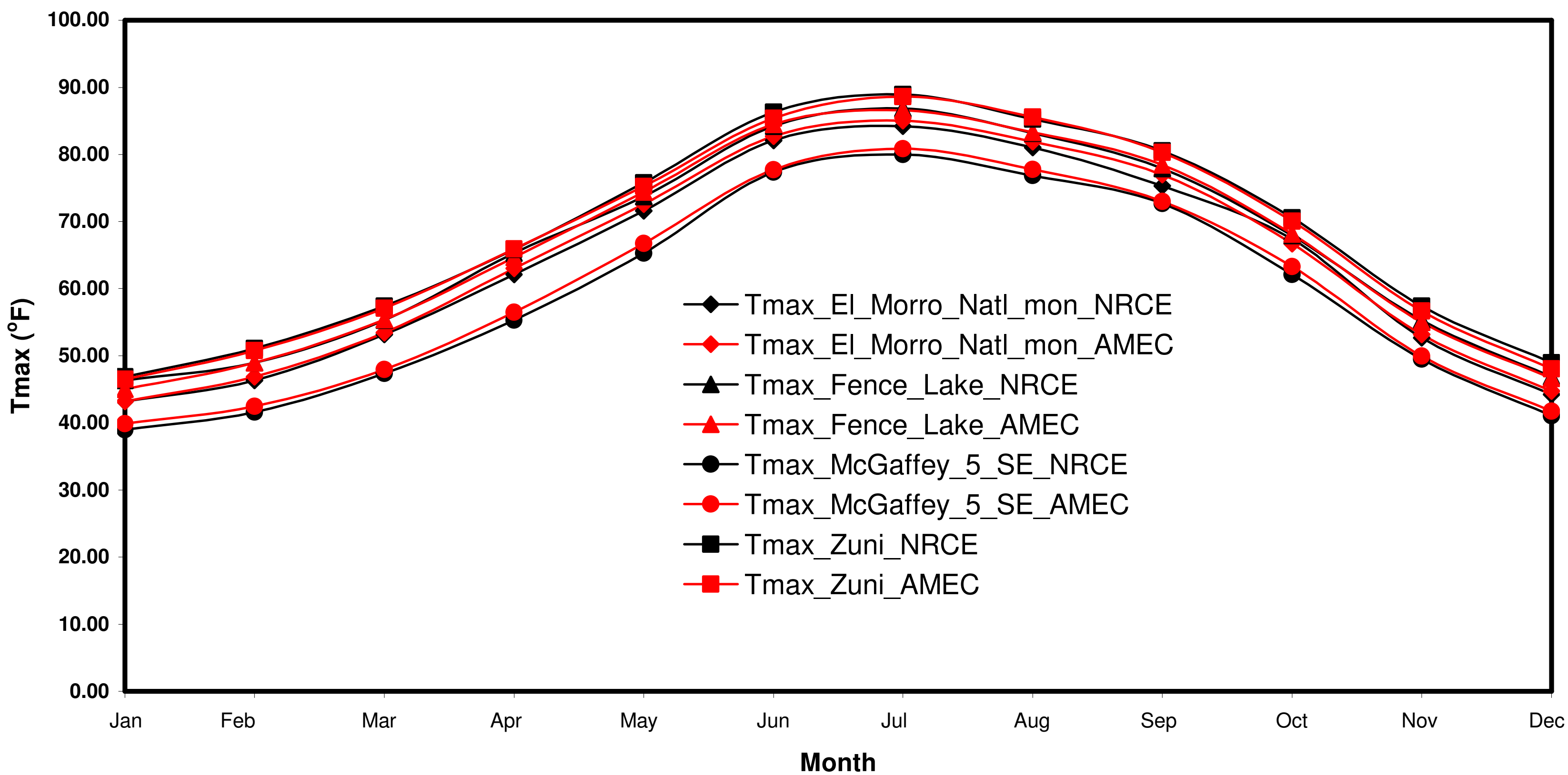

Figure 3: Comparison of the NRCE calculated and AMEC calculated pattern of the monthly Tmax

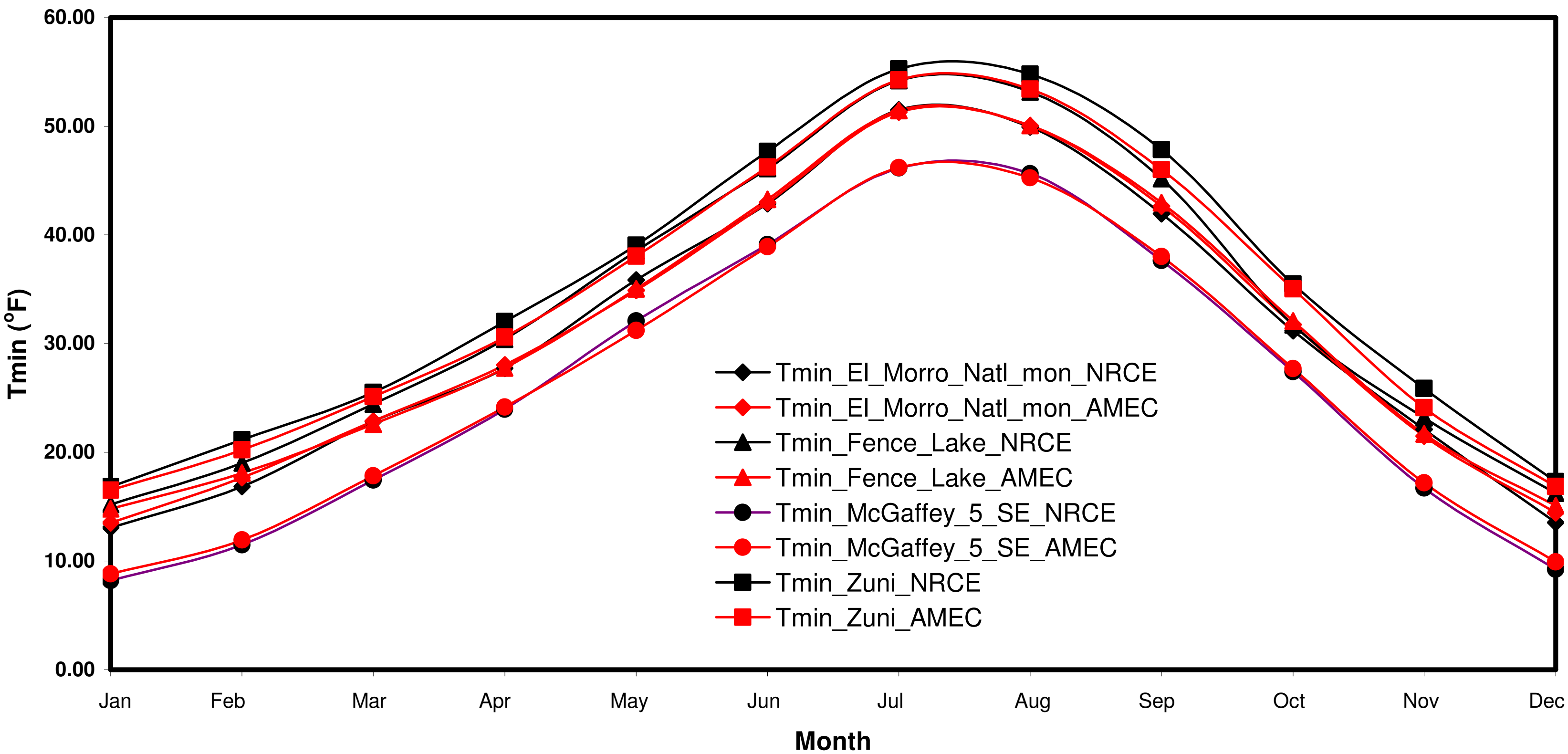

Figure 4: Comparison of the NRCE calculated and AMEC calculated pattern of the monthly Tmin.

Tdew

For ET_o calculation for each agricultural unit, Tdew data from the Gallup municipal airport weather station is used. However, Tdew is missing for number of days (from July 1, 1948, to July 7, 1973) for the considered period of record from July 1, 1948 to December 31, 2004 at this station. The missing Tdew data is filled by the available data from the Albuquerque airport weather station. Table 1 shows a summary of the missing Tdew data for both Gallup municipal airport and Albuquerque International airport weather stations. The missing Tdew data is filled/extended using the available data from the Albuquerque airport weather station using the same procedures as used for Tmax and Tmin described above. Table 4 shows a summary of the filled/extended Tdew data for the Gallup station. Figure 5 shows the monthly pattern for Tdew and compares it to the NRCE, 2008, reported pattern for this parameter.

Table 4. A summary of the filling/extension of Tdew data for the Gallup municipal airport weather station.

Filled Station	Filling station	Intercept	slope	R^2	Total days filled by Regression	Total days filled by linear interpolation	Total days filled
23081	23050	1.41	0.85	0.91	9152	0	9152

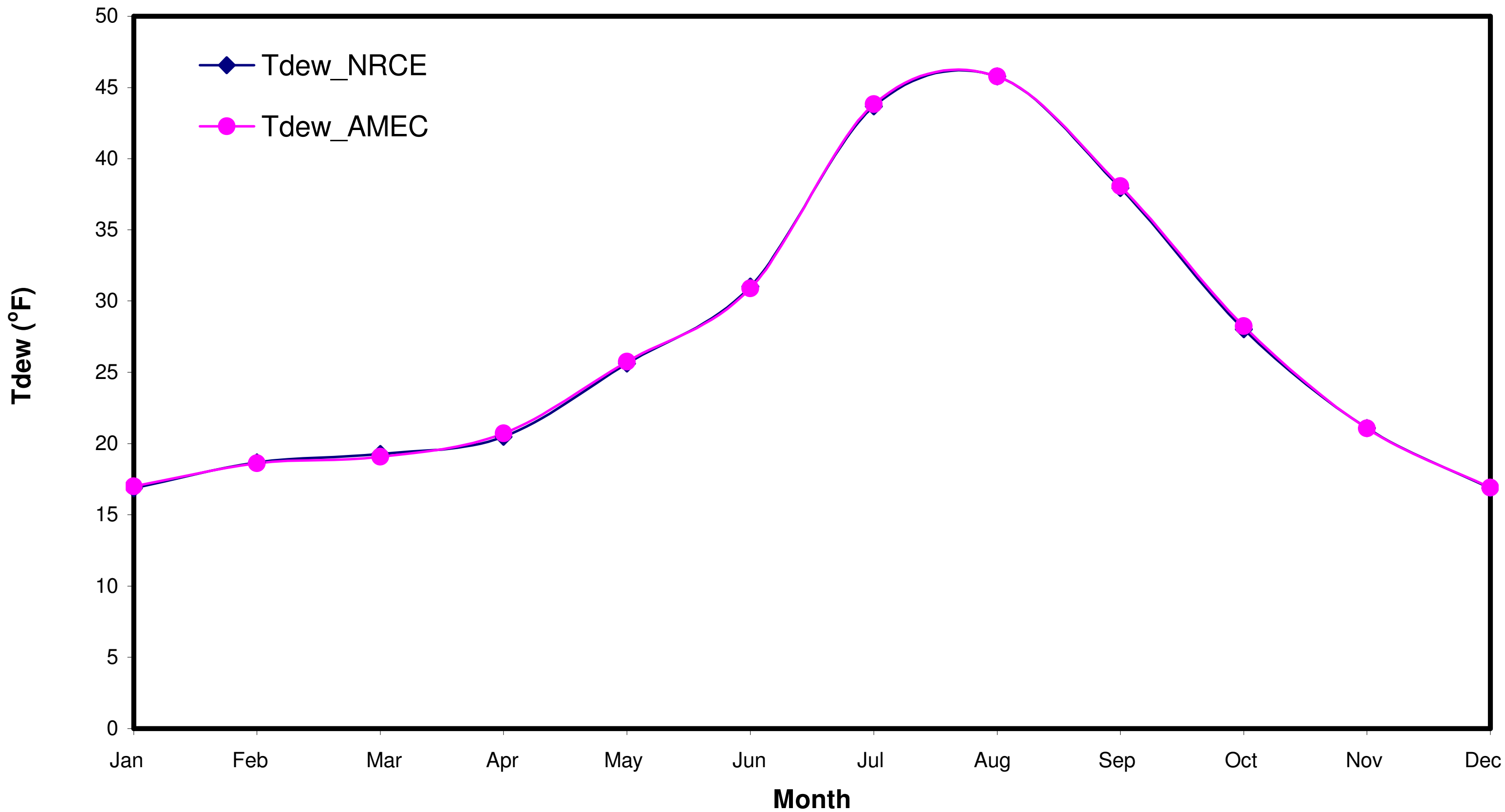

Figure 5. Comparison of the NRCE calculated and AMEC calculated monthly pattern of Tdew for the Gallup municipal Airport weather station.

Total sky cover for the sunlight hours (Tskc)

For calculating ET_o for a daily time-step using the standard ASCE-PM equation, a parameter is required to estimate the net solar radiation. Following the NRCE procedure, Total Sky Cover Tskc, is used to estimate the daily net solar radiation. Because Tskc data is not available at the local weather stations or for any agricultural unit, Tskc data from the Gallup municipal airport weather station is used for all agricultural units. As there are many missing Tskc data for this station, Tskc data from the Albuquerque International airport weather station is used to fill/extend the missing Gallup Tskc data. Table 1 shows a summary of the missing Tskc data for both the stations. The missing Tskc data for the Gallup station is filled using the following procedures (procedures are listed in order of preference):

i) Linear regression: The missing Tskc data for the Gallup station are filled using the Albuquerque International airport Tskc data using the linear regression method as described for Tmax and Tmin.

ii) Thornton and Running, 2009, method: If Tskc data is missing for both Gallup and Albuquerque stations, the linear regression method will not be helpful. Under such circumstances, the Thornton and Running, 1999, method is used to fill the missing Tskc data. This method is explained below.

Let $T_{max,i}$ and $T_{min,i}$ are the maximum and minimum temperatures for the ith day. Then,

$$\Delta T_i = T_{\max,i} - 0.5(T_{\min,i} + T_{\min,i-1}) \qquad (5)$$

Let Θ be the 30-day moving average of ΔT_i for the period from ith day to last i-29 days.

$$B = b_o + b_1 \exp(-b_2 . \Theta^C) \qquad (6)$$

where, b_o, b_1, and b_2 are 0.031, 0.201, and 0.185 (Thornton and Running, 1999), respectively.

The attenuation of the solar radiation due to cloud cover, f_{cloud}, for the ith day is computed from the following equation:

$$f_{cloud,i} = 1.0 - 0.9\exp(-B.\Delta T_i^{\,C}) \qquad (7)$$

where, C is 1.5, B is calculated from equation (6), and ΔT_i is defined previously.

After calculating $f_{cloud,i}$ from equation (7), Tskc for the ith day ($Tskc_i$) can be calculated from the following equation:

$$Tskc_i = 100\sqrt{\frac{1 - f_{cloud,i}}{A}} \qquad (8)$$

where, A is 0.65 (TVA, 1972).

As pointed out in Thornton and Running, 1999, when there is a precipitation on ith day, Tskc on that that day needs to be scaled by a factor of 0.75. So, the Tskc parameter for the ith day, as computed from equation (8), is multiplied by 0.75 to get the final Tskc for the ith day, if there is a precipitation on the ith day.

After linear regression and the Thornton and Running, 1999, methods, linear interpolation (as explained above for Tmax and Tmin) is used to fill any further missing Tskc data. Table 5 shows a summary of the filled/extended Tskc data. Figure 6 shows a comparison of the monthly pattern of Tskc as computed from this exercise to the NRCE reported pattern.

Table 5. A summary of the filling/extension of Tskc data for the Gallup municipal airport weather station.

Filled Station	Filling station	Intercept	slope	R^2	Total days filled by Regression	Total days filled by Thornton and Running, 1999, method	Total days filled by linear interpolation	Total days filled
23081	23050	10.2824	0.8008	0.8032	8957	2071	32	11060

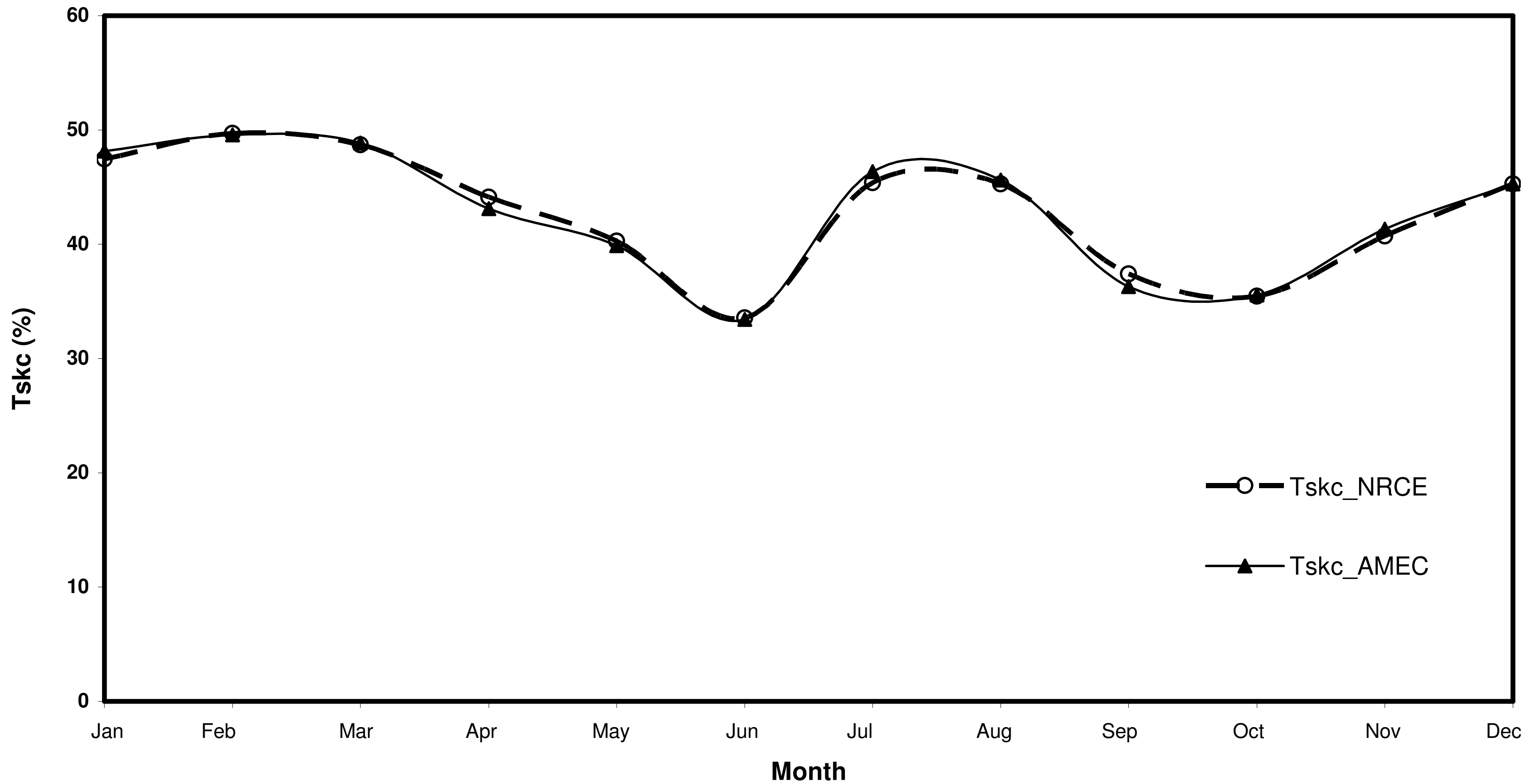

Figure 6. Comparison of NRCE, 2008, calculated and AMEC calculated monthly pattern of T_{SKC} for the Gallup municipal Airport weather station.

Wind

The daily ET_o calculation for all the agricultural units requires the daily wind data. However, the data is not available for any unit. Therefore, the Gallup municipal airport wind data is used for each agricultural unit. There are many missing wind data for this station for the period of record. For missing wind data at the Gallup station, data from the Albuquerque International Airport weather station is used by following the Ratio of Monthly Mean (RMM) method, as described in the NRCE, 2008, report. The RMM method is explained below.

Let x be the available wind data at the Albuquerque International airport weather station, and y is the filled wind data at the Gallup municipal airport weather station for a particular day. Then,

$$y = b_m * x \tag{9}$$

where,

$$b_m = \frac{\overline{y_m}}{\overline{x_m}} \tag{10}$$

where, $\overline{x_m}$ and $\overline{y_m}$ are the monthly means for wind for the common period of record for the two stations for month m. The wind speed measurements at the two stations are carried out at 33 feet height above the ground surface (Stephens, 2010).

After filling the missing wind data for the Gallup station using the Albuquerque data, linear interpolation method is used to fill any additional missing wind data for the Gallup station. Table 6 shows a summary of the filled/extended wind data for the Gallup station. Figure 7 shows a monthly pattern of wind at the Gallup station and compares it to the NRCE, 2008, reported pattern (assuming month 1 in Figure E-4 represents January). The AMEC pattern reproduces the high spring winds common to the Southwestern United States.

Table 6. A summary of the filling/extension of wind data for the Gallup municipal airport weather station.

Filled Station	Filling station	Ratio of monthly means												Total days filled by the RMM method	Total days filled by the linear interpolation method	Total days filled
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
23081	23050	0.661	0.734	0.839	0.853	0.848	0.807	0.767	0.741	0.757	0.714	0.728	0.671	8988	0	8988

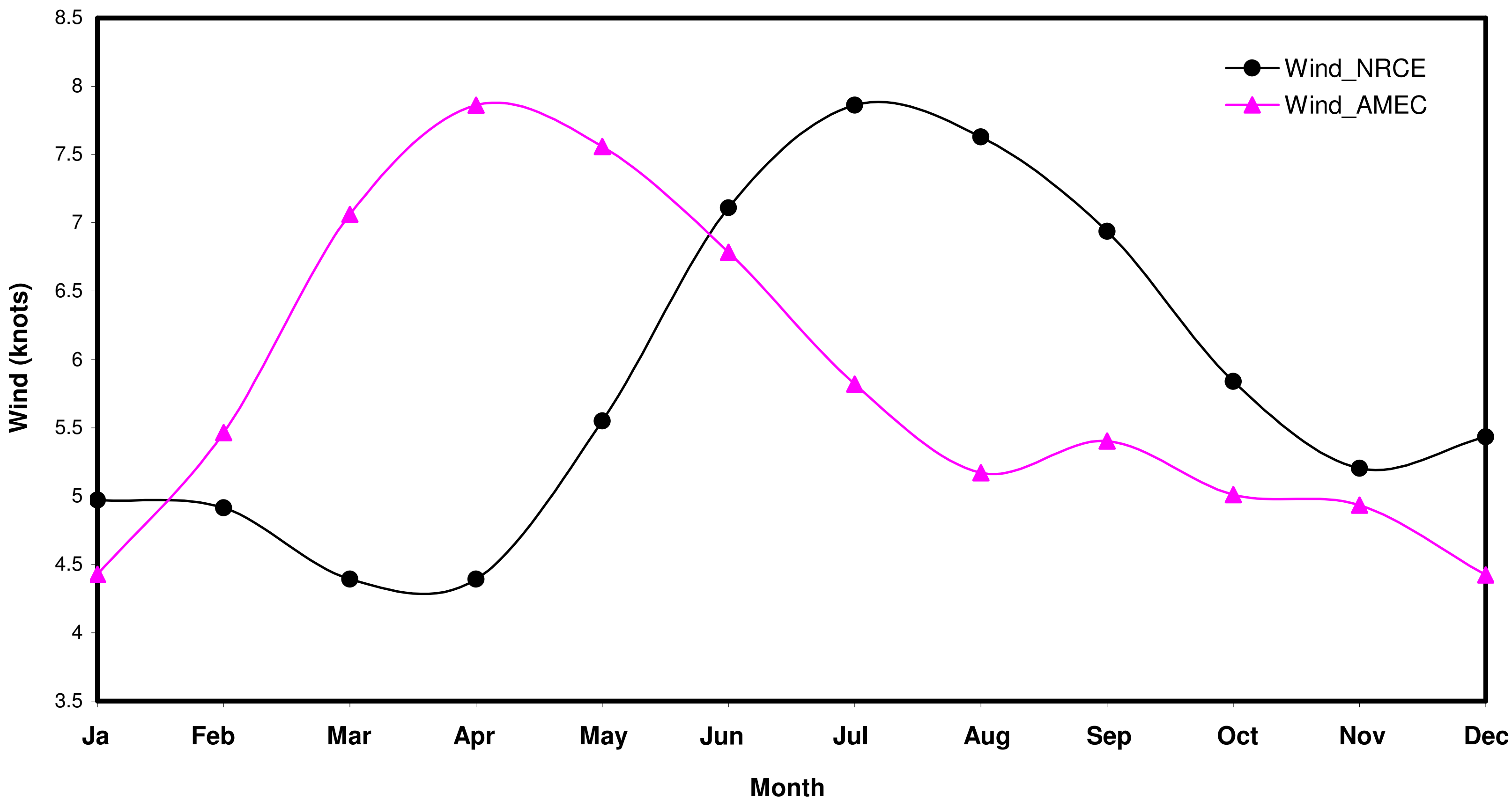

Figure 7: Comparison of the NRCE reported and AMEC calculated monthly pattern of the wind data for the Gallup municipal airport weather station

Precp

In order to estimate the effective precipitation for each crop type grown in each agricultural unit, precipitation (Precp) data at each agricultural unit is required. NRCE, 2008 has used only two stations, namely, McGaffey 5 SE and Zuni-Black Rock, to get the Precp data for each agricultural unit. These two stations are, however, filled using the available data from various near-by stations. Table 7 (NRCE, 2008) lists all the stations used in filling/extension of the Precp data for the McGaffey 5 SE and Zuni-Black-Rock weather stations. To fill the missing Precp data, a method similar to the NRCE, 2008 method is followed as explained below.

Let y be the missing Precp data at the filled station (Y) and xi is the available Precp data at the filling station Xi (see Figure 8).

If there are n numbers of surrounding stations with respect to the filled station Y, which meet the following criteria:

- Y and Xi have at least 4 years of the common period of record
- Y and Xi have a daily cross-correlation coefficient of 0.3
- Xi lie with-in 50 miles distance from Y
- There is a minimum azimuth difference of 45^{o} between the spatial group of the surrounding stations X1, X2, …., Xi, …, Xn

Once a spatial group of the filling stations (X1, X2, …., Xi, …, Xn) for the filled station Y is selected, *POPp* (probability of precipitation) at the station Y is calculated using the following equation:

$$POPp = \frac{\sum_{i=1}^{n} \frac{PO_i}{d_i^{\ 2}}}{\sum_{i=1}^{i=n} d_i^{\ -2}} \tag{11}$$

In equation 11, PO_i is a binomial variable for the station Xi. This variable takes a value 1 if there is a precipitation on a certain day at the station Xi, and zero otherwise. d_i, in the same equation represents distance between the filled station (Y) and the filling station (Xi). Now, if the *POPp* for a certain day for the filled station is less than 0.5 (this value is used by the NRCE, 2008), the Precp at the station Y is zero. Otherwise:

$$y = \frac{\sum_{i=1}^{n} \frac{PO_i}{d_i^{\ 2}} x_i bm_i}{\sum_{i=1}^{i=n} \frac{PO_i}{d_i^{\ 2}}} \tag{12}$$

where, bm_i is the ratio of monthly means between stations Y and Xi for the common period of record for the month m.

Table 7. Stations used to fill the missing Precp data for the McGaffey 5 SE and Zuni-Black Rock weather stations (NRCE, 2008).

Station ID	Latitude (d:m:s)	Longitude (d:m:s)	Elevation (feet)	Begin Date	End Date	Coverage (%)	Record Years	Station Name
74	N35:03:00	W107:43:00	6,585	1/1/1941	4/28/1953	98.8	13	ACOMITA CAA AP
1080	N35:15:00	W108:02:00	6,804	7/ 1/1896	11/30/1959	75.9	55	BLUEWATER 3 WSW
2219	N35:41:00	W108:09:00	6,965	7/1/1914	11/12/1969	92.1	56	CROWNPOINT
2780	N35:01:00	W108:24:00	7,123	3/1/1940	2/14/1949	93.0	10	EL MORRO CAA AIRPORT
2785	N35:02:17	W108:20:57	7,223	3/1/1938	12/31/2004	98.9	67	EL MORRO NATL MON
3180	N34:39:10	W108:40:35	7,065	11/1/1933	12/31/2004	64.5	52	FENCE LAKE
3305	N35:28:00	W108:32:00	7,005	3/ 1/1897	7/22/1966	56.1	43	FORT WINGATE
3420	N35:32:00	W108:39:00	6,604	8/1/1918	12/31/1979	54.9	39	GALLUP 5 E
3422	N35:30:40	W108:47:22	6,472	7/1/1973	12/31/2004	100.0	32	GALLUP FAA AP
3431	N35:36:00	W108:46:00	6,745	7/1/1922	5/31/1951	98.1	30	GAMERCO
3626	N35:20:00	W108:45:00	7,306	4/26/1919	12/24/1948	63.9	23	GOWER
3678	N35:10:00	W107:52:00	6,506	6/1/1945	10/31/1956	94.3	12	GRANTS
5560	N35:20:11	W108:26:41	8,000	1/1/1949	12/1/2004	98.0	56	MCGAFFEY 5 SE
7180	N34:20:41	W108:29:32	6,878	7/1/1915	12/31/2004	76.5	81	QUEMADO
7435	N34:31:02	W109:24:10	5,790	8/26/1901	12/31/2004	92.4	101	SAINT JOHNS
7488	N35:13:26	W109:19:20	5,853	11/1/1942	12/31/2004	74.6	53	SANDERS
7827	N35:06:00	W107:36:00	6,165	5/1/1920	9/30/1976	91.5	57	SAN FIDEL 2 E
8261	N35:27:00	W108:34:00	7,106	8/1/1943	7/31/1966	86.6	23	GALLUP RANGER STN
8919	N35:51:00	W108:44:00	6,424	7/14/1914	4/30/1979	82.5	64	TOHATCHI 1 ESE
9410	N35:37:01	W109:07:28	6,920	3/1/1937	9/1/1999	95.0	62	WINDOW ROCK 4 SW
1018-9897	N35:04:14	W108:50:20	6,311	6/1/1908	12/1/2004	95.2	97	ZUNI / BLACK ROCK
3969-6812	N34:29:35	W107:53:18	7,961	9/1/1943	12/1/2004	91.6	60	PIETOWN 19 NE / HICKMAN

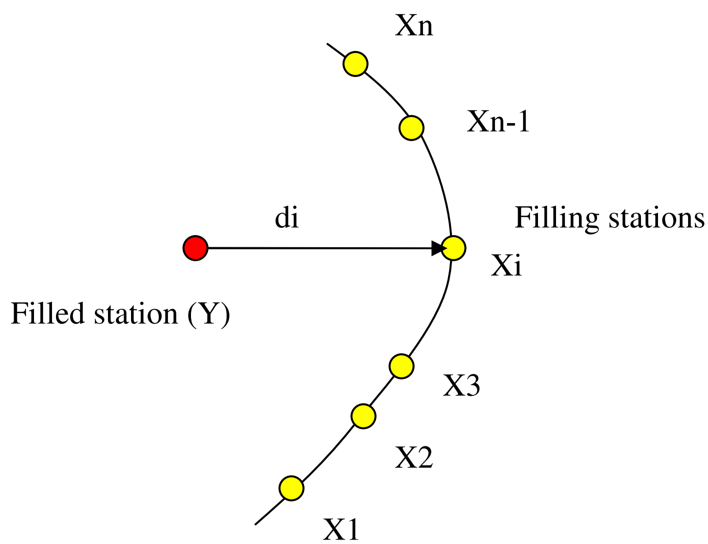

Figure 8. Schematic diagram of the location of the filled and the spatial group of the filling stations.

Note that in Table 9, station 7440 is not used to fill/extend Precp data for the Zuni-Black Rock station. So its rank is not reported. Note also that AMEC calculation has shown the cross-correlation coefficient less than 0.3 for two stations, namely: 2780 and 3431. This difference is primarily caused by the difference in the NRCE and AMEC estimated days for the common period of record for these stations (from July 1, 1948, to December 31, 2004).

Table 10 shows total number of days (also in percentage) of climate data filled for each pertinent weather station for the considered period of record from July 1, 1948, to December 31, 2004. This table shows that Tdew, wind, and Tskc data for the Gallup municipal airport weather station is largely filled (minimum percentage: 43.55% and maximum percentage: 53.59%) using various methods.

Table 8. A summary of the stations used in filling/extending the Precp data for the McGaffey 5 SE weather station.

	Station rank		**Common Period Of Record**		**Ratio of Means**		**Cross Correlation Coefficient**	
Station ID	**AMEC**	**NRCE, 2008**	AMEC	NRCE, 2008	AMEC	NRCE, 2008	AMEC	NRCE, 2008
8261	1	1	2,968	6,156	1.355	1.324	0.562	0.574
3305	2	2	6,145	6,145	1.477	1.475	0.449	0.449
1018-9897	3	3	19,157	19,157	1.576	1.574	0.443	0.443
2785	4	4	19,821	19,821	1.373	1.373	0.427	0.427
3420	5	5	10,389	10,389	1.817	1.818	0.401	0.400
3180	6	6	14,290	14,290	1.442	1.442	0.381	0.381
9410	7	7	17,240	17,240	1.618	1.618	0.377	0.377
2219	9	8	7,012	6,964	1.727	1.728	0.332	0.338
74	8	9	1,557	1,557	1.944	1.939	0.335	0.336
8919	10	10	10,269	10,116	2.034	1.842	0.327	0.319
3678	11	11	2,591	2,591	1.722	1.722	0.314	0.314
3422	12	12	11,177	11,270	1.819	1.774	0.312	0.311

Note: Station rank is based on its cross-correlation coefficient with the filled station.

Table 9. A summary of the stations used in filling/extending the Precp data for the Zuni-Black Rock weather station.

	Station rank		**Common Period Of Record**		**Ratio of Means**		**Cross Correlation Coefficient**	
Station ID	AMEC	NRCE, 2008	AMEC	NRCE, 2008	AMEC	NRCE, 2008	AMEC	NRCE, 2008
3180	1	1	13726	15949	0.908	0.904	0.508	0.494
2785	2	2	19659	23095	0.875	0.875	0.469	0.473
3626	7	3	177	6703	0.645	0.930	0.391	0.450
5560	3	4	19157	19157	0.635	0.635	0.443	0.443
7488	4	5	15496	16102	1.039	1.024	0.441	0.425
8261	8	6	2424	7254	1.110	0.846	0.364	0.414
3420	5	7	10042	11521	1.209	1.182	0.415	0.406
3422	6	8	10702	10795	1.101	1.072	0.402	0.404
2780	13	9	229	2809	0.824	1.070	0.244	0.400
3305	10	10	6558	10296	0.930	0.900	0.316	0.389
9410	9	11	16803	20641	1.076	1.037	0.348	0.368
7440	Not used	12	Not used					
3431	12	13	1065	10197	0.836	0.970	0.298	0.332
1080	11	14	3884	14582	1.247	1.214	0.310	0.304

Note: Station rank is based on its cross-correlation coefficient with the filled station.

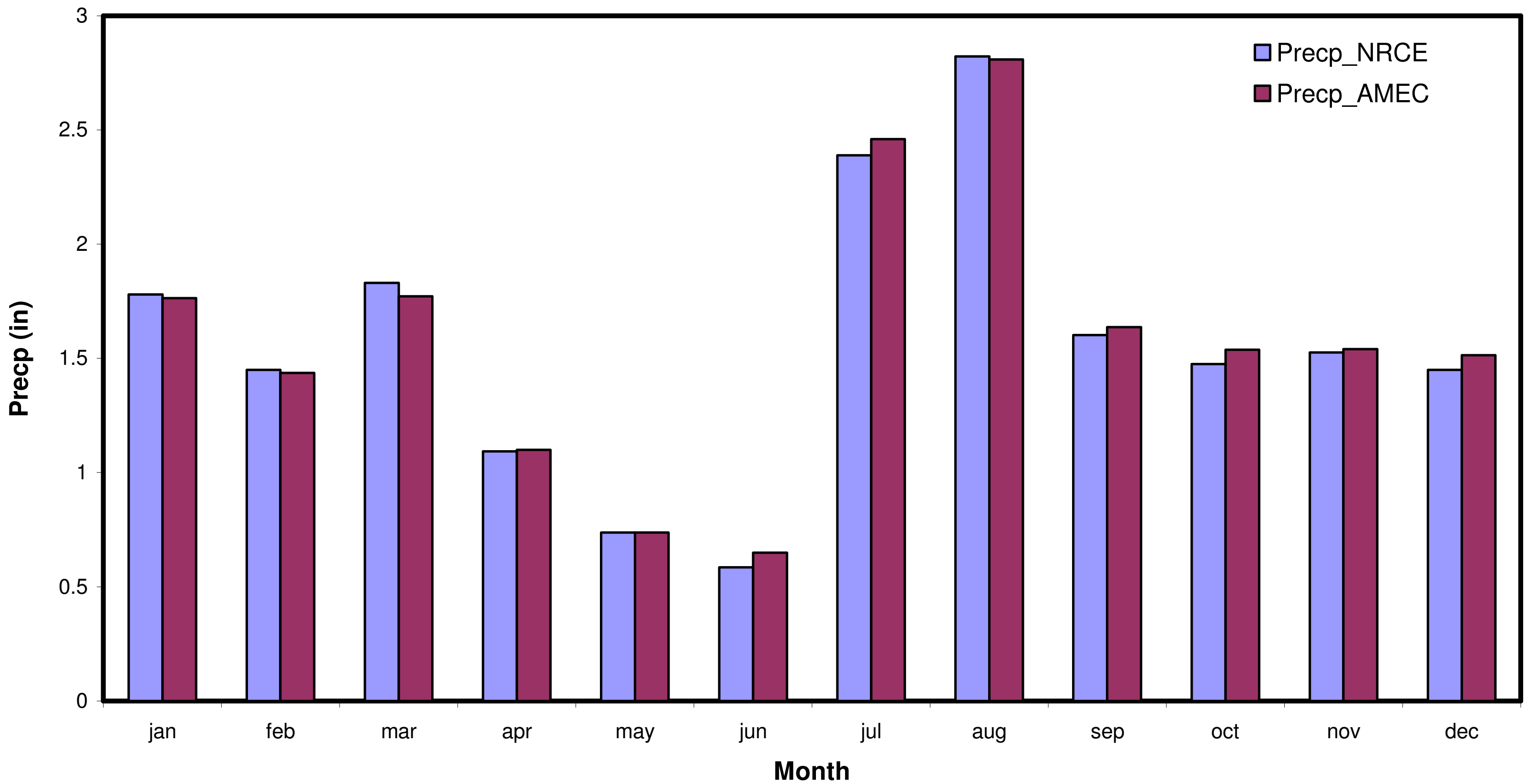

Figure 9. Comparison of the NRCE, 2008 and AMEC calculated monthly pattern of Precp for the McGaffey 5 SE weather station.

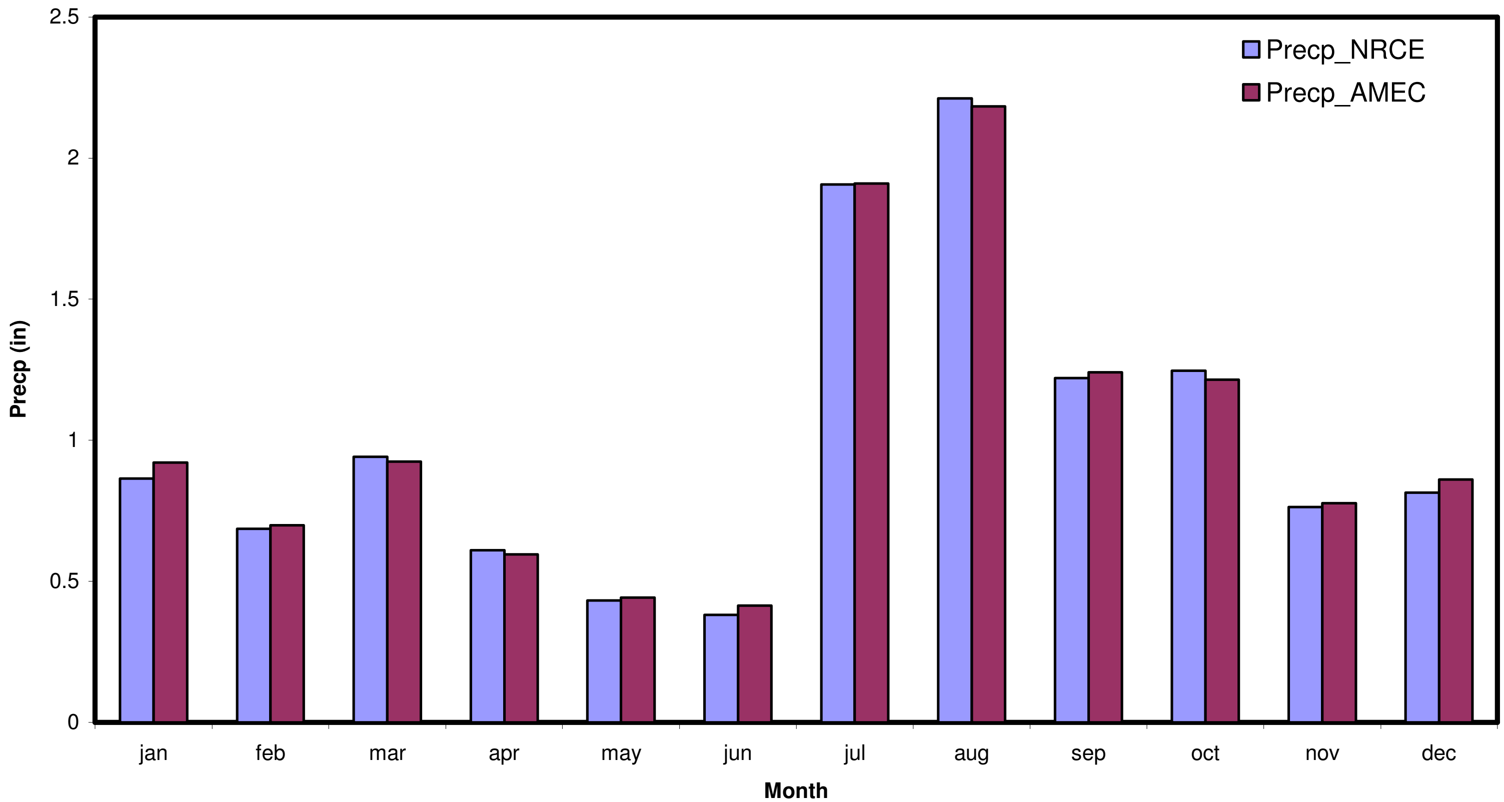

Figure 10. Comparison of the NRCE, 2008, and AMEC calculated monthly pattern of Precp for the Zuni-Black Rock weather station.

Table 10: Total and percentage of climate data filled at each pertinent weather station for the considered period of record (from July 1, 1948, to December 31, 2004)

Station	Climate paramters											
	Tmax		Tmin		Precp		Tdew		Wind		Tskc	
	Total filled/extended	% filled/extended	Total filled/extended	% filled/extended	Total filled/extended	% filled/extended	Total filled/extended	% filled/extended	Total filled/extended	% filled/extended	Total filled/extended	% filled/extended
9897-1018	1043	5.0537843	1267	6.1391608	842	4.0798527	NA	NA	NA	NA	NA	NA
2785	145	0.7025875	187	0.9060956	NA	NA	NA	NA	NA	NA	NA	NA
3180	6235	30.211261	6258	30.322706	NA	NA	NA	NA	NA	NA	NA	NA
5560	1010	4.8938851	1122	5.4365733	690	3.3433472	NA	NA	NA	NA	NA	NA
23081	NA	NA	NA	NA	NA	NA	9152	44.345382	8988	43.550732	11060	53.590464
23050	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Note: NA in the table shows that the particular climate parameter from the corresponding weather station is not used in ET_o calculation for any agricultural unit.

Elevation adjustment for the climate data

NRCE, 2008 states that the climate parameters Tmax, Tmin, Tdew, and Precp, show a strong correlation with the elevation of a measurement site. So, these parameters are elevation-adjusted using the following equations:

$$T\max_{ag.unit} = T\max_{station} - \alpha_1 (z_{ag.unit} - z_{station}) \tag{13}$$

$$T\min_{ag.unit} = T\min_{station} - \alpha_2 (z_{ag.unit} - z_{station}) \tag{14}$$

$$Tdew_{ag.unit} = \frac{9}{5}\left(Tdew_{station} - \frac{\frac{\beta(Z_{ag.unit} - Z_{station})}{17.27}(237.3+\theta)}{\frac{\beta(Z_{ag.unit} - Z_{station})}{17.27} + \frac{237.3}{237.3+\theta}}\right) + 32 \tag{15}$$

$$\mathrm{Pr}\,ecp_{ag.unit} = \mathrm{Pr}\,ecp_{station}\left(1 + \frac{\alpha_3}{\overline{P}_{station}}(z_{ag.unit} - z_{station})\right) \tag{16}$$

where, α_1 , α_2, α_3 are the lapse rates for Tmax, Tmin, and Precp, respectively. $\overline{P}_{station}$ is the long-term annual Precp average in inch. θ and $Tdew_{station}$ are the long-term averaged dew-point temperature and dew point temperature in ^{o}C at the weather station, respectively. The numerical values of $\overline{P}_{station}$, θ are computed by taking the average of Precp and Tdew (after converting the temperatures in ^{o}C) at the weather station, whose climate data is used for the corresponding agricultural unit. In equations 13, 14, 16, $z_{ag.\ unit}$ and $z_{station}$ are the elevations of an agricultural unit (taken as the elevation band as used by the NRCE, 2008, report) and weather station in miles, while in equation 15, $Z_{ag.\ unit}$ and $Z_{station}$ are the agricultural unit and weather station elevation in km. The parameter β is taken as 0.44 from Reitan, 1963. The equation 15 is the corrected equation for Tdew as mentioned in the NRCE memo titled “Corrections and Clarifications for Report by NRCE titles, Zuni Indian Reservation Identification of Lands and Estimation of Water Requirements for Past and Present Lands Served by Permanent Irrigation Works, November 3, 2008”.

To estimate required lapse rates the regional stations as listed in Table 11 are used. Figure 13 shows Tmax vs. Elevation plot using the long-term (1971-2000) average Tmax data for the stations as listed in Table 11. The lapse rate for Tmax is determined by fitting the best linear trend line to the data points. The slope of the line is the lapse rate for Tmax (α_1). Similar procedure is followed for Tmin and Precp. Figures 14 and 15 show the long-term (1971 to 2000) average Tmin vs. Elevation and Precp vs. Elevation plot using the same stations as listed in Table 11, respectively. The slope of the best fit linear trend line provides lapse rates for Tmin (α_2) and Precp (α_3).

Table 11. Stations used in the long-term (1971-2000) estimation of Tmax, Tmin, and Precp.

State #	COOP ID #	Station name	Latitude (d m) N	Longitude (d m) W	State	Elevation (ft)	Precp (in)	Tmax (^oF)	Tmin (^oF)
25	021169	CAMERON 1 NNE	35 53	111 24	AZ	4165	5.56	75.50	42.60
169	029439	WINSLOW AP	35 02	110 43	AZ	4886	8.03	70.40	40.00
148	028792	TUBA CITY	36 08	111 14	AZ	4988	6.35	69.60	40.90
66	024089	HOLBROOK	34 55	110 09	AZ	5085	9.20	73.60	38.60
102	026468	PETRIFIED FOREST N P	34 48	109 53	AZ	5446	10.44	70.80	38.80
120	027435	SAINT JOHNS	34 31	109 24	AZ	5790	11.47	69.80	37.20
71	024586	KEAMS CANYON	35 49	110 12	AZ	6205	10.16	67.00	34.60
55	023303	GANADO	35 43	109 34	AZ	6340	11.59	65.20	34.70
75	024686	KLAGETOH 12 WNW	35 33	109 42	AZ	6500	9.34	65.60	39.70
168	029410	WINDOW ROCK 4 SW	35 37	109 07	AZ	6920	11.31	63.10	32.70
142	299897	ZUNI	35 04	108 50	NM	6311	12.78	68.70	33.40
66	293422	GALLUP MUNICIPAL AP	35 31	108 48	NM	6471	11.45	66.90	28.80
106	297180	QUEMADO	34 21	108 30	NM	6878	11.18	66.50	29.60
60	293180	FENCE LAKE	34 39	108 40	NM	7065	14.23	65.80	31.40
51	292785	EL MORRO NATL MONUMENT	35 03	108 21	NM	7223	15.30	64.30	31.40
94	295560	MCGAFFEY 5 SE	35 20	108 27	NM	8000	20.32	59.00	26.40

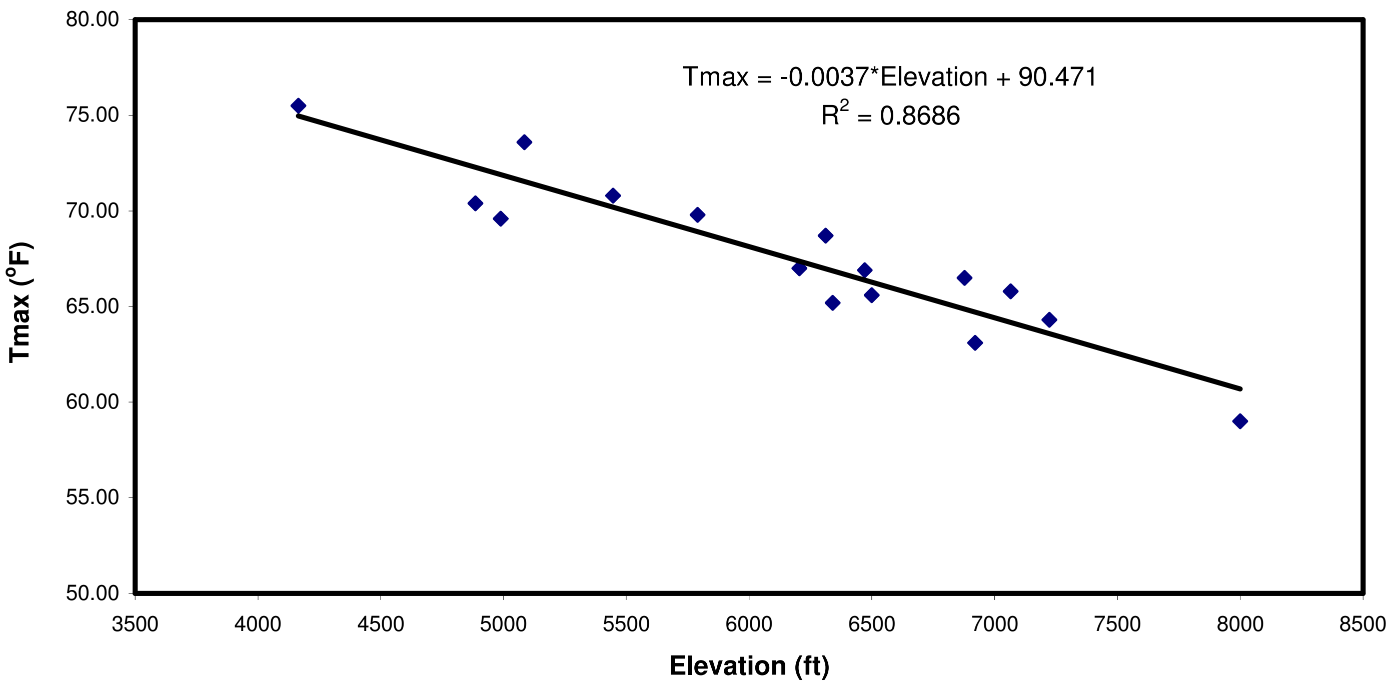

Figure 9. A long-term (1971-2000) Tmax vs. Elevation plot for the regional stations as listed in Table (11)

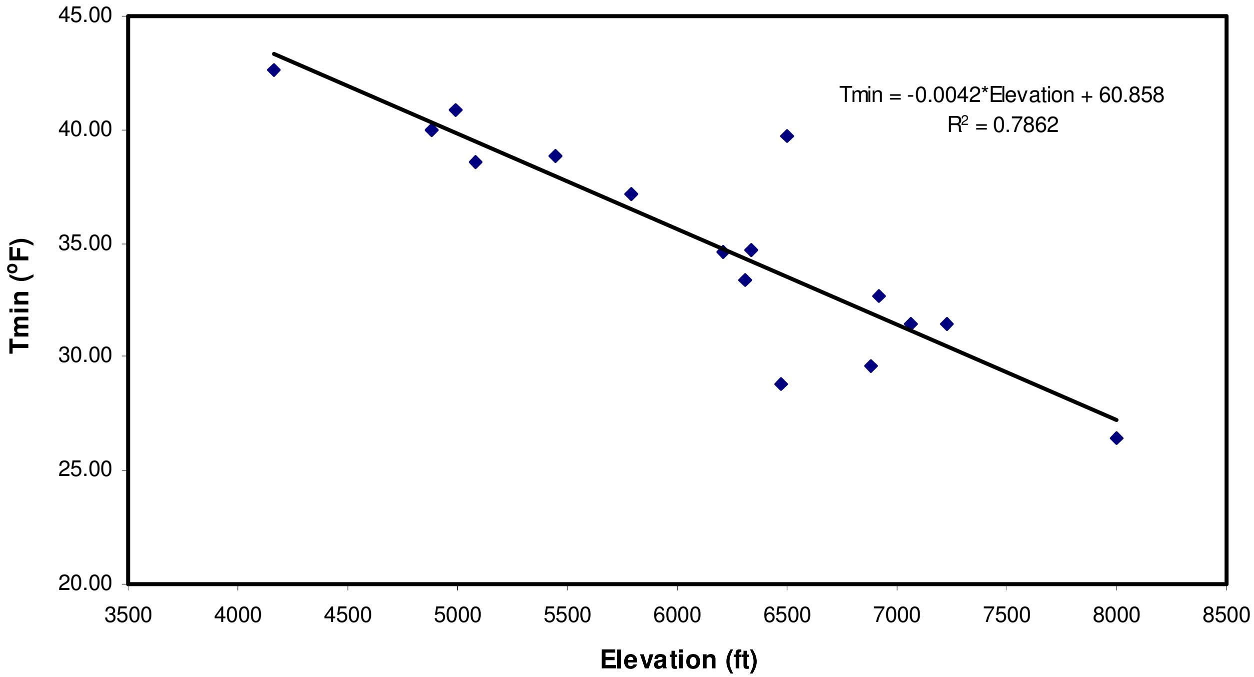

Figure 10. A long-term (1971-2000) Tmin vs. Elevation plot for the regional stations as listed in Table (11).

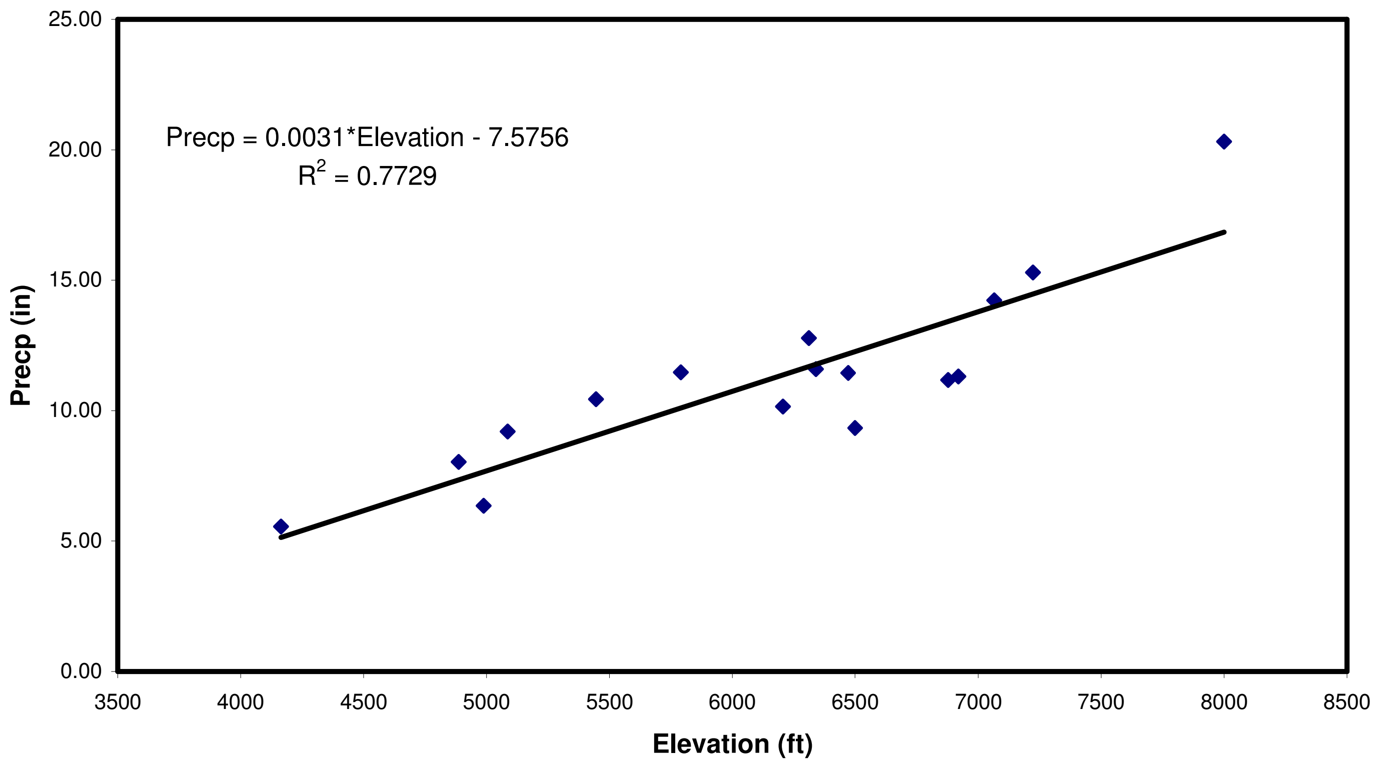

Figure 11. A long-term (1971-2000) Precp vs. Elevation plot for the regional stations as listed in Table (11).

Arid climate adjustment for the climate data

For arid climate, Tmax, Tmin, and Tdew are corrected by following Allen et al., 1998 (FAO-56 Annex-6) suggestions and using the following logic:

Let Δt=Tmin-Tdew in ^{o}C for a daily time-step.

For a particular month:

Count_1=number of days when Δt is greater than 2^{o}C

Count_2=number of days when Δt is less than or equal to 2^{o}C

If Count_1 is greater than or equal to Count_2

Δt_average=average Δt for that month

$$T\max_{corr} = T\max_{obs} - 0.5(\Delta t\_average - Ko) \quad (17)$$

$$T\min_{corr} = T\min_{obs} - 0.5(\Delta t\_average - Ko) \quad (18)$$

$$Tdew_{corr} = Tdew_{obs} + 0.5(\Delta t\_average - Ko) \quad (19)$$

else

$$T\max_{corr} = T\max_{obs} \quad (20)$$

$$T\min_{corr} = T\min_{obs} \quad (21)$$

$$Tdew_{corr} = Tdew_{obs} \quad (22)$$

In equations 17 to 22, subscripts *corr* and *obs* represent corrected and observed temperature at an agricultural unit, and a *Ko* value of 2°C is used by following the suggestions from Allen et al., 1998.

Note that wind and Tskc data are not elevation-adjusted, as NCDC, 2002 suggests that these parameters do not show strong correlation with the elevation of the measurement site.

Using equations 17 to 22, new Tmax, Tmin, and Tdew are calculated. This data set along with wind and Tskc dataset is used to calculate the final daily *ETo*.

Crop Coefficients (K_c)

The reference *ET* (ET_o) calculated using the standard ASCE-PM equation is for a short grass with no scarcity of water supply which may hinder its growth. In calculating ET_o, one of the major assumptions that the crop covers the majority of the soil surface below it. This assumption does not hold generally when the crop is in its initial growth stage (i.e., planting and canopy development) or at its end stage (i.e., maturation). Therefore, there is a possibility of relatively more wet soil evaporation from the bare soil than plant transpiration during certain crop growth stages. The wet soil evaporation from a soil surface depends on the top soil moisture characteristics, crop-root zone characteristics, and the surrounding climatic conditions (Allen, 1998, ASCE, 2005, and NEH, 1993). These factors are not included in ET_o calculation. Therefore, it is essential to modify ET_o to account for non-standard conditions. This modification to ET_o is made through a term known as the crop coefficient.

The crop coefficient depends on crop type, cropping pattern, soil characteristics, crop-root zone characteristics, and the surrounding climate conditions (Allen, 1998, ASCE, 2005, and NEH, 1993). In the next subheadings a systematic description of the major categories of crops grown in each agricultural unit is provided, along with their growing seasons, and a final cropping pattern for the whole project area is determined. The final cropping pattern is used to estimate the crop coefficient for each major category of crop types grown each agricultural unit.

Cropping pattern

To determine the cropping pattern for each agricultural unit, Bureau of Indian Affairs (BIA) annual crops reports are used. Notice that:

(a) The BIA crop reports used[1] are only for the following years 1934, 1952 (only a summary for the whole project area is available), 1981 to 1993, 1997 to 2001, and 2003 to 2004.

(b) The crop reports available from BIA sometimes lack consistency. For example, irrigated pasture is only reported for the year 1934.

Table 12 provides a list of the major categories of crops grown historically in each agricultural unit.

In Table 12, major categories of crops are:

- Corn
- Small grains, Hay represents Hay, Oat Hay, and Rye Hay
- Small grains, grains represents Oat, Rye, and Wheat
- Alfalfa
- Garden crops category includes: Garden, Beans, Chili, Melons, Orchards, Pumpkins, and the “other” categories of the BIA reported crop categories
- Irrigated pasture
- Non crops category includes winter wheat and fallow

[1] The 1947 – 1950 BIA crop reports were received on the morning of 5/20/2010, and therefore data from these were not incorporated into this part of the report.

Note that the NRCE (2008) report appears to have double-counted irrigated pasture category by representing it as a separate category, and then also counting this category together with non-crops, and listing them together as a single non-crop category. In AMEC calculations, irrigated pasture and non-crops are considered as separate categories until the last step, when they are added together to provide a single crop category. Table 13 lists the cropping pattern for all agricultural units together for various years. It can be inferred from Tables 12 and 13 that the cropping pattern in each agricultural unit is quite dynamic and varies from year to year.

Table 14 lists an overall cropping pattern for each agricultural unit when irrigated pasture and non-crop categories are added together and represent a single category. Non-crop and irrigated pasture in this table are adjusted to represent a single percentage, which is determined by taking median of this category values for each agricultural unit. In this table, the crop categories are adjusted with respect to the irrigated pasture and non-crop category to sum up to 100%. Finally, an acreage-weighted average is performed for each major category of crops to determine the final pattern of the major categories of crops (see Table 15).

Table 12. Crop grown in each agricultural unit by percent of total acreage for each unit.

Unit / Crop category	Nutria	Ojo Caliente	Pescado	Tekapo	Zuni
Corn	26.96	32.87	18.89	77.60	46.73
small grains, hay	10.86	7.70	6.28	0.48	3.88
small grains, grain	15.59	12.41	11.28	0.46	8.20
Alfalfa	37.26	37.93	61.42	8.37	35.89
Garden crops	4.20	5.68	1.59	10.86	1.55
Irrigated pasture	0.53	0.00	0.55	0.00	0.65
Non crops	4.61	3.42	0.00	2.22	3.10
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

Table 13. Crop grown in various time periods (for all agricultural units together).

year / Crop category	1934	1952	1981-1993	1997-2001	2003-2004
Corn	4.9	34.8	43.9	15.4	13.2
small grains, hay	0.0	21.1	8.9	0.0	0.0
small grains, grain	59.9	13.1	7.5	10.6	12.2
Alfalfa	21.5	17.0	30.2	74.0	74.7
Garden crops	5.7	14.0	5.8	0.0	0.0
Irrigated pasture	8.0	0.0	0.0	0.0	0.0
Non crops	0.0	0.0	3.7	0.0	0.0
Total	100	100.0	100	100	100

Table 14. Crops grown in each project area, adjusted for non-crop and irrigated pasture.

Agricultural unit / Crop Category	Nutria	Ojo Caliente	Pescado	Tekapo	Zuni
Corn	27.28	32.67	18.23	76.19	46.61
Small Grains, Hay	10.99	7.65	6.06	0.47	3.87
Small grains, Grain	15.77	12.33	10.88	0.45	8.18
Alfalfa	37.71	37.70	59.29	8.22	35.79
Garden crops	4.25	5.64	1.54	10.66	1.55
Irrigated Pasture and non crop	4.00	4.00	4.00	4.00	4.00
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

Table 15. The final cropping pattern for all agricultural units together.

Crop Category	% by area
Small grains, Grain	10
Small Grains, Hay	6
Alfalfa	39
Garden crops	3
Corn	38
Irrigated Pasture and non crop	4

Growing season

The growing seasons for each major crop categories are determined by following the same procedure as described by NRCE, 2008. Also, the elevation and arid climate adjusted temperature data for each agricultural unit is used to estimate the growing season length. Note that the temperature data for Pescado, Tekapo, Ojo Caliente, and Zuni is derived from the filled/extended data for the Zuni-Black Rock station. For Nutria agricultural unit, the filled/extended temperature data from McGaffey 5 SE station is used. The seasons are listed in Table 16. In Table 16, the start and end dates of a growing season for a category from AMEC estimation are found closer to the NRCE, 2008, estimation, except for the Irrigated pasture and non-crops category for the Pescado agricultural unit (marked by a * in Table 16).

Table 16. Growing season for agricultural unit for various crop categories.

Agricultural units	Crop	Growing season		
		start	end	Total days
Nutria	Small grains, Grain	4-Apr	1-Aug	120
	Small Grains, Hay	4-Apr	8-Jul	96
	Alfalfa	29-Apr	19-Oct	174
	Garden crops	15-May	1-Sep	110
	Corn	15-May	16-Sep	125
	Irrigated Pasture and non-crop	22-Apr	26-Oct	188
Pescado	Small grains, Grain	19-Mar	16-Jul	120
	Small Grains, Hay	19-Mar	22-Jun	96
	Alfalfa	6-May	23-Oct	171
	Garden crops	13-May	30-Aug	110
	Corn	13-May	14-Sep	125
	Irrigated Pasture and non-crop	30-Apr	30-Oct	185*
Tekapo/Ojo Caliente/Zuni	Small grains, Grain	13-Mar	10-Jul	120
	Small Grains, Hay	13-Mar	16-Jun	96
	Alfalfa	24-Apr	28-Oct	187
	Garden crops	9-May	26-Aug	110
	Corn	9-May	10-Sep	125
	Irrigated Pasture and non-crop	17-Apr	3-Nov	201

The crop coefficient for a particular variety of a crop can be represented by the following equation (Allen et al., 1998):

$$K_c = K_{cb} K_s + K_w \tag{23}$$

where, K_{cb} is the basal crop coefficient, which represents water demand of a healthy crop when it is not subjected to any water stress. Ks is a water stress factor whose numerical value is 1 for the Zuni-water right claim (NRCE, 2008). K_s equals to 1 represents a condition when crops are not subjected to any water stress. K_w is a wet soil evaporation factor.

Basal crop coefficient

It is a variable crop coefficient whose value depends on a particular stage of the growing season (see Figure 12). In Figure 12, the basal crop coefficient (K_{cb}) is plotted against a growing season for any given variety of a crop. In this figure:

(a) K_{ini} is known as the initial crop coefficient, and represents the basal crop coefficient from planting to early canopy development stage

(b) K_{cp} is known as the mid-season crop coefficient, and represents the basal crop coefficient when the crop effectively covers the majority of the ground surface below it

(c) K_{cm} is the basal crop coefficient at maturity

The basal crop coefficient curve for any crop can be developed if in addition to K_{ini}, K_{cp}, and K_{cm}, the parameters Fs1, Fs2, and Fs3 also are known. Fs1 represents fraction of the growing season length (T) for planting and initial canopy development period. Fs2 is the fraction of the growing season when canopy development is complete, and Fs3 in the fraction of the growing season when crop maturation begins.

Table 17 lists the K_{cb} values with Fs1, Fs2, and Fs3 for each major crop category identified in the previous subheadings.

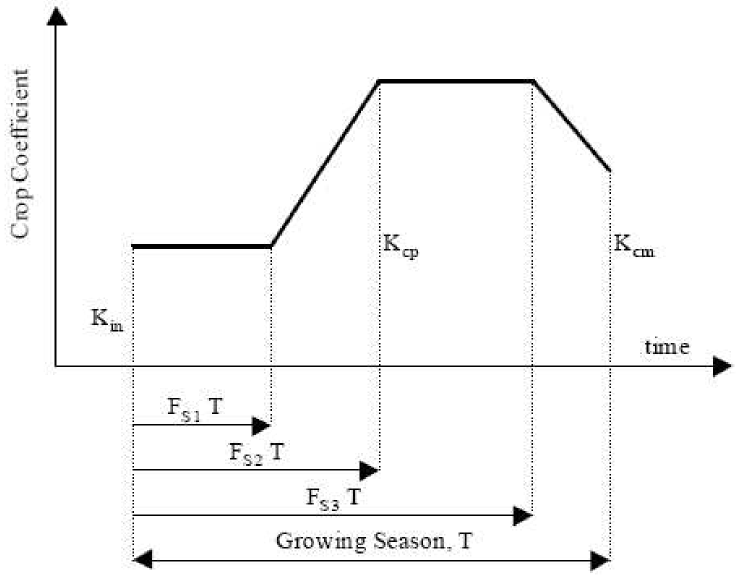

Figure 12. Pattern of the basal crop coefficient (K_{cb}) during a growing season (Source: NRCE, 2008).

Table 17. The basal crop coefficient (K_{cb}) for each crop along with the fraction of the growing season length (T).

Crop category	**Crop coefficient parameters**						
	Kin	Kcp	Kcm	Fs1	Fs2	Fs3	T (Nutria, Pescado, Tekapo-Zuni-Ojo Caliente)
Small grains, Grain	0.25*	1.15$	0.25$	0.125$	0.33	0.75$	120, 120, 120
Small Grains, Hay	0.85+	1.10+	1.05+	Cut at 80* % of Small grains			96, 96, 96
Alfalfa	0.40$	1.15$	1.15$	1st cycle of 75# days, 2nd of 46#, and 3rd for remaining days			174,171,187
Garden crops	0.15+	1.06+	0.81+	0.21*	0.52*	0.85*	110, 110, 110
Corn	0.25$	1.15$	0.60$	0.17$	0.45$	0.78$	125, 125, 125
Irrigated Pasture and non-crop	0.30+	0.89+	0.89+	10+ days	30+ days	NA	188,185, 201

Note: all numbers with: (a) * on them are taken from NRCE, 2008, (b) + are either taken directly from Allen et al., 1998, or estimated from Allen et al., 1998, from tables 12, 17, and equation 70, (c) $ are taken from NEH, 1993, (d) # on them are taken from Jensen et al., 1990.

In Table 17, the fraction of the growing season length for alfalfa depends on the harvesting schedule. However, for the identified length of the growing seasons for Nutria, Pescado, Tekapo, Ojo Caliente, and Zuni, only three harvesting schedule can be accommodated. Guidance for the growing season length for each harvesting cycle is received from Jensen, 1990. This manual suggests that the first cycle for alfalfa takes longer (approximately 75 days) and each subsequent cycle takes approximately 46 days. Thus, for the growing season length for any agricultural unit, only the first full cycle of 75 days, 2^{nd} full cycle of 46 days, and the last cycle of more than 46 days but less than 66 days can be accommodated. The growing season's length for alfalfa is longest for Tekapo, Ojo Caliente, and Zuni agricultural units. All the basal crop coefficients in Table 17 are for an arid climate (minimum relative humidity is less than 20%) and for moderate wind (wind speed less than 250 mi/day). The crop coefficients are determined from Tables 12, 17 and equation 70 of Allen et al., 1998, and Tables 2-20 and 2-21 of NEH, 1993. The other points regarding the K_{cb} values as listed in Table 16 for various major crop categories are:

- K_{cb} for an irrigated pasture is for rotational grazing
- For small grains-Hay category, values for Rye grass hay from Allen et al., 1998, are used; these values are for an average cutting effect
- For garden crops, medians of K_{ini}, K_{cp}, and K_{cm} of the following categories (in Allen et al, 1998, Table 17): small vegetables, vegetables-Cucumber family, and Legumes, are used
- For alfalfa, K_{ini} is used for the first 50% of each harvesting cycle and K_{cp} is used for the remaining days of the cycle

Note that some of the K_{cb} values as listed in Table 17 are from NRCE, 2008, table, which were found to be very close to the suggested values in either Allen et al., 1998, or NEH, 1993, or Jensen et al., 1990.

Wet Soil Evaporation factor

Whereas K_{cb} represents the water demand for a healthy crop which does not suffer from water stress, it does not include the wet soil evaporation factors when a crop does not completely covers the ground surface blow it. This makes it essential to add a factor to the basal crop coefficient to include the wet soil evaporation factor. The procedure to do so is explained below:

Let K_w be the wet soil evaporation factor, which can be estimated from the following equation (NEH, 1993).

$$K_w = Fw(1 - K_{cb}) f(t) \tag{24}$$

In the above equation, F_w is the fraction of the soil surface that is wetted by any particular irrigation methods, and f(t) is a evaporation decay function. Figure 21 shows a pattern of K_c (see equation 25) for a growing season length for a given variety of a crop, which is the sum of the basal crop coefficient and the wet soil evaporation factor.

$$K_c = K_{cb} + Fw(1 - K_{cb}) f(t) \tag{25}$$

Note: in Figure 12 that that K_w is 0 when K_{cb} is greater than or equals to 1.

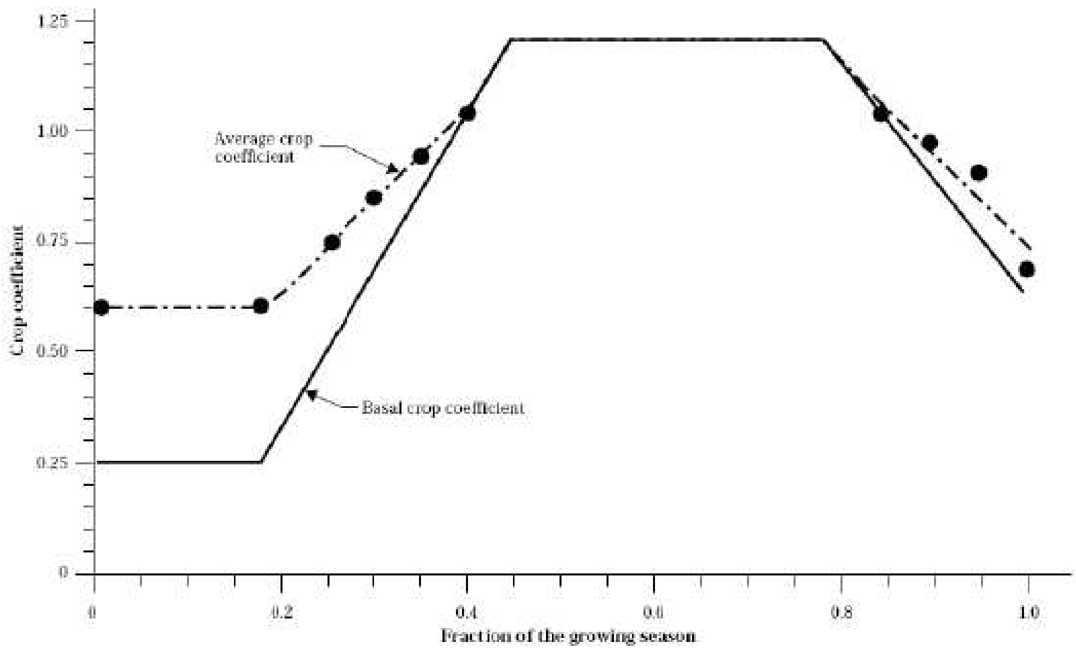

Figure 13. Pattern of the total crop coefficient (K_c) for a growing season length (source: NEH, 1993)

Average ($\overline{K}_c$) estimation

For this project, when ET_o and crop ET are required for a long-period of record, it is impractical to use the daily crop coefficient. Therefore, an average crop coefficient ($\overline{K}_c$) is required for each crop category. The average crop coefficient for a relatively long time-step can be estimated from the following equation (NEH, 1993):

$$\overline{K}_c = \overline{K}_{cb} + Fw(1-\overline{K}_{cb})A_f \qquad (26)$$

For the Zuni project, *Fw* equals to 1 is used as the Zuni Indian Reservation is using three types of irrigation methods: floodwater, canal system, and waffle gardens. For these types of irrigation practices/methods, NEH, 1993, suggests *Fw* equals to 1. A_f is the average wet soil evaporation factor, whole value is listed in Table 2-30 of NEH, 1993, for various recurrence intervals. An irrigation frequency of 14 days for Hay and Garden crops, and 21 days for all other crop categories are used (NRCE, 2008), and clay soil is assumed. The justification for the latter is that an albedo of 0.23 (this value is suggested by ASCE, 2005 and Allen et al., 1998) is used in *ETo* calculation. Table 2-2 from NEH, 1993, corresponds this albedo value to a dry clay soil.

There are few additional points to note. For each major crop category and for each agricultural unit, NEH, 1993, suggests using $\overline{K}_c$ for the 15th day of a month, if the growing season covers at least the first 15 days of a month. When a growing season starts after 15th day of a month, a median $\overline{K}_c$ for the remaining days of that month is used for that particular month. Similarly, if the growing season ends before 15th day of a moth, a median $\overline{K}_c$ for the initial days (1 to less than 15) of that month is used in crop *ET* estimation for that particular month. Tables 18, 19, and 20 list the monthly $\overline{K}_c$ values for the Nutria, Pescado, and Tekapo-Ojo Caliente-Zuni agricultural units, respectively. Note that the $\overline{K}_c$ values for the Tekapo, Ojo Caliente, and Zuni agricultural units are same, as they use the temperature data from the Zuni-Black Rock station.

Table 18. Average crop coefficients used for various crop categories for the Nutria agricultural unit.

Month	Small grain, grain	Small grain, Hay	Alfalfa	Garden crops	Corn	Irrigated pasture and non-crop
Jan	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00
Mar	0.00	0.00	0.00	0.00	0.00	0.00
Apr	0.39	0.89	0.51	0.00	0.00	0.43
May	1.15	1.10	0.51	0.39	0.39	0.77
Jun	1.15	1.10	1.15	0.56	0.61	0.91
Jul	0.80	1.08	0.51	1.05	1.15	0.91
Aug	0.39	0.00	1.15	1.05	1.15	0.91
Sep	0.00	0.00	0.51	0.86	0.69	0.91
Oct	0.00	0.00	1.15	0.00	0.00	0.91
Nov	0.00	0.00	0.00	0.00	0.00	0.00
Dec	0.00	0.00	0.00	0.00	0.00	0.00

Table 19. Average crop coefficients used for various crop categories for the Pescado agricultural unit.

Month	Small grain, grain	Small grain, Hay	Alfalfa	Garden crops	Corn	Irrigated pasture and non-crop
Jan	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00
Mar	0.39	0.89	0.00	0.00	0.00	0.00
Apr	0.76	0.98	0.00	0.00	0.00	0.43
May	1.15	1.10	0.51	0.39	0.39	0.57
Jun	1.15	1.10	1.15	0.59	0.63	0.91
Jul	0.41	0.00	1.15	1.05	1.15	0.91
Aug	0.00	0.00	1.15	1.04	1.15	0.91
Sep	0.00	0.00	0.51	0.00	0.78	0.91
Oct	0.00	0.00	1.15	0.00	0.00	0.91
Nov	0.00	0.00	0.00	0.00	0.00	0.00
Dec	0.00	0.00	0.00	0.00	0.00	0.00

Table 20. Average crop coefficients used for various crop categories for the Tekapo-Zuni-Ojo Caliente agricultural units (together).

Month	Small grain, grain	Small grain, Hay	Alfalfa	Garden crops	Corn	Irrigated pasture and non-crop
Jan	0.00	0.00	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00	0.00	0.00
Mar	0.39	0.89	0.00	0.00	0.00	0.00
Apr	0.94	1.04	0.51	0.00	0.00	0.43
May	1.15	1.10	0.51	0.39	0.39	0.89
Jun	1.00	1.06	1.15	0.67	0.74	0.91
Jul	0.50	0.00	0.51	1.05	1.15	0.91
Aug	0.00	0.00	1.15	0.99	1.13	0.91
Sep	0.00	0.00	1.15	0.00	0.75	0.91
Oct	0.00	0.00	1.15	0.00	0.00	0.91
Nov	0.00	0.00	0.00	0.00	0.00	0.91
Dec	0.00	0.00	0.00	0.00	0.00	0.00

After estimation of an average crop coefficient, these values are then multiplied to ET_o to obtain crop ET.

Precipitation estimation with 80% exceedence probability

As suggested in NEH, 1993, as a conservative approach to get the effective precipitation, NRCE has used Precp with 80% exceedence probability to estimate crop water demand. In order to get the precipitation for growing seasons with 80% exceedence probability, total precipitation for the growing season for each year is calculated for the years from 1949 to 2004 by following NEH, 1993 guidelines. With the growing season precipitation data, Weibull probability curve is drawn for the probability of occurrence for each precipitation value by first ranking the total growing season precipitations by their magnitudes. One such curve is shown in Figure 14 for the Nutria agricultural unit. In Figure 14, Precp with 20% probability of occurrence represents Precp with 80% exceedence probability. From this figure, Precp with 80% and 50% exceedence probability are estimated. The ratio of the two values (Precp with 80% and 50% exceedence probability) provides a factor which when multiplied to the monthly Precp for the growing season, provides Precp with 80% exceedence probability for the growing season.

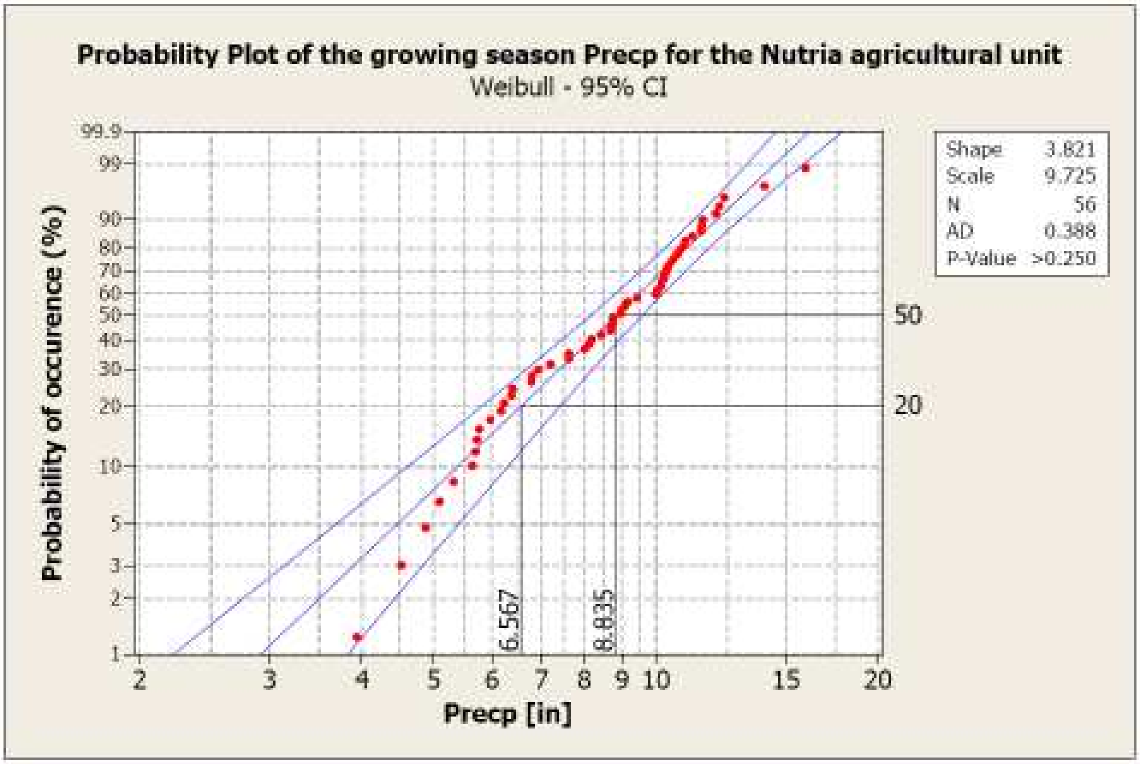

Figure 14. Probability plot of the growing season Precp for the Nutria agricultural unit (Precp with 80% and 50% exceedence probability are shown on the plot).

Effective Precipitation

The effective precipitation represents a fraction of the total precipitation that becomes available as a water source to a crop. The effective precipitation (P_e) for a crop is calculated using the following equations from NEH, 1993.

$$P_e = SF(0.70917 P_t^{0.82416} - 0.11556)(10^{0.02426 ET_c}) \quad (27)$$

where, P_t is the Precp with 80% exceedence probability, ET_c is the crop *ET*, and *SF* is the soil water evaporation factor. SF can be estimated from the following equation:

$$SF = 0.531747 + 0.295164D - 0.057697D^2 + 0.003804D^3) \quad (28)$$

In equation (28), D is the usable water storage in inch. The value of this parameter is taken as 3 in by following the NRCE, 2008, report. The effective precipitation for each crop type for each growing season month for each agricultural unit are listed in Tables from 22 to 26 for each agricultural unit.

Irrigation requirement

Net Irrigation Requirement (NIR)

NIR for each crop category for each agricultural unit is calculated by taking the difference between crop *ET* and P_e for a given category of a crop and for a given growing season month. NIR values for various crop categories and for each agricultural unit are listed in Tables from 22 to 26.

Monthly weighting factor for each crop

It is calculated by taking the product of the crop category percentage to the NIR for a given growing season month. The value of this parameter for each agricultural unit is listed in Tables from 22 to 26.

Weighted monthly average NIR

It is estimated as the sum of the monthly weighting factors for each growing season month.

Unit diversion requirement

The unit diversion requirment is estimated the weighted average monthly NIR divided by the overall efficiency. Note that NRCE, 2008 and Franzoy, 2010 have suggested different set of overall efficiency for each agricultural unit. The values are listed in Table 21.

Table 21. Estimated overall efficiency for each agricultural unit (sources: NRCE, 2008 and Franzoy, 2010).

Agricultural unit	Overall efficiency (%) from NRCE, 2008	Overall efficiency (%) from Franzoy, 2010
Nutria	42	43
Pescado	48	35
Ojo Caliente	54	48
Tekapo	48	43
Zuni	42	40

For estimation of the net unit diversion requirement, both sets of the overall efficiency are used to calculate two different sets of the unit diversion requirements. The unit diversion requirements for each agricultural unit are listed in Tables 22 to 26. In these tables, the unit diversion requirement which uses NRCE, 2008, suggested overall efficiency is marked by * and which uses Franzoy, 2010, suggested overall efficiency is marked by **.

Note: Table 22 includes two additional columns in which Stetson, 2009 calculated ET_o for the Nutria agricultural unit is compared with the AMEC calculation for the same unit.

Table 22: ET_o, crop ET, effective precipitation, net irrigation requirement and cropping pattern for the Nutria agricultural unit.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	NRCE estimation	% diff. wrt NRCE	Stetson estimation	% diff. wrt Stetson
ETo (in)	1.42	1.90	3.23	4.43	5.94	6.88	6.99	6.14	5.06	3.62	2.10	1.43	49.13	48.56	-1.17	50.76	3.21
80% exceedence monthly precipitation (in)	1.05	0.86	1.06	0.66	0.44	0.39	1.44	1.65	0.96	0.90	0.90	0.89	11.19	10.95	-2.23		
Crop ET																	
Small grains, Grain	0.00	0.00	0.00	1.73	6.83	7.92	5.59	2.39	0.00	0.00	0.00	0.00	24.46	21.41	-14.25		
Small Grains, Hay	0.00	0.00	0.00	3.94	6.53	7.57	7.55	0.00	0.00	0.00	0.00	0.00	25.60	19.70	-29.93		
Alfalfa	0.00	0.00	0.00	2.26	3.03	7.92	3.56	7.06	2.58	4.17	0.00	0.00	30.57	31.26	2.20		
Garden crops	0.00	0.00	0.00	0.00	2.32	3.86	7.34	6.45	4.35	0.00	0.00	0.00	24.31	21.42	-13.47		
Corn	0.00	0.00	0.00	0.00	2.32	4.20	8.04	7.06	3.49	0.00	0.00	0.00	25.10	21.79	-15.21		
Irrigated Pasture and non-crop	0.00	0.00	0.00	1.90	4.57	6.26	6.36	5.59	4.60	3.30	0.00	0.00	32.59	29.40	-10.84		
calculated Effective precipitation																	
Small grains, Grain	0.00	0.00	0.00	0.42	0.36	0.33	1.15	1.09	0.00	0.00	0.00	0.00	3.36	2.14	-56.81		
Small Grains, Hay	0.00	0.00	0.00	0.48	0.35	0.32	1.29	0.00	0.00	0.00	0.00	0.00	2.44	1.17	-108.64		
Alfalfa	0.00	0.00	0.00	0.44	0.29	0.33	1.03	1.42	0.66	0.68	0.00	0.00	4.84	4.22	-14.61		
Garden crops	0.00	0.00	0.00	0.00	0.28	0.26	1.27	1.37	0.73	0.00	0.00	0.00	3.91	2.96	-32.02		
Corn	0.00	0.00	0.00	0.00	0.28	0.26	1.32	1.42	0.69	0.00	0.00	0.00	3.98	3.32	-19.79		
Irrigated Pasture and non-crop	0.00	0.00	0.00	0.43	0.32	0.30	1.20	1.30	0.74	0.64	0.00	0.00	4.93	4.29	-15.02		
Calculated Net Irrigation Requirement																	
Small grains, Grain	0.00	0.00	0.00	1.30	6.47	7.59	4.44	1.30	0.00	0.00	0.00	0.00	21.11	19.27	-9.53		
Small Grains, Hay	0.00	0.00	0.00	3.46	6.18	7.25	6.26	0.00	0.00	0.00	0.00	0.00	23.15	18.53	-24.96		
Alfalfa	0.00	0.00	0.00	1.82	2.74	7.59	2.53	5.64	1.92	3.49	0.00	0.00	25.74	27.04	4.82		
Garden crops	0.00	0.00	0.00	0.00	2.04	3.60	6.07	5.08	3.62	0.00	0.00	0.00	20.40	18.46	-10.50		
Corn	0.00	0.00	0.00	0.00	2.04	3.93	6.71	5.64	2.80	0.00	0.00	0.00	21.13	18.47	-14.38		
Irrigated Pasture and non-crop	0.00	0.00	0.00	1.47	4.26	5.97	5.16	4.28	3.86	2.65	0.00	0.00	27.65	25.11	-10.13		
Cropping Pattern	**Monthly weighting factors for each crop**																
Small grains, Grain (10%)	0.00	0.00	0.00	0.13	0.65	0.76	0.44	0.13	0.00	0.00	0.00	0.00	2.11	1.73	-22.00		
Small Grains, Hay (6%)	0.00	0.00	0.00	0.21	0.37	0.44	0.38	0.00	0.00	0.00	0.00	0.00	1.39	0.74	-87.74		
Alfalfa (39%)	0.00	0.00	0.00	0.71	1.07	2.96	0.99	2.20	0.75	1.36	0.00	0.00	10.04	8.38	-19.78		
Garden crops (3%)	0.00	0.00	0.00	0.00	0.06	0.11	0.18	0.15	0.11	0.00	0.00	0.00	0.61	0.37	-65.39		
Corn (38%)	0.00	0.00	0.00	0.00	0.77	1.50	2.55	2.14	1.06	0.00	0.00	0.00	8.03	5.54	-44.91		
Irrigated Pasture and non-crop (4%)	0.00	0.00	0.00	0.06	0.17	0.24	0.21	0.17	0.15	0.11	0.00	0.00	1.11	6.03	81.66		
Weightage Average Monthly NIR (in)	0.00	0.00	0.00	1.11	3.09	6.00	4.75	4.80	2.07	1.47	0.00	0.00	23.28	22.79	-2.16		
Unit Diversion Requirement* (in)	0.00	0.00	0.00	2.63	7.36	14.28	11.30	11.43	4.94	3.49	0.00	0.00	55.44	54.27	-2.15		
Unit Diversion Requirement (in)**	0.00	0.00	0.00	2.57	7.19	13.95	11.04	11.16	4.82	3.41	0.00	0.00	54.15	54.27	0.23		

Table 23: ET_o, crop ET, effective precipitation, net irrigation requirement and cropping pattern for the Pescado agricultural unit.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	NRCE estimation	% diff. wrt NRCE
ETo (in)	1.47	2.07	3.52	4.82	6.26	7.08	7.12	6.25	5.14	3.66	2.14	1.45	50.98	50.54	-0.87
80% exceedence monthly precipitation (in)	0.74	0.56	0.74	0.48	0.36	0.33	1.51	1.72	0.98	0.96	0.61	0.68	9.66	9.60	-0.63
Crop ET															
Small grains, Grain	0.00	0.00	1.37	3.67	7.20	8.14	2.92	0.00	0.00	0.00	0.00	0.00	23.29	20.27	-14.91
Small Grains, Hay	0.00	0.00	3.13	4.73	6.89	7.79	0.00	0.00	0.00	0.00	0.00	0.00	22.53	17.48	-28.87
Alfalfa	0.00	0.00	0.00	0.00	3.19	8.14	8.18	7.19	2.62	4.21	0.00	0.00	33.54	30.44	-10.18
Garden crops	0.00	0.00	0.00	0.00	2.44	4.18	7.47	6.50	0.00	0.00	0.00	0.00	20.59	22.07	6.69
Corn	0.00	0.00	0.00	0.00	2.44	4.46	8.18	7.19	4.01	0.00	0.00	0.00	26.28	22.47	-16.98
Irrigated Pasture and non-crop	0.00	0.00	0.00	2.07	3.57	6.44	6.48	5.69	4.68	3.33	0.00	0.00	32.26	29.28	-10.17
calculated Effective precipitation															
Small grains, Grain	0.00	0.00	0.47	0.33	0.28	0.27	1.03	0.00	0.00	0.00	0.00	0.00	2.39	1.52	-57.09
Small Grains, Hay	0.00	0.00	0.52	0.35	0.27	0.26	0.00	0.00	0.00	0.00	0.00	0.00	1.41	0.91	-55.19
Alfalfa	0.00	0.00	0.00	0.00	0.22	0.27	1.39	1.49	0.67	0.72	0.00	0.00	4.76	4.31	-10.43
Garden crops	0.00	0.00	0.00	0.00	0.21	0.21	1.33	1.43	0.00	0.00	0.00	0.00	3.19	3.03	-5.41
Corn	0.00	0.00	0.00	0.00	0.21	0.22	1.39	1.49	0.73	0.00	0.00	0.00	4.03	3.42	-17.97
Irrigated Pasture and non-crop	0.00	0.00	0.00	0.30	0.23	0.24	1.26	1.37	0.75	0.69	0.00	0.00	4.85	4.45	-8.88
Calculated Net Irrigation Requirement															
Small grains, Grain	0.00	0.00	0.90	3.33	6.92	7.87	1.88	0.00	0.00	0.00	0.00	0.00	20.91	18.75	-11.50
Small Grains, Hay	0.00	0.00	2.61	4.38	6.61	7.52	0.00	0.00	0.00	0.00	0.00	0.00	21.12	16.57	-27.43
Alfalfa	0.00	0.00	0.00	0.00	2.97	7.87	6.80	5.70	1.95	3.49	0.00	0.00	28.78	26.13	-10.14
Garden crops	0.00	0.00	0.00	0.00	2.23	3.96	6.14	5.07	0.00	0.00	0.00	0.00	17.40	19.04	8.61
Corn	0.00	0.00	0.00	0.00	2.23	4.24	6.80	5.70	3.28	0.00	0.00	0.00	22.25	19.05	-16.80
Irrigated Pasture and non-crop	0.00	0.00	0.00	1.77	3.34	6.20	5.21	4.32	3.92	2.65	0.00	0.00	27.41	24.83	-10.41
Cropping Pattern	**Monthly weighting factors for each crop**														
Small grains, Grain (10%)	0.00	0.00	0.09	0.33	0.69	0.79	0.19	0.00	0.00	0.00	0.00	0.00	2.09	1.69	-23.70
Small Grains, Hay (6%)	0.00	0.00	0.16	0.26	0.40	0.45	0.00	0.00	0.00	0.00	0.00	0.00	1.27	0.66	-91.96
Alfalfa (39%)	0.00	0.00	0.00	0.00	1.16	3.07	2.65	2.22	0.76	1.36	0.00	0.00	11.22	8.10	-38.57
Garden crops (3%)	0.00	0.00	0.00	0.00	0.07	0.12	0.18	0.15	0.00	0.00	0.00	0.00	0.52	0.38	-37.37
Corn (38%)	0.00	0.00	0.00	0.00	0.85	1.61	2.58	2.17	1.25	0.00	0.00	0.00	8.46	5.72	-47.82
Irrigated Pasture and non-crop (4%)	0.00	0.00	0.00	0.07	0.13	0.25	0.21	0.17	0.16	0.11	0.00	0.00	1.10	5.96	81.60
Weightage Average Monthly NIR (in)	0.00	0.00	0.25	0.67	3.29	6.29	5.81	4.72	2.16	1.47	0.00	0.00	24.66	22.51	-9.53
Unit Diversion Requirement* (in)	0.00	0.00	0.51	1.39	6.86	13.10	12.11	9.83	4.51	3.06	0.00	0.00	51.37	46.89	-9.55
Unit Diversion Requirement (in)**	0.00	0.00	0.70	1.91	9.41	17.96	16.61	13.48	6.18	4.19	0.00	0.00	70.44	46.89	-50.23

Table 24. ET_o, crop ET, effective precipitation, net irrigation requirement and cropping pattern for the Zuni agricultural unit.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	NRCE estimation	% diff. wrt NRCE
ETo (in)	1.52	2.14	3.61	4.93	6.38	7.19	7.20	6.33	5.22	3.73	2.20	1.50	51.95	51.55	-0.77
80% exceedence monthly precipitation (in)	0.67	0.51	0.68	0.44	0.32	0.30	1.37	1.57	0.89	0.87	0.56	0.62	8.82	8.93	1.26
Crop ET															
Small grains, Grain	0.00	0.00	1.40	4.63	7.33	7.19	3.59	0.00	0.00	0.00	0.00	0.00	24.14	20.58	-17.31
Small Grains, Hay	0.00	0.00	3.48	5.05	6.69	7.25	0.00	0.00	0.00	0.00	0.00	0.00	22.47	17.07	-31.64
Alfalfa	0.00	0.00	0.00	2.52	3.26	8.27	3.68	7.28	6.00	4.29	0.00	0.00	35.30	34.63	-1.95
Garden crops	0.00	0.00	0.00	0.00	4.07	5.82	7.56	6.21	0.00	0.00	0.00	0.00	23.66	22.51	-5.10
Corn	0.00	0.00	0.00	0.00	2.48	5.28	8.28	7.15	3.91	0.00	0.00	0.00	27.11	23.02	-17.76
Irrigated Pasture and non-crop	0.00	0.00	0.00	2.52	5.63	6.48	6.50	5.71	4.71	3.37	1.98	0.00	36.90	32.16	-14.75
calculated Effective precipitation															
Small grains, Grain	0.00	0.00	0.43	0.31	0.25	0.22	0.99	0.00	0.00	0.00	0.00	0.00	2.20	1.30	-69.47
Small Grains, Hay	0.00	0.00	0.48	0.32	0.24	0.22	0.00	0.00	0.00	0.00	0.00	0.00	1.27	0.86	-47.60
Alfalfa	0.00	0.00	0.00	0.28	0.20	0.24	0.99	1.37	0.74	0.66	0.00	0.00	4.48	4.28	-4.70
Garden crops	0.00	0.00	0.00	0.00	0.21	0.21	1.23	1.29	0.00	0.00	0.00	0.00	2.94	2.67	-10.04
Corn	0.00	0.00	0.00	0.00	0.19	0.20	1.28	1.36	0.66	0.00	0.00	0.00	3.70	3.13	-18.07
Irrigated Pasture and non-crop	0.00	0.00	0.00	0.28	0.23	0.21	1.16	1.26	0.69	0.63	0.36	0.00	4.82	4.27	-12.81
Calculated Net Irrigation Requirement															
Small grains, Grain	0.00	0.00	0.97	4.31	7.08	6.96	2.61	0.00	0.00	0.00	0.00	0.00	21.94	19.29	-13.73
Small Grains, Hay	0.00	0.00	2.99	4.73	6.46	7.02	0.00	0.00	0.00	0.00	0.00	0.00	21.20	16.21	-30.79
Alfalfa	0.00	0.00	0.00	2.24	3.06	8.03	2.69	5.91	5.26	3.63	0.00	0.00	30.82	30.36	-1.53
Garden crops	0.00	0.00	0.00	0.00	3.87	5.61	6.33	4.91	0.00	0.00	0.00	0.00	20.72	19.84	-4.44
Corn	0.00	0.00	0.00	0.00	2.29	5.08	7.00	5.79	3.25	0.00	0.00	0.00	23.41	19.89	-17.71
Irrigated Pasture and non-crop	0.00	0.00	0.00	2.24	5.40	6.27	5.34	4.46	4.02	2.74	1.62	0.00	32.09	27.88	-15.08
Cropping Pattern	**Monthly weighting factors for each crop**														
Small grains, Grain (10%)	0.00	0.00	0.10	0.43	0.71	0.70	0.26	0.00	0.00	0.00	0.00	0.00	2.19	1.54	-42.46
Small Grains, Hay (6%)	0.00	0.00	0.18	0.28	0.39	0.42	0.00	0.00	0.00	0.00	0.00	0.00	1.27	0.65	-95.70
Alfalfa (39%)	0.00	0.00	0.00	0.87	1.19	3.13	1.05	2.31	2.05	1.42	0.00	0.00	12.02	9.41	-27.75
Garden crops (3%)	0.00	0.00	0.00	0.00	0.12	0.17	0.19	0.15	0.00	0.00	0.00	0.00	0.62	0.40	-55.40
Corn (38%)	0.00	0.00	0.00	0.00	0.87	1.93	2.66	2.20	1.23	0.00	0.00	0.00	8.90	6.16	-44.43
Irrigated Pasture and non-crop (4%)	0.00	0.00	0.00	0.09	0.22	0.25	0.21	0.18	0.16	0.11	0.06	0.00	1.28	6.69	80.82
Weightage Average Monthly NIR (in)	0.00	0.00	0.28	1.68	3.49	6.60	4.37	4.83	3.45	1.53	0.06	0.00	26.29	24.86	-5.75
Unit Diversion Requirement* (in)	0.00	0.00	0.66	4.00	8.31	15.71	10.41	11.50	8.21	3.64	0.15	0.00	62.59	59.18	-5.77
Unit Diversion Requirement (in)**	0.00	0.00	0.69	4.20	8.73	16.50	10.93	12.08	8.62	3.82	0.16	0.00	65.72	59.18	-11.06

Table 25. ET_o, crop ET, effective precipitation, net irrigation requirement and cropping pattern for the Ojo Caliente agricultural unit.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	NRCE estimation	% diff. wrt NRCE
ETo (in)	1.52	2.14	3.61	4.93	6.38	7.19	7.20	6.33	5.22	3.73	2.20	1.50	51.95	51.55	-0.77
80% exceedence monthly precipitation (in)	0.67	0.51	0.68	0.44	0.32	0.30	1.37	1.57	0.89	0.87	0.56	0.62	8.82	8.93	1.26
Crop ET															
Small grains, Grain	0.00	0.00	1.41	4.63	7.33	7.19	3.60	0.00	0.00	0.00	0.00	0.00	24.16	20.58	-17.40
Small Grains, Hay	0.00	0.00	3.21	5.13	7.01	7.62	0.00	0.00	0.00	0.00	0.00	0.00	22.97	17.07	-34.55
Alfalfa	0.00	0.00	0.00	2.51	3.25	8.27	3.67	7.28	6.00	4.29	0.00	0.00	35.29	34.63	-1.89
Garden crops	0.00	0.00	0.00	0.00	2.49	4.82	7.56	6.27	0.00	0.00	0.00	0.00	21.14	22.51	6.10
Corn	0.00	0.00	0.00	0.00	2.49	5.32	8.28	7.16	3.91	0.00	0.00	0.00	27.16	23.02	-17.99
Irrigated Pasture and non-crop	0.00	0.00	0.00	2.12	5.67	6.54	6.55	5.76	4.75	3.40	2.00	0.00	36.80	32.16	-14.42
calculated Effective precipitation															
Small grains, Grain	0.00	0.00	0.43	0.31	0.25	0.22	0.99	0.00	0.00	0.00	0.00	0.00	2.20	1.30	-69.52
Small Grains, Hay	0.00	0.00	0.48	0.32	0.24	0.23	0.00	0.00	0.00	0.00	0.00	0.00	1.27	0.86	-47.97
Alfalfa	0.00	0.00	0.00	0.28	0.20	0.24	0.99	1.37	0.74	0.66	0.00	0.00	4.48	4.28	-4.69
Garden crops	0.00	0.00	0.00	0.00	0.19	0.20	1.23	1.30	0.00	0.00	0.00	0.00	2.91	2.67	-9.14
Corn	0.00	0.00	0.00	0.00	0.19	0.20	1.28	1.36	0.66	0.00	0.00	0.00	3.70	3.13	-18.10
Irrigated Pasture and non-crop	0.00	0.00	0.00	0.27	0.23	0.22	1.16	1.26	0.69	0.63	0.36	0.00	4.82	4.27	-12.93
Calculated Net Irrigation Requirement															
Small grains, Grain	0.00	0.00	0.98	4.32	7.08	6.96	2.61	0.00	0.00	0.00	0.00	0.00	21.96	19.29	-13.83
Small Grains, Hay	0.00	0.00	2.73	4.80	6.77	7.39	0.00	0.00	0.00	0.00	0.00	0.00	21.70	16.21	-33.84
Alfalfa	0.00	0.00	0.00	2.23	3.05	8.03	2.68	5.91	5.26	3.63	0.00	0.00	30.81	30.36	-1.47
Garden crops	0.00	0.00	0.00	0.00	2.30	4.62	6.33	4.97	0.00	0.00	0.00	0.00	18.22	19.84	8.16
Corn	0.00	0.00	0.00	0.00	2.30	5.12	7.00	5.79	3.25	0.00	0.00	0.00	23.46	19.89	-17.97
Irrigated Pasture and non-crop	0.00	0.00	0.00	1.85	5.45	6.33	5.39	4.50	4.06	2.77	1.64	0.00	31.98	27.88	-14.69
Cropping Pattern	**Monthly weighting factors for each crop**														
Small grains, Grain (10%)	0.00	0.00	0.10	0.43	0.71	0.70	0.26	0.00	0.00	0.00	0.00	0.00	2.20	1.54	-42.58
Small Grains, Hay (6%)	0.00	0.00	0.16	0.29	0.41	0.44	0.00	0.00	0.00	0.00	0.00	0.00	1.30	0.65	-100.27
Alfalfa (39%)	0.00	0.00	0.00	0.87	1.19	3.13	1.05	2.31	2.05	1.42	0.00	0.00	12.01	9.41	-27.67
Garden crops (3%)	0.00	0.00	0.00	0.00	0.07	0.14	0.19	0.15	0.00	0.00	0.00	0.00	0.55	0.40	-36.66
Corn (38%)	0.00	0.00	0.00	0.00	0.87	1.94	2.66	2.20	1.24	0.00	0.00	0.00	8.92	6.16	-44.75
Irrigated Pasture and non-crop (4%)	0.00	0.00	0.00	0.07	0.22	0.25	0.22	0.18	0.16	0.11	0.07	0.00	1.28	6.69	80.88
Weightage Average Monthly NIR (in)	0.00	0.00	0.26	1.67	3.47	6.61	4.37	4.84	3.45	1.53	0.07	0.00	26.25	24.86	-5.61
Unit Diversion Requirement* (in)	0.00	0.00	0.48	3.08	6.42	12.24	8.10	8.96	6.39	2.83	0.12	0.00	48.62	46.03	-5.62
Unit Diversion Requirement (in)**	0.00	0.00	0.54	3.47	7.22	13.76	9.11	10.07	7.19	3.18	0.14	0.00	54.70	46.03	-18.83

Table 26. ET_o, crop ET, effective precipitation, net irrigation requirement and cropping pattern for the Tekapo agricultural unit.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	NRCE estimation	% diff. wrt NRCE
ETo (in)	1.52	2.14	3.61	4.93	6.38	7.19	7.20	6.33	5.22	3.73	2.20	1.50	51.95	51.55	-0.77
80% exceedence monthly precipitation (in)	0.67	0.51	0.68	0.44	0.32	0.30	1.37	1.57	0.89	0.87	0.56	0.62	8.82	8.93	1.26
Crop ET															
Small grains, Grain	0.00	0.00	1.40	4.63	7.33	7.19	3.59	0.00	0.00	0.00	0.00	0.00	24.14	20.58	-17.31
Small Grains, Hay	0.00	0.00	3.48	5.05	6.69	7.25	0.00	0.00	0.00	0.00	0.00	0.00	22.47	17.07	-31.64
Alfalfa	0.00	0.00	0.00	2.52	3.26	8.27	3.68	7.28	6.00	4.29	0.00	0.00	35.30	34.63	-1.95
Garden crops	0.00	0.00	0.00	0.00	4.07	5.82	7.56	6.21	0.00	0.00	0.00	0.00	23.66	22.51	-5.10
Corn	0.00	0.00	0.00	0.00	2.48	5.28	8.28	7.15	3.91	0.00	0.00	0.00	27.11	23.02	-17.76
Irrigated Pasture and non-crop	0.00	0.00	0.00	2.52	5.63	6.48	6.50	5.71	4.71	3.37	1.98	0.00	36.90	32.16	-14.75
calculated Effective precipitation															
Small grains, Grain	0.00	0.00	0.43	0.31	0.25	0.22	0.99	0.00	0.00	0.00	0.00	0.00	2.20	1.30	-69.47
Small Grains, Hay	0.00	0.00	0.48	0.32	0.24	0.22	0.00	0.00	0.00	0.00	0.00	0.00	1.27	0.86	-47.60
Alfalfa	0.00	0.00	0.00	0.28	0.20	0.24	0.99	1.37	0.74	0.66	0.00	0.00	4.48	4.28	-4.70
Garden crops	0.00	0.00	0.00	0.00	0.21	0.21	1.23	1.29	0.00	0.00	0.00	0.00	2.94	2.67	-10.04
Corn	0.00	0.00	0.00	0.00	0.19	0.20	1.28	1.36	0.66	0.00	0.00	0.00	3.70	3.13	-18.07
Irrigated Pasture and non-crop	0.00	0.00	0.00	0.28	0.23	0.21	1.16	1.26	0.69	0.63	0.36	0.00	4.82	4.27	-12.81
Calculated Net Irrigation Requirement															
Small grains, Grain	0.00	0.00	0.97	4.31	7.08	6.96	2.61	0.00	0.00	0.00	0.00	0.00	21.94	19.29	-13.73
Small Grains, Hay	0.00	0.00	2.99	4.73	6.46	7.02	0.00	0.00	0.00	0.00	0.00	0.00	21.20	16.21	-30.79
Alfalfa	0.00	0.00	0.00	2.24	3.06	8.03	2.69	5.91	5.26	3.63	0.00	0.00	30.82	30.36	-1.53
Garden crops	0.00	0.00	0.00	0.00	3.87	5.61	6.33	4.91	0.00	0.00	0.00	0.00	20.72	19.84	-4.44
Corn	0.00	0.00	0.00	0.00	2.29	5.08	7.00	5.79	3.25	0.00	0.00	0.00	23.41	19.89	-17.71
Irrigated Pasture and non-crop	0.00	0.00	0.00	2.24	5.40	6.27	5.34	4.46	4.02	2.74	1.62	0.00	32.09	27.88	-15.08
Cropping Pattern	**Monthly weighting factors for each crop**														
Small grains, Grain (10%)	0.00	0.00	0.10	0.43	0.71	0.70	0.26	0.00	0.00	0.00	0.00	0.00	2.19	1.54	-42.46
Small Grains, Hay (6%)	0.00	0.00	0.18	0.28	0.39	0.42	0.00	0.00	0.00	0.00	0.00	0.00	1.27	0.65	-95.70
Alfalfa (39%)	0.00	0.00	0.00	0.87	1.19	3.13	1.05	2.31	2.05	1.42	0.00	0.00	12.02	9.41	-27.75
Garden crops (3%)	0.00	0.00	0.00	0.00	0.12	0.17	0.19	0.15	0.00	0.00	0.00	0.00	0.62	0.40	-55.40
Corn (38%)	0.00	0.00	0.00	0.00	0.87	1.93	2.66	2.20	1.23	0.00	0.00	0.00	8.90	6.16	-44.43
Irrigated Pasture and non-crop (4%)	0.00	0.00	0.00	0.09	0.22	0.25	0.21	0.18	0.16	0.11	0.06	0.00	1.28	6.69	80.82
Weightage Average Monthly NIR (in)	0.00	0.00	0.28	1.68	3.49	6.60	4.37	4.83	3.45	1.53	0.06	0.00	26.29	24.86	-5.75
Unit Diversion Requirement* (in)	0.00	0.00	0.58	3.50	7.27	13.75	9.11	10.07	7.18	3.18	0.13	0.00	54.77	51.77	-5.79
Unit Diversion Requirement (in)**	0.00	0.00	0.64	3.90	8.12	15.35	10.17	11.24	8.02	3.55	0.15	0.00	61.14	51.77	-18.09

Total annual diversion and depletion

Total annual diversion requirement and depletion

The total annual diversion requirement for each agricultural unit is calculated by multiplying the agricultural unit acreage and the unit diversion requirement. We developed two separate estimates based on different values for the unit irrigated acreage.

- In the first, we used the past and present irrigated acreage for each agricultural unit from NRCE, 2008 Appendix A; the acreage was used for computing the agricultural unit diversion amounts listed at the bottom of Tables 22 to 26, as well as summarized in Table 27.
- In the second, we used the maximum single-year acreage as documented in the BIA crop reports reviewed for this study. This second approach was taken as a more realistic measure recognizing that the NRCE, 2008, acreage represents a composite of all lands that had ever been subjected to irrigation in the past. The diversion results from using the maximum single-year acreage are presented in Table 27.

The total annual depletion is estimated as the sum of the product of NIR to the acreage and 20 % of the total annual diversion requirement to account for incidental depletions that occur in the conveyance system and on-farm. Table 27 lists the total annual diversion requirement and the total annual depletion for each agricultural unit from AMEC calculations, and compares them to the NRCE, 2008, estimates.

In addition to using two different acreages as described above, this table shows two sets of diversion and depletion requirements that depend on which set of efficiencies were used;.the first set (marked by *) uses NRCE, 2008, suggested overall efficiency, while the second set (marked by **) uses Franzoy, 2010, suggested overall efficiency.

Table 27. Comparison of the NRCE estimated annual diversion and depletion values with the corresponding AMEC estimated values.

						With NRCE (2008) estimated irrigated acreage								With maximum single-year acreage			
		NRCE (modified claim)		NRCE (Original claim)		AMEC_weather_data				AMEC_gridded_weather_data				AMEC_weather_data		AMEC_gridded_weather_data	
Agricultural Unit	**Irrigated area (acres)**	**Diversion (ac-ft)**	**Depletion (ac-ft)**	**Diversion (ac-ft)**	**Depletion (ac-ft)**	**Diversion* (ac-ft)**	**Depletion* (ac-ft)**	**Diversion** (ac-ft)**	**Depletion** (ac-ft)**	**Diversion* (ac-ft)**	**Depletion* (ac-ft)**	**Diversion** (ac-ft)**	**Depletion** (ac-ft)**	**Diversion** (ac-ft)**	**Depletion** (ac-ft)**	**Diversion** (ac-ft)**	**Depletion** (ac-ft)**
Nutria	976.61	4401.70	2359.30	4338.70	2325.80	4511.94	2797.01	4406.95	2776.01	4550.19	2820.94	4444.39	2799.78	2202.10	1387.14	2220.81	1399.01
Pescado	1317.88	5096.90	2976.60	5195.00	3033.70	5641.62	3836.57	7735.96	4255.43	5481.28	3727.62	7517.41	4134.85	2359.74	1298.06	2293.08	1261.28
Ojo Caliente	773.73	2967.90	1875.70	2973.40	1879.40	3134.90	2319.51	3526.92	2397.92	3049.79	2256.71	3430.85	2332.92	2233.58	1518.59	2172.74	1477.43
Teakpo	320.57	1383.00	807.70	1583.90	848.90	1463.13	994.94	1633.30	1028.98	1446.04	983.24	1614.34	1016.90	779.54	491.10	770.48	485.34
Zuni	3629.78	17901.40	9595.10	17934.90	9611.80	18932.33	11738.71	19879.10	11928.06	18366.69	11386.62	19283.21	11569.92	8863.99	5318.66	8598.28	5158.97
Total	**7018.57**	**31750.90**	**17614.40**	**32025.90**	**17699.60**	**33683.92**	**21686.74**	**37182.23**	**22386.40**	**32893.98**	**21175.14**	**36290.19**	**21854.38**	**16438.94**	**10013.55**	**16055.39**	**9782.03**

Summary

When using equivalent acreage, the total annual diversion requirement and total annual depletion for each agricultural unit from AMEC estimates are relatively higher than the corresponding NRCE, 2008, estimates. Some of the factors responsible for this difference are:

- In their crop *ET* calculation, NRCE accepted mistakenly multiplied ET_o by only the basal crop coefficient to get the crop ET (see page H-1 of NRCE, 2008) while it should multiplied the overall crop coefficient (sum of basal crop coefficient and the wet soil evaporation factor) to ET_o to get the crop *ET*.
- Cropping pattern as estimated by the NRCE is very different than AMEC, while both uses the same source for the crop irrigation pattern for the whole project area (BIA crop reports).

ET_o for the Nutria agricultural unit from AMEC calculation is slightly low (by 3.21%) with respect to the Stetson, 2009 calculated ET_o. Some of the reasons for this difference may be:

- Stetson, 2009 has used different procedures to fill/extend the missing climate data with respect to AMEC (or NRCE, 2008) procedures
- The elevation-adjusted Tdew data, as calculated by Stetson, 2009 is based on the NRCE, 2008, reported relation. However, the NRCE has accepted its mistake and suggested a new equation for elevation adjustment of Tdew data in its memo titled "Corrections and Clarifications for report by NRCE titles, Zuni Indian Reservation Identification of Lands and Estimation of Water Requirements for Past and Present Lands Served by Permanent Irrigation Works, November 3, 2008".

Finally, given that the standard application of the standardized ASCE reference ET method required extensive filling of required weather station data, AMEC estimates of the net annual diversion requirement and the net annual depletion based on the grid-estimate of the local climate data near to the centroid of each agricultural unit (Appendix C) should be relatively more reliable.

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